TECHNICAL REFERENCE MANUAL

Anki Vector

A LOVE LETTER TO THE LITTLE DUDE

AUTHOR RANDALL MAAS

OVERVIEW This book explores how the Anki Vector was realized in hardware and software.

drawing by Steph Dere

RANDALL MAAS has spent decades in Washington and Minnesota. He consults in embedded systems development, especially medical devices. Before that he did a lot of other things… like everyone else in the software industry. He is also interested in geophysical models, formal semantics, model theory and compilers.

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Preface

The Anki Vector is a charming little robot – cute, playful, with a slightly mischievous character. It is everything I ever wanted to create in a bot. Sadly, Anki went defunct shortly after its release. Almost a year later Anki's software and designs were purchased by Digital Dream Labs, who are presently developing plans for future support and development.

This book is my attempt to understand the Anki Vector and its construction; it is not authoratative and is based on speculation. Speculation informed by Anki's SDKs, blog posts, patents and FCC filings; by articles about Anki, presentations by Anki employees; by PCB photos, and hardware teardowns from others; by a team of people (Project Victor) analyzing the released software; and by experience with the parts, and the functional areas. When you do find errors (and typos), please contact me (my email is on the second page.)

1. ORGANIZATION OF THIS DOCUMENT

- PREFACE. This introduction describes the organization of the chapters and appendices.
- CHAPTER 1: OVERVIEW OF VECTOR'S ARCHITECTURE. Introduces the overall design of the Anki Vector robot.

PART I: ELECTRICAL DESIGN. This part provides an overview of the design of the electronics in Vector and his accessories:

- CHAPTER 2: VECTOR'S ELECTRONICS DESIGN. An overview of the Vector's electronics design.
- CHAPTER 3: HEAD-BOARD ELECTRONICS DESIGN. A detailed look at the electronics design of Vector's main processing board.
- CHAPTER 4: BACKPACK & BODY-BOARD ELECTRONICS DESIGN. A detailed look at the electronics design of Vector's backpack and motor driver boards.
- CHAPTER 5: ACCESSORY ELECTRONICS DESIGN. A look at the electronics design of Vector's accessories.

PART II: BASIC OPERATION. This part provides an overview of Vector's software design.

- CHAPTER 6: ARCHITECTURE. A detailed look at Vector's overall software architecture.
- CHAPTER 7: STARTUP. A detailed look at Vector's startup, and shutdown processes
- CHAPTER 8: POWER MANAGEMENT. A detailed look at Vector's architecture for battery monitoring, changing and other power management.
- CHAPTER 9: BUTTON & TOUCH INPUT AND OUTPUT LEDS. A look at the push button, touch sensing, surface proximity sensors, time of flight proximity sensing, and backpack LEDs.
- CHAPTER 10: INERTIAL MOTION SENSING

PART III: COMMUNICATION. This part provides details of Vector's communication protocols. These chapters describe structure communication, the information that is exchange, its encoding, and the sequences needed to accomplish tasks. Other chapters will delve into the functional design that the communication provides interface to.

- CHAPTER 11: COMMUNICATION. A look at Vector's communication stack.
- CHAPTER 12: COMMUNICATION WITH THE BODY-BOARD. The protocol that the body-board responds to.
- CHAPTER 13: VECTOR'S BLUETOOTH LE COMMUNICATION PROTOCOL. The Bluetooth LE protocol that Vector responds to.
- CHAPTER 14: CUBE'S BLUETOOTH LE COMMUNICATION PROTOCOL. The Bluetooth LE protocol that the cube responds to.
- CHAPTER 15: SDK PROTOCOL. The HTTPS protocol that Vector responds to.
- CHAPTER 16: WEB-VISUALIZATION PROTOCOL. The web-sockets protocol(s) that Vector provides for debugging in development builds.
- CHAPTER 17: CLOUD. A look at how Vector syncs with remote services.

PART IV: ADVANCED FUNCTIONS. This part describes items that are Vector's primary function.

- CHAPTER 18: AUDIO INPUT. A look at Vector's ability to hear spoken commands, and ambient sounds.
- CHAPTER 19: IMAGE PROCESSING. Vector vision system is sophisticated, with the ability to recognize marker, faces, and objects; to take photographs, and acts as a key part of the navigation system.
- CHAPTER 20: MAPPING & NAVIGATION. A look at Vector's mapping and navigation systems.
- CHAPTER 21: ACCESSORIES. A look at Vector's home (charging station), companion cube and custom objects.

PART V: ANIMATION. Vector uses animations – "sequence[s] of highly coordinated movements, faces, lights, and sounds" – "to demonstrate an emotion or reaction." This part describes how the animation system works.

- CHAPTER 22: ANIMATION. An overview how Vector's scripted animations represents the "movements, faces, lights and sounds;" and how they are coordinated.
- CHAPTER 23: LIGHT ANIMATION. An overview of the backpack and cube light animation.
- CHAPTER 24: DISPLAY & PROCEDURAL FACE. Vector displays a face to convey his mood and helps forms an emotional connection with his human.
- CHAPTER 25: AUDIO PRODUCTION. A look at Vector's sound effects and how he speaks
- CHAPTER 26: MOTION CONTROL. At look at how Vector's moves.
- CHAPTER 27: ANIMATION FILE FORMAT. The format of Vector's binary animation file

PART VI: HIGH-LEVEL AI.

- CHAPTER 28: BEHAVIOR. A look at Vectors behaviors, and emotions.
- CHAPTER 29: EMOTION/MOOD MODEL. At Vector's emotions, where they come from and how they impact the sounds and choices he makes.
- CHAPTER 30: BEHAVIOR TREES. A look at how the behaviors are selected and their settings.

PART VII: MAINTENANCE. This part describes items that are not Vector's primary function; they are practical items to support Vector's operation.

- CHAPTER 31: SETTINGS, PREFERENCES, FEATURES AND STATISTICS. A look at how Vector syncs with remote servers
- CHAPTER 32: SOFTWARE UPDATES. How Vector's software updates are applied.
- CHAPTER 33: DIAGNOSTICS. The diagnostic support built into Vector, including logging and usage statistics.

REFERENCES AND RESOURCES. This provides further reading and referenced documents.

APPENDICES: The appendices provide extra material supplemental to the main narrative. These include tables of information, numbers and keys.

- APPENDIX A: ABBREVIATIONS, ACRONYMS, & GLOSSARY. This appendix provides a gloss of terms, abbreviations, and acronyms.
- APPENDIX B: TOOL CHAIN. This appendix lists the tools known or suspected to have been used by Anki to create, and customize the Vector, and for the servers. Tools that can be used to analyze Vector
- APPENDIX C: ALEXA MODULES. This appendix describes the modules used by the Alexa client
- APPENDIX D: FAULT AND STATUS CODES. This appendix provides describes the system fault codes, and update status codes.
- APPENDIX E: BODY-BOARD CONNECTOR AND PIN MAP. This appendix lists the electrical connections on the body-board.
- APPENDIX F: FILE SYSTEM. This appendix lists the key files that are baked into the system.
- APPENDIX G: BLUETOOTH LE SERVICES & CHARACTERISTICS. This appendix provides information on the Bluetooth LE interface GUIDs to the companion Cube, and to Anki Vector.
- APPENDIX H: SERVERS. This appendix provides the servers that the Anki Vector and App contacts.
- APPENDIX I: FEATURES. This appendix enumerates the Vector OS "features" that can be enabled and disabled; and the AI behavior's called "features."
- APPENDIX J: PHRASES. This appendix reproduces the phrases that Vector keys off of.
- APPENDIX K: EMOTION EVENTS. This appendix provides a list of the emotion events that Vector internally responds to.
- APPENDIX L: DAS EVENTS. This appendix describes the identified DAS events
- APPENDIX M: PLEO. This appendix gives a brief overview of the Pleo animatronic dinosaur, an antecedent with many similarities.

Note: I use many diagrams from Cozmo literature. They're close enough

1.1. ORDER OF DEVELOPMENT

A word on the order of development; the chapters are grouped in sections of related levels of functionality and (usually) abstraction.

Most chapters will description a vertical slice or stack of the software. The higher levels will discuss features and interactions with other subsystems that have not been discussed in detail yet. For instance, the section on the basic operation of Vectors hardware includes layers that link to the behavior and communication well ahead of those portions. Just assume that you'll have to flip forward and backward from time to time.

The communication interface has its own section with the relevant interactions, commands, structures and so on.

1.2. VERSION(S)

The software analyzed here is mostly version 1.5 and 1.6 of Vector's production software, as well as some of the development version of 1.7. There are incremental differences with each version; I have not always described the places that only apply to a specific version.

- Version 1.6 was the last release to customers as Anki ceased operation. This release includes more software elements that are unused, but are nonetheless telling.
- Version 1.7 was completed and released by Digital Dreams Labs.

1.3. CUSTOMIZATION AND PATCHING

What can be customized – or patched – in Vector?

- The software in the main processor may be customizable; that will be discussed in many areas of the rest of the document
- The body-board firmware is field updatable, and will take expertise to construct updates.
- The cube firmware can be updated, but that appears to be the hardest to change, and not likely to be useful.

1.4. CODE NAMES OR VECTOR VS VICTOR

Vector's working name during development – aka code name – was Victor. Early products used ad hoc code names. After the development of Cozmo, Anki used NATO phonetic alphabet code words for their products:

***Table 1:** Anki code names*

Product	Code Word	Description
	Bingo	A larger, two-wheeled self-balancing robot that was more dog-like in inspiration. It would have a larger battery, depth-sensing camera (instead of time of flight sensing), could traverse floors, etc. The software was based on Vector's. The large version (called Big Bingo) was requested by the investors for use in security related applications. The smaller, home unit is referred to as Mini Bingo, and initial prototypes were ~15 cm tall. *Note: Bravo is the correct NATO alphabet codeword, so that rule of thumb isn't 100%*
Cozmo	Cozmo	Cozmo a predecessor to Vector. Named after the pet Pomeranian dog (Cosmo) of Patrick DeNeale, an early employee.
Fast and Furious	Foxtrot	Part of the Anki Drive car racing products.
Overdrive	Overdrive	Part of the Anki Drive car racing products.
Drive	Rush Hour	Part of the Anki Drive car racing products.

Vector	Victor	The name Vector was selected both for its similarity to Victor, its uniqueness (e.g., not already trademarked), and working well as a trigger word across many accents and locales.
	Whiskey	This was intended to be a lower cost Cozmo, with less memory, less expensive plastics, only a single cube.

CHAPTER 1

Overview of Vector

Anki Vector is a cute, palm-sized robot; a buddy with a playful, slightly mischievous character. This chapter provides an overview of Vector:

- Overview of Vector and his features
- Privacy and Security
- Ancestry: Cozmo
- Alexa Built-in

2. OVERVIEW

Vector is an emotionally expressive, life-like, animatronic robot pet that people connect with and feel affection for.

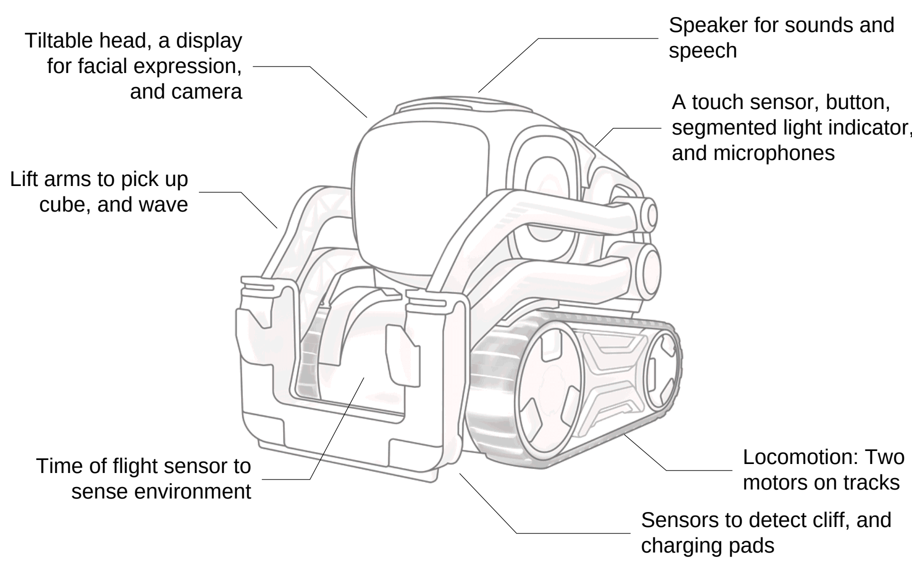

Figure 1: *Vector's main features*

2.1. COMPELLING CHARACTER

Anki's hallmark is that creating compelling, life-like robot characters, with film-style animations. What does that mean?

- A character has identifiable traits, and moods, something that we can empathize with.
- A compelling character *tries* but doesn't always succeed. As Pixar said, "we admire a character trying more than for their successes"
- He can sense the environment and has some awareness of what they and others are doing…
- He knows that he succeeded – or didn't – and that affects his mood.. So a character has moods, emotions and that affects what it does and how it does it.

- A living thing is never entirely at rest or silent; even when sleeping it moves a little and makes little sounds
- Movements vary and are never quite the same. When they look repetitive, they break the illusion. This is true for choices, reactions and other behaviors too.
- There are little motions, sounds and body's affect that anticipate what a character is thinking and going to do

Vector has a wide variety of behaviors, little motions (animations), and even some emotions that give him a personality. He can express emotions thru expressive eyes (on an LCD display), raising and lower his head, sounds, wiggling his body (by using his treads), or lifting his arms… or shaking them. He can sense surrounding environment, interact and respond to it. He can recognize his name[1], follow the gaze of a person looking at him, and seek petting.[2]

2.2. FEATURES

Although cute, small, and affordable,[3] Vector's design is structured like many other robots.

He has a set of operator inputs:

- A touch sensor is used detect petting
- Internal microphone(s) to listen, hear commands and sense the ambient activity level
- A button that is used to turn Vector on, to cause him to listen – or to be quiet (and not listen), to reset him (wiping out his robot-specific information).
- He can detect his arms and head being raised or lowered.

He has a set of indicators/annunciators:

- Segmented lights on Vector's backpack are used to indicate when he is on, needs the charger, has heard the wake word, is talking to the Cloud, can't detect WiFi, is booting, is resetting (wiping out his personality and robot-specific information).
- An LCD display, primarily to show eyes of a face. Robot eyes were Anki's strongest piece of imagery. Vector smiles and shows a range of expressions with his eyes.
- Speaker for cute sounds and speech synthesis

He has other means to express affect as well:

- His head can be tilted up and down to represent sadness, happiness, etc.
- His arms flail to represent frustration
- He can use his treads to shake or wiggle, usually to express happiness or embarrassment

He has environmental sensors:

- A camera is used to map the area, detect and identify objects and faces.
- Fist-bump and being lifted can be detected using an internal *inertial measurement unit* (IMU)
- A forward facing "time of flight" proximity sensor aids in mapping and object avoidance

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[1] Vector can't be individually named.
[2] Admittedly this is a bit hit and miss.
[3] Although priced as an expensive toy, this feature set in a robot is usually an order of magnitude more expensive, with less quality.

- Ground sensing proximity sensors that are used to detect cliffs at the edge of his area and to following lines when he is reversing onto his charger.

His internal sensing includes:

- Battery voltage, charging; charging temperature
- IMU for orientation and position (6-axis) tracking
- Encoders provide feedback on motor rotation

His other articulation & actuators are:

- Vector drives using two independent treads to do skid-steering
- Using his arms Vector can lift or flip a cube; he can pop a wheelie, or lift himself over a small obstacle.
- Vector can raise and lower his head

Communication (other than user facing):

- Communication with the external world is thru WiFi and Bluetooth LE.
- Internally RS-232 (CMOS levels) and USB

Motion control

- At the lowest level can control each of the motors speed, degree of rotation, etc. This allows Vector to make quick actions.
- Combined with the internal sensing, he can drive in a straight line and turn very tightly.
- Driving is done using a skid-steering, kinematic model
- To do all this, the motion control takes in feedback from the motor encoder, IMU-gyroscope. May also use the image processing for SLAM-based orientation and movement.

Guidance, path planning

- Vector plans a route to his goals – if he knows where his goal is – along a path free of obstacles; he adapts, moving around in changing conditions.
- A*, Rapidly-Expanding Random Tree (RRT), D*-lite
- Paths are represented as arcs, line segments, and turn points

Mapping and Navigation:

- Maps are built using *simultaneous location and mapping* (SLAM) algorithms, using the camera and IMU gyroscope movement tracking, time of flight sensor to measure distances, and particle system algorithms to fill in the gaps.
- The maps are represented uses quad-tree (position, pose)

Behaviour system:

- Variety of behaviors animations
- Goals, linking up to the guidance system to accomplish them
- A simple emotion model to drive selection of behaviours

Emotion model. Dimensions to emotional state:

- Happy (also referred to as his default state)
- Confident
- Social
- Stimulated

Vision. This is one of Anki's hallmarks: they used vision where others used beacons. For instance, iRobot has a set of IR beacons to keep the robots of out areas, and to guide it to the dock. Mint has an IR beacon that the mint robots use to navigate and drive in straight lines. Although Vector's companion cube is powered, this is not used for localization. It has markers that are visually recognized by Vector.

- Illumination sensing
- Motion sensing
- Links to Navigation system for mapping, (SLAM etc)
- Recognizing marker symbols in his environment
- Detecting faces and gaze detection allows him to maintain eye contact

3. PRIVACY AND SECURITY

Vector's design includes a well thought out system to protect privacy. This approach protects the following from strangers gaining access to:

- Photos taken by Vector
- The image stream from the camera
- The audio stream from the microphone — if it had been finished being implemented
- Information about the owner
- Control of the robot's movement, speech & sound, display, etc.

Vector's software is protected from being altered in a way that would impair its ability to secure the above.

4. COZMO

We shouldn't discuss Vector without mentioning the prior generation. Vector's body is based heavily on Cozmo; the mechanical refinements and differences are relatively small. Vector's software architecture also borrows from Cozmo and extends it greatly. Many of Vector's behaviours, senses, and functions were first implemented in Cozmo (and/or in the smartphone application). One notable difference is that Cozmo did not include a microphone.

Cozmo includes a wide variety of games, behaviours, and ~940 animation scripts. Cozmo's engine is reported to be "about 1.8 million lines of code, the AI, computer vision, path planning, everything."[4] This number should be discounted somewhat, as it likely includes many large 3rd party modules… Nonetheless, it represents the scale of work to migrate Cozmo's code base for reuse in Vector.

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[4] https://www.reddit.com/r/IAmA/comments/7c2b5k/were_the_founders_of_anki_a_robotics_and_ai/

Not all of Cozmo's functionality was ported to Vector at one time. Instead, key features and behaviours were incrementally brought to Vector in its regular software updates. It is likely the intent was to follow-up with much more in future updates, piling on features until September and then switch to a focus on bug fixes and stability for the upcoming Christmas sales. This was, perhaps, a faster schedule than they were able to deliver.

5. ALEXA INTEGRATION

Vector includes Amazon Alexa functionality, but it is not intimately integrated. Vector only acts like an Echo Dot, as pass thru for Alexa service. By using the key word "Alexa," Vector will suppress his activity, face and speech, and the Alexa functionality takes over. Vector has no awareness of Alexa's to-do list, reminders, messages, alarms, notifications, question-and-answers, and vice-versa; nor can he react to them.

The most likely reason for including Alexa is the times: everything had to include Alexa to be hip, or there would be great outcry. Including Alexa may have also been intended to provide functionality and features that Anki couldn't, to gain experience with the features that Amazon provides, and (possibly) with the intent to more tightly integrate those features into Anki products while differentiating themselves in other areas.

Alexa clearly took a lot of effort to integrate, and a lot of resources:

> "[Alexa Voice Service] solutions for Alexa Built-in products required expensive application processor-based devices with >50MB memory running on Linux or Android"[5]

Alexa's software resources consume as much space as Vector's main software. And the software is not power efficient. Even casual use of Alexa noticeably reduces battery life, and (anecdotally) increases the processor temperature.

See Appendix C for a list for a list of the Alexa modules.

[5] https://aws.amazon.com/blogs/iot/introducing-alexa-voice-service-integration-for-aws-iot-core/
Alexa's SDK and services have continued to evolve. New Alexa SDKs allow simpler processors and smaller code by acting as little more than a remote microphone.

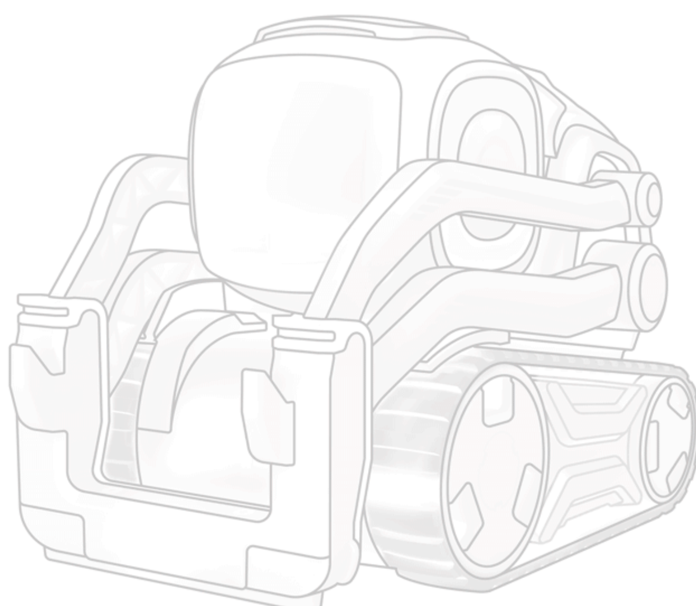
PART I

Electronics Design

This part provides an overview of the design of the electronics in Vector and his accessories

- VECTOR'S ELECTRONICS DESIGN. An overview of the Vector's electronics design.
- HEAD-BOARD ELECTRONICS DESIGN. A detailed look at the electronics design of Vector's main processing board.
- BACKPACK & BODY-BOARD ELECTRONICS DESIGN. A detailed look at the electronics design of Vector's backpack and motor driver boards.
- ACCESSORY ELECTRICAL DESIGN. A look at the electrical design of Vectors accessories.

Note: In previous versions called the circuit board in the bottom half the "*base-board".* It is now referred to as "body-board" to match Anki's naming



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CHAPTER 2

Electronics Design Description

This chapter describes the design of Vector's electronics:

- Design Overview, outlining the main subsystems
- Power distribution

Subsequent chapters will examine in detail the design of the subsystems

6. DESIGN OVERVIEW

Vector's design includes numerous features to sense and interact with his environment, other to interact with people and express emotion and behaviour.

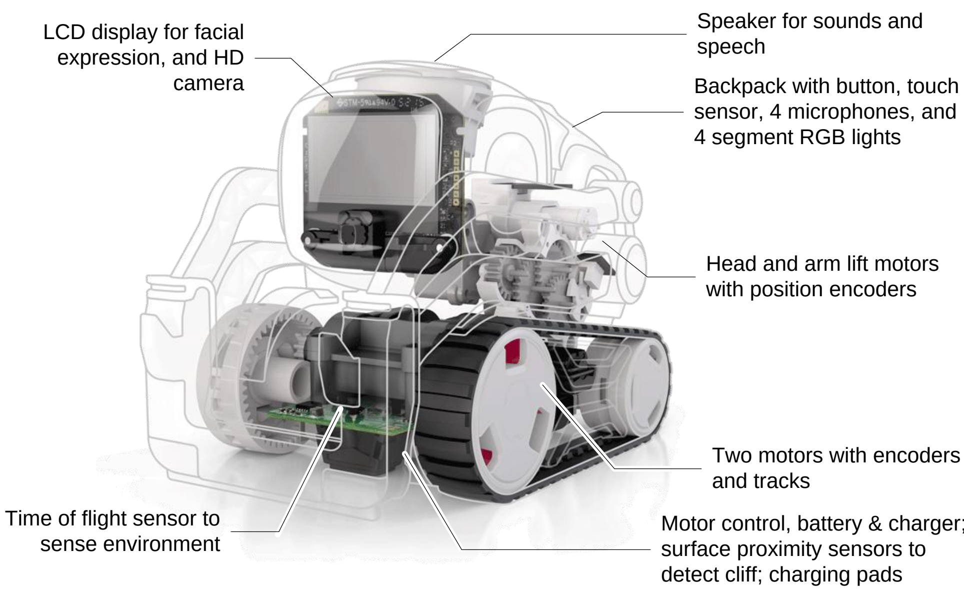

***Figure 2:** Vector's main elements*

Vector's functional elements are:

Table 2: Vector's main elements

Element	Description
backpack	The top of Vector, where he has a button, segmented lights, and a touch sensor.
battery	An internal battery pack is used as Vector's source of energy.
button	A momentary push button is used to turn Vector on, to cause him to listen – or to be quiet (and not listen) – to reset him (wiping out his personality and robot-specific information).
camera	Vector uses an HD camera to visualize his environment, and recognize his human companions.
charging pad	Two pads on the bottom are used to replenish the energy in the battery pack from the dock. The pads also serve as the communication interface during some manufacturing test steps.
LCD display	An IPS LCD, with an active area is 23.2mm x 12.1mm. It has a resolution of 184 x 96 pixels, with RGB565 color.
microphones	There are 4 internal far-field microphone(s) to listen to commands and ambient activity level. Employs beam forming to localize sounds.
motors & encoders	There are four motors each with single-step optical encoders to measure their position and approximate speed. One motor controls the tilt of the head assembly. Another controls the lift of his arms. Two are used to drive him in a skid-steering fashion.
segmented RGB lights	There are 4 LEDs used to indicate when he is on, needs the charger, has heard the wake word, is talking to the Cloud, can't detect WiFi, is booting, is resetting (wiping out his robot-specific information).
speaker	A speaker is used to play sounds, and for speech synthesis
surface proximity sensors	4 infrared proximity sensors are used to detect the surface beneath Vector – and to detect drop offs ("cliffs") at the edge of his driving area, and to follow lines.
time of flight sensor	A time of flight sensor is used to aid in mapping (by measuring distances) and object avoidance.
touch sensor	A touch allows Vector to detect petting and other attention.

Vector has 6 circuit boards

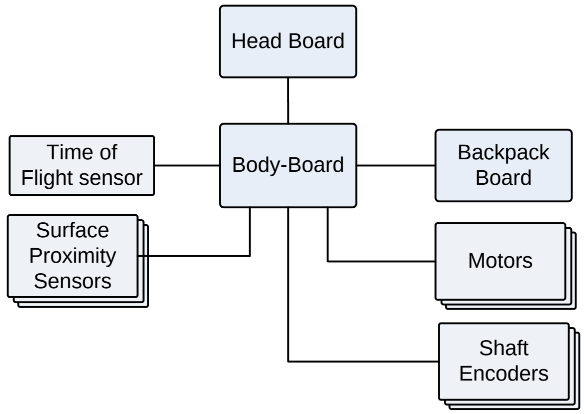

Figure 3: Circuit board topology

The main two boards are the head-board where the major of Vector's processing occurs, and the body-board, which drives the motors and connects to the other boards.

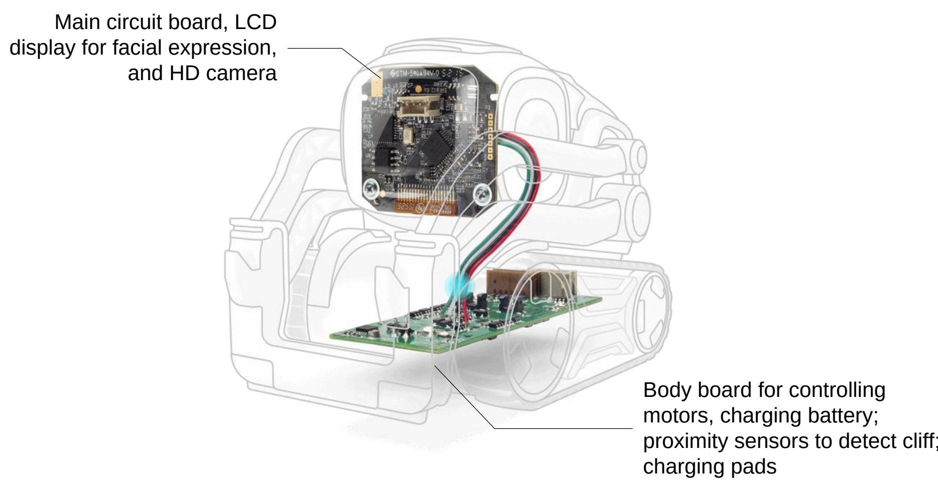

Figure 4: Vector's main microcontroller circuit boards

The table below summarizes the boards:

Table 3: Vector's circuit boards

Circuit Board	Description
backpack board	The backpack board has 4 RGB LEDs, 4 MEMS microphones, a touch wire, and a button. This board connects to the body-board.
body-board	The body board drives the motors, provides power management, and the battery charger. It has two photo-interrupters – one for each of the tread motors – to encode the speed of movement.
encoder-boards	The two encoder boards have dual-channel photo-interrupters each. These are used to monitor the position and direction of movement of the arms and head, either as driven by the motor, or by a person manipulating them.
head-board	The head-board includes the main processor, flash & RAM memory storage, an IMU, and a PMIC. The WiFi and Bluetooth LE are built into the processor. The camera and LCD are attached to the board, thru a flex tape. The speaker is also attached to this board.
time of flight sensor board	The time of flight sensor is on a separate board, allowing it to be mounted in Vector's front.

6.1. POWER SOURCE AND DISTRIBUTION TREE

Vector is powered by a rechargeable battery pack, and the energy is distributed by the body-board:

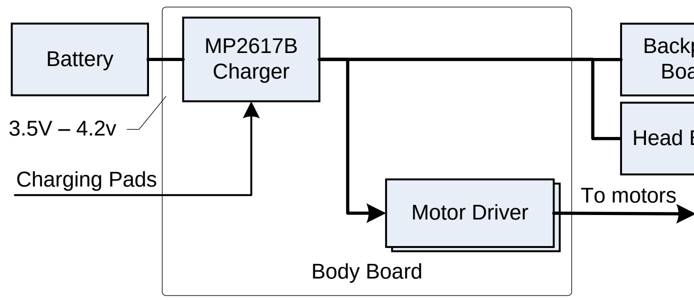

Figure 5: *Power distribution*

When the charging pads are energized – when Vector is in the charging dock – the system is powered by the external power source.

Excessive current demand – such as from a stalled motor – can trigger a system brown-out and shutdown.

6.1.1 Battery

battery

Vector battery is a single-cell 3.7v 320mAh "toy safe" lithium-ion polymer battery. The battery is connected to the body-board. The pack is not a "smart" battery – it only has positive and negative leads, lacking an onboard temperature sensor or battery management system (BMS).

Battery heat is the most significant source of battery "aging" – its effective service life. High recharge rates internally heat the cells, causing them to deteriorate. Vector's battery thinness gives it a high surface area to volume ratio allowing it shed heat much faster, greatly reducing the internal heating from charging and heavy loads. The battery is physically separated from the body-board, isolating it from the heat generated in the charging, power distribution and motor driver circuits. This increases the battery service life.

Vector takes care to thermally manage the battery, to promote a longer service life. The software monitors the body board temperature (as a proxy of the battery temperature). When the temperature gets above one or more thresholds (e.g. 50C), Vector can slow down or stops his activities and charging to allow the battery cool.

The battery has a low internal resistance. This reduces the internal heating and allowing it to usefully deliver higher currents without resulting in a brown-out. "Vector has brief but high (2A) peak currents when doing certain computations or flipping himself with his lift."

Anki engineers certainly desired easy-to-replace batteries, and larger batteries. But there were challenges. Battery replacement requires more parts and design features. A larger battery would allow longer play time between charges, but they often have higher internal resistance (thus more prone to brown out). So it would have taken finding one with good thermal characteristics (i.e. didn't get too hot), was toy safe despite holding more charge and chemicals, and so on. Ultimately schedule prevented finding a suitable larger battery.

6.1.2 Battery management

The MP2617B is a central element to managing the battery. It acts as a battery charger, a power switch and power converter for the whole system.

- When Vector is going into an *off* state – such as running too low on power, going into a ship state before first use, or has been turned off by a human companion – the MP2617B charger and power converted can be signaled to turn off.
- When Vector is turned off the boards are not energized. The exception is that the high side of the push button is connected to the battery. When closed, the signals the MP2617B to connect the battery to the rest of the system, powering it up.
- The MP2617B is also responsible for charging the battery. There are two pads that mate the dock to supply energy to charge the battery.

In many rechargeable lithium ion battery systems there is a coulomb counter to track the state of charge. Vector does not have one. The need for recharge is triggered solely on the battery voltage.

6.2. MANUFACTURING TEST SUPPORT

Vector has an interface for test and manufacturing. The charging pads allow limited communication with the software. This supports DVT testing, manufacturing tests, as well as entering the serial number and other per unit information. This access is removed after manufacturing test.

7. REFERENCES & RESOURCES

Anki, *Lithium single-cell battery data sheet*
https://support.anki.com/hc/article_attachments/360018003653/Material%20Safety%20Data%20Sheet_April%202018.pdf

CHAPTER 3

Head-board Electronics Design Description

This chapter describes the electronic design of Vector's head-board:

- Detailed design of the head-board

8. THE HEAD-BOARD (THE MAIN PROCESSOR BOARD)

The head-board handles the display, playing sounds, communication, and all of Vector's real processing. It is powered by a quad-core Arm-A7 Qualcomm APQ8009 microprocessor. The processor also connects to Bluetooth LE and WiFi transceivers, an HD camera, LCD display, speakers and an IMU.

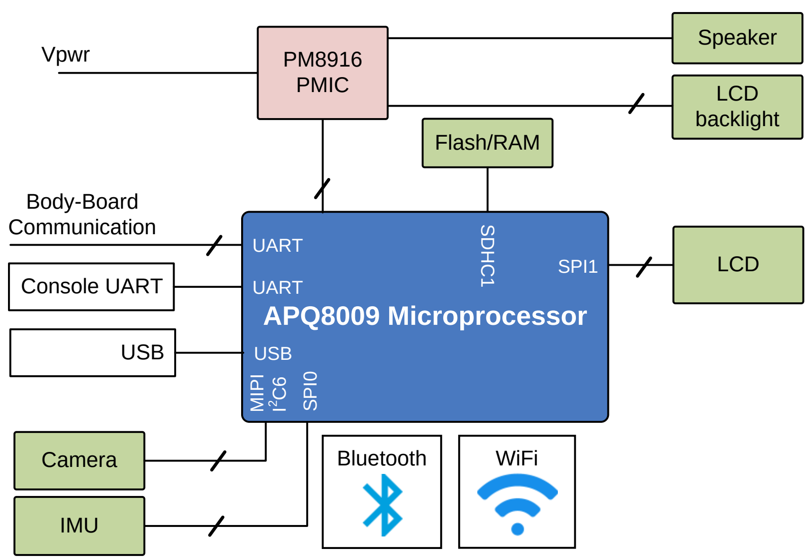

Figure 6: *Head-board block diagram*

The head-board's functional elements are:

Element	Description
Bluetooth LE transceiver	A Bluetooth LE transceiver is built into the package
camera	Vector uses a 720P camera to visualize his environment and recognize his human companions.
flash/RAM (eMMC)	Flash and RAM are provided by single external package, a Kingston 04EMCP04-NL3DM627 mixed memory chip with 4 GB flash and 512MB RAM.
inertial measurement unit (IMU)	The headboard includes a 6-axis IMU – gyroscope and accelerometer – used for navigation and motion control.
LCD backlight	There are two LEDs used to illuminate the LCD display.
LCD display	An IPS LCD, with an active area is 23.2mm x 12.1mm. It has a resolution of 184 x 96 pixels, with RGB565 color.
microprocessor	The head-board is based on a Qualcomm APQ8009 (Snapdragon 212). The processor is a quad-core Arm A7 (32-bit) CPU.
power management IC (PMIC)	The PM8916 power management IC provides voltage regulation for the processor, flash/RAM and other parts; it also provides audio out to the speaker and controls the LCD backlight.
speaker	A speaker is used to play sounds, and for speech synthesis
WiFi transceiver	An 802.11AC WiFi transceiver is built into the processor package

Table 4: *The head-boards functional elements*

8.1. THE APQ8009 PROCESSOR

The head-board is based on the Qualcomm "Snapdragon 212" APQ8009 SOC. It is a quad-core processor; each core is a 32-bit ARM Cortex A7. It also includes a DSP ("Hexagon 536"), and GPU (Adreno 304); these are not used by the software. It also includes WiFi and Bluetooth LE transceivers. The processor has interfaces to external memory, for the camera (using MIPI), the display, and the audio playback.

The APQ8009 processor is a sibling to the MSM8909 processor employed in cell phones, where APQ is short for "Application Processor Qualcomm" and MSM is short for "Mobile Station Modem." The difference is that the later includes some form of modem, such as HPSA, CDMA, or LTE. Both designators are used in software code-bases employed by Vector. The most likely reason is the naming of registers, drivers, and other useful software didn't carefully limit the use of MSMxxxx references to just the processors with modems.

The flash & RAM are connected to the processor on SDHC1. The device tree file shows that during development Vector's also supported an SD card slot on SDHC2.

The processor dynamically adjusts its clock frequency, within an allowed region. The processor can be configured to limit its speed.

8.2. SPEAKER

The speaker is driven at 16bits, single channel, with a sample rate of 8000-16025 samples/sec.

8.3. CAMERA

Vector has a 720p camera with a 120° field of view. The camera is calibrated at manufacturing time. The camera vertical sync (frame sync) is connected to the interrupt input on the IMU to synchronize the samples.

***Table 5:** The camera controls*

GPIO	Description
26	Camera interface clock
48	Camera reset
83	Camera power enable (from PM8916 PMIC)
94	Camera standby

8.4. THE LCD

LCD display

Vector's LCD is a backlit IPS display assembly made by Truly. The processor is connected to the LCD via SPI. Two LEDs are used to illuminate the LCD. The backlight is PWM controlled by the PM8916 PMIC.

US Patent 20372659

The prior generation, Cozmo, used an OLED display for his face and eyes. This display had the strengths of high contrast and self-illumination. However, OLEDs are susceptible to burn-in and uneven dimming or discoloration of overused pixels. Anki addressed this with two accommodations. First it gave the eyes regular motion, looking around and blinking. Second, the LCD's illuminated rows were regularly alternated to give a retro-technology interlaced row effect, like old CRTs.

Vector's IPS display gives a smoother imagery – Cozmo's OLED was simply black and white. The LCD is also much less susceptible to burn-in, at the expense of higher power. Vector's LCD can also develop dead lines (or pixels) that grow in number until the display is non-functional. Some units have a defective LCD, where the glass is not properly sealed. This allows moisture in, causing progressive damage to the LCD. It is also speculated that these lines come from shocks to the head, causing breaks in the LCD connections.

8.5. POWER MANAGEMENT

The PM8916 PMIC is responsible for providing power and managing most of the power. The headboard is capable of being the highest power consumer in Vector. By limiting the clock rate of the processor, the power use can be capped.

The headboard can be put into a lower power state by reducing the clock rate of processor and using its sleep features; dimming or turning off the LCD, and reducing the camera frame rate (or turning it off). The APQ8009 processor has many sophisticated power controls, but these were not fully realized in Vector's software.

8.6. TRIM, CALIBRATION SERIAL NUMBERS AND KEYS

Each Vector has a set of per unit calibrations:

- The camera is calibrated
- The IMU is calibrated

- The motor position is calibrated, this is performed with each startup

There are per unit keys, MAC addresses and serial numbers

- Each processor has its own unique key called the silicon-based hardware key (SHK), burned into its fuse mask. This key is used to with the Trust Zone, and secure boot; but it is not accessible outside of these. There are several modules (trustlets) that must run in the TrustZone, most provide security on keys that the main system uses. Each of these trustlets are signed with a certificate chain that is rooted in the unique hardware key. (That is, they cannot be copied and used on another processor.)
- The WiFi and Bluetooth have assigned, unique MAC addresses.
- Each Vector has an assigned serial number

8.7. MANUFACTURING TEST CONNECTOR/INTERFACE

It is a common practice to include at least one interface on a product for use during manufacture. This is used to load software and firmware, unique ids – WiFi MACs, serial number – to perform any calibration steps and to perform run-up checks that the device functions / is assembled correctly. It is intended to be a fast interface that doesn't cause yield fallout. Typically (but there are exception) this is not radio based, as they can interfere or have fiddly issues.

The USB interface is used to load firmware. The microprocessors include a built-in boot-loader (ABOOT), which includes support for loading firmware into the devices flash.

For the other functions, there are three possibilities

- There is a UART, that provides a boot console, but does not accept input
- There is a USB connector that probably is used to load firmware.
- The WiFi, once MAC addresses have been loaded into the unit

9. REFERENCES & RESOURCES

Kingston Technology, *Embedded Multi-Chip Package 04EMCP04-NL3DM627-Z02U*, rev 1.2, 2016
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https://www.qualcomm.com/products/apq8009

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https://developer.qualcomm.com/qfile/29367/lm80-p0436-35_c_pm8916pm8916_power_management_ics.pdf

CHAPTER 4

Backpack & Body-board Electronics Design Description

This chapter describes the electronic design of the Anki Vector's supplemental boards:

- Detailed design of the backpack-board, which is a peripheral to the body-board
- Detailed design of the body-board
- Power characteristics

See also Appendix E for the body-board connectors and pin maps.

10. THE BACKPACK BOARD

The backpack board is effectively daughter board to the body-board. It provides extra IO and a couple of smart peripherals:

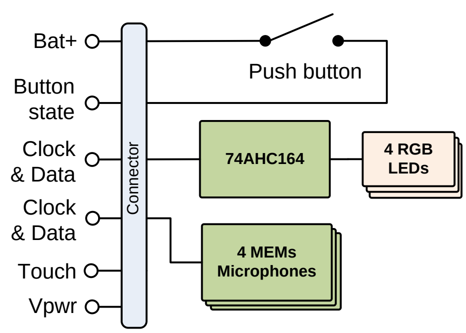

***Figure 7:** Backpack board block diagram*

The table below summarizes the functional elements of the backpack board:

Elements	Description
74AHC164	A SPI-like GPIO expander. This is used to drive the RGB LEDs.
microphones	There are 4 far-field MEMS PDM microphones. The microphones are accessed via SPI, in an output only mode. These are designated MK1, MK2, MK3, MK4
push button	A momentary push button is connected to the battery terminal, allowing a press to wake Vector, as well as signal the processor(s).
RGB LEDs	There are 4 RGB LEDs to make up a segmented display. Each segment can be illuminated individually (in a time multiplexed manner) or may share a colour configuration with its counterparts.
touch sensor	A touch-sensing wire (and passive components)

Table 6: *Backpack board functional elements*

10.1. BACKPACK CONNECTION

The backpack connection includes:

- Power and ground connections. This includes connection to the battery rail.
- The touch wire as an analog signal to the body-board
- A quasi digital signal out from the momentary push button
- A SPI-like clock, *two* master-in-slave-out (MISO) signals for the microphones
- A SPI-like clock and master-out-slave-in (MOSI) for the 74AHC164 LED controller

10.2. ELECTRO-STATIC DISCHARGE (ESD) PROTECTION

The touch sensing uses an insulated wire separated from the external touch plate. There is no direct path of conduction from the external plate for ESD. The separation reduces transient voltage to levels that the electronics can suppress.

10.3. OPERATION

The touch sensor conditioning and sensing is handled by the body-board. The touch sense wire is merely an extension from the body-board through the backpack board.

The push-button is wired to the battery. When pressed, the other side of the push button signals both body-board microcontroller, and (if Vector is off) the charger chip to connect power. The theory of operation will be discussed further in the body-board section below.

The 74AHC164 serial-shift-register is used as a GPIO expander. It takes a clock signal and serial digital input, which are used to control up to 8 outputs. The inputs determine the state of 8 digital outputs used to control the RGB LEDs.

Each of the 4 MEMS microphones take a clock signal, and provide a serial digital output. The body-board reads all four microphones by simultaneously. (This will be discussed in the body-board section).

10.3.1 The LED controls

Backpack LED control scheme corrections by Melanie T

8 outputs are not enough to drive 4 RGB LEDs (each with 3 inputs) simultaneously with independent colors. While 3 of the LEDs often the same colour , they can have independent colors.

There are two possible topologies that can multiple the RGB signals on the 74AHC164 directing different RGB configurations to each light.[6] The first possibility is two lights are driven at a time. LEDs 1 & 2 share the same red, green, and blue signals, but their low side is connected to separate GPIO lines, acting as a LED select. LEDs 3 & 4 are the same – sharing red, green, and blue. The even LEDs would share the same select line, and the odd LEDs would share the same. This is the simplest.

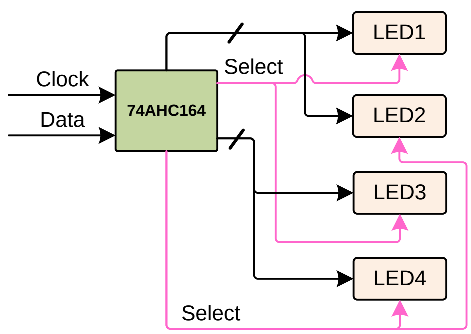

Figure 8: *Possible light topology on backpack board*

The process of illuminating the lights would be:

1. The firmware would send the RGB signals for LEDs 1 and 3, enabling them and disabling LEDs 2 and 4.
2. Delay
3. Repeat for LEDs 2 and 4

The second possibility is that each LED's red signal goes to the same signal on 74AHC164; similar for green and blue. However each LED's low side is connected to separate signals on 74AHC164.

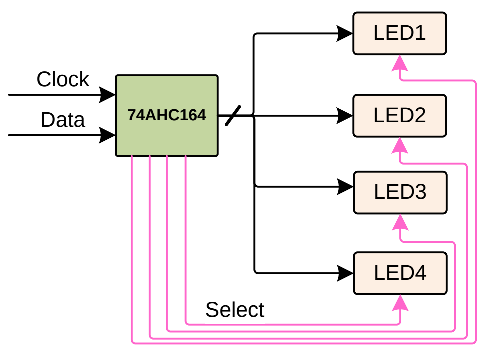

Figure 9: *Another possible light topology on backpack board*

This approach takes more work. The process of illuminating the lights in this configuration would be:

1. The RGB color and light 1 signal enables are sent, illuminating the first light
2. Then the RGB color and light 2 signal enables are sent – but the first light signal is disabled – illuminating the second light

[6] I'd need to physically examine a backpack board. This is the limit of examining the available photos

3. This is repeated for each of the other lights.

With either approach, if the switching between the LED's is done quickly enough – in a short time interval – the off period isn't visible. LED's don't immediate turn off, rather their brightness decays over a short period. And the human eye doesn't perceive short flickers. Although the lights are "pulse width modulated" – they are turned off a portion of the time, dimming them – current limiting resistors may have been set to achieve the desired maximum brightness for the fastest multiplexing time.

The body-board controller can dim the brightness of the LEDs further by choosing larger numbers of time slots to not illuminate a light.

11. THE BODY-BOARD

The body board is a battery charger, smart IO expander, and motor controller. It connects the battery to the rest of the system and is responsible for charging it. It is based on an STM32F030 which acts as second processor in the system.

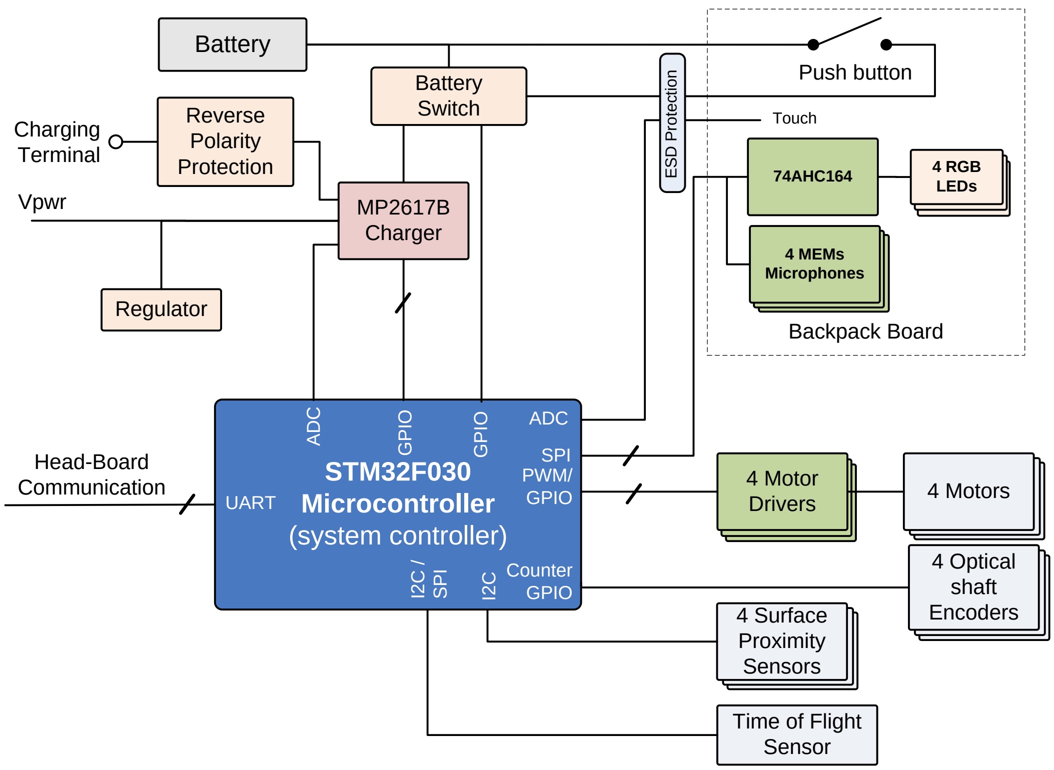

Figure 10: Body-board block diagram

The functional elements of the body-board are:

Table 7: The body-board functional elements

Element	Description
battery	An internal, rechargeable battery pack (3.7v 320 mAh)
battery switch	Used to disconnect the battery to support off-mode (such as when stored) and to reconnect the battery with a button press.
charging pad	Two pads on the bottom are used to replenish the energy in the battery pack from the dock. The right, positive charging pad acts a communication interface as well.
motor driver	There are four motor drivers, based on an H-bridge design. This allows a motor to be driven forward and backward.
motors	There are four motors: one motor controls the tilt of the head assembly; another controls the lift of his arms; and two are used to drive him in a skid-steering fashion.
MP2617B charger	The Monolithic Power Systems MP2617B serves as the battery charger. It provides a state of charge to the microcontroller. It also directs power from the charging pads to the rest of the system while the robot is on the charging dock.
optical shaft encoder	The 4 shaft encoders are implemented with photo-interrupters, in conjunction with a slotted disc on a motor's shaft, is used to measure the amount a shaft has turned, and its speed. The two tread motors use a Sharp GP1S092HCPIF photo-interrupter. The lift and head motors use a dual-channel photo-interrupter to allow discerning the direction of rotation.
regulator	A 3.3v regulator is used to supply power to the microcontroller and logical components.
reverse polarity protection	Protects the circuitry from energy being applied to the charging pads in reverse polarity, such as putting Vector onto the charging pads in reverse.
STM32F030 microcontroller	The "brains" of the body-board, used to drive the motors, and RGB LEDs; to sample the microphones, time of flight sensor, proximity sensor, temperature, and the touch sense;, and monitoring the battery charge state. It communicates with the head-board.
surface proximity sensors	4 infrared proximity sensors are used to detect the surface beneath Vector – and to detect drop offs ("cliffs") at the edge of his driving area and to follow lines.
VL53L0x time of flight sensor	A ST Microelectronics VL53L0x time of flight sensor is used to measure distance to objects in front of Vector. This sensor is connected by I^2C.

11.1. POWER MANAGEMENT

The battery charging is based on a MP2617B IC, which also provides some protection functions. There is no Coulomb counter; the state of charge is based solely on the battery voltage.

11.1.1 Protections

The charging pads have reverse polarity protection.

The MP2617B has an over-current cut off. If the current exceeds ~5A (4-6A), the battery will be disconnected from the system bus. Such a high-current indicates a short. There is no fuse.

The MP2617B has a low voltage cut off. If the battery voltage drops below ~2.4 (2.2-2.7V) the battery will be disconnected from the system bus (TBD) until the battery voltage rises above ~2.6V (2.4-2.8V).

The MP2617B may have a temperature sense. If the temperature exceeds a threshold, charging is paused until the battery cools. The temperature sense is not on the battery. It would be on the circuit board.

11.1.2 Battery connect/disconnect

To preserve the battery there is a need to isolate the battery from the rest of the system when in an off state. If there is minute current draw, the battery will irreversibly deplete while in storage even before the first sale. This constraint shapes the battery disconnect-reconnect logic. The schematic below shows one way to do this:

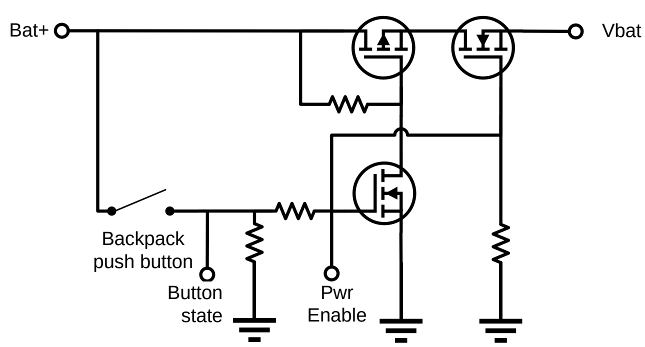

Figure 11: *A representative battery connect switch*

Two MOSFETS (a PFET and NFET)[7] act as a switch. These are in a single package, the DMC2038LVT. (This part is also used in the motor drivers.)

- When the system is in an off state, the MOSFETs are kept in an off state with biasing resistors. The PFET's gate is biased high with a resistor. The NFET gate is biased low, to ground. There is no current flow. Two MOSFETS are needed due to internal body diodes. The PFET body diode would allow current to flow from the battery (from the source to the drain). However, this current is blocked by the NFET body diode, which has a different polarity
- The push button can wake the system. When the button is closed, the battery terminal (Bat+) is connected to the gate of the NFET, turning it on. A second NFET is also energized, pulling the PFET gate to ground, turning it on as well. When the button is open, Bat+ is not connected to anything, so there is no leakage path draining the battery.
- To keep the system energized when the button is open, the STM32F030 MCU must drive the Pwr Enable line high, which has the same effect as the button closed. The gate threshold voltage is 1V, well within the GPIO range of the MCU.
- The MCU can de-energize the system by pulling Pwr Enable line low. The switches will open, disconnect the battery.
- The MCU needs to be able to sense the state of the button while Pwr Enable is pulled high. The MCU can do this by sampling the Button State signal. This signal is isolated from from Pwr Enable by a large resistor and pulled to ground by smaller resistor. This biases the signal to ground while the button is open.

This circuit also provides reverse polarity protection. It will not close the switch if the battery is connected backwards.

11.1.3 Charging

charging station pads

The charging station pads are connected to a MP2617B charger IC thru a reverse polarity protection circuit. The reverse polarity protection[8] is a DMG2305UX PFET in a diode

[7] Q11 and/or Q12
[8] Q14

configuration.   This approach has much lower losses than using an equivalent diode.

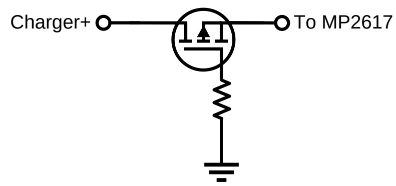

***Figure 12:** A representative PFET based reversed polarity protection*

supplying power from the charging station

The MP2617B internally switches the charger input voltage to supply the system with power, and to begin charging the battery. This allows the charger to power the system whenever the robot is in the charging station, even when the battery is depleted, or disconnected.

The presence of the dock power, and the state of MP2617B (charging or not) are signaled to the microcontroller.

charging states

The charger goes through different states as it charges the battery. Each state pulls a different amount of current from the charging pads and treats the battery differently.

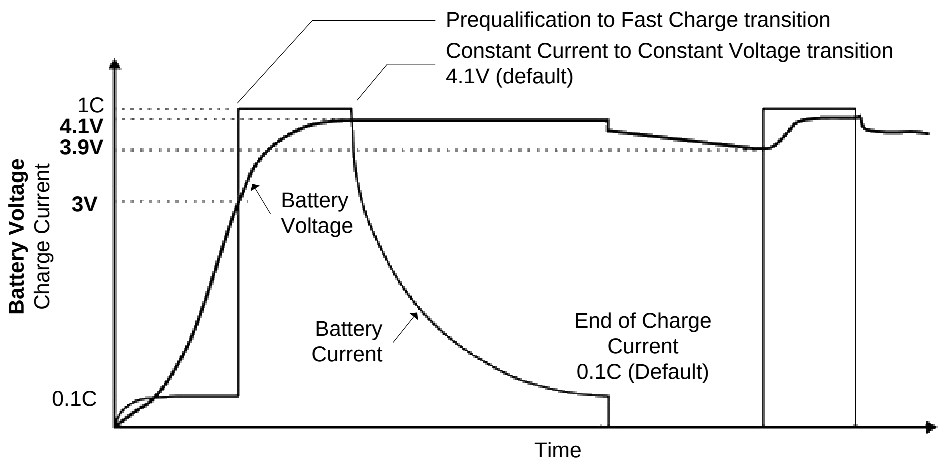

***Figure 13:** Charging profile* (adapted from Texas Instruments)

constant current constant voltage

The basic idea is that the charger first applies a low current to the battery to bring it up to a threshold; this is called *prequalification* in the diagram. Then it applies a high current, call *constant current*. Once the battery voltage has risen to a threshold, the charger switches to *constant voltage*, and the current into the battery tapers off. I refer to the data sheet for more detail.

The MP2617B measures the battery temperature by proxy using a thermistor on the PCBA. If the temperature exceeds a threshold, charging is paused until the battery cools. The microcontroller also samples this temperature.

input current limits

The MP2617B supports limiting the input current, to accommodate the capabilities of external USB power converts. There are four different possible levels that the IC may be configured for: 2A is the default limit, 450mA to support USB2.0 limits, 825mA to support USB3.0 limits, and a custom limit that can be set by resistors. The input limit appears to be set for either default (up to ~2A input), or a programmable input.

Higher charge rates are acceptable

Commentary. In my testing, using a USB battery pack charging pulls up to 1A during the constant current, then falls off to 100mA-200mA during constant voltage, depending on the head-board's processing load. Stepped down to the ~4V battery the applied current at peak is approximately 1A.[9]

With larger batteries this would be too high. Battery cells are normally charged at no more than a "1C" rate – e.g. the battery maximum charge rate "should" be 320mA at max. Vector's battery can be charged at a rate higher than 1C. Heat is what damages batteries. This battery's low internal resistance doesn't produce as much heat; and its large surface to volume ratio lets it shed heat.

11.1.4 Brown-out

motor stall & brown out effects

The motor stall current is enough to cause Vector to brown-out and shut down unexpectedly. This indicates two possible mechanisms:

- If the system browns out the STM32F030, the MCU will no longer hold the power switch closed, and the system power will be disconnected.
- If the current exceeds a threshold, the MP2617B will disconnect power to the system. This threshold is very high – ~5A – and is unlikely to ever be encountered in operation.

Commentary: It may be interesting to modify either the MCU's Vdd to have a larger retaining capacitor, or to add a current limiting mechanism for the motors, such as an inline resistor.

11.1.5 Reducing power

The sensors – the encoders, cliff sensors, and time of flight sensor – have power controls. This allows them to be turned off to reduce power consumption. The time of flight sensor's sampling and communication interval can be controlled to greatly reduce power consumption, while still providing measurements. The other sensors can be duty cycled to maintain a lower power use, but still detect activity (albeit not measure it accurately).

11.2. ELECTRO-STATIC DISCHARGE (ESD) PROTECTION

The body-board employs a Vishay GMF05, TVS diode (U4) for electro-static discharge (ESD) protection, likely on the pushbutton and touch input.

11.3. STM32F030 MICROCONTROLLER

The body-board is controlled by a STM32F030C8T6 microcontroller (MCU), in a LQFP48 package. This processor essentially acts as a smart IO expander and motor controller. The microcontroller is also referred to as the *system controller*

The MCU's digital inputs include:

- 4 photo-interrupters used as shaft encoders, one for each motor (left, right, head, lift)
- Charger state

The MCU's digital outputs include:

- 12 motors driver signals
- Charger enable
- Power controls for the sensors

[9] Other reports suggest up to 2As into the battery, possible with the use of high-power USB adapters intended to support tablet recharge. As a preventative measure, I have a current limiter between my USB power adapter and Vector's charging dock. 1Ω on the USB power. I tried 1Ω -14Ω; these should have limited the current to 1A and 500mA respectively. Instead, Vector would only pull 40mA - 370mA; in many cases, not enough to charge. Most likely the resistor acted as a part of resistive divider and undermined the chargers feedback loops.

The MCU's analog inputs include:

- Touch sensor; the momentary push button works by pulling this signal high
- Battery voltage
- Charging pad voltage
- Temperature sensor (measured internally)

The communication signals include:

- 2 SPI-like signals to LED outputs. Uses a clock and data line to send the state to the LEDs.
- 6 SPI from microphones – an SPI MCLK to clock out, a timer divider (in and out), and 2 MISO to receive state of the data from the microphones.
- 4 I^2C pins for communication with the time of flight sensor and IR proximity sensors used to detect cliffs and lines,
- 2 UART, for communication with the head board

Note: The microcontroller does not have an external crystal and uses an internal RC oscillator instead.

11.3.1 Manufacturing test connections

The body-board includes SWD pads intended for programming at manufacturing time. After programming, the firmware cannot be updated via the SWD pads (more on this below). The firmware can only be updated via a boot-loader.

The body-board also provides RS232-style bidirectional communication that can be used issue commands, query results, and store calibration and serial number information. See Chapter 12 *Body-Board Communication Protocol* for more information. The positive (right hand) charging contact is used for this communication.[10]

11.3.2 Firmware updates

The firmware is referred to as "`syscon`" (as in "system controller"). The microcontroller includes a boot loader, allowing the firmware to be updated by the head-board. The firmware can be updated in OTA software releases.

STM32 Readout-protection is set to the highest level in the microcontroller. This is intended to prevent a SWD-based reading or modification of the firmware (including the boot-loader). STM32 processors include a different boot-loader from ST as well; this alternative boot-loader will crash if any access to program memory is attempted with the readout protection flags set. It is possible to disable the read-out protection – but mass erasing the chip in the process – with physical access and SWD tools.[11] To extract the boot-loader will more skilled and invasive techniques.[12]

Future changes to the body-board firmware will require expertise. The STM32F030 firmware can be analyzed using the `syscon.dfu` file (or be extracted with a ST-Link) and disassembled. Shy of recreating the firmware source code, patches replacing a key instruction here and there with a jump to the patch, created in assembly (most likely) code to fix or add feature, then jump back.

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[10] According to the forums, this is also present on Cozmo and Drive.
[11] https://stackoverflow.com/questions/32509747/stm32-read-out-protection-via-openocd
[12] https://rtfm.newae.com/Capture/ChipWhisperer-Nano/
https://www.cl.cam.ac.uk/~sps32/mcu_lock.html

Emulation (such as QEMU-STM32) , ST-link ($25) and a development environment will be required to debug and modify the firmware initially. The development environment ranges from free to several thousand dollars, the later being the more productive tools.

11.4. SENSING

11.4.1 Temperature sensing

The body-board measures temperature using the microcontrollers internal temperature sense. This value is higher than the ambient, and can bounce around with activity. The firmware filters the value to reduce the noise.

11.4.2 Time of Flight sensor

The MCU interfaces with a ST Microelectronics VL53L0x time of flight sensor, which can measure the distance to objects in front of vector. It "has a usable range 30mm to 1200mm away (max useful range closer to 300mm for Vector) with a field of view of 25 degrees."

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These sensors work by timing how long it takes for a coded pulse to return. The time value is then converted to a distance. Items too close return the pulse faster than the sensor can measure. The measured distance is available to the microcontroller over I^2C.

11.4.3 Proximity sensing

Vector has 4 IR proximity sensors that are used to used to detect drops offs ("cliffs") and to follow lines. The exact model hasn't been identified, but the Everlight EAAPMST3923A2 is a typical proximity sensor. The sensor is an LED and IR detector pair. The sensor reports, via I^2C, the brightness sensed by the detector.   A sensor often pulses its emitter, to reject to sunlight; and uses a configurable threshold to reduce sensitivity to ambient light.

The IR proximity sensors all share the same I^2C address. To address this, the body board does something clever. The STM32F030 allows switching the pins that the I^2C clock and data lines go to. The cliff sensors are connected so that no two shares both the same data and clock line – that is the clock and data lines combinations are unique to the device being talked with. The firmware rotates thru which pins to use with I^2C to talk to each of the four different cliff sensors. The pins on the micro are reconfigured to use each of these.

11.4.4 Touch sensing

The touch sensing works by alternating pulsing and sampling (with the ADC) the touch wire. The samples will vary "by various environmental factors such as whether the robot is on its charger, being held, humidity, etc."

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11.4.5 Motor encoders

The position encoders are built using photo-interrupters. The tread motors have slotted photo-interrupters with a single emitter and detector. The detectors are connected to pins capable of raising interrupts.

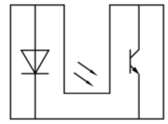

Figure 14: *Single channel slotted photo-interrupter*

The lift and head motors have dual channel photo-interrupters – two detectors. This allows discerning the direction of rotation, by the sequence that the detectors trigger in.

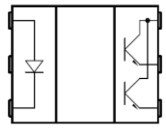

***Figure 15:** Dual channel slotted photo-interrupter*

Power control: The microcontroller has a pin connected to the low side of the emitters. When set low, the emitters are powered (connect to ground); otherwise the emitters are in a low power state.

11.4.6 PDM Microphones

SPI communication with 4 microphones simultaneously

The body-board is responsible to driving and sampling the 4 PDM MEMs microphones. The communication with the backpack board to accomplish this is unique: the four microphones are read at a time, using a shared SPI clock and two separate data lines.

The microphones take a clock signal as input, and always drive one bit per clock; they have no chip select. Two microphones can share a single data line. We'll refer to them as "left" and "right" here.

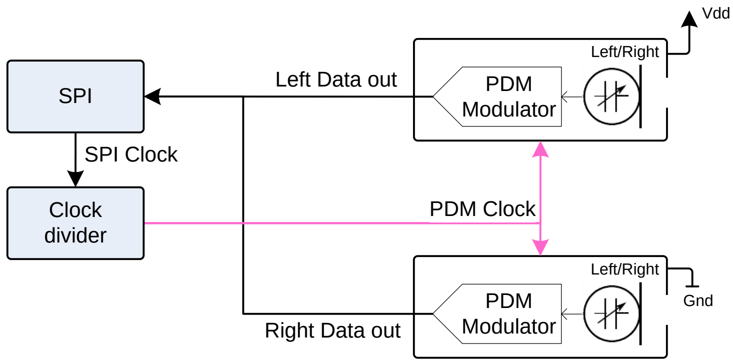

***Figure 16:** Sampling two microphones with a single SPI master* (adapted from ST Microelectronics)

Pulling the left microphone's "left/right" signal low will configure it to emit the data bit while the PDM clock is low. It does not drive the data line when the clock is high. Similarly, pulling the right microphone's "left/right" signal high on will cause it to drive the data bit while the PDM clock is high.

SPI, however, only receives data bits on the clock's falling transition– not the rising edge. The trick is to run the SPI clock at twice the frequency of the PDM clocks, so that the SPI clock's first transition low is for the left microphone bit, and the second transition low is for the right microphone. This is done by dividing the SPI clock by two to produce the PDM clock to the microphones:

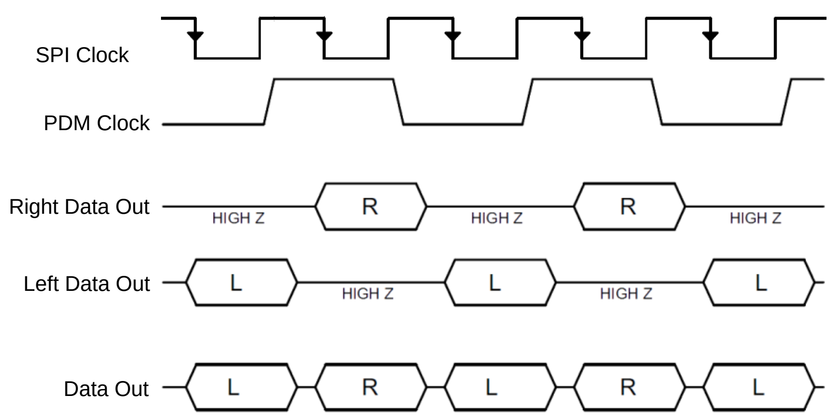

***Figure 17:** Microphone clock and signals*

The received data bits (in each byte) will alternate between the left and right microphones, and will need to be separated and converted by firmware. The SPI peripheral along with a DMA can be configured to clock in large batches of bytes into a buffer for further processing.

Dividing the clock by two can be performed by a timer built into the STM32. The SPI clock signal is connected to the input of an STM32 timer (TIMxCHIN). The timer is configured to use an external input clock source, and generate an output after a divide by two. The output of the timer (TIMxCHOUT) can then be used as the clock for the PDM microphones.

The clock rates have a limited range on the body board. PDM MEMS microphones clock rates must be in the range 1 MHz to 3.25MHz. (The products are pretty consistent about this range.) The SPI clock rate is 2x that PDM's clock, so the SPI clock rate must be in the range of 2MHz to 6.5MHz. The ST processor's clock is 48MHz, and its SPI clock must be this frequency divided by a power of two. This means there are only two possibilities: A 32:1 divider gives an SPI clock frequency of 6 MHz, and A 16:1 divider gives a clock rate of 3 MHz.

This approach can be extended to sample all four microphones, by coordinating with a second SPI peripheral:

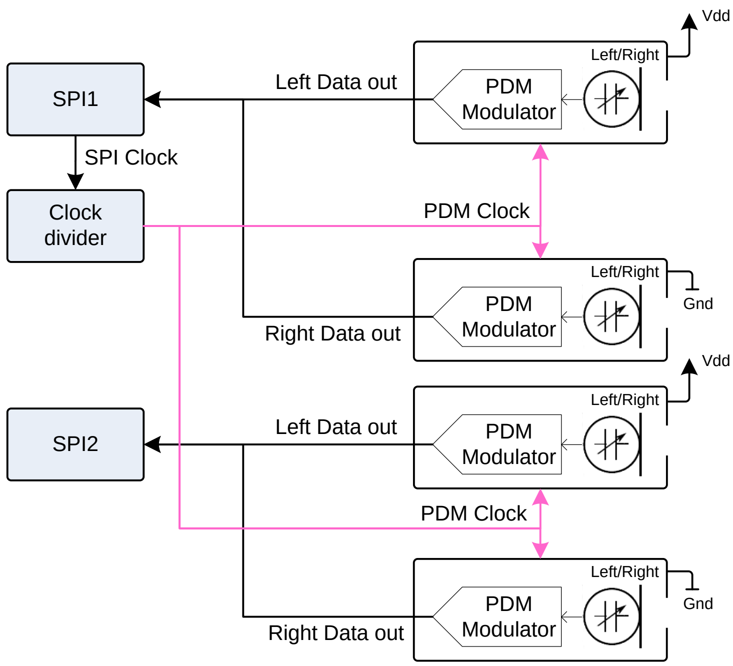

Figure 18: *Sampling four microphones with two SPI masters* (adapted from ST Microelectronics)

11.5. OUTPUTS

11.5.1 Light control

An earlier section (see section *10.3.1 The LED controls*) described how the 74AHC164 receives its GPIO settings from a serial interface, and uses these to illuminate the LED segments within 4 RGB LEDs.

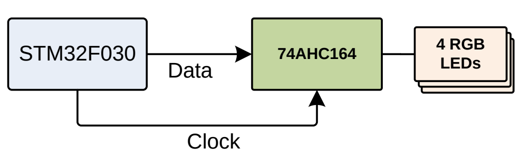

Figure 19: *SPI-like interface to the 74AHC164 and RGB LEDs*

The 74AHC164 does not share a clock or data line with the PDM's microphones. The data and clock are bit-banged – the firmware manually raises and lowers the clock and data lines to send the data.

Note: care must be taken so that an extra clock edge isn't received by the 74AHC164. (For instance, during body board initialization.)   There is no synchronization to indicate the first bit of the 8 bits sent to the 74AHC164.

11.5.2 Motor Driver and control

Each motor driver is an H-bridge, allowing a brushed-DC motor to turn in either direction.

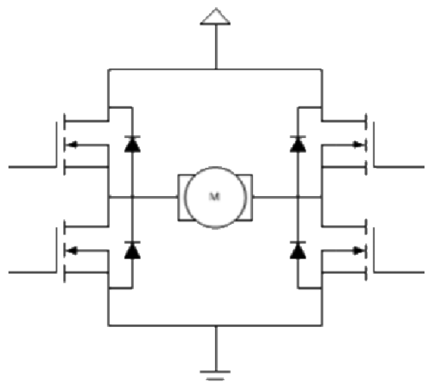

Figure 20: *Motor driver H-bridge*

Each side of the H-bridge based on the DMC2038LVT, which has a P-FET and N-FET in each package. Two of these are needed for each motor.

The MCU (probably) independently controls the high side and low side to prevent shoot thru. This is done by delaying a period of time between turning off a FET and turning on a FET. The microcontroller drives the PFET by using its GPIO output in open-collector/open-drain configuration: it turns the FET on by pulling gate low, and lets a resistor pull the gate high (to battery supply) to turn the FET off.

The motors can be controlled with a control loop that takes feedback from the optical encoder to represent speed and position.   The firmware must take care to prevent burn out if they have been stalled at full power for 15 seconds or more.

11.6. COMMUNICATION

The communication protocols are described in Chapter 12.

11.7. COMMUNICATION WITH THE HEAD-BOARD

The body-board communicates with the head-board via RS-232 3.3V (3 Mbits/sec[13]). As the MCU does not have a crystal, there may be communication issues from clock drift at extreme temperatures; since Vector is intended for use at room temperature, the effect may be negligible.

The body-board does something clever to communicate at such a high rate, while supporting the other functions. The issue is that the microcontroller does not have enough DMA resources for the UART and the SPI channels. The DMA has fixed channels to support the SPI receive, but this is

[13] Value from analyzing the firmware, RAMPOST and vic-switchboard programs. Melanie T measured it on an oscilloscope and estimated it to be 2Mbps.

the same as the channel available for the UART TX. But there are two remaining DMA channels available for the UART RX function.

To send data to the head board, the firmware retasks one of these DMA channels. The DMA peripheral doesn't care which address it sends to or receives from; nor does it enforce direction. What it means to be a "UART RX" channel is that it looks at the high bits of the address of the peripheral it is connected to – the UART in this case – and uses that to transfer each byte when a "received byte" event is received from the UART. The firmware configures the DMA channel to transfer a byte to the UART TX channel… and the DMA will transfer a byte only when the UART receives a byte. To ensure that a byte is received, a weak resistor is connected from the TX to the RX line so that the UART is receiving each byte it sends, triggering the next byte to be sent.

The firmware can be updated over the serial communication by the head-board.

11.7.1 Communication with manufacturing test station

The body-board communicates with the test station using a RS-232 1.8V (115.2 Kbits/sec[14]) half-duplex protocol. The communication pin is also used for measuring the charger input voltage.

The firmware can be updated over the serial communication by the head-board.

Note: this communication is only implemented in DVT firmware; it is not implemented in production firmware.

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[14] Value from analyzing the firmware.

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CHAPTER 5

Accessory Electronics Design Description

This chapter describes the electronic design of the Anki Vector accessories:

- The charging station
- The habitat (Vector space)
- The companion cube

13. CHARGING STATION

The charging station is intended to provide energy to Vector, allowing him to recharge.

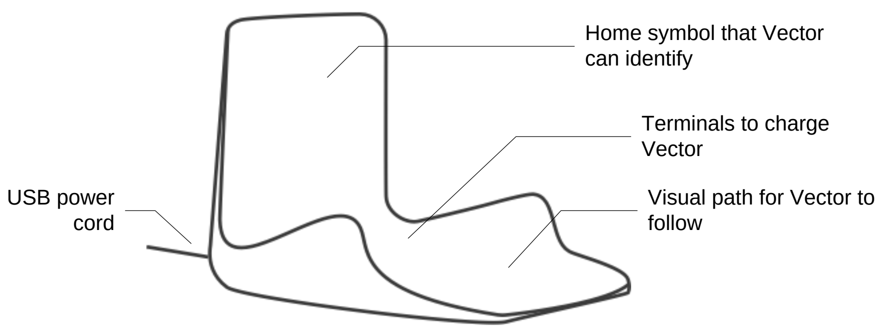

Figure 21: *Charging station main features*

The charging station has a USB cable that plugs into an outlet adapter or battery. The adapter or battery supplies power to the charging station. The base of the station has two terminals to supply +5V (from the power adapter) to Vector, allowing him to recharge. The terminals are offset in such a way to prevent Vector from accidentally being subject to the wrong polarity. Vector has to be backed into charging station in mate with the connectors. Vector face-first, even with his arms lifted, will not contact the terminals.

The charging station has an optical marker used by Vector to identify the charging station and its pose (see chapter 21).

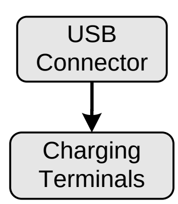

Figure 22: *Charging station block diagram*

14. HABITAT (VECTOR SPACE)

Vector's habitat – cheekily called a Vector Space – is a 12"x12" tray with curved edge, and a corner for a charging dock to sit. It serves as a place that Vector can be active in during the day, without driving off of the table or getting lost. This lets him remain powered on, and respond when his human companion returns. When a person would like to play with Vector, they would take him out of this little area.

There seems to be some references to the habitat in the behavior tree, and in the developer visualization tools to habitat. It is possible that they created or were creating the ability for Vector to recognize the habitat and adjust his behaviors. The bottom of the habitat is dark, but with a thick white line around the perimeter near the edge. The line likely serves as a signal to Vector to turn away before running into the edge, or to drive along. It may be detected by Vector's cliff sensors.

15. CUBE

The companion cube is a small toy for Vector play with. He can fetch it, roll it, and use it to pop-wheelies. Each face of the cube has a unique optical marker used by Vector to identify the cube and its pose (see Chapters 19 and 21).

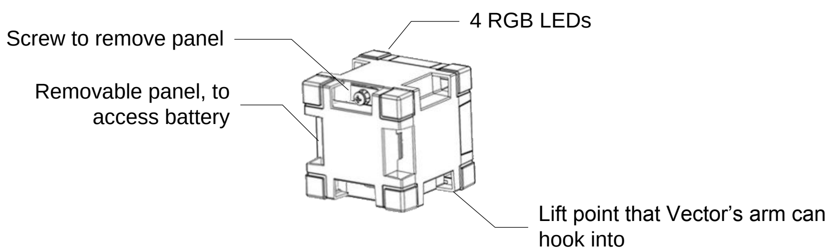

Figure 23: *Cube's main features*

Although the companion cube is powered, this is not used for localization or pose. The electronics are only used to flash lights for his human companion, and to detect when a person taps, moves the cube or changes the orientation.

The cube has holes near the corners to allow the lift to engage, allowing Vector to lift the cube. Not all corners have such holes. The top – the side with the multicolour LEDs – does not have these. Vector is able to recognize the cubes orientation by symbols on each face, and to flip the cube so that it can lift it.

The electronics in the cube are conventional for a small Bluetooth LE accessory:

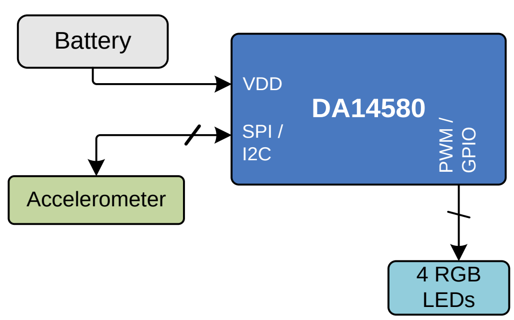

Figure 24: *Block diagram of the Cube's electronics*

The Cube's electronic design includes the following elements:

Element	Description
accelerometer	The accelerometer is used to detect movement and taps of the cube.
battery	The cube is powered by a 1.5 volt N / E90 / LR1 battery cell.[15]
crystal	The crystal provides the accurate frequency reference used by the Bluetooth LE radio.
Dialog DA14580	This is the Bluetooth LE module (transmitter/receiver, as well as microcontroller and protocol implementation).
RGB LEDs	There are 4 RGB LEDs. They can flash and blink. Unlike the backpack LEDs, two LEDs can have independent colors.

***Table 8:** The Cube's electronic design elements*

The communication protocol is described in Chapter 14, and the GUIDs for the services and characteristics are given in Appendix G.

15.1. OVER THE AIR APPLICATION FIRMWARE DOWNLOAD

The DA14580 has a minimal ROM boot loader that initializes hardware, moves a secondary boot loader from "One Time Programmable" ROM (OTP) into SRAM, before passing control to it. The firmware is executed from SRAM to reduce power consumption. The secondary boot-loader is passed the application firmware from Vector over Bluetooth LE. This application is loaded into SRAM and passed control.

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[15] The size is similar to the A23 battery, which will damage the cube's electronics.

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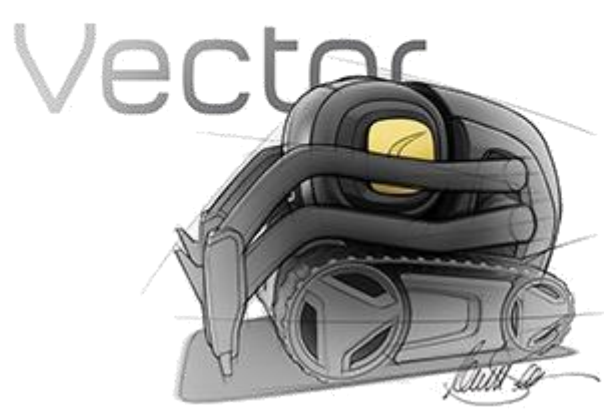
PART II

Basic Operation

This part provides an overview of Vector's software design.

- THE SOFTWARE ARCHITECTURE. A detailed look at Vector's overall software architecture and main modules.
- STARTUP. A detailed look at Vector's startup and shutdown processes
- POWER MANAGEMENT. A detailed look at Vector's architecture for battery monitoring, changing and other power management.
- BASIC INPUT AND OUTPUT. A look at push button, touch sensing, surface proximity sensors, time of flight proximity sensing, and backpack LEDs.
- INERTIAL MOTION SENSING



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CHAPTER 6

Architecture

This chapter describes Vector's software architecture:

- The architecture
- The emotion-behaviour system
- The communication infrastructure
- Internal support

16. OVERVIEW OF VECTOR'S COMMUNICATION INFRASTRUCTURE

Vector's architecture has a structure something like:

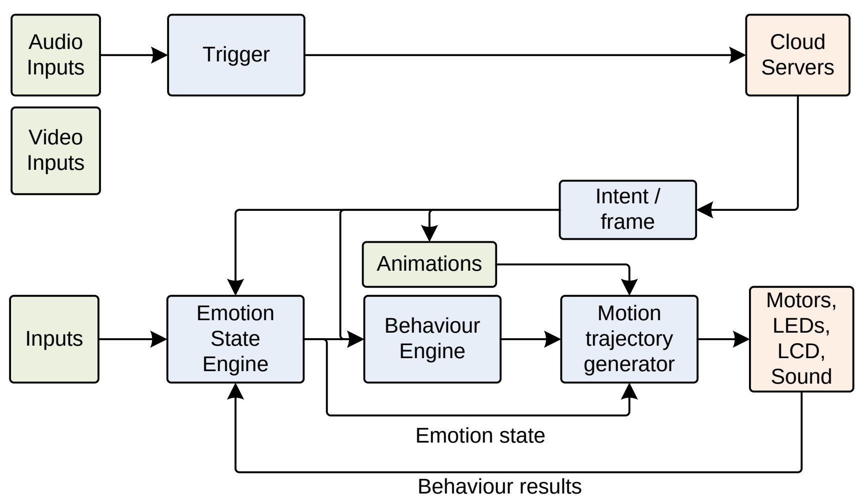

***Figure 25:** The overall functional block diagram*

Fast control loops — to respond quickly — are done on the Vector's hardware. Speech recognition, natural language processing – very processing heavy items – are sent to the cloud. Face recognition, and training for faces are not sent to the cloud.

Vector is built on a version of Yocto Linux. Anki selected this for a balance of reasons: some form of Linux is required to use the Qualcomm processor, the low up front (and no royalty) costs, the availability of tools and software modules. Qualcomm pushes the Android stack of tools in particular for their processors. The Qualcomm is a multi-processor, with four main processing cores and a GPU. Vector runs a handful of different application programs, in addition to the OS's foundational service tasks and processes.

explored in Casner, *and* Wiltz

16.1. APPLICATION SERVICES ARCHITECTURE

Vector's software is divided into the following services:

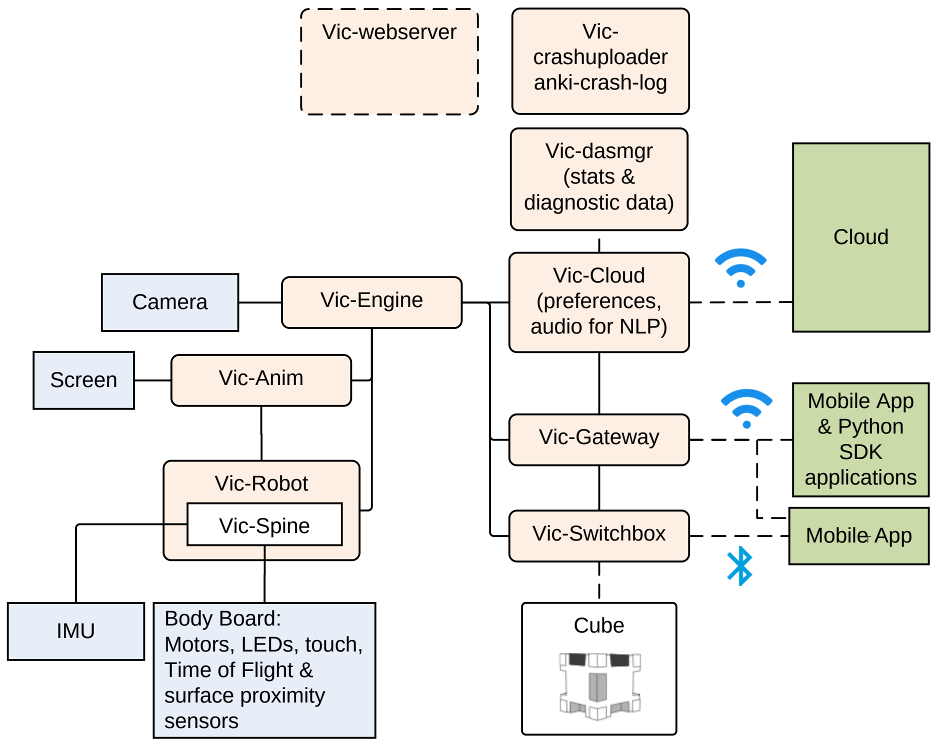

***Figure 26:** The overall communication infrastructure*

These services are:

***Table 9:** Vector services & processes*

Services	Speculated purpose
vic-anim	This service plays multi-track animations (which include motions as well as LCD display and sound) config file: /anki/etc/config/platform_config.json /anki/data/assets/cozmo_resources/webserver/webServerConfig_anim.json
vic-bootAnim	LCD and sound animations during boot.
vic-cloud	This service connects to the cloud services for natural language services.
vic-crashuploader anki-crash-log	A service that sends logs (especially crash logs and mini-dumps) to remote servers for analysis.
vic-dasmgr	Gathering data on processor and feature usage, servin as a foundation for gathering data when performing experiments on settings and features.
vic-engine	The vision system and behaviour / emotion engine. Hooks into the camera and face recognizer.
vic-gateway	Responsible for the local API/SDK services available as gRPC services on https.
vic-robot	Drives Vector along a path, and has all of the motor controls. It also includes the sensor filtering to detect lift, fall, etc. as well as basic power management. Internally has "vic-spine" that communicates with the body-board,and resets the watchdog timers.
vic-switchboard	Supports the Bluetooth LE communication interface, including the mobile

	application protocol (see Chapter 13). Routes messages between the other services? Manages the access keys
vic-webserver	A developer-only tool that aids in visualizing the internal state of the software.

Within the each vic- server processes, there are one or more event-driven communication threads. A thread likely has the following basic structure:

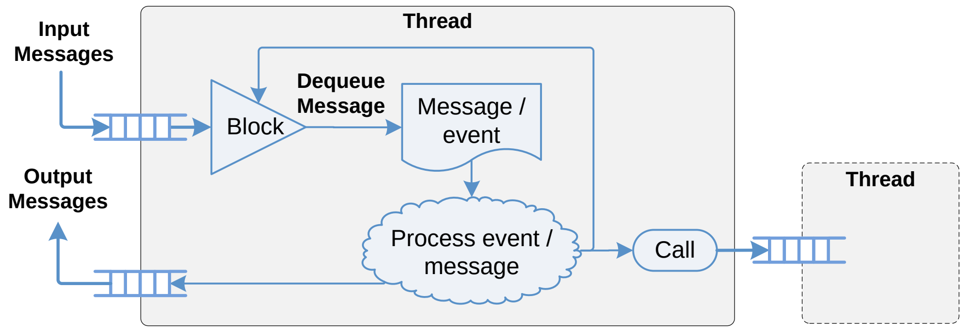

Figure 27: *Basic communication thread structure*

The communication threads have an input message queue. On Vector these include

- A socket, between processes
- A serial interface with the body board
- A web-socket
- Other, inter-thread message queue

The communication thread blocks on one or more message queue events. It wakes when there is an incoming event/message, or there has been an error or timeout while waiting. When it wakes, it dequeues the message, takes action and goes back to waiting. It may post messages (or other signals) to other threads, possibly indirectly as a result of framework/library/system calls.

Within a server process, convenient C++ data structures are used. The vic- servers also use CLAD, and JSON data structures, and include many helper procedures to convert between the two. It appears that a process interprets and generates a JSON data structure. To communicate with another process, it converts the JSON to a CLAD (since it is a contiguous span of bytes), sends that to the other process; the other process reverses the process, converting it JSON and using that interpret the message.

16.2. EMOTION MODEL, BEHAVIOUR ENGINE, ACTIONS AND ANIMATION ENGINE

Vector's high-level AI is organized around an *emotion model*, and a *behaviour engine* that drives goals, responses and other actions.

Anki Vector SDK

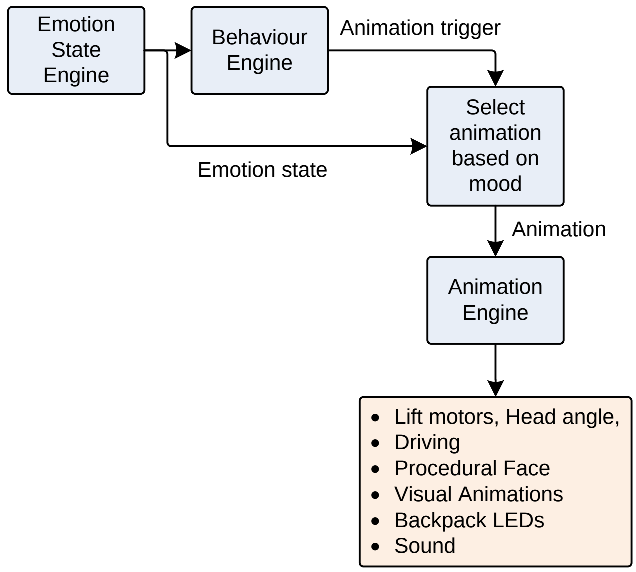

Figure 28: *The behaviour-animation flow*

There are many similar terms used within Vector's AI model, but there are subtle distinctions between them:

- An *AI Feature* is the high level behaviors as a person would experience. There are about 70 of these. Note the name shouldn't be confused with a *feature flag* or *feature toggle;* that is a different concept, for software elements that are not ready yet, but included in the code base.
- A *behavior* is "a complex task [that] may include combinations of animation, path planning or other functionality. Examples include" driving to the charger, set the lift height, etc. An AI Feature takes at least one behavior to carry out; it often takes many. The current emotional state can influence which behavior is selected, and affect how it is carried out. Intents (response to voice interaction) can initiate behaviors. Behaviors can initiate actions.
- An *action* is like a mini-behavior, with some differences. Multiple actions can run at a time – so long as they don't use the same resources– but only one behavior can run at a time. Actions can wait in a queue.
- An a*nimation* is a scripted motion, sound, light pattern, and/or facial animation (or picture on the display) that Vector carries out. Behaviors and actions can initiate animations. The animation engine selects the specific animation, from a pool of alternatives, based on context and current emotional state. An animation can't use the sensors, so it can't adapt to the environmental conditions. For instance, to drive up to a hand (or a cube) requires the time of flight sensor; so an action is required.

17. STORAGE SYSTEM

Vector's system divides the storage into many regions, primarily based on whether the region is modifiable (and when), and which subsystem manages the data. Appendix F describes the flash partitions and file system structure. See chapter 7 for a description of the partitions used for system start up and restore.

Most of the partitions on the flash storage are not modifiable – and are checked for authenticity (and alteration). These partitions hold the software and assets as delivered by Anki (and Qualcomm) for a particular release of the firmware. They are integrity checked as part of the start procedure. (See Chapter 7 for a description.)

Data that is specific to the robot, such as settings, security information, logs, and user data (such as pictures) are stored in modifiable partitions. Some of this data is erased when the unit is "reset" to factory conditions

These are described below.

17.1. ELECTRONIC MEDICAL RECORD (EMR)

Vector's "Electronic Medical Record" (EMR) partition holds the following information:

***Table 10:** Electronic Medical Record (EMR)*

Offset	Size	Type	Field	Description
0	4	uint32_t	*ESN*	Vector's electronic serial number (ESN). This is the same serial number as printed on the bottom of Vector. Serial numbers starting with 00e are engineering units.
4	4	uint32_t	*HW_VER*	Hardware revision code
8	4	uint32_t	*MODEL*	The model number of the product
12	4	uint32_t	*LOT_CODE*	The manufacturing lot code
16	4	uint32_t	*PLAYPEN_READY_FLAG*	The manufacturing fixture tests have passed; it is ok to run play pen tests.
20	4	uint32_t	*PLAYPEN_PASSED_FLAG*	Whether or not Vector has passed the play pen tests.
24	4	uint32_t	*PACKED_OUT_FLAG*	
28	4	uint32_t	*PACKED_OUT_DATE*	(In unix time?)
32	192	uint32_t[4]	*reserved*	
224	32	uint32_t[8]	*playpen*	
256	768	uint32_t[192]	*fixture*	

This information is not modified after manufacture; it persists after a device reset or wipe.

17.1.1 FAC (Factory) Mode

Vector has a "FAC" mode, used in the factory to test and calibrate the robot. When in FAC mode, the display has a red background, with either the letters "FAC" or one two two digits displayed (these are likely the testing stage to be performed), and his backpack lights have an unusual color pattern – red, green, and blue.

***Figure 29:** The LED pattern when in FAC mode*

This mode is never intended to be seen outside of the factory, so little is known. Only a couple of units have been found in this mode; one after it had been intentionally damaged, and its calibration & EMR data were corrupted or inaccessible.[16] In all likelihood, the software checks its EMR to see if it has been released; if not, it enters the FAC mode at whatever the "next" stage is according to the EMR. At that point Vector expects to be placed into manufacturing test fixtures, such as the playpen.

17.1.2 Manufacturing Lot Codes

A manufacturing lot code is an identifier that used to track the components, and robot subassemblies that were used in robots, as well as the date they were made. "If there's a problem in a particular batch of components (or maybe the people working at the factory that day), we can identify which robots were affected."

"A lot code is 4 numbers. A typical lot code is 2 18 36 201.

- "2 is the factory. All Vectors were made at factory 2."
- 18 is the last two digits of the year, 2018.
- "36 means week 36 of 2018 - that's first week of September.
- "201 means 'Standard Edition Vector, US-only version'"

The robots were made "in big batches in July/August, and they didn't start coming back [to customer service] until January/February," when Anki would "put the fixes into the next big batch the upcoming year."

17.1.3 Playpen Data

The playpen is a testing area with ramps, barriers, camera targets at a variety of angles, cube and a charging station. Vector is put into one during manufacture to check his sensors, camera calibration, motor function, microphone and a check over his overall functions. The playpen tests involve many checks to ensure that his head is assembled and attached correctly, as wells that his lower body is assembled correctly. These use almost of all of his functions: that he can correctly navigate, detect cliffs, see and count dots, see markers (getting their type and size correct), dock, and charge.

The images that Vector sees during these tests are kept with unit. This way, if the unit is returned later with a vision-related problem, the images from the manufacturing are there to see if, as part of the manufacturing record for analysis of returned products, "we can go back to those images and see if it's a new problem or was always there."

There is also a sound booth that checked that his speaker was working properly and did not exceed limits.

[16] https://forums.anki.com/t/any-one-know-what-error-code-50-is/40891

17.2. OEM PARTITION FOR OWNER CERTIFICATES AND LOGS

The OEM partition is a read/writeable ext2 file-system. It is used to hold information from the robots testing at the factory, and its cloud access certificates:

Table 11: *OEM partition file hierarchy*

Folder	Description
	The top level holds the log files.
cloud	Holds the SDK TLS certificate and signing keys. With newer firmware, the folder may also hold some other calibration information.
nvStorage	Holds some binary "`.nvdata`" files

18. SECURITY AND PRIVACY

Anki Security & Privacy Policy

Vector's design includes a well thought-out system to protect against disclosing (i.e. providing to strangers) sensitive information, and allowing the operator to review and delete it at any time:

- Photographs taken by Vector are not sent to (nor stored in) a remote server. They are stored in encrypted file system, and only provided to authenticated applications on the local network. Each photograph can be individually deleted (via the mobile application).
- The image stream from Vector's camera is not sent to a remote server. It is only provided to authenticated applications on the local network.
- The data used to recognize faces[17] and the names that Vector knows are not sent to (nor stored in) a remote server. The information is stored in an encrypted file system. The list of known faces (and their names) is only provided to authenticated applications on the local network. Any facial recognition data not associated with a name is deleted when Vector goes to sleep. Facial data associated with an individual name can be deleted (along with the name) via the mobile application.
- "[After] you say the wake words, "Hey Vector", Vector streams your voice command to the cloud, where it is processed. Voice command audio is deleted after processing. Text translations of commands are saved for product improvement not associated with a user."
- The audio stream from the microphone — if it had been finished being implemented – would have been provided to authenticated applications on the local network.
- Information about the owner can be erased using the Clear User Data menu option.
- Control of the robots movement, speech & sound, display, etc. is limited to authenticated applications on the local network.

Vector's software is protected from being altered in a way that would impair its ability to secure the above. At the high level, this is done by requiring signed software files, and a signed file system that is checked for alteration. The protections extend all the way to low-level electronics, where the JTAG access fuses are blown, so that extracting or modifying RAM, flash or other data can not be done. (Anki did this as a matter of standard operating procedure on all electronic products.)

[17] The Anki privacy and security documents logically imply that the face image is not sent to Anki servers to construct a recognition pattern. There are no communication structures to send images to the cloud.

Vector also indicates when it is doing something sensitive:

- When the microphone is actively listening, it is always indicated on the backpack lights (blue).
- The microphone is enabled by default, but only listening for the wake word, unless Vector's microphone has been disabled.
- When the camera is taking a picture (to be saved), Vector makes a sound.
- When the camera is on?
- Unless the backpack lights are all orange, the WiFi is enabled. (All orange indicates it is disabled.)

18.1. ENCRYPTED COMMUNICATION

The personally identifying information and other data about the owner — photos, account information, WiFi passwords, and so one — is only sent on encrypted channels.

18.2. ENCRYPTED FILESYSTEM

The file system with the user's data — photos, account information, WiFi passwords, and so one — is encrypted. The encryption key is unique to each robot and not shared elsewhere.

18.3. THE OPERATING SYSTEM

There is a chain of firmware signed by Qualcomm and Anki. This is intended to protect Vector's software from being altered in a way that would impair its ability to secure the information above.

Android boot loaders typically include a few powerful (but unchecked) bits that disable the signature checking, and other security features. These bits typically are set either thru commands to the firmware during boot up, by applications, or possibly by hack/exploit. Sometimes this requires disassembling the device and shorting some pins on the circuit board.

Vector doesn't support those bits, nor those commands. Signature checking of the boot loader, kernel and RAM disk can't be turned off.

18.3.1 The possibility for future modifications to Vector's software

Anki created special Vectors for internal development. The software for these units has a special version of the kernel and RAM disk that does not check system room file system, and makes it writable. This file system has Vector's application software, supports SSH. This software was tightly controlled, and "only .,. available inside the Anki corporate network." For purposes of customizing and updating Vector, this version is essential. (Note: the kernel and RAM disk can't be modified.) Jane Fraser, 2019

Note: the OTA software has a "dev" (or development) set of OTA packages. Those packages are not the same; they are essential software release candidates being pushed out for test purposes.

18.4. AUTHENTICATION

The web services built into Vector require a token. This is used to prove that you have authenticated (with the more capable — and not physically accessible — servers). This authentication is to protect:

- Photos already on Vector
- The image stream from the camera
- The audio stream from the microphone — if it had finished being implemented
- The sensitive owner information
- Controlling the robot

(That is to say, to prevent disclosure)

19. CONFIGURATION AND ASSET FILES

Vector's software is configured by JSON files. Some of the JSON files were probably created by a person (for the trivial ones). Others were created by scripting / development tools; a few of these were edited by developers. These JSON files are clearly intended to be edited by people:

- The files are cleanly spaced, not in the most compact minimized size
- The JSON parser supports comments, which is not valid JSON. Many files have comments in them. Many have sections of the configuration that are commented out.

19.1. CONFIGURATION FILES

The top-level configuration file provides the paths to the network other configuration files. It is found at:

`/anki/etc/config/platform_config.json`

This path is hardcoded into the `vic-dasmgr`, and provided in the editable startup files for `vic-anim` and `vic-engine`. The configuration file contains a JSON structure with the following fields:

Field	Value	Description & Notes
DataPlatformCachePath	"/data/data/com.anki.victor/cache"	This folder is used to hold logs and diagnostic information until it can be sent to the cloud servers.
DataPlatformPersistentPath	"/data/data/com.anki.victor/persistent"	This folder holds the settings for the Vector application software.
DataPlatformResourcesPath	"/anki/data/assets/cozmo_resources"	The path to most configuration files and assets

***Table 12:** The platform config JSON structure*

When describing the configuration and asset files, a full path will be provided. When the path is constructed from different parts, the part that is specified in another configuration or binary file will be outlined. The path to a settings file might look like:

`/anki/assets/cozmo_resources/config/engine/settings_config.json`

The path leading up to the settings file (not outlined in red) is specified in an earlier configuration file, usually the platform configuration file described above.

20. SOFTWARE-HARDWARE LAYERS

- Body-board input/output software architecture
- The LCD display
- Camera

20.1. THE BODY BOARD INPUT/OUTPUT

The body-board input-output software has a structure like so:

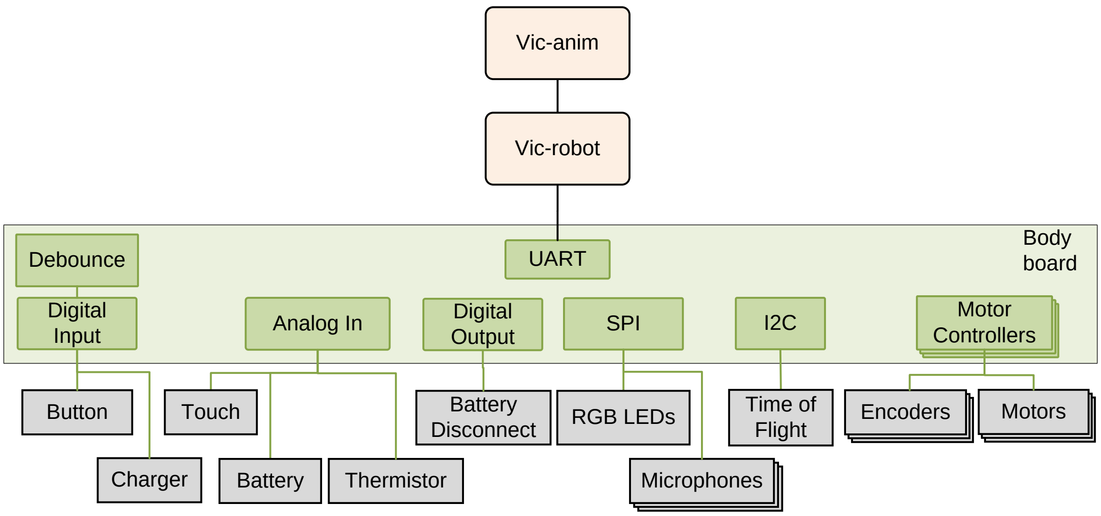

Figure 30: *The body board-related architecture*

20.2. THE LCD DISPLAY

Four different applications may access the display, albeit not at the same time:

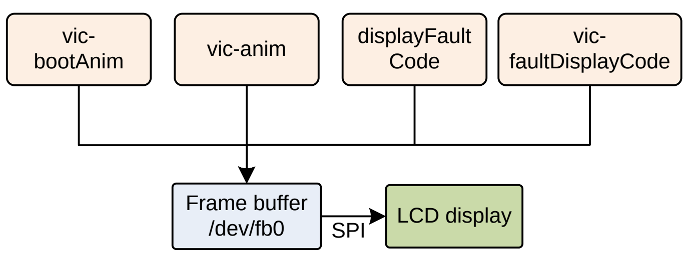

Figure 31: *The LCD architecture*

Note: displayFaultCode is present on Vector, but it is not called by any program.

The LCD is connected to the MPU via an SPI interface (/dev/spidev1.0). The frame buffer (/dev/fb0) is essentially a buffer with metadata about its width, height, pixel format, and orientation. Application modifies the frame buffer by write() or memmap() and modifies the bytes. Then the frame buffer has the bytes transfer (via SPI) tot the display.

vic-anim employs a clever screen compositing system to create Vector's face (his eyes), animate text jumping and exploding, and small videos, such as rain or fireworks.

The vic-faultDisplayCode and Customer Care Information Screen of vic-anim have a visual aesthetic is unlike the rest of Vector. These modes employ a barebones system for the display.

The text appears to rendered into the buffer using OpenCV's `putText()` procedure, and transferring it to the display without any further compositing.

Not sure if the transfer is in a driver, in the kernel, or in user space... or which process would have it in user space.

20.3. THE CAMERA

The camera subsystem has the following architecture:

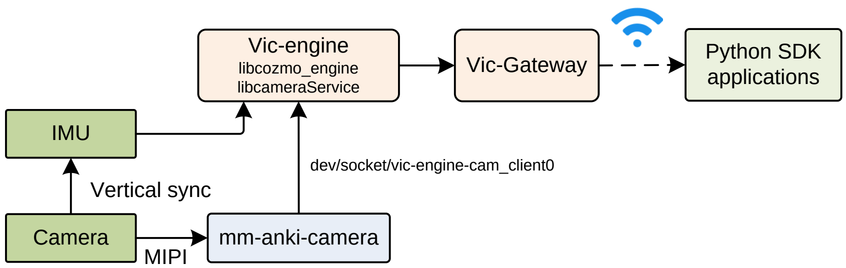

Figure 32: *The camera architecture*

The camera's vertical synchronization signal is connect to the interrupt line on IMU, triggering accelerometer and gyroscope sampling in sync with the camera frame. The vision is used as a navigation aid, along with the IMU data. The two sources of information are fused together in the navigation system (see chapter 19) to form a more accurate position and relative movement measure. The image must be closely matched in time with the IMU samples. However the transfer of the image from the camera to the processor, then thru several services to vic-engine introduces variable or unpredictable delays. The camera's vertical sync – an indication of when the image is started being sampled – is used to trigger the IMU to take a sample at the same time.

Daniel Casner, 2019 Embedded Vision Summit

The camera is also used as an ambient light sensor when Vector is in low power mode (e.g. napping, or sleeping). In low power mode, the camera is suspended and not acquiring images. Although in a low power state, it is still powered. The software reads the camera's auto exposure/gain settings and uses these as an ambient light sensor. (This allows it to detect when there is activity and Vector should wake.)

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CHAPTER 7

Startup

This chapter describes Vector's start up and shutdown processes:

- The startup process
- The shutdown steps

22. STARTUP

Vector's startup is based on the Android boot loader and Linux startup.[18] These are otherwise not relevant to Vector, and their documentation is referred to. The boot process gets quite far before knowing why it booted up or being able to response in complex fashion.

1. The backpack button is pressed, or Vector is placed into the charger. This powers the body board, and the head-board.
   a. The body-board boot loader checks the application for validity, using a private key. The application is run only if it passes the integrity checks.
2. The body-board displays an animation of the backpack LEDs while turning on.
   a. If turned on from a button press and the button is released before the LED segments are fully lit, the power will go off.
   b. If the button is held down – for about 5 seconds – the head-board will have reach a point in its boot process to direct the body-board to keep the battery switch closed.
   c. If held for 15 seconds, the body-board will hold is TX line – the head-boards RX line – low during the boot process. This tells the system to boot into recovery mode.
3. While the head-board boots, the body-board performs several self tests. These include checking that the microcontroller can communicate with the 4 cliff (surface proximity) sensors, and the time of flight sensor.

22.1. QUALCOMM'S PRIMARY AND SECONDARY BOOT-LOADER

Meanwhile, on the head-board:

1. "Qualcomm's Primary Boot Loader is verified and loaded into [RAM] memory[19] from BootROM, a non-writable storage on the SoC. [The primary boot-loader] is then executed and brings up a nominal amount of hardware," Nolen Johnson
2. The primary boot-loader checks to see if a test point is shorted on the board, the unit will go into emergency download (EDL) mode. It is known that when F_USB pad on the head-board is pulled to Vcc, USB is enabled; this may be the relevant pin. Roee Hay

[18] An ideal embedded system has a fast (seemingly instant) turn on. Vector's startup *isn't* fast. The steps to check the integrity of the large flash storage – including checking the security signatures – and the complex processes that Linux provides each contribute to the noticeable slow turn on time. Checking the signatures is inherently slow, by design.
[19] The boot loader is placed into RAM for execution to defeat emulators.

3. If the primary-boot loader is not in EDL mode it "then verifies the signature of the next boot-loader in the chain [the secondary boot-loader], loads it, [and] then executes it." The secondary boot-loader is stored in the flash partition SBL. Nolen Johnson

4. If the secondary boot-loader does not pass checks, the primary boot loader will go into emergency down load mode.

5. "The next boot-loader(s) in the chain are SBL*/XBL (Qualcomm's Secondary/eXtensible Boot Loader). These early boot-loaders bring up core hardware like CPU cores, the MMU, etc. They are also responsible for bringing up core processes .. [for] TrustZone. The last purpose of SBL*/XBL is to verify the signature of, load, and execute aboot/ABL [Android boot loader]."
   The TrustZone firmware is signed and verified against the processor's unique key.
   The Android boot-loader (aboot) is stored on the "ABOOT" partition.
   The secondary boot-loader also supports the Sahara protocol; it is not known how to activate it.

Note: The keys for the boot-loaders and TrustZone are generated by Qualcomm, with the root public key programmed into the hardware fuses before delivery to Anki or other customers. (This is called the *silicon-based hardware key,* or *SHK.)* The signed key pair for the secondary boot-loader, the TrustZone and for aboot are not necessarily the same signed key pair. They are unique for each of Qualcomm's customer. Being fuses, the SHK cannot be modified, even with physical access. The SHK is only accessible to TrustZone firmware and its trustlets; keystores that are encrypted and decrypted by the SHK must be to the TrustZone for processing. *silicon-based hardware key, processor fuses*

22.2. ANDROID BOOT-LOADER (ABOOT)

1. "Aboot brings up most remaining core hardware then in turn normally verifies the signature of the boot image, reports the verity status to Android Verified boot through dm-verity… On many devices, Aboot/ABL can be configured to skip cryptographic signature checks and allow booting any kernel/boot image."

   a. On other Android devices, aboot reads the DEVINFO partition for a structure. It checks the header of the structure for a magic string ("ANDROID-BOOT!") and then uses the values within the structure to indicate whether or not the device is unlocked, whether verity-mode is enabled or disabled, as well as a few other settings. By writing a version of this structure to the partition, the device can be placed into unlock mode. Roee Hay

      Vector does *not* support this method of unlocking.

   b. "The build system calculates the SHA256 hash of the raw boot.img and signs the hash with the user's private key… It then concatenates this signed hash value at the end of raw boot.img to generate signed boot.img." Qualcomm LM80 P0436

   c. "During bootup, [Aboot[20]] strips out the raw boot.img and signed hash attached at the end of the image. [Aboot] calculates the SHA256 hash of the complete raw boot.img and compares it with the hash provided in the boot.img. If both hashes match, kernel image is verified successfully."

2. ABoot can either program the flash with software via boot loader mode, or load a kernel. The kernel can be flagged to use a recovery RAM disk or mount a regular system.

[20] The Qualcomm document speaks directly about Little Kernel; ABoot is based on Little Kernel.

3. If recovery mode, it will load the kernel and file systems from the RECOVERY partitions.
    a. Recovery is entered if the active regular partition cannot be loaded, e.g. doesn't exist or fails signature check, or
    b. The RX signal from the body-board may be held low when aboot starts, indicating that the operator has held the button and wishes to initiate recovery mode.[21] If this is the case, "anki.unbrick=1" is prepended to the command line passed to the kernel.
4. ABoot loads the kernel and RAM file system from the active "BOOT" partition and passes it command line to perform a check of the boot and RAM file system the signatures.[22] The command line is stored in the header of the boot partition; it is checked as part of the signature check of the boot partition and RAM file system. If the ABoot is compiled for a developer robot, it will add an "anki.dev" to the command line.

Many of these elements will be revisited in Chapter 32 where updating aboot, boot, and system partitions are discussed.

22.3. RECOVERY BOOT

The recovery system is, in part, based on an older version of Vector software.

USER DATA FILE SYSTEM. The recovery system does not use the user data file system. Here's why:

1. The recovery system is risk averse. It is not updated (due to the risk), and has older software. This software likely has bugs that could be a path for exploitation. By not using the user data, the user data is protected against these exploits.
2. The user data may be corrupted, erased or gone. This may be the reason that the system in recovery mode.
3. The files and formats of the user data, and the TrustZone key blobs may have changed with newer formats and files. The recovery system might not be able to read them. Or it may not be able to write something that the regular system can write.

FACTORY FILE SYSTEM. The recovery system normally mounts the factory file system (OEM partition) in read only mode. It can be put into a "factory mode" (FAC) that remounts this file system as a modifiable.

22.4. REGULAR SYSTEM BOOT

The boot partition holds the linux kernel, and a small RAM disk to initialize the system. It is passed parameters on the command line from aboot and from the boot.img. The purpose of the extra (Anki-specific) command line parameters are:

Table 13: *linux command line parameters*

Field	Description
anki.unbrick	This is used to trigger a boot into recovery mode.
anki.dev	This is set to confirm (to the linux system) that this robot is a development robot and can run development software systems.
dm=	The dm-verity command line used to verify the system file system

[21] The body-board may body-board a resets/restarts the head-board so that the bootloader runs again.
[22] The check specifies the blocks on the storage to perform a SHA256 check over and provides expected signature result.

After the kernel has finished loading, it launches init. In Vector, it is a shell script with Anki-specific system checks:

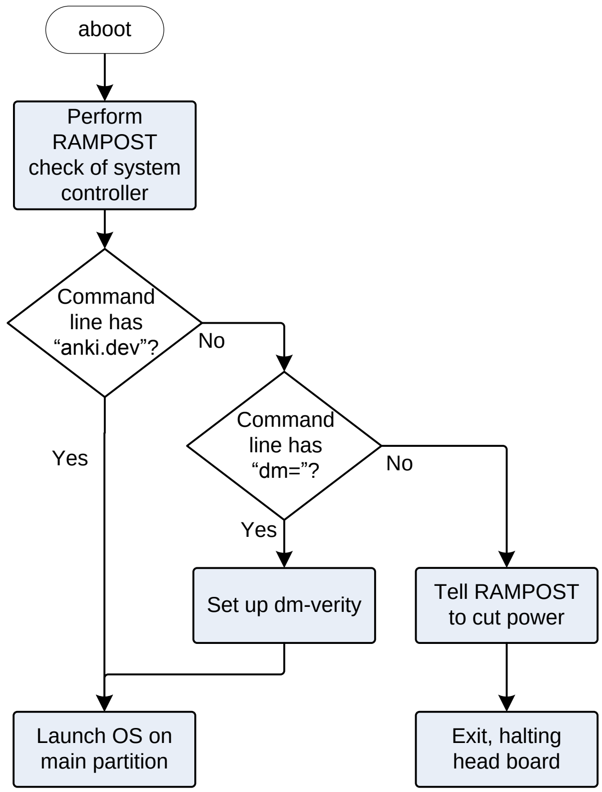

***Figure 33:** The linux boot-partition init-script flow*

These Anki-specific system steps are:

1. The RAM file system contains primarily of two programs: init and /bin/rampost. init is a shell script and the first program launched by the kernel. This script turns on the LCD, its backlight and initiate communication with the body-board. (These occur ~6.7 seconds after power-on is initiated).
   a. rampost initializes the LCD, clearing the display. It also shows a start up screen on the display of developer units.
   b. rampost will perform a firmware upgrade of the body-board if its version is out of date. It loads the firmware from syscon.dfu (Note: the firmware in the body-board is referred to as syscon.)
   c. rampost checks the battery voltage, temperature and error flags. It posts any issues to /dev/rampost_error. See Appendix D *Table 605: RAMPOST DFU status codes* for DFU related error codes.
   d. All messages from rampost are prefixed with "@rampost."
2. Next, init performs a signature check of the system partition to ensure integrity. This is triggered by the command line which includes dm-verity options prefixed with "dm=". If the system does not pass checks, init fails and exits.
   a. Note: none of the file systems in fstab marked for verity checking, so this is the only place where it is performed.

3. The main system file-system is mounted and launches the main system initialization.

The regular boot uses systemd to allow of the startup steps to be performed in parallel. The rough start up sequence is:

1. Starts the Qualcomm Secure Execution Environment Communicator (dev-qseecom.device) and ION memory allocator (dev-ion.device)
2. The encrypted user file system is checked and mounted (via the mount-data service). This file system is where the all of the logs, people's faces, and other information specific to the individual Vector are stored. The keys to this file system are stored in a blob within "switchboard" but are encoded and decoded by a TrustZone key manager (which uses the processor's secret key). This file system can only be read by the MPU that created it.
   a. If "anki.unbrick" is on the command line, the user data partition is not touched; instead a temporary file system is created and used instead.[23] This flag is not meaningful in the regular system since the boot-loader will only launch the recovery partition software with "anki.unbrick"
   b. If the data partition is empty (i.e., erased to clear the user data), the user data partitions is formatted;
3. The MPU's clock rate is limited to 533Mhz, and the RAM is limited to 400MHz to prevent overheating.
4. The camera power is enabled
5. If Vector doesn't have a robot name, Vic-christen is called to give it one.
6. After that several mid-layer communication stacks are started:
   a. usb-service any time after that
   b. the WiFi connection manager (connman)
   c. The time client (chronyd), to retrieve network time. (Vector does not have a clock that keeps time when turned off)
   d. init-debuggerd
7. multi-user, sound, init_post_boot
8. The "Victor Boot Animator" is started (~8 seconds after power on) and shows the sparks turning into the "V" splash screen on the display.
9. Victor Boot completes ~20.5 after power on, and the post boot services launches
10. The vic-crashuploader service is started to gather crash logs and dump files, some of which may have been created during a previous boot attempt. These will be uploaded when internet access is restored.
11. The vic-robot and main robot services are started.
12. Once the startup has sufficiently brought up enough the next set of animations the sound of boot

[23] I'm not sure how this would be useful as is with the regular system software. It seems like Vector could boot up, appear like everything is wiped, and needs to be re-set up… then some time later, Vector would reboot, and appear to be his previous self – including any misconfiguration that motivated the unbrick the first time.

13. VicOS is running ~32 seconds after power on. The boot is complete, and Vector is ready to play

22.5. ABNORMAL SYSTEM BOOT

If there is a problem during startup – such as one of the services is unable to successfully start, a fault code associated with that service is stored in `/run/fault_code` and the fault code displayed. See chapter 33 for a description of the display of fault codes and diagnostics. See Appendix D for fault codes.

22.6. REGULAR REBOOTS

Vector reboots nightly (if left on) and checks for software updates. See chapter 32 for information.

23. REFERENCES & RESOURCES

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lm80-p0436-1_little_kernel_boot_loader_overview.pdf

https://github.com/ alephsecurity
A set repositories researching tools to discover commands in Sahara and EDL protocols

https://github.com/openpst
A set of repositories researching and implementing an interface to the Sahara protocol.

CHAPTER 8

Power management

This chapter describes Vector's power management:

- The battery management
- Load shedding
- Charger info

24. POWER MANAGEMENT

24.1. BATTERY MANAGEMENT

Vector does not employ a coulomb counter to track the remaining energy in the battery. The batteries had too much variation to allow the capacity tracking to work well. At the broadest strokes, the battery voltage is used to predict the battery state of charge.

24.1.1 Battery levels

Vector maps the battery voltage into a battery level, taking into account whether or not the charger is active:

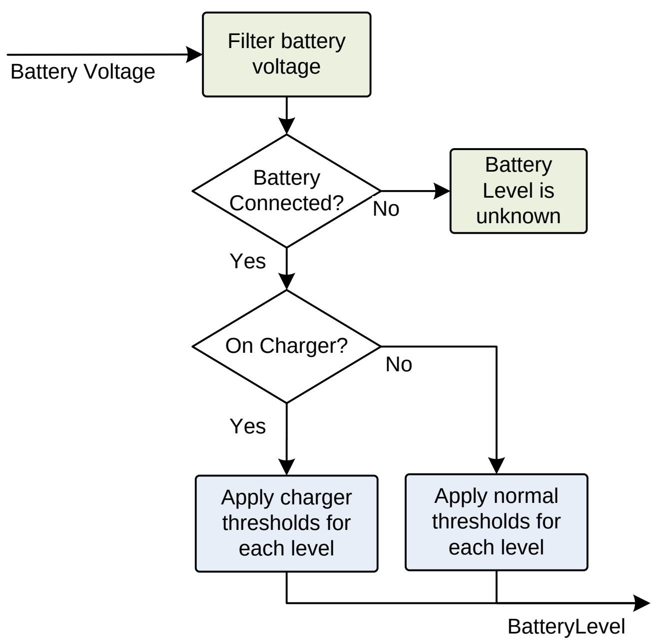

Figure 34: *The battery level classification tree*

Note: The battery voltage is filtered – the voltage will bounce around with activity by the motors, driving the speaker and processors.

The `BatteryLevel` enumeration is used to categorize the condition of the Vector battery:

Table 14: *BatteryLevel codes[24] as they apply to Vector*

Name	Value	Description
BATTERY_LEVEL_FULL	3	Vector's battery is at least 4.1V
BATTERY_LEVEL_LOW	1	Vector's battery is 3.6V or less; or if Vector is on the charger, the battery voltage is 4V or less.
BATTERY_LEVEL_NOMINAL	2	Vector's battery level is between low and full.
BATTERY_LEVEL_UNKNOWN	0	If the battery is not connected, Vector can't measure its battery.

The battery levels are organized conventionally:

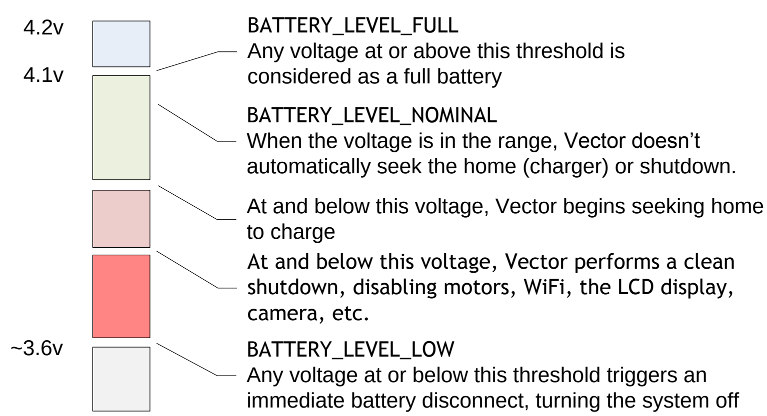

Figure 35: *The battery thresholds*

The current battery level and voltage can be requested with the Battery State command (see Chapter 15, section *51.2 Battery State*). The response will provide the current battery voltage, and interpreted level.

24.1.2 A software "fuel gauge"

It is typical for larger battery packs to include a coulomb counter, often called a fuel gauge. They include it for a serious reason: it prevents fire and explosions that can result from overcharging a large multi-cell pack. The fancy "fuel gauge" and estimated useful life is a bonus.

For Vector, a fuel gauge would given him smarts about knowing he will need to plan to return home, or is getting low. His hardware doesn't have a coulomb counter, for a variety of reasons. Any effort, beyond simple battery voltage, to estimate the remaining play time would have to be based on software and tracking the battery performance.

24.2. RESPONSES, SHEDDING LOAD / POWER SAVING EFFORTS

Vector's main (power-related) activity modes are:

- active, interacting with others
- calm, where primarily sitting still, waiting for assistance or stimulation

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[24] The levels are from robot.py

▪ sleeping

Depending on the state of the battery – and charging – Vector may engage in behaviours that override others.

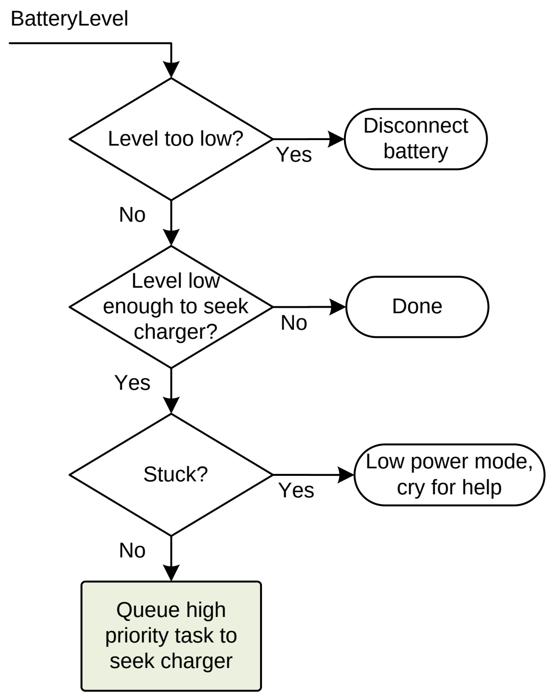


***Figure 36:** The response to battery level*

If his power is low, Vector will launch a behavior to seek the charger out, and recharge. If he is stuck, his behaviors will have him cry out.

If Vector is unable to dock (or even locate a dock) he sheds load as he goes into a lower state:

- He no longer responds to his trigger word or communicates with WiFi servers
- He turns off camera and LCD; presumable the time of flight sensor as well.
- He reduces processing on the processor
- Eventually the power will be turned off completely.

24.2.1 Temperature limits and related processing

The software tracks the temperature of the battery and head. As the temperature rises, more aggressive actions are taken to protect the battery and let the chips cool down.

- Around 90C, Vector displays the overheating icon.
- If the body board is overheated, a flag in the HTTPS API `RobotStatus` bit mask is set (see Chapter 15, section *44.1.2 RobotStatus Note: this is speculated, not proven.*
- At some point past 90C, Vector starts a clean shut down (see earlier). The software in the head is idle, and turns off as many peripherals (e.g. WiFi, display, etc.) with "the goal to save enough power in the head to let the chip cool off, so we could continue driving home."
- If the APQ8009 processor is hot, it will throttle its clocks. If the MP2617B charging chip is reaching the thermal limits related to charging, it will throttle the charging.

- If either the body or head board exceeds a maximum temperature, the system is completely shut down, and power is cut.

The battery overheated icon is displayed by `vic-faultCodeDisplay`, which has a hard coded path to the icon:

> `/anki/data/assets/cozmo_resources/config/devOnlySprites/independentSprites/battery_overheated.png`

Version 1.6 uses very conservative thresholds (to protect the battery) with the intention of follow up releases fine tuning the thresholds.

24.2.2 Calm Power mode

Vector has a high-level power mode called "calm power mode." This mode "is generally when Vector is sleeping or charging." Vector [probably] turns off the sensors, lowers the CPU and camera clock rate – or may even suspend the camera. (See Chapter 19, section *79.5 Illumination level sensing* for a description).

Whether Vector is in calm power mode (or not) is reported in the `RobotStatus` message in the `status` field. (See chapter 15 for details.) Vector is in a calm power model if the `ROBOT_STATUS_CALM_POWER_MODE` bit is set (in the status value).

24.2.3 When not moving

When Vector isn't driving (or using his head and lift), he puts his motors and related sensors into a low power state:

- The encoders are mostly turned off; they "pulsed at 1% duty cycle and watched for changes" to detect someone moving Vector around;
- The time of flight sensor is turned to a lower sampling period

24.3. SLEEP STATES

Vector has variety of sleep states, based on his power level, what he can potentially do, and where he is at. These include:

- Comatose
- Deep sleep
- Emergency sleep
- Asleep, but held in palm
- Asleep, on palm
- Asleep on charger
- Light sleep

24.3.1 Sleep Debt

Vector "has a "sleep debt" system to make him get sleepier if he's been on longer as a way of keeping the battery and electronics from overheating (it heats up with a lot of use, but after a few seconds of sleeping can throttle down)."

Brad Neuman
reddit post

Internally Vector tracks this as an amount of time he needs to sleep (*sleep_debt_hours*, a floating point number). This increments with activity (and charging), and decrements (at a different rate) when sleeping.

24.4. ACTIVITY LEVEL MANAGEMENT

Version 1.5 slowed down a lot of Vectors activities (by lowering his max clock rate), to reduce heat (prolonging the battery service life) and allow him to play longer between charge cycles. Some of his behaviors were modified so that he doesn't initiate exploring and playing as much, choosing instead to stay on the charger longer until there was more signs that people were around to play.

Version 1.6 may have gone further.

Behaviors are responsible for requesting that Vector enter a power saving or other sleep state.

24.5. SHUTDOWN

- Turning Vector off manually
- Vector turning off spontaneously due to brown-out or significant loss of power
- Vector turning off (under low power) by direction of the head-board
- Vector turning off if key software crashes

Vector cannot be turned off via Bluetooth LE, or the local HTTPS SDK access. There are no exposed commands that do this. Using a verbal command, like "turn off" does not direct Vector to shut off (disconnect the battery). Instead it goes into a quiet mode. Although it may be possible for a Cloud command to turn Vector off, this seems unlikely.

However, there is likely a command to automate the manufacture and preparation for ship process.

24.5.1 Turning Vector Off (intentionally)

When the system decides it needs to shutdown, it internally posts one of the following codes as the reason for shutdown:

Table 15: *Vector shutdown codes*

Name	**Value**	**Description& Notes**
SHUTDOWN_BATTERY_CRITICAL_TEMP	3	Vector shut down automatically because the battery temperature was too high.
SHUTDOWN_BATTERY_CRITICAL_VOLT	2	Vector shut down automatically because the battery voltage was too low.
SHUTDOWN_BUTTON	1	Vector was shut down by a long button press.
SHUTDOWN_GYRO_NOT_CALIBRATING	4	Vector shut down automatically because of an IMU problem.
SHUTDOWN_UNKNOWN	0	Vector shut down unexpectedly; the reason is not known. Likely a brown-out or battery voltage dipped low faster than Vector could respond to.

The shutdown code is logged, and broadcast but not otherwise stored.

24.5.2 Unintentionally

The body-board is responsible for keeping the battery connected. However brownouts, self-protects when the voltage get to too low, and bugs can cause the battery to be disconnected. The body board will turn off power if it doesn't hear from the head-board in a regular fashion. This could be because of software crash.

24.5.3 Going into an off state

When Vector wants to intentionally turn off, it cleans up its state to gracefully shutdown the linux system and tells the body-board to disconnect the battery.

24.6. THE CUBE POWER MANAGEMENT

Vector manages the Cube's power usage by managing the link. Vector disconnects from the cube (saving the most power) when sleeping, or the cube is not used by the behavior tree. When connected to the cube, higher and lower update rates are selected, based on the active behavior and the kind of interaction. Since higher update rates consume more power, Vector only employs them if there is an indication that someone is moving or tapping the cube. Lower update rates are used to detect the possibility of interaction, such as motion. See chapter 14 for more information.

25. CHARGING

Vector tracks whether is charging is in process, and how long. The software has some initial estimates how long before charging is complete. This is similar to the software "fuel gauge." It takes some model of the batteries capacity, and typical charging times given that.

The state of the charger is reported in the `RobotStatus` message in the `status` field. (See chapter 15 for details.) Vector is on the charger if the `ROBOT_STATUS_IS_ON_CHARGER` bit is set (in the status value), and charging if the `ROBOT_STATUS_IS_CHARGING` bit is set.

Version 1.5 slowed down the charging, to reduce heat, prolonging the battery life.

Additional information about the state of the charger can be requested with the Battery State command (see Chapter 15, section *51.2 Battery State*). The response will provide flags indicating whether or not Vector is on the charger, and if it is charging. The response also provides a suggested amount of time to charge the batteries.

CHAPTER 9

Basic Inputs and Outputs

This chapter describes Vectors most basic input and output: his button, touch and LEDs:

- Touch and button input
- Backpack Lights control

Note: the audio sampling will be covered in a later chapter (Chapter 18)

26. BUTTON, TOUCH AND CLIFF SENSOR INPUT

Vector's backpack button is used to wake (and silence) Vector, or to place him into recovery mode. Touch is used to pet Vector and provide him stimulation. Four surface proximity IR sensors are used to detect cliffs and line edges. The responsibility for the button, touch, and proximity sensor input functions are divided across multiple processes and boards in Vector:

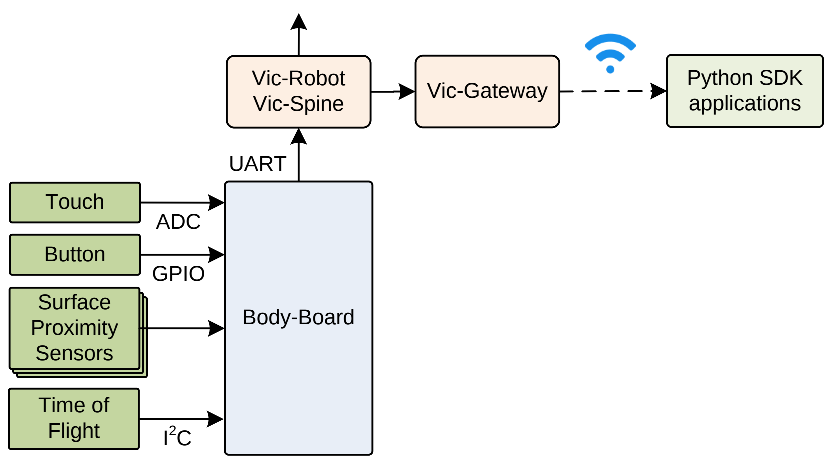


***Figure 37:** The touch and button input architecture*

The states of the inputs (button, touch, surface proximity and time of flight sensors) are reported in the RobotStatus message. (See chapter 15 for details.) The button state can be found in the status field. The button is pressed if the ROBOT_STATUS_IS_BUTTON_PRESSED bit is set (in the status value).

cliff sensors

The surface proximity sensors (aka "cliff sensors") are used to determine if there is a cliff, or potentially in the air. The individual sensor values are not accessible. The cliff detection state can be found in the status field. A cliff is presently detected if the ROBOT_STATUS_CLIFF_DETECTED bit is set (in the status value).

26.1. TOUCH SENSING INFORMATION

The touch sensor is driven by the body-board, and the sample values are processed in the head-board. The sensors samples are filtered, to get a sense of the current "level" the sensor is at. A standard deviation is used as a measure of how solid the signal, to help distinguish between a real signal and ambient conditions like humidity and weather. These two measures – along with a timer to screen out transitory noise – can be used to decide that Vector is being touched or not.

***Figure 38:** The touch sensor and petting detector*

These measures could potentially distinguish between light touch (e.g. tip of the finger), heavy touch (e.g. a full palm?), and perhaps even changing touch.

The touch sensor readings can be found in the `touch_data` field of the `RobotStatus` message. The values indicate whether Vector is being touched (e.g. petted).

The touch sensor module produces a JSON structure for internal use:

***Table 16:** Touch sensor structure*

Field	Type	Units	Description
max	float		The maximum value seen
min	float		The minimum value seen
stddev	float		The standard deviation

26.2. TIME OF FLIGHT PROXIMITY SENSOR

The time of flight reading is given in the `prox_data` field. This indicates whether there is a valid measurement, the distance to the object, and a metric that indicates how good the distance measurement is. This will be processed by the mapping system. See *Chapter 20 section 89 Measuring* the distance to objects.

27. BACKPACK LIGHTS CONTROL

The backpack lights are used to show the state of the microphone, charging, WiFi and some other behaviours. (It is also used to show unusual error states.)

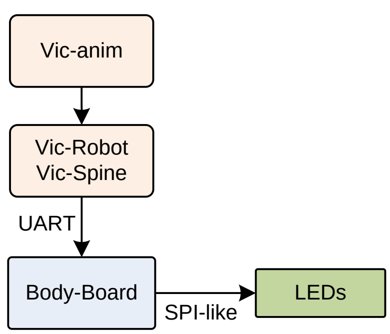


***Figure 39:** The backpack lights output architecture*

The software can direct the body-board to illuminate the backpack lights with individually different colors and brightness's. The body-board "pulse width modulates" (PWM's) the LEDs to achieve different colors and intensities.

The body-board doesn't directly interface with the LED's (they're connected to a logic chip on a separate board), so it cannot delegate the work to an internal PWM peripheral. The body-board must implement its PWM in firmware, and send the GPIO states to the backpack every time there is a change. (See Chapter 4, section *10.3.1 The LED controls*)

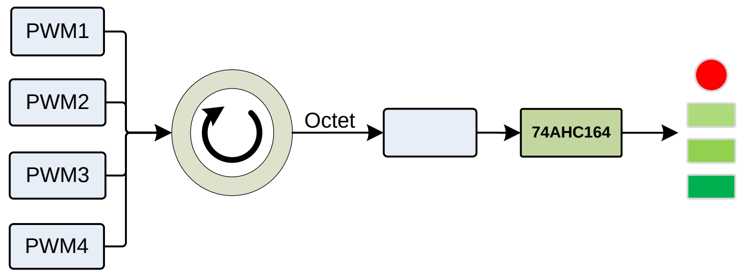


Figure 40: *The firmware driving of the LEDs*

The basic logic to drive the LEDs is:

1. Select LEDs for the time slice
2. Get the LED bit settings from the PWM(s)
3. Organize these into a format for the 74AHC164
4. Send the bits to the 74AHC164
5. Delay until the next time slice, and repeat

CHAPTER 10

Inertial Motion Sensing

This chapter describes Vector's motion sensing:

- Sensing motion and cliffs
- Detecting external events
- Measuring motion as feedback to motion control, and allow moving along paths in a smooth and controlled fashion

28. MOTION SENSING

Vector employs an IMU – an accelerometer and gyroscope in the same module – to detect motion, such as falling or being bumped, as well as measuring the results of motor-driven motions.

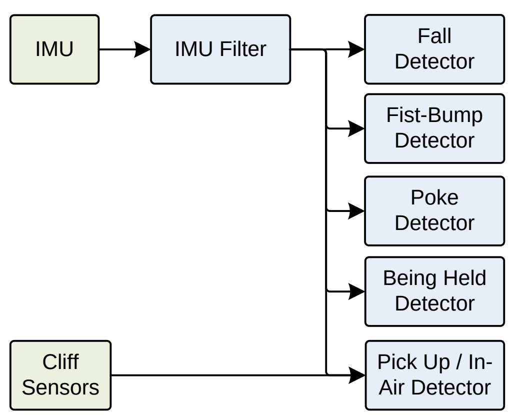


Figure 41: *Sensing motion events*

28.1. ACCELEROMETER AND GYROSCOPE

Neither the accelerometer nor gyroscope by itself is sufficient to accurately measure change in position and orientation. Accelerometers measure force along 3 (XYZ) axes, including gravity. The accelerometer provides the orientation – if there is no other motion. The drawback is that accelerometers cannot correctly measure spins, and other rotations from other movements. Gyroscopes can measure rotations around the axes, but cannot measure linear motion along the axis. Gyroscopes also have a slight bias in the signal that they measure, giving the false signal that there is always some motion occurring.

By blending the accelerometer and gyroscope signals together, they can compensate and cancel each other's weaknesses out.

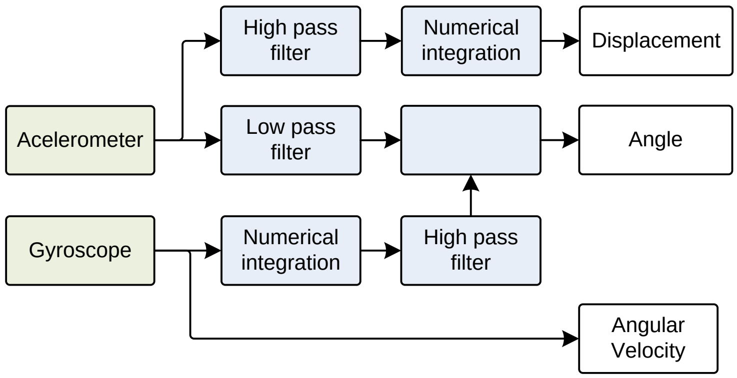


Figure 42: *Complementary filtering of the accelerometer and gyroscope*

28.2. TILTED HEAD

The IMU can also measure how tilted Vector's head is. The IMU is located in Vector's head. This presents a small extra step of processing for the software to accommodate the impact of the head. By combining the position & orientation of the IMU within the head, the current estimated angle of the head, the known joint that the head swivels on, and working backwards the IMU measures can be translated to body-centered measures.

28.3. SENSING MOTION

The IMU's primary function is detect motion – to help estimate the change in position, and changes in orientation of Vector's body, and how fast it is moving.

The IMU can be used to detect the angle of Vector's body. This is important, as the charging behaviour uses the tilt of the charging station ramp to know that it is in the right place.

28.4. SENSING INTERACTIONS

The IMU (with some help from the cliff sensors) is also used to sense interactions and other environmental events – such as being picked up or held by a person, being poked or given a fist bump, or falling.

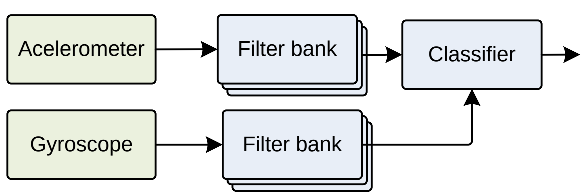
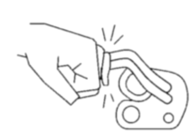


Figure 43: *Classify movement by filtering the accelerometer and gyroscope signals*

By using combinations of high, low pass, and band filters, and looking for signature patterns, Vector identify the kinds of physical interactions that are occurring.

The taps and pokes may tilt Vector, but will also provide a "frequency" response to the signals that can be used to trigger on. The movement will change his position quickly and slight in small distance, but Vector will resume his prior position very quickly.



Fist-bumps are like pokes, except that the lift has already been raised, and most of the frequency response and motion will be predictable from receiving the bump on the lift.

Fall detection is similar. In free-fall, the force measured by the accelerometer gets very small. If Vector is tumbling, there is a lot of angular velocity that is taking Vector off of his driving surface.

Being picked up is distinct because of the direction of acceleration and previous orientation of Vector's body.

Being held is sensed, in part by first being picked up, and by motions that indicate it is not on a solid surface.

A similar set of interaction sensing is present with the cube. It can sense that it is being tapped (or double tapped), picked up, and held. See Chapter 21.

Patent filings (e.g. WO 2019/173321 indicates that Anki had ideas of how this could be extended to detect riding in a car, and even estimating how fast it is moving.

29. REFERENCES AND RESOURCES

AdaFruit, https://github.com/adafruit/Adafruit_9DOF/blob/master/Adafruit_9DOF.cpp
An example of how accelerometer and gyroscope measurements are fused.

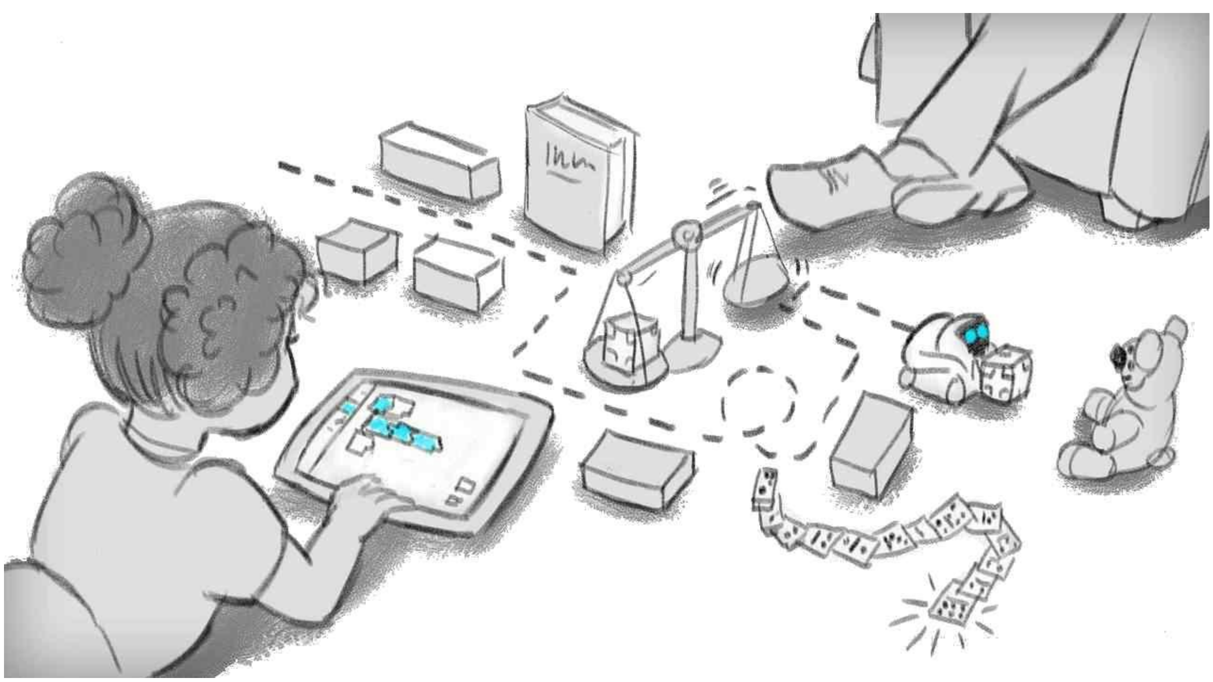
Anderson, Ross *Robot Transportation Mode Classification*, Anki, WIPO WO 2019/173321 A1, 2019 Sept 12

PART III

Communication

This part provides details of Vector's communication protocols. These chapters describe structure communication, the information that is exchange, its encoding, and the sequences needed to accomplish tasks. Other chapters will delve into the functional design that the communication provides interface to.

- COMMUNICATION. A look at Vector's communication stack.
- COMMUNICATION WITH THE BODY-BOARD. The protocol that the body-board responds to.
- VECTOR'S BLUETOOTH LE COMMUNICATION PROTOCOL. The Bluetooth LE protocol that Vector responds to.
- CUBE'S BLUETOOTH LE COMMUNICATION PROTOCOL. The Bluetooth LE protocol that the companion cube responds to.
- SDK PROTOCOL. The HTTPS protocol that Vector responds to.
- WEB-VISUALIZATION PROTOCOL. The web-sockets protocol(s) that Vector provides for debugging in development builds.
- CLOUD. A look at how Vector interacts with remote services



drawing by Jesse Easley

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CHAPTER 11

Communication

This chapter describes the system of communication system with the devices internal and external to Vector:

- Internal communication with the body-board, and internal peripherals
- Bluetooth LE: with the Cube, and with the application
- WiFi: with the cloud, and with the application
- Internal support

30. OVERVIEW OF VECTOR'S COMMUNICATION INFRASTRUCTURE

A significant part of Vector's software is focused on communication:

- Internal IPC between processes
- Communication with local peripherals and the body-board processor
- Communication with external accessories and applications.

From a high-level, the communication stacks look like:

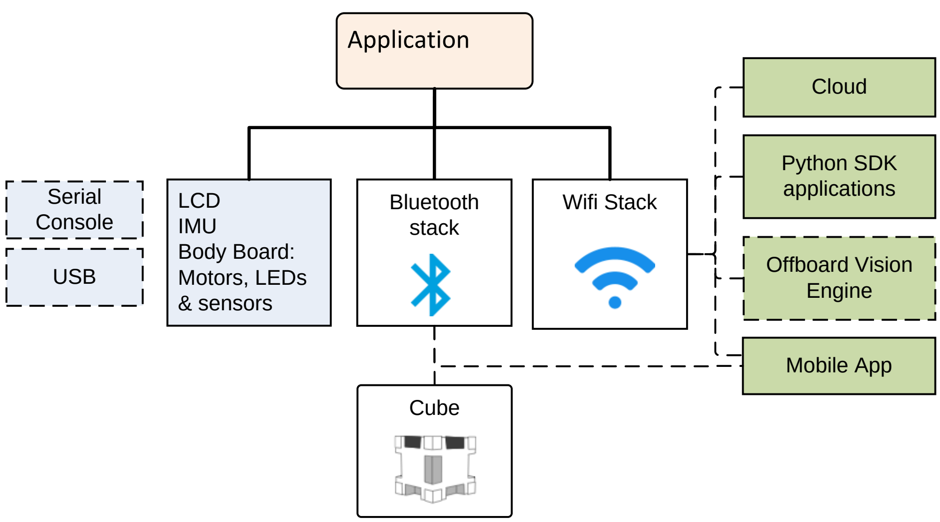


Figure 44: *The overall communication infrastructure*

31. INTERNAL COMMUNICATION WITH PERIPHERALS

The communication stack within the software is one part Linux, one part Qualcomm, and a big heaping dose of Anki's stuff.

31.1. COMMUNICATION WITH THE BODY-BOARD

The head board communicates with the body board using a serial interface. The device file is `/dev/ttyHS0`.

31.2. SERIAL BOOT CONSOLE

The head-board employs a serial port to display kernel boot up and log messages. The parameters are 115200 bits/sec, 8 data bits no parity, 1 stop bit; the device file is `/dev/ttyHSL0`. This serial port is not bi-directional, and can not be used to login. Melanie T

31.3. USB

There are pins for USB on the head board. Asserting "F_USB" pad to VCC enables the port. During power-on, and initial boot it is a Qualcomm QDL port. The USB supports a Qualcomm debugging driver (QDL), but the readout is locked. It appears to be intended to inject software during manufacture. Melanie T

The `/etc/initscriptsusb` file enables the USB and the usual functionfs adb. It lives in `/sbin/usr/composition/9091` (I think, if I understand the part number matching correctly). This launches ADB (DIAG + MODEM + QMI_RMNET + ADB)

Vectors log shows the USB being disabled 24 seconds after linux starts. It is enabled only on development units.

32. BLUETOOTH LE

Bluetooth LE is used for two purposes:

1. Bluetooth LE is used to initially configure Vector, to reconfigure him when the WiFi changes; and to pair him to with the companion cube accessory. Potentially allows some diagnostic and customization.

2. Bluetooth LE is used to communicate with the companion Cube: to detect its movement, taps, and to set the state of its LEDs.

Vector's Bluetooth LE stack looks like:

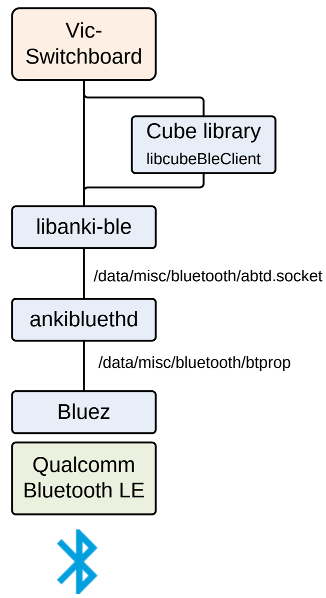


Figure 45: *The Bluetooth LE stack*

The elements of the Bluetooth LE stack include:

Table 17: *Elements of the Bluetooth LE stack*

Element	Description & Notes
ankibluetoothd	A server daemon. The application layer communicates with it over a socket; `/data/misc/bluetooth/abtd.socket`
BlueZ	Linux's official Bluetooth stack, including Bluetooth LE support. The Anki Bluetooth daemon interacts with it over a socket: `/data/misc/bluetooth/btprop`
bccmd	A Bluetooth core command
btmon	A command-line Bluetooth tool
libanki-ble.so	Communicates with Anki Bluetooth daemon probably serves both the external mobile application interface and communication with the companion cube.
libcubeBleClient.so[25]	A library to communicate with the companion cube, play animations on its LEDs, detect being held, taps and the cube's orientation.
viccubetool	Probably used to update the firmware in the Cube.

[25] The library includes a great deal of built in knowledge of the state of application ("game engine"), animations, and other elements

33. WIFI

WiFi networking is used by Vector for six purposes:

1. WiFi is used to provide the access to the remote servers for Vector's speech recognition, natural language processing
2. WiFi is used to provide the access to the remote servers for software updates, and providing diagnostic logging and troubleshooting information to Anki
3. To provide time services to so that Vector knows the current time
4. To provide an interface, on the local network, that the mobile application can use to configure Vector, and change his settings.
5. To provide an interface, on the local network, that SDK applications can use to program Vector.
6. To provide interfaces, on the local network, that allow development Vectors (special internal versions) to be debugged and characterized

The WiFi network stack looks like:

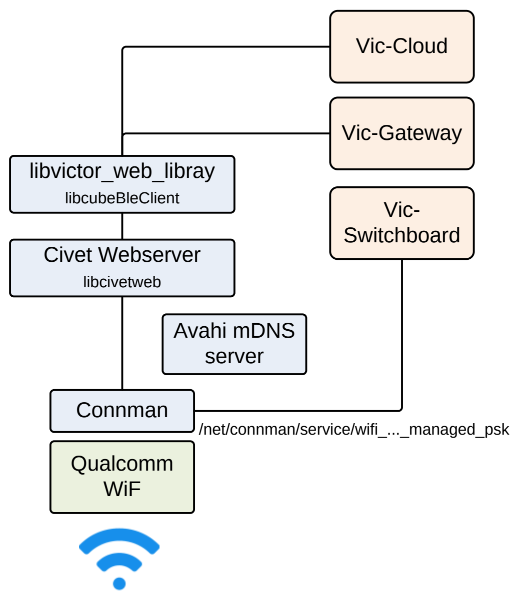


Figure 46: *The WiFi stack*

The elements of the stack include:[26]

Table 18: *Elements of the Bluetooth LE stack*

Element	Description & Notes
avahi 0.6.31	A mDNS server that registers Vector's robot name (with his network address) on the local network;
chronyd	Fetches the time from a network time server.
libcivetweb.so.1.9.1	Embedded web server
libvictor_web_library.so	Anki Vector Web Services.

[26] All of the software versions include an Anki webserver service systemd configuration file whose executable is missing. The most likely explanation is that early architecture (and possibly early versions) included this separate server, and that the systemd configuration file is an unnoticed remnant.

33.1. FIREWALL

The network configuration includes a firewall set up with the usual configuration files:

```
/etc/iptables/iptables.rulesiptables
/etc/iptables/ip6tables.rulesiptables
```

Is set to block incoming traffic (but not internal traffic), except for:

1. Responses to outgoing traffic
2. DHCP
3. TCP port 443 for vic-gateway
4. UDP port 5353 for mDNS (Avahi)
5. And the ping ICMP

In developer builds the firewall also allows:

1. SSH access
2. Android Debugger (ADB) over TCP access
3. "Web-viz" access, which has web-server / websockets / webdav ports
4. Webots support
5. WWise profiler support

The firewall does not block outgoing traffic

33.2. WIFI CONFIGURATION

The WiFi is configured by the Vic-switchboard over Bluetooth LE. The WiFi settings cannot be changed by the remote servers or thru the WiFi-based API; nor is information about the WiFi settings is not stored remotely.

The WiFi is managed by connman thru the Vic-Switchbox:

- To provide a list of WiFi SSIDs to the mobile app
- To allow the mobile app to select an SSID and provide a password to
- Tell it forget an SSID
- To place the WiFi into Access Point mode

The connman settings – files for accessing known WiFi access points – are stored on the encrypted file-system /data, in the folder:

```
/data/lib/connman
```

The path is hard-coded into connman itself. This folder is created (if it doesn't exist) by mount-data when it sets /data up for the robot (such as when it is new or has had its user data erased via the "Clear User Data" menu). The contents of /var/lib/connman are copied here with each system start.

33.3. ACCESS POINT MODE

Vector can acted as a wifi access point, instead of connecting to a router. This was primarily intended to ease development of Vector. With the OpenSource Kit this is more useful. Vector can be put into access point mode by issuing a command over the Bluetooth LE channel.

34. NETWORK COMMUNICATION

34.1. COMMUNICATING WITH MOBILE APP AND SDK

Vector's *robot name* is something that looks like "Vector-E5S6". This name is used consistently; it will be Vector's:

- advertised Bluetooth LE peripheral name (although spaces are used instead of dashes)
- mDNS network name (dashes are used instead of spaces),
- the name used to sign certificates, and
- it will be the name of his WiFi Access Point, when placed into Access Point mode

34.1.1 Certificate based authentication

A *certificate* is generated by Vector for use with the HTTPS API and `vic-gateway`. The certificate allows the mobile application and SDK-based application to validate that they are talking to the robot that they think they are. This is *optional*: the applications don't need to use it, if they do not wish to. So what are certificates?

"Certificates can be thought of as policy documents. Any X.509 certificate consists of

Phil Vachon

- "a public key,
- "an indication who the certificate was issued for,
- "what actions the authority allows the certificate holder to perform,
- "the date the certificate is first valid on,
- "the date the certificate expires on,
- "metadata about how to check if the certificate has been revoked (optional, but highly recommended),
- "the authority who issued the certificate, and
- "a signature across all this metadata, from the authority."

The certificate is created by the `vic-gateway-cert.service` (which in turn calls the `/sbin/vic-gateway-cert` script) at start-up, after the "factory reset." When the user data is cleared, the old certificates and robot name are cleared as well. Vector is assigned a new robot name when the system restarts (after clearing), and then creates a new certificate.

The certificate is stored on the robot at:

`/data/vic-gateway/gateway.cert`

The path is hard-coded into both `vic-cloud` and `vic-gateway`. Vector posts the certificate to the cloud servers using `vic-cloud`. The mobile application and SDK-based applications receive the certificate from these servers.

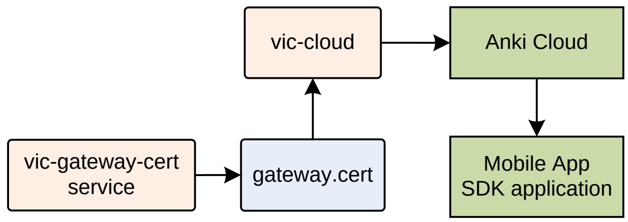


Figure 47: *The certificate flow from the robot to the mobile application*

The following is a synopsis of the files and scripts involved with the API certificate:

Table 19: *The files, scripts and programs involved with the API certificate*

File	Description
/anki/etc/vic-gateway-cert.env	Holds the fault code if the vic-gate-cert.service fails.
/data/etc/robot.pem	The private key is generated after a factory reset by mount-data.
/data/vic-gateway/gateway.cert	The certificate used by the mobile application and SDK apps to validate the authenticity of the robot.
/etc/systemd/system/vic-gateway-cert.service	The startup service responsible for creating the certificate (if there isn't one already)
/etc/vic-gateway-cert.conf.in	The template (default field values) used in creating the certificate.
/sbin/vic-gateway-cert	The script that creates the certificate
vic-cloud	Posts the certificate to the cloud
vic-gateway	Uses the robot.pem as the private key for TLS communication with the mobile application and SDK.

This certificate is intended to be added to the trusted SSL certificates store before a HTTPS communication session. The certificate issued by Vector is good for 100 years. The following is information typically embedded in a Vector certificate:

Table 20: *Elements of a Vector certificate*

Element	Value
Common Name	*Vector's robot name*
Subject Alternative Names	*Vector's robot name*
Organization	Anki
Locality	SF
State	California
Country	US
Valid From	*the date the certificate was created*
Valid To	*100 years after the date the certificate was created*
Issuer	*Vector's robot name*, Anki
Serial Number	

34.1.2 Token

A *session token* is provided by Anki servers[27] to the mobile application and HTTPS-based SDK application. This token is *required* to by the robot to validate that they application is talking to has authenticated itself as an owner.

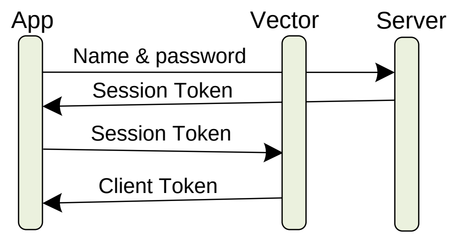


Figure 48: *Sequence for acquiring a client token*

When the application(s) receive the session token from the server, they must pass it to Vector via the Bluetooth LE RTS protocol or the HTTPS SDK protocol. The process to is generated it is initiated in one of two ways. One method is by the Bluetooth LE command (section *40.9 Cloud session*); the other is by send a User Authentication command (see Chapter 15 section *52.5 User Authentication*). Vector will return a *client token*. (The session token is single use only.) The application(s) should save this client token for future uses (it can be used indefinitely).

Vector stores information about the session and client tokens in a file at:

`/data/vic-gateway/token-hashes.json`

This file has a single structure with the following fields:

Field	Type	Description
client_tokens	ClientToken[]	The array of client tokens.

Table 21: *The token hashes structure*

The ClientToken structure has the following fields:

Field	Type	Description
app_id	string	This is the name given by an application using the API. Common ones include "companion-app" for the mobile application, and "SDK" for the python SDK based authentication. *Optional.*
client_name	string	The name of computer requesting the client token. *Optional.*
hash	base64 string	
is_primary	bool	Unknown This is always false.
issued_at	string	The date-time that the hash / client token was created

Table 22: *The ClientToken structure*

34.2. WEB-VIZ, A VISUAL CHARACTERIZATION TOOL

Development builds of Vectors software include an optional web-sockets API and web-visualization (webviz) tool. This feature is not present in the production releases, nor many of the development releases. With this tool has some of the vic-server processes provide an HTTP web-server, and web socket over it:

[27] https://groups.google.com/forum/#!msg/anki-vector-rooting/YlYQsX08OD4/fvkAOZ91CgAJ
https://groups.google.com/forum/#!msg/anki-vector-rooting/XAaBE6e94ek/OdES50PaBQAJ

Port	Description
8887	The webserver built into vic-webserver
8888	The webserver built into vic-engine
8889	The webserver built into vic-anim
8890	Not used

***Table 23:** Web-viz HTTP & web-socket server ports*

The web-sockets provide access to internal variables and other software state. In some cases provide points of control. The web-server, esp thru the webdav support, allows files to be downloaded and uploaded into Vector. This includes the ability to add animation files that can be tested.

Note: the tool is rumoured to be consume a lot of resources, causing unusual faults to occur on Vector. It has a small overlap with the functions can be taken via the SDK interface.

35. CLOUD SERVERS

The cloud servers are used for natural language processing, storing settings, tracking diagnostic information, and software updates.

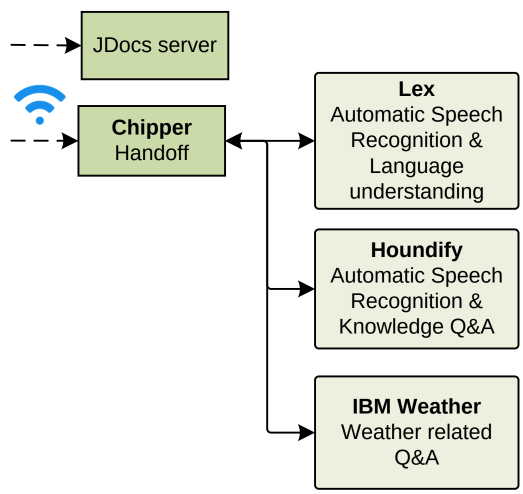


***Figure 49:** The cloud servers*

For natural language processing, the audio stream (after the "Hey Vector") is sent to a group of remote servers for processing. The functions are divided up across several different servers which can provide specialized services:

Server	Description
Chipper	Chipper is a server that that hands off the audio processing.
Houndify	The "knowledge graph" Q&A server is handled by Sound Hound (Houndify). Note: the speech is sent to Houndify only if Lex is unable to handle the query.
IBM Weather	IBM handles the Weather related questions.
Lex	Lex handles most of Vectors speech recognition, natural language understanding, return an intent. (This is discussed a bit more in Chapter 18) The "I have a question" queries are handed off to Houndify. This server is hosted by AWS.

***Table 24:** Natural language processing servers*

Chapter 17 describes the communication with these servers, including the responses that they send back.

Chapter 18 describes typical natural language processing, and the processing of intents.

35.1. ROBOT CERTIFICATE

Each Vector has supporting TLS certificates and signing keys are stored in the OEM partition, located in the /factory/cloud folder:

File	Description
AnkiRobotDeviceCert.pem	The certificate used
AnkiRobotDeviceKeys.pem	The private key used
Info$(serialNum}.json	A configuration file that
${serialNum}	empty

***Table 25:** OEM cloud folder*

The Info${serialNum}.json file has the following structure:

Field	Type	Description
CertDigest	base64 string	
CertSignature	base64 string	
CertSignatureAlgorithm	string	The name of openSSL signature algorithm to use, "sha256WithRSAEncryption"
CommonName	string	'vic:' followed by the serial number. (This is also called the "thing id" in other structures.
KeysDigest	base64 string	

***Table 26:** Cloud Info${serialNum} structure*

36. REFERENCES & RESOURCES

PyCozmo.
https://github.com/zayfod/pycozmo/blob/master/docs/protocol.md
https://github.com/zayfod/pycozmo/blob/master/pycozmo/protocol_declaration.py

Vector has a couple UDP ports open internally; likely this is inherited from libcozmo_engine. The PyCozmo project has reverse engineered much of Cozmo's UDP protocol.

Vachon, Phil *Application Trust is Hard, but Apple does it Well — Security Embedded*
https://www.security-embedded.com/blog/2020/11/14/application-trust-is-hard-but-apple-does-it-well

CHAPTER 12

Body-board Communication Protocol

This chapter describes Vector's body-board communication protocol.

- The kinds of activities that can be performed
- The interaction sequences
- The communication protocol stack.

37. COMMUNICATION PROTOCOL OVERVIEW

Communication with the body-board, once established, is structured as a request-response protocol and a streaming data update. The data of the messages was packaged using an proprietary tool called "C-Like Abstract Data structures" (CLAD) that made it easy for Anki to define message structures – fields and values in a defined format – and generate code to encode and decode them.

The messages from the head board to the body-board have the content:

- Checking that the application firmware is running and its version
- Boot-loader updates to the firmware: Entering the boot-loader, erasing flash, writing a new application, and verifying it
- The 4 LED RGB states
- Controls for the motors: possible direction and enable; direction and duty cycle; or a target position and speed.
- Power control information: disable power to the system, turn off distance, cliff sensors, etc.

In turn, the body board messages to the head-board can contain (depending on the type of packet):

- The touch sensor ADC value, and state of the backpack button
- The microphone samples for all 4 microphones. (Most likely as 16 bits per sample)
- The battery voltage,
- The charging terminal voltage
- State of the charger – on docked, charging, battery critically low
- The temperature of the charger/battery
- The state of 4 motor encoders, possibly as encoder counters, possibly as IO state

- The time of flight readings, these are used to reconstruct histogram counts and SPAD reflectivity measures.
- The values from each of the 4 cliff proximity sensors
- Which peripherals are enabled and disabled (powered down)

37.1. BASIC STRUCTURES

The data structures passed between the head and the body are packaged as frames:

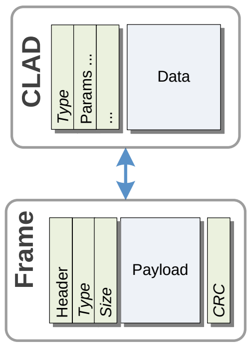


Figure 50: *Overview of the body-board frames*

THE RS232 SERIAL LINK is the used as the transport. It handles the delivery of the bytes between the body board and the head board. The data rate: 3 Mbits/sec[28]

THE FRAME identifies the start and end of a message, includes the message itself and error detection. It also includes the kind of CLAD message that is contained.

THE C-LIKE ABSTRACT DATA (CLAD) is the layer that decodes the messages into values for fields, and interprets them.

TIMEOUTS. The body-board maintains a timer to detect the loss of communication from the head-board – perhaps from a software crash. If the body-board does not receive communication within sending 200 Data Frame messages, it will turn off power.

37.2. THE MESSAGE FRAMES

To transport the messages between the head and body boards, there is a framing layer. This holds the messages:

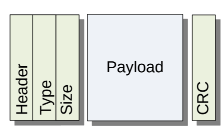


Figure 51: *The format of a frame*

When the head-board sends messages to the body-board, the header is:

AA_{16} ‘H’ ‘2’ ‘B’

The body-board sends messages in response to commands, and at regular intervals to the head-board. The header of a message is:

AA_{16} ‘B’ ‘2’ ‘H’

[28] Value from analysis of the RAMPOST, vic-robot, and dfu programs.

The rest of the frame:

- The payload type is 16 bits. The packet type implies both the size of the payload, and the contents. If the packet type is not recognized, or the implied size does not match the passed payload size, the packet is considered in error.
- The payload size is a 16 bit number. The maximum payload size is 1280 bytes.
- The CRC is 32 bits. It is computed on the payload only.

The tag and CLAD payload are passed to the application for interpretation.

37.3. ACKNOWLEDGEMENT AND NEGATIVE ACKNOWLEDGEMENT OF MESSAGES

Sends a message to the body-board. If the message doesn't pass CRC checks, or the command is not recognize, the body-board sends a NAK.

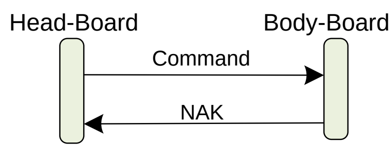


Figure 52: *Body-board NAK a CRC-error or bad command*

Otherwise it may attempt to carry out the command, and it may send back an ACK or other response on success… or a NAK on error.

37.4. UPDATING THE FIRMWARE APPLICATION

The head-board can update the firmware in the body-board, by putting it into DFU (device firmware upgrade) mode and downloading the replacement firmware image. If the head-board application decides to download a (new) application to the body-board – for instance, if the version is out of date – it does so with a sequence like:

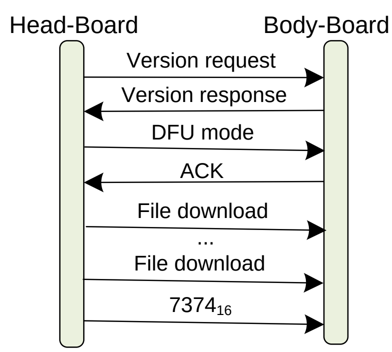


Figure 53: *Sequence for updating the body-board*

1. Checking the version. Compares this with the version of the latest file.
2. It sends the 7878_{16} command to erase the current application
3. It sends a serial sequence of the application data using the 6675_{16} command.
4. Then the 7374_{16} command is sent to validate the command (including checking its authenticity using a digital signature), and start the application.
5. The boot-loader sends the results of the check in a $6B61_{16}$ response. The head-board application check results, then if successful,

6. It waits for message frames from the body-board application.

37.4.1 The format of the firmware update file

The first 16 bytes of the firmware update files holds the version. This is used only for comparing versions. It is not sent. The remainder of the file holds the application firmware. The following summarizes where the application firmware is placed into the STM32F030 program memory:

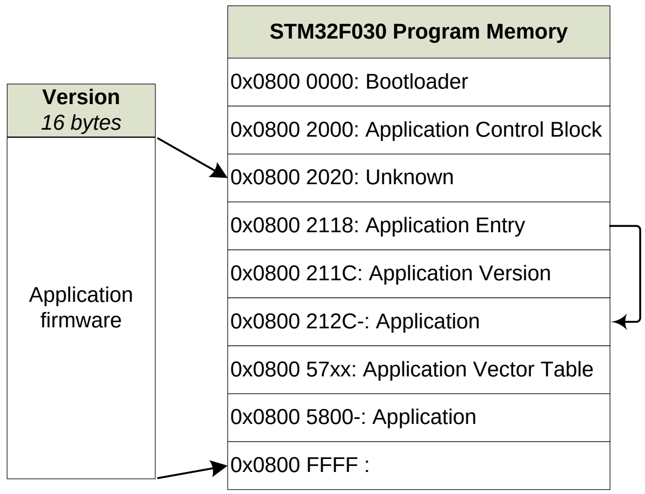


Figure 54: *The STM32F030 program memory map*

Note: I don't know what points to the vector table.

37.5. COMMAND-LINE INTERFACE

The body-board has a bidirectional serial interface for test purposes. This is located on the charger positive pad. The single connection is half-duplex – it is used to both send and receive. The data rate is 115.2 Kbits/sec.

Note: this communication is only implemented in DVT firmware; it is not implemented in production firmware. It is not known how to put the DVT firmware into this mode.

When the body board powers on it sends a few header bytes and a string:

FF_{16} 92_{16} $1F_{16}$ CF_{16} FF_{16} FF_{16} FF_{16} FF_{16} "\\nbooted\n"

Thereafter body-board can receive characters from this interface and forward them with the 6364_{16} message to the head-board for processing by vic-robot.

1. vic-robot receives these characters, and buffers them. When it sees a new line or carriage return, it examines the line. If the line starts with a '>' and is followed by a valid 3-letter command, it will carry out the command. This may include reporting sensed values, writing the factor calibration values or EMR.

2. If vic-robot wishes to send text, via the body-boards outgoing serial port, it uses the 6364_{16} command to send the text characters to the body-board, which then sends them out the charger port.

The text commands from this port are that vic-robot recognizes are:

- esn
- bsv
- mot

- get
- fcc
- rlg
- eng
- smr
- gmr
- pwr
- led

38. MESSAGE FORMATS

This section describes the format and interpretation of the CLAD messages that go between the body-board and head-board. It describes the fields and how they are encoded, etc.

- All multi-byte values are in little endian order
- The letters to describe the frame type are in the order sent (effectively the opposite of the 16-bit values)

The following kinds of messages can be sent from the head-board to the body-board:

Table 27: *Summary of the commands from the head-board to the body-board*

Frame type	Payload Size	Description
6364_{16} *'dc'*	32	Appears to allow sending text back to the body board and out its backs end. [Data character? charger data?] *Note: this message is not supported in production application firmware (i.e. 1.6).*
6466_{16} *'fd'*	64	Data frame. This has all the bits for the LEDs, motor drivers, power controls, etc.
6473_{16} *'sd'*	0	Shutdown: disconnect the battery, to shutoff the system.
6675_{16} *'uf'*	1028	Update firmware frame. Sends a 1024B as part of the DFU payload. The first 16b is the offset in the program memory to update; the next 16b are the number of 32-bit words in the payload to write. (The packet is a fixed size, so may be padded out)
$6D64_{16}$ *'dm'*	0	Go to DFU mode? Goto app mode? Change the mode: enter the boot-loader? start regular reports?
7276_{16} *'vr'*	0	Requests the application version. If there is an application, it responds with a 7276_{16}. If there isn't application, the boot-loader responds with a $6B61_{16}$ with a 0 payload (a NAK).
$736C_{16}$ *'ls'*	16	LED control
7374_{16} *'ts'*	0	Validate the flash, to check that the newly downloaded program and that it passed signature checks. The boot-loader sends back a $6B61_{16}$ to ACK to indicate that the firmware passed checks, or NACK that it does not. If successful, the application is started. [Test?]
7878_{16} *'xx'*	0	Erases the current program memory (the currently installed image). The boot-loader sends back a $6B61_{16}$ to acknowledge that the erase when it has completed.

The following kinds of messages can be sent from the body-board to the head-board:

Fame type	Payload Size	Description
6364_{16} *'dc'*	32	Appears to include characters. *Note: this message is not supported in production application firmware (i.e. 1.6).*
6466_{16} *'fd'*	768	Data frame. Battery state – level, temperature, flags The size of the message suggests that it holds 128 samples from one to three microphones (4 microphones × 2bytes/sample × 80 samples/microphone == 768 bytes) for the voice activity detection audio processing.
6662_{16} *'bf'*		Boot-loader frames
$6b61_{16}$ *'ak'*	4	The value is non-zero if an ack
7276_{16} *'vr'*	40	The first 28 payload bytes are TBD. This is followed by a 16-byte version (often printable characters). The first 16 bytes of the DFU file are also the version.
7376_{16} *'vs'*	16	*Note: this message is not supported in production application firmware (i.e. 1.6).*

***Table 28:** Summary of the messages from the body-board to the head-board*

38.1. ENUMERATIONS

These are the indices that the communication uses to refer to sensors, motors, etc.

38.1.1 Cliff Sensors

The cliff sensors indices are:

Index	Meaning
0	The front-left cliff sensor.
1	The front-right cliff sensor.
2	The back-left cliff sensor.
3	The back-right cliff sensor.

***Table 29:** Cliff sensor enumeration*

38.1.2 Motors

The motor indices are:

Index	Meaning
0	The left wheel motor.
1	The right wheel motor
2	The lift motor.
3	The head motor.

***Table 30:** Motor enumeration*

38.2. STRUCTURES

These are the data structures used within the messages.

38.2.1 Motor Status

The motor status structure is:

Offset	Size	Type	Parameter	Description
0	4	int32_t	*position*	The new position
4	4	int32_t	*dlt*	Change in encoder count from the previous position.
8	4	uint32_t	*tm*	The number of ticks since of last change

Table 31: *Parameters for motor status structure*

38.3. DATA FRAME FROM BODY BOARD

The messages are sent fast enough to support microphone sample rate of 15625 samples/second for each of the 4 microphones.

The parameters for the message from the body-board are:

Offset	Size	Type	Parameter	Description
0	4	uint32_t		
4	2	uint16_t	*status*	See bit fields below.
6	1	uint8_t	*I2C device fault*	0 if no fault, otherwise the I^2C address of the sensor that can't communicate: 0x52: The time of flight distance sensor failed during power on self test 0xA6: a cliff sensor failed. See the minor code for which sensor.
7	1	uin8_t	*I2C fault item*	If the fault is 0xA6, this is the index of the first cliff sensor that was detected to have failed. See the enumeration above.
8	48	motor status[4]	*motor status*	The motor status (see structure above) for each of the motors
56	8	uint16_t[4]	*cliff sensor*	Sensor readings for each of the cliff sensors
64	2	int16_t	*battery voltage*	The battery voltage, scale by 0.00136719 to get volts
66	2	int16_t	*charger voltage*	The charger voltage, scale by 0.00136719 to get volts
68	2	int16_t	*Body Temperature C*	The body-board MCU temperature (proxy for the battery temperature)
72	2	uint16_t	*battery flags*	see below
0x4c	1	uint8_t	*prox sigma mm*	The low 4 bits are some sort of state
0x4e	2	uint16_t	*prox raw range (mm)*	The time of flight sensor's reported range
0x50	2	uint16_t	*prox signal rate (mcps)*	The time of flight sensor's reported signal strength

Table 32: *Parameters for Data Frame from the body board*

0x52	2	uint16_t	*prox ambient*	The time of flight sensor's reported ambient noise
0x54	2	uint16_t	*prox SPAD count*	The time of flight sensor's reported SPAD count
0x56	2	uint16_t	*prox sample count*	The time of flight sensor's reported sample count
0x58	4	uint32_t	*prox calibration result*	
92	4	uint16_t[2]		Index 1 is the button, 0 is the touch sense ADC?
96	4	uint16_t[2]		Something to do with the microphones, appears to be indices to the buffers being used.
100	2	uint16_t		Something related to the button inputs
102-128		UNKNOWN		
128	640	uint16_t[320]	*mic samples*	The microphone samples. The size of the message suggests that it holds 80 samples from each microphones (4 microphones × 2bytes/sample × 80 samples/microphone == 640 bytes) for the voice activity detection audio processing.

That status byte bit indices are:

***Table 33:** Status condition indices*

Bit Index	Meaning
0	This bit is set if the cliff sensor and time of flight sensor are on; it is clear if they are off.
1	This bit is set if the motor encoders have been turned off. This is done to save power when the motors are idle. If the bit is not set, the encoders are enabled.
2	The head encoder has changed value (the head moved).
3	The lift encoder has changed value (the lift moved)

Battery condition bit indices are:

***Table 34:** Battery condition indices*

Bit Index	Meaning
0	The charger is connected to a power source – that is, the charger IC has detected a voltage supplied to the charging pins.
1	The battery is charging
2	The battery is disconnected.
3	The battery is overheated
4	unknown/reserved
5	The battery voltage is low, below a critical threshold (probably as defined by the charger).
6	Emergency shutdown imminent.

Some of these bits may have had different meaning in the past, and became unused with body-board firmware revisions.

38.4. DATA FRAME FROM HEAD BOARD TO BODY BOARD

The parameters for the message from the body-board are:

Table 35: *Parameters for Data Frame from the head-board*

Offset	Size	Type	Parameter	Description
0	4	uint32_t		Sequence number(?)
4	4	uint32_t		Two bit are checked.. Charger control (?)
8	8	iint16_t[4]	*Motor settings*	
24	12	uint8_t[12]	*LED RGB values*	
36	28			ignored

CHAPTER 13

Vector Bluetooth LE Communication Protocol

This chapter describes Vector's Bluetooth LE communication protocol.

- The kinds of activities that can be done thru communication channels
- The interaction sequences
- The communication protocol stack, including encryption, fragmentation and reassembly.

Note: communication with the Cube is simple reading and writing a characteristic, and covered in Appendix G.

39. COMMUNICATION PROTOCOL OVERVIEW

Vector advertises services on Bluetooth LE, with the Bluetooth LE peripheral name the same as his robot name (i.e. something that looks like "Vector-E5S6".)

Communication with Vector, once established, is structure as a request-response protocol. The request and responses are referred to as "C-Like Abstract Data structures" (CLAD) which are fields and values in a defined format, and interpretation. Several of these messages are used to maintain the link, setting up an encryption over the channel.

The application layer messages may be arbitrarily large. To support Bluetooth LE 4.1 (the version in Vector, and many mobile devices) the CLAD message must be broken up into small chunks to be sent, and then reassembled on receipt.

Combined with application-level encryption, the communication stack looks like:

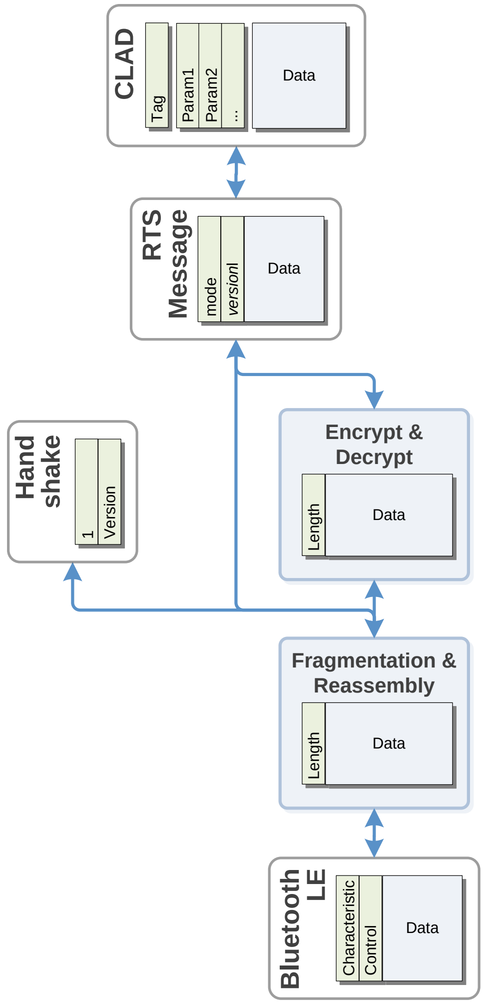


Figure 55: *Overview of encryption and fragmentation stack*

THE BLUETOOTH LE is the link/transport media. It handles the delivery, and low-level error detection of exchanging message frames. The frames are fragments of the overall message. The GUID's for the services and characteristics can be found in Appendix G.

THE FRAGMENTATION & REASSEMBLY is responsible for breaking up a message into multiple frames and reassembling them into a message.

THE ENCRYPTION & DECRYPTION LAYER is used to encrypt and decrypt the messages, after the communication channel has been set up.

THE RTS is extra framing information that identifies the kind of CLAD message, and the version of its format. The format changed with version, so this version code is embedded at this layer.

THE C-LIKE ABSTRACT DATA (CLAD) is the layer that decodes the messages into values for fields, and interprets them,

39.1. SETTING UP THE COMMUNICATION CHANNEL

It sometimes helps to start with the overall process. This section will walk thru the process, referring to later sections where detailed information resides.

If you connect for the "first time" – or wish to re-pair with him – put him on the charger and press the backpack button twice quickly. He'll display a screen indicating he is getting ready to pair.

If you have already paired the application with Vector, the encryption keys can be reused.

The process to set up a Bluetooth LE communication with Vector is complex. The sequence has many steps:

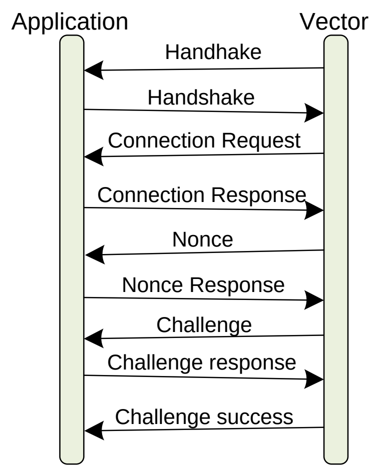


Figure 56: *Sequence for initiating communication with Vector*

1. The application opens Bluetooth LE connection (retrieving the service and characteristics handles) and subscribes to the "read" characteristic (see Appendix G for the UUID).
2. Vector sends *handshake* message; which the application receives. The handshake message structure is given below. The handshake message includes the version of the protocol supported.

Table 36: *Parameters for Handshake message*

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*type*	?
1	4	uint32_t	*version*	The version of the protocol/messages to employ

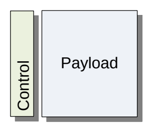
3. The application sends the handshake back
4. Then the Vector will send a *connection request,* consisting of the public key to use for the session. The application's response depends on whether this is a first-time pairing, or a reuse.
    a. First time pairing requires that Vector have already been placed into pairing mode prior to connecting to Vector. The application keys should be created (see section *39.3.1 First time pairing* above).
    b. Reconnection can reuse the public and secret keys, and the encryption and decryption keys from a prior pairing
5. The application should then send the publicKey in the response

6. If this is a first-time pairing, Vector will display a *pin code*. This is used to create the public and secret keys, and the encryption and decryption keys (see section *39.3.1 First time pairing* above). These can be saved for use in future reconnection.
7. Vector will send a *nonce* message. After the application has sent its response, the channel will now be encrypted.
8. Vector will send a *challenge* message. The application should increment the passed value and send it back as a challenge message.
9. Vector will send a *challenge success* message.
10. The application can now send other commands

If the user puts Vector on the charger, and double clicks the backpack button, Vector will usually send a *disconnect* request.

39.2. FRAGMENTATION AND REASSEMBLY

An individual frame sent over Bluetooth LE is limited to 20 bytes. (This preserves compatibility with Bluetooth LE 4.1) A frame looks like:



The control byte is used to tell the receiver how to *reassemble* the message using this frame.

- If the MSB bit (bit 7) is set, this is the start of a new message. The previous message should be discarded.
- If the 2nd MSB (bit 6) is set, this is the end of the message; there are no more frames.
- The 6 LSB bits (bits 0..5) are the number of payload bytes in the frame to use.

The receiver would append the payload onto the end of the message buffer. If there are no more frames to be received it will pass the buffer (and size count) on to the next stage. If encryption has been set up, the message buffer will be decrypted and then passed to the RTS and CLAD. If encryption has not been set up, it is passed directly to the RTS & CLAD.

Fragmenting reverses the process:

1. Set the MSB bit of the control byte, since this is the start of a message.
2. Copy up to 19 bytes to the payload.
3. Set the number of bytes in the 6 LSB bits of the control byte
4. If there are no more bytes remaining, set the 2nd MSB it of the control byte.
5. Send the frame to Vector
6. If there are bytes remaining, repeat from step 2.

39.3. ENCRYPTION SUPPORT

For the security layer, you will need the following:

```
uint8_t Vectors_publicKey[32];
uint8_t publicKey [crypto_kx_PUBLICKEYBYTES];
uint8_t secretKey [crypto_kx_SECRETKEYBYTES];
uint8_t encryptionKey[crypto_kx_SESSIONKEYBYTES];
uint8_t decryptionKey[crypto_kx_SESSIONKEYBYTES];
uint8_t encryptionNonce[24];
uint8_t decryptionNonce[24];
uint8_t pinCode[16];
```

***Example 1:** Bluetooth LE encryption structures*

The variables mean:

***Table 37:** The encryption variables*

Variable	Description
decryptionKey	The key used to decrypt each message from to Vector.
decryptionNonce	An extra bit that is added to each message. The initial nonce's to use are provided by Vector.
encryptionKey	The key used to encrypt each message sent to Vector.
encryptionNonce	An extra bit that is added to each message as it is encrypted. The initial nonce's to use are provided by Vector.
pinCode	6 digits that are displayed by Vector during an initial pairing.
Vectors_publicKey	The public key provided by Vector, used to create the encryption and decryption keys.

There are two different paths to setting up the encryption keys:

- First time pairing, and
- Reconnection

39.3.1 First time pairing

First time pairing requires that Vector be placed into pairing mode prior to the start of communication. This is done by placing Vector on the charger, and quickly double clicking the backpack button.

The application should generate its own internal *public* and *secret keys* at start.

```
crypto_kx_keypair(publicKey, secretKey);
```

***Example 2:** Bluetooth LE key pair*

The application will send a *connection response* with first-time-pairing set, and the public key. After Vector receives the connection response, he will display the *pin code*. (See the steps in the next section for when this will occur.)

The session *encryption* and *decryption keys* can then created:

```
crypto_kx_client_session_keys(decryptionKey, encryptionKey, publicKey, secretKey,
      Vector_publicKey);
size_t pin_length = strlen(pin);

crypto_generichash(encryptionKey, sizeof(encryptionKey), encryptionKey,
      sizeof(encryptionKey), pin, pin_length);
crypto_generichash(decryptionKey, sizeof(decryptionKey), decryptionKey,
      sizeof(decryptionKey), pin, pin_length);
```

***Example 3:** Bluetooth LE encryption & decryption keys*

39.3.2 Reconnecting

Reconnecting can reused the public and secret keys, and the encryption and decryption keys. It is not known how long these persist on Vector.

39.3.3 Encrypting and decryption messages

Vector will send a *nonce* message with the *encryption* and *decryption nonces* to employ in encrypting and decrypting message.

Each received enciphered message can be decrypted from cipher text (cipher, and cipherLen) to the message buffer (message and messageLen) for further processing:

```
crypto_aead_xchacha20poly1305_ietf_decrypt(message, &messageLen, NULL, cipher,
      cipherLen,  NULL, 0L, decryptionNonce, decryptionKey);
sodium_increment(decryptionNonce, sizeof decryptionNonce);
```

Example 4: *Decrypting a Bluetooth LE message*

Note: the decryptionNonce is incremented each time a message is decrypted.

Each message to be sent can be encrypted from message buffer (message and messageLen) into cipher text (cipher, and cipherLen) that can be fragmented and sent:

```
crypto_aead_xchacha20poly1305_ietf_encrypt(cipher, &cipherLen, message,
     messageLen, NULL, 0L, NULL, encryptionNonce, encryptionKey);
sodium_increment(encryptionNonce, sizeof encryptionNonce);
```

Example 5: *Encrypting a Bluetooth LE message*

Note: the encryptionNonce is incremented each time a message is encrypted.

39.4. THE RTS LAYER

There is an extra, pragmatic layer before the messages can be interpreted by the application. The message has two to three bytes at the header:

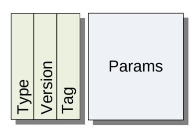


Figure 57: *The format of an RTS frame*

- The type byte is either 1 or 4. If it is 1 the version number is 1.
- If type byte is 4, the version is held in the next byte. (If the type is 1, there is no version byte).
- The next byte is the tag – the value used to interpret the message.

The tag, parameter body, and version are passed to the CLAD layer for interpretation. This is described in the next section.

39.5. FETCHING A LOG

The process to set up a Bluetooth LE communication with Vector is moderately complex. The sequence has many steps:

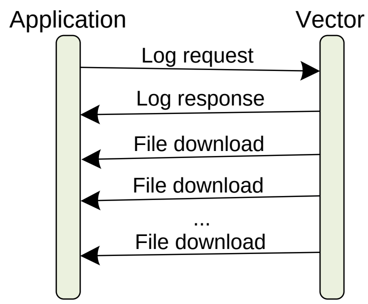


Figure 58: *Sequence for initiating communication with Vector*

The log request is sent to Vector. In principal this includes a list of the kinds of logs (called filter names) to be included. In practice, the "filter name" makes no difference.

Vector response, and if there will be a file sent, includes an affirmative and a 32-bit file identifier used for the file transfer.

Vector zips the log files up (as a tar.bz2 compressed archive) and sends the chunks to the application. Each chunk has this file identifier. (Conceptually there could be several files in transfer at a time.)

The file transfer is complete when the packet number matches the packet total.

39.6. A BLE SHELL CONNECTION

The process to set up a Bluetooth LE communication with Vector's shell is moderately complex. The sequence has many steps:

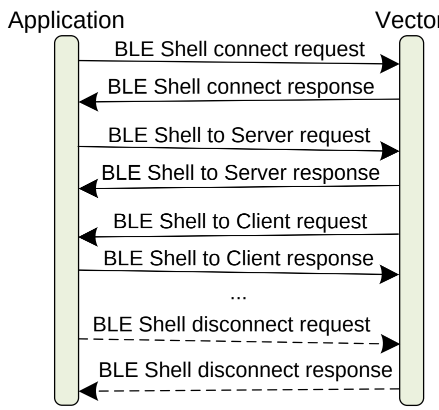


Figure 59: *Sequence for communication with a command shell on Vector*

The BLE Shell Connect request is sent to Vector. Vector response will include a status code indicating success or not. If successful a bi-directional stream can be sent.

The client has the option to close the shell connection at any time by sending a BLE Shell Disconnect request.

Note: The BLE Shell connection requires Version 6 of the BLE protocol to be honored by Vector. No version of the Vector software has been identified that supports this version.

40. MESSAGE FORMATS

This section describes the format and interpretation of the CLAD messages that go between the App and Vector. It describes the fields and how they are encoded, etc. Fields that do not have a fixed location, have no value for their offset. Some fields are only present in later versions of the protocol. They are marked with the version that they are present in.

Except where otherwise stated:

- Requests are from the mobile application to Vector, and responses are Vector to the application
- All are values in little endian order

Table 38: *Summary of the commands*

	Request	Response	Min Version
Application connection id	$1F_{16}$	20_{16}	4
BLE shell connect	26_{16}	27_{16}	6
BLE shell disconnect	$2C_{16}$	$2D_{16}$	6
BLE shell to client	$2A_{16}$	$2B_{16}$	6
BLE shell to server	28_{16}	29_{16}	6
Cancel pairing	10_{16}		0
Challenge	04_{16}	04_{16}	0
Challenge success	05_{16}		0
Connect	01_{16}	02_{16}	0
Cloud session	$1D_{16}$	$1E_{16}$	3
Disconnect	11_{16}		0
File download		$1a_{16}$	2
Log	18_{16}	19_{16}	2
Nonce	03_{16}	12_{16}	
OTA cancel	17_{16}		2
OTA update	$0E_{16}$	$0F_{16}$	0
SDK proxy	22_{16}	23_{16}	5
Response		21_{16}	4
SSH	15_{16}	16_{16}	0
Status	$0A_{16}$	$0B_{16}$	0
Versions list	24_{16}	25_{16}	6
WiFi access point	13_{16}	14_{16}	0
WiFi connect	06_{16}	07_{16}	0
WiFi forget	$1B_{16}$	$1C_{16}$	3
WiFi IP	08_{16}	09_{16}	0
WiFi scan	$0C_{16}$	$0D_{16}$	0

40.1. APPLICATION CONNECTION ID

Assigns a DAS/Analytics id to use with the appication for this Bluetooth LE session.

40.1.1 Request

The parameters of the request body are:

***Table 39:** Parameters for Application Connection Id request*

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*id length*	The length of the id; may be 0
2	*varies*	uint8_t[id length]	*id*	The DAS/Analytics id to associate with the Application for this Bluetooth LE session.

40.1.2 Response

There is no response.

40.2. BLE SHELL CONNECT

40.2.1 Request

The request body has no parameters.

40.2.2 Response

The parameters of the response body are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*status*	The error code (or indication of success) for the command.

Table 40: *Parameters for BLE Shell Connect response*

40.3. BLE SHELL DISCONNECT

40.3.1 Request

The request body has no parameters.

40.3.2 Response

The parameters of the response body are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*status*	The error code (or indication of success) for the command.

Table 41: *Parameters for BLE Shell Disconnect response*

40.4. BLE SHELL TO CLIENT

40.4.1 Request

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*text length*	The length of the text; may be 0
2	*varies*	uint8_t[text length]	*text*	The text to send to the client from the shell.

Table 42: *Parameters for BLE Shell to Client request*

40.4.2 Response

The parameters of the response body are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*status*	The error code (or indication of success) for the command.

Table 43: *Parameters for BLE Shell to Client response*

40.5. BLE SHELL TO SERVER

40.5.1 Request

The parameters of the request body are:

Table 44: Parameters for BLE Shell to Server request

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*text length*	The length of the text; may be 0
2	*varies*	uint8_t[text length]	*text*	The text to send to the shell (server) from the client.

40.5.2 Response

The parameters of the response body are:

Table 45: Parameters for BLE Shell to Server response

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*status*	The error code (or indication of success) for the command.

40.6. CANCEL PAIRING

Speculation: this is sent by the application to cancel the pairing process

40.6.1 Request

The command has no parameters.

40.6.2 Response

There is no response.

40.7. CHALLENGE

This challenge is sent by Vector to the application if he liked the response to a nonce message.

40.7.1 Request

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	4	uint8_t	*value*	The challenge value

Table 46: *Parameters for challenge request*

The application, when it receives this message, should increment the value and send the response (a challenge message).

40.7.2 Response

The parameters of the response body are:

Offset	Size	Type	Parameter	Description
0	4	uint8_t	*value*	The challenge value; this is 1 + the value that was received.

Table 47: *Parameters for challenge response*

If Vector accepts the response, he will send a *challenge success.*

40.8. CHALLENGE SUCCESS

The challenge success is sent by Vector if the challenge response was accepted.

40.8.1 Request

The command has no parameters.

40.8.2 Response

There is no response.

40.9. CLOUD SESSION

This command is used to request a cloud session.

40.9.1 Command

The parameters of the request body are:

Table 48: *Parameters for Cloud Session request*

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*session token length*	The number of bytes in the session token; may be 0
2	varies	uint8_t	*session token*	The session token, as received from the cloud server.[29]
	1	uint8_t	*client name length*	The number of bytes in the client name string; may be 0 version >= 5
	varies	uint8_t[]	*client name*	The client name string. Informational only. The mobile app uses the name of the mobile device. version >= 5
	1	uint8_t	*application id length*	The number of bytes in the application id string; may be 0; version >= 5
	varies	uint8_t[]	*application id*	The application id. Informational only. The mobile uses "companion-app". version >= 5

40.9.2 Response result

The parameters for the connection response message are:

Table 49: *Parameters for Cloud Session Response*

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*success*	0 if failed, otherwise successful
1	1	uint8_t	*status*	See *Table 50: Cloud status enumeration*
2	1	uint16_t	*client token GUID length*	The number of bytes in the client token GUID; may be 0
	varies	uint8_t[]	*client token GUID*	The client token GUID. The client token GUID should be saved for future use.

The cloud status types are:

Table 50: *Cloud status enumeration*

Index	Meaning
0	unknown error
1	connection error
2	wrong account
3	invalid session token
4	authorized as primary
5	authorized as secondary
6	reauthorization

[29] https://groups.google.com/forum/#!msg/anki-vector-rooting/YlYQsX08OD4/fvkAOZ91CgAJ
https://groups.google.com/forum/#!msg/anki-vector-rooting/XAaBE6e94ek/OdES50PaBQAJ

40.10. CONNECT

The connect request *comes from Vector* at the start of a connection. The response is from the application.

40.10.1 Request

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	32	uint8_t[32]	*publicKey*	The public key for the connection

***Table 51:** Parameters for Connection request*

The application, when it receives this message, should use the public key for the session, and send a response back.

40.10.2 Response

The parameters for the connection response message are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*connectionType*	See *Table 53: Connection types enumeration*
1	32	uint8_t[32]	*publicKey*	The public key to use for the connection

***Table 52:** Parameters for Connection Response*

The connection types are:

Index	Meaning
0	first time pairing (requests pin code to be displayed)
1	reconnection

***Table 53:** Connection types enumeration*

The application sends the response, with its publicKey (see section *39.3 Encryption support*). A "first time pairing" connection type will cause Vector to display a pin code on the screen

If a first time pairing response is sent:

- If Vector is not in pairing mode – was not put on his charger and the backpack button pressed twice, quickly – Vector will respond. Attempting to enter pairing mode now will cause Vector to send a *disconnect* request.
- If Vector is in pairing mode, Vector will display a pin code on the screen, and send a nonce message, triggering the next steps of the conversation.

If a reconnection is sent, the application would employ the public and secret keys, and the encryption and decryption keys from a prior pairing.

40.11. DISCONNECT

This may be sent by Vector if there is an error, and it is ending communication. For instance, if Vector enters pairing mode, it will send a disconnect.

The application may send this to request Vector to close the connection.

40.11.1 Request

The command has no parameters.

40.11.2 Response

There is no response.

40.12. FILE DOWNLOAD

This command is used to pass chunks of a file from Vector to the application. Files are broken up into chunks and sent.

40.12.1 Request

There is no direct request.

40.12.2 Response

The parameters of the response body are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*status*	
1	4	uint32_t	*file id*	
5	4	uint32_t	*packet number*	The chunk within the download
9	4	uint32_t	*packet total*	The total number of packets to be sent for this file download
13	2	uint16_t	*length*	The number of bytes to follow (can be 0)
	varies	uint8_t[length]	*bytes*	The bytes of this file chunk

Table 54: *Parameters for File Download response*

40.13. LOG

This command is used to request the Vector send a compressed archive of the logs.

40.13.1 Request

The parameters of the request body are:

Table 55: Parameters for Log request

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*mode*	
1	2	uint16_t	*num filters*	The number of filters in the array
3	varies	filter[num filters]	*filters*	The filter names

Each filter entry has the following structure:

Table 56: Log filter

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*filter length*	The length of the filter name; may be 0
2	*varies*	uint8_t[filter length]	*filter name*	The filter name

40.13.2 Response

It can take several seconds for Vector to prepare the log archive file and send a response. The response will be a "log response" (below) and a series of "file download" responses.

The parameters for the response message are:

Table 57: Parameters for Log Response

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*exit code*	
1	4	uint32_t	*file id*	A 32-bit identifier that will be used in the file download messages.

40.14. NONCE

A nonce is sent by Vector after he has accepted the application's key. The application is to send a response.

40.14.1 Request

The parameters for the nonce request message are:

Table 58: *Parameters for Nonce request*

Offset	Size	Type	Parameter	Description
0	24	uint8_t[24]	*toVectorNonce*	The nonce to use for sending stuff to Vector
24	24	uint8_t[24]	*toAppNonce*	The nonce for receiving stuff from Vector

40.14.2 Response

After receiving a nonce, if the application is in first-time pairing the application should send a response, with a value of 3.

Table 59: *Parameters for Nonce response*

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*connection tag*	This is always 3

After the response has been sent, the channel will now be encrypted. If vector likes the response, he will send a challenge message.

40.15. OTA UPDATE

This command is used to request the Vector download software from a given server URL.

40.15.1 Request

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*length*	The length of the URL; may be 0
1	*varies*	uint8_t[length]	*URL*	The URL string

***Table 60:** Parameters for OTA request*

40.15.2 Response

The response will be one or more "OTA response" indicating the status of the update, or errors. Status codes >= 200 indicate that the update process has completed. The update has completed the download when the current number of bytes match the expected number of bytes.

The parameters for the response message are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*status*	See *Table 62: OTA status enumeration*
1	8	uint64_t	*current*	The number of bytes downloaded
9	8	uint64_t	*expected*	The number of bytes expected to be downloaded

***Table 61:** Parameters for OTA Response*

The OTA status codes are:

Status	Meaning
0	idle
1	unknown
2	in progress
3	complete
4	rebooting
5	error
200…	Status codes from the update-engine. See Appendix D, *Table 606: OTA update-engine status codes*.

***Table 62:** OTA status enumeration*

Note: the status codes 200 and above are from the update-engine, and are given in Appendix D.

40.16. RESPONSE

This message will be sent on the event of an error. Primarily if the session is not cloud authorized and the command requires it.

Table 63: Parameters for Response

Offset	Size	Type	Parameter	Description
0	1	uint16_t	*code*	0 if not cloud authorized, otherwise authorized
1	1	uint8_t	*length*	The number of bytes in the string that follows.
	varies	uint8_t [length]	*text*	A text error message.

40.17. SDK PROXY

This command is used to pass the gRPC/protobufs messages to Vector over Bluetooth LE. It effectively wraps a HTTP request/response. Note: the HTTPS TLS certificate is not employed with this command.

40.17.1 Request

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*GUID length*	The number of bytes in the GUID string; may be 0
2	*varies*	uint8_t[GUID length]	*GUID*	The GUID string
	1	uint8_t	*msg length*	The number of bytes in the message id string
	varies	uint8_t[msg id length]	*msg id*	The message id string
	1	uint8_t	*path length*	The number of bytes in the URL path string
	varies	uint8_t[path length]	*path*	The URL path string
	2	uint16_t	*JSON length*	The length of the JSON
	varies	uint8_t[JSON length]	*JSON*	The JSON (string)

Table 64: *Parameters for the SDK proxy request*

40.17.2 Response

The parameters for the response message are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*msg id length*	The number of bytes in the message id string; may be 0
2	*varies*	uint8_t[msg id length]	*msg id*	The message id string
	2	uint16_t	*status code*	The HTTP-style status code that the SDK may return.
	1	uint8_t	*type length*	The number of bytes in the response type string
	varies	uint8_t[type length]	*type*	The response type string
	2	uint16_t	*body length*	The length of the response body
	varies	uint8_t[body length]	*body*	The response body (string)

Table 65: *Parameters for the SDK proxy Response*

40.18. SSH

This command is used to request the Vector allow SSH. SSH is supported only in developer releases (and not all). SSH is not supported in the production release software.

40.18.1 Request

The SSH key command passes the authorization key by dividing it up into substrings and passing the list of substrings. The substrings are appended together by the recipient to make for the overall authorization key.

The parameters for the request message are:

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*num substrings*	The number of SSH authorization keys; may be 0
2	*varies*	substring[num substrings]	*substrings*	The array of authorization key strings (see below).

Table 66: *Parameters for SSH request*

Each authorization key substring has the following structure:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*substring length*	The length of the substring; may be 0
1	*varies*	uint8_t[substringlength]	*substring*	UTF8 substring of the SSH authorization key

Table 67: *SSH authorization key substring*

40.18.2 Response

The response has no parameters.

40.19. STATUS

This command is used to request basic info from Vector.

40.19.1 Request

The request has no parameters.

40.19.2 Response

The parameters for the response message are:

Table 68: Parameters for Status Response

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*SSID length*	The number of bytes in the SSID string; may be 0
2	*varies*	uint8_t[SSID length]	*SSID*	The WiFi SSID (hex string).
	1	uint8_t	*WiFi state*	See *Table 69: WiFi state enumeration*
	1	uint8_t	*access point*	0 not acting as an access point, otherwise acting as an access point
	1	uint8_t	*Bluetooth LE state*	0 if the Bluetooth
	1	uint8_t	*Battery state*	
	1	uint8_t	*version length*	The number of bytes in the version string; may be 0 version >= 2
	varies	uint8_t [version length]	*version*	The version string; version >= 2
	1	uint8_t	*ESN length*	The number of bytes in the ESN string; may be 0 version >= 4
	varies	uint8_t[ESN length]	*ESN*	The *electronic serial number* string; version >= 4
	1	uint8_t	*OTA in progress*	0 over the air update not in progress, otherwise in process of over the air update; version >= 2
	1	uint8_t	*has owner*	0 does not have an owner, otherwise has an owner; version >= 3
	1	uint8_t	*cloud authorized*	0 is not cloud authorized, otherwise is cloud authorized; version >= 5

Note: a *hex string* is a series of bytes with values 0-15. Every pair of bytes must be converted to a single byte to get the characters. Even bytes are the high nibble, odd bytes are the low nibble.

The WiFi states are:

Table 69: WiFi state enumeration

Index	Meaning
0	Unknown
1	Online
2	Connected
3	Disconnected

40.20. VERSIONS LIST

40.20.1 Request

The request body has no parameters.

40.20.2 Response

The parameters of the response body are:

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*length*	The length of the array; may be 0
2	*varies*	uint16_t[length]	*versions*	An array of version numbers.

Table 70: *Parameters for Version List response*

40.21. WIFI ACCESS POINT

This command is used to request that the Vector act as a WiFi access point. This command requires that a "cloud session" have been successfully started first (see section *40.9 Cloud session*).

If successful, Vector will provide a WiFi Access Point with an SSID that matches his robot name.

40.21.1 Request

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*enable*	0 to disable the WiFi access point, 1 to enable it

***Table 71:** Parameters for WiFi Access Point request*

40.21.2 Response

If the Bluetooth LE session is not cloud authorized a "response" message will be sent with this error. Otherwise the WiFi Access Point response message will be sent.

The parameters for the response message are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*enabled*	0 if the WiFi access point is disabled, otherwise enabled
1	1	uint8_t	*SSID length*	The number of bytes in the SSID string; may be 0
2	*varies*	uint8_t[SSID length]	*SSID*	The WiFi SSID (hex string)
	1	uint8_t	*password length*	The number of bytes in the password string; may be 0
	varies	uint8_t [password length]	*password*	The WiFi password

***Table 72:** Parameters for WiFi Access Point Response*

40.22. WIFI CONNECT

This command is used to request Vector to connect to a given WiFi SSID. Vector will retain this WiFi for future use.

A pretty Wi-Fi for the little guy

40.22.1 Request

The parameters for the request message are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*SSID length*	The number of bytes in the SSID string; may be 0
1	*varies*	uint8_t[SSID length]	*SSID*	The WiFi SSID (hex string)
	1	uint8_t	*password length*	The number of bytes in the password string; may be 0
	varies	uint8_t [password length]	*password*	The WiFi password
	1	uint8_t	*timeout*	How long to given the connect attempt to succeed.
	1	uint8_t	*auth type*	The type of authentication to employ; see *Table 74: WiFi authentication types enumeration*
	1	uint8_t	*hidden*	0 the access point is not hidden; 1 it is hidden

***Table 73:** Parameters for WiFi Connect request*

The WiFi authentication types are:

Index	Meaning
0	None, open
1	WEP
2	WEP shared
3	IEEE8021X
4	WPA PSK
5	WPA2 PSK
6	WPA2 EAP

***Table 74:** WiFi authentication types enumeration*

40.22.2 Response

The parameters for the response message are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*SSID length*	The length of the SSID that was deleted; may be 0
1	*varies*	uint8_t[SSID length]	*SSID*	The SSID (hex string) that was deleted
	1	uint8_t	*WiFi state*	See *Table 69: WiFi state enumeration*
	1	uint8_t	*connect result*	version >= 3

***Table 75:** Parameters for WiFi Connect command*

40.23. WIFI FORGET

This command is used to request Vector to forget a WiFi SSID.

40.23.1 Request

The parameters for the request message are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*delete all*	0 if Vector should delete only one SSID; otherwise Vector should delete all SSIDs
1	1	uint8_t	*SSID length*	The length of the SSID that to be deleted; may be 0
2	*varies*	uint8_t[SSID length]	*SSID*	The SSID (hex string) to be deleted

Table 76: *Parameters for WiFi Forget request*

40.23.2 Response

The parameters for the response message are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*did delete all*	0 if only one; otherwise Vector deleted all SSIDs
1	1	uint8_t	*SSID length*	The length of the SSID that was deleted; may be 0
2	*varies*	uint8_t[SSID length]	*SSID*	The SSID (hex string) that was deleted

Table 77: *Parameters for WiFi Forget response*

40.24. WIFI IP ADDRESS

This command is used to request Vector's WiFi IP address.

40.24.1 Request

The request has no parameters

40.24.2 Response

The parameters for the response message are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*has IPv4*	0 if Vector doesn't have an IPv4 address; other it does
1	1	uint8_t	*has IPv6*	0 if Vector doesn't have an IPv6 address; other it does
2	4	uint8_t[4]	*IPv4 address*	Vector's IPv4 address
6	32	uint8_t[16]	*IPv6 address*	Vector's IPv6 address

Table 78: *Parameters for WiFi IP Address response*

40.25. WIFI SCAN

This command is used to request Vector to scan for WiFi access points.

finding hot signals in Vectors area

40.25.1 Request

The command has no parameters.

40.25.2 Response

The response lists the Wi-Fi access points Vector can find. The parameters for the response message are:

***Table 79:** Parameters for WiFi scan response*

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*status code*	
1	1	uint8_t	*num entries*	The number of access points in the array below
2	*varies*	AP[num entries]	*access points*	The array of access points

Each access point has the following structure:

***Table 80:** Parameters access point structure*

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*auth type*	The type of authentication to employ; see *Table 74: WiFi authentication types enumeration*
1	1	uint8_t	*signal strength*	The number of bars, 0..4
2	1	uint8_t	*SSID length*	The length of the SSID string
3	*varies*	uint8_t[SSID length]	*SSID*	The SSID (hex string)
	1	uint8_t	*hidden*	0 not hidden, 1 hidden; version >= 2
	1	uint8_t	*provisioned*	0 not provisioned, 1 provisioned; version>= 3

CHAPTER 14

Cube Bluetooth LE Communication Protocol

This chapter describes communication protocol to talk with the Cube.

- The kinds of activities that can be performed
- The interaction sequences
- The characteristics.

41. CUBE COMMUNICATION PROTOCOL OVERVIEW

Vector can be "paired" with a cube – or he'll automatically pair with the first cube he finds during setup – and will treat this as his preferred cube. If he is unable can't connect with his preferred cube, he falls back to connecting the first cube found in the area while playing.

Vector manages the link with the cube, and data is sent and received using Bluetooth LE characteristics. Vector may send values, fetch values from the Cube, or ask to be sent values when they change.

When Bluetooth LE is in an unconnected state, it sends out advertisements at a regular interval, but not too speedy. When Vector connects with the cube, it doesn't open a stream of continuous bits. Instead, it negotiates a new interval that is appropriate for speed of interaction, distance, and battery life.

41.1. SENDING THE FIRMWARE APPLICATION

The Cube has a boot-loader built in, but the application firmware is held in SRAM. It has to be downloaded to the cube by Vector. The Vector application is determines if the application is already present by reading the application firmware version. The application download is done with a sequence like:

Paul m Brett

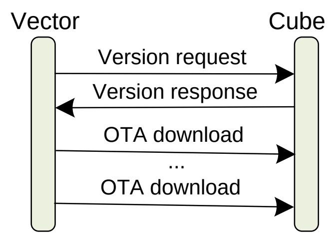


Figure 60: *Sequence for sending the Cube firmware*

7. Checking the version. Compares this with the version of the latest file. If the version identifier is matches, it skips the reset of the steps

8. Vector then sends the bytes of the application (from the cube firmware file) down in 20 byte chunks.

41.1.1 The format of the firmware update file

The first 16 bytes of the firmware update files holds the version. This is used only for comparing versions. It is not sent. The remainder of the file holds the application firmware:

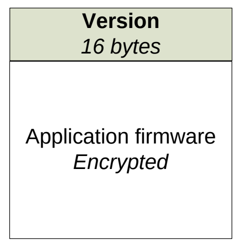


Figure 61: *The Cube firmware file*

41.2. RETRIEVING AND STREAMING ACCELEROMETER DATA

Based on the level interaction, Vector may increase the rate that the Cube sends updates from its accelerometer:

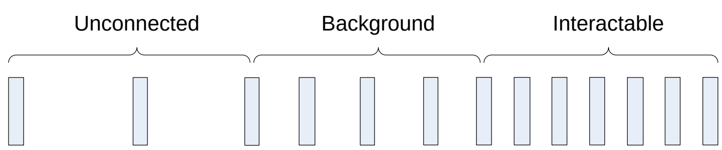


Figure 62: *A representation of the different rates of communication*

The three different rates of communication are used between the Cube and Vector:

1. The lowest level is *unconnected* –the Cube is just sending out advertisements (that is, "a hello-world I exist") a modest interval; there isn't an active Bluetooth LE connection.

2. The next level is *background*. The application is getting just enough information from the cube to know its orientation, broad movements (and maybe that it was tapped).

3. The highest update rate is the *interactable* level. The cube is configured to send much more responsive information on the cube orientation, sent fast (or sensitive) enough to detect taps, and tell if the cube is being held. This rate consumes the most power.

The behavior system drives the level interest in the cube. The condition or active behavior requests a level of service. The request can be temporary, using a timeout, so that if nothing interesting is detected in a reasonable period, it falls back to the lower rate.

42. CHARACTERISTIC MESSAGE FORMATS

This section describes the format and interpretation of the characteristics that go between the Vector and the Cube. It describes the fields and how they are encoded, etc.

Paul m Brett

- All multi-byte values are in little endian order

See Appendix G for the GUIDs for the characteristics

42.1. STRUCTURES

These are the data structures used within the messages.

42.1.1 Accelerometer data

The structure for the accelerometer data is:

Offset	Size	Type	Parameter	Description
0	2	int16_t	*X*	The measurement (in milli-gs) along the X-axis.
2	2	int16_t	*Y*	The measurement (in milli-gs) along the Y-axis.
4	2	int16_t	*Z*	The measurement (in milli-gs) along the Z-axis.

Table 81: *Parameters for accelerometer structure*

42.1.2 LED data

The structure for the LED data is:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*index*	Sequential index, starting at 0. This is the step in the light sequence pattern to play.
1	1	uint8_t	*red*	The red-channel color value
2	1	uint8_t	*green*	The green-channel color value
3	1	uint8_t	*blue*	The blue-channel color value
4	1	uint8_t	*alpha*	The alpha-channel color value. Usually 0
5	1	uint8_t	*duration*	The amount of time, in milliseconds(?), to show the color before proceeding to the next step.

Table 82: *Parameters for LED control structure*

This structure is related to the ones given Chapter 23 section *103 Cube lights Animation* for cube light animation. Probably separate for each of the LEDs.

42.2. LED CONTROL

The parameters of the LED control characteristic are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*trigger*	1 set light information
1	18	LED data[3]	*LED data*	The LED settings for each step

Table 83: *Parameters for accelerometer characteristic*

The parameters of the LED control characteristic are:

Table 84: Parameters for accelerometer characteristic

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*trigger*	0 Trigger s or starts it
1	1	uint8_t[4]	*sequence Id*	The sequence index to start with for that LED.

42.3. APPLICATION VERSION

This is used to retrieve the version string for the application. It is used to determine if the application is present in the Cube, or needs to be sent to the Cube. The parameters of the application version are:

Table 85: Parameters for version characteristic

Offset	Size	Type	Parameter	Description
0	varies	char[]	*version*	Empty if there is no application. Otherwise, the version of the application. The version is also the date and time of the firmware build.

42.4. BATTERY AND ACCELEROMETER CHARACTERISTIC

The parameters of the battery and accelerometer characteristic are:

Table 86: Parameters for accelerometer characteristic

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*battery*	battery ADC value
2	18	Accel_t[3]	*accelerometer*	Accelerometer samples

42.5. OTA DOWNLOAD

This characteristic is used to send the firmware. These are sent as a series of 20 byte chunks. The application firmware is encrypted and will be decrypted by the boot-loader.

42.6. REFERENCES & RESOURCES

Brett, Paul, *Communicating with vectors cube*
https://forums.anki.com/t/communicating-with-vectors-cube/43042
Paul digs into emulating the Vector's cube and identifies elements of the protocol. This chapter was adapted from this information.

CHAPTER 15

The HTTPS based API

This chapter describes the communication with Vector via the local HTTPS.

Note: the information in this chapter comes from the protobuf specification files in the python SDK, from the SDK itself, and some analysis of the mobile application. All quotes (unless otherwise indicated) are from the SDK.

43. OVERVIEW OF THE SDK HTTPS API

The descriptions below[30] give the JSON keys, and their value format. It is implemented as gRPC/protobufs interaction over HTTP. (Anki has frequently said that the SDK included code (as python) with the protobuf spec so that others could use their own preferred implementation language.) Each command is requested by POST-ing the request structure to the given relative URL (relative to Vector's address or local network name) and interpreting the returned body as the response structure.

The HTTPS header should include

- Bearer *BASE64KEY*
- Content-Type: application/json

(The JSON request is posted in the body)

43.1. SDK MESSAGE GROUPINGS

The major groups of messages here are:

- Accessories and custom objects
- Actions and behaviors – setting the current priority and cancelling actions
- Alexa configuration – configuring Vector to use Alexa's services
- Audio – playing sounds on Vector, and submitting text to speech
- Battery – the current state of charge
- Connection – authenticating with the remote servers to allow access to Vector, connection management, event stream, and end-point version info
- Cube – commands to manage and interact with the cube
- Diagnostics – checking the connection with the cloud, and uploading log information
- Display – display images on Vector's LCD

[30] The protocol was specified in Google Protobuf.

- Faces (of people, not Vector's face) – changing the name of a face, deleting a face
- Features and entitlements – the features that are enabled (or disabled)
- Image processing – Getting a video stream, and enabling (or disabling) video processing steps, retrieving & changing the camera exposure settings.
- Interactions with objects (outside of the cube)
- JDocs, the JSON document storage interface
- Map and Navigation
- Motion Control
- Motion Sensing – how Vector senses that he is moving
- Onboarding
- Photos – commands to access (and delete) photographs and their thumbnails
- Settings and Preferences
- Software Updates, used to update Vector's software – operating system, applications, assets, etc.

44. COMMON ELEMENTS

The enumerations and structures in this section are common to many commands.

44.1. ENUMERATIONS

44.1.1 ResultCode

The ResultCode enumeration has the following named values:

Table 87: *ResultCode Enumeration*

Name	Value	Description
ERROR_UPDATE_IN_PROGRESS	1	The settings could not be applied; there is already another update to the settings in process.
SETTINGS_ACCEPTED	0	The settings were successfully saved.

44.1.2 RobotStatus

The RobotStatus is a bit mask used to indicate what Vector is doing, and the status of his controls. It is used in the RobotState message. The enumeration has the following named bits (any number may be set). Note that some bits have two names; the second name is one employed by Anki's python SDK.

Table 88: *RobotStatus Enumeration*

Name	Value	Description
ROBOT_STATUS_NONE	00000_{16}	
ROBOT_STATUS_IS_MOVING *ROBOT_STATUS_ARE_MOTORS_MOVING*	00001_{16}	This bit is set "if Vector is currently moving any of his motors (head, arm or wheels/treads)."
ROBOT_STATUS_IS_CARRYING_BLOCK	00002_{16}	This bit is set "if Vector is currently carrying a block."
ROBOT_STATUS_IS_PICKING_OR_PLACING *ROBOT_STATUS_IS_DOCKING_TO_MARKER*	00004_{16}	This bit is set "if Vector has seen a marker and is actively heading toward it (for example his charger or cube)."
ROBOT_STATUS_IS_PICKED_UP	00008_{16}	This bit is set "if Vector is currently picked up (in the air)," being held or is on his side. Vector "uses the IMU data to determine if the robot is not on a stable surface with his treads down." If Vector is not on stable surface (with his treads down), this bit is set.
ROBOT_STATUS_IS_BUTTON_PRESSED	00010_{16}	This bit is set "if Vector's button is pressed."
ROBOT_STATUS_IS_FALLING	00020_{16}	This bit is set "if Vector is currently falling."
ROBOT_STATUS_IS_ANIMATING	00040_{16}	This bit is set "if Vector is currently playing an animation."
ROBOT_STATUS_IS_PATHING	00080_{16}	This bit is set "if Vector is currently traversing a path."
ROBOT_STATUS_LIFT_IN_POS	00100_{16}	This bit is set "if Vector's arm is in the desired position." It is clear "if still trying to move it there."
ROBOT_STATUS_HEAD_IN_POS	00200_{16}	This bit is set "if Vector's head is in the desired position." It is clear "if still trying to move there."
ROBOT_STATUS_CALM_POWER_MODE	00400_{16}	This bit is set "if Vector is in calm power mode.

		Calm power mode is generally when Vector is sleeping or charging.”
ROBOT_STATUS_IS_BATTERY_DISCONNECTED	00800_{16}	<u>*Not officially defined*</u>. This bit is set if the battery is disconnected.
ROBOT_STATUS_IS_ON_CHARGER	01000_{16}	This bit is set “if Vector is currently on the charger.” (As determined by the charging electronics.) Note: Vector may be on the charger without charging.
ROBOT_STATUS_IS_CHARGING	02000_{16}	This bit is set “if Vector is currently charging.”
ROBOT_STATUS_CLIFF_DETECTED	04000_{16}	This bit is set “if Vector detected a cliff using any of his four cliff sensors.”
ROBOT_STATUS_ARE_WHEELS_MOVING	08000_{16}	This bit is set “if Vector's wheels/treads are currently moving.”
ROBOT_STATUS_IS_BEING_HELD	10000_{16}	This bit is set “if Vector is being held.” Note: ROBOT_STATUS_IS_PICKED_UP will also be set when this bit is set. Vector “uses the IMU to look for tiny motions that suggest the robot is actively being held in someone's hand.” This is used to distinguish from other cases, such as falling, on its side, etc.
ROBOT_STATUS_IS_MOTION_DETECTED *ROBOT_STATUS_IS_ROBOT_MOVING*	20000_{16}	This bit is set “if Vector is in motion. This includes any of his motors (head, arm, wheels/tracks) and if he is being lifted, carried, or falling.”
ROBOT_STATUS_IS_BATTERY_OVERHEATED	40000_{16}	<u>*Not official defined.*</u> This bit is set if Vector’s battery temperature is considered too hot.
reserved	80000_{16}	<u>*reserved*</u>
ROBOT_STATUS_ENCODERS_DISABLED	100000_{16}	<u>*Not officially defined.*</u> This bit is set if Vector has turned off the motor encoders. This is done to save power when the motors are idle.
ROBOT_STATUS_ENCODER_HEAD_INVALID	200000_{16}	<u>*Not officially defined.*</u> This bit is set if Vector the encoder for the head is not valid.
ROBOT_STATUS_ENCODER_LIFT_INVALID	400000_{16}	<u>*Not officially defined.*</u> This bit is set if Vector the encoder for the head is not valid.
ROBOT_STATUS_IS_BATTERY_LOW	1000000_{16}	<u>*Not officially defined.*</u> This bit is set if Vector battery voltage is critically low; if not on a charger, Vector will power down.
ROBOT_STATUS_IS_SHUTDOWN_IMMINENT	2000000_{16}	<u>*Not officially defined.*</u> This bit is set if the body board will turn off power very soon. This may be due to excessive temperature or battery under voltage.

Note: the RobotStatus is maintained by vic-robot

44.2. STRUCTURES

44.2.1 CladPoint

The CladPoint is used to represent a 2D rectilinear point on an image or in the 2D map. It has the following fields:

Field	Type	Units	Description
x	float	*pixels*	The x-coordinate of the point
y	float	*pixels*	The y-coordinate of the point

***Table 89:** CladPoint JSON structure*

44.2.2 CladRect

The CladRect is used to represent a 2D rectilinear rectangle on an image. It has the following fields:

Field	Type	Units	Description
height	float	*pixels*	The height of the rectangle
width	float	*pixels*	The width of the rectangle
x_top_left	float	*pixels*	The x-coordinate of the top-left corner of the rectangle within the image.
y_top_left	float	*pixels*	The y-coordinate of the top-left corner of the rectangle within the image.

***Table 90:** CladRectangle JSON structure*

44.2.3 PoseStruct

The PoseStruct is used to represent a 3D rectilinear point and orientation on the map. It has the following fields:

Field	Type	Units	Description
origin_id	uint32		Which version of the map this pose is in (0 for none or unknown). See Chapter 19 for a description of the mapping origin id.
q0	float		Part of the rotation quaternion
q1	float		Part of the rotation quaternion
q2	float		Part of the rotation quaternion
q3	float		Part of the rotation quaternion
x	float	*mm*	The x coordinate
y	float	*mm*	The y coordinate
z	float	*mm*	The z coordinate

***Table 91:** PoseStruct JSON structure*

44.2.4 ResponseStatus

The ResponseStatus is "a shared response message sent back as part of most requests. This will indicate the generic state of the request." It has the following fields:

Field	Type	Units	Description
code	StatusCode		"The generic status code to give high-level insight into the progress of a given message."

Table 92: *ResponseStatus JSON structure*

The StatusCode is used to indicate state of the request.

Table 93: StatusCode Enumeration

Name	Value	Description
UNKNOWN	0	
RESPONSE_RECEIVED	1	"The message has completed as expected."
REQUEST_PROCESSING	2	"The message has been sent to the robot."
OK	3	"The message has been handled successfully at the interface level."
FORBIDDEN	100	"The user was not authorized."
NOT_FOUND	101	"The requested attribute was not found."
ERROR_UPDATE_IN_PROGRESS	102	"Currently updating values from another call."

45. ACCESSORIES AND CUSTOM OBJECTS

This section describes the objects that Vector can see and track in his map. Specialized accessories – the charger and cube – are broken out into their own sections.

See also section *53 Cube* and section *59 Interactions with Objects*

You too can create custom objects for Vector to… at least see and perceive. Maybe even love. There are four kinds of custom objects that you can define:

- A fixed, unmarked cube-shaped object. The object is in a fixed position and orientation, and it can't be observed (since it is unmarked). So there won't be any events related to this object. "This could be used to make Vector aware of objects and know to plot a path around them."
- A flat wall with only a front side,
- A cube, with the same marker on each side.
- A box with different markers on each side.

A note about object id's: The object id may change: "a cube disconnecting and reconnecting it's removed and then re-added to robot's internal world model which results in a new ID."

The client should employ a timer for each potential visual object. If there isn't an "object observed" event received in the time period, it should be assumed "that Vector can no longer see an object."

45.1. ENUMERATIONS

- The CustomObjectMarker enumerates the marker symbols
- The CustomType refers to the one of the 20 possible custom objects that can be defined
- The ObjectFamily is an older, now deprecated method, of enumerating the kind of object (as in, charger, light cube, wall, box, or custom cube).
- The ObjectType enumeration is the preferred method of enumerating the kinds of objects

45.1.1 CustomObjectMarker

The CustomObjectMarker is used represent the marker symbol used. The symbols are predefined, with the images that Vector recognizes included in the SDK. The enumeration has the following named values:

Table 94: *CustomObjectMarker Enumeration*

Name	Value	Description
CUSTOM_MARKER_UNKNOWN	0	
CUSTOM_MARKER_CIRCLES_2	1	
CUSTOM_MARKER_CIRCLES_3	2	
CUSTOM_MARKER_CIRCLES_4	3	
CUSTOM_MARKER_CIRCLES_5	4	
CUSTOM_MARKER_DIAMONDS_2	5	
CUSTOM_MARKER_DIAMONDS_3	6	
CUSTOM_MARKER_DIAMONDS_4	7	
CUSTOM_MARKER_DIAMONDS_5	8	
CUSTOM_MARKER_HEXAGONS_2	9	
CUSTOM_MARKER_HEXAGONS_3	10	
CUSTOM_MARKER_HEXAGONS_4	11	
CUSTOM_MARKER_HEXAGONS_5	12	
CUSTOM_MARKER_TRIANGLES_2	13	
CUSTOM_MARKER_TRIANGLES_3	14	
CUSTOM_MARKER_TRIANGLES_4	15	
CUSTOM_MARKER_TRIANGLES_5	16	
CUSTOM_MARKER_COUNT	16	

45.1.2 CustomType

The CustomType is used to represent the identifier of object that a symbol is attached to. The enumeration has the following named values:

Table 95: *CustomType Enumeration*

Name	Value	Description
INVALID_CUSTOM_TYPE	0	
CUSTOM_TYPE_00	1	
CUSTOM_TYPE_01	2	
CUSTOM_TYPE_02	3	
CUSTOM_TYPE_03	4	
CUSTOM_TYPE_04	5	
CUSTOM_TYPE_05	6	
CUSTOM_TYPE_06	7	
CUSTOM_TYPE_07	8	
CUSTOM_TYPE_08	9	
CUSTOM_TYPE_09	10	
CUSTOM_TYPE_10	11	
CUSTOM_TYPE_11	12	
CUSTOM_TYPE_12	13	
CUSTOM_TYPE_13	14	
CUSTOM_TYPE_14	15	
CUSTOM_TYPE_15	16	
CUSTOM_TYPE_16	17	
CUSTOM_TYPE_17	18	
CUSTOM_TYPE_18	19	
CUSTOM_TYPE_19	20	
CUSTOM_TYPE_COUNT	20	

45.1.3 ObjectFamily

The ObjectFamily is a deprecated method used to represent the type of object that a symbol is attached to. ObjectType should be used instead, where possible. The enumeration has the following named values:

Table 96: ObjectType Enumeration

Name	Value	Description
INVALID_FAMILY	0	This value represents a kind of object that is not properly set.
UNKNOWN_FAMILY	1	This value is used when there is an object, but its kind is not known.
BLOCK	2	This is the identifier used for blocks/cubs other than the companion-cube
LIGHT_CUBE	3	This is the identifier used for the companion-cube
CHARGER	4	This is the identifier used for the home charging station.
CUTSTOM_OBJECT	7	This is the identifier used for as custom object definition.
OBJECT_FAMILY_COUNT	7	

45.1.4 ObjectType

The ObjectType is used represent the type of object that a symbol is attached to. The enumeration has the following named values:

Table 97: ObjectType Enumeration

Name	Value	Description
INVALID_OBJECT	0	This value represents an object id used when there isn't an object associated.
UNKNOWN_OBJECT	1	This value is used when there is an object, but it is not recognized.
BLOCK_LIGHTCUBE1	2	This is the identifier used for the companion-cube
CHARGER_BASIC	6	This is the identifier used for the home charging station.
FIRST_CUSTOM_OBJECT_TYPE	15	The custom objects all have types greater than or equal to this.

45.2. EVENTS

These are the events that are sent to inform the application of an objects state (and availability).

45.2.1 ObjectEvent

The ObjectEvent event is sent (see *Event* message) when the state of an object has changed. The structure has one (and only one) of the following fields:

Table 98: *ObjectEvent JSON structure*

Field	Type	Description
cube_connection_lost	CubeConnectionLost	This event is sent when cube no longer is connected via Bluetooth LE.
robot_observed_object	RobotObservedObject	This even is sent the object is visually seen by Vector.
object_available	ObjectAvailable	This event is sent when cube a Bluetooth LE connection to the cube is established.
object_connection_state	ObjectConnectionState	The information about the Bluetooth LE identity of the cube, and whether is connected (or not).
object_moved	ObjectMoved	The object has changed position.
object_stopped_moving	ObjectStoppedMoving	The object had change position previously, but has now come to rest.
object_tapped	ObjectTapped	The cube was tapped.
object_up_axis_changed	ObjectUpAxisChanged	The object was rotated and has a new upward face.

45.2.2 ObjectAvailable

The ObjectAvailable event is sent (see section *45.2.1 ObjectEvent*) when Vector has received Bluetooth LE advertisements from the object (cube).

See also section *53.2.2 CubeConnectionLost*

This event structure has the following fields:

Table 99: *ObjectAvailable JSON structure*

Field	Type	Units	Description
factory_id	string		The identifier for the cube. This is built into the cube.

45.2.3 ObjectConnectionState

The ObjectConnectedState event is to "indicate that a cube has connected or disconnected to the robot. This message will be sent for any connects or disconnects regardless of whether it originated from us or underlying robot behavior."

See also section *53.2.2 CubeConnectionLost*

This event structure has the following fields:

Field	Type	Units	Description
connected	bool		True if Vector has a Bluetooth LE connection with the Cube.
factory_id	string		The identifier for the cube. This is built into the cube.
object_id	uint32		The identifier of the object that Vector is (or was) connected to.
object_type	ObjectType		The type of object referred to.

***Table 100:** ObjectConnectedState JSON structure*

45.2.4 ObjectMoved

The ObjectMoved event is sent (see section *45.2.1 ObjectEvent*) when an object has changed its position. The structure has the following fields:

Field	Type	Units	Description
object_id	uint32		The identifier of the object that moved.
timestamp	uint32		The time that the event occurred on. The format is milliseconds since Vector's epoch.

***Table 101:** ObjectMoved JSON structure*

45.2.5 ObjectStoppedMoving

The ObjectStoppedMoving event is sent (see section *45.2.1 ObjectEvent*) when an object previously identified as moving has come to rest. The structure has the following fields:

Field	Type	Units	Description
object_id	uint32		The identifier of the object that was moving.
timestamp	uint32		The time that the event occurred on. The format is milliseconds since Vector's epoch.

***Table 102:** ObjectStoppedMoving JSON structure*

45.2.6 ObjectUpAxisChanged

The ObjectUpAxis event is sent (see section *45.2.1 ObjectEvent*) if the orientation of the object has significantly changed, leaving it with a new face upward. The structure has the following fields:

Field	Type	Units	Description
object_id	uint32		The identifier of the object whose axis has changed.
timestamp	uint32		The time that the event occurred on. The format is milliseconds since Vector's epoch.
up_axis	UpAxis		The orientation of object, represented as which axis is pointing upwards

***Table 103:** ObjectUpAxis JSON structure*

The UpAxis is used represent the orientation of an object. The enumeration has the following named values:

Table 104: UpAxis Enumeration

Name	Value	Description
INVALID_AXIS	0	The orientation of the object is not known.
X_NEGATIVE	1	The positive direction along the body's x-axis is upward.
X_POSITIVE	2	The negative direction along the body's x-axis is upward.
Y_NEGATIVE	3	The positive direction along the body's y-axis is upward.
Y_POSITIVE	4	The negative direction along the body's y-axis is upward.
Z_NEGATIVE	5	The positive direction along the body's z-axis is upward.
Z_POSITIVE	6	The negative direction along the body's z-axis is upward.
NUM_AXES	7	

45.2.7 RobotObservedObject

The RobotObservedObject event is sent when "an object with [the] specified ID/Type was seen at a particular location in the image and the world." This event structure has the following fields:

Table 105: RobotObservedObject JSON structure

Field	Type	Units	Description
img_rect	CladRect		The position of the object within the vision image.
is_active	uint32		
object_family	ObjectFamily		*Deprecated.* "Use ObjectType instead to reason about groupings of objects."
object_id	int32		The identifier of the object that has been seen. Note that this is signed (int32 instead of uint32) for internal compatibility reasons.
object_type	ObjectType		The type of object referred to.
pose	PoseStruct		The observed pose of this object. *Optional*.
timestamp	uint32		The time that the object was most recently observed. The format is milliseconds since Vector's epoch.
top_face_orientation_rad	float	*radians*	"Angular distance from the current reported up axis. " "absolute orientation of top face, iff isActive==true"

45.3. CREATE FIXED CUSTOM OBJECT

This command "creates a permanent custom [cube-shaped] object instance in the robot's world" except this object has "no markers associated with it." The object "will remain in the specified pose as an obstacle forever (or until deleted)." The object can't be observed, and won't create any events related to being observed. The fixed, custom object can "be used to make Vector aware of objects and know to plot a path around them."

Post: "/v1/create_fixed_custom_object"

45.3.1 Request

The CreateFixedCustomObjectRequest structure has the following fields:

Field	Type	Units	Description
pose	PoseStruct		The position and orientation of this object.
x_size_mm	float	*mm*	The size of the object that the marker symbol is on, along the x-axis.
y_size_mm	float	*mm*	The size of the object that the marker symbol is on, along the y-axis.
z_size_mm	float	*mm*	The size of the object that the marker symbol is on, along the z-axis.

Table 106: *CreateFixedCustomObjectRequest JSON structure*

45.3.2 Response

The CreateFixedCustomObjectResponse structure has the following fields:

Field	Type	Description
object_id	uint32	The object identifier assigned to this object.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 107: *CreateFixedCustomObjectResponse JSON structure*

45.4. DEFINE CUSTOM OBJECT

"Creates a custom object with distinct custom marker(s)" on one or more its faces. This can create a wall, a box, a cube (similar to a box, but each side is the same size as every other, and has the same marker). Once the object has been created, "the robot will now detect the markers associated with this object and send a RobotObservedObject message when they are seen. The markers must be placed in the center of their respective sides."

Note: "No instances of this object are added to the world until they have been seen."

See also *Create Fixed Custom Object, Delete Custom Objects*

Post: "/v1/define_custom_object"

45.4.1 Request

The DefineCustomObjectRequest structure has the following fields:

Field	Type	Units	Description
custom_type	CustomType		The object type to be assigned to this object.
is_unique	bool		If true, "there is guaranteed to be no more than one object of this type present in the world at a time."
custom_box	CustomBoxDefinition		The definition of a box with different markers on each side.
custom_cube	CustomCubeDefinition		The definition of a cube, with the same marker on each side.
custom_wall	CustomWallDefinition		The definition of a flat wall with only a front side.

Table 108: DefineCustomObjectRequest JSON structure

Note: only one of "*custom_box*," "*custom_cube*," or "*custom_wall*" can be used in the request.

The CustomBoxDefinition "defines a custom object of the given size with the given markers centered on each side." The structure has the following fields:

Table 109: CustomBoxDefinition JSON structure

Field	Type	Units	Description
marker_back	CustomObjectMarker		The marker symbol used on the back surface of the box. This marker must be unique (not used by any of the other side's on this box or in any other shape).
marker_bottom	CustomObjectMarker		The marker symbol used on the bottom surface of the box. This marker must be unique (not used by any of the other side's on this box or in any other shape).
marker_front	CustomObjectMarker		The marker symbol used on the front surface of the box. This marker must be unique (not used by any of the other side's on this box or in any other shape).
marker_left	CustomObjectMarker		The marker symbol used on the left-hand side of the box. This marker must be unique (not used by any of the other side's on this box or in any other shape).
marker_right	CustomObjectMarker		The marker symbol used on the right-hand side of the box This marker must be unique (not used by any of the other side's on this box or in any other shape).
marker_top	CustomObjectMarker		The marker symbol used on the top surface of the box. This marker must be unique (not used by any of the other side's on this box or in any other shape).
marker_height_mm	float	*mm*	The height of the marker symbol.
marker_width_mm	float	*mm*	The width of the marker symbol.
x_size_mm	float	*mm*	The size of the object, along the x-axis, that the marker symbol is on.
y_size_mm	float	*mm*	The size of the object, along the y-axis, that the marker symbol is on.
z_size_mm	float	*mm*	The width of the object, along the z-axis, that the marker symbol is on.

The CustomCubeDefinition "defines a custom cube of the given size." The structure has the following fields:

Table 110: CustomCubeDefinition JSON structure

Field	Type	Units	Description
marker	CustomObjectMarker		The marker symbol used on all of the cube surfaces; "the same marker [must] be centered on all faces."
marker_height_mm	float	*mm*	The height of the marker symbol
marker_width_mm	float	*mm*	The width of the marker symbol
size_mm	float	*mm*	The height, width, and depth of the object that the marker symbol is on.

The CustomWallDefinition “defines a custom wall of the given height and width... The wall's thickness is assumed to be 1cm (and thus there are no markers on its left, right, top, or bottom).” The structure has the following fields:

Field	Type	Units	Description
marker	CustomObjectMarker		The marker symbol used on the wall surfaces; “the same marker centered on both sides (front and back)”
marker_height_mm	float	*mm*	The height of the marker symbol
marker_width_mm	float	*mm*	The width of the marker symbol
height_mm	float	*mm*	The height of the object that the marker symbol is on.
width_mm	float	*mm*	The width of the object that the marker symbol is on.

Table 111: *CustomWallDefinition JSON structure*

45.4.2 Response

The DefineCustomObjectResponse type has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
success	bool	True if the thumbnail was successfully retrieved; otherwise there was an error.

Table 112: *DefineCustomObjectResponse JSON structure*

45.5. DELETE CUSTOM OBJECTS

This command "causes the robot to forget about custom objects it currently knows about." All custom objects that match the given pattern are removed.

Post: "/v1/delete_custom_objects"

45.5.1 Request

The DeleteCustomObjectsRequest type has the following fields:

Field	Type	Description
mode	CustomObjectDeletionMode	The kind of custom objects to remove.

Table 113: DeleteCustomObjectsRequest JSON structure

The CustomObjectDeletionMode is used to specify which kinds of custom objects should be deleted from the internal database. The enumeration has the following named values:

Name	Value	Description
DELETION_MASK_UNKNOWN	0	
DELETION_MASK_FIXED_CUSTOM_OBJECTS	1	Delete the custom objects that are "fixed" – the ones that don't have any marker symbols.
DELETION_MASK_CUSTOM_MARKER_OBJECTS	2	Delete the objects with marker symbols.
DELETION_MASK_ARCHETYPES	3	Deletes everything but the fixed objects and their marker symbols.

Table 114: CustomObjectDeletionMode Enumeration

45.5.2 Response

The DeleteCustomObjectsResponse type has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 115: DeleteCustomObjectsResponse JSON structure

46. ACTIONS AND BEHAVIOUR

Actions and "behaviors represent a complex task which requires Vector's internal logic to [carry out]. This may include combinations of animation, path planning or other functionality."

See also section *53 Cube*, and section *59 Interactions with Objects*, which covers actions/behaviors that involve interacting with objects and faces.

Actions often have tags (an arbitrary value given to it by the SDK application), and have result code. And action can be cancelled using this tag. Behaviors do not have tags.

Behaviors are part of the behavior tree, and can potentially submit other behaviors based on prevailing conditions. See Chapter 27 for more detail on behaviors.

Behaviors are submitted at the priority level associated with the connection. If the connection has released control, requested behaviors and actions are ignored. When control is requested, a priority level is requested by the SDK application at the time. Behaviors requested by Vector's internal AI with a lower priority will be ignored; behaviors with a high priority will take control (causing the SDK to lose control). By giving up control, or changing the control priority the SDK can effectively cancel the behavior it requested.

Request control at the *RESERVE_CONTROL* priority level "can be used to suppress the ordinary idle behaviors of the Robot and keep Vector still between SDK control instances. Care must be taken when blocking background behaviors, as this may make Vector appear non-responsive."

See chapter *27 Behaviors* for a description of behaviors and priorities.

46.1. ENUMERATIONS

46.1.1 ActionTagConstants

This is the range of numbers in which we can assign an identifier for the action so that we can cancel it later.

Table 116: *ActionTagConstants Enumeration*

Name	Value	Description
INVALID_SDK_TAG	0	
FIRST_SDK_TAG	2000001	An assigned action tag must be equal to or greater than this value.
LAST_SDK_TAG	3000000	An assigned action tag must be less than or equal to this value.

46.1.2 BehaviorResults

The BehaviorResults is used TBD. The enumeration has the following named values:

Table 117: *BehaviorResults Enumeration*

Name	Value	Description
BEHAVIOR_INVALID_STATE	0	
BEHAVIOR_COMPLETE_STATE	1	
BEHAVIOR_WONT_ACTIVATE_STATE	2	

46.2. EVENTS

46.2.1 FeatureStatus

The FeatureStatus status event is sent as Vector's behavior focus changes. The structure has the following fields:

Field	Type	Description
feature_name	string	The current active behaviour (feature). See Appendix I, table *Table 637: The AI behaviour features* for a list and description.
source	string	Where the direction to do this behavior came from: "Voice", "App", "AI", "Unknown". Voice is for responses to voice commands and intents; "App" is for application submitted intents; AI is behaviors initiated by the high-level AI.

***Table 118:** FeatureStatus JSON structure*

Note: for Vector-OS feature flags, see section *57 Features & Entitlements.*

46.2.2 StimulationInfo

The StimulationInfo event is used report events that impact Vector's emotion state and overall stimulation level. The structure has the following fields:

Field	Type	Units	Description
accel	float	*mm/sec^2*	The acceleration at the time of the stimulation.
emotion_events	string[]		The list of event names related to the emotion. The names of emotion events and their description can be found in Appendix K *Table 641: The emotion event names*. *Optional.*
max_value	float		The minimum stimulation value. Typically 1
min_value	float		The maximum stimulation value. Typically 0
value	float		The stimulation value after applying the events.
value_before_event	float		The stimulation value before the event(s). "matches value if there were no emotion events"
velocity	float	*mm/sec*	The speed at the time of the stimulation.

***Table 119:** StimulationInfo JSON structure*

46.3. STRUCTURES

46.3.1 ActionResults

"The possible results of running an action." The structure has the following fields:

Field	Type	Description
code	ActionResultCode	The results

***Table 120:** ActionResults JSON structure*

The ActionResultCode is used to provide "the possible results of running an action."

Name	Value	Description
ACTION_RESULT_SUCCESS	0	"Action completed successfully."
ACTION_RESULT_RUNNING	16777216	"Action is still running."
ACTION_RESULT_CANCELLED_WHILE_RUNNING	33554432	"Action was cancelled by SDK request"
NOT_STARTED	33554433	"Initial state of an Action to indicate it has not yet started."
ABORT	50331648	"Action aborted itself (e.g. had invalid attributes, or a runtime failure)."
ANIM_ABORTED	50331649	"Animation Action aborted itself (e.g. there was an error playing the animation)."
BAD_MARKER	50331650	"There was an error related to vision markers."
BAD_MESSAGE_TAG	50331651	"There was a problem related to a subscribed or unsupported message tag"
BAD_OBJECT	50331652	"There was a problem with the Object ID provided (e.g. there is no Object with that ID)."
BAD_POSE	50331653	"There was a problem with the Pose provided."
BAD_TAG	50331654	"The SDK-provided tag was bad."
CHARGER_UNPLUGGED_ABORT	50331655	"Vector is on the charger but cannot sense the contacts. Charger may be unplugged."
CLIFF_ALIGN_FAILED_TIMEOUT	50331656	
CLIFF_ALIGN_FAILED_NO_TURNING	50331657	
CLIFF_ALIGN_FAILED_OVER_TURNING	50331658	
CLIFF_ALIGN_FAILED_NO_WHITE	50331659	
CLIFF_ALIGN_FAILED_STOPPED	50331660	
FAILED_SETTING_CALIBRATION	50331661	"Shouldn't occur outside of factory."
FOLLOWING_PATH_BUT_NOT_TRAVERSING	50331662	"There was an error following the planned path."
INTERRUPTED	50331663	"The action was interrupted by another Action or Behavior."
INVALID_OFF_TREADS_STATE	50331664	"The robot ended up in an "off treads state" not valid for this action (e.g. the robot was placed on its back while executing a turn)."
MISMATCHED_UP_AXIS	50331665	"The Up Axis of a carried object doesn't match the desired placement pose."

***Table 121:** ActionResultCode Enumeration*

NO_ANIM_NAME	50331666	"No valid Animation name was found."
NO_DISTANCE_SET	50331667	"An invalid distance value was given."
NO_FACE	50331668	"There was a problem with the Face ID (e.g. Vector doesn't know where it is)."
NO_GOAL_SET	50331669	"No goal pose was set."
NO_PREACTION_POSES	50331670	"No pre-action poses were found (e.g. could not get into position)."
NOT_CARRYING_OBJECT_ABORT	50331671	"No object is being carried, but the action requires one."
NOT_ON_CHARGER_ABORT	50331672	"Vector is expected to be on the charger, but is not."
NULL_SUBACTION	50331673	"No sub-action was provided."
PATH_PLANNING_FAILED_ABORT	50331674	"Vector was unable to plan a path."
PICKUP_OBJECT_UNEXPECTEDLY_MOVING	50331675	"The object that Vector is attempting to pickup is unexpectedly moving (e.g it is being moved by someone else)."
SEND_MESSAGE_TO_ROBOT_FAILED	50331676	"Shouldn't occur in SDK usage."
STILL_CARRYING_OBJECT	50331677	"Vector is unexpectedly still carrying an object."
TIMEOUT	50331678	"The Action timed out before completing correctly."
TRACKS_LOCKED	50331679	"One or more movement tracks (Head, Lift, Body, Face, Backpack Lights, Audio) are already being used by another Action."
UNEXPECTED_DOCK_ACTION	50331680	"There was an internal error related to an unexpected type of dock action."
UNKNOWN_TOOL_CODE	50331681	"Shouldn't occur outside of factory."
UPDATE_DERIVED_FAILED	50331682	"There was a problem in the subclass's update on the robot."
VISUAL_OBSERVATION_FAILED	50331683	"Vector did not see the expected result (e.g. unable to see cube in the expected position after a related action)."
SHOULDNT_DRIVE_ON_CHARGER	50331684	"Action is not permitted on the charger."
RETRY	67108864	"The Action failed, but may succeed if retried."
DID_NOT_REACH_PREACTION_POSE	67108865	"Failed to get into position."
FAILED_TRAVERSING_PATH	67108866	"Failed to follow the planned path."
LAST_PICK_AND_PLACE_FAILED	67108867	"The previous attempt to pick and place an object failed."
MOTOR_STOPPED_MAKING_PROGRESS	67108868	"The required motor isn't moving so the action cannot complete."
NOT_CARRYING_OBJECT_RETRY	67108869	"Not carrying an object when it was expected, but may succeed if the action is retried."
NOT_ON_CHARGER_RETRY	67108870	"Driving onto the charger failed, but may succeed if the action is retried."
PATH_PLANNING_FAILED_RETRY	67108871	"Vector was unable to plan a path, but may succeed if the action is retried."
PLACEMENT_GOAL_NOT_FREE	67108872	"There is no room to place the object at the desired

		destination."
PICKUP_OBJECT_UNEXPECTEDLY_NOT_MOVING	67108873	"The object that Vector thought he was lifting didn't start moving, so he must have missed."
STILL_ON_CHARGER	67108874	"Vector failed to drive off the charger."
UNEXPECTED_PITCH_ANGLE	67108875	"Vector's pitch is at an unexpected angle for the Action."

46.4. BEHAVIOR CONTROL AND ASSUME BEHAVIOR CONTROL

These commands are used to setup the ability to submit actions and behaviors into Vector's AI system. This control is needed "to be able to directly control Vector's motors, override his screen, play an animation, etc."

The request specifies a priority level. After control is granted, Vector's AI will suppress internal behaviors with a lower priority. When a behavior is commanded by the SDK, it will be associated with the priority level selected here. Note: the priority level is represented by a number where lower values represent higher priorities, and higher values represent lower priorities. See Chapter 28 for a detailed description of behavior priorities.

There are two entry points: AssumeBehaviorControl and BehaviorControl. Both employ the same request and response message structures. The response is a stream that includes information when the control was acquired, and lost.

Post: "/v1/assume_behavior_control"

46.4.1 Request

The BehaviorControlRequest is used to request control of Vector's behavior stream, and to release it. This structure includes one (and only one) of the following fields:

Field	Type	Description
control_release	{}	This is used to when the application is releasing control back to Vector; the value is an empty dictionary.
control_request	ControlRequest	This is used when the application is requesting control of Vector; see below for a description.

Table 122: *BehaviorControlRequest JSON structure*

The ControlRequest is used to request control of the behavior system at a given priority. This structure has the following fields:

Field	Type	Description
priority	Priority	This is the priority level that should be employed for requested behaviors; internal behaviors with a priority lower than this will be suppressed.

Table 123: *ControlRequest JSON structure*

The Priority enumeration has the following named priority level values:

Name	Value	Description
UNKNOWN	0	"Unknown priority. Used for versions that doesn't understand old priority levels."
OVERRIDE_BEHAVIORS	10	"Highest priority level. Suppresses most automatic physical reactions, use with caution."
DEFAULT	20	"Normal priority level. Directly under mandatory physical reactions."
RESERVE_CONTROL	30	This priority level is "used to disable idle behaviors." It is intended to "enable long-running SDK control between script executions. Not.. for regular behavior control."

Table 124: *Priority level Enumeration*

46.4.2 Response

The response is a stream of BehaviorControlResponse structures that includes information when the control was acquired, and lost. This structure includes one (and only one) of the following fields:

Field	Type	Units	Description
control_granted_response	{}		The application is now in control of the behavior stream and is "free to run any actions and behaviors they like. Until a ControlLostResponse is received, they are directly in control of Vector's behavior system."
control_lost_event	{}		"This informs the user that they lost control of the behavior system... to a higher priority behavior." "This control can be regained through another" BehaviorControlRequest.
keep_alive	KeepAlivePing		"Used by Vector to verify the connection is still alive."
reserved_control_lost_event	{}		The "behavior system lock has been lost to another connection." "This control can be regained through another" BehaviorControlRequest. This is sent when the SDK is at RESERVE_CONTROL priority level.

Table 125: *BehaviorControlResponse JSON structure*

46.5. CANCEL ACTION BY ID TAG

Cancel "a previously-requested action."

Post: "/v1/cancel_action_by_id_tag"

46.5.1 Request

The CancelActionByIdTagRequest structure has the following fields:

Field	Type	Description
id_tag	uint32	"Use the id_tag provided to the action request"

Table 126: *CancelActionByIdTagRequest JSON structure*

46.5.2 Response

The CancelActionByIdTagResponse type has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 127: *CancelActionByIdTagResponse JSON structure*

46.6. CANCEL BEHAVIOR

Cancels the current running SDK behavior. Note this is only in version 1.7 and later.

Post: "/v1/cancel_behavior"

46.6.1 Request

The CancelBehaviorRequest structure has no fields.

46.6.2 Response

The CancelBehaviorResponse type has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 128: *CancelBehaviorResponse JSON structure*

46.7. LOOK AROUND IN PLACE

This has Vector turn around (in place) and see what is around him. See also section *56.2.6 RobotObservedFace*, section *45.2.7 RobotObservedObject*

Post: "/v1/look_around_in_place"

46.7.1 Request

The LookAroundInPlaceRequest structure has no fields.

46.7.2 Response

The LookAroundInPlaceResponse structure has the following fields:

Field	Type	Description
result	BehaviorResults	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 129: *LookAroundInPlaceResponse JSON structure*

47. ALEXA

47.1. ENUMERATIONS

47.1.1 AlexaAuthState

The AlexaAuthState is used represent how far in the Alexa Voice Services authorization process Vector is. The enumeration has the following named values:

Table 130: AlexaAuthState Enumeration

Name	Value	Description
ALEXA_AUTH_INVALID	0	"Invalid/error/versioning issue"
ALEXA_AUTH_UNINITIALIZED	1	"Not opted in, or opt-in attempted but failed"
ALEXA_AUTH_REQUESTING_AUTH	2	"Opted in, and attempting to authorize"
ALEXA_AUTH_WAITING_FOR_CODE	3	"Opted in, and waiting on the user to enter a code"
ALEXA_AUTH_AUTHORIZED	4	"Opted in, and authorized / in use"

47.2. EVENTS

47.2.1 AlexaAuthEvent

The AlexaAuthEvent is used to post updates to SDK application (via the *Event* message) when the authorization with Alexa Voice Services change. The structure has the following fields:

Table 131: AlexaAuthEvent JSON structure

Field	Type	Description
auth_state	AlexaAuthState	
extra	string	

47.3. ALEXA AUTHORIZATION STATE

This is used to find out whether Vector has been authenticated and authorized to use Alexa Voice Services.

Post: "/v1/alexa_auth_state"

47.3.1 Request

The AlexaAuthStateRequest structure has no fields.

47.3.2 Response

The AlexaAuthStateResponse structure has the following fields:

Field	Type	Description
auth_state	AlexaAuthState	
extra	string	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 132: *AlexaAuthStateResponse JSON structure*

47.4. ALEXA OPT IN

This is used to enable Alexa Voice Services on Vector.

Post: "/v1/alexa_opt_in"

47.4.1 Request

The AlexaOptInRequest structure has the following fields:

Field	Type	Description
opt_in	bool	True, if Vector should employ Alexa Voice services; otherwise Vector should not.

Table 133: *AlexaOptInRequest JSON structure*

47.4.2 Response

The AlexaOptInResponse structure has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 134: *AlexaOptInResponse JSON structure*

48. ANIMATION

Some things related to animation but we haven't figured it all out yet.

48.1. STRUCTURES

48.1.1 Animation

This structure is used to provide the name of an animation. The Animation structure has the following fields:

Field	Type	Description
name	string	"The name of a given animation"

***Table 135:** Animation JSON structure*

48.1.2 AnimationTrigger

This structure is used to provide the name of an animation group (aka its trigger name). The AnimationTrigger structure has the following fields:

Field	Type	Description
name	string	"The name of a given animation trigger"

***Table 136:** AnimationTrigger JSON structure*

48.2. LIST ANIMATIONS

"Constructs and returns a list of animations."

Post: "/v1/list_animations"

48.2.1 Request

The ListAnimationsRequest has no fields.

48.2.2 Response

The ListAnimationsResponse structure has the following fields:

Field	Type	Description
animation_names	Animation[]	"The animations that Vector knows.."
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 137:** ListAnimationsResponse JSON structure*

48.3. LIST ANIMATION TRIGGERS

"Constructs and returns a list of animation triggers."

Post: "/v1/list_animation_triggers"

48.3.1 Request

The ListAnimationTriggerssRequest has no fields.

48.3.2 Response

The ListAnimationTriggersResponse structure has the following fields:

Field	Type	Description
animation_tigger_names	AnimationTrigger[]	"The animations triggers that Vector knows."
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 138: *ListAnimationTriggersResponse JSON structure*

48.4. PLAY ANIMATION

"Requests that Vector play an animation."

48.4.1 Request

The PlayAnimationRequest structure has the following fields:

Field	Type	Units	Description
animation	Animation		"The animation to play."
ignore_body_track	bool		"Ignore any movement of Vector's body when playing the animation."
ignore_head_track	bool		"Ignore any movement of Vector's head when playing the animation."
ignore_lift_track	bool		"Ignore any movement of Vector's lift when playing the animation."
loops	uint32		"The number of times to play the animation in a row."

Table 139: *PlayAnimationRequest JSON structure*

48.4.2 Response

The PlayAnimationResponse structure has the following fields:

Field	Type	Description
animation	Animation	"The animation that the robot executed."
result	BehaviorResults	"Information on whether the animation played successfully."
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 140: *PlayAnimationResponse JSON structure*

48.5. PLAY ANIMATION TRIGGER

"Requests that Vector play an animation trigger."

48.5.1 Request

The PlayAnimationTriggerRequest structure has the following fields:

Field	Type	Units	Description
animation_trigger	AnimationTrigger		"The animation trigger to play."
ignore_body_track	bool		"Ignore any movement of Vector's body when playing the animation."
ignore_head_track	bool		"Ignore any movement of Vector's head when playing the animation."
ignore_lift_track	bool		"Ignore any movement of Vector's lift when playing the animation."
loops	uint32		"The number of times to play the animation in a row."
use_lift_safe	bool		"Automatically ignore the lift track if Vector is currently carrying an object."

Table 141: *PlayAnimationTriggerRequest JSON structure*

48.5.2 Response

See the response for Play Animation.

49. ATTENTION TRANSFER

Note: this attention event is unlikely to be sent and the response to getting the latest attention transfer is likely to invalid or empty, as the "AttentionTransfer" feature is disabled in all software releases.

49.1. EVENTS

49.1.1 AttentionTransfer

This event is sent when TBD. The AttentionTransfer structure has the following fields:

Field	Type	Description
reason	AttentionTransferReason	The reason that the attention was changed.
seconds_ago	float	How long ago the attention was changed.

Table 142: *AttentionTransfer JSON structure*

The AttentionTransferReason is used to represent why the attention was transferred. The enumeration has the following named values:

Name	Value	Description
Invalid	0	
NoCloudConnection	1	
NoWifi	2	
UnmatchedIntent	3	

Table 143: *AttentionTransferReason Enumeration*

49.2. GET LATEST ATTENTION TRANSFER

Part of the behaviour component

Post: "/v1/get_latest_attention_transfer"

49.2.1 Request

The GetLatestAttentionTransferRequest has no fields.

49.2.2 Response

The GetLatestAttentionTransferResponse has the following fields:

Field	Type	Description
latest_attention_transfer	LatestAttentionTransfer	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 144: *GetLatestAttentionTransferResponse JSON structure*

The LatestAttentionTransfer structure has the following fields:

Field	Type	Description
attention_transfer	AttentionTransfer	When and why the attention was changed.

Table 145: *LatestAttentionTransfer JSON structure*

50. AUDIO

This section describes events and commands related to Vectors audio input and output.

50.1. ENUMERATIONS

50.1.1 AudioProcessingMode

The AudioProcessingMode is used to represent the different ways that Vector can process the microphone audio. The enumeration has the following named values:

Name	Value	Description
AUDIO_UNKNOWN	0	"error value"
AUDIO_OFF	1	The audio settings from the HTTPS API will not be used.
AUDIO_FAST_MODE	2	The spatial audio processing is disabled; the sound is used from a single microphone. This has the lowest processing overhead.
AUDIO_DIRECTIONAL_MODE	3	Use "beamforming support for focusing on specific direction – [this] sounds cleanest"
AUDIO_VOICE_DETECT_MODE	4	Use "multi-microphone non-beamforming. [This is] best for voice detection programs."

Table 146: *AudioProcessingMode Enumeration*

50.1.2 MasterVolumeLevel

The MasterVolumeLevel is used to control the volume of audio played by Vector, including text to speech. It is used in the MasterVolumeLevelRequest. The enumeration has the following named values:

Name	Value	Description
VOLUME_LOW	0	
VOLUME_MEDIUM_LOW	1	
VOLUME_MEDIUM	2	
VOLUME_MEDIUM_HIGH	3	
VOLUME_HIGH	4	

Table 147: *MasterVolumeLevel Enumeration*

50.1.3 UtteranceState

The UtteranceState is used to represent the state of audio playback by Vector, including text to speech. It is used in the SayTextResponse. The enumeration has the following named values:

Name	Value	Description
INVALID	0	
GENERATING	1	Vector is generating the audio and other animation for the text to speech.

Table 148: *UtteranceState Enumeration*

READY	2	Vector has completed generating the audio and animation.
PLAYING	3	Vector is playing the speech and related animation.
FINISH	4	Vector has finished playing the audio and animation.

50.2. EVENTS

The following events are sent in the *Event* message. When a person speaks the wake word, the *WakeWordBegin* event will be sent, followed by the *WakeWordEnd* event and possibly a *UserIntent* event.

50.2.1 AudioSendModeChanged

Note: *this event is not available*; it was defined in the API protocol, but never implemented and removed. It is reproduced here for information purposes; it may be in future releases.

This event is "sent when the robot changes the mode it's processing and sending audio" in.

See Chapter 17, section *76.2 Spatial audio processing* for more information

The event structure has the following fields:

Field	Type	Description
mode	AudioProcessingMode	The requested audio processing mode.

Table 149: *AudioSendModeChanged JSON structure*

50.2.2 UserIntent

The UserIntent event is sent by Vector when an intent is received (from the cloud), after a person has said the wake word and spoken. The UserIntent structure has the following fields:

Field	Type	Description
intent_id[31]	uint32	The identifier for the intent. See Appendix J *Table 640: Mapping of different intent names* for an enumeration.
json_data	string	The parameters as a JSON formatted string. This may be empty if there is not additional information.

Table 150: *UserIntent JSON structure*

50.2.3 WakeWord

This event is sent when the wake word is heard, and then when the cloud response is received. The WakeWord structure has the following fields, only one is present at any time:

Field	Type	Description
wake_word_begin	WakeWordBegin	This is sent when the wake word is heard. The structure has no contents.

Table 151: *WakeWord JSON structure*

[31] The use of an enumeration rather than a string is unusual here, and seems limiting.

wake_word_end	WakeWordEnd	This is sent when the response (and potential intent) is received from the cloud. This is sent before the *UserIntent* event (if any).

The WakeWordEnd structure has the following fields:

Table 152: *WakeWordEnd JSON structure*

Field	Type	Description
intent_heard	bool	True if a sentence was recognized with an associated intent; false otherwise.
intent_json	string	The intent and parameters as a JSON formatted string. This is empty if an intent was not heard (intent_heard will be false), or if the client does not have control. In the later case, a *UserIntent* event with the intent JSON data will be sent.

50.3. APP INTENT

This command is allows the mobile application or SDK application to send an intent to Vector.

See also section *50.2.2 UserIntent,* and section *50.2.3 WakeWord*

Post: "/v1/app_intent"

50.3.1 Request

The AppIntentRequest structure has the following fields:

Field	Type	Description
intent	string	The name of the intent to request; Vector (probably) will only honor the intents listed in the "App Intent" column in Appendix J, *Table 640: Mapping of different intent names*
param	string	The parameters for the intent. This is usually a JSON formatted string. This can be empty if the intent does not require any additional information.

Table 153: *AppIntentRequest JSON structure*

This intent_meet_victor intent has the parameter following fields:

Field	Type	Units	Description
param			

Table 154: *intent_meet_victor parameters*

The intent_clock_settimer intent parameter isn't used. Instead the length of the param is used as the number of seconds to set the timer for.

50.3.2 Response

The AppIntentResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 155: *AppIntentResponse JSON structure*

50.4. AUDIO FEED (FROM THE MICROPHONES)

Note: *this command is not available*; it was defined in the API protocol, but never implemented and removed. It is reproduced here for information purposes; it may be in future releases.

This command is used to request an audio feed from Vector.

See Chapter 18, section *76.2 Spatial audio processing* for more information

Post: "/v1/audio_feed"

50.4.1 Request

This AudioFeedRequest has no fields.

50.4.2 Response

The response is a stream of the following AudioFeedResponse structure. This structure has the following fields:

***Table 156:** AudioFeedResponse JSON structure*

Field	Type	Description
direction_strengths	bytes	"Histogram data of which directions this audio chunk came from."
group_id	uint32	"The index of this audio feed response"
noise_floor_power	uint32	The background noise level, as a "power value, convert to db with $\log_{10}$(value)"
robot_time_stamp	uint32	The "robot time at the transmission of this audio sample group"
signal_power	bytes	The stream of sound that Vector hears, as a "mono audio amplitude samples". This is 1600 "16-bit little-endian PCM audio" samples, at 11025 samples/sec.
source_confidence	uint32	The "accuracy of the calculated source_direction"
source_direction	uint32	0-11: The index of the direction that the voice or key sound is coming. 12: There is no identifiable sound or the direction cannot be determined.

50.5. AUDIO PROCESSING MODE

Note: *this command is not available*; it was defined in the API protocol, but never implemented and removed. It is reproduced here for information purposes; it may be in future releases.

This command is used to "request how the robot should process and send audio." Specifically it can turn off the audio processing, and enable or disable the spatial audio processing.

See Chapter 18, section *76.2 Spatial audio processing* for more information

50.5.1 Request

This AudioSendModeRequest has the following fields:

Field	Type	Description
mode	AudioProcessingMode	The requested audio processing mode.

Table 157: *AudioSendModeRequest JSON structure*

50.5.2 Response

There is no response.

50.6. EXTERNAL AUDIO STREAM PLAYBACK

This command is used to stream sound files to Vector to play on his speaker. The audio is sent as single channel (mono) 16-bit little-endian PCM (i.e. without compression or other format) at a sample rate between 8000 samples/sec to 16205 samples/sec.

The audio is sent by:

1. Setting up the audio playback, by sending the "audio_stream_prepare" substructure with the audio rate and value
2. Sending the audio data in chunks (up to 1024 bytes, or 512 samples) using the "audio_stream_chunk" structure
3. repeating #2 until all of the sound data has been sent
4. Sending the "audio_stream_complete" or "audio_stream_cancel" to end the playback.

50.6.1 Request

The ExternalAudioStreamRequest is used to stream a chunk of audio to Vector. This structure has one (and only one) of the following fields:

Field	Type	Description
audio_stream_cancel	{}	"Cancel a playing external robot audio stream"
audio_stream_chunk	ExternalAudioStreamChunk	"Send chunk of audio data to stream on robot."
audio_stream_complete	{}	"Send notification of last chunk of audio sent to robot"
audio_stream_prepare	ExternalAudioStreamPrepare	This is used to set up the audio channel, with the sample rate and playback volume.

Table 158: ExternalAudioStreamRequest JSON structure

The ExternalAudioStreamPrepare structure has following fields:

Field	Type	Description
audio_frame_rate	uint32	The sample rate for the audio. This must be in the range of 8000 to 16025 samples/sec.
audio_volume	uint32	The volume to play the audio at. 0-100

Table 159: ExternalAudioStreamPrepare JSON structure

The ExternalAudioStreamChunk structure has following fields:

Field	Type	Description
audio_chunk_samples	byte[]	The audio samples, encoded as 16-bit values in little-endian order. This must be 1024 or few bytes
audio_chunk_size_bytes[32]	uint32	The number of bytes sent; the max is 1024 (i.e. a max of 512 samples).

Table 160: ExternalAudioStreamChunk JSON structure

[32] I am curious. Why does this field exist? The array intrinsically knows it size…

50.6.2 Response

The ExternalAudioStreamResponse is provides the response to streamed a audio chunk. This structure has one (and only one) of the following fields:

Field	Type	Description
audio_stream_playback_complete	{}	"Audio has been played on the Robot"
audio_stream_playback_failyer[33]	{}	There was an error playing the audio.
audio_stream_buffer_overrun	ExternalAudioStreamBufferOverrun	"Audio has been sent to robot that would overrun the memory buffer"

Table 161: *ExternalAudioStreamResponse JSON structure*

The ExternalAudioStreamBufferOverrun structure has following fields:

Field	Type	Description
audio_samples_played	uint32	The number of samples that were played.
audio_samples_sent	uint32	The number of audio samples that were sent [To Vector? To the audio subsystem?]

Table 162: *ExternalAudioStreamBufferOverrun JSON structure*

[33] Yes, that mis-spelling is correct

50.7. MASTER VOLUME

This command is used to set the volume of Vector's audio playback and sound effects.

50.7.1 Request

The MasterVolumeResponse has the following fields:

Field	Type	Description
volume_level	MasterVolumeLevel	This is used to set the volume of Vector's audio playback.

Table 163: *MasterVolumeRequest JSON structure*

50.7.2 Response

The MasterVolumeResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 164: *MasterVolumeResponse JSON structure*

50.8. SAY TEXT

This command is used to request the state of Vector speak the given text.

Post: "/v1/say_text"

50.8.1 Request

The SayTextRequest structure has the following fields:

Field	Type	Units	Description
duration_scalar	float	*ratio*	This controls the speed at which Vector speaks. 1.0 is normal rate, less than 1 increases the speed (e.g. 0.8 causes Vector to speak in just 80% of the usual time), and a value larger than one slows the speed (e.g. 1.2 causes Vector to take 120% of the usual time to speak). Allowed range is 0.5..20.0. Default: 1.0
pitch_scalar	float		Negative values lower the pitch, higher values raise the pitch. Allowed range is -1.0..1.0 Default: 0.0. *Note: this field is optional, and available only in 1.7 or later versions.*
text	string		The text (the words) that Vector should say.
use_vector_voice	bool		True if the text should be spoken in "Vector's robot voice; otherwise, he uses a generic human male voice."

***Table 165:** SayTextRequest JSON structure*

50.8.2 Response

The SayTextResponse structure has the following fields:

Field	Type	Description
state	UtteranceState	Where in the speaking process Vector is currently.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 166:** SayTextResponse JSON structure*

TBD: are multiple responses sent as the task progresses?

51. BATTERY

See section *44.1.2 RobotStatus* for a flag indicating that Vector is charging.

See section *59 Interactions with Objects* for actions to drive onto and off of the charger.

51.1. ENUMERATIONS

The BatteryLevel enumeration is located in Chapter 8, Power Management, *Table 14: BatteryLevel codes as they apply to Vector*

51.2. BATTERY STATE

This command is used to request the state of Vector's battery and the cube battery. The state includes its voltage, and whether Vector is charging.

Post: "/v1/battery_state"

51.2.1 Request

No parameters

51.2.2 Response

The BatteryStateResponse structure has the following fields:

Field	Type	Units	Description
battery_level	BatteryLevel		The interpretation of the battery level.
battery_volts	float	*volts*	The battery voltage.
cube_battery	CubeBatteryLevel		The status of the companion Cube's battery.
is_on_charger_platform	bool		True if Vector is on his "home," aka charger.
is_charging	bool		True if Vector is charging, false otherwise.
status	ResponseStatus		A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
suggested_charger_sec	float	*seconds*	Suggested amount of time to charge.

***Table 167:** BatteryStateResponse JSON structure*

52. CONNECTION

This section describes the events and commands used to establish and maintain a connection with Vector. This includes the ability to get the versions of the connection protocol, ant the software used.

52.1. EVENTS

52.1.1 ConnectionResponse

The ConnectionResponse structure has the following fields:

Field	Type	Description
is_primary	bool	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 168: *ConnectionResponse JSON structure*

52.1.2 Event

The Event structure is to deliver messages that some event has occurred. It is received in periodic response to the part of the *Event Stream* command. All the events are carried in this one has one (and only) of the following fields:

Field	Type	Description
alexa_auth_event	AlexaAuthEvent	
attention_transfer	AttentionTransfer	*Not implemented?*
camera_settings_update	CameraSettingsUpdate	This event is sent when the camera exposure settings change.
check_update_status_response	CheckUpdateStatusResponse	This event is sent when the update status has changed.
connection_response	ConnectionResponse	
cube_battery	CubeBattery	This event is sent when the cube's battery level has changed.
jdocs_changed	JdocsChanged	This event is sent when Vector's preference settings have changed.
keep_alive	KeepAlivePing	"Used by Vector to verify the connection is still alive."
mirror_mode_disabled	MirrorModeDisabled	This event is sent when the display system has disabled mirror mode.
object_event	ObjectEvent	This event is sent when an object is seen, tapped, lost, moved, a connection was established or lost.
onboarding	Onboarding	
photo_taken	PhotoTaken	This event is sent when a photograph has been taken.
robot_state	RobotState	This event is regularly sent to give the status of the robot.

Table 169: *Event JSON structure*

robot_changed_observed_face_id	RobotChangedObservedFaceID	This event is sent when Vector recognizes a face.
robot_erased_enrolled_face	RobotErasedEnrolledFace	This event is sent when a named face is removed from the database.
robot_observed_face	RobotObservedFace	This event is sent when a face is seen.
robot_observed_motion	RobotObservedMotion	This event is sent when some visual motion is seen.
robot_renamed_enrolled_face	RobotRenamedEnrolledFace	This event is sent when the name of a face is changed.
stimulation_info	StimulationInfo	This event is sent when stimulation from internal or external events is received.
time_stamped_status	TimeStampedStatus	
unexpected_movement	Unexpected Movement	This event is sent when Vector's body moves in a way that was not expected.
user_intent	UserIntent	This event is sent when a user intent has been received and is being acted upon.
vision_modes_auto_disabled	VisionModesAutoDisabled	This event is sent when the vision system has disabled further updates.
wake_word	WakeWord	This event is sent when the wake word has been heard.

52.1.3 KeepAlivePing

This is "a null message used by streams to verify that the client is still connected." This message has no fields.

52.1.4 TimeStampedStatus

The TimeStampedStatus structure has the following fields:

Table 170: *TimeStampedStatus JSON structure*

Field	Type	Description
status	Status	
timestamp_utc	uint32	The time that the status occurred on. The format is unix time: seconds since 1970, in UTC.

The Status structure has one (and only one) of the following fields:

Table 171: *Status JSON structure*

Field	Type	Description
face_enrollment_completed	FaceEnrollmentComplete	
feature_status	FeatureStatus	This event is sent when the high-level AI changes Vector's behavior.
meet_victor_face_scan_complete	Meet Victor Face Scan Complete	
meet_victor_face_scan_started	Meet Victor Face Scan Started	

52.2. EVENT STREAM

This command is used to request a stream of events from Vector.

Post: “"/v1/event_stream”

Get: “"/v1/event_stream”

52.2.1 Request

The EventRequest has the following fields:

Field	Type	Description
black_list	FilterList	The list of events to not include. ?
connection_id	string	
white_list	FilterList	The list of events to include.

***Table 172:** EventRequest JSON structure*

The FilterList structure has the following fields:

Field	Type	Description
list	string[]	A list of events

***Table 173:** FilterList JSON structure*

52.2.2 Response

The response is a stream of EventResponse structures. These have the following fields:

Field	Type	Description
event	Event	The event that occurred. This structure is described above in the subsection *Eents*
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 174:** EventResponse JSON structure*

52.3. PROTOCOL VERSION

"Checks the supported protocol version by passing in the client version and minimum host version and receiving a response to see whether the versions are supported."

Post: "/v1/protocol_version"

"The valid versions of the protocol. Protocol versions are updated when messages change significantly: new ones are added and removed, fields deprecated, etc. The goal is to support as many old versions as possible, only bumping the minimum when there is no way to handle a prior version."

52.3.1 Request

The ProtocolVersionRequest has the following fields:

Field	Type	Description
client_version	int64	The version of the protocol that the client is using.
min_host_version	int64	The minimum version level of the protocol that robot should support.

Table 175: *ProtocolVersionRequest JSON structure*

52.3.2 Response

The ProtocolVersionResponse has the following fields:

Field	Type	Description
host_version	int64	The version of the protocol that the robot supports.
result	Result	Whether or not the protocol version supported by the robot is compatible with the client. See below.

Table 176: *ProtocolVersionResponse JSON structure*

The Result is used to indicate whether the client version is supported. The enumeration has the following named values:

Name	Value	Description
SUPPORTED	1	The protocol supports the client version and the minimum host (robot) version of the protocol.
UNSUPPORTED	0	The protocol is unable to support the client; either the client version is not supported, or the host is unable to support a compatible version of the protocol.

Table 177: *Result Enumeration*

52.4. SDK INITIALIZATION

"SDK-only message to pass version info for device OS, Python version, etc."

Post: "/v1/sdk_initialization"

52.4.1 Request

The SDKInitializationRequest has the following fields:

Field	Type	Description
cpu_version	string	The CPU model that the client (SDK) is using; *informational only*.
os_version	string	The version of operating system that the client (SDK) is using; *informational only.*
python_implementation	string	
python_version	string	The version of python that the client (SDK) is using. *Informational only.*
sdk_module_version	string	The version of the SDK software that the client is using.

Table 178: *SDKInitializationRequest JSON structure*

52.4.2 Response

The SDKInitializationResponse type has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 179: *SDKInitializationResponse JSON structure*

52.5. USER AUTHENTICATION

This command is used to authenticate

Post: “/v1/user_authentication”

52.5.1 Request

The UserAuthenticationRequest has the following fields:

Field	Type	Description
client_name	bytes	
user_session_id	bytes	

Table 180: *UserAuthenticationRequest JSON structure*

52.5.2 Response

The UserAuthenticationResponse has the following fields:

Field	Type	Description
client_token_guid	bytes	The token bytes to be included in subsequent HTTPS postings. This token should be saved for future use.
code	Code	The result of the authentication request
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 181: *UserAuthenticationResponse JSON structure*

The Code enumeration is:

Name	Value	Description
UNAUTHORIZED	0	
AUTHORIZED	1	

Table 182: *Code Enumeration*

52.6. VERSION STATE

Retrieves Vector's version information.

Post: "/v1/version_state"

52.6.1 Request

The VersionStateRequest has no fields.

52.6.2 Response

The VersionStateResponse type has the following fields:

Table 183: VersionStateResponse JSON structure

Field	Type	Description
engine_build_id	string	The robot's software build identifier.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
os_version	string	The identifier of the robot's software version.

53. CUBE

This section describes the structures and commands to interact with the cube.

Comment: Many of the commands are specific to interacting with a cube, but appear to have been intended to be generalized to work with a wider range of objects.

See also section *45.4 Define Custom Object* for a description how to create custom box and cube objects.

The cube's unique identifier is called "factory_id" in these messages.

53.1. ENUMERATIONS

53.1.1 AlignmentType

The AlignmentType is used to indicate how Vector should align with the object. The enumeration has the following named values:

Name	Value	Description
ALIGNMENT_TYPE_UNKNOWN	0	
ALIGNMENT_TYPE_LIFT_FINGER	1	"Align the tips of the lift fingers with the target object"
ALIGNMENT_TYPE_LIFT_PLATE	2	"Align the flat part of the lift with the object (useful for getting the fingers in the cube's grooves)"
ALIGNMENT_TYPE_BODY	3	"Align the front of Vector's body (useful for when the lift is up)"
ALIGNMENT_TYPE_CUSTOM	4	"For use with distanceFromMarker parameter"

Table 184: *AlignmentType Enumeration*

53.1.2 CubeBatteryLevel

The CubeBatteryLevel enumeration is used to categorize the condition of the Cube battery:

Name	Value	Description
BATTERY_LEVEL_LOW	0	The Cube battery is 1.1V or less.
BATTERY_LEVEL_NORMAL	1	The Cube battery is at normal operating levels, i.e. >1.1v

Table 185: *CubeBatteryLevel codes[34] as they apply to Vector*

[34] The levels are from robot.py

53.2. EVENTS

53.2.1 CubeBattery

The CubeBattery structure has the following fields:

Table 186: CubeBattery JSON structure

Field	Type	Units	Description
battery_volts	float	*volts*	The battery voltage.
factory_id	string		The text string reported by the cube via Bluetooth LE.
level	CubeBatteryLevel		The interpretation of the battery level.
time_since_last_reading_sec	float	*seconds*	The number of seconds that have elapsed since the last Bluetooth LE message from the cube with a battery level measure.

53.2.2 CubeConnectionLost

"Indicates that the connection subscribed through ConnectCube has been lost."

See also *ObjectConnectionState*

The ConnectCubeRequest has no fields.

53.2.3 ObjectTapped

The ObjectTapped event is sent (see *ObjectEvent*) when an object has received a finger-tap. This event is only sent by the cube. Note: this event can have false triggers; it may sent when Vector is picking up, carrying, or putting down the Cube.

The structure has the following fields:

Table 187: ObjectTapped JSON structure

Field	Type	Units	Description
object_id	uint32		The identifier of the object tapped.
timestamp	uint32		The time that the event occurred on. The format is milliseconds since Vector's epoch.

53.3. CONNECT CUBE

"Attempt to connect to a cube. If a cube is currently connected, this will do nothing."

Post: "/v1/connect_cube"

53.3.1 Request

The ConnectCubeRequest has no fields.

53.3.2 Response

The ConnectCubeResponse type has the following fields:

Field	Type	Description
factory_id	string	The identifier for the cube. This is built into the cube.
object_id	uint32	The identifier of the cube that we connected with. This is Vector's internal identifier, and only the preferred cube is assigned one.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
success	bool	True if Vector was able to successfully connect, via Bluetooth LE, with the cube.

Table 188: ConnectCubeResponse JSON structure

53.4. CUBES AVAILABLE

Have Vector scan for cubes via Bluetooth LE and report the ones heard.

Post: "/v1/cubes_available"

53.4.1 Request

The CubesAvailableRequest has no fields.

53.4.2 Response

The CubesAvailableResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Field	Type	Description
factory_ids	string[]	A list of the cubes that were seen via Bluetooth LE. The cubes internal identifier (it's factor id) is sent.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 189: CubesAvailableResponse JSON structure

53.5. DISCONNECT CUBE

"Requests a disconnection from the currently connected cube."

Post: "/v1/disconnect_cube"

53.5.1 Request

The DisconnectCubeRequest has no fields.

53.5.2 Response

The DisconnectCubeResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 190: *DisconnectCubeResponse JSON structure*

53.6. DOCK WITH CUBE

"Tells Vector to dock with a light cube with [an optional] given approach angle and distance." "While docking with the cube, Vector will use path planning."

This action requires the use of the wheels (tracks). "Actions that use the wheels cannot be performed at the same time; otherwise you may see a TRACKS_LOCKED error."

Post: "/v1/dock_with_cube"

53.6.1 Request

The DockWithCubeRequest structure has the following fields:

Table 191: DockWithCubeRequest JSON structure

Field	Type	Units	Description
alignment_type	AlignmentType		"Which part of the robot to align with the object."
approach_angle_rad	float	*radians*	"The angle to approach the cube from. For example, 180 degrees will cause Vector to drive past the cube and approach it from behind."
distance_from_marker_mm	float	*mm*	"The distance from the object to stop. This is the distance between the origins." 0mm to dock.
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
motion_prof	PathMotionProfile		Modifies how Vector should approach the cube. *Optional.*
num_retries	int32		Maximum of times to attempt to reach the object. A retry is attempted if Vector is unable to reach the target object.
object_id	int32		The identifier of the object to dock with.
use_approach_angle	bool		If true, Vector will approach the cube from the given approach angle; otherwise Vector will approach from the most convenient angle.
use_pre_dock_pose	bool		If true, "try to immediately [dock with the] object or first position the robot next to the object." Recommended to set this to the same as use_approach_angle.

53.6.2 Response

The DockWithCubeResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Table 192: DockWithCubeResponse JSON structure

Field	Type	Description
result	ActionResult	An error code indicating the success of the action, the detailed reason why it failed, or that the action is still being carried out.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

53.7. FLASH CUBE LIGHTS

"Plays the default cube connection animation on the currently connected cube's lights."

Note: "This [command] is intended for app level user surfacing of cube connectivity, not for SDK cube light control."

Post: "`/v1/flash_cube_lights`"

53.7.1 Request

The `FlashCubeLightsRequest` has no fields.

53.7.2 Response

The `FlashCubeLightsResponse` is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 193:** FlashCubeLightsResponse JSON structure*

53.8. FORGET PREFERRED CUBE

"Forget the robot's preferred cube. This will cause the robot to connect to the cube with the highest RSSI (signal strength) next time a connection is requested. Saves this preference to disk. The next cube that the robot connects to will become its preferred cube."

See also section *53.15 Set Preferred Cube*

Post: "`/v1/forget_preferred_cube`"

53.8.1 Request

The `ForgetPreferredCubeRequest` has no fields.

53.8.2 Response

The `ForgetPreferredCubeResponse` is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 194:** ForgetPreferredCubeResponse JSON structure*

53.9. PICKUP OBJECT

"Instruct the robot to pick up the supplied object." "While picking up the cube, Vector will use path planning."

"Note that actions that use the wheels cannot be performed at the same time, otherwise you may see a TRACKS_LOCKED error."

53.9.1 Request

The PickupObjectRequest structure has the following fields:

Field	Type	Units	Description
approach_angle_rad	float	*radians*	"The angle to approach the cube from. For example, 180 degrees will cause Vector to drive past the cube and approach it from behind."
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
motion_prof	PathMotionProfile		*Optional.*
num_retries	int32		Maximum of times to attempt to reach the object. A retry is attempted if Vector is unable to reach the target object.
object_id	int32		The identifier of the object to pick up. `Negative value means currently selected object'
use_approach_angle	bool		If true, Vector will approach the cube from the given approach angle; otherwise Vector will approach from the most convenient angle.
use_pre_dock_pose	bool		"Whether or not to try to immediately pick up an object or first position the robot next to the object."

Table 195: *PickupObjectRequest JSON structure*

53.9.2 Response

The PickupObjectResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Field	Type	Description
result	ActionResult	An error code indicating the success of the action, the detailed reason why it failed, or that the action is still being carried out.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 196: *PickupObjectResponse JSON structure*

53.10. PLACE OBJECT ON GROUND HERE

"Ask Vector to place the object he is carrying on the ground at the current location."

53.10.1 Request

The PlaceObjectOnGroundRequest structure has the following fields:

Field	Type	Units	Description
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
num_retries	int32		Maximum of times to attempt to reach the object. A retry is attempted if Vector is unable to reach the target object.

***Table 197:** PlaceObjectOnGroundRequest JSON structure*

53.10.2 Response

The PlaceObjectOnGroundResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Field	Type	Description
result	ActionResult	An error code indicating the success of the action, the detailed reason why it failed, or that the action is still being carried out.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 198:** PlaceObjectOnGroundResponse JSON structure*

53.11. POP A WHEELIE

"Tell Vector to `pop a wheelie' using his cube." Vector will approach the cube, then "push down on [it] with [his] lift, to start the wheelie."

53.11.1 Request

The PopAWheelieRequest structure has the following fields:

Table 199: *PopAWheelieRequest JSON structure*

Field	Type	Units	Description
approach_angle_rad	float	*radians*	"The angle to approach the cube from. For example, 180 degrees will cause Vector to drive past the cube and approach it from behind."
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
motion_prof	PathMotionProfile		*zOptional.*
num_retries	int32		Maximum of times to attempt to reach the object. A retry is attempted if Vector is unable to reach the target object.
object_id	int32		The identifier of the object to used to pop a wheelie. Negative value means currently selected object'
use_approach_angle	bool		If true, Vector will approach the cube from the given approach angle; otherwise Vector will approach from the most convenient angle.
use_pre_dock_pose	bool		"Whether or not to try to immediately [use the] object or first position the robot next to the object." Recommended to set this to the same as use_approach_angle.

53.11.2 Response

The PopAWheelieResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Table 200: *PopAWheelieResponse JSON structure*

Field	Type	Description
result	ActionResult	An error code indicating the success of the action, the detailed reason why it failed, or that the action is still being carried out.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

53.12. ROLL BLOCK

"Make Vector roll his block, regardless of relative position and orientation." This triggers a behaviour, where Vector will look for his block, then "move into position as necessary based on relative distance and orientation."

See also section *53.13 Roll Object*

Post: "/v1/roll_block"

53.12.1 Request

The RollBlockRequest has no fields.

53.12.2 Response

The RollBlockResponse structure has the following fields:

Field	Type	Description
result	BehaviorResults	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 201: *RollBlockResponse JSON structure*

53.13. ROLL OBJECT

"Tell Vector to roll his cube." This triggers an action.

53.13.1 Request

The RollObjectRequest structure has the following fields:

Field	Type	Units	Description
approach_angle_rad	float	*radians*	"The angle to approach the cube from. For example, 180 degrees will cause Vector to drive past the cube and approach it from behind."
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
motion_prof	PathMotionProfile		*Optional.*
num_retries	int32		Maximum of times to attempt to reach the object. A retry is attempted if Vector is unable to reach the target object.
object_id	int32		The identifier of the object to roll. `Negative value means currently selected object'
use_approach_angle	bool		If true, Vector will approach the cube from the given approach angle; otherwise Vector will approach from the most convenient angle.
use_pre_dock_pose	bool		"Whether or not to try to immediately [roll the] object or first position the robot next to the object." Recommended to set this to the same as use_approach_angle.

Table 202: *RollObjectRequest JSON structure*

53.13.2 Response

The RollObjectResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Field	Type	Description
result	ActionResult	An error code indicating the success of the action, the detailed reason why it failed, or that the action is still being carried out.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 203: *RollObjectResponse JSON structure*

53.14. SET CUBE LIGHTS

"Set each of the lights on the currently connected cube based on two RGB values each and timing data for how to transition between them."

"Sets each LED on [Vector]'s cube. Two states are specified designated 'on' and 'off', each with a color, duration, and state transition time."

See also the Chapter 23 section *103 Cube lights Animation*

53.14.1 Request

The SetCubeLightsRequest event is used to specify the light pattern on the cube. The structure has the following fields:

Table 204: *SetCubeLightsRequest JSON structure*

Field	Type	Units	Description
object_id	uint32		The internal id for the cube.
make_relative	MakeRelativeMode		*Should be off (1)*
off_color	array of uint32[]		Each color corresponds to each of the 4 cube lights. Each color is represented as four values (red, green, blue, and alpha), in the range of 0..255.
off_period_ms	uint32[]	*ms*	The "off" duration for each of the 4 cube lights. This is the duration to show each cube light in its corresponding "off" color (in off_color).
offset	int32[4]		*recommended: set four 0's.*
on_color	array of uint32[]		Each color corresponds to each of the 4 cube lights. Each color is represented as four values (red, green, blue, and alpha), in the range of 0..255.
on_period_ms	uint32[]	*ms*	The "on" duration for each of the 4 cube lights. This is the duration to show each cube light in its corresponding "on" color (in onColors).
relative_to_x	float		Should be 0.0
relative_to_y	float		Should be 0.0
rotate	boolean		? Possibly to have the colors be assigned to the next clockwise (or counterclockwise) light periodically? Should be *false*
transition_off_period_ms	uint32[]	*ms*	The time (in ms) to transition from the on color to the off color.
transition_on_period_ms	uint32[]	*ms*	The time (in ms) to transition from the off color to the on color

The MakeRelativeMode is used to indicate how Vector should align with the object. The enumeration has the following named values:

Name	Value	Description
UNKNOWN	0	
OFF	1	
BY_CORNER	2	
BY_SIDE	3	

***Table 205:** MakeRelativeMode Enumeration*

53.14.2 Response

The SetCubeLightsResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 206:** SetCubeLightsResponse JSON structure*

53.15. SET PREFERRED CUBE

"Set the robot's preferred cube and save it to disk. The robot will always attempt to connect to this cube if it is available. This is only used in simulation ~~for now~~."

Post: "/v1/set_preferred_cube"

53.15.1 Request

The SetPreferredCubeRequest structure has the following fields:

Field	Type	Units	Description
factory_id	string		The identifier of the cube to use. This is built into the cube.

***Table 207:** SetPreferredCubeRequest JSON structure*

53.15.2 Response

The SetPreferredCubeResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 208:** SetPreferredCubeResponse JSON structure*

54. DIAGNOSTICS

This section include commands intended to help diagnose trouble: checking the connection with the cloud servers; and uploading logs from Vector to help diagnose his problems.

54.1. CHECK CLOUD CONNECTION

This command is used to check the connection with the remote servers.

Post: "/v1/check_cloud_connection"

54.1.1 Request

The CheckCloudRequest has no fields.

54.1.2 Response

The CheckCloudResponse has the following fields:

Field	Type	Description
code	ConnectionCode	Whether the cloud is available, or the relevant connection error.
expected_packets	int32	The number of packets expected to have been exchanged with the cloud server.
num_packets	int32	The number of packets actually exchanged with the cloud server.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
status_message	string	

Table 209: *CheckCloudResponse JSON structure*

The ConnectionCode is used to indicate whether the cloud is available. It is used in the response to the CheckCloudConnectionRequest command. The ConnectionCode enumeration has the following named values:

Name	Value	Description
AVAILABLE	1	The cloud is connected, and has authenticated successfully.
BAD_CONNECTIVITY	2	The internet or servers are down.
FAILED_AUTH	4	The cloud connection has failed due to an authentication issue.
FAILED_TLS	3	The cloud connection has failed due to [TLS certificate?] issue.
UNKNOWN	0	There is an error connecting to the cloud, but the reason is unknown.

Table 210: *ConnectionCode Enumeration*

54.2. UPLOAD DEBUG LOGS

TBD: Request that the logs be uploaded to the server for analysis.

Post: "/v1/upload_debug_logs"

54.2.1 Request

The UploadDebugLogsRequest structure has no fields.

54.2.2 Response

The UploadDebugLogsResponse structure has the following fields:

Table 211: *UploadDebugLogsResponse JSON structure*

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
url	string	

55. DISPLAY

This section describes commands that are used to display imagery on Vector's LCD.

55.1. EVENTS

55.1.1 MirrorModeDisabled

The MirrorModeDisabled event is sent (see *Event*) "if MirrorMode (camera feed displayed on face) is currently enabled but is automatically being disabled."

The MirrorModeDisabled structure has no fields.

55.2. DISPLAY IMAGE RGB

"Sets screen (Vector's face) to" display the passed image.

Post: "/v1/display_face_image_rgb"

55.2.1 Request

The DisplayFaceImageRGBRequest structure has the following fields:

Field	Type	Units	Description
duration_ms	uint32	*ms*	"How long to display the image on the face."
face_data	bytes		The raw data for the image to display. The LCD is 184x96, with RGB565 pixels (16 bits/pixel).
interrupt_running	bool		"If this image should overwrite any current images on the face."

***Table 212:** DisplayFaceImageRGBRequest JSON structure*

55.2.2 Response

The DisplayFaceImageRGBResponse structure has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 213:** DisplayFaceImageRGBResponse JSON structure*

55.3. ENABLE MIRROR MODE

"When enabled, camera feed will appear on the robot's face, along with any detections" (if enabled).

Post: "/v1/enable_mirror_mode"

55.3.1 Request

The EnableMirrorModeRequest message has the following fields:

Field	Type	Description
enable	bool	If true, enables displaying the camera feed (and detections) on the LCD.

***Table 214:** EnableMirrorModeRequest JSON structure*

55.3.2 Response

The EnableMirrorModeResponse structure has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 215:** EnableMirrorModeResponse JSON structure*

55.4. SET EYE COLOR

This is used to set Vector's current eye color. See also section *66 Settings and Preferences*

Post: "/v1/set_eye_color"

55.4.1 Request

The SetEyeColorRequest has the following fields:

Field	Type	Description
hue	float	The hue to set Vector's eyes to.
saturation	float	The saturation of the color to set Vector's eyes to.

***Table 216:** SetEyeColorRequest JSON structure*

55.4.2 Response

The SetEyeColorResponse structure has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 217:** SetEyeColorResponse JSON structure*

56. FACES

This section describes the commands and queries related to Vector's detection of faces, and managing what he knows about them. For a description of the facial detection and recognition process, see Chapter 19 section *82 Face and Facial features recognition.*

Note: an int32 identifier is used to distinguish between faces that are seen. Each face will have a separate identifier. A positive identifier is used for a face that is known (recognized). This value will be the same when the face disappears and reappears later; the value likely persists across reboots. A negative identifier is used for face that is not recognized; as unknown faces appear and disappear they may be assigned different subsequent negative numbers. If a face becomes recognized, a RobotChangedObservedFaceID event will be sent, along with a change in identifier used.

see also section *64 On* boarding

56.1. ENUMERATIONS

56.1.1 FaceEnrollmentResult

The FaceEnrollmentResult is used to represent the success of associating a face with a name, or an reason code if there was an error. The enumeration has the following named values:

Table 218: *FacialExpression Enumeration*

Name	Value	Description
SUCCESS	0	A face was seen, its facial signature and associated name were successfully saved.
SAW_WRONG_FACE	1	
SAW_MULTIPLE_FACES	2	Too many faces were seen, and Vector did not know which one to associate with the name.
TIMED_OUT	3	
SAVED_FAILED	4	There was an error saving the facial signature and associated name to non-volatile storage.
INCOMPLETE	5	
CANCELLED	6	See Cancel Face Enrollment.
NAME_IN_USE	7	
NAMED_STORAGE_FULL	8	There was no more room in the non-volatile storage to hold another facial signature and associated name.
UNKOWN_FAILURE	9	

56.1.2 FacialExpression

The FacialExpression is used to estimate the emotion expressed by each face that vector sees. The enumeration has the following named values:

Table 219: *FacialExpression Enumeration*

Name	Value	Description
EXPRESSION_UNKNOWN	0	The facial expression could not be estimated. Note: this could be because the facial expression

		estimation is disabled.
EXPRESSION_NEUTRAL	1	The face does not appear to have any particular expression.
EXPRESSION_HAPPINESS	2	The face appears to be happy
EXPRESSION_SURPRISE	3	The face appears to be surprised.
EXPRESSION_ANGER	4	The face appears
EXPRESSION_SADNESS	5	The face appears to be sad.

56.2. EVENTS

56.2.1 FaceEnrollmentComplete

The FaceEnrollmentComplete structure has the following fields:

Table 220: *FaceEnrollmentComplete JSON structure*

Field	**Type**	**Description**
face_id	int32	The identifier code for the face.
name	string	The name associated with the face.
result	FaceEnrollmentResult	Whether or not the face enrollment was successful; an error code if not.

56.2.2 Meet Victor Face Scan Complete

The MeetVictorFaceScanComplete structure has no fields.

56.2.3 Meet Victor Face Scan Started

The MeetVictorFaceScanStarted structure has no fields.

56.2.4 RobotChangedObservedFaceID

This event occurs when a tracked (but not yet recognized) face is recognized and receives a positive ID. This happens when Vector's view of the face improves. This event can also occur "when face records get merged" "(on realization that 2 faces are actually the same)."

The RobotChangeObservedFaceID structure has the following fields:

Field	Type	Description
new_id	int32	The new identifier code for the face that has been recognized.
old_id	int32	The identifier code that was used for the face until now. Probably negative

Table 221: *RobotChangedObservedFaceID JSON structure*

56.2.5 RobotErasedEnrolledFace

The RobotErasedEnrolledFace event is sent to confirm that an enrolled face has been removed from the robot. This structure has the following fields:

Field	Type	Description
face_id	int32	The identifier code for the face; negative if the face is not recognized, positive if it has been recognized.
name	string	The name associated with the face. Empty if a name is not known.

Table 222: *RobotErasedEnrolledFace JSON structure*

56.2.6 RobotObservedFace

The RobotObservedFace event is sent when faces are observed within the field of view. This event is only sent if face detection is enabled. This structure has the following fields:

Field	Type	Description
face_id	int32	The identifier code for the face; negative if the face is not recognized, positive if it has been recognized.
expression	FacialExpression	The estimated facial expression seen on the face.
expression_values	uint32[]	An array that represents the histogram of confidence scores in each individual expression. If the expression is not known (e.g. expression estimation is disabled), the array will be all zeros. Otherwise, will sum to 100.
img_rect	CladRect	The area within the camera view holding the face.
name	string	The name associated with the face (if recognized). Empty if a name is not known.
pose	PoseStruct	The position and orientation of the face.
left_eye	CladPoint[]	A polygon outlining the left eye, with respect to the image rectangle.
mouth	CladPoint[]	A polygon outlining the mouth; the coordinates are in the camera image.
nose	CladPoint[]	A polygon outlining the nose; the coordinates are in the camera image.
right_eye	CladPoint[]	A polygon outlining the right eye; the coordinates are in the camera image.
timestamp	uint32	The time that the most recent facial information was obtained. The format is milliseconds since Vector's epoch.

Table 223: *RobotObservedFace JSON structure*

56.2.7 RobotRenamedEnrolledFace

The RobotRenamedEnrolledFace event is sent to confirm that an enrolled face has been given a new name. This structure has the following fields:

Field	Type	Description
face_id	int32	The identifier code for the face; negative if the face is not recognized, positive if it has been recognized
name	string	The name now associated with the face. Empty if a name is not known.

Table 224: *RobotRenamedEnrolledFace JSON structure*

56.3. CANCEL FACE ENROLLMENT

Cancels the request to look for a face and associate the face with a name.

post: "/v1/cancel_face_enrollment"

56.3.1 Request

The CancelFaceEnrollmentRequest structure has no fields.

56.3.2 Response

The CancelFaceEnrollmentResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 225: *CancelFaceEnrollmentResponse JSON structure*

56.4. ENABLE FACE DETECTION

This command enables (or disables) face detection, facial expression detection, blink and gaze detection. Disabling one or more of these features reduces the number of events sent by Vector, and reduces his processing overhead.

post: "/v1/enable_face_detection"

56.4.1 Request

The EnableFaceDetectionRequest structure has the following fields:

Field	Type	Description
enable	bool	If true, face detection (and recognition) is enabled; otherwise face detection processes are disabled.
enable_blink_detection	bool	If true, Vector will attempt "to detect how much detected faces are blinking." Note: the blink amount is not reported.
enable_expression_estimation	bool	If true, Vector will attempt to estimate facial expressions.
enable_gaze_detection	bool	If true, Vector will attempt "to detect where detected faces are looking." Note: the gaze direction is not reported.
enable_smile_detection	bool	If true, Vector will attempt "to detect smiles in detected faces." Note: the smile is not reported.

Table 226: *EnableFaceDetectionRequest JSON structure*

56.4.2 Response

The EnableFaceDetectionResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 227: *EnableFaceDetectionResponse JSON structure*

56.5. ENROLL FACE

This command is used to add a face to the database.

post: "/v1/enroll_face"

56.5.1 Request

The EnrollFaceRequest structure has no fields.

56.5.2 Response

The EnrollFacesResponse structure has the following fields:

Field	Type	Description
result	BehaviorResults	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 228: *EnrollFacesResponse JSON structure*

56.6. ERASE ALL ENROLLED FACES

This command is used to erase all of the known faces (and their identity).

post: "/v1/erase_all_enrolled_faces"

56.6.1 Request

The EraseAllEnrolledFacesRequest structure has no fields.

56.6.2 Response

The EraseAllEnrolledFacesResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 229: *EraseAllEnrolledFacesResponse JSON structure*

56.7. ERASE ENROLLED FACE BY ID

This command is used to erase the indentify feature (and identity) of a known face.

post: "/v1/erase_enrolled_face_by_id"

56.7.1 Request

The EraseEnrolledFaceByIDRequest structure has the following fields:

Field	Type	Description
face_id	int32	The identifier code for the face to erase.

Table 230: *EraseEnrolledFaceByIDRequest JSON structure*

56.7.2 Response

The EraseEnrolledFaceByIDResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 231: *EraseEnrolledFaceByIDResponse JSON structure*

56.8. FIND FACES

This causes Vector to look around for faces. He does this by turning in place and moving his head up and down. This is carried out by the TBD behaviour.

post: "/v1/find_faces"

56.8.1 Request

The FindFacesRequest structure has no fields.

56.8.2 Response

The FindFacesResponse structure has the following fields:

Field	Type	Description
result	BehaviorResults	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 232: *FindFacesResponse JSON structure*

56.9. REQUEST ENROLLED NAMES

This command is used to list the faces known to Vector, their names, and some other useful information.

post: "/v1/request_enrolled_names"

56.9.1 Request

The RequestEnrolledNamesRequest structure has no fields.

56.9.2 Response

The RequestEnrolledNamesRequest structure has the following fields:

Table 233: RequestEnrolledNames Response JSON structure

Field	Type	Description
faces	LoadedKnownFace[]	An array of the faces that are associated with names.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

The LoadedKnownFace structure has the following fields:

Table 234: LoadedKnownFace JSON structure

Field	Type	Units	Description
face_id	int32		The identifier code for the face.
last_seen_seconds_since_epoch	int64	*seconds*	The timestamp of the time the face was last seen. The format is unix time: seconds since 1970, in UTC?
name	name		The name associated with the face.
seconds_since_first_enrolled	int64	*seconds*	The number of seconds since the face was first associated with a name and entered into the known faces database.
seconds_since_last_seen	int64	*seconds*	The number of seconds since the face was last seen
seconds_since_last_updated	int64	*seconds*	The number of seconds since (?) the name associated with the face was last changed.(?)

56.10. SET FACE TO ENROLL

This command is can used to assign a name to unrecognized face, or to update the recognition pattern (and name) for an already known face. This command initiates a behaviour that can be configured.

post: "/v1/set_face_to_enroll"

56.10.1 Request

The SetFaceToEnrollRequest structure has the following fields:

Field	Type	Description
name	string	The name to associate with the face.
observed_id	int32	If non-zero, the identifier code for a specific observed face to enroll. Note the identifier is negative if the face is not already recognized, positive if it has been recognized. If zero, Vector will use the next face he sees.
save_id	int32	If non-zero, Vector will use this ID as the ID for the face. (Note: this must be "the ID of an existing face"). If zero, Vector will use the observedID for the ID.
save_to_robot	bool	If true, "save to robot's NVStorage when done (NOTE: will (re)save everyone enrolled!)"
say_name	bool	If true, "play say-name/celebration animations on success before completing."
use_music	bool	If true, "starts special music during say-name animations (will leave music playing!)"

Table 235: SetFaceToEnrollRequest JSON structure

56.10.2 Response

The SetFaceToEnrollResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 236: SetFaceToEnrollResponse JSON structure

56.11. UPDATE ENROLLED FACE BY ID

This command is used to change the name associated with a face.

post: "/v1/update_enrolled_face_by_id"

56.11.1 Request

The UpdateEnrolledFaceByIDRequest structure has the following fields:

Field	Type	Description
face_id	int32	The identifier code for the face.
new_name	string	The new name to associate with the face.
old_name	string	The name associated (until now) with the face. This name must match the one Vector has for the face_id. If not the command will not be honored.

Table 237: *UpdateEnrolledFaceByIDRequest JSON structure*

56.11.2 Response

The UpdateEnrolledFaceByIDResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 238: *UpdateEnrolledFaceByIDResponse JSON structure*

57. FEATURES & ENTITLEMENTS

Vector has granular features that can be enabled and disabled thru the use of feature flags. This section describes the queries related to list Vector's features flags, and their state. For a description of feature flags, see Chapter 31 *Settings, Preferences, Features, and Statistics.* For a list of the features, and a description of each, see Appendix I, *Table 636: The features.*

Note: the API does not include the ability to enable a feature.

Note: For AI behaviour "features" see section *46.2.1 FeatureStatus.*

57.1. ENUMERATIONS

57.1.1 UserEntitlement

The `UserEntitlement` enumeration has the following named values:

Name	Value	Description
KICKSTARTER_EYES	0	*Note: This was an entitlement that was explored, but not used.*

Table 239: *UserEntitlement Enumeration*

57.2. GET FEATURE FLAG

Request the current setting of a feature flag.

post: "/v1/feature_flag"

57.2.1 Request

The FeatureFlagRequest message has the following fields:

Field	Type	Description
feature_name	string	The name of the feature; this feature name should be one of those listed in response to *Get Feature Flag List* (section 57.3). See Appendix I, *Table 636: The features*

Table 240: *FeatureFlagRequest JSON structure*

57.2.2 Response

The FeatureFlagResponse type has the following fields:

Field	Type	Description
feature_enabled	bool	True if the feature is enabled, false if not
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
valid_feature	bool	True if the given feature name is a valid name of a feature; false if not.

Table 241: *FeatureFlagResponse JSON structure*

57.3. GET FEATURE FLAG LIST

Request the list of the current feature flags. Note: to see which flags are enabled, use the *Get Feature Flag* command (section *57.2*).

post: "/v1/feature_flag_list"

57.3.1 Request

The following is streamed… to the robot?

Field	Type	Description
request_list	string	

Table 242: *FeatureFlagListRequest JSON structure*

57.3.2 Response

The FeatureFlagListResponse type has the following fields:

Field	Type	Description
list	string[]	An array of the feature flags; see Appendix I, *Table 636: The features* for a description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 243: *FeatureFlagListResponse JSON structure*

57.4. UPDATE USER ENTITLEMENTS

UpdateUserEntitlements

Post: "/v1/update_user_entitlements"

57.4.1 Request

The UpdateUserEntitlementsRequest has the following fields:

Field	Type	Description
user_entitlements	UserEntitlementsConfig	

***Table 244:** JSON Parameters for UpdateUserEntitlementsRequest*

The UserEntitlementsConfig has the following fields:

Field	Type	Description
kickstarter_eyes	bool	

***Table 245:** JSON Parameters for UserEntitlementsConfig*

57.4.2 Response

The UpdateUserEntitlementsResponse type has the following fields:

Field	Type	Description
code	ResultCode	
doc	Jdoc	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 246:** UpdateUserEntitlements Response JSON structure*

58. IMAGE PROCESSING

This section describes camera setting, and properties, and retrieve pictures/video stream. See also section *56 Faces*, for detecting and recognizing faces, and enabling the features

58.1. ENUMERATIONS

58.1.1 ImageEncoding

The ImageEncoding is used to describe the format of the image data contained in the chunk. The enumeration has the following named values:

Name	Value	Description
NONE_IMAGE_ENCODING	0	Image is not encoded. TBD: does this mean no image?
RAW_GRAY	1	"No compression"
RAW_RGB	2	"no compression, just [RGBRGBRG...]"
YUYV	3	
YUV420SP	4	
BAYER	5	
JPEG_GRAY	6	
JPEG_COLOR	7	
JPEG_COLOR_HALF_WIDTH	8	
JPEG_MINIMIZED_GRAY	9	"Minimized grayscale JPEG - no header, no footer, no byte stuffing"
JPEG_MINIMIZED_COLOR	10	"Minimized grayscale JPEG – no header, no footer, no byte stuffing, with added color data."

Table 247: *ImageEncoding Enumeration*

58.2. EVENTS

58.2.1 CameraSettingsUpdate

This CameraSettingsUpdate event is sent when the camera exposure settings change. This structure has the following fields:

Field	Type	Units	Description
auto_exposure_enabled	bool		
exposure_ms	uint32	*ms*	
gain	float		

Table 248: *CameraSettingsUpdate parameters*

58.2.2 RobotObservedMotion

This RobotObservedMotion event structure has the following fields:

Table 249: RobotObservedMotion parameters

Field	Type	Units	Description
bottom_img_area	float	*area fraction*	"Area of the supporting region for the point, as a fraction of the bottom region"
bottom_img_x	int32	*pixel*	"Pixel coordinate of the point in the image, relative to top-left corner."
bottom_img_y	int32	*pixel*	"Pixel coordinate of the point in the image, relative to top-left corner."
ground_area	float	*area fraction*	"Area of the supporting region for the point, as a fraction of the ground ROI. If unable to map to the ground, area=0."
ground_x	int32	*mm*	"Coordinates of the point on the ground, relative to robot, in mm."
ground_y	int32	*mm*	"Coordinates of the point on the ground, relative to robot, in mm."
img_area	float	*area fraction*	"Area of the supporting region for the point, as a fraction of the image"
img_x	int32	*pixel*	"Pixel coordinate of the point in the image, relative to top-left corner."
img_y	int32	*pixel*	"Pixel coordinate of the point in the image, relative to top-left corner."
left_img_area	float	*area fraction*	"Area of the supporting region for the point, as a fraction of the left region."
left_img_x	int32	*pixel*	"Pixel coordinate of the point in the image, relative to top-left corner."
left_img_y	int32	*pixel*	"Pixel coordinate of the point in the image, relative to top-left corner."
right_img_area	float	*area fraction*	"Area of the supporting region for the point, as a fraction of the right region."
right_img_x	int32	*pixel*	"Pixel coordinate of the point in the image, relative to top-left corner."
right_img_y	int32	*pixel*	"Pixel coordinate of the point in the image, relative to top-left corner."
timestamp	uint	*ms*	"Timestamp of the corresponding image"
top_img_area	float	*area fraction*	"Area of the supporting region for the point, as a fraction of the top region"
top_img_x	int32	*pixel*	"Pixel coordinate of the point in the image, relative to top-left corner."
top_img_y	int32	*pixel*	"Pixel coordinate of the point in the image, relative to top-left corner."

58.2.3 VisionModesAutoDisabled

The VisionModesAutoDisabled event is "sent when vision modes [have been] automatically disabled due to the SDK no longer having control of the robot."

The VisionModesAutoDisabled structure has no fields.

58.3. CAMERA FEED

This command is used to "request a camera feed from the robot."

Post: "/v1/camera_feed"

58.3.1 Request

The CameraFeedRequest has no fields.

58.3.2 Response

The response is a stream of the following CameraFeedResponse structure. This structure has the following fields:

Table 250: *CameraFeedResponse JSON structure*

Field	Type	Description
data	bytes	The bytes of the image
frame_time_stamp	uint32	The time that the image frame was captured.
image_encoding	ImageEncoding	The data format used for the image.
image_id	uint32	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

58.4. CAPTURE SINGLE IMAGE

"Request a single image to be captured and sent from the robot" to the application

Post: "/v1/capture_single_image"

58.4.1 Request

The CaptureSingleImageRequest has the following fields:

Field	Type	Description
enable_high_resolution	bool	True if the image should be capture in high resolution; false to capture in 640x360 resolution. Default: false. *Optional*. Note: this field is only honoured in version 1.7 and later of the software.

***Table 251:** CaptureSingleImageRequest JSON structure*

58.4.2 Response

The CaptureSingleImageResponse structure has the following fields:

Field	Type	Description
data	bytes	The bytes of the image
frame_time_stamp	uint32	The time that the image frame was captured.
image_encoding	ImageEncoding	The data format used for the image.
image_id	uint32	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 252:** CaptureSingleImageResponse JSON structure*

58.5. ENABLE IMAGE STREAMING

"Toggle image streaming at the given resolution"

Post: "/v1/enable_image_streaming"

58.5.1 Request

The EnableImageStreamingRequest type has the following fields:

Field	Type	Description
enable	bool	True if Vector should send a stream of images from the camera.
enable_high_resolution	bool	True if the image should be captured in high resolution; false to capture in 640x360 resolution. Default: false. *Optional*. Note: this field is only honoured in version 1.7 and later of the software.

Table 253: EnableImageStreamingRequest JSON structure

58.5.2 Response

The EnableImageStreamingResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 254: EnableImageStreamingResponse JSON structure

58.6. ENABLE MARKER DETECTION

This enables and disables the processing of custom marker symbols and generating events when a marker symbol is seen. If enabled, when an marker symbol is see, the RobotObservedObject event will be sent.

Note: The custom marker detection may remain internally enabled, even if disabled by the SDK, "if another subscriber (including one internal to the robot) requests this vision mode be active."

Post: "/v1/enable_marker_detection"

58.6.1 Request

The EnableMarkerDetectionRequest has the following fields:

Field	Type	Description
enable	bool	If true, enable search for maker symbols, and generating events when they are detected,

Table 255: *JSON Parameters for EnableMarkerDetection Request*

58.6.2 Response

The EnableMarkerDetectionResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 256: *EnableMarkerDetection Response JSON structure*

58.7. ENABLE MOTION DETECTION

Enables detecting visual motion, and sending RobotObservedMotion events in response.

Post: "/v1/enable_motion_detection"

58.7.1 Request

The EnableMotionDetectionRequest structure has the following fields:

Field	Type	Description
enable	bool	True if RobotObservedMotion events should be sent.

Table 257: *EnableMotionDetection Request JSON structure*

58.7.2 Response

The EnableMotionDetectiontResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 258: *EnableMotionDetection Response JSON structure*

58.8. GET CAMERA CONFIG

Requests the camera calibration and exposure settings. See Chapter 19 for more information on these.

Post: "/v1/get_camera_config"

58.8.1 Request

The CameraConfigRequest has no fields.

58.8.2 Response

The CameraConfigResponse structure has the following fields:

Field	Type	Units	Description
center_x	float		"The position of the optical center of projection within the image. It will be close to the center of the image, but adjusted based on the calibration of the lens at the factory."
center_y	float		
focal_length_x	float		The "focal length combined with pixel skew (as the pixels aren't perfectly square), so there are subtly different values for x and y."
focal_length_y	float		
fov_x	float	*degree*	The full field of view along the x-axis.
fov_y	float	*degree*	The full field of view along the y-axis.
max_camera_exposure_time_ms	uint32	*ms*	The maximum duration allowed for a frame exposure.
min_camera_exposure_time_ms	uint32	*ms*	The minimum allowed duration for a frame exposure.
max_camera_gain	float		The maximum allowed camera gain setting.
min_camera_gain	float		The minimum allowed camera gain setting.

Table 259: *CameraConfigResponse JSON structure*

58.9. IS IMAGE STREAMING ENABLED

This command is used to inquire "whether or not image streaming is enabled on the robot"

Post: "/v1/is_image_streaming_enabled"

58.9.1 Request

The IsImageStreamingRequest has no fields.

58.9.2 Response

The IsImageStreamingResponse "indicates whether or not image streaming is enabled on the robot." The structure has the following fields:

Field	Type	Description
enable	bool	True if image streaming is enabled, false otherwise

Table 260: *IsImageStreamingResponse JSON structure*

58.10. SET CAMERA SETTINGS

This command is used to change the camera exposure settings.

Post: "/v1/set_camera_config"

58.10.1 Request

The SetCameraSettingsRequest has the following fields:

Field	Type	Units	Description
auto_exposure_enabled	bool		True if the camera suhould use auto-exposure mode.
exposure_ms	uint32	*ms*	The requested duration of exposure, when in manual settings.
gain	float		

Table 261: *SetCameraSettings parameters*

58.10.2 Response

The SetCameraSettingsResponse structure has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
status_string	string	

Table 262: *SetCameraSettingsResponse JSON structure*

59. INTERACTIONS WITH OBJECTS

These commands are used to interact with faces and objects. These initiate behaviours.

- Some behaviours can be assigned a tag that can be used to cancel it later.
- Some behaviours accept a parameter to modify their motion profile.
- Behaviour results value

Actions

- Actions can be assigned a tag that can be used to cancel it later.
- Action results value

See also section *46 Actions and Behaviour*, and section *53 Cube*

59.1. STRUCTURES

59.1.1 PathMotionProfile

This structure contains "all the information relevant to how a path should be modified or traversed."

Field	Type	Units	Description
accel_mmps2	float	*mm/sec*^{2}	How fast Vector should accelerate to achieve the target speed.
decel_mmps2	float	*mm/sec*^{2}	How fast Vector should decelerate to the target speed.
is_custom	bool		
dock_accel_mmps2	float	*mm/sec*^{2}	How fast Vector should accelerate when performing the docking procedure.
dock_decel_mmps2	float	*mm/sec*^{2}	How fast Vector should decelerate when performing the docking procedure.
dock_speed_mmps	float	*mm/sec*	The speed that Vector should perform the docking procedure at.
point_turn_accel_mmps2	float	*mm/sec*^{2}	How fast Vector should accelerate when turning (in place).
point_turn_decel_mmps2	float	*mm/sec*^{2}	How fast Vector should decelerate when turning (in place).
point_turn_speed_mmps	float	*mm/sec*	The speed that Vector should perform a turn (in place).
reverse_speed_mmps	float	*mm/sec*	How fast Vector should moved when backing up
speed_mmps	float	*mm/sec*	The speed that Vector should move along the path

Table 263: *PathMotionProfile JSON structure*

59.2. DRIVE OFF CHARGER

This command directs Vector to drive off his charger – if he is on the charger. This will initiate a behavior.

Post: "/v1/drive_off_charger"

59.2.1 Request

The DriveOffChargerRequest structure has no fields.

59.2.2 Response

The DriveOffChargerResponse type has the following fields:

Field	Type	Description
result	BehaviorResults	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 264: *DriveOffChargerResponse JSON structure*

59.3. DRIVE ON CHARGER

This command directs Vector to drive onto his charger – if he is not already on the charger. "Vector will attempt to find the charger and, if successful, he will back onto it and start charging. Vector's charger has a visual marker so that the robot can locate it for self-docking." This will initiate a behavior.

Post: "/v1/drive_on_charger"

59.3.1 Request

The DriveOnChargerRequest structure has no fields.

59.3.2 Response

The DriveOnChargerResponse type has the following fields:

Field	Type	Description
result	BehaviorResults	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 265: *DriveOnChargerResponse JSON structure*

59.4. GO TO OBJECT

"Tell Vector to drive to the specified object" (i.e. his cube). Note: custom objects "are not supported." This initiates an action.

59.4.1 Request

The GoToObjectRequest structure has the following fields:

Table 266: GoToObjectRequest JSON structure

Field	Type	Units	Description
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
motion_prof	PathMotionProfile		*Optional.*
num_retries	int32		The maximum number of times to attempt to reach the object. A retry is attempted if Vector is unable to reach the target object.
object_id	int32		The identifier of the object to drive to. Note: custom objects "are not supported"
distance_from_object_origin_mm	float	*mm*	"The distance from the object to stop. This is the distance between the origins. For instance, the distance from the robot's origin (between Vector's two front wheels) to the cube's origin (at the center of the cube) is ~40mm."
use_pre_dock_pose	bool		Set this to false

59.4.2 Response

The GoToObjectResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Table 267: GoToObjectResponse JSON structure

Field	Type	Description
result	ActionResult	An error code indicating the success of the action, the detailed reason why it failed, or that the action is still being carried out.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

59.5. TURN TOWARDS FACE

"Tell Vector to turn towards" the specified face. This initiates an action.

59.5.1 Request

The TurnTowardsFaceRequest structure has the following fields:

Table 268: TurnTowardsFaceRequest JSON structure

Field	Type	Description
face_id	int32	The identifier of the face to look for
id_tag	int32	This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
max_turn_angle_rad	float	Recommend value of 180°
num_retries	int32	Maximum of times to attempt to reach the object. A retry is attempted if Vector is unable to reach the target object.

59.5.2 Response

The TurnTowardsFaceResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Table 269: TurnTowardsFaceResponse JSON structure

Field	Type	Description
result	ActionResult	An error code indicating the success of the action, the detailed reason why it failed, or that the action is still being carried out.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

60. JDOCS

This section discusses the commands for "Jdocs" (short for "JSON Documents"), which are JSON objects that are passed to Vic-Engine and then onto Vic-Cloud. See the next chapter for interactions with a remote Jdocs server, using a sibling protocol.

60.1. ENUMERATIONS

60.1.1 JdocType

The JdocType enumeration has the following named values:

Table 270: JdocType Enumeration

Name	Value	Description
ACCOUNT_SETTINGS	2	Refers to the owner's account settings
ROBOT_LIFETIME_STATS	1	Refers to the robot's settings (owner preferences)
ROBOT_SETTINGS	0	Refers to the robot's lifetime stats.
USER_ENTITLEMENTS	3	Refers to the owner's entitlements.

Items of these types are described in more detail in Chapter 31.

60.2. STRUCTURES

60.2.1 Jdoc

The Jdoc type has the following fields:

Table 271: Jdoc JSON structure

Field	Type	Description
client_meta	string	Probably an empty string.
doc_version	uint64	A number used to uniquely identify changes to the setting structure, and be able to tell which ones is the more recent settings. Most often this is the number of times that the settings have been changed.
fmt_version	uint64	The version number of the jdoc structure schema; this is always 1.
json_doc	string	The jdoc structure serialized as a string.

60.2.2 NamedJdoc

The NamedJdoc type has the following fields:

Table 272: JSON NamedJdoc structure

Field	Type	Description
doc	Jdoc	The JSON structure and meta-data about the document
jdoc_type	JdocType	The type of document provided in "doc"

60.3. EVENTS

60.3.1 JdocsChanged

The JdocsChanged message is sent when a Jdoc objct has been changed. This message has the following fields:

Field	Type	Description
jdoc_types	JdocType[]	The list of Jdoc's to retrieve.

***Table 273:** JSON JdocsChanged request structure*

60.4. PULL JDOCS

This command is used to retrieve a Jdocs object.

Post: "/v1/pull_jdocs"

60.4.1 Request

The PullJdocsRequest has the following fields:

Field	Type	Description
jdoc_types	JdocType[]	Each of the retrieved Jdoc objects.

***Table 274:** JSON PullJdocsRequest structure*

60.4.2 Response

The PullJdocResponse has the following fields:

Field	Type	Description
named_jdocs	NamedJdoc[]	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 275:** JSON PullJdocsResponse structure*

61. MAPPING

61.1. THE NAVIGATION MAP FEED

This is used to request a stream of navigation map data.

Post: "/v1/nav_map_feed"

61.1.1 Request

"Requests [navigation] map data from the robot at a specified maximum update frequency. Responses in the [navigation] map stream may be sent less frequently if the robot does not consider there to be relevant new information."

The NavMapFeedRequest has the following fields:

Field	Type	Description
frequency	float	The frequency that updates to the map should be sent

***Table 276:** JSON NavMapFeedRequest structure*

61.1.2 Response

"A full [navigation] map sent from the robot. It contains an origin_id that which can be compared against the robot's current origin_id, general info about the map, and a collection of quads representing the map's content."

The NavMapFeedResponse has the following fields:

Field	Type	Description
map_info	NavMapInfo	A description of the map as a whole.
origin_id	uint32	Which version of the map this pose is in (0 for none or unknown). See Chapter 20 for a description of the mapping origin id.
quad_infos	NavMapQuadInfo[]	The individual elements of the map.

***Table 277:** JSON NavMapFeedResponse structure*

The NavMapInfo is used to describe the map as a whole. It has the following fields:

Field	Type	Units	Description
root_center_x	float	*mm*	The x coordinate of the maps center
root_center_y	float	*mm*	The y coordinate of the maps center
root_center_z	float	*mm*	The z coordinate of the maps center
root_depth	int		The depth of the quad tree: the number levels to the leaf nodes.
root_size_mm	float	*mm*	The length and width of the whole map. (The map is square).

***Table 278:** NavMapInfo JSON structure*

The NavMapQuadInfo is "an individual sample of Vector's [navigation] map. This quad's size will vary and depends on the resolution the map requires to effectively identify boundaries in the environment." It has the following fields:

Table 279: *NavMapQuadInfo structure*

Field	Type	Description
color_rgba	uint32	Suggested color for the area of the map, used when visualizing the map.
content	NavNodeContentType	A tag of what Vector has identified as located in this area.
depth	uint32	The depth within the tree.

"Every tile in the [navigation] map will be tagged with a content key referring to the different environmental elements that Vector can identify." The NavNodeContentType is used to represent the kind of environmental element.

Table 280: *NavNodeContentType Enumeration*

Name	Value	Description
NAV_NODE_UNKNOWN	0	It is not known what is in the area
NAV_NODE_CLEAR_OF_OBSTACLE	1	Vector has confirmed that an obstacle is not present in this area.
NAV_NODE_CLEAR_OF_CLIFF	2	Vector has confirmed that an obstacle is not present in this area.
NAV_NODE_OBSTACLE_CUBE	3	The cube is in this area
NAV_NODE_OBSTACLE_PROXIMITY	4	The time of flight sensor (the proximity sensor) indicates that there is an obstacle in this area.
NAV_NODE_OBSTACLE_PROXIMITY_EXPLORED	5	
NAV_NODE_OBSTACLE_UNRECOGNIZED	6	
NAV_NODE_CLIFF	7	There is a cliff here
NAV_NODE_INTERESTING_EDGE	8	
NAV_NODE_NON_INTERESTING_EDGE	9	

62. MOTION CONTROL

This section describes commands to drive Vector, and to control his lift & head position. See also section *59 Interactions with Objects*.

62.1. DRIVE STRAIGHT

This will initiate an action of Vector driving in a straight line.

Note: “Vector will drive for the specified distance (forwards or backwards) Vector must be off of the charger for this movement action. [A] that use the wheels cannot be performed at the same time; otherwise you may see a TRACKS_LOCKED error.”

62.1.1 Request

The DriveStraightRequest has the following fields:

Field	Type	Units	Description
dist_mm	float	*mm*	The distance to drive. (Negative is backwards)
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
is_absolute	uint32		If 0, turn by angle_rad relative to the current orientation. If 1, turn to the absolute angle given by angle_rad.
num_retries	int32		Maximum of times to attempt to move the head to the height. A retry is attempted if Vector is unable to reach the target angle
should_play_animation	bool		If true, “play idle animations whilst driving (tilt head, hum, animated eyes, etc.)”
speed_mmps	float	*mm/sec*	The speed to drive at. This should be positive.

Table 281: *DriveStraightRequest JSON structure*

62.1.2 Response

The DriveStraightResponse has the following fields:

Field	Type	Description
response	ActionResult	Whether the action is able to be run. If not, an error code indicating why not.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 282: *DriveStraightResponse JSON structure*

62.2. DRIVE WHEELS

Sets the speed and acceleration for Vector's wheel motors.

62.2.1 Request

The DriveWheelsRequest has the following fields:

Field	Type	Units	Description
left_wheel_mmps	float	*mm/sec*	The initial speed to set the left wheel to.
left_wheel_mmps2	float	*mm/sec*^{2}	How fast to increase the speed of the left wheel.
right_wheel_mmps	float	*mm/sec*	The initial speed to set the right wheel to.
right_wheel_mmps2	float	*mm/sec*^{2}	How fast to increase the speed of the right wheel.

***Table 283:** DriveWheelsRequest JSON structure*

To unlock the wheels, set all values to 0.

62.2.2 Response

The DriveWheelsResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 284:** DriveWheelsResponse JSON structure*

62.3. GO TO POSE

"Tells Vector to drive to the specified pose and orientation." This will initiate an action. "In navigating to the requested pose, Vector will use path planning. "Since the robot understands position by monitoring its tread movement, it does not understand movement in the z axis. This means that the only applicable elements of pose in this situation are position.x position.y and rotation.angle_z.

"Note that actions that use the wheels cannot be performed at the same time, otherwise you may see a TRACKS_LOCKED error."

Post: "/v1/go_to_pose"

62.3.1 Request

The GoToPoseRequest structure has the following fields:

Field	Type	Units	Description
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
motion_prof	PathMotionProfile		
num_retries	int32		Maximum of times to attempt to reach the pose. A retry is attempted if Vector is unable to reach the target pose.
rad	float	*radians*	The angle to change orientation to.
x_mm	float	*mm*	The x-coordinate of the position to move to.
y_mm	float	*mm*	The y-coordinate of the position to move to.

Table 285: *GoToPoseRequest JSON structure*

62.3.2 Response

The GoToPoseResponse is sent to indicate whether the action successfully completed or not. This structure has the following fields:

Field	Type	Description
result	ActionResult	An error code indicating the success of the action, the detailed reason why it failed, or that the action is still being carried out.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 286: *GoToPoseResponse JSON structure*

62.4. MOVE HEAD

Move Vector's head

62.4.1 Request

The MoveHeadRequest has the following fields:

Field	Type	Units	Description
speed_rad_per_sec	float	*radian/sec*	The speed to drive the head motor at. Positive values tilt the head up, negative tilt the head down. A value of 0 will unlock the head track.

***Table 287:** MoveHeadRequest JSON structure*

62.4.2 Response

The MoveHeadResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 288:** MoveHeadResponse JSON structure*

62.5. MOVE LIFT

Move Vector's lift

62.5.1 Request

The MoveLiftRequest has the following fields:

Field	Type	Units	Description
speed_rad_per_sec	float	*radian/sec*	The speed to drive the lift at. Positive values move the lift up, negative move the lift down. A value of 0 will unlock the lift track.

***Table 289:** MoveLiftRequest JSON structure*

62.5.2 Response

The MoveLiftResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 290:** MoveLiftResponse JSON structure*

62.6. SET HEAD ANGLE

This will initiate an action to move Vector's head to a given angle.

62.6.1 Request

The SetHeadAngleRequest has the following fields:

Field	Type	Units	Description
accel_rad_per_sec2	float	*radian/sec²*	How fast to increase the speed the head is moving at. Recommended value: 10 radians/sec²
angle_rad	float	*radians*	The target angle to move Vector's head to. This should be in the range -22.0° to 45.0°.
duration_sec	float	*sec*	"Time for Vector's head to move in seconds. A value of zero will make Vector try to do it as quickly as possible."
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
max_speed_rad_per_sec	float	*radian/sec*	The maximum speed to move the head. (This clamps the speed from further acceleration.) Recommended value: 10 radians/sec
num_retries	int32	*count*	Maximum of times to attempt to move the head to the height. A retry is attempted if Vector is unable to reach the target angle

***Table 291:** SetHeadAngleRequest JSON structure*

62.6.2 Response

The SetHeadAngleResponse has the following fields:

Field	Type	Description
response	ActionResult	Whether the action is able to be run. If not, an error code indicating why not.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 292:** SetHeadAngleResponse JSON structure*

62.7. SET LIFT HEIGHT

This will initiate an action to move Vector's lift to a given height.

62.7.1 Request

The SetLiftRequest has the following fields:

Field	Type	Units	Description
accel_rad_per_sec2	float	*radian/sec^2*	How fast to increase the speed the lift is moving at/ Recommended value: 10 radians/sec^2
duration_sec	float	*sec*	"Time for Vector's lift to move in seconds. A value of zero will make Vector try to do it as quickly as possible."
height_mm	float	*mm*	The target height to raise the lift to. Note: the python API employs a different range for this parameter
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
max_speed_rad_per_sec	float	*radian/sec*	The maximum speed to move the lift at. (This clamps the speed from further acceleration.) Recommended value: 10 radians/sec
num_retries	int32	*count*	Maximum of times to attempt to move the lift to the height. A retry is attempted if Vector is unable to reach the target height.

Table 293: *SetLiftRequest JSON structure*

62.7.2 Response

The SetLiftResponse has the following fields:

Field	Type	Description
response	ActionResult	Whether the action is able to be run. If not, an error code indicating why not.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 294: *SetLiftResponse JSON structure*

62.8. STOP ALL MOTORS

Stop all motor commands for the head, lift and wheels

62.8.1 Request

The StopAllMotorsRequest structure has no fields.

62.8.2 Response

The StopAllMotorsResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 295: *StopAllMotorsResponse JSON structure*

62.9. TURN IN PLACE

This command initiates an action to turn Vector around its current position.

Note: "Vector must be off of the charger for this movement action. Note that actions that use the wheels cannot be performed at the same time, otherwise you may see a TRACKS_LOCKED error."

62.9.1 Request

The TurnInPlaceRequest has the following fields:

Field	Type	Units	Description
accel_rad_per_sec2	float	*radian/sec^2*	How fast to increase the speed the body is moving at
angle_rad	float	*radians*	If is_absolute is 0, turn relative to the current heading by this number of radians; positive means turn left, negative is turn right. Otherwise, turn to the absolute orientation given by this angle.
id_tag	int32		This is an action tag that can be assigned to this request and used later to cancel the action. *Optional.*
is_absolute	uint32		If 0, turn by angle_rad relative to the current orientation. If 1, turn to the absolute angle given by angle_rad.
num_retries	int32	*count*	Maximum of times to attempt to turn to the target angle. A retry is attempted if Vector is unable to reach the target angle.
speed_rad_per_sec	float	*radian/sec*	The speed to move around the arc.
tol_rad	float	*count*	"The angular tolerance to consider the action complete (this is clamped to a minimum of 2 degrees internally)."

Table 296: *TurnInPlaceRequest JSON structure*

62.9.2 Response

The TurnInPlaceResponse has the following fields:

Field	Type	Description
response	ActionResult	Whether the action is able to be run. If not, an error code indicating why not.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 297: *TurnInPlaceResponse JSON structure*

63. MOTION SENSING AND ROBOT STATE

This section describes the structures and events that describe the sensed motions.

The values are given with respect to a "coordinate space is relative to Vector, where Vector's origin is the point on the ground between Vector's two front wheels. The X axis is Vector's forward direction, the Y axis is to Vector's left, and the Z axis is up."

63.1. ENUMERATIONS

63.1.1 UnexpectedMovementSide

The UnexpectedMovementSide enumeration has the following named values:

Name	Value	Description
UNKOWN	0	
FRONT	1	
BACK	2	
LEFT	3	
RIGHT	4	

Table 298: *UnexpectedMovementSide Enumeration*

63.1.2 UnexpectedMovementType

The UnexpectedMovementType enumeration has the following named values:

Name	Value	Description
TURNED_BUT_STOPPED	0	
TURNED_IN_SAME_DIRECTION	1	
TURNED_IN_OPPOSITE_DIRECTION	2	
ROTATING_WITHOUT_MOTORS	3	

Table 299: *UnexpectedMovementType Enumeration*

63.2. STRUCTURES

63.2.1 AccelData

This structure is used to report the accelerometer readings, as part of the RobotState structure. The accelerometer is located in Vector's head, so its XYZ axes are not the same as Vector's body axes. When motionless, the accelerometer can be used to calculate the angle of Vectors head. The AccelData has the following fields:

Field	Type	Units	Description
x	float	*mm/s²*	The acceleration along the accelerometers X axis.
y	float	*mm/s²*	The acceleration along the accelerometers Y axis.
z	float	*mm/s²*	The acceleration along the accelerometers Z axis.

Table 300: *AccelData JSON structure*

When at rest, there will be a constant 9810 mm/s^2 downward acceleration from gravity. This most likely will be distributed over multiple axes.

63.2.2 GyroData

This structure is used to report the gyroscope readings, as part of the RobotState structure. The gryoscope is located in Vector's head, so its XYZ axes are not the same as Vector's body axes. The GyroData has the following fields:

Table 301: *GyroData JSON structure*

Field	Type	Units	Description
x	float	*radian/s*	The angular velocity around the X axis.
y	float	*radian/s*	The angular velocity around the Y axis.
z	float	*radian/s*	The angular velocity around the Z axis.

63.2.3 ProxData

This structure is used to report the "time of flight" proximity sensor readings, as part of the RobotState structure.

proximity sensor

"The proximity sensor is located near the bottom of Vector between the two front wheels, facing forward. The reported distance describes how far in front of this sensor the robot feels an obstacle is. The sensor estimates based on time-of-flight information within a field of view which the engine resolves to a certain quality value."

The distance measurement may not be valid. The sensor may be blocked Vector's lift or the item he is carying. Or the sensor may not have picked up anything significant. These are indicated by "four additional flags are supplied by the engine to indicate whether this proximity data is considered valid for the robot's internal pathfinding." It is recommended that an application track the most recent proximity data from the robot, and the most recent proximity data which did not have the lift blocking.

The ProxData has the following fields:

Table 302: *ProxData JSON structure*

Field	Type	Units	Description
distance_mm	uint32	*mm*	The distance to the object (if any)
found_object	bool		True if "the sensor detected an object in the valid operating range."
is_lift_in_fov	bool		True if "Vector's lift (or an object in the lift) is blocking the time-of-flight sensor. While the lift will send clear proximity signals, it's not useful for object detection."
signal_quality	float		An estimate of the "reliability of the measurement." "The proximity sensor detects obstacles within a given field of view; this value represents the likelihood of the reported distance being a solid surface."
unobstructed	bool		True if "the sensor has confirmed it has not detected anything up to its max range." (The opposite of found_object)

63.2.4 TouchData

This structure is used to report the touch sensor readings, as part of the RobotState structure. The TouchData has the following fields:

Table 303: TouchData JSON structure

Field	Type	Units	Description
is_being_touched	bool		True if Vector is currently being touched.
raw_touch_value	uint32		"Raw input from the touch sensor."

63.3. EVENTS

63.3.1 RobotState

The RobotState structure is periodically posted in an *Event* message. The structure has the following fields:

Table 304: RobotState JSON structure

Field	Type	Units	Description
accel	AccelData		The accelerometer readings
carrying_object_id	int32		-1 if no object is being carried. Otherwise the identifier of the cube (or other object) being carried.
carrying_object_on_top_id	int32		*Not supported*
gyro	GyroData		The gyroscope readings
head_angle_rad	float	*radian*	The angle of Vector's head (how much it is tilted up or down).
head_tracking_object_id	int32		The identifier "of the object the head is tracking to." If no object is being tracked, this will be -1.
last_image_time_stamp	uint32		"The robot's timestamp for the last image seen." The format is milliseconds since Vector's epoch.
left_wheel_speed_mmps	float	*mm/s*	The speed of Vector's left wheel.
lift_height_mm	float	*mm*	"Height of Vector's lift from the ground."
localized_to_object_id	int32		The identifier "of the object that the robot is localized to." If no object, this will be -1.
pose	PoseStruct		"The current pose (position and orientation) of Vector."
pose_angle_rad	float	*radian*	"Vector's pose angle (heading in X-Y plane)."
pose_pitch_rad	float	*radian*	"Vector's pose pitch (angle up/down)."
right_wheel_speed_mmps	float	*mm/s*	The speed of Vector's right wheel.
prox_data	ProxData		The time-of-flight proximity sensor readings.
status	uint32		A bit map of active states of Vector; the bits are described in the RobotStatus enumeration. "This status provides a simple mechanism to, for example, detect if any of Vector's motors are moving, determine if Vector is being held, or if he is on the charger."
touch_data	TouchData		The touch sensor readings.

63.3.2 Unexpected Movement

The UnexpectedMovement structure is posted in an *Event* message when a movement is sensed, but the robot had not intended it. The structure has the following fields:

Field	Type	Description
movement_side	UnexpectedMovementSide	
movement_type	UnexpectedMovementType	
timestamp	uint32	The time that the movement was sensed. The format is unix time: seconds since 1970, in UTC.

Table 305: *UnexpectedMovement JSON structure*

64. ON BOARDING

The section describes the command and events used to introduce Vector to his new human, and his human to Vector's features.

64.1. ENUMERATIONS

64.1.1 OnboardingPhase

The OnboardingPhase enumeration has the following named values:

Name	Value	Description
InvalidPhase	0	
Default	1	
LookAtPhone	2	
WakeUp	3	
LookAtUser	4	
TeachWakeWord	5	
TeachComeHere	6	
TeachMeetVictor	7	

Table 306: *OnboardingPhase Enumeration*

64.1.2 OnboardingPhaseState

The OnboardingPhaseState enumeration has the following named values:

Name	Value	Description
PhaseInvalid	0	
PhasePending	1	
PhaseInProgress	2	
PhaseComplete	3	

Table 307: *OnboardingPhaseState Enumeration*

64.2. EVENTS

The following are events related to onboarding.

64.2.1 Onboarding

The Onboarding event is sent as different stages of the onboarding process have been completed. This structure has the following fields:

Field	Type	Description
onboarding_1p0_charging_info	Onboarding1p0ChargingInfo	
onbaording_state	OnboardingState	
onboarding_wakeup_finished	{}	This structure contains no fields.

***Table 308:** Onboarding JSON structure*

64.2.2 Onboarding1p0ChargingInfo

This structure is used to report whether Vector needs to charge, and an estimated (or recommended) duration. It is part of the Onboarding event structure. This structure has the following fields:

Field	Type	Units	Description
needs_to_charge	bool		If true, Vector needs to charge before onboarding can continue.
on_charger	bool		If true, Vector is on his charger, and there is power supplied to the charger.
suggested_charger_time	float		The estimated amount of time to charger Vector before completing the onboarding process.

***Table 309:** Onboarding1p0ChargingInfoJSON structure*

64.2.3 OnboardingState

The OnboardingState type has the following fields:

Field	Type	Description
stage	OnboardingStages	Where in the onboarding process we are

***Table 310:** OnboardingState JSON structure*

The OnboardingStages enumeration has the following named values:

Name	Value	Description
NotStarted	0	The onboarding process has not started yet.
TimedOut	1	The onboarding process has halted because an operation timed out.
Complete	3	The onboarding has completed.
DevDoNothing	4	

***Table 311:** OnboardingStages Enumeration*

64.3. ONBOARDING COMPLETE REQUEST

64.3.1 Request

The OnboardingCompleteRequest structure has no fields.

64.3.2 Response

The OnboardingCompleteResponse type has the following fields:

Field	Type	Description
completed	bool	True if the onboarding process has completed.

Table 312: *OnboardingCompleteResponse JSON structure*

64.4. ONBOARDING INPUT

Post: "/v1/send_onboarding_input"

64.4.1 Request

The OnboardingInputRequest has one (and only one) of the following fields:

Field	Type	Description
onboarding_charge_info_request	{}	This is a request for charging information; it contains no fields.
onboarding_complete_request	{}	This is a request to complete the onboarding; it contains no fields.
onboarding_mark_complete_and_exit	{}	This contains no fields.
onboarding_restart	{}	This is a request to restart the onboarding process; it contains no fields.
onboarding_skip_onboarding	{}	This is a request to skip the onboarding; it contains no fields.
onboarding_phase_progress_request	{}	This contains no fields.
onboarding_set_phase_request	OnboardingSetPhaseRequest	See below.
onboarding_wake_up_request	{}	This is a request to wake up Vector; it contains no fields.
onboarding_wake_up_started_request	{}	This contains no fields.

Table 313: *OnboardingInputRequest JSON structure*

The OnboardingSetPhaseRequest type has the following fields:

Field	Type	Description
phase	OnboardingPhase	The desired phase to be in

Table 314: *OnboardingSetPhaseRequest JSON structure*

64.4.2 Response

The OnboardingInputResponse has a status field one (and only one) of the remaining following fields (which will correspond to the one sent in the request):

Table 315: OnboardingInputResponse JSON structure

Field	Type	Description
onboarding_charge_info_response	OnboardingChargingInfoResponse	*See below*
onboarding_complete_response	OnboardingCompleteResponse	*See below*
onboarding_phase_progress_response	{}	*See below*
onboarding_set_phase_response	OnboardingSetPhaseResponse	*See below*.
onboarding_wake_up_response	OnboardingWakeupResponse	*See below*
onboarding_wake_up_started_response	OnboardingWakeupStartedResponse	
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

OnboardingChargingInfoResponse

This structure is used to report whether Vector needs to charge, and an estimated (or suggested) duration. It is part of the OnboardingInputResponse event structure. This structure has the following fields:

Table 316: OnboardingInputResponse structure

Field	Type	Units	Description
needs_to_charge	bool		If true, Vector needs to charge before onboarding can continue.
on_charger	bool		If true, Vector is on his charger, and there is power supplied to the charger.
required_charge_time	float		The estimated amount of time to charger Vector before completing the onboarding process.
status	ResponseStatus		A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Note: this structure is similar to the Onboarding1p0ChargingInfo structure. That structures is older, but retained as software had already been developed against it.

OnboardingCompleteResponse

The OnboardingCompleteResponse type has the following fields:

Table 317: OnboardingCompleteResponse JSON structure

Field	Type	Description
completed	bool	True if the onboarding has completed

ONBOARDINGPHASEPROGRESSRESPONSE

This structure is used to report how far we are in a particular phase of onboarding. It is part of the OnboardingInputResponse event structure. This structure has the following fields:

Field	Type	Units	Description
last_set_phase	OnboardingPhase		
last_set_phase_state	OnboardingPhaseState		
percent_completed	int32	%	How far we are in the phase.
status	ResponseStatus		A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 318:** OnboardingPhaseProgressResponse structure*

ONBOARDINGSETPHASERESPONSE

The OnboardingSetPhaseResponse type has the following fields:

Field	Type	Units	Description
last_set_phase	OnboardingPhase		
last_set_phase_state	OnboardingPhaseState		
status	ResponseStatus		A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 319:** OnboardingSetPhaseResponse JSON structure*

ONBOARDINGWAKEUPRESPONSE

The OnboardingWakeupResponse type has the following fields:

Field	Type	Description
charging_info	Onboarding1p0ChargingInfo	Whether or not Vector needs to charge after waking up.
waking_up	bool	True if Vector is waking up.

***Table 320:** OnboardingWakeupResponse JSON structure*

ONBOARDINGWAKEUPSTARTEDRESPONSE

The OnboardingWakeupStartedResponse type has the following fields:

Field	Type	Description
already_started	bool	True if the onboarding has completed

***Table 321:** OnboardingWakeupStartedResponse JSON structure*

64.5. ONBOARDING STATE

This command is used to request the state of the onboarding process.

Post: "/v1/get_onboarding_state"

64.5.1 Request

The OnboardingStateRequest structure has no fields.

64.5.2 Response

The OnboardingStateResponse type has the following fields:

Field	Type	Description
onboarding_state	OnboardingState	Where in the onboarding process we are.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

***Table 322:** OnboardingStateResponse JSON structure*

64.6. ONBOARDING WAKE UP REQUEST

64.6.1 Request

The OnboardingWakeUpRequest structure has no fields.

64.6.2 Response

The OnboardingWakeUpResponse type has the following fields:

Field	Type	Description
already_started	bool	True if the process of waking Vector up for onboarding has already been started.

***Table 323:** OnboardingWakeUpResponse JSON structure*

64.7. ONBOARDING WAKE UP STARTED REQUEST

64.7.1 Request

The OnboardingWakeUpStartedRequest structure has no fields.

64.7.2 Response

The OnboardingWakeUpStartedResponse type has the following fields:

Field	Type	Description
charging_info	Onboarding1p0ChargingInfo	The state of Vectors initial charging
waking_up	bool	True if TBD

***Table 324:** OnboardingWakeUpStartedResponse JSON structure*

65. PHOTOS

This section describes the commands and queries related to accessing and managing photographs (and their thumbnail images) on Vector. For a description of the photos, see Chapter 18 *Image Processing*.

65.1. STRUCTURES

65.1.1 Photo Path

The PhotoPathMessage type has the following fields:

Field	Type	Description
full_path	string	
success	bool	True if the photograph exists; otherwise, the photograph does not exist.

Table 325: *PhotoPathMessage JSON structure*

65.1.2 Thumbnail Path

The ThumbnailPathMessage type has the following fields:

Field	Type	Description
full_path	string	
success	bool	True if the thumbnail image exists; otherwise, the thumbnail does not exist.

Table 326: *ThumbnailPathMessage JSON structure*

65.2. EVENTS

65.2.1 PhotoTaken

The PhotoTaken event is sent after Vector has taken a photograph and stored it. This structure has the following fields:

Field	Type	Description
photo_id	uint32	The identifier of the photograph taken.

Table 327: *PhotoTaken JSON structure*

65.3. DELETE PHOTO

This command is used to delete a photograph and its thumbnail

Post: "/v1/delete_photo"

65.3.1 Request

The DeletePhotoRequest has the following fields:

Field	Type	Description
photo_id	uint32	The identifier of the photograph to delete.

***Table 328:** DeletePhotoRequest JSON structure*

65.3.2 Response

The DeletePhotoResponse type has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
success	bool	True if the photograph was successfully removed; otherwise there was an error.

***Table 329:** DeletePhotoResponse JSON structure*

65.4. PHOTO

This command is used to retrieve the photograph's image.

Post: "/v1/photo"

65.4.1 Request

The PhotoRequest structure has the following fields:

Field	Type	Description
photo_id	uint32	The identifier of the photograph to request.

***Table 330:** PhotoRequest JSON structure*

65.4.2 Response

The PhotoResponse type has the following fields:

Field	Type	Description
image	bytes	The data that make up the photograph's image
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
success	bool	True if the photograph was successfully retrieved; otherwise there was an error.

***Table 331:** PhotoResponse JSON structure*

65.5. PHOTOS INFO

This command is used to get the list of photographs available on Vector.

Post: "/v1/photos_info"

65.5.1 Request

The PhotosInfoRequest structure has no fields.

65.5.2 Response

The PhotosInfoResponse type has the following fields:

Table 332: *PhotosInfoResponse JSON structure*

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
photo_infos	PhotoInfo[]	An array of information about the photographs available on Vector.

The PhotoInfo type has the following fields:

Table 333: *PhotoInfo JSON structure*

Field	Type	Description
photo_copied_to_app	bool	True if the photograph has been downloaded to the application.
photo_id	uint32	The identifier of this photograph. This can be used to retrieve the thumbnail, photograph or to delete it.
thumb_copied_to_app	bool	True if the thumbnail image has been downloaded to the application.
timestamp_utc	uint32	The time that the photograph was taken. The format is unix time: seconds since 1970, in UTC.

65.6. THUMBNAIL

This command is used to retrieve the thumbnail image of a photograph.

Post: "/v1/thumbnail"

65.6.1 Request

The ThumbnailRequest structure has the following fields:

Field	Type	Description
photo_id	uint32	The identifier of the photograph to request a thumbnail for.

Table 334: *ThumbnailRequest JSON structure*

65.6.2 Response

The ThumbnailResponse type has the following fields:

Field	Type	Description
image	bytes	The data that make up the thumbnail's image
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
success	bool	True if the thumbnail was successfully retrieved; otherwise there was an error.

Table 335: *ThumbnailResponse JSON structure*

66. SETTINGS AND PREFERENCES

This section describes the commands and queries related to settings and preferences on Vector. For a description of the settings and what they mean, see Chapter 30 *Settings, Preferences, Features, and Statistics.* That chapter includes definitions for the following types:

- RobotSettingsConfig

66.1. STRUCTURES

66.1.1 AccountSettingsConfig

The AccountSettingsConfig type has the following fields:

Field	Type	Description
app_locale	string	The IETF language tag of the human companion's language preference – American English, UK English, Australian English, German, French, Japanese, etc. default: "en-US"
data_collection	boolean	True if data collection – crash logs and DAS events – are allowed to be uploaded ot the server.

Table 336: *AccountSetting JSON structure*

66.2. UPDATE SETTINGS

This command is used to update the settings on the robot.

Post: "/v1/update_settings"

66.2.1 Request

The UpdateSettingsRequest has the following fields:

Field	Type	Description
settings	RobotSettingsConfig	The settings to apply to the robot.

Table 337: *UpdateSettingsRequest JSON structure*

66.2.2 Response

The UpdateSettingsResponse type has the following fields:

Field	Type	Description
code	ResultCode	Whether or not the update was accepted and completed.
doc	Jdoc	The Jdoc with the updated settings.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 338: *UpdateSettingsResponse JSON structure*

66.3. UPDATE ACCOUNT SETTINGS

This command is used to update the account wide settings, such as opning into or out of data collection.

Post: "/v1/update_account_settings"

66.3.1 Request

The UpdateAccountsSettingsRequest has the following fields:

Field	Type	Description
account_settings	AccountSettingsConfig	The new account settings.

Table 339: *JSON Parameters for UpdateAccountSettings Request*

66.3.2 Response

The UpdateAccountsSettingsResponse type has the following fields:

Field	Type	Description
code	ResultCode	Whether or not the update was accepted and completed.
doc	Jdoc	The Jdoc with the updated settings.
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 340: *UpdateAccountSettings Response JSON structure*

67. SOFTWARE UPDATES

These commands are siblings to the OTA Update and related commands in Chapter 13 Bluetooth LE protocol. However, they differ: in some cases, less information, in others they present the same information in different ways.

67.1. ENUMERATIONS

67.1.1 UpdateStatus

The UpdateStatus enumeration has the following named values:

Name	Value	Description
IN_PROGRESS_DOWNLOAD	2	The software update is currently being downloaded.
NO_UPDATE	0	There are no software updates available.
READY_TO_INSTALL	1	The software update has been downloaded and is ready to install.

Table 341: *UpdateStatus Enumeration*

67.2. START UPDATE ENGINE

"StartUpdateEngine cycles the update-engine service (to start a new check for an update) and sets up a stream of UpdateStatusResponse events."

Post: "/v1/start_update_engine"

This command uses the same request and response structures as CheckUpdateStatus

67.3. CHECK UPDATE STATUS

"CheckUpdateStatus tells if the robot is ready to reboot and update."

Post: "/v1/check_update_status"

67.3.1 Request

The CheckUpdateStatusRequest structure has no fields.

67.3.2 Response

This is streamed set of update status. The CheckUpdateStatusResponse type has the following fields:

Field	Type	Description
expected	int64	The number of bytes expected to be downloaded
progress	int64	The number of bytes downloaded
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.
update_status	UpdateStatus	Whether the update engine is active, and where in the update process it is.
update_version	string	The version of software being updated to.

Table 342: *CheckUpdateStatusResponse JSON structure*

67.4. UPDATE AND RESTART

Post: "/v1/update_and_restart"

67.4.1 Request

The UpdateAndRestartRequest structure has no fields.

67.4.2 Response

The UpdateAndRestartResponse has the following fields:

Field	Type	Description
status	ResponseStatus	A generic status of whether the request was able to be carried out, or an error code indicating why it was unable to be carried out.

Table 343: *UpdateAndRestartResponse JSON structure*

68. HISTORICAL ODDITIES

The Github repository is interesting for the SDK commands that were *removed*. The last version of the repository for many of these commands is:

https://github.com/anki/vector-python-sdk/tree/c14082af5a947c23016111c1f73a445d8356dbf8

Some commands removed from this repository (possibly later) because they were not implemented on Vector include:

- Network statistics
- Ability to set and fetch the camera settings
- Motion observed events
- An audio stream from Vector's microphone to the SDK application

CHAPTER 16

The Web Visualization Protocol

This chapter describes the internal web visualization ("web-viz") and web-sockets interface.

69. COMMUNICATION OVERVIEW

Development builds of Vectors software include an optional web-visualization (webviz) tool, built on a web-socket interface. This protocol predates the HTTPS based protocol, which has since superseded, at least in some areas. Studying the protocol does provide some insight into the internal structures of Vectors modules.

Cavaet: This feature is not present in the production releases, nor many of the development releases. As this is a debugging tool, the schema for the data provided over the web-socket was subject to change with each software version.

The developer build includes some special URLs for listing a manifest of the control variables:

Table 344: *WebViz special URLs*

File	Description
/consolevars	A web-GUI with tabs and display features for variables broken output module grouping.
/devData.json	A table mapping the modules names to their current state; This is not included in 1.7.

It also provides an HTTP GET interface to access the control variables, and initiate functions:

Table 345: *WebViz GET URLs supported by the internal web server*

File	Description
/consolefunclist	The list of functions
/consolefunccall	The consolefunccall?func=playanimation&args=
/consolevarget	This is used to fetch the current value of a console variable
/consolevarlist	Produces a list of variables; each variable terminated with a , one per line
/dasinfo	
/daslog	
/getAppMessages	
/getinitialconfig	The web server configuration variables
/getmainrobotinfo	Serial number, linux version string, command line, robot ID, WiFi access point name, etc.
/getperfstats	

/getprocessstatus
/processstatus
/sendAppMessage
/systemctl

69.1. CONSOLE VARIABLES

The control variables are the module settings, and internal measurements. All variable names are lexical numbers, digits, and underscore – no spaces, no periods, etc. The list of console variables can be found in a few different ways:

- /consolevars is not convenient, and would required a lot of scrapping
- /consolevarlist
- /consolefunccall?func=List_Variables will provide the list of variables, their associated module, and their current value

note: the module name can have spaces; it can also be dotted, as in Major and Minor name.

69.1.1 Getting A Console Variable's Current Value

The value associated with a console variable can be fetched with an HTTP GET:

/consolevarget?key=*name_of_variable*

69.1.2 Setting A Console Variable to a Value

A console variable can be set with an HTTP GET:

/consolevarset?key=*name_of_variable*&value=*new_value*

70. WEBSOCKET OVERVIEW

From the application level the protocol is organized into as stream of module-specific JSON messages that share a common web-socket, plus some management of that stream:

- Subscribe, and unsubscribe to module-specific events
- Receiving module-specific messages from the robot
- Sending module-specific message to the robot

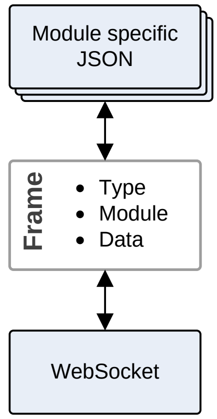


***Figure 63:** Overview of the websocket wrapper*

Before we go further we'll need to know the module identifiers. The modules differ by ports that vend their events:

***Table 346:** Module names and their ports*

Module Name	Port(s)	Description
Alexa	8889	Alexa related events
AnimationEngine	8888	Animation trigger events
Animations	8889	Events related to the start and completion of animations.
AudioEvents	8889	The starting and stopping audio
BeatDetector	8888	Events related to listening for music and its beat
Behaviors	8888	Events related to the current behavior tree
BehaviorConds	8888	Events related to the current behavior tree, and conditions
CloudIntents	8888	Events related to connecting to the cloud voice server
Cpu	8888	
CpuProfile	8888 8889	
Cubes	8888	Provides events related to the cube communication link and interaction.
Features	8888	Provides which feature toggles are enabled and disabled.
Habitat	8888	Events related to detecting the habitat (sold as "Vector Space")
HeldInPalm	8888	Events related to being held in palm; appears to be unimplemented.
IMU	8888	
Intents	8888	Events related to processing intents
MicData	8889	
Mood	8888	Events related to Vector's current emotional state (or mood).
NavMap	8888	
ObservedObjects	8888	Event related to observed faces, cubes, and other

		marked objects.
Power	8888	Changes in who is requesting Vector to enter a power save state.
Sleeping	8888	Events related to Vector's sleep behavior
SoundReactions	8888	
SpeechRecognizerSys	8889	
Touch	8888	Events related to the touch sensor
VisionScheduleMediator	8888	Events related to the management of the image processing system.

70.1. SETTING UP THE COMMUNICATION CHANNEL

The URL to connect to is:

ws://*address*:*port*/socket

Where the *address* is the address of the Vector of interest, and the *port* is the shared port for the modules of interest, given in the earlier table.

To subscribe to events from a module post the following JSON structure to the web socket:

Table 347: *Subscribing to a module's events*

Field	Type	Description
module	string	The *lower case* name of the module to subscribe to events from. See *Table 346: Module names and their ports* for the module names
type	string	"subscribe"

To unsubscribe from events from a module post the following JSON structure to the web socket:

Table 348: *Unsubscribing from a module's events*

Field	Type	Description
module	string	The *lower case* name of the module to unsubscribe to events from. See *Table 346: Module names and their ports* for the module names
type	string	"unsubscribe"

Events related to the module will come with the following structure:

Table 349: *Module event parameters*

Field	Type	Description
data	JSON	The event structure for the given module.
module	string	The name of the module to unsubscribe to events from. See *Table 346: Module names and their ports* for the module names. The module name is not guaranteed to be in lower case; any matching should be performed in a case-less fashion.

To send a request to the module, it is wrapped with:

Table 350: Posting an setting parameters

Field	Type	Description
data	JSON	The event structure for the given module.
module	string	The *lower case* name of the module to send the data to. See *Table 346: Module names and their ports* for the module names
type	string	"data"

70.2. RECEIVED EVENTS

70.2.1 Alexa State

These Alex state events have the following fields:

Table 351: Alexa state event parameters

Field	Type	Description
authState	uint	Whether or not Alexa is authenticated
uxState	uint	

These Alex state events have the following fields:

Table 352: Alexa state visualization parameters

Field	Type	Description
data		
type	string	"directive"

70.2.2 Animation Engine (AnimationEngine)

This may come before or after the animation start.

These animation engine events have the following fields:

Table 353: Animation engine event parameters

Field	Type	Description
clip	string	The name of the specific animation selected
group	string	The animation group name
headAngle_deg	float	The angle of the head
mood	string	The simple mood name (e.g. "MedStim")
trigger	string	The animation trigger name

70.2.3 Animations

This animation state event includes a *type* field that describes how to interpret the rest of the structure. The events have the following fields:

Field	Type	Description
animation	string	The name of the animation
type	string	"start" if the animation is starting. "stop" if the animation has completed.

Table 354: *Animation state event parameters*

70.2.4 Audio events

See Chapter 25 for details of the audio events. The event includes a *type* field that describes how to interpret the rest of the structure.

When an audio event is sent, the event structure has the following fields:

Field	Type	Description
eventName	string	The name of the event (or its identifier) that was sent to the audio engine.
gameObjectId	string	The identifier that the audio engine will use for the object; this identifier is expected to link to items within Vector's "game world" – his mental model.
hasCallback	boolean	
time	float	The time that this occurred at (seconds since power on)
type	string	"PostAudioEvent"

Table 355: *Audio post event parameters*

When all audio events are stopped, the event structure has the following fields:

Field	Type	Description
eventName	string	The name of the event (or its identifier) that was sent to the audio engine.
gameObjectId	string	The identifier that the audio engine will use for the object; this identifier is expected to link to items within Vector's "game world" – his mental model.
time	uint	The time that this occurred at (seconds since power on)
type	string	"StopAllAudioEvents"

Table 356: *Audio stop all event parameters*

When an audio group is set to a new state, an event structure with the following fields is sent:

Field	Type	Description
stateGroupId	string	The state group to modify
stateId		The new state that the group is being put into
time	uint	The time that this occurred at (seconds since power on)
type	string	"SetState"

Table 357: *Audio state group event parameters*

When an audio switch group is set to a new state, the event structure has the following fields:

Table 358: *Audio switch group event parameters*

Field	Type	Description
gameObjectId	string	The new state that the switch is being changed into.
switchGroupId	string	The switch being modified.
switchStateId		The new state that the switch is being put into
time	float	The time that this occurred at (seconds since power on)
type	string	"SetSwitchState"

70.2.5 Beat Detector (BeatDetector)

See Chapter 18 section *76.5 Beat Detection* for the event structures.

70.2.6 Behaviors

Todo There are two forms of events send by the behaviors module.

Can also be an array of strings. Which lists every behavior name.

When a behavior event is sent, the event structure has the following fields:

Table 359: *Behavior event parameters*

Field	Type	Description
activeFeature	string	The name of the active AI feature (given as associated ActiveFeature in the behavior node, appendix I) followed by space and "(AI)". *Optional*
debugState	string	example: driving. *Optional*
stack	string[]	An array of behavior identifiers. The last item is the current active behavior. *Optional*
time	float	The time that this occurred at (seconds since power on). *Optional*
tree	TreeNode[]	The behavior's and their parents. *Optional*

The behavior TreeNode structure has the following fields:

Table 360: *TreeNode parameters*

Field	Type	Description
behaviorID	string	The identifier for a given behavior node
parent	string	The identifier of the parent node for this behavior. Some are prefixed by an @ symbol

70.2.7 Behavior Conditions (BehaviorConds)

Note: "when the stack changes, we'll receive new conditions before receiving the stack."

When a behavior condition event is sent, the event structure has the following fields:

Table 361: *Behavior condition events parameters*

Field	Type	Description
factors	Factor[]	The current set of factors being examined. *Optional*
inactive	string	The name of condition that is now inactive. *Optional*

owner	string	The name of the owning behavior. *Optional*. Note: if factors is present, this is not.
stack	string[]	An array of behavior identifiers. The last item is the current active behavior. *Optional*
time	float	The time that this occurred at (seconds since power on)
tree	TreeNode[]	The behaviors and their parents. *Optional*

The Factor structure has the following fields:

Table 362: *Factor parameters*

Field	Type	Description
areConditionsMet	boolean	True of the conditions for the behavior were met: they have all been true
conditionLabel	string	The name of the condition
ownerDebugLabel	string	The name of the owning behavior.

70.2.8 Cloud Intent

The cloud intent event is a structure or an array of structures with the following fields:

Table 363: *Cloud event parameters*

Field	Type	Description
file	string	Path, internal to the system, to the capture debug file. Remove the leading "/data/data/com.anki.victor" to get the URL resource path. Only present if type is "debugFile". *Optional*
time	int	The time in UTC seconds
type	string	"debugFile" or …

The cloud intent event is a structure or an array of structures with the following fields:

Table 364: *Cloud event parameters*

Field	Type	Description
error	string	"Token" if there hasn't been a token passed to vector {Also write up why this is important.}
time	int	The time in UTC seconds
type	string	"error"

70.2.9 CPU

When a CPU event is sent, the event structure has the following fields:

Table 365: *CPU parameters*

Field	Type	Description
deltaTime_ms	int	The time step in milliseconds
usage	string[]	An array of processor usage stats from procstat[35], one for each processor

[35] http://www.linuxhowtos.org/System/procstat.htm

70.2.10 CPU Profile

When a CPU profile event is sent, the event structure has the following fields:

Field	Type	Description
sample	Sample[]	An array of CPU usage samples for the thread
threadName	string	The name of the thread that was measured for this CPU profile
time	float	Time stamp

Table 366: *CPU profile parameters*

The Sample structure has the following fields:

Field	Type	Description
max	float	The maximum CPU usage during the time interval
mean	float	The average CPU usage during the time interval
min	float	The minimum CPU usage during the time interval
name	string	The name of the thread that this belongs to

Table 367: *Sample parameters*

70.2.11 Cubes

Note: The Cube events are sent regardless of whether Vector is communication with his cube.

When a Cube event is sent, the event structure has the following fields:

Field	Type	Description
cccInfo	CCCInfo	*Optional*
citInfo	CitInfo	*Optional*
commInfo	CommInfo	Information about the connected cube, and the state of the connection. *Optional*

Table 368: *Cube event parameters*

The CCCInfo structure has the following fields:

Table 369: CCCInfo parameters

Field	Type	Description
connectionState	string	The state of the connection. "Unconnected" or "UnConnected"[36], "Connecting"., "ConnectedBackground", or "Interactable" or.. "ConnectedInteractable" "ConnectedSwitchingToBackground"
stateCountdown	StateCountDown[]	The time left before the temporary connection expires
subscriberData	SubscriberData[]	Information about which modules have requested which level of connection with the cube.

The CitInfo structure has the following fields:

Table 370: CitInfo parameters

Field	Type	Description
heldProbability		The probability that the cube is being held.
movedFarRecently	boolean	"Recently Moved Far, assuming is held"
movedRecently	boolean	True if the cube has recently moved; false otherwise.
NoTarget	boolean	True if the cube is not visible; false otherwise. *Optional*
targetInfo	TargetInfo	This is included if the cube is observed. *Optional*
timeSinceHeld	float	The number of seconds since the cube was last held
timeSinceMoved	float	The number of seconds since the cube was last moved
timeSinceObserved	float	The number of seconds since the cube was last observed
timeSinceTapped	float	The number of seconds since the cube was last tapped
trackingState	string	Tracking State ("Idle" "TrackingConnected)
userHoldingCube	boolean	True if someone holding the cube; false otherwise.
visibleRecently	boolean	True if the cube is visually seen; false otherwise.
visTrackingRate	string	VSM Tracking Rate Request: "High" or "Low"

The CommInfo structure has the following fields:

Table 371: CommInfo parameters

Field	Type	Description
connectedCube	string	The identifier for the cube that Vector is connected with. "(none)" if not connected with a cube.
connectionState	string	The state of the connection: "UnconnectedIdle", "PendingConnect", "Connected", "ScanningForCubes", "PendingDisconnect"
cubeData	CubeData[]	The cubes that Vector has received Bluetooth LE advertisements from.
preferredCube	string	The identifier for the cube that Vector would prefer to connect with, if available.

[36] What does this mean if there are both?

Note: this implies that Vector will try first to connect with his preferred cube, and, if necessary, fall back to the next first cube he can find.

The CubeData structure has the following fields:

Table 372: CubeData parameters

Field	Type	Description
address	string	The MAC address of the cube
lastRssi	int	The last received "received signal strength indicator" (RSSI) measurement from the cube.

The StateCountDown structure has the following fields:

Table 373: StateCountDown parameters

Field	Type	Description
DisconnectingIn		The duration before the connection will exit
SwitchingToBackgroundIn	string	

The SubscriberData structure has the following fields:

Table 374: SubscriberData parameters

Field	Type	Description
ExpiresIn		The duration before the connection will exit. This field is only present if the subscriber has included a timeout. *Optional*
SubscriberName	string	The name of the behavior (the ID) that requested this connection.
SubscriptionType	string	"Background" or "Interactable"

The TargetInfo structure has the following fields:

Table 375: TargetInfo parameters

Field	Type	Units	Description
angle	float	*degrees*	Relative angle to the cube face
distance	float	*mm*	The distance to the cube (or cube center?)
distMeasuredByProx	boolean		True if the distance to the cube as measured by the time of flight sensor.

70.2.12 Features

The features event is an array of structures with the following fields:

Table 376: Feature event parameters

Field	Type	Units	Description
default	string	*"none", "enabled", "disabled"*	Whether or not the feature is enabled or disabled by default.
name	string		The name of the AI feature
override	string	*"none", "enabled", "disabled"*	Whether or not the feature is enabled or disabled

70.2.13 Habitat

The habitat event is sent to convey information about being in, and driving around in the habitat tray. See Chapter 5 for a brief description of the habitat. The event is a structure with the following fields:

Table 377: Habitat event parameters

Field	Type	Units	Description
habitatState	string	*HabitatState*	Whether or not Vector has detected his habitat (tray). See habit state enumeration for possible values.
reason	string		"CliffDetected"
stopOnWhiteEnabled	string	*"yes", "no"*	
whiteThresholds	string		Example: "[400,400] 0 readings so far""

The HabitatState enumeration has the following possible values:

Table 378: Habitat state enumeration

State	Description
InHabitat	Vector is in the habitat area.
NotInHabitat	Vector is not in the habitat.
Unknown	Vector does not (yet) know if he is in the habitat.

70.2.14 Held In Palm

Not implemented?

70.2.15 IMU State

When an IMU state event is sent, the event structure has the following fields:

Table 379: IMU state event parameters

Field	Type	Description
fall_impact_count	uint	Fall impact count

70.2.16 Intents

The intents events can come in two different forms. In one kind, as an array of the following structure:

Table 380: Intents structure parameters

Field	Type	Description
intentType	string	"user" or "cloud"
list	string[]	A list of the intent names available for this type of intent.
type	string	"all-intents"

In the other as a structure for a single intent in response to a user interaction:

Table 381: Intents structure parameters

Field	Type	Description
intentType	string	"user"
type	string	"current-intents"

value	string		The intent from the cloud

70.2.17 Microphone data (MicData)

See also section *76.5 Beat Detection*.

The microphone data event is a structure with the following fields:

Table 382: *Microphone data event parameters*

Field	Type	Units	Description
activeState	boolean		True if a voice has been detected.
beatDetector	BeatDetector		Information about the beat(s) heard
delayTime	float	*ms*	
direction	uint		The direction to the origin of the strongest sound.
directions	uint[]		The confidence in each of the directions
latestNoiseFloor	float		A measure of the ambient noise level.
latestPowerValue	float		A measure of the most recent sound loudness
maxConfidence	int		The maximum confidence value in the directions array
selectedDirection	uint		The direction that is picked for the origin of the sound of interest.
time	float	*seconds*	The time that this occurred at (seconds since power on)
triggerDetected	boolean		True if the trigger word has been detected

The BeatDetector structure has the following fields:

Table 383: *BeatDetecto parameters*

Field	Type	Units	Description
confidence	float		How confident the analysis is in the tempo measurement.
tempo_bpm	float	*beats / minute*	The measured number of beats per minute.

70.2.18 Mood

These structures are similar to, but differ from, those in Chapter 29.

When mood event is sent, the event structure has the following fields:

Table 384: *Mood event parameters*

Field	Type	Units	Description
emotionEvent	string		The name of the event (see appendix K *Table 641: The emotion event names*). *Optional*
info	Info[]		This is sent when the event is first subscribed to. *Optional.*
moods	Mood[]		An array emotion event structures (see below).
simpleMood	string		One of the simple mood names. *Optional*
time	float	*seconds*	The time that this occurred at (seconds since power on)

The Emotion structure has following fields:

Field	Type	Description
emotionType	string	The dimension or type of emotion (“Happy”, “Confident”, “Stimulated”, “Social”, or “Trust”)
max	float	The maximum value that the dimension can take on.
min	float	The minimum value that the dimension can take on.

Table 385: *Emotion structure parameters*

The Info structure has following fields:

Field	Type	Description
emotions	Emotion[]	An array of each emotion dimension and its range of values. (Some are in the range -1..1, other are 0..1)
simpleMoods	dictionary	This dictionary maps a mood name (e.g. “Frustrated”) to a dictionary mapping emotion type (e.g. “Happy”) to a floating point value.

Table 386: *Emotion Info structure parameters*

The Mood structure has following fields:

Field	Type	Description
emotion	string	The dimension or type of emotion (“Happy”, “Confident”, “Stimulated”, “Social”, or “Trust”)
value	float	The value to add to the emotional state. The range is -1 to 1

Table 387: *Emotion affector parameters*

70.2.19 NavMap

The NavMap events are used to transfer the current navigational map, and location of items in the map. Map events won’t be sent unless the application has sent a request to enable the events. (See section *70.3.7 NavMap*)

The navigation map events include a *type* field that describes how to interpret the rest of the structure. Note: the observed object events are also sent to NavMap subscriber, to update their positions.

When the map is sent, there are several different structures: one to begin, one or more contents, and then one to end. The beginning has the following fields:

Field	Type	Description
mapInfo	MapInfo	A description of the map as a whole.
originId	uint	Which version of the map this information is for (0 for none or unknown). See Chapter 20 for a description of the mapping origin id.
type	string	“MemoryMapMessageVizBegin”

Table 388: *Map begin parameters*

The MapInfo is used to describe the map as a whole. It has the following fields:

Table 389: MapInfo structure

Field	Type	Units	Description
identifier	string		Unique name of the map version
rootCenterX	float	*mm*	The X coordinate of the maps center
rootCenterY	float	*mm*	The y coordinate of the maps center
rootCenterZ	float	*mm*	The z coordinate of the maps center
rootDepth	int		The depth of the quad tree: the number levels to the leaf nodes.
rootSize_mm	float	*mm*	The length and width of the whole map. (The map is square).

This is followed by a stream of the following structure:

Table 390: Map message parameters

Field	Type	Description
originId	uint	The generation/version of the map this information is for (0 for none or unknown). See Chapter 20 for a description of the mapping origin id.
seqNum	uint	Each part of the map transfer has a different sequence number.
quadInfos	QuadInfo[]	The individual elements of the map.
type	string	"MemoryMapMessageViz"

The QuadInfo is "an individual sample of Vector's [navigation] map. This quad's size will vary and depends on the resolution the map requires to effectively identify boundaries in the environment." It has the following fields:

Table 391: QuadInfo structure

Field	Type	Description
colorRGBA	uint32	Suggested color for the area of the map, used when visualizing the map.
content	string	A tag of what Vector has identified as located in this area. "Unknown", "ClearOfObstacle" , "ClearOfCliff", "ObstacleCube", "ObstacleCharger", "ObstacleProx", "ObstacleProxExplored", "ObstacleUnrecognized", "Cliff", "InterestingEdge", "NotInterestingEdge"
depth	uint32	The depth within the tree.

The end of the map transfer the following fields:

Table 392: Map end parameters

Field	Type	Description
originId	uint	The generation/version of the map this information is for (0 for none or unknown). See Chapter 20 for a description of the mapping origin id.
robot	Pose	The robot's position and orientation within the map.
type	string	"MemoryMapMessageVizEnd"

The Pose structure has the following fields:

Table 393: Pose parameters

Field	Type	Units	Description
qW	float		Part of the rotation quaternion
qX	float		Part of the rotation quaternion
qY	float		Part of the rotation quaternion
qZ	float		Part of the rotation quaternion
x	float		The x coordinate
y	float		The y coordinate
z	float		The z coordinate

The cube location is updated with an event with the following fields:

Table 394: Map cube location parameters

Field	Type	Description
cubes	Cube[]	A list of the cube's location and orientatios
type	string	"MemoryMapCubes"

The Cube structure has the following fields:

Table 395: Cube parameters

Field	Type	Units	Description
angle	float	*degrees*	Relative angle to the cube face
x	float	*mm*	The x coordinate
y	float	*mm*	The y coordinate
z	float	*mm*	The z coordinate

A face location is updated with an event with the following fields:

Table 396: Map face location parameters

Field	Type	Description
faceID	int	The identifier for the face that was observed
pose	Pose	The face position and orientation
type	string	"MemoryMapFace"

70.2.20 Observed Objects

The observed object event includes a *type* field that describes how to interpret the rest of the structure.

The deleted face event is sent when Vector no longer sees a given face. The structure has the following fields:

Table 397: Deleted face event parameters

Field	Type	Description
faceID	int	The identifier for the face that was removed.
type	string	"RobotDeletedFace"

The deleted object event is sent when Vector no longer sees a given object. The structure has the following fields:

Table 398: Deleted located object event parameters

Field	Type	Description
objectID	int	The identifier for the object that was removed.
type	string	"RobotDeletedLocatedObject"

This observed face event is sent while Vector sees and tracks a face in his view. The structure has the following fields:

Table 399: Observed face event parameters

Field	Type	Description
faceID	int	The identifier for the face that was observed
name	string	*Optional*
originID	uint	Which version of the map this pose is in (0 for none or unknown). See Chapter 20 for a description of the mapping origin id.
timestamp	uint	The event time stamp (milliseconds since power on)
type	string	"RobotObservedFace"

This observed object event is sent while Vector sees and tracks a face in his view. The structure has the following fields:

Table 400: Observed object event parameters

Field	Type	Description
isActive	int	1, 0
objectID	int	The identifier for the face that was observed
objectType	string	"UnknownObject", "Block_LIGHTCUBE1", "Block_LIGHTCUBE2", "Block_LIGHTCUBE3", "Block_LIGHTCUBE_GHOST", "Charger_Basic", "CustomType00", "CustomType01", "CustomType02", "CustomType03", "CustomType04", "CustomType05", "CustomType06","CustomType07", "CustomType08", "CustomType09", "CustomType10", "CustomType11", "CustomType12", "CustomType13", "CustomType14", "CustomType15", "CustomType16", "CustomType17", "CustomType18","CustomType19", "CustomFixedObstacle"
timestamp	uint	The event time stamp (milliseconds since power on)
type	string	"RobotObservedObject"

Note the code has object observed events sent on two websockets!

70.2.21 Power

The power event is a structure with the following fields (or an array of these structures):

Table 401: Power event parameters

Field	Type	Description
powerSaveEnabled	boolean	True if in power saving mode, false otherwise
powerSaveRequesters	JSON string	A string. The square bracketed and internally has a comma delimited list of the names of the modules requesting that the system go into low power state. The names are not quoted. An

			empty list is [].

70.2.22 Sleeping

The sleeping event is structure with the following fields:

Table 402: *Sleeping event parameters*

Field	Type	Units	Description
last_sleep_reason	string		Example: "Emergency", "Sleepy" *Optional*
last_wake_reason	string		Possibly: Jolted, NotInAir, PickedUp, Poked, Sound, LightsOn "NotSleepy", "Poked" *Optional*
reaction_state	string		Example: "NotReacting", "TriggerWord*" Optional*
sleep_cycle	string		"Awake", "CheckingForPerson", "Comatose", "DeepSleep", "EmergencySleep" , "GoingToCharger", "HeldInPalmSleep", "LightSleep", "Nothing", "PreSleepAnimation", "SleepOnCharger", "SleepOnPalm" *Optional*
sleep_debt_hours	float	*hours*	This goes up the longer he is active, and down as he sleeps. *Optional*

See Chapter 8 for a brief description of the sleep debt.

70.2.23 SoundReactions

See also section *70.2.23 SoundReactions*

The sound reaction event is a structure with the following fields:

Table 403: *SoundReactions event parameters*

Field	Type	Units	Description
activeState	boolean		True if a voice has been detected. False otherwise.
confidence	int		The confidence in the direction.
direction	uint		The index of the direction to the origin of the strongest sound.
isTriggered	boolean		True if sound activity (above the noise level) has been heard
latestNoiseFloor	float		A measure of the ambient noise level.
latestPowerValue	float		A measure of the most recent sound loudness
powerScore	float		A measure of how loud it is at this instance.
powerScoreAvg	float		A measure of loud it has been over the past few seconds.
powerScoreThreshold	float		This is greater than or equal to the powerScoreMinThreshold. Note: this value can be less than the latestNoiseFloor.
powerScoreMinThreshold	float		
selectedDirection	uint		The direction that is picked for the origin of the sound of interest.
time	float	*seconds*	The time that this occurred at (seconds since power on)
triggerDirection	uint		The index of the direction register when the sound activitywas most recently heard.
triggerConfidence	int		The confidence in the trigger direction.

triggerScore	float	A score given to how likely the trigger was correctly detected.

70.2.24 Speech Recognizer

The speech recognizer event is structure with the following fields (or an array of these structures):

Table 404: *Speech recognizer event parameters*

Field	Type	Units	Description
endSampleIndex	uint	*index*	
endTime_ms	uint	*ms*	
result	string		The text said, e.g. "hey vector"
notch	boolean		
playback	boolean		
score	uint		A score given to how likely the trigger was correctly detected.
startSampleIndex	uint	*index*	
startTime_ms	uint	*ms*	

70.2.25 Touch Sensor

The touch sensor event message has the following fields:

Table 405: *Touch sensor event parameters*

Field	Type	Description
calibrated	string	"yes" or "no"
count	uint	
enabled	string	"true" "false"
esn	string	The robot's electronic serial number.
osVersion	string	The version of the software running on Vector.

70.2.26 Vision Schedule Mediator

The vision schedule event message has the following fields:

Table 406: *Vision schedule mediator event parameters*

Field	Type	Units	Description
fullSchedule	Schedule[]		When the modes run and such
numActiveModes	uint	*count*	The number of vision modes that are currently enabled.
patternWidth	uint		

The Schedule structure has the following fields:

Table 407: *Schedule parameters*

Field	Type	Units	Description
offset	uint	*frames*	
updatePeriod	uint	*frames*	The number of frames between updates.

visionMode	string	The name of the vision processing step.

70.3. POSTED EVENTS

This section describes the events posted by Vector.

70.3.1 Behaviors

The following command is sent to submit a behavior. Not sure if it bypasses the condition checks.

Field	Type	Description
behaviorName	string	The name of a behavior. TBD: is the identifier?
presetConditions	boolean	Force the behavior conditions to evaluate to this; if true, the behavior has "met" its conditions

Table 408: *Behavior parameters*

70.3.2 Cubes

The following command is sent to enable and disable features on the cube:

Field	Type	Description
connectCube	boolean	Connect to the cube. *Optional*
disconnectCube	boolean	Disconnect from the cube. *Optional*
flashCubeLights	boolean	Flash the cube's lights. *Optional*
forgetPreferredCube	boolean	Forget (unpair with) the cube that Vector is currently using. *Optional*
subscribeBackground	boolean	If true, subscribe to If false, unsusbscribe. *Optional*
subscribeInteractable	boolean	If true, subscribe to events related to interacting with the cube. If false, unsusbscribe. *Optional*
subscribeTempBackground	boolean	If true, subscribe to If false, unsusbscribe. *Optional*
subscribeTempInteractable	boolean	If true, subscribe to If false, unsusbscribe. *Optional*

Table 409: *Cube control parameters*

70.3.3 Features

The feature settings can be enabled, disabled, or reset. The posted structure includes a *type* field that describes how to interpret the rest of the structure.

The following command is sent to enable or disable a feature:

Field	Type	Units	Description
name	string		The name of the AI feature to enable or disable.
override	string	*"none", "enabled", "disabled"*	Whether or not the feature should be enabled or disabled

Table 410: *Enable/disable Feature parameters*

type	string	"override"

The following command is sent to reset all of the features to their default state:

Table 411: *Reset all features parameters*

Field	Type	Description
type	string	"reset"

70.3.4 Habitat

The following command is sent to force Vector to think that he is in or out of his habitat:

Table 412: *Habitat setting parameters*

Field	Type	Description
forceHabitatState	string	The state to set the habit state to. See *Table 378: Habitat state enumeration* for possible values.

70.3.5 Intent

The following command is sent to submit an intent to AI engine:

Table 413: *Intent sensor event parameters*

Field	Type	Description
intentType	string	The name of the intent.
request	string	

70.3.6 Mood

The following command is sent to enable and disable features on the cube:

Table 414: *Mood parameters*

Field	Type	Description
Confident	float	How confident Vector is. -1…1. *Optional*
Happy	float	How happy Vector is. -1…1. *Optional*
Social	float	How social Vector is feeling. -1…1. *Optional*
Stimulated	float	How stimulated Vector is feeling. 0…1. *Optional*
Trust	float	How trusting Vector is feeling. 0…1. *Optional*

70.3.7 NavMap

The following command is sent to request an updated map:

Table 415: *NavMap parameters*

Field	Type	Description
update	boolean	True to request an updated map be sent

70.3.8 Power

The following command is sent to force Vector into (or out of) a power saving state:

Field	Type	Description
enablePowerSave	boolean	True if Vector should enter a power save state, false otherwise

Table 416: *Power save parameters*

70.3.9 Touch Sensor

The following command is sent to enable and disable the touch sensor:

Field	Type	Description
enabled	string	"true" to enable the touch sensor. "false" to disable the touch sensor. *Optional*
resetCount	string	"true" to reset the touch count. *Optional.*

Table 417: *Touch sensor control parameters*

CHAPTER 17

The Cloud Services

This chapter describes the remote servers that provide functionality for Vector.

- JSON document storage server
- The crash uploader
- The diagnostic logger
- The token/certificate system
- The natural language processing

71. CONFIGURATION

The server URLs are specified in

`/anki/data/assets/cozmo_resources/config/server_config.json`

The path to this JSON file is hardcoded in `vic-cloud`

Table 418: *The cloud services configuration file*

Element	Description & Notes
appkey	A base64 token used to communicate with servers. "oDoa0quieSeir6goowai7f"
check	The server to use for connection checks
chipper	The natural language processing server
jdocs	The remote JSON storage server
logfiles	The server to upload log files to
tms	The token server where Vector gets authentication items like certificates and tokens

The URL to upload crash logs to is given in

`/anki/etc/vic-crashuploader.env`

The URL to automatically download OTA files from is given in

`/anki/etc/update-engine.env`

The DAS server to contact is given in

`/anki/data/assets/cozmo_resources/config/DASConfig.json`

(This path is hardcoded in `vic-DASMgr`)

72. JDOCS SERVER

The Vic-Cloud services stores information on a "JDocs" server. This unusual name appears to be short for "JSON Documents." Vic-Cloud uses the "jdocs" tag in the cloud services configuration file to know which server to contact. It uses the file

/anki/data/assets/cozmo_resources/config/engine/jdocs_config.json

to set how often it contacts the server. (The path to this JSON file is hardcoded in libcozmo_engine.) The configuration also lists the base name of the json file (without the .json extension) used to store the jdoc file locally.

The interactions are basic: store, read, and delete a JSON blob by an identifier. The description below[37] gives the JSON keys, value format. It is implemented as gRPC/protobuf interaction over HTTP.

72.1. JDOCS INTERACTION

The JDoc message has the following fields:

Field	Type	Description
client_meta	string	Probably an empty string.
doc_version	uint64	A number used to uniquely identify changes to the setting structure, and be able to tell which ones is the more recent settings. Most often this is the number of times that the settings have been changed.
fmt_version	uint64	The version number of the jdoc structure schema; this is always 1.
json_doc	string	The jdoc structure serialized as a string.

***Table 419:** JSON Parameters for JDoc request*

[37] The protocol was specified in Google Protobuf. Vic-Cloud and Vic-Gateway were both written in Go. There is enough information in those binaries to reconstruct significant portions of the Protobuf specification in the future.

72.2. DELETE DOCUMENT

72.2.1 Request

The DeleteDocReq request message has the following fields:

Field	Type	Description
account	string	The account to read from
doc_name	string	The name of the document to delete.
thing	string	The thing id is a 'vic:' followed by the serial number

***Table 420:** JSON Parameters for JDoc request*

72.2.2 Response

The DeleteDocResp response message has the following fields:

Field	Type	Description
latest_version	uint64	The current version of the document in the repository.
status	string	

***Table 421:** JSON Parameters for JDoc request*

72.3. ECHO TEST

72.3.1 Request

EchoReq

- data

72.3.2 Response

EchoResp

- data

72.4. READ DOCUMENTS

72.4.1 Request

The ReadDocsReq request message has the following fields

Field	Type	Description
account	string	The account to read from
items	[]	Array of names document names(?)
thing	string	The thing id is a 'vic:' followed by the serial number

Table 422: *JSON Parameters for JDoc read request*

72.4.2 Response

ReadDocsResp

- items

The ReadDocsResp response message has the following fields:

Field	Type	Description
items	ReadDocsReq_item[]	The documents (?)

Table 423: *JSON Parameters for JDoc read response*

72.5. READ DOCUMENT ITEM

72.5.1 Request

The ReadDocsReq_Item request message has the following fields

Field	Type	Description
doc_name	string	The name of the document to request
my_doc_version	UInt64	The version to retrieve(?)

Table 424: *JSON Parameters for JDoc read item request*

72.5.2 Response

The ReadDocsResp_Item response message has the following fields:

Field	Type	Description
doc	JDoc	The document structure.
status	string	

Table 425: *JSON Parameters for JDoc read item response*

72.6. WRITE DOCUMENT

72.6.1 Request

The WriteDocReq request message has the following fields

Field	Type	Description
account	string	The account to write to
doc	JDoc	The document structure.
doc_name	string	The name of the document to write.
thing	string	The thing id is a 'vic:' followed by the serial number

Table 426: *JSON Parameters for JDoc write request*

72.6.2 Response

The WriteDocResp response message has the following fields:

Field	Type	Description
latest_doc_version	uint64	The current version of the document in the repository.
status	string	

Table 427: *JSON Parameters for JDoc write response*

72.7. OTHER AREAS

The vic-cloud service and the remove server perform periodic performance tests to check latency of the DNS servers and cloud data servers.

73. NATURAL LANGUAGE PROCESSING

The audio after a "Hey Vector" is sent to servers for processing. They send a response back, in the form of an *intent*. This is a code and a structure that represents an action to carry out in response to the spoken request, query, or statement; it may represent the action requested, an answer to a query, or an action that emotionally responds to what was said. The intents received are listed in the "Cloud Intent" column in Appendix J, *Table 640: Mapping of different intent names*.

73.1.1 Response

The request sent to the server has the following fields

Field	Type	Description
session	string	Weirdo hex line thing
type	string	e.g. "streamOpen"

***Table 428:** Parameters for ASR request*

Not sure where the stream open goes. Does it upload the file, or live stream it?

73.1.2 Response

The server response message has the following fields

Field	Type	Description
intent	string	The type of intent
metadata	string	This can be an empty string, but it can also be a string with colon delimited parameters. It often has the pattern "text: unquoted-string confidence: float handler: LEX" The "text:" can be followed by transcription of the spoken text, the "confidence:" followed by a floating point number representing how confident the speech-to-text engine is in the transcription.
parameters	JSON string	This is a string containing the JSON serialization of the intent parameters.
type	string	e.g. "result"

***Table 429:** Parameters for ASR response*

73.2. PARAMETERS FOR THE CLOUD INTENTS

The following are the parameters for each of the cloud intents. These structures are serialized as a JSON string and passed in the parameters field of the ASR response.

This intent_clock_settimer_extend intent has the parameter following fields:

Field	Type	Units	Description
timer_duration	int	*seconds*	The number of seconds to set the timer to.

***Table 430:** intent_clock_settimer_extend parameters*

This intent_global_delete_extend intent has the parameter following fields:

Field	Type	Units	Description
entity_behavior_deletable	bool		

***Table 431:** intent_global_stop_deletable parameters*

This intent_global_stop_extend intent has the parameter following fields:

Field	Type	Units	Description
entity_behavior_stoppable	bool		

Table 432: intent_global_stop_extend parameters

This intent_imperative_eyecolor_extend intent has the parameter following fields:

Field	Type	Units	Description
eye_color	string		The name of the color to set the eye color to

Table 433: intent_imperative_eyecolor_extend parameters

This intent_imperative_volumelevel_extend intent has the parameter following fields:

Field	Type	Units	Description
volume_level	string		

Table 434: intent_imperative_volumelevel_extend parameters

This intent_knowledge_response_extend intent has the parameter following fields:

Field	Type	Description
answer	string	The text to be spoken
answer_type	string	"NoResultCommand"
query_tyext	string	The text of the question asked

Table 435: intent_knowledge_response_extend parameters

This intent_message_playmessage_extend intent has the parameter following fields:

Field	Type	Units	Description
given_name	string		The name of the person to send the message to

Table 436: intent_message_playmessage_extend parameters

This intent_names_username_extend intent has the parameter following fields:

Field	Type	Units	Description
username	string		The name of the user

Table 437: intent_names_username_extend parameters

This intent_photo_take_extend intent has the parameter following fields:

Field	Type	Units	Description
entity_photo_selfie	string		Empty string if taking a photo, "photo_selfie" if taking a selfie.

Table 438: intent_photo_take_extend parameters

This intent_weather_extend intent has the parameter following fields:

Field	Type	Units	Description
condition	string		The current weather conditions. One of "Clear", "Cloudy", "Cold", "Rain", "Snow", "Stars", "Sunny", "Thunderstorms", or "Windy"
is_forecast	string	*"false" or "true"*	"false" if it is the current weather conditions; "true" if forecasted weather conditions.
local_datetime	string		The local time (where the weather conditions apply) in UTC ISO 8601 format.
speakable_location_string	string		The location name that Vector could employ in his verbal description of the temperature.
temperature	string	*degrees*	The current or forecasted temperature, in the given units.
temperature_unit	string		F or C, for the units

Table 439: *intent_weather_extend parameters*

74. LOGS AND TRACE DATA

There are 4 log uploading systems

- Two log uploaders
- A crash minidump log uploader
- DAS event logs upload

74.1. LOG UPLOADER

Vector has two different log uploaders:

74.1.1 vic-log-upload

vic-log-upload sends logs to an Amazon S3 server, with the bucket information in the server-config.json file. See chapter 33, section *145.3 Gathering logs, regularly* for more details on this file.

74.1.2 vic-logmgr-upload

This section describes how logs are uploaded by vic-logmgr-upload. That program is not called. See chapter 33, section *145.2 Vic-logmgr-upload* for more details.

The logs are uploading by performing a HTTP PUT to the server. The URL is the "logfiles" URL in the server configuration file, with a file name of the form:

victor-*electronic serial number*-*timestamp*-*pid*.log.gz

Where the time stamp has the following format:

year-month-day-hour-minute-seconds

The HTTP headers are:

HTTP header	Description
Anki-App-Key	The appKey from the server configuration file.
Usr-RobotESN	Vector's serial number
Usr-RobotOSRevision	The OS revision string from /etc/os-version-rev
Usr-RobotOSVersion	The OS version string from /etc/os-version
Usr-RobotRevision	The Anki revision string from /anki/etc/revision
Usr-RobotTimestamp	The time of Vector's internal clock.
Usr-RobotVersion	The Anki version string from /anki/etc/version
Usr-Username	

***Table 440:** Log upload HTTP header fields*

74.2. CRASH UPLOADER

Minidumps produced after a crash are uploaded to a backtrace.io server using a HTTP POST by the vic-crashuploader program. The HTTP headers are:

Form fields	Description
attachment_messages.log	The ".log" file associated with the minidump. This is optional; only included if /run/das_allow_upload exists
hostname	${hostname}
robot.esn	Vector's serial number
robot.os_version	The OS version string from /etc/os-version
robot.anki_version	The Anki version string from /anki/etc/version
upload_file	The minidump ".dmp" file

***Table 441:** Crash upload form fields*

The URL (including the key) is set in the vic-crashuploader configuration file. See chapter 33 section *145.7 Crash Logs* for more details on vic-crashuploader and how minidumps are acquired.

74.3. DAS MANAGER

DAS Manager uploads event traces to an Amazon "Simple Queue Service" (SQS) server, with the blobstore specified in the "logfiles" field of the server_config.json configuration file. Amazon's API uses the following key/value pairs in a URL encoded form:

***Table 442:** DAS Manager SQS key-value pairs*

Keys	Value
Action	SendMessage
MessageAttribute.1.Name	DAS-Transport-Version
MessageAttribute.1.Value.DataType	Number
MessageAttribute.1.Value.StringValue	2
MessageAttribute.2.Name	Content-Encoding
MessageAttribute.2.Value.DataType	String
MessageAttribute.2.Value.StringValue	gzip, base64
MessageAttribute.3.Name	Content-Type
MessageAttribute.3.Value.DataType	String
MessageAttribute.3.Value.StringValue	application/vnd.anki.json; format=normal; product=vic
MessageBody	
Version	2012-11-05[38]

Note: there may be a body of compressed JSON data. These values are hardcoded in vic-dasmgr and libcozmo_engine. The URL is set in the vic-dasmgr configuration file.

Each entry of the upload JSON data includes a profile id; it can be tied to the user account, but

> Unless you create an account and log in, Analytics Data is stored under a unique ID and not connected to you.

See Chapter 33, section *147.2 DAS* for more information on the DAS events and configuration file.

75. REFERENCES AND RESOURCES

Davis, Jason; *File Attachments in Backtrace*, Backtrace.io
https://help.backtrace.io/en/articles/1852523-file-attachments-in-backtrace

[38] This date is very far in the past, before Vector or Cozmo were developed. This was the time frame of the Overdrive product development.

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PART IV

Advanced Functions

This part describes items that are Vector's primary function.

- AUDIO INPUT. A look at Vector's ability to hear spoken commands, and ambient sounds.
- IMAGE PROCESSING. Vector vision system is sophisticated, with the ability to recognize marker, faces, and objects; to take photographs, and acts as a key part of the navigation system.
- MAPPING, NAVIGATION. A look at Vector's mapping and navigation systems
- ACCESSORIES. A look at Vector's home (charging station), companion cube and custom objects.

drawing by Steph Dere

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CHAPTER 18

Audio Input

This chapter describes the sound input system:

- The audio input
- The audio filtering, and triggering of the speech recognition

76. AUDIO INPUT

The audio input is used to both give Vector verbal interaction, and to give him environmental stimulation:

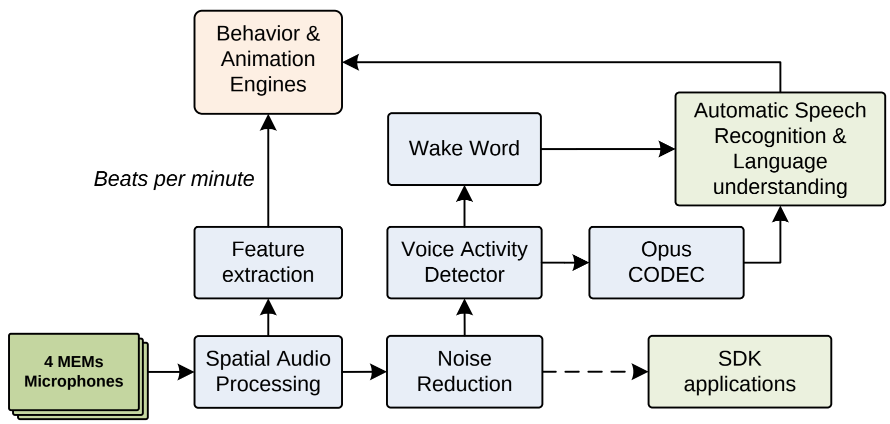


Figure 64: *The audio input functional block diagram*

- Spatial audio processing localizes the sound of someone talking from the background music.
- The feature extraction detects the ambient activity, and the tempo of the music. If the tempo is right, Vector will dance to it. This also provides basic stimulation to Vector.
- Noise reduction makes for the best sound.
- Voice activity detector usually triggered off of the signal before the beam-forming.
- A wake word is used to engage the automatic speech recognition system. *Note: the wake word is also referred to as the trigger word.*
- A CODEC is used to compress the audio before sending it to the remote server; Alexa Voice Services use the Opus audio CODEC.
- The speech recognition system is on a remote server. The audio sent to the automatic speech recognition system is compressed to reduce data usage.

The responsibility for these functions is divided across multiple processes and boards in Vector:

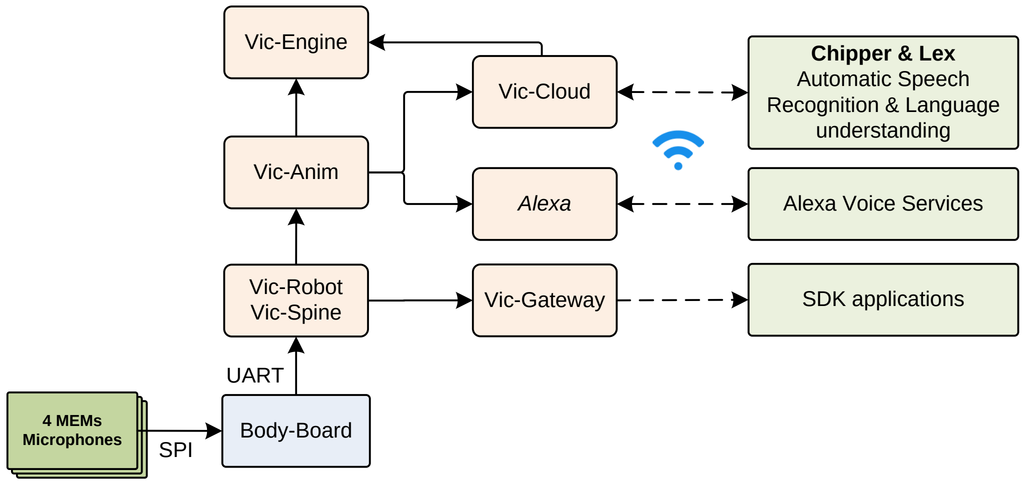


***Figure 65:** The audio input architecture*

Note: providing the audio input to the SDK (via Vic-gateway) was never completed. It will be discussed based on what was laid out in the protobuf specification files.

The audio processing blocks, except where otherwise discussed, are part of Vic-Anim. These blocks were implemented by Signal Essence, LLC. They probably consulted on the MEMs microphones and their configuration. Although the Qualcomm family includes software support for these tasks, as part of the Hexagon DSP SDK; it is believed that Signal Essence did not take advantage of it.

76.1. THE MICROPHONES AND CONVERSION TO AUDIO SAMPLES

microphone array architecture

The microphone array is 4 far-field MEMs PDM microphones that sample the incoming sound and transfer the samples to body-board. (See Chapter 4 section *11.4.6 PDM Microphones* for a description of the low-level bit-moving.)

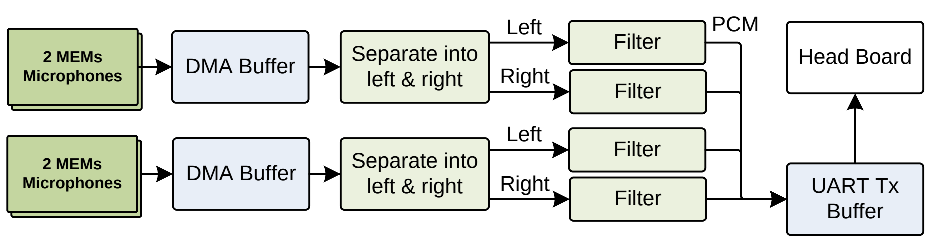


***Figure 66:** Sampling the microphones and converting to PCM format*

The body-board samples each microphone at 1.5 M samples/sec – but at only 1 bit/sample! It passes the stream of samples thru a filter, produces audio at 15,625 samples/sec, with 16 bits/sample (effectively it may have anything in the range 10 to 16 bits, and padding out the rest). The filter also acts as a low pass filter, removing high frequency sampling artifacts. The most important part is that it preserves "phase information" so that the beam forming and direction finding steps work well. (More on this in a later section).

The audio samples are transferred to the Vic-spine module (part of Vic-robot) in regular communication with the head-board. The message from the body-board to the head board for sending 4 channels of audio samples includes 80 samples per channel (320 samples total).

The samples are extracted from the received message and forward to the Vic-Anim process. The software treats the audio as if it its sample rate was 16,000 samples/sec. ("As a result, the pitch is altered by 2.4%.") The signal processing is done in chunks of 160 samples.

76.1.1 The likely operation

transferring 4Mb/s from 4 microphones and filtering it into PCM audio

Each SPI is configured to run at 3Mb/s (the slowest it can drive the microphones), using a DMA to transfer data into a buffer (~1536 bytes in size). The DMA's are configured to use *circular mode*, where they never stop; instead they automatically wrap around to the start of the buffer after filling it. Because both SPI's are tied together, only one DMA is configured to generate interrupts.

The input system triggers the SPIs to start gathering the data into their respective buffers. After that:

1. When the DMA has filled half of the buffer, it generates an interrupt. The filtering on all four channels is initiated for this half of the buffer, puts the result into the outgoing message buffer.
2. When the DMA has filled the second half of the buffer, it generates and end of transfer interrupt. The filtering on all four channels is initiated for this second half of the buffer, again putting the result into the outgoing message buffer. (In the mean time, the DMA has automatically looped back to the start of buffer and kept the SPI transferring the bits.)
3. If the outgoing buffer is full (i.e., after the DMA buffers have been filled twice), the UART transmit is initiated.

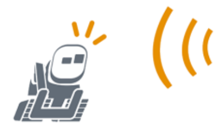
It is possible that the firmware uses two buffers, one that is filled by the filtering, and another that is sending data on the UART, and swapping every time it's filled. It is more likely that only that the body-board *fills the same output buffer as data is being sent from it to the head-board,* to save on memory usage. Although the SPI is 2-3x faster than the UART, the filter stage takes 6 bits for every for every data bit that is sent to the head board. The UART can effectively send data at least 2x faster than the SPIs receive.

- Each microphone is driven at 1.5 M samples/sec (half the SPI clock frequency). The ratio between this input sample rate and the output sample rate (15,625) – called the *decimation* – is 96:1.
- Since it takes 96 input samples (bits) to get one output 16-bit sample[39], the bit-rate reduction is 6:1.

Altogether the audio sampling, filtering/decimation, and sending to the head-board uses at least 4KB of the MCU's 8KB of RAM.

[39] The filtering may give the audio samples an effective range ~11 or 12 bits. The Customer Care Information Screen (CCIS) shows the microphones to be about 1024 when quiet.

76.2. SPATIAL AUDIO PROCESSING



The spatial audio processing uses multiple microphones to pick-out the desired sound signal and cancel out the unwanted. Note: The spatial audio processing is bypassed until voice activity has been detected. The direction finding can isolate the audio from 12 different directions, each 30° wide:

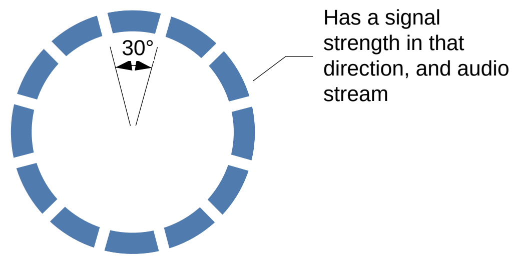


Figure 67: *The audio can be isolated into one of 12 different directions*

Note: forward is 0°.

The direction finding and isolation is typically a two-stage process:

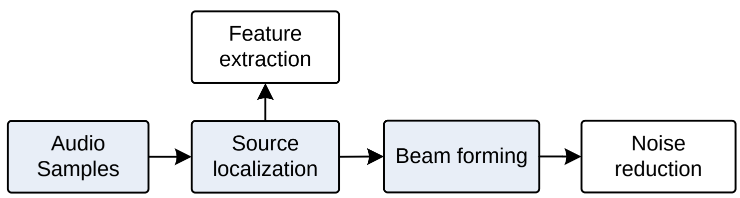


Figure 68: *Typical spatial audio processing flow*

THE SOURCE LOCALIZATION estimates direction of arrival of the person talking.

BEAM-FORMING combines the multiple microphone inputs to cancels audio coming from other directions.

The output of this stage includes:

- A histogram of the directions that the sound(s) in this chunk of audio came from. There are 12 bins, each representing a 30° direction.
- A measure of the background noise
- The direction that is picked for the origin of the sound of interest
- A confidence value for that direction
- The sound stream isolated for the picked direction, in the form of 160 16-bit PCM audio samples.

See also:

- Chapter 15, section *50.5 Audio Processing Mode* for a potential method to enable and disable the spatial sound processing;
- Chapter 15, section *50.4 Audio Feed (from the Microphones)* for potential access to the audio stream via the HTTPS API.

76.3. NOISE REDUCTION

Noise reduction identifies and eliminates noise and echo in the audio input:

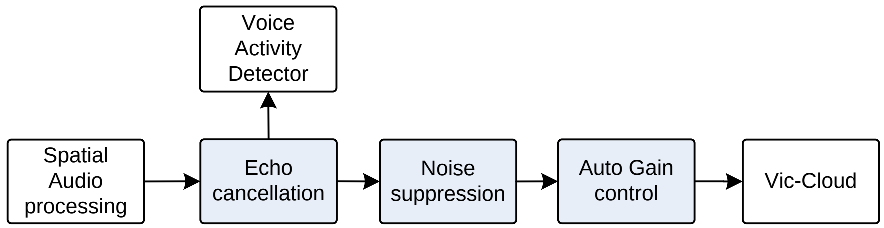


Figure 69: *Typical audio noise reduction flow*

ACOUSTIC ECHO CANCELLATION cancels slightly delayed repetitions of a signal.

NOISE SUPPRESSION is used to eliminate noise.

The combination of spatial processing and noise reduction gives the cleanest sound (as compared with no noise reduction and/or no spatial processing).

Vector is also likely to ignore the microphones while sounds are playing.

76.4. DETECTING ACTIVITY

Vector includes a module to detect sound activity (as distinguished from noise). The sound reaction behavior uses this to stimulate Vector from his sleep, get his attention, and encourage him to be more active. One way this could be done is through a set of filters to measure power levels:

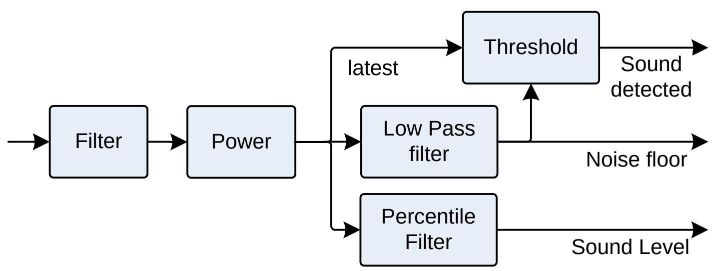


Figure 70: *Sound and noise level estimator, and activity detector*

The TBD {loudness estimator} might use an algorithm similar to the following steps:

1. First, the sound filter is to make the sound better reflect how our ears hear it, and/or remove elements that would cause false triggers. Two popular approaches are "equal loudness" by David Robinson and "a-weighting." Both take into account how people perceive sounds loudness by giving less weight to some frequencies regions (the very low and high), and more weight to others (the very middle).
2. Every few tens or hundreds of milliseconds the "power" level of the sound is computed. This is the logarithm of the root mean square (RMS) of the filtered values –squaring each value, averaging that, taking the square root and then computing its logarithm. Often this calculation is rearrange to be a bit faster, by skipping the square root and adjusting the logarithm scaling factor.
3. The computed power can then be compared against an estimate of the noise floor (the generic ambient sound level), to see if there is some activity, even the beat of a music.
4. The power levels are also tracked for a second (or a few seconds). The values could be averaged. Or the values could be sorted, from smallest to largest. The first value ~95% of

the way into the sorted before could be used as the current overall sound level. (This avoids taking the loudest transient sound.).

The noise floor could be taken from the lowest value in the sorted array (step 4) – or the value that is, say, 5% into the array can be treated as the noise floor. Or it could be estimated by taking a low pass filter on the lowest values. The key is that so even though the sound level is increasing, the noise level is it is slow move up. A low pass filter has the advantage of not taking a large amount of memory – using a large the percentile filter window (and using the lowest value in it) would take much more memory to prevent confusing several minutes of music with silence.

76.5. BEAT DETECTION

The details of how Vector's beat detection is implemented are not known, but beat detection is a common signal processing task. This section describes a typical implementation.

The beat detection is made of two related sub-functions. The first is a fast detector that can be used for quick dance responses in time to the music. The second finds the tempo – the beats per minute – of the music, which is also good indication that there is music playing (and not other activity).

Note: See chapter 25, section *111.1.1 Pitch tracker* for how to find the pitch.

76.5.1 A quick beat-detector

A simple responsive beat detector works by filtering the sound thru a band pass filter (say with a range of 100 Hz to 350 Hz) and then look for the magnitude to above a threshold:

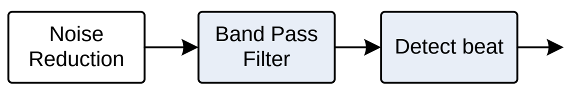


Figure 71: *Typical beat detection*

Once a beat is detected, it holds off sending another event until the signal has dropped below a threshold for at least half a second or more. Another timer may be used to tell when the music has stopped: the timer is reset whenever a new beat is detected, and expires if a beat has not been detected for a few seconds.

Although simple to implement, loud noises can trick it, and it is not very good at measuring the tempo (the speed of the music in beats per second).

76.5.2 Tempo

A more accurate approach is to use a spectrogram to measure the tempo. The beats are very low frequency signals in the spectrograph. Music might be in the range of 50-110bpm (0.7Hz to 2Hz). The approach is to search the spectrogram in this frequency range for signals above a minimum threshold (to screen out generic sounds), and pick the strongest.

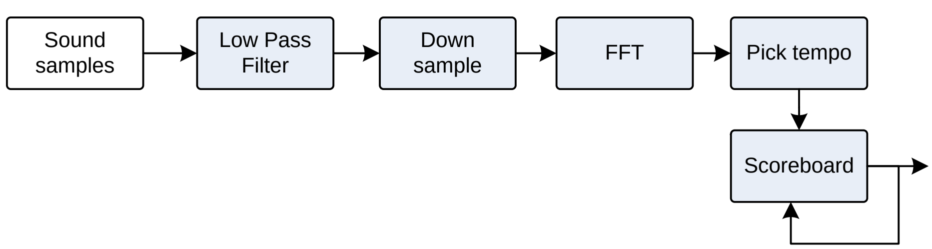


Figure 72: *Typical tempo measurement*

This will use an FFT to compute the spectrogram. It will need a wide window – a few seconds wide – to detect the beats, since they are at such a low frequency. This is down-sampled to s lower sampling rate – this reduces the memory required, and the amount of computation required to fit the task at hand. The basic algorithm is:

1. Take the sound input, and perform a low pass filter in it; this eliminates aliasing noises that can come down-sampling
2. Next is to down sample the audio to only a few samples per second, and hold the results in a window a few seconds wide.
3. Periodically – every few seconds – an FFT is performed to create a new spectrograph. Note: the window can be "rolling" (instead of being thrown out and repopulated each time) to allow faster updates to the measured beats.
4. The FFT results are examined to find frequencies with a power above a threshold. These are the potential beats (in Hz)
5. The beats are then tracked in a scoreboard. The scoreboard tracks which beats are consistent and which are transitory. The beat-rates that haven't been heard in a while are discounted or cleared out with time.
6. A tempo, perhaps the highest persistent beats/minute, is then reported as the most likely rate.

The drawback of this approach is that is "slow" and can't be used to dance in time to the music with. The time window to find slower beats (the ones about every second) is very long, it can take a few seconds before it will have anything about the music beats.

76.5.3 Beat Detector Outputs

The beat detection modules produce several JSON structures for developer websocket and internal use. The main structure has the following fields:

Table 443: *Beat detection event parameters*

Field	Type	Units	Description
beatInfo	BeatInfo[]		Information on the beat (or different possible tempos present in the music)
detectorInfo	DetectorInfo		Information from the detector on the beats

The DetectorInfo structure has the following fields:

Table 444: *DetectorInfo parameters*

Field	Type	Units	Description
beatDetected	boolean		True if a beat has just been detected.
latestConf	float		How confident the analysis is in the tempo measurement.
latestTempo_bpm	float	*beats / minute*	The measured number of beats per minute.
possibleBeatDetected	string	*"yes" or "no"*	Whether or not a potential music beat was detected.

The BeatInfo structure has the following fields:

Field	Type	Units	Description
aboveThresh	boolean		Are the beats per minute above a threshold??
conf	float		How confident the analysis is in the tempo measurement.
tempo_bpm	float	*beats / minute*	The measured number of beats per minute.
timeSinceBeat	float	*seconds*	The number of seconds since the last beat; this can useful for deciding that the music has stopped.

***Table 445:** BeatInfo parameters*

76.6. RECORDING TO A FILE

The microphone module can store sound – either raw or processed – to a wave file. This may be for diagnostic purposes, left over as part of testing different microphone settings.

76.7. VOICE ACTIVITY DETECTOR AND WAKE WORD

The voice activity detector is given cleaned up sound from multiple microphones without beam-forming. When it detects voice activity, then the spatial audio processing is fully enabled.[40] Detecting that speaking is going on is more refined and specific than simply detecting that there is some interesting sound.

The voice activity detector and the wake word are used so that downstream processing – the wake word detection, and the automatic speech recognition system – are not engaged all the time. They are both expensive (in terms of power and CPU load), and the speech recognition is prone to misunderstanding.

When the voice activity detector triggers – indicating that a person may be talking – the spatial audio processing is engaged (to improve the audio quality) and the audio signals are passed to the Wake Word Detector.

The detector for the "Hey, Vector" is provided by Sensory, Inc. Pryon, Inc provided the detector for "Alexa."[41] The recognition is locale dependent, detecting different wake words for German, etc. It may be possible to create other recognition files for other wake words.

When the "Hey, Vector" wake word is heard,

1. A connection (via Vic-Cloud) is made to the remote speech processing server for automatic speech recognition.
2. If there was an intent found (and control is not reserved), the intent is mapped to a local behaviour to be carried out. This is described in a later section.

76.7.1 Wake work configuration file

The configuration file for the wake word is located at:

/anki/data/assets/cozmo_resources/config/micData/micTriggerConfig.json

[40] Vector's wake word detection, and speech recognition is pretty hit and miss. Signal Essence's demonstration videos show much better performance. The differences are they used more microphones and the spatial audio filtering in their demos. . Version 1.7 improved echo cancellation and wake word detection.
[41] This appears to be standard for Alexa device SDKs.

This file has dictionary structure with the following fields:[42]

Field	Type	Description & Notes
alexa_pryon	WakeWordLocale[]	The wake word speech recognition models for Alexa in each of the supported locales, using models for Pryon's toolkit (the default for Alexa Voice Services).
alexa_thf	WakeWordLocale[]	The wake word speech recognition models for Alexa in each of the supported locales, using models for Sensory's Truly HandsFree toolkit.
hey_vector_thf	WakeWordLocale[]	The wake word speech recognition models for "Hey Vector" in each of the supported locales, using models for Sensory's Truly HandsFree toolkit

***Table 446:** The micTriggerConfig JSON structure*

A WakeWordLocale is used to map a language locale to the wake word recognition models to use. This structure has the following fields:

Field	Type	Description & Notes
defaultModelType	string	e.g. "size_500kb" or "size_1mb"
locale	string	The IETF language tag of the human companion's language preference – American English, UK English, Australian English, German, French, Japanese, etc. default: "en-US"
modelList	WakeWordModel[]	The wake word speech recognition models, in a variety of sizes

***Table 447:** The WakeWordLocale JSON structure*

Each WakeWordModel provides a set of word recognition models that can be used. The structure has the following fields:

Field	Type	Description & Notes
dataDirectory	string	The path (relative to the TBD) holding the recognition models.
defaultSearchFileIndex	uint	The index of the model (in searchFileList) to use by default.
modelType	string	e.g. "size_500kb" or "size_1mb"
netFileName	string	Name of a file.
searchFileList	WakeWordFile[]	The wake word speech recognition models, in a variety of sizes

***Table 448:** The WakeWordLocale JSON structure*

Each WakeWordFile structure has the following fields:

Field	Type	Description & Notes
searchFileIndex	uint	The index of the model (in searchFileList) to use by default.
searchFileList	string	The name of the file…? (relative to the data directory). "NA" if a file name is not applicable.

***Table 449:** The WakeWordLocale JSON structure*

[42] The names of the structures here were created for clarity; they are not actually used in the files.

76.8. CONNECTIONS WITH VIC-GATEWAY AND SDK ACCESS

An application has access to the wake-word events and the received user intent events as they occur. When the "Hey, Vector" wake word is heard,

1. A WakeWordBegin (see Chapter 14 section *50.2.3 WakeWord*) event message is posted to Vic-Engine and Vic-Gateway. Vic-Gateway may forward the message on to a connected application.
2. A StimulationInfo (see Chapter 14, section *46.2.2 StimulationInfo*) event message, an emotion event "ReactToTriggerWord," is posted to Vic-Gateway for possible forwarding to a connected application.
3. A WakeWordEnd (see Chapter 14 section *50.2.3 WakeWord*) event message is sent (to Vic-Gateway for possible forwarding to a connected application) when the Vic-cloud has received a response back. If control has not been reserved, and intent was received, the intent JSON data structure is included.
4. If there was no intent found, a StimulationInfo (see Chapter 14, section *46.2.2 StimulationInfo*) event message is post (to Vic-Gateway), with an emotion event such as NoValidVoiceIntent
5. If there was an intent found (and control is reserved), a UserIntent (see Chapter 14, section *50.2.2 UserIntent*) event is posted to Vic-Gateway for possible forwarding to a connected application. In this case, the intent will not be carried out.

An external application can send an intent to Vector using the AppIntent command (see Chapter 15, section *50.3 App Intent*).

76.8.1 Audio Stream

It is clear that Anki made provisions to connect the audio stream to Vic-Gateway but were unable to complete the features before they ceased operation. The SDK would have been able to:

- Enable and disable listening to the microphone(s)
- Select whether the audio would have the spatial audio filter and noise reduction processing done on it.
- Include the direction of sound information from the spatial audio processing (see section *76.2 Spatial audio processing)*
- 1600 audio samples; Note: this is 10x the chunk size of the internal processing size

77. CLOUD SPEECH RECOGNITION

The audio stream (after the "Hey Vector") sent to a group of remote servers for processing. The servers perform automatic speech recognition (ASR), language understanding steps, and craft a response.

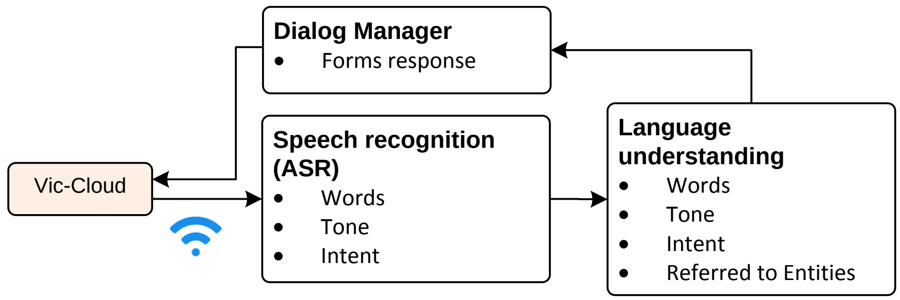


***Figure 73:** Typical speech recognition processes*

What the user said is mapped to a *user intent*. This is a code and structure that represents an action to carry out in response to the spoken request, query, or statement; it may represent the action requested, an answer to a query, or an action that emotionally responds to what was said. The intent includes some supporting information – the colour to set the eyes to, for instance. Many of the phrase patterns and the intent they map to can be found in Appendix J. The intent may be further handled by Anki servers; the intent is eventually sent back to Vector.

The intent system does some replacement on the intent names and parameters[43] from the cloud and SDK application to names used internally within Vector's engine.

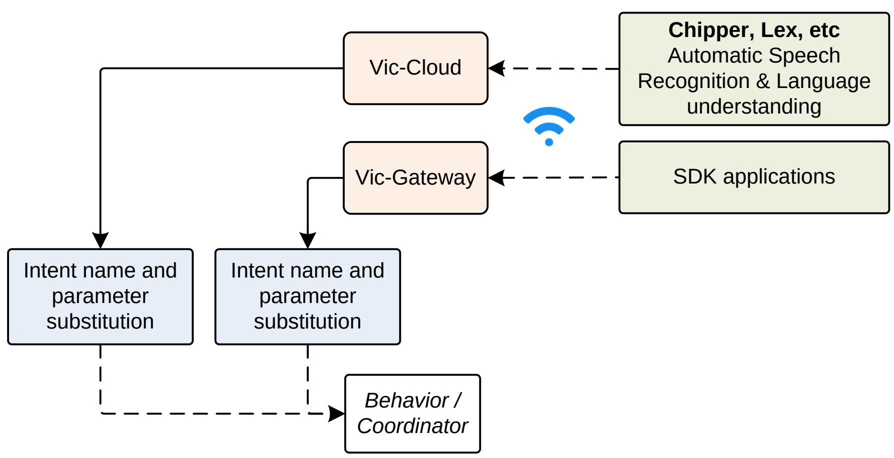


***Figure 74:** The filtering of intents*

It uses separate tables for the intents passed by the cloud and those passed from an SDK application. With the cloud based intent,

1. Looks up to see if there is a rule matching the name of the passed intent. If there is no match, the intent (may be) is passed to the next stage. If the internal intent name associated with the rule will be used, and
2. Each of the passed intent parameter names is checked to see if the name should be changed to an internal name. If so it is changed to the internal name; otherwise the parameter's passed name is (probably) used.

[43] The complexity suggests that the development of the server, mobile application and Vector were not fully coordinated and needed this to bridge a gap.

The intents passed by the SDK application also go thru a filtering phase:

1. Looks up to see if there is a rule matching the name of the passed intent. If there is no match, the intent is *discarded*. If the internal intent name associated with the rule will be used, and
2. Each of the passed intent parameter names is checked to see if the name should be changed to an internal name. If so it is changed to the internal name; otherwise the parameter is *discarded.*

The intent is also checked to see if it is enabled. Each intent can be associated with a feature flag; if it is, the flag is looked up to see if the corresponding feature is enabled. (see also Chapter 30 section *134 Feature Flags*).

An intent may initiate a behavior, or a coordinator. A coordinator is receptive to further intents in addition to physical stimulation.

77.1. INTENT PARAMETERS

The global_delete intent has the parameter following fields:

Field	Type	Units	Description
what_to_stop	string		

Table 450: *global_delete parameters*

The global_stop intent has the parameter following fields:

Field	Type	Units	Description
what_to_stop	string		

Table 451: *global_stop parameters*

This imperative_eyecolor_specific intent has the parameter following fields:

Field	Type	Units	Description
eye_color	string		The name of the color to set the eye color to

Table 452: *imperative_eyecolor_specific parameters*

This imperative_volumelevel intent has the parameter following fields:

Field	Type	Units	Description
volume_level	string		

Table 453: *imperative_volumelevel parameters*

This knowledge_response intent has the parameter following fields:

Field	Type	Units	Description
answer	string		The text to be spoken(?)
query_text	string		The text of the question asked(?)

Table 454: *knowledge_response parameters*

This meet_victor intent has the parameter following fields:

Field	Type	Units	Description
username			

Table 455: meet_victor parameters

This message_playback intent has the parameter following fields:

Field	Type	Units	Description
given_name	string		The name of the person to send the message to

Table 456: message_playback parameters

The set_timer intent has the parameter following fields:

Field	Type	Units	Description
time_s	int	*seconds*	The number of seconds to set the timer to

Table 457: set_timer parameters

The take_a_photo intent has the parameter following fields:

Field	Type	Units	Description
empty_or_selfie	string		Empty string if taking a photo, "photo_selfie" if taking a selfie.

Table 458: take_a_photo parameters

This test_name intent has the parameter following fields:

Field	Type	Units	Description
name	string		

Table 459: test_name parameters

This test_timeWithUnits intent has the parameter following fields:

Field	Type	Units	Description
time	uint		
units	string		

Table 460: test_timeWithUnits parameters

This weather_response intent has the parameter following fields:

Table 461: weather_response parameters

Field	Type	Units	Description
condition	string		The current weather conditions. One of "Clear", "Cloudy", "Cold", "Rain", "Snow", "Stars", "Sunny", "Thunderstorms", or "Windy"
isForecast	string	*"false" or "true"*	"false" if it is the current weather conditions; "true" if forecasted weather conditions.
localDateTime	string		The local time (where the weather conditions apply) in UTC ISO 8601 format.
speakableLocationString	string		The location name that Vector could employ in his verbal description of the temperature.
temperature	string	*degrees*	The current or forecasted temperature, in the given units.
temperatureUnit	string		F or C, for the units

77.2. INTENT MAPPING CONFIGURATION FILE

The configuration file holding the mapping of the clouds external intent names and parameters to those used internally within Vector's engine is located at:

/anki/data/assets/cozmo_resources/config/engine/behaviorComponent/user_intent_map.json

The path is hard coded into libcozmo_engine.so. The file has the following structure:

Table 462: The user_intent_map JSON structure

Field	Type	Description
simple_voice_responses	array of SimpleVoiceResponse	A table that maps the intent received from the cloud intent to animation and emotion responses.
user_intent_map	array of UserIntentMap	A table that maps the intent received from the cloud or application to the intent name used internally. This includes renaming the parameters.
unmatched_intent	string	The intent to employ if cloud's intent cannot be found in the table above. Default: "unmatched_intent"

Each of the simple voice response mapping entries has the following structure:

Table 463: The simple voice response JSON structure

Field	Type	Description
cloud_intent	string	The intent name returned by the cloud. See the "Cloud Intent" column in Appendix J *Table 640: Mapping of different intent names* for a list of intent names.
response	X	The animation and emotion changes that should occur in response to the intent.

The response structure has the following fields:

Field	Type	Description
active_feature	string	The AI behavior feature that should be activated. See Appendix H *Table 637: The AI behaviour features* for a list of AI features.
anim_group	string	The trigger name of the animation to play.
disable_wakeword_turn	bool	Default: false. *Optional.*
emotion_event	string	The name of the emotion event, describing how this intent affects Vector's current mood. See Chapter 29 for a description.

Table 464: *The response JSON structure*

Each of the user intent mapping entries has the following fields:

Field	Type	Description
app_intent	string	The intent name sent by the SDK application. See the "App Intent" column in Appendix J *Table 640: Mapping of different intent names* for a list of intent names. *Optional.*
app_substitutions	dictionary	A dictionary whose keys are the keys provided by the application's intent structure, and maps to the keys used internally. *Optional.*
cloud_intent	string	The intent name returned by the cloud. See the "Cloud Intent" column in Appendix J *Table 640: Mapping of different intent names* for a list of intent names.
cloud_numerics	array of strings	Names of keys that used as parameter values by the behaviour..?? *Optional.*
cloud_substitutions	dictionary	A dictionary whose keys are the keys provided by the cloud's intent structure, and maps to the keys used internally. *Optional.*
feature_gate	string	The name of the feature that must be enabled before this intent can be processed. *Optional.*
test_parsing	bool	Default: true. *Optional.*
user_intent	string	The name of the intent used internally within Vector's engine.

Table 465: *The intent mapping JSON structure*

78. REFERENCES AND RESOURCES

https://github.com/ARM-software/ML-KWS-for-MCU
A reference keyword listener for ARM microcontrollers.

https://github.com/MTG/essentia/tree/master/test/src/descriptortests/equalloudness
A reference implementation of an equal-loudness measure

Hydrogen Audio, *ReplayGain 1.0 specification*, 2018 Nov 19
http://wiki.hydrogenaud.io/index.php?title=ReplayGain_1.0_specification

A detailed description of how the sound loudness can be measured and used to adjust the volume of music playback.
Note: the filter implementation for audio effects can be very complex; for sound detection it is very simple.

ST Microelectronics, *Reference manual, STM32F030x4/x6/x8/xC and STM32F070x6/xB advanced ARM®-based 32-bit MCUs*, 2017 Apr, Rev 4
https://www.st.com/resource/en/reference_manual/dm00091010-stm32f030x4-x6-x8-xc-and-stm32f070x6-xb-advanced-arm-based-32-bit-mcus-stmicroelectronics.pdf

Wikipedia, *A-weighting*
https://en.wikipedia.org/wiki/A-weighting

Wikipedia, *Robinson–Dadson curves*
https://en.wikipedia.org/wiki/Robinson%E2%80%93Dadson_curves

CHAPTER 19

Image Processing

Vector has a clever vision processing system:

- Camera operation including calibration
- Visual stimulation
- Recognizing symbols and specially marked objects
- Detecting faces, recognizing people, and estimating emotion
- Hand, pet and other object detection
- Taking photos
- Sending video stream to the SDK
- Vision is primarily used for navigation purposes: Recognizing the floor (or ground), odometry and "simultaneous localization and mapping"

79. CAMERA OPERATION

Vector has a 1280x720 camera with a wide field of view to see around it without moving its head, similar to how an animal can see a wide area around it by moving its eyes. The camera is connected to the processor through a MIPI interface. The data from the camera passes to device drivers, then to a separate daemon service and eventually passes to Vic-engine for the processing:

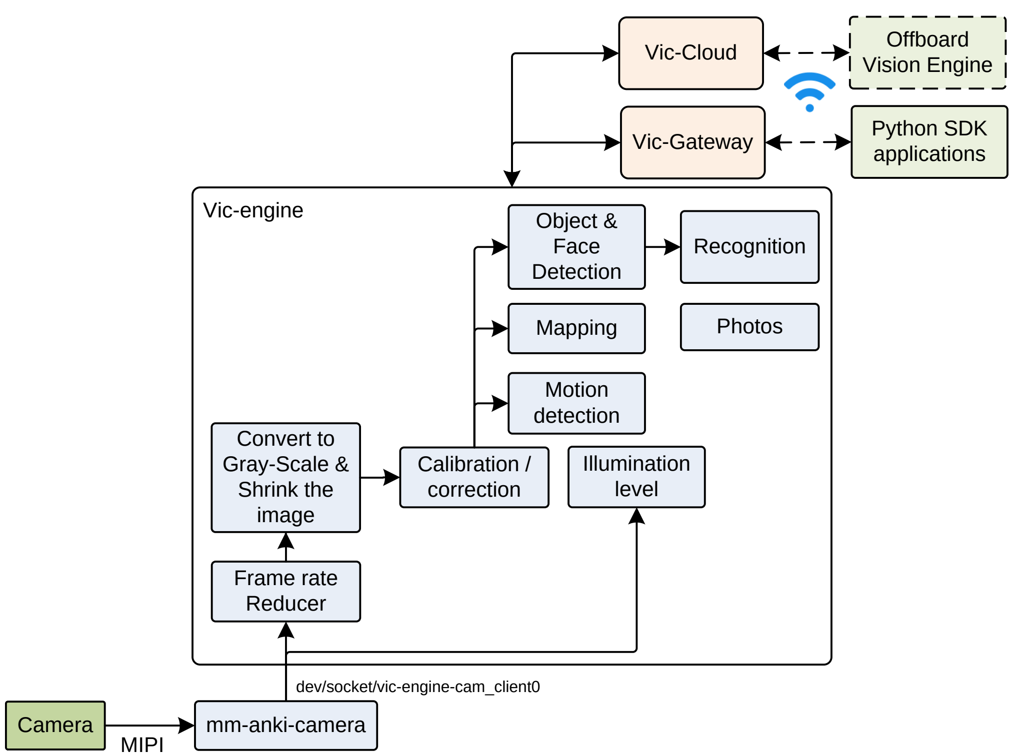


Figure 75: *The camera architecture*

Vector visually recognizes the following elements in its environment:

- Special visual markers; Vector treats all marked objects as moveable… and all other objects in its driving are as fixed & unmovable.
- Faces
- Hands
- Pets (feature not completed)
- Other objects, like fruit, etc. (feature not completed)
- LASER pointers (feature not completed)

79.1. CAMERA OPERATION

To reduce computing load the camera frame rate is reduced and the image size is scaled down. This pattern is common throughout the image processing:

- More pixels require much more memory at each stage of image the image processing.
- It takes much, much longer (and more power) to process larger frames. There is the added time to process each of the added pixels. Second, the neural-net models (used for human, pet and object recognition) are much larger as well, taking much longer to process with the many stages involved in these models.
- That extra processing is among the most power expensive items in Vector, and rapidly depleting his battery, shortening the time between charges,
- The extra processing also generates heat in the head board, and
- Image processing tasks don't need more pixels. There is rarely any improvement in visual detection from using more pixels or higher frame rates

The software in reduces the frame rate by skipping frames (no fancy interpolation needed). Then the image is converted to gray scale and scaled down to quarter size (640x360). (This was also the case with Cozmo.)

79.2. CAMERA CALIBRATION

The camera is calibrated at manufacturing time. This is necessary so that the Vector can accurately dock with a cube, getting the small lift fingers into the cube's holes. The calibration primarily compensates for the image being slightly offset, and unit to unit variation of focal length.

Vector's camera has ~120° diagonal *field of view*.[44] For comparison the iPhone's camera has a 73˚ field of view, and the human eye is approximately 95˚. The cropped sensor image has a 90° horizontal field of view and a 50° vertical field of view.

[44] The press release for Vector reported a 120° field of view, but should be discounted as this number does not match the frame field of view numbers given in the SDK documentation.

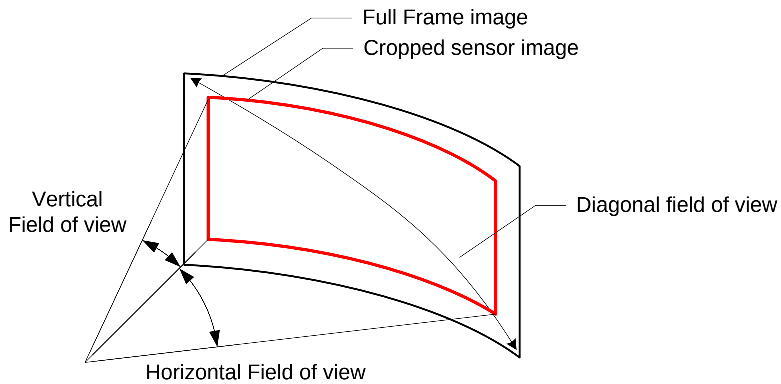


***Figure 76:** The camera field of view*

Vector's calibration uses focal length instead of field of view. The two values are related:

$$fieldOfView = 2\arctan\frac{sensor\ size}{2\ focalLength}$$

***Equation 1:** Relationship between field of view and focal length*

The following structure is reported in the robot logs for the camera calibration:

***Table 466:** The camera calibration JSON structure*

Field	**Type**	**Description**
cx *cy*	float	"The position of the optical center of projection within the image. It will be close to the center of the image, but adjusted based on the calibration of the lens at the factory."
distortionCoeffs	float[]	
fx *fy*	float	The "focal length combined with pixel skew (as the pixels aren't perfectly square), so there are subtly different values for x and y."
ncols	int	The width of the image in pixels. The value given is 640.
nrows	int	The height of the image in pixels. The value given is 360
skew	float	

Quotes are from Anki Cozmo SDK.

"A full 3x3 calibration matrix for doing 3D reasoning based on the camera images would look like:"

$$\begin{pmatrix} focalLength_x & 0 & center_x \\ 0 & focalLength_y & center_y \\ 0 & 0 & 1 \end{pmatrix}$$

***Equation 2:** Camera calibration matrix*

79.3. CORRECTION

With each image frame to be processed, the software applies some processing to improve the image contrast. This helps with the low-light that is common in rooms and at night. (The software also monitors the illumination levels and tweaks the exposure settings so that image is as good as possible before it gets to the software stage.)

One technique to improve the contrast is *contrast-limited adaptive histogram equalization* (CLAHE). This looks at a histogram of the pixel gray-scale values in a wide window around each pixel, and then maps the used gray-scale to a different set of gray values. This spreads the grays out a bit further. Being adaptive, it helps with different lighting levels across the scene – some areas being well lit, others in shadow – as well as vignetting (the darkening toward the edges and corners) that may occur with the camera and lens.

79.4. VISION MODES

The vision process happen at different rates, many execute together in a shared group.

The vision processing system has many detectors, and functions. Some have their software run at different rates. While most are independent of each other, they are often grouped together.

Table 467: *The Vision processes*

Vision Mode	Executes with	Description and notes
AutoExp		This mode is used to control the auto-exposure control level.
AutoExp_Cycling	AutoExp	This mode is used to detect
AutoExp_MinGain	AutoExp	
BrightColors		This mode is used to detect colors that may be interesting to explore.
Faces		Used for face detection, and to trigger facial identification.
Faces_Blink	Faces	This mode is used to detect and count eye blinks.
Faces_Crop	Faces	This mode is used to detect faces that are obscured or partly out of view.
Faces_Expression	Faces	This mode is used to estimate the facial expression.
Faces_Gaze	Faces	Detects the gaze and looks deep into their eyes with wonder and the hope of biscuits.
Faces_Smile	Faces	This mode is used to detect smiles.
Illumination		This mode is used to estimate the level of illumination in the scene.
Lasers		This mode is used to detect laser pointer activity.
Markers		Detects Vector's special square marker symbols.
Markers_Off	Markers	
Markers_ChargerOnly	Markers	This part of the process of detecting Vector's special square marker symbols.
Markers_Composite	Markers	This part of the process of detecting Vector's special square marker symbols.
Markers_FastRotation	Markers	This part of the process of detecting Vector's special square marker symbols.
Markers_FullFrame	Markers	This part of the process of detecting Vector's special square marker symbols.
Markers_FullHeight	Markers	This part of the process of detecting Vector's

		special square marker symbols.
Markers_FullWidth	Markers	This part of the process of detecting Vector's special square marker symbols.
MirrorMode		Displays the camera image on the LCD
Motion		The mode is used to detect visual motion
OverheadEdges		
OverheadMap		disabled
People		This mode is used to detect people, rather than faces
Pets		This mode is used to detect pets, such as cats and dogs.
Hands		Used to detect hands (for purposes of pouncing on them).
SaveImages		This mode is used to save the camera image as a photograph.
Stats		This is probably used to compute statistics about the images or image processing
Viz		This module creates a marked up image showing where Vector see's the charger, cubes, faces, and other interesting things.
WhiteBalance		This mode is used to estimate the

79.5. ILLUMINATION LEVEL SENSING

Vector estimations the amount of illumination in the room. Dark rooms would encourage him to go to sleep, while bright or changing illumination would encourage him to be active. The illumination is pretty easy to compute: sum up the brightness of each pixel in the image, or the number of pixels above a threshold of brightness.

The camera is also used as an ambient light sensor when Vector is in low power mode (e.g. napping, or sleeping). In low power mode, the camera is suspended and not acquiring images. Although in a low power state, it is still powered. The software reads the camera's auto exposure/gain settings and uses these as an ambient light sensor. (This allows it to detect when there is activity and Vector should wake.)

79.6. VISUAL MOTION DETECTION

Note: this is not the same as chapter 10, which sensed Vector's motion.

Vector can detect visual movement in its field of view. This motion detector looks in two regions of the camera view (the low left and the top right) for movement, and it looks at its projected view of the ground for movement.

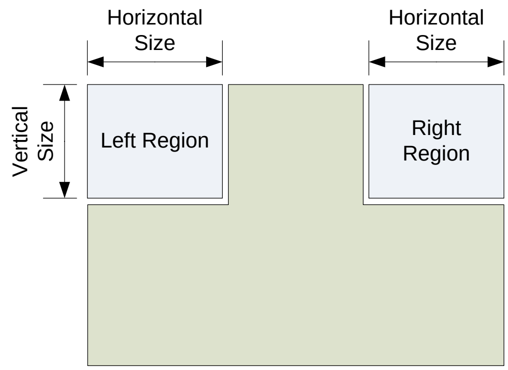


Figure 77: *The movement detection regions*

The detector likely does pixel subtraction in these regions between frames, computing a score for the number of pixels that changed and how wide of an area it was (the centroid). Then it adds this with the past value (using the inverse of DecreaseFactor as a weight). If score is above a threshold (MaxValue?) it concludes that there is motion in that region.

See Section *85.1.7 MotionDetector* for a description of the motion detectors configuration.

The motion detector is used by the pouncing behaviors – see Chapter 30, section *125.2 Pouncing*

The RobotObservedMotion event (see Chapter 15 section *58.2.2 RobotObservedMotion*) is intended to indicate when visual motion is detected. {Note: this event is not supported in current software}

80. THE CAMERA POSE: WHAT DIRECTION IS CAMERA POINTING IN?

The camera is located in Vector's head. The pose of Vector's camera – its position and orientation, including its tilt up or down, can be estimated from Vector's pose, the angle of his head, the known position of the camera within the head and the position of the joint around which the head swivels. Note: the values are for Cozmo, but are assumed to be representative of Vector:

Example 6: *Computing the camera pose source: Anki*[45]

```
# Neck joint relative to robot origin
NECK_JOINT_POSITION = [-13, 0, 49]

# camera relative to neck joint
HEAD_CAM_POSITION = [17.52, 0, -8]
DEFAULT_HEAD_CAM_POS = list(HEAD_CAM_POSITION)

DEFAULT_HEAD_CAM_ROTATION = [
  0,      -0.0698,   0.9976,
 -1,       0,        0,
  0,      -0.9976,  -0.0698 ]

# Compute pose from robot body to camera
# Start with a pose defined by the DEFAULT_HEAD_CAM_ROTATION (rotation matrix)
# and the initial position DEFAULT_HEAD_CAM_POS
default_head_pose = Matrix3d(DEFAULT_HEAD_CAM_ROTATION, DEFAULT_HEAD_CAM_POS)

# Rotate that by the head angle
rotation_vector = RotationVectorAroundYAxis(-robot.head_angle.radians);
current_head_pose = default_head_pose.rotate_by(rotation_vector)

# Get the neck pose (transform the initial offset by the robot's pose)
neck_pose = TransformPose(NECK_JOINT_POSITION, robot.pose)

# Precompose with robot-to-neck-pose
camera_pose = current_head_pose.pre_compose_with(neck_pose);
```

[45] https://forums.anki.com/t/camera-matrix-for-3d-positionning/13254/5

81. MARKERS

Anki considered QR codes to mark accessories and special items… but they were universally rejected in the feedback received during development. So Anki created their own visual labeling system, starting with Cozmo. Vector has a newer set of visual labels that is not compatible with Cozmos. (There isn't a clear reason for the incompatibility.) The algorithm used is among the most documented of Anki's internally developed modules for Vector.

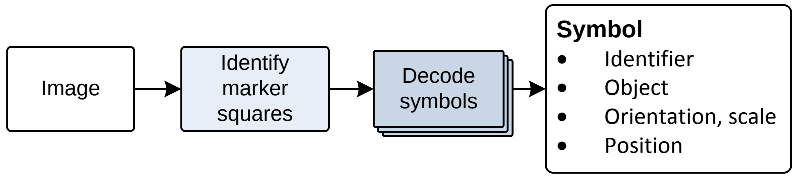


Figure 78: The processing of the image for symbols and objects

A key characteristic of the markers is a big, bold square line around it:

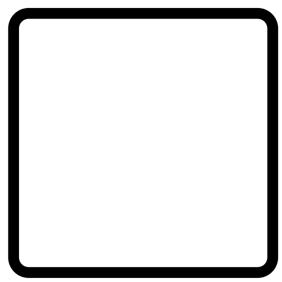


Figure 79: A typical rectangle around the visual markers

The square is used to estimate the distance and relative orientation (pose) of the marker and the object is on. Vector, internally, knows the physical size of marker. The size of the square in the view — and being told how big the shape really is —lets Vector know enough to compute the likely physical distance to the marked item. And since the "true" mark has parallel lines, Vector can infer the pose (relative angles) of the surface the mark is on.

The process of finding and decoding the marker symbols is very straightforward, since there is quite a lot known about the structure of the marker image ahead of time. This allows the use of computation friendly algorithms.

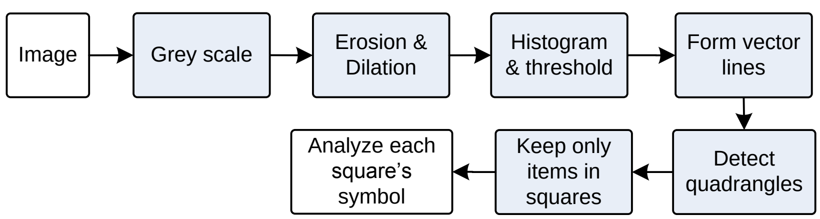


Figure 80: Preparing image for scanning for symbols

The steps in processing are:

1. Acquire a gray scale image,
2. Apply classic erosion-dilation and Sobel transforms to build a vector representation (no pun intended) of the image; this is most familiar as "vector drawing" vs bitmap images
3. Detect the squares – the parallel and perpendicular lines – in the vector drawing. This will be the potential area that a symbol is in.
4. Analyze square to determine is size, and affine transform – how it is tilted up-and-down, and tilted away from the camera.

5. Screen the squares, tossing out that those that are horribly distorted,
6. Analyze the pixels in the square to identify the code

81.1. THE INITIAL PREPARATION STEPS

The image is initially prepared for analysis by:

1. The image is converted to grey scale, since color is of no value.
2. Performs (erosion, dilation) that strip out noise, fill in minor pixel gaps. There are no small features, so fine detail is not important.
3. The image is then converted to high-contrast black and white (there is no signal in grey scale). This is done by performing a histogram of the grey scale colors, finding a median value. This value is used as a threshold value: greys darker than this are consider black (a 1 bit), and all others are white (0 bit).

81.2. DETECT AND ANALYZE SQUARES

The detection of squares then:

1. Typically a pair of Sobel filters is applied to identify edges of the black areas, and the gradients (the x-y derivative) of the edges.
2. The adjacent (or nearby) pixels with similar gradients are connected together into a list. Straight line segments will have very consistent gradients along them. In other words, the bitmap is converted into a vector drawing. In jargon, this is called the *morphology.*
3. The lists of lines are organized into a containment tree. A bounding box (min and max positions of the points in the list) can be used to find which shapes are around others. The outer most shape is the boundary.
4. "Corners of the boundaries are identified… by filtering the (x,y) coordinates of the boundaries and looking for peaks in curvature. This yields a set of quadrilaterals (by removing those shapes that do not have four corners)." Stein, 2017
5. A perspective transformation is computed for the square (based on the corners), using homography ("which is a mathematical specification of the perspective transformation"). This tells how tilted the square is.
6. The list of squares is filtered, to keeping those that are big enough to analyze, and not distorted with a high skew or other asymmetries.

81.3. DECODING THE SQUARES

The next step is to decode the symbol. Vector has a set of probe locations within the marker square that it probes for black or white reading. These are usually centered in the cells of a grid.

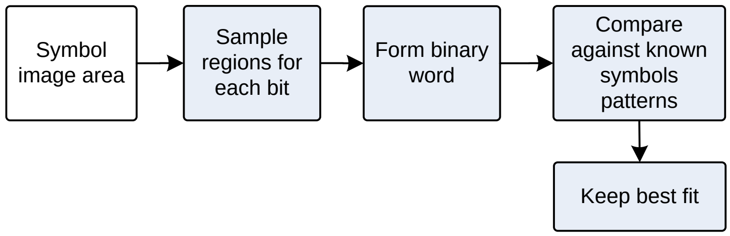


Figure 81: *Decoding the symbol*

The steps in decoding the symbol are:

1. The software uses the perspective transform to map the first point location to one in the image;
2. The pixels at that point in the image are sampled and used to assign a 0 or 1 bit for the sample point.
3. The bit is stored, in a small binary word
4. The above steps are repeated for the rest of the probe locations

This process allows Vector to decode images warped by the camera, its lens, and the relative tilt of the area.

Next, the bit patterns are compared against a table of known symbol patterns. The table includes multiple possible bit patterns for any single symbol, to accommodate the marker being rotated. There is always a good chance of a mistake in decoding a bit. To find the right symbol, Vector:

1. XOR's the decoded bit pattern with each in its symbol table,
2. Counts the number of bits in the result that are set. (A perfect match will have no bits set, a pattern that is off by one bit will have a single bit set in the result, and so on.)
3. Vector keeps the symbol with the *fewest* bits set in the XOR result.

81.4. REVAMPING SIZE AND ORIENTATION

The different rotations of the symbol would change the order that it sees the bits. Each bit pattern in the table might also include a note on how much the symbol is rotated (i.e. 0, +90°, -90°, or 180°). When matching a bit pattern, Vector can know the major rotation of the symbol. Combined with the angle of the symbol square, the full rotation of the symbol can be computed.

81.5. INFERRING KNOWLEDGE ABOUT OBJECTS

Vector associates an object with symbol. Some objects can have many symbols associated with them. Cubes have different symbols used for sides of cubes. This allows Vector to know what object it is looking at, and what side of the object. And, with some inference, the orientation of the object.

Vector knows (or is told) the physical size of the symbol, and the object holding the symbol. Combining this with the visual size of the object, time of flight distance measurement (if any), and Vector's known position, this allows Vector infer the objects place in the map.

82. FACE AND FACIAL FEATURES RECOGNITION

Vector "is capable of recognizing human faces, tracking their position and rotation ("pose") and assigning names to them via an enrollment process." Vector's facial detection and recognition is based on the OKAO vision library. This lets Vector know when one (or more) people are looking at it. This library is primarily used by Vector for facial recognition tasks:

Anki Cozmo SDK

- Face detection ability – the ability to sense that there is a face in the field of view, and locate it within the image.
- Face recognition, the ability to identify whose face it is, looking up the identify for a set of known faces
- Recognize parts of the face, such as eyes, nose and mouth, and where they are located within the image.

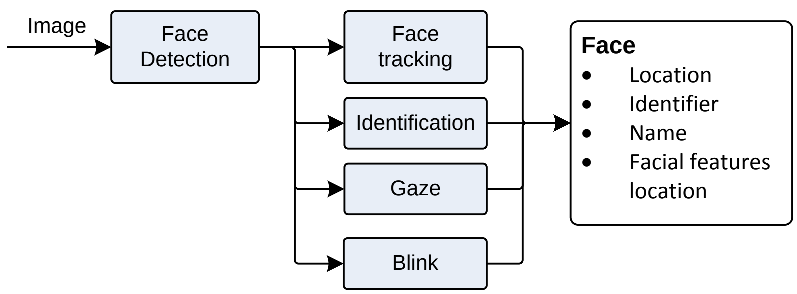


Figure 82: *The face detection and recognition processes*

There are a couple of areas that Vector includes access to in the SDK API, but did not incorporate fully into Vector's AI:

- The ability to recognize the facial expression: happiness, surprise, anger, sadness and neutral. This is likely to be unreliable; that is the consensus of research on facial expression software.
- Ability to estimate the direction of gaze

And there are several features in OKAO that are not used

- The ability to estimate the gender and age of the person
- Human upper body detection
- Hand detection and the ability to detect an open palm. The hand detection used in Vector is done in a different way (which we will discuss in a section below.)

82.1. FACE DETECTION

OpenCV also has facial detection, but not recognition. OpenCV's classic face detector is an implementation of an algorithm developed by Viola-Jones. Since we know how that works, we can discuss it as representative of how OKAO may work. Viola-Jones applies a series of fast filters (called a "cascade" in the jargon) to detect low-level facial features (called Haar feature selection) and then applies a series of classifiers (also called a cascade). This divides up interesting areas of the image, identify facial parts, and makes conclusions about where a face is.

Vector's face detector (and facial recognition) can't tell that it is looking at an image of face – such as a picture, or on a computer screen – rather than an actual face. One thing that Anki was considering for future products was to move the time of flight sensor next to the camera. This

Daniel Casner, 2019

would allow Vector to estimate the size of the face (and its depth variability) but measuring the distance.

Side note: Anki was exploring ideas (akin to the idea of object permanence) to keep track of a known person or object in the field of view even when it was too small to be recognized (or detected).

82.2. FACE IDENTIFICATION AND TRAINING

When it sees a face, it forms a description of the facial features using twelve points:

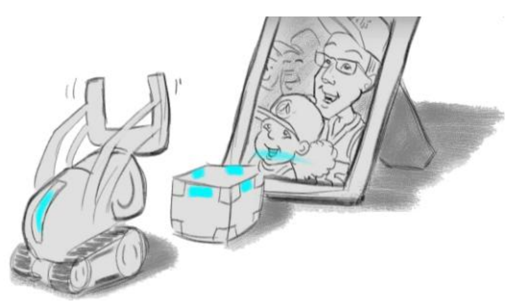
- Each eye has three points,
- The nose has two,
- The mouth has four points

If you introduce yourself to Vector by voice, you are permitting the robot to associate the name you provide with Facial Features Data for you. Facial Features Data is stored with the name you provide, and the robot uses this data to enhance and personalize your experience and do things like greet you by that name. This data is stored locally on the robot and in the robot's app. It is not uploaded to Anki nor shared, and you can delete it anytime.

82.3. COMMUNICATION INTERFACE

There are several commands to manage the faces that Vector recognizes, and to keep informed of the faces that Vector sees. See Chapter 15 section *56 Faces* for more details.

- The Enable Face Detection (see Chapter 15 section *56.4 Enable Face Detection*) command enables and disables face detection and analysis stages.
- The RobotChangedObservedFaceID and RobotObservedFace (see Chapter 15 section *56.2.4 RobotChangedObservedFaceID* and *56.2.6 RobotObservedFace*) events are used to indicate when a face is detected, and tracking it: the identity of the face (if known), where it is in the field of view, the facial expression, where key parts of the face are (in the view), etc
- The Set Face to Enroll (see Chapter 15 section *56.10 Set Face to Enroll*) command is used to ability assign a name to face, and the Update Enrolled Face By ID (see Chapter 15 section *56.10 Set Face to Enroll*) command is used to change the name of a known face
- The Request Enrolled Names (see Chapter 15 section *56.9 Request Enrolled Names*) command is used to retrieve a list the known faces
- The ability to remove a facial identity (see Chapter 15 section *56.7 Erase Enrolled Face By Id*), or all facial entities (see Chapter 15 section *56.6 Erase All Enrolled Faces*)
- The Find Faces (see Chapter 15 section *56.8 Find Faces*) command initiates the search for faces



drawing by Jesse Easley

83. TENSORFLOW LITE, DETECTING HANDS, PETS… AND THINGS?

Vector includes support to detect hands, and has preliminary support for detecting pets and a wide variety of objects. These are done using TensorFlow Lite[46] (aka TFLite), an inference only neural-net discriminator.

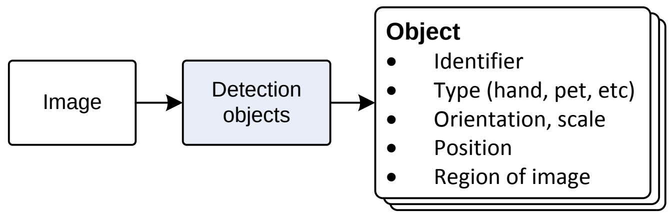


***Figure 83:** The processing of the image for symbols and objects*

Vector's hand detection is done with a custom TensorFlow Lite DNN model.[47] Vector also has a custom person detector; this may be used to quickly identify whether there is a face in view before engaging the potentially more expensive OKAO framework.

83.1. DETAILS ON TENSORFLOW LITE

Warden & Situnayake, 2019

From a distance, the TensorFlow Lite framework acts much the same as a classification trees, taking inputs, examining properties and producing a result, such as "this is a hand." Internally the framework is a designed as a modular virtual machine for signal-processing-like computation. A "model" is the program for this virtual machine, with information describing its memory structures, inputs, outputs and the instructions. The analog of a software procedure in the model are called a *graph.* The instructions are called *operations*. Full TensorFlow supports 800+ different operations out of the box, and custom ones can be added. TensoreFlow Lite supports 122+ different operations, and custom ones can be added as well. TensorFlow Lite supports one graph in a model.

The host application has to do preprocessing such as feature extraction, prepare the input for the system. For instance, the image must be converted to grey scale and scaled down to 128 pixels by 128 pixels. (More pixels require much more memory and processing steps often with no improvement in detection; some higher quality models do use slightly larger image sizes.)

Then each of the operations in the model is carried out. An operation might perform a simple calculation light summing values, keeping the smallest or largest, etc or an operation might be a complex calculation such as a convolution. Once all of the operations have completed, the results are not a "this is a hand" or other conventional software result. Instead, the results are big list of values on how confident it is for each possible item. An application typically chooses the top item or two as the output – if their confidence is high enough.

[46] Since Tensorflow Lite was both introduced at the end of 2017, there has been a steady trickle of improvements to TensorFlow Lite. There is a lower power version that targets microcontrollers.
[47] There are four different hand detector models – only one is used – which suggests that the hand detector was actively being tweaked and improved.

TensorFlow Lite includes build time support to replace the key operation implementations with fast, processor-specific ones:

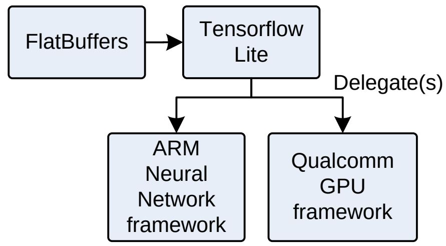


Figure 84: *TensorFlow lite with hardware specific accelerators*

In addition, applications using TensorFlow Lite can provide their own, faster or more efficient implementations of operations.

Each TensorFlow Lite model is probably run in its own thread. The benchmarks posted by TensorFlow[48] using smartphones to run model tens to hundreds of milliseconds. Putting each model on its own thread and waiting for posted results allows the rest of the processing to execute in a consistent fashion.

83.1.1 SalientPoint data structure

The `SalientPoint` JSON data structure is produced from the neural networks analysis of the image. These points are used by the behavior system as something interesting to react to as well. The structure has the following fields:

Table 468: *SalientPoint parameters*

Field	Type	Units	Description
area_fraction	float		Area of the region that was identified as a salient point.
color_rgba	uint	*RGBA*	How to color this region, for web visualization
description	string		
salientType	string		An enumerated type describing the kind of salient point found.
score	float		A metric relating how interesting the point/region is
shape	array of points?		An array of points outlining the interesting area?
timestamp	uint	*ms*	The timestamp that this point was identified on
x_img	float	*pixel*	Pixel coordinate of the upper left hand corner of the region.
y_img	float	*pixel*	Pixel coordinate of the upper left hand corner of the region.

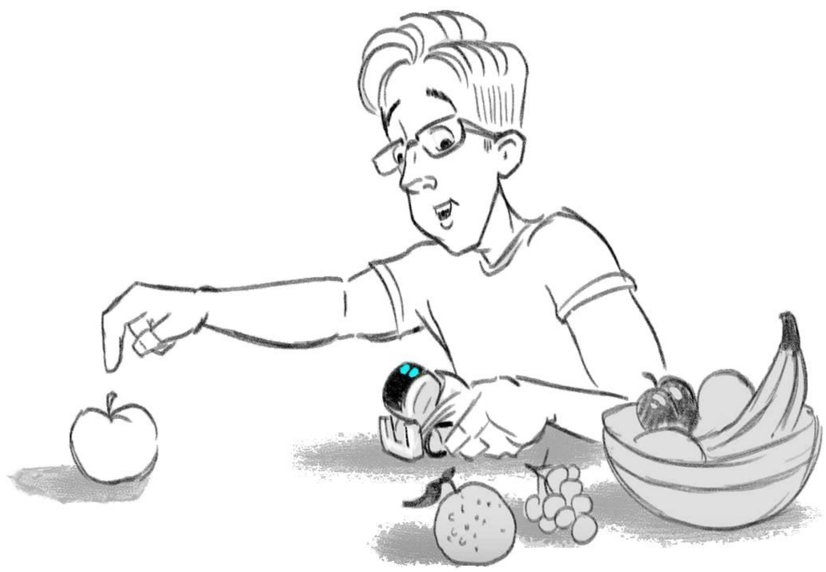
[48] https://www.tensorflow.org/lite/performance/benchmarks

83.2. OTHER IDEAS THAT WEREN'T FULLY REALIZED AND FUTURE POTENTIAL

Vector also includes the stock MobileNet V1 (0.5, 128) model to classify images, although it does not appear to have been used yet. This model was likely intended to give Vector the ability to identify a wide variety of things, and pets.[49]

MobileNet V1 includes higher quality models than the one employed that may be explored. Since this model was released, a version 2 and version 3 of MobileNet have been developed and released. Version 2 is reported to be faster, higher quality, and/or require fewer processor resources. (Version 3 is slower and takes more processor resources, but is much more accurate.)

The configuration file shows experimentation with MobileNet V2 (using 192x192 input images), but it was disabled.



drawing by Jesse Easley

[49] Or a special model for recognizing pets may have been under development

84. PHOTOS/PICTURES

Vector has the ability to take pictures. The photographs were taken with less than the full camera resolution. (It isn't known if Anki intended to eventually take photographs at a higher resolution.) These pictures are stored on Vector, not in the cloud. The mobile application and SDK applications can view, delete or share pictures taken by Vector.

The camera/image processing pipeline in Vector is entirely focused on his AI features with as low as practical battery impact. The images available for taking a picture are not filtered, or cleaned up, so the pictures that Vector takes are noisy and smaller.

Commentary: The quality of photos seen on a mobile phone is achieved using a camera processing pipeline to enhance the images, removing noise and applying special filters to reconstruct textures. It is conceivable that the camera processing framework(s) from Qualcomm and Android could be added to an open-source Vector. That would come at the cost of battery performance, heat, and potentially overwhelm the memory resources (there are still bugs in Vector where the memory use becomes too high, and the system thrashes, slowing noticeably down and eventually crashes.)

It is more practical, in a future open-source Vector, to export the raw camera images (in its RAW format and at different illumination levels) and process the images on a PC or mobile device. The availability of sophisticated image processing frameworks are much wider for those devices. See Chapter 15, section *58 Image Processing* for the camera access API.

84.1. COMMUNICATION INTERFACE

There are several commands to manage the photographs that Vector has taken. See Chapter 15 section *65 Photos* for more details.

- The PhotoTaken event (see Chapter 15 section *65.2.1 PhotoTaken*) is used to receive a notification when Vector has taken a photograph.
- The Photos Info (see Chapter 15 section *65.5 Photos Info*) command is used to retrieve a list of the photographs that Vector currently has
- The Photo (see Chapter 15 section *65.4 Photo*) command is used to retrieve a photo
- The Delete Photo command (see Chapter 15 section *65.3 Delete Photo*) removes a photo from the system
- The Thumbnail (see Chapter 15 section *65.6 Thumbnail*) command retrieves a small version of the image, suitable for displaying as a thumbnail

85. CONFIGURATION FILES

85.1. VISION CONFIG

The vision system' main configuration file is located at:

`/anki/data/assets/cozmo_resources/config/engine/vision_config.json`

This path is hardcoded into `libcozmo_engine.so`. It configures each of the image processing module, and the schedule defaults. The file is a structure with the following fields:

Field	Type	Description
ColorImages	boolean	"whether color images are enabled on startup (can still be toggled later)"
FaceAlbum	string	
FaceRecognition	struct	Configures when the face recognition runs
GroundPlaneClassifier	struct	Configuration of the ground plane classifier
IlluminationDetector	struct	Configuration of the illumination detector, and a link to the configuration file for the classifier
ImageCompositing	struct	Configuration of the image compositing module
ImageQuality	struct	Controls the cameras auto-exposure settings.
InitialModeSchedule	Struct	"VisionModes that need to be scheduled by default go here. Basically things that are always running."
MotionDetector	struct	Configuration of the motion detection – the size of image area to look for peripheral motion
NeuralNets	NeuralNets struct	Configures the use of the TensorFlow Lite detection modules
NumOpenCvThreads	int	"Number of threads to use with OpenCV. 0 means no threading according to docs. Only affects calls from VisionSystem thread."
OverheadMap	struct	The size of the overhead map
PerformanceLogging	struct	Configures how often to log information about the image processing stats
PetTracker	struct	Configures the pet tracker – the number of pets, face size, thresholds, etc.

Table 469: *The vision configuration JSON structure*

85.1.1 FaceRecognition

The FaceRecognition structure includes the following fields:

Field	Type	Description
RunMode	string	Can be either "asyncrhonous" or "synchronous"

Table 470: *The FaceRecognition structure*

85.1.2 GroundPlaneClassifier

The GroundPlaneClassifier (also called "desk classifier") is used to visually identify where the driving surface is. The structure includes the following fields:

Field	Type	Description
FileOrDirName	string	Path to the ground plane classifier file.
MaxDepth	uint	
MinSampleCount	uint	
OnTheFlyTrain	booleab	
PositiveWeight	float	
TruncatePrunedTree	boolean	
Use1SERule	boolean	

Table 471: *The GroundPlaneClassifier structure*

Note: The Ground Plane classifier is a bit unusual. It is one of only two YAML files. The YAML file is an openCV based classifier tree, instead of TensorFlow Lite. This suggests it may have been older (i.e. from Cozmo), and/or it may have been more efficient to implement in openCV.

85.1.3 IlluminationDetector

The IlluminationDetector structure includes the following fields:

Field	Type	Description
AllowMovement	boolean	If true, "continue to run even if robot is moving"
ClassifierConfigPath	string	Path to the illumination classifier configuration file
DarkenedMaxProbability	float	The "max probability to result in 'Darkened' class"
FeaturePercentileSubsample	uint	"Stride for building histogram to compute percentiles"
IlluminatedMinProbability	float	The "min probability to result in 'Illuminated' class"

Table 472: *The IlluminationDetector structure*

85.1.4 InitialModeSchedules

The InitialModeSchedules provides the default frequency that each vision processing step is run. (And step not listed here, the default is that it is not scheduled to run). The structure includes the following fields:

Field	Type	Description
AutoExp	uint	Run the auto exposure step every n frames.
Markers	uint	Run the markers step every n frames.
WhiteBlance	uint	Run the white balance step every n frames

Table 473: *The InitialModeSchedules structure*

85.1.5 ImageCompositing

The ImageCompositing The structure includes the following fields:

Table 474: The ImageCompositing structure

Field	Type	Description
imageReadyPeriod	uint	
numImageReadyCyclesBeforeReset	uint	
percentileForMaxIntensity	uint	

85.1.6 ImageQuality

The ImageQuality structure includes the following fields:

Table 475: The ImageQuality structure

Field	Type	Description
CyclingTargetValues	float[]	"When 'cycling' exposure is enabled, the target values to use." Each value must be in the range 0 to 255
HighPercentile	float	Range 0.0 to 1.0
InitialExposureTime_ms	uint	"Sent each time we request camera calibration"
LowPercentile	float	Range 0.0 to 1.0
MaxChangeFraction	float	"Relative amount we can change current exposure/wb each update, zero disables." Range: 0.0 to inf
MeterFromDetections	boolean	"Base auto-exposure on detected markers, faces, etc, if any"
RepeatedErrorMessageInterval_ms	uint	The "time between error messages once triggered"
SubSample	uint	
TargetPercentile	float	Range 0.0 to 1.0
TargetValue	uint	"Try to make targetPercentile have this value." Range 0 to 254
TimeBeforeErrorMessage_ms	uint	"How long [the] Vision System must detect `bad' quality before notifying game"
TooBrightValue	uint	"'Too Bright' if LowPercentile is above this"
TooDarkValue	uint	"'Too Dark' if HighPercentile is below this"

85.1.7 MotionDetector

The MotionDetector structure includes the following fields:

Table 476: The MotionDetector structure

Field	Type	Description
CentroidStability	float	"How quickly should peripheral motion detection track the source of motion."
DecreaseFactor	float	"The higher this number, the more quickly motion detection forgets about motion."
HorizontalSize	float	"Fraction of the width of the image to be used for peripheral motion detection (right and left)."

IncreaseFactor	float	"The higher this number, the more sensitive is motion detection to motion."
MaxValue	float	"The higher this value, the sooner peripheral motion detection will be triggered."
VerticalSize	float	"Fraction of the height of the image to be used for peripheral motion detection (top)"

85.1.8 NeuralNets

The NeuralNets structure includes the following fields:

Table 477: *The NeuralNets structure*

Field	Type	Description
Models	Model[]	An array of TensorFlow Lite model configuration structures (see below).
ProfilingEventLogFrequency_ms	uint	How often to log information about the model execution timing.
ProfilingPrintFrequency_ms	uint	How often to print (to TBD) information about the model execution timing.

The Models is an array of structures. Each structure has the following fields:

Table 478: The TensorFlow Lite model configuration structure

Field	Type	Description
architecture	string	
benchmarkRuns	uint	If non-zero, gather duration and resource usage information for each run.
graphFile	string	The name of the TensorFlow Lite file (.tflite) to load to implement this model
inputHeight	uint	The height, in pixels, of the input image. Typically 128
inputLayerName	string	The name of the input layer in the TensorFlow Lite file.
inputWidth	uint	The width, in pixels, of the input image. Typically 128
inputScale	float	When the input data type is "float", the data is first scaled by this number, then the shift value is added: float_input = data / inputScale + inputShift
inputShift	int	
labelsFile	string	The name of the text file (.txt) that gives text strings for the classification output of the model.
memoryMapGraph	uint	?If non-zero, memory-map the TensorFlow Lite file in, rather than loading it with file reads.
minScore	float	If the highest "score" for a label is below this value, none of the items was recognized in the image.
modelType	string	"TFLite" for TensorFlow Lite files.
networkName	string	The name of the vision processing step.
numGridCols	uint	*Optional.*
numGridRows	uint	*Optional.*
outputLayerNames	string	The name of the output layer in the TensorFlow Lite file.
outputType	string	"classification" vs "binary_localization"
pollPeriod_ms	uint	
timeoutDuration_sec	float	?The time to allow the model to run in a background thread without any results before it is considered timed out, and must be restarted?
useFloatInput	uint	If non-zero, use float data type within the model
useGrayscale	uint	
verbose	uint	If non-zero, provide verbose output during the interpretation of the model.

TensorFlow model files

The TensorFlow Lite models are stored in:

/anki/data/assets/cozmo_resources/config/engine/dnn_models

The last part of the path is hardcoded into libcozmo_engine.so.

85.1.9 OverheadMap

The OverheadMap is a floor map being constructed by Vector. This structure is used to configure the size. "Bigger sizes do not impact computation, only memory." This structure includes the following fields:

Table 479: The OverheadMap structure

Field	Type	Description
NumCols	uint	The number of columns in the map.
NumRows	uint	The number of rows in the map.

85.1.10 PerformanceLogging

The PerformanceLogging provides the frequency to log stats about the vision processing. The structure includes the following fields:

Table 480: The PerformanceLogging structure

Field	Type	Description
DropStatsWindowLength_sec	uint	"How long to average dropped image stats"
TimeBetweenProfilerDasLogs_sec	uint	"How often to print Profiler info messages to the logs"
TimeBetweenProfilerInfoPrints_sec	uint	"How often to log Profiler DAS events"

85.1.11 PetTracker

The PetTracker structure includes the following fields:

Table 481: The PetTracker structure

Field	Type	Description
DetectionThreshold	uint	Range is 0 to 1000
InitialSearchCycle	uint	Range is 1 to 45
NewSearchCycle	uint	Range is 5 to 45
MaxFaceSize	uint	
MaxPets	uint	The maximum number animals that are detectable & trackable at the same time.
MinFaceSize	uint	
TrackSteadiness	uint	"10 to 30 in Percentage change required to actually update size/position"

Comment: The ability to search for a lost pet would have been *really cool*.

85.2. SCHEDULE MEDIATOR CONFIGURATION FILES

The scheduling for the different vision system modules – how often each processing step is run – is configuration in file located at:

/anki/data/assets/cozmo_resources/config/engine/visionScheduleMediator_config.json

This path is also hardcoded into libcozmo_engine.so.

This is an array of structures. Each structure gives the frequency to run a given image processing step, for each of the vision processing subsystems modes. 1 means "runs every frame," 4 every fourth frame, and so on. The structure has the following fields:

Field	Type	Description
high	uint	When in high "mode" run the image processing step every n frames. This value must be a power of two.
low	uint	When in low "mode" run the image processing step every n frames. This value must be a power of two.
med	uint	When in medium "mode" run the image processing step every n frames. This value must be a power of two.
mode	string	The name of the image processing step
relativeCost	uint	A "heuristic weighting to drive separation of heavy-weight tasks between frames where 1 should indicate our lowest cost process e.g. "Markers" is ~16x as resource intensive as "CheckingQuality"
standard	uint	When in medium "mode" run the image processing step every n frames. This value must be a power of two.

Table 482: *The vision schedule configuration JSON structure*

85.3. PHOTOGRAPHY CONFIGURATION FILES

The photography subsystem configuration in file located at:

/anki/data/assets/cozmo_resources/config/engine/photography_config.json

This path is also hardcoded into libcozmo_engine.so.

This is structure has the following fields:

Field	Type	Description
MaxSlots	uint	
MedianFilterSize	uint	"If > 0, enables a median filter before saving. Must be odd. 3 or 5 are reasonable values."
SharpeningAmount	float	0.0 disables sharpening
RemoveDistortion	boolean	
SaveQuality	uint	
ThumbnailScale	float	

Table 483: *The photography configuration JSON file*

86. RESOURCES & RESOURCES

ARM, Neural-network Machine learning software repo
https://github.com/ARM-software/armnn

Barrett, L. F., Adolphs, R., Marsella, S., Martinez, A. M., & Pollak, S. D. Emotional *expressions reconsidered: Challenges to inferring emotion from human facial movements*. Psychological Science in the Public Interest, 20, 1–68. (2019). doi:10.1177/1529100619832930
https://journals.sagepub.com/stoken/default+domain/10.1177%2F1529100619832930-FREE/pdf

This paper describes the limitations and high error rate of facial expression software.

FloydHub, *Teaching My Robot With TensorFlow*, 2018 Jan 24,
https://blog.floydhub.com/teaching-my-robot-with-tensorflow/

Google, *MobileNets: Open-Source Models for Efficient On-Device Vision, 2017*, Jun 14,
https://ai.googleblog.com/2017/06/mobilenets-open-source-models-for.html

Hollemans, Matthijs. *Google's MobileNets on the iPhone*, 2017 Jun 14
https://machinethink.net/blog/googles-mobile-net-architecture-on-iphone/

MobileNet version 2, 2018 Apr 22
https://machinethink.net/blog/mobilenet-v2/

These two blog posts give an excellent overview of the mechanics of the MobileNet architecture.

Omron, *Human Vision Component (HVC-P2) B5T-007001 Evaluation Software Manual*, 2016
http://www.farnell.com/datasheets/2553338.pdf

Omron, *OKAO Vision Software Library*
https://www.components.omron.com/sensors/image-sensing/solution/software-library

Qualcomm, *How can Snapdragon 845's new AI boost your smartphone's IQ?*, 2018 Feb 1
https://www.qualcomm.com/news/onq/2018/02/01/how-can-snapdragon-845s-new-ai-boost-your-smartphones-iq

Qualcomm, *Snapdragon Neural Processing Engine SDK Reference Guide*,
https://developer.qualcomm.com/docs/snpe/overview.html

Qualcomm Neural Processing software development kit (SDK) for advanced on-device AI, the Qualcomm Computer Vision Suite

Situnayake, Daniel; Pete Warden, *TinyML*, O'Reilly Media, Inc. 2019 Dec,
https://www.oreilly.com/library/view/tinyml/9781492052036/

Stein, Andrew; *Decoding Machine-Readable Optical codes with Aesthetic Component*, Anki, Patent US 9,607,199 B2, 2017 Mar. 28

TensorFlow, Mobile Net v1
https://github.com/tensorflow/models/blob/master/research/slim/nets/mobilenet_v1.md

"small, low-latency, low-power models" that can recognize a variety of objects (including animals) in images, while running on a microcontroller

TensorFlow, *TensorFlow Lite GPU delegate*
https://www.tensorflow.org/lite/performance/gpu

TensorFlow, *TensorFlow Lite inference*
https://www.tensorflow.org/lite/guide/inference

This Week in Machine Learning (TWIMLAI), episode 102, *Computer Vision for Cozmo, the Cutest Toy Robot Everrrrr! with Andrew Stein*
https://twimlai.com/twiml-talk-102-computer-vision-cozmo-cutest-toy-robot-everrrrr-andrew-stein/

Viola, Paul; Michael Jones, *Rapid Object Detection using a Boosted Cascade of Simple Features,* Accepted Conference on Computer Vision and Patter Recognition, 2001 http://wearables.cc.gatech.edu/paper_of_week/viola01rapid.pdf

Wikipedia, *Adaptive histogram equalization* https://en.wikipedia.org/wiki/Adaptive_histogram_equalization

Wikipedia, *Viola-Jones object detection framework* https://en.wikipedia.org/wiki/Viola%E2%80%93Jones_object_detection_framework

Viola, Paul; Michael Jones, *Robust Real-time Object Detection,* International Journal of Computer Vision (2001) http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.110.4868

Example code for running a TensorFlow Lite model on a PC https://github.com/ctuning/ck-tensorflow/blob/master/program/object-detection-tflite/detect.cpp

CHAPTER 20

Mapping & Navigation

Vector builds an internal map to track where he can drive, where objects and faces are.

- Mapping Overview
- Navigation and Path Planning

87. MAPPING OVERVIEW

Vector tracks objects in two domains:

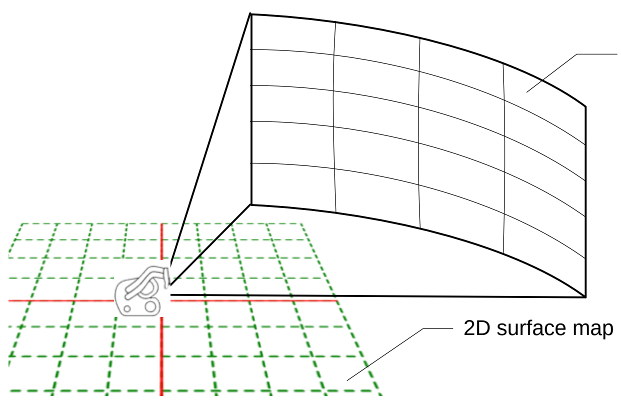


Figure 85: *Mapping contexts*

- A 2D map that is used to track where objects (especially objects whose marker symbols he recognizes), cliffs, and other things are on the surfaces that he can drive on. Vector uses this map to navigate. This map has an arbitrary origin and orientation.
- Vector also tracks where faces, pets and some kinds of recognized objects are in his camera image area; these objects are tracked in the image pixels. (Never mind that the camera pose can change!)

Vector's 2-D surface map system works with the localization and navigation subsystem. It uses several sensors to know

- Cliff sensors to detect edge, and lines
- Time of flight sensor to measure distances
- Vision to detect the edges, and the location of a hand
- Vision to identify accessories by recognizing markers

88. MAP REPRESENTATION

Vector keeps tracks of the surface that he can drive on with a navigable 2D map. The map's orientation and position of its origin are arbitrary – Vector just picks a spot and goes with it. The surface map is represented in a compressed format called a quad-tree.

Vector tracks accessory objects, immovable obstacles, and cliffs in terms of this map. The map's units are in mm.

88.1. QUAD-TREE MAP REPRESENTATION BASICS

A *quad-tree* is a structured way of "compressing" the information in the map, to reduce the amount of memory required. A quad-tree that recursively breaks down a grid into areas that are interesting, and those that are note.

quad-tree

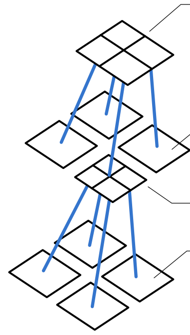


Figure 86: *Structure of a quad-tree*

The tree has two kinds of nodes: inner nodes and leaf nodes:

- The inner nodes do not hold any information about the region (except its size). Instead they point to 4 child nodes at the next lower layer. The top most node is called the *root node.*
- The *leaf nodes* of the tree are square cells (called *quads*) that hold information about what is there (or that the area is unexplored).

Each node represents a square area. The size of the square depends on how many levels it is from the root node. The root node covers the whole map. The nodes in the next layer down are half the width and height of the root node. (In general, a node is half the width and height of a node the next layer up.) *Nodes (including quads) at the same level – the same distance from the root node – are the same size*. Each node's coordinates can be figured in a similar way by knowing the coordinates of the root node.

When Vector reaches the edge of his map area and needs to expand it, he has to add a new node at the top (this becomes the new root node) and adds nodes down until it can contain the info at the edge of the map.

88.2. THE MAP'S STARTING POINT

Vector doesn't have a "north pole" or other global reference point to center his map on. When he powers on, or "whenever Vector is delocalized (i.e. whenever Vector no longer knows where he is – e.g. when he's picked up), Vector creates a new pose starting at (0,0,0) with no rotation. As Vector drives around, his pose (and the pose of other objects he observes – e.g. faces, his [cube], charger, etc.) is relative to this initial position and orientation."

Anki SDK

Client applications (the ones that talk via the HTTPS API) may also wish to know that the map was thrown out and a new one created – and thus know they should toss out their map and location of objects. Vector associates a unique identifier with each generation of the map called `origin_id`. Whenever a new map is created the "`origin_id` [is] incremented to show that [the] poses [of the map, Vector, and objects in the world] cannot be compared with earlier ones." "Only poses of the same origin_id can safely be compared or operated on."

88.3. HOW THE MAP IS SENT FROM VECTOR TO SDK APPLICATIONS

sending the quad-tree

The full quad-tree is not sent from Vector to an SDK, only the leaf nodes (quads). Quads are the only part of the tree that hold information about what is in an area. They also have sufficient information to reconstruct a quad-tree, which is a useful access structure.

89. MEASURING THE DISTANCE TO OBJECTS

Vector has a time of flight sensor, pointing straight ahead. (See Chapter 2 for a description of the physical location.) He can use the sensor to measure the distance to the objects, barriers, open spots on the map, and to estimate his position. The sensor can be blocked by the arms, if they are in just the right lowered position – such as approaching an object and docking with it.

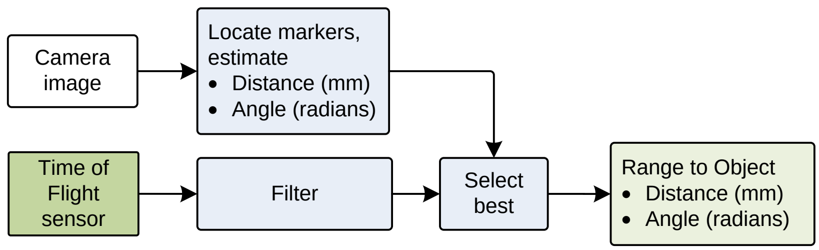


Figure 87: *A typical localization and mapping functional block diagram*

If the sensor is not blocked:

- The samples of distances reported by the sensor are gathered,
- A filter is applied to them (probably a median filter), throwing out values that are too near or too far.
- Combining this with Vectors current position and orientation, and the distance to the object, he can estimate the objects position; and
- Vector can infer that the space between him and the object are free of other objects and obstacles. (This means splitting up the map quads into a fine-grained resolution along the narrow beam path.)

In addition to this, if the object has a known marker, the vision system estimates the angle of the object, and a distance to it. This is based on the known visual size of the marker, and the observed size. If the time of flight sensor is not blocked, only the angle need be used. If the sensor *is blocked*, the visually estimated distance to the object can be used instead.

89.1. FILTERING

The time of flight sensor emits a stream of pulses that are detected by a grid of *single photon avalanche diode* (SPAD) detectors. The detectors measure two things:

1. The duration from the time that the pulse was emitted; this is a direct measure of the distance to the object.
2. A count of the number of photons received back from the object. This is a measure of how reflective the object is. This can potentially be used to distinguish between two different objects.

The sensor gathers the distances into a histogram counting the number of times each distance was measured. At regular intervals the body-board firmware gets the data from the sensor, resetting the counts and the histogram. The data is then sent to the head-board.

The software has to clean up the histogram since it is very noisy, with lots of spikes:

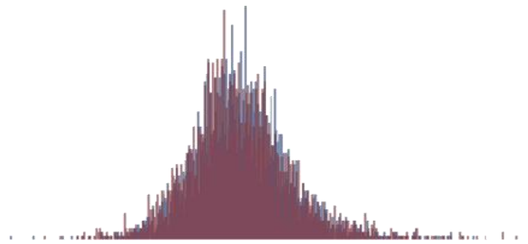


Figure 88: *A typical histogram from a time of flight sensor.*
ST Microelectronics

Comment: The histogram is actually part of how the sensor cleverly rejects noise. The detectors will pick up light from other sources, such as bright sunlight. By using pulses and controlling when they are sent, the sensor can measure the background (or ambient) light level, and better discriminate its own light pulses from the rest. The noise can come from the light be reflected back by dirt on the sensor lens, dust in the atmosphere, light bouncing around and coming back a little later than the directly reflected light. Gathering the measurements into a histogram spreads the noise out, mostly randomly, making it easier to pick out the useful measurement.

The easiest way to eliminate the histogram spikes is to do a pass over, setting each points value to be the weighted average of the values to the left and right. Values below a noise floor can be tossed out.

Then a good distance measurement can be found by looking for the peak or by finding the median.

89.1.1 VL53L1X next generation sensor

Vector is built with a VL53L0X sensor. But Vector's software is structured to support processing data from its much more powerful sibling VL53L1X sensor. Anki was investigating this sensor for use in future Cozmo generations, and performing engineering evaluations using a modified Vector.

The VL53L1X's detector is a 16x16 grid of SPAD detectors. The sensor can be configured to use rectangular areas of the detector grid, called the *region of interest* (ROI), instead of the whole grid:

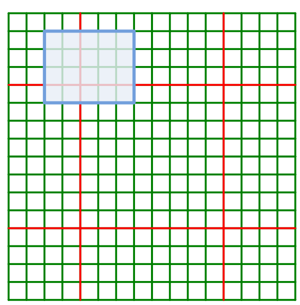


Figure 89: *Sensing regions of interest*

With the sensors field of view, different regions look in different directions. By creatively choosing regions to get measurements from – and using the reflectivity measurement to distinguish between objects – the software could look around, track multiple objects and scan the driving surface. In other words, it could work like a low-resolution depth sensing camera, with a very good measurement of depth and surface reflectivity. It can even detect swiping motions.

Since Anki had placed the time of flight sensor in the robot's *head*, near the camera, there was more potential for smarter interaction. Obviously, the head could scan up and down, giving a much wider range of looking for cliffs, distance to objects higher than a few centimeters and such. The recognition would have had another signal to help it improve hand, face, and pet detection. The face recognition software would have better ability to tell if it was looking at an image or a real face – by knowing the distance, it could tell if the face was a plausible size.

89.2. INTERNAL DATA STRUCTURES

The ranging modules produce several JSON structures for internal use. The first main output structure, DistanceSensorData, has the following fields:

Field	Type	Units	Description
proxDistanceToTarget_mm	float	*mm*	The distance to object, as measured by the time of flight sensor.
visualAngleAwayFromTarget_rad	float	*radians*	The targets relative orientation angle, as estimated by the vision system.
visualDistanceToTarget_mm	float	*mm*	The distance to object, as estimated by the vision system.

Table 484: *DistanceSensorData parameters*

89.2.1 Raw Range Data

The second main output data structure, RangeSensorData, is very similar, but links to source data. It has the following fields:

Field	Type	Units	Description
headAngle_rad	float	*radians*	The angle (tilt) of the robots head.
rangeData	RangeDataRaw		The data from the time of flight sensor.
visualAngleAwayFromTarget_rad	float	*radians*	The targets relative orientation angle, as estimated by the vision system.
visualDistanceToTarget_mm	float	*mm*	The distance to object, as estimated by the vision system.

Table 485: *RangeSensorData parameters*

The sensor-related data structures involve a complex nesting of structures. To help clarify:

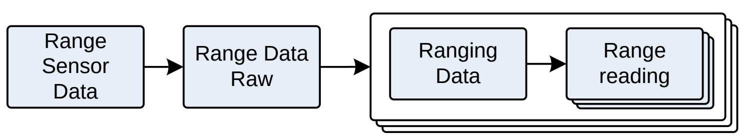


Figure 90: *The time of flight data structures.*

The RangeDataRaw structure is just a link to an array of arrays of measurements. It has the following fields:

Field	Type	Units	Description
data	RangingData[]		An array of the sensor data to process, and the results.

Table 486: *RangeDataRaw parameters*

The RangingData structure has the following fields:

Field	Type	Units	Description
numObjects	uint	*count*	A count of the number of objects seen in the regions.
processedRange_mm	int	*mm*	The range to the object after processing & filtering of the data
readings	RangeReading[]		The range readings reported from the time of flight sensor
roi	uint		The region of interest that was measured.
roiStatus	uint		A code indicating whether there is a valid measurement for this region.
spadCount	float		"the time difference (shift) between the reference and return [detector] arrays." This translates to distance to the target.

Table 487: *RangingData parameters*

The RangeReading structure is basically identical to the structure in ST's software to interface with the time of flight sensor. It has the following fields:

Field	Type	Units	Description
ambientRate_mcps	float	*mcps*	The ambient number of counts; this is the noise floor
rawRange_mm	int	*mm*	
sigma_mm	float	*mm*	The distance to the target
signalRate_mcps	float	*mcps*	The "return signal rate measurement… represents the amplitude of the signal reflected from the target and detected by the device."
status	uint		A code with 0 indicating a valid measurement, otherwise indicating an error during measurement or processing.

Table 488: *RangeReading parameters*

Note: *mcps* is mega counts per second.

89.2.2 Display-Ready Range Data

The RangeDataDisplay structure is just a link to an array of arrays of measurements. It has the following fields:

Field	Type	Units	Description
data	RangingDataDisplay[]		The ranging data, for potential display.

Table 489: *RangeDataDisplay parameters*

The RangingDataDisplay structure is basically identical to the structure in ST's software to interface with the time of flight sensor. It has the following fields:

Table 490: RangingDataDisplay parameters

Field	Type	Units	Description
padding	uint		Likely a CLAD structure field that is reserved for future use that was automatically converted to JSON.
processedRange_mm	float	*mm*	The range to the object after processing & filtering of the data
roi	uint		The region of interest that was measured.
roiStatus	uint		A code indicating whether there is a valid measurement for this region.
spadCount	float	*count*	"the time difference (shift) between the reference and return [detector] arrays." This translates to distance to the target.
signalRate_mcps	float	*mcps*	The "return signal rate measurement… represents the amplitude of the signal reflected from the target and detected by the device."
status	uint		A code with 0 indicating a valid measurement, otherwise indicating an error during measurement or processing.

90. BUILDING THE MAP

The map is made as Vector drives around – when he is on a mission, or just exploring. Each of the leaf quads (in the map) is associated with information about that space and what is contained there:

- What Vector knows is in the quad –a cliff, the edge of a line, an object with a marker symbol on it, or an object without a symbol (aka an obstacle),
- A list of what Vector *doesn't* know about quad – i.e. that he doesn't know whether or not there is a cliff or interesting line edge there,
- Whether Vector has visited the quad or not.

Vector subdivides quads to better represent the space. The quad probably is only slight bigger than the object in it. But the quad (probably) can be smaller than the object, to accommodate the object not oriented and aligned to fit quite perfectly in the quad. More than quad can refer to a contained object.

90.1. MAPPING CLIFFS AND EDGES

If a cliff (surface proximity) sensor has a large, significant change in value, Vector will make a note that there is a cliff sensor there. If the value has a smaller, but still noticeable change, he might make a note that there is a line edge there – an edge between a dark area and a light area.

90.2. TRACKING OBJECTS

Vector tracks objects (especially objects with markers) using the map, and other cross-referencing structures. Vector associates the following information with each object it tracks:

- The object's kind (dock, cube, etc)
- A pose. The image skew of the marker symbol gives some partial attitude (relative orientation) information about the object and Vector can compute an estimated orientation (relative to the coordinate system) of the object from this and Vector's own pose. Vector can estimate the objects position from his own position, orientation, and the distance measured by the time of flight sensor.
- A size of the object. Vector is told the size of objects with the given symbol.
- A link to a control structure for the kind of object. For instance, accessory cubes can be blinked and sensed.

If he sees a symbol, he uses the objects known size, the image scale, its pose (if known) and any time-of-flight information to (a) refine his estimated location on the map, (b) update the location and orientation of that object.

90.3. BUILDING A MAP WITH SLAM

Vector employs a mapping technique known as *simultaneous location and mapping* (SLAM) to integrate these (and other) steps. SLAM is a method to identify Vector's current position and orientation (relative to the map), and to construct that map.

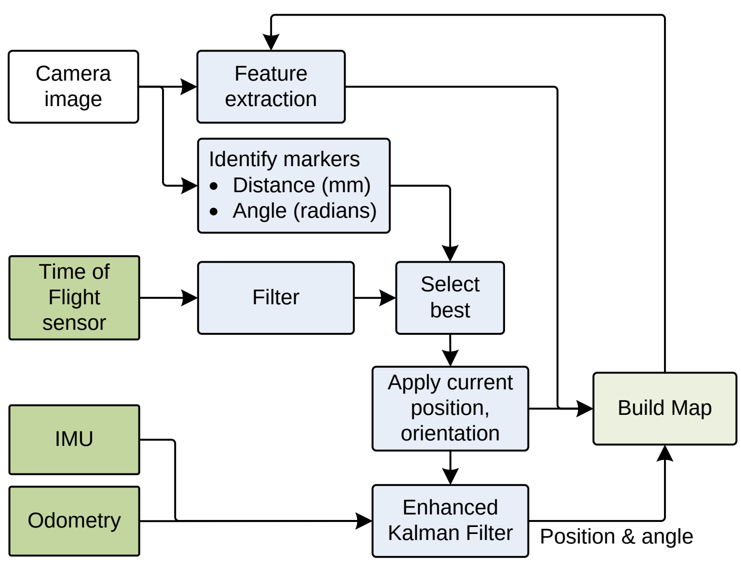


Figure 91: *A typical localization and mapping functional block diagram*

SLAM consists of multiple parts. It integrates the sensor for distance and movement. It also uses image processing to figure it out where it is at. It identifies landmarks, and information about them. In a sophisticated integration process, it can estimate Vector's orientation *and* if an object has moved. The estimate of Vectors orientation is based on turn information from the IMU, and refined by what it can see.

91. NAVIGATION AND PLANNING

Path planning is devising a path around obstacles without collision, to accomplish some goal, such as docking with the "home" (charger) or accessory cube. Intuitively, all you need to with a rectilinear grid is to figuring out the x-y points to go from point A to B. Vector (and Cozmo) is longer than they are wide – especially when carrying a cube. If this isn't taken into account by the planner, Vector could get stuck going down some path he can't fit in or turn around in. Cozmo had an XY-theta planner to construct paths that he could traverse.

Vector's path planning approach is unknown.

92. RESOURCES & RESOURCES

Riisgaard, Søren; Morten Rufus Blas; *SLAM for Dummies: A Tutorial Approach to Simultaneous Localization and Mapping*
http://www-inst.eecs.berkeley.edu/~ee290t/fa18/readings/Slam-for-dummies-mit-tutorial.pdf

ST Microelectronics, *UM2039 World smallest Time-of-Flight ranging and gesture detection sensor Application Programming Interface*, Rev, 2016 Jun
https://www.st.com/resource/en/user_manual/dm00279088-world-smallest-timeofflight-ranging-and-gesture-detection-sensor-application-programming-interface-stmicroelectronics.pdf

ST Microelectronics, *UM2600 Counting people with the VL53L1X long-distance ranging Time-of-Flight sensor*, Rev 1, 2019 Jun
https://www.st.com/resource/en/user_manual/dm00626942-counting-people-with-the-vl53l1x-longdistance-ranging-timeofflight-sensor-stmicroelectronics.pdf

Wikipedia, *Occupancy grid mapping*,
https://en.wikipedia.org/wiki/Occupancy_grid_mapping

Vector's map is based on occupancy grids, except it does not use probabilities.

CHAPTER 21

Accessories

Vector's accessories include his charging station, companion cube, and custom items that can be defined thru the SDK.

- Accessories in general: symbols, docking
- Home & Charging Station
- Companion cube, which is "smart," sensing movement, orientation, taps being held and is able to provide feedback via lights
- Custom items

93. ACCESSORIES IN GENERAL

Accessories have at least one maker symbol that Vector can recognize. Vector tracks the location and orientation based on this.

93.1. DOCKING

Docking is a behaviour/action that is used for both approaching the cube, charging station (home), and other marked items.

It has specialized steps depending on whether it is a cube, the home, etc.

94. HOME & CHARGING STATION

Vector has a rich set of behaviours associated with its Home / Charger. In retrospect, this makes sense, as it is Vectors home, his nest, his comfy chair.

94.1. DOCKING

Vector's step in docking with the charging station are:

1. Approach and line up with the charger
2. Turn around (rotate 180°)
3. Reverse and back up the ramp. Vector uses a line follower, with his cliff sensors, to drive straight backwards. (Since he is going backwards, he can't use vision.) He uses the tilt of the ramp to confirm that he is on the charger
4. He also checks that he is in the right spot by looking for power to his charging pads, as reported by body-board charging circuit. If he is unable to find the spot, he grumbles about it, drives off and retries.

Vector has a cute low light mode that turns on most of the pixels on his display to see a bit more, and locate his home.

95. COMPANION CUBE

Vector has a companion cube that he can pickup, illuminate the lights on, and detect taps. The cubes design is described in chapter 5.

Vector can roll his cube, shove it around, use it to "pop a wheelie," and pick it up. To do these, he must line up squarely with cube. Vision was found to be needed in the Cozmo to align precisely enough to get the lift hooks into the cube.

95.1. COMMUNICATION

Vector connects with the cube via Bluetooth LE. This communication link provides the ability for Vector to:

- Discover cubes
- Pair with a cube (note that Vector can pair with only one cube, and if he is not already paired, he will automatically pair with the first cube he receives Bluetooth LE advertising for.)
- Check the firmware version
- Update the cube firmware
- Check the cube's battery level
- Detect the cube orientation
- Detect taps on the cube
- Turn the cubes lights on and off.

The HTTPS API provides the following Cube-related commands:

- List the available cubes, see Chapter 15, section *53.4 Cubes Available*
- Forget (or unpair) from his preferred cube, see Chapter 15, section *53.8 Forget Preferred Cube*
- Pair to the first cube detected, see Chapter 15, section *53.15 Set Preferred Cube*
- Connect to his cube , see Chapter 15, section *53.3 Connect Cube*
- Disconnect from the cube, see Chapter 15, section *53.5 Disconnect Cube*
- Dock with his cube, see Chapter 15, section *53.6 Dock With Cube*
- Flash cube lights, see Chapter 15, section *53.7 Flash Cube Lights* and *53.14 Set Cube Lights*. The later allows using a complex pattern
- Pick up an object (his cube), see Chapter 15, section *53.9 Pickup Object*
- Place his object (his cube) on the ground, see Chapter 15, section *53.10 Place Object on Ground Here*
- Pop a wheelie, see Chapter 15, section *53.11 Pop A Wheelie*
- Roll his cube, see Chapter 15, section *53.12 Roll Block* and *53.13 Roll Object*

The state of the cube is reported to the HTTPS API.

As the state of the cube changes, the following events are posted to the API:

- The cubes battery level, see Chapter 15, section *53.2.1 CubeBattery*
- A loss of the connection with the cube, see Chapter 15, section *53.2.2 CubeConnectionLost*
- The robot state event (see Chapter 15, section *63.3.1 RobotState*) provides other info about Vector's attempt to interact with the cube. This includes what object he is carrying. There are bits to indicate when
    - Vector is carrying his cube
    - His picking up or moving to dock with his cube
- The object event (see Chapter 15, section *45.2.1 ObjectEvent*) provides other info about the state of the cube as it happens: taps, loss of connection, state of connection, being moved, etc.

95.2. ACCELEROMETER

cube sensing

The cube has an accelerometer built in – the software can used this to determine the cube's orientation, whether it is being held, and to detect taps (or double taps). The software detects these by have the Cube stream accelerometer data, filtering and looking for patterns. In that way, the orientation and being held sensing is very similar to how Vector measure his own orientation and decides if he is being held:

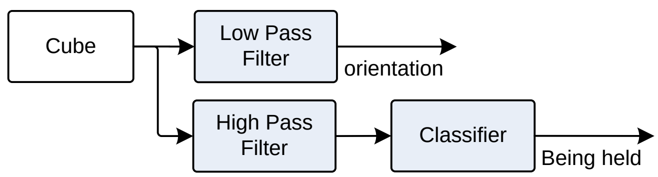


***Figure 92:** Sensing motion events*

The software also detects taps by filtering and looking for shock pattern:

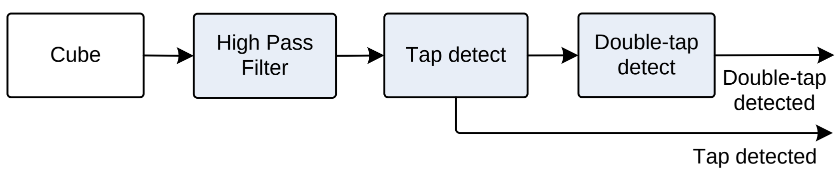


***Figure 93:** The tap detector*

95.3. DOCKING

The docking with a cube is based on the Hanns Maneuver, named for Hanns Tappeiner who described it to his team.

96. CUSTOM ITEMS

Vector can be told about custom objects. Once Vector knows about these, he can identify the object and track it on his map, or navigate around them. Objects with markers are reported to SDK based applications for custom processing.

Defining a custom object takes three kinds of information. First, the shape of the item – whether it is a "wall," box or cube. Second, assign some of the handful of predefined symbols to the item; this is optional. And third, measure the size of the marker symbols and object.

There are four kinds of custom objects that can be defined:

- A fixed, unmarked cube-shaped object.
- A flat wall with only a front side,
- A cube, with the same marker on each side.
- A box with different markers on each side.

96.1. A FIXED, UNMARKED OBJECT (CUBE-SHAPED)

The object is in a fixed position and orientation. This cube can't be observed since it is unmarked. So there won't be any events related to this object. "This could be used to make Vector aware of objects and know to plot a path around them."

96.2. CUSTOM WALL DEFINITION

The second type of custom object is a *wall*. It has a single marker on the front face.

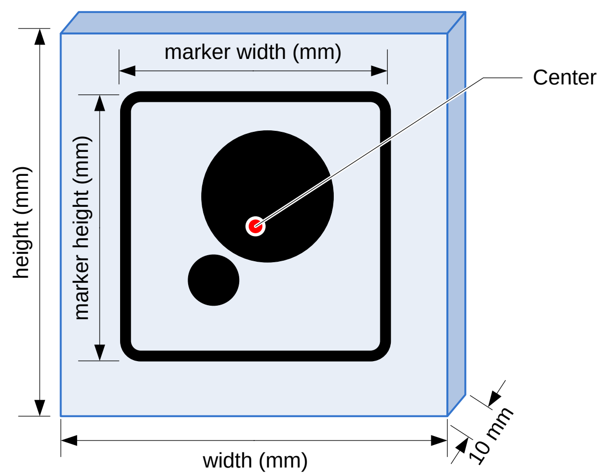


Figure 94: *The custom wall parameters*

The marker must be horizontally and vertically centered. The width of the marker doesn't have to be the same as the height… but probably should be.

The body origin is the 5mm behind the center of the face. When Vector is tracking the position and orientation of this object, the position it gives for the point in the wall 5mm behind the face, at half the height and width – the center of the wall.

96.3. CUSTOM CUBE DEFINITION

The third type of custom object is a *cube*. A cube's width, height and depth are all the same size. A cube has the same marker on all 6 faces (not shown below):

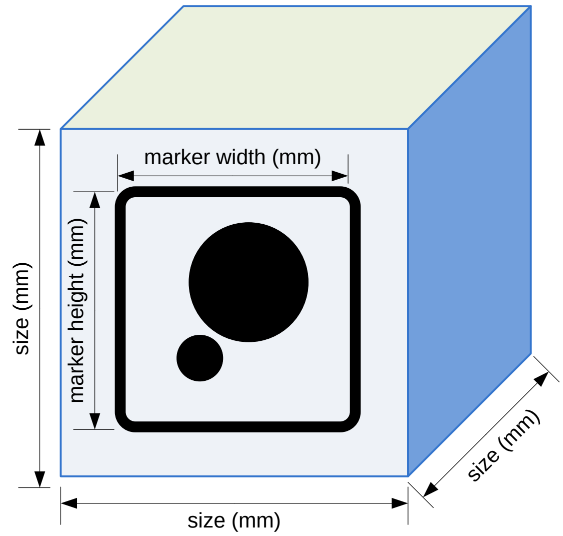


Figure 95: *The custom cube parameters*

The marker must be horizontally and vertically centered on each face. The width of the marker doesn't have to be the same as the height… but probably should be.

The body origin is the very center of the cube. When Vector is tracking the position and orientation of this object, the position it gives is for the very center of the cube, not for a visible face.

96.4. CUSTOM BOX DEFINITION

The fourth (and final) type of custom object is a *box*. Although they have similar names, a custom box differs from a custom cube in two ways. With a box, the height, width and depth can all be different sizes. Second, each face has a different marker symbol associated with it, so that Vector can match it up with the size of that side.

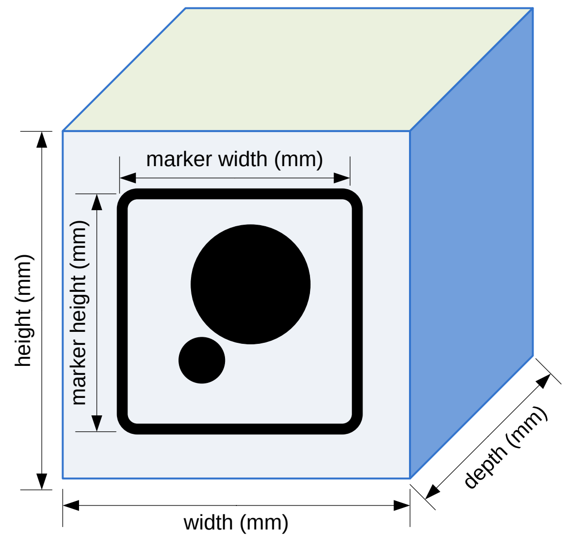


Figure 96: *The custom box parameters*

The marker must be horizontally and vertically centered on each face. The width of the marker doesn't have to be the same as the height… but probably should be.

The body origin is the very center of the box. When Vector is tracking the position and orientation of this object, the position it gives is for the very center of the box, not for a face.

96.5. COMMUNICATION

The Chapter 15 HTTPS API provides the following custom-object related commands:

- Create a custom unmarked object (see Chapter 15 section *45.3 Create Fixed Custom Object*) or one with markers that can be tracked (see Chapter 14 section *45.4 Define Custom Object*)
- Drive to the object, see Chapter 15 section *59.4 Go To Object*. Note Vector thinks in terms of the center of the object, not the face; for larger objects add the distance from the center to the face for Vector's position.

As the state of the cube changes, the following events are posted to the API:

- The object event (see Chapter 15, section *45.2.1 ObjectEvent*) provides other info about the state of the object as it happens: that is observed or lost,, being moved, that it's orientation has changed etc.

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PART V

Animation

Vector uses animations – "sequence[s] of highly coordinated movements, faces, lights, and sounds" – "to demonstrate an emotion or reaction." This part describes how the animation system works.

- ANIMATION. An overview how Vector's scripted animations represents the "movements, faces, lights and sounds;" and how they are coordinated
- LIGHT ANIMATION. An overview of the backpack and cube light animation.
- DISPLAY & PROCEDURAL FACE. Vector displays a face to convey his mood and helps form an emotional connection with his human.
- AUDIO PRODUCTION. A look at Vector's sound effects and how he speaks
- MOTION CONTROL. A look at how Vector's moves.
- ANIMATION FILE FORMAT. The format of Vector's binary animation file.

drawing by Steph Dere

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CHAPTER 22

Animation

This chapter describes Vector's animation engine:

- Animation Engine, animation groups, triggers, and events
- Animation file formats

97. ANIMATION TRIGGERS AND ANIMATION GROUPS

animation

An *animation* is a scripted "sequence of highly coordinated movements, faces, lights, and sounds." Vector uses animations "to demonstrate an emotion or reaction" as well as many other physical moments. Vector's small, light frame allows him to make quick physicals motions to represent his little tantrums and other emotions.

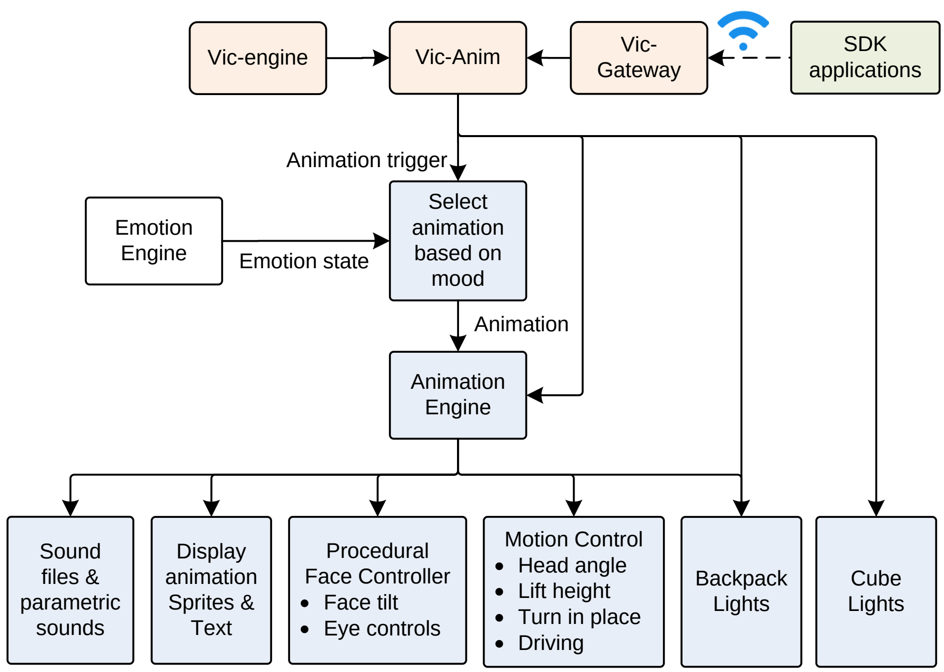

Figure 97: *The behaviour-animation flow*

Not surprising, much of the animation is carried out by vic-anim. The motor controls, including driving along a path, are performed in vic-robot.

animation name
animation trigger name

Vector employs two levels of referring to an animation. Individual animations have an *animation name*. Animations are also grouped together by type, with an identified for the group called an *animation trigger name*. Vector "pick[s] one of a number of actual animations to play based on Vector's mood or emotion, or with random weighting. Thus playing the same trigger twice may not result in the exact same underlying animation playing twice."

97.1. FILES

The animation system employs many files, working in concert to effect the animation. The top level files map trigger names to the next level, which may be groups of animations, display compositing tables, or (in the case the lights) the patterns to illuminate the lights with. In the case of animation groups, these further map to sprite sequences to display (which then maps to image files), and sounds play. The compositing image maps also map to these sprite sequences.

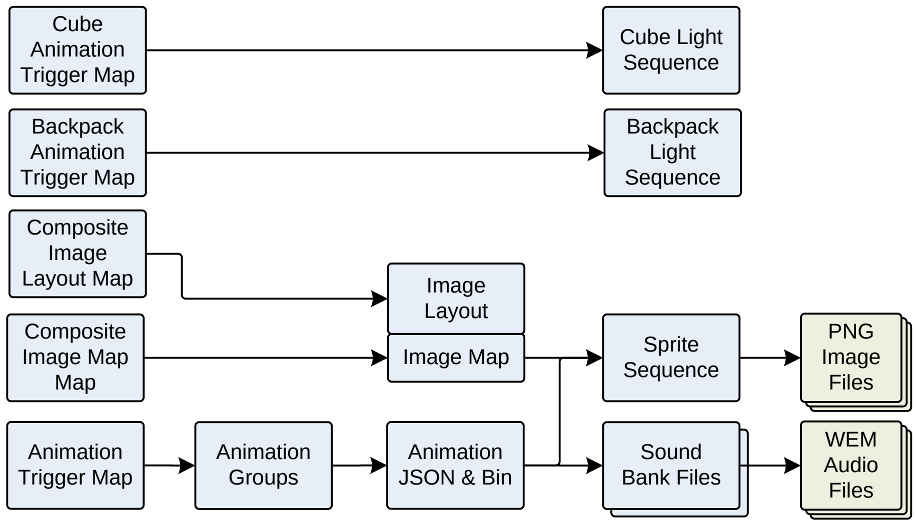

Figure 98: *The behaviour-animation flow*

There are seven types of animation files and other animation sources:

- JSON files that describe how the backpack lights should behave (see Chapter 23)
- JSON files that describe how the cube lights should behave (see Chapter 23)
- Binary animation files holding one or more of related animations that coordinate sophisticated sounds, eye animations, linking together sprite sequences, and coordinate head & lift movements with driving (see Chapter 27 for details of this file)
- JSON animation files are very similar to binary animation files. They hold one or more of related animations that coordinate sophisticated sounds, eye animations, linking together sprite sequences, and coordinate head & lift movements with driving (see Chapter TBD for details of this file)
- Sprite sequences (see Chapter 24), which are folders of PNG image files to display in sequence
- Composited screens (see Chapter 24) showing icons and text information driven by the behaviors and cloud server intents.
- Sound files (see Chapter 25) holding pre-recorded sound effects
- Procedural animations are generated by vic-anim. These perform text to speech, driving around obstacles, animating Vector's eyes, and other tasks that are not practical to script in a file.

And there are four kinds of files gluing these together:

- JSON files that map the trigger names to the *animation groups*, and to the backpack and cube light animations. (These will be described below.)

- The animation group files with rules on how to select one or more individual animations, including with the weighted randomization and emotion filters. (These will be described below.)
- The animation binary file may direct a sprite sequence and/or audio file to play. These will be described in Chapter 27
- JSON files to layout the display; these may call out animation sequences and places to composite icons and text. These will be described in Chapter 24

97.2. NAMING CONVENTIONS

Helpfully, many of the animation files in the resource folders follow a naming convention. The prefix in the name indicates its intended use:

***Table 491:** Animation file prefixes*

Prefix	Used by
*ag_*	Animation groups
*anim_*	Animation files (both binary and JSON)
*face_*	A sprite sequence

The files mapping a name to other files, or other information, end with "Map".

The names of the animation clips start with the base name of the animation file that contains them. (It may even be the same name). This makes it easier to find the animation file given the clip name.

97.3. TRIGGER MAP CONFIGURATION FILES

mapping trigger names to animation groups

The list of animation triggers provided to the SDK is built into libcozmo_engine.so. The internal configuration files support a much wider range of animation triggers; it is not known if passing one these will work, or will be filtered out.

The animation trigger name is mapped to an animation file (and group of animations). The table that defines this mapping is found in the following file:

```
/anki/data/assets/cozmo_resources/assets/cladToFileMaps/AnimationTriggerMap.json
```

(This path is hardcoded into libcozmo_engine.so.)

The format of the files is the same. The file is an array of structures. Each structure has the following fields:

***Table 492:** JSON structure mapping trigger name to animation group*

Field	Type	Description
AnimName	string	The name of the animation group. This is the name of a JSON file, without the ".json" suffix.
CladEvent	string	This is the animation trigger name to match when looking up the animation.

The cube's and backpack light animation file name is usually the same as the trigger, except that the first letter is lower case.

97.4. ANIMATION GROUP FILES

animation groups

In the "AnimationTriggerMap.json" file (describe above), the "AnimName" field value maps (when the suffix ".json" is appended) to animation groups are located in the following folder tree:

```
/anki/data/assets/cozmo_resources/assets/animationGroups
```

This path is hardcoded into libcozmo_engine. Inside are folders (grouping the animation groups), each of which holds the JSON files. By convention, the animation group file names are all lower case. Some names may look similar to the trigger name (but not always).

Each animation group JSON file is a structure with the following fields:

***Table 493:** Animation group file JSON structure*

Field	Type	Description
animations	AnimationGroupItem[]	An array of animations to select from to play.

The AnimationGroupItem structure describes the specific animation clip to use. It may also specify some head movement, with some variability; this is optional. The structure has the following fields:

***Table 494:** AnimationGroupItem structure*

Field	Type	Units	Description
CooldownTime_Sec	float	*seconds*	The minimum duration, after this animation has completed, before it can be used again. Typically 0.0
HeadAngleMin_Deg	float	*degree*	The head is to move to random angle greater (or equal) to this. This should be in the range -22.0° to 45.0°. Only used if UseHeadAngle is true.
HeadAngleMax_Deg	float	*degree*	The head is to move to random angle les than (or equal) to this. This should be in the range -22.0° to 45.0°. Only used if UseHeadAngle is true.
Mood	string	*emotion name*	The name of a "simple mood" that should be applied or "Default". See Chapter 29 for more information on simple moods.
Name	string		The name of the animation clip to play. This clip is defined within one of the animation binary files. The binary file (without the ".bin" suffix) or the JSON file (without the ".json" suffix) for the animation.
UseHeadAngle	bool		If true, this enables the head to be moved to some random within the specified range. *Optional, default is false*
Weight	float		How much "weight' to give to this entry. Typically 1.0

The possible animations are screened for being applicable to the current emotional state (with Mood). The result set is randomly selected from: The weights (of the select items) are summed up and normalized, giving the probability that that entry would be selected.

98. ANIMATIONS

98.1. ANIMATION TRACKS

animation tracks

Each animation may use one more tracks. The tracks can control:

- The display graphics – compositing a movie , text, and eyes layers

- Animating the backpack and cube lights
- Audio effects
- Moving the head
- Moving the lift
- Moving the treads, or navigating

When an animation is played, it locks the tracks that it is using, for the duration of the animation. If one of the tracks that it needs to use is already locked, the animation can't be played (and generates an internal error).

When an animation is submitted to be played, a several of tracks (the lift, head and body) can be flagged to be ignored if they already used elsewhere by animation system.

98.2. ANIMATION FILES

There are two kinds of files: binary and JSON files. The animation binary files are held in the following folder:

`/anki/data/assets/cozmo_resources/assets/animations`

This path is hardcoded into vic-anim. Each of these files may contain several animations (called clips). By convention, the name of the animation starts with the name of the file. See Chapter 27 for a detailed description of these files.

98.3. ANIMATION NAMES MANIFEST

animation duration manifest

A list of animation names and their duration is located in manifest file at:

`/anki/data/assets/cozmo_resources/assets/sprites/anim_manifest.json`

This path is hardcoded into libcozmo_engine. The file is an array of structures. Each structure has the following fields:

Table 495: *JSON structure mapping animation name to duration*

Field	Type	Units	Description
length_ms	int	*ms*	The duration of the animation (when played)
name	string		The name of the animation clip within one of the animation binary or JSON files.

99. SDK COMMANDS TO PLAY ANIMATIONS

The HTTPS SDK includes commands to list and play animations.

- A list of animations triggers can be retrieved with the List Animation Triggers command (see Chapter 15 section *48.3 List Animation Triggers*).
- A list of animations can be retrieved with the List Animation command (see Chapter 15 section *48.2 List Animations*).
- An animation can be play by selecting the animation trigger (see Chapter 15 section *48.5 Play Animation Trigger* command). Vector will select the specific animation from the group. Or,

- An animation can be play by the giving the specific animation name (see Chapter 15 section*48.4 Play Animation*).

As the individual animations are low-level they are the most likely to change, be renamed or removed altogether in software updates. Anki strongly recommends using the trigger names instead. "Specific animations may be renamed or removed in future updates of the app."

CHAPTER 23

Lights Animation

This chapter describes the light animations:

- The Cube Spinner game, which is one user of this type of lights animation
- Backpack Lights animation
- Cube Lights Animation

100. LIGHTS ANIMATION OVERVIEW

The backpack lights are used to show the state of the microphone, charging, WiFi and some other behaviours. The companion cube lights are show setting up the cube, entertainment while Vector is interacting with it, and for games. There are three interrelated sources of light animation.

- Animation binary file to animate the backpack lights. This drives most of the light animation.
- JSON files for the Cube and backpack light animation. There are four kinds of JSON files: files for the Cube's light sequence, files for the backpack light sequence, two files to map animation trigger names to each of those light sequences.
- The Cube Spinner game, which is a notable client of the JSON-driven light animations..

The light animations may be triggered by the cube spinner game configuration, or by behaviors (within libcozmo_engine), such as those related to exploring, interaction, pouncing etc.

The companion cube and backpack light animations are very similar, so they have been grouped here for discussion.

101. CUBE SPINNER GAME

cube spinner game

The cube spinner game was "like a little roulette wheel on the cube. The lights would spin around and you and Vector competed to make them stop at the right combination." Although developed early, it was not enabled in any of the Anki software releases. It is thought that version 1.7 would have enabled it.

The Cube Spinner game's configuration file is located with the behavior folders:

/anki/data/assets/cozmo_resources/$\boxed{\text{config/engine/behaviorComponent/cubeSpinnerLight}}$ $\boxed{\text{Maps.json}}$

This is path hardcoded into libcozmo_engine.

This configuration file is unlike the behavior files in that it doesn't have a behavior class or ID. It is used to map game events to animation triggers for backpack and cube lights. The events names are defined in libcozmo_engine.so. The configuration file structure has the following fields:

***Table 496:** Cube spinner light map JSON structure*

Field	Type	Description
lightMap	LightMap[]	This is an array of alternatives mappings from events to the animation triggers.
playerErrorCubeLights	string	The animation trigger name for the playerErrorCubeLights event.
startGameCubeLights	string	The animation trigger name for the startGameCubeLights event.

Each of the LightMap structures has the following fields:

***Table 497:** LlightMap JSON structure*

Field	Type	Description
backpackLights	BackpackLightMap	This structure maps event to animation trigger names appropriate for the backpack light animation.
cubeLights	CubeLightMap	This structure maps event to animation trigger names appropriate for the cube light animation.
debugColorName	string	A name like "blue". This likely is used to provide the active mapping to a tool during development.

BackpackLightMap is a structures used to map an event to an animation trigger name. The animation trigger name is mapped to backpack light animation, see chapter 22. This structure has the following fields:

***Table 498:** BackpackLightMap JSON structure*

Field	Type	Description
celebration	string	The animation trigger name for the celebration event.
holdTarget	string	The animation trigger name for the holdTarget event.
selectTarget	string	The animation trigger name for the selectTarget event.

CubeLightMap is a structures used to map an event to an animation trigger name. The animation trigger name is mapped to cube light animation, see chapter 22. This structure has the following fields:

***Table 499:** CubeLightMap JSON structure*

Field	Type	Description
celebration	string	The animation trigger name for the celebration event.
cycle	string	The animation trigger name for the cycle event.
locked	string	The animation trigger name for the locked event.
lockedPulse	string	The animation trigger name for the lockedPulse event.
lockIn	string	The animation trigger name for the lockIn event.

102. BACKPACK LIGHTS ANIMATION

The sequence to illuminate the backpack lights is found by

1. The Cube Spinner name produces an animation trigger name
2. The animation trigger name is mapped to an animation file
3. The animation file provides the sequence to illuminate the backpack lights.

102.1. TRIGGER MAP CONFIGURATION FILES

mapping trigger names to light sequences

The table mapping the animation trigger name to the backpack lights animation file is found in the following file:

/anki/data/assets/cozmo_resources/assets/cladToFileMaps/BackpackAnimationTriggerMap.json

This path is hard coded into vic-anim. This file maps the trigger name to the name of the animation file. The file's schema is the same as in Chapter 22, section *97.3 Trigger Map Configuration files*

102.2. THE BACKPACK LIGHTS PATTERN

Vic-anim controls the backpack lights based on specifications in JSON files in

/anki/data/assets/cozmo_resources/config/engine/lights/backpackLights/

The path is hard coded into vic-anim. All of the JSON files have the same structure with the following fields:

***Table 500:** The Backpack LEDs JSON structure*

Field	Type	Units	Description
offColors	array of 3 colors	*RGBA*	Each color corresponds to each of the 3 lower back pack lights. Each color is represented as an array of 4 floats (red, green, blue, and alpha), in the range 0..1. Alpha is always 1.
offPeriod_ms	int[3]	*ms*	The "off" duration for each of the 3 back pack lights. This is the duration to show each light in its corresponding "off" color (in offColors).
offset	int [3]	*ms*	This holds how many milliseconds each light's clock is advanced from the clock driving the animation. This is used to stagger each lights progression through the animation sequence.
onColors	array of 3 colors	*RGBA*	Each color corresponds to each of the 3 lower back pack lights. Each color is represented as an array of 4 floats (red, green, blue, and alpha), in the range 0..1. Alpha is always 1 (the value is ignored).
onPeriod_ms	int[3]	*ms*	The "on" duration for each of the 3 lights. This is the duration to show each light in its corresponding "on" color (in onColors).
transitionOffPeriod_ms	int [3]	*ms*	The time to transition from the on color to the off color.
transitionOnPeriod_ms	int [3]	*ms*	The time to transition from the off color to the on color.

Note: These sequences do not have the parametric variation based on emotion or random weighting.

103. CUBE LIGHTS ANIMATION

The sequence to illuminate the backpack lights is found by

1. The Cube Spinner name produces an animation trigger name
2. The animation trigger name is mapped to an animation file
3. The animation file provides the sequence to illuminate the cube lights.

103.1. TRIGGER MAP CONFIGURATION FILES

The table mapping the animation trigger name to the cube lights animation file is found in the following file:

/anki/data/assets/cozmo_resources/assets/cladToFileMaps/CubeAnimationTriggerMap.json

This path is hardcoded into libcozmo_engine.so. This file maps the trigger name to the name of the animation file.

The file's schema is the same as in Chapter 22, section *97.3 Trigger Map Configuration files,*

103.2. CUBE ANIMATIONS

The cube light animation files are located in:

/anki/data/assets/cozmo_resources/config/engine/lights/cubeLights

and within folders (and sub-folders) therein. This path is hard-coded into libcozmo-engine.

All of the cube light animation JSON files have the same structure. They are an array of structures. (There is usually one item, but there may be more.) Each structure may contain the following fields:

Table 501: *The Cube LEDs JSON structure*

Field	Type	Units	Description
canBeOverridden			Default is true. *Optional.*
duration_ms	float	*ms*	If zero, do this until told to stop, otherwise perform the animation for this period and proceed to next structure or stop.
pattern	*see below*		A structure describing the light patterns. Described below.
patternDebugName	string		A text name that is associated with this structure. *Optional.*

The pattern structure contains the following fields:

Table 502: The Cube LEDs pattern structure

Field	Type	Units	Description
offColors	array of 4 colors	*RGBA*	Each color corresponds to each of the 4 cube lights. Each color is represented as an array of 4 integers (red, green, blue, and alpha), in the range 0..255. Alpha is always 255.
offPeriod_ms	int[4]	*ms*	The "off" duration for each of the 4 cube lights. This is the duration to show each cube light in its corresponding "off" color (in offColors).
offset	int[4]		This holds how many milliseconds each light's clock is advanced from the clock driving the animation. This is used to stagger each lights progression through the animation sequence.
onColors	array of 4 colors	*RGBA*	Each color corresponds to each of the 4 cube lights. Each color is represented as an array of 4 integers (red, green, blue, and alpha), in the range 0..255. Alpha is always 255.
onPeriod_ms	int[4]	*ms*	The "on" duration for each of the 4 cube lights. This is the duration to show each cube light in its corresponding "on" color (in onColors).
rotate	boolean		? Possibly to have the colors be assigned to the next clockwise (or counterclockwise) light periodically?
transitionOffPeriod_ms	int[4]	*ms*	The time to transition from the on color to the off color.
transitionOnPeriod_ms	int[4]	*ms*	The time to transition from the off color to the on color.

This structure is very similar to that used by the backpack lights. The obvious differences are:

- There are 4 lights (instead) of three,
- The RGBA value range is 0..255; and
- There is a boolean "rotate" field.

CHAPTER 24

Video Display & Face

Vector's LCD is used to display his face, which conveys his mood and forms an emotional connection with his human, and to display the results of behaviour interactions:

- The image compositor
- The sprite manager
- Animated compositions
- Procedural face

104. OVERVIEW OF THE DISPLAY

Vector displays imagery – often moving imagery – on his display. The items drawn on the screen include:

- Full screen sprites — each frame is a PNG image that covers the whole display. A sequence of frames (PNGs) is drawn regularly to create the animated effect.
- Composited images and text
- Procedural face to draw the face in a complex way (more on this later)

The first two are used as part of behaviors and intents. A visual "movie" is shown when the behavior starts and another is to provide the response. The compositor map allows mixing in iconography, digits and text to show information in the response.

Vector's eyes are drawn in one of two ways:

- Using the full-screen sprites above, with the eyes pre-drawn in the PNG's
- Using procedural face which synthesizes the eyes

Note: the sprite and procedural face can be drawn at the same time, with sprites drawn over the eyes. This is done to create weather effects over Vector's face.

104.1. ORIGIN

US Patent 20372659

The display system – especially the procedural face module – was pioneered in Cozmo. To prevent burn in and discoloration of the OLED display, Cozmo was given two features. First, Cozmo was given regular eye motion, looking around and blinking. Second, the illuminated rows were regularly alternated to give a retro-technology interlaced row effect, like old CRTs.

Vector's eyes are more refined, but kept the regular eye motion. The interlacing was made optional, and disabled by default.

104.2. RENDERING SYSTEM

The display is layered, placing sprites on top, followed by the compositional layout and, finally, the procedural face.

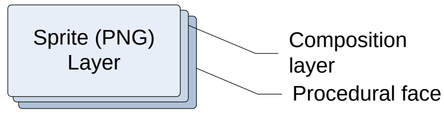

Figure 99: *The display layers*

The rending and compositing these different layers look like:

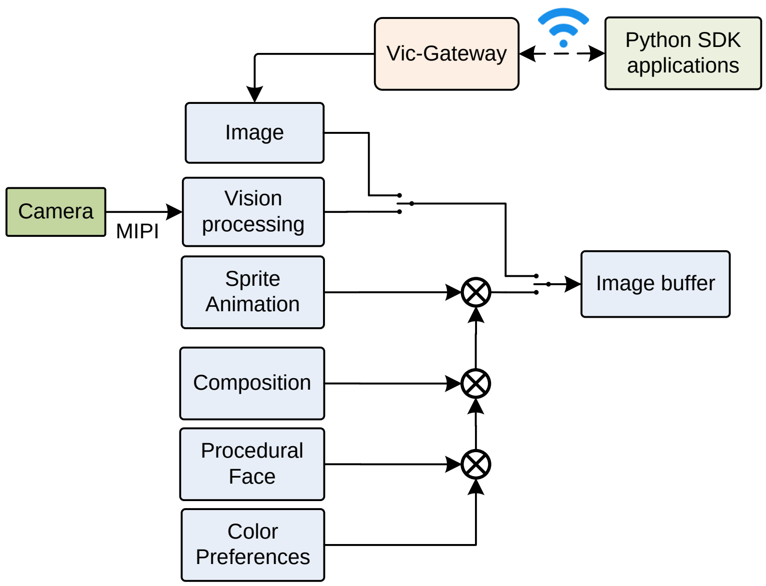

Figure 100: *The display animations composition*

As a functional flow, the top level is:

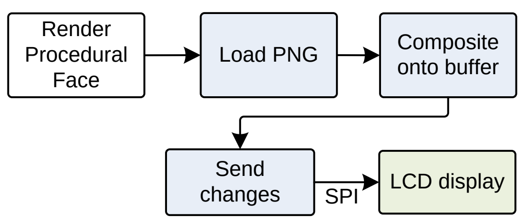

Figure 101: *The display animations functional flow*

104.2.1 Frame buffer

Prior to version 1.0, Vector used the kernel-based frame buffer (/dev/fb0). The frame buffer driver was responsible for buffering the screen image, then transferring it via SPI to the LCD. The frame buffer device driver also tracks the width and height of the screen, and the pixel format, and making the pixel memory available as buffer that processes could memory-map to composite to.

Vector switched to using TBD in the application software to composite the frame, and to transfer the changes to the LCD. It skipped the kernel drivers, except the SPI driver. The effective frame rate was sped up by sending only the changes.

The applications vic-anim, vic-boot-anim, and vic-rescue still reference the frame-buffer /dev/fb0. This is most likely compatibility or fall-back support, and would have been removed in a future release.

105. IMAGE LAYOUT, COMPOSITION, AND SPRITE SEQUENCES

The animation system maps some trigger names to:

- A screen layout defining rectangular areas on the display (called *sprite boxes)* where images and sprite sequences will be drawn.
- Sprite sequence to display in the layout areas. Not all screen layouts have an associated sprite sequence.

These forms are only used by a couple of behaviors, to support the weather, timers, and the blackjack game. Version 1.7 began the process of migrating to a slightly different structure that used the binary animation file.

105.1. BOOT ANIMATION

Vector, while his system starts up, plays an animation on the screen. The boot animation file is a series of uncompressed frames that are played in a loop. Each frame is 184x96 pixels; each pixel is in the RGB565 format. This boot animation is held in the following file:

/anki/data/assets/cozmo_resources/config/engine/animations/boot_anim.raw

The full path is hardcoded into vic-bootAnim.

105.2. MAPPING ANIMATION TRIGGER NAMES TO LAYOUTS

There are two related files used to map animation trigger names to the layout and possible sprite sequence to display.

105.2.1 Maps to layout

The table mapping the layout trigger name to the layout file is found in the following file:

/anki/data/assets/cozmo_resources/assets/cladToFileMaps/CompositeImageLayoutMap.json

This path is hardcoded into libcozmo_engine.so. The format of the file is an array of structures. Each structure has the following fields:

***Table 503:** JSON structure mapping trigger name to composite image layout map*

Field	Type	Description
CladEvent	string	This is the layout trigger name to match when looking up the animation. (This name is also defined in libcozmo_engine)
LayoutName	string	The name of the JSON file (without the ".json" suffix) for the animation.

105.2.2 Maps to Image maps

The following table is used to translate an map trigger name to an image map. This translation table is:

/anki/data/assets/cozmo_resources/assets/cladToFileMaps/CompositeImageMapMap.json

This path is hardcoded into libcozmo_engine.so. The format of the file is an array of structures. Each structure has the following fields:

Field	Type	Description
CladEvent	string	This is the map trigger name to match when looking up the animation. (This name is also defined in libcozmo_engine)
MapName	string	The name of the JSON file (without the ".json" suffix) for the animation.

Table 504: *JSON structure mapping an animation trigger name to an image map*

105.3. LAYOUT FILE

A screen layout defines rectangular areas on the display where images and sprite sequences will be drawn. The layouts are held in folders within:

/anki/data/assets/cozmo_resources/assets/compositeImageResources/imageLayouts

This path is hardcoded into libcozmo_engine.

Each layout is formatted as the array of zero or more structures, although most have a single structure. Each structure has the following fields:

Field	Type	Description
images	SpriteBox[]	An array of sprite boxes for showing icons and other images.
layerName	string	The name of the layer. (This name is also defined in vic-anim and libcozmo_engine) The animation engine may use this to select the procedure(s) in charge managing the layer and sprite boxes.

Table 505: *Display layout JSON structure*

A sprite box defines a rectangular region on the display to draw an imagefrom a file. Each SpriteBox structure has the following fields:

Field	Type	Units	Description
height	int	*pixels*	The height of the sprite box. This should be less than or equal to 96.
spriteBoxName	string		The name of the sprite box. (This name is also defined in vic-anim and libcozmo_engine.) The animation engine may use this to select the procedure(s) in charge managing the layer and sprite boxes. If an image map is available for this animation, the sprite sequence it describes will be displayed in this rectangle.
spriteRenderMethod	string		"CustomHue" if the PNG images should be converted from gray scale to the colour using the current eye colour setting. "RGBA" if the image should be drawn as is.
width	int	*pixels*	The width of the sprite box. This should be less than or equal to 184.
x	int	*pixel*	The x coordinate of the upper left hand corner of the sprite box. The x coordinate can be outside of the display area; only the portion of the image within the display area (0..183) will be shown. This allows an image to slide in.

Table 506: *Sprite box JSON structure placing an image on the display*

y	int	*pixel*	The y coordinate of the upper left hand corner of the sprite box. The y coordinate can be outside of the display area; only the portion of the image within the display area (0..95) will be shown. This allows an image to slide in.

See also Chapter 27 section *117.16 RobotAudio* for an alternate method to define a sprite box.

105.4. IMAGE MAP FILE

An image map describes which sprite sequence to display (it just has a lot of extra steps). The image map files are held in folders within:

/anki/data/assets/cozmo_resources/assets/compositeImageResources/imageMaps

This path is hardcoded into libcozmo_engine.

Each image map file is formatted as the array of zero or more structures, although most have a single structure. Each structure has the following fields:

Table 507: *Image map JSON structure*

Field	Type	Description
images	SpriteMapBox[]	An array of sprite boxes for showing sprite sequences.
layerName	string	The name of the layer. This name is also defined in vic-anim and libcozmo_engine. The animation engine may use this to select the procedure(s) in charge managing the layer and sprite boxes.

Each SpriteMapBox structure has the following fields:

Table 508: *Sprite map box JSON structure*

Field	Type	Units	Description
spriteBoxName	string		The name of the sprite box. (This name is also defined in vic-anim and libcozmo_engine.)
spriteName	string		The name of a sprite sequence. Note: the case of this string may differ from the case used in the sprite sequence folder name.

105.5. INDEPENDENT SPRITES

independent sprites

Independent sprites are PNG files. These image files are held in the following folders:

/anki/data/assets/cozmo_resources/assets/sprites/independentSprites
/anki/data/assets/cozmo_resources/config/sprites/independentSprites
/anki/data/assets/cozmo_resources/config/facePNGs
/anki/data/assets/cozmo_resources/config/devOnlySprites/independentSprites

These paths are hardcoded into libcozmo_engine, vic-anim. and vic-faultCodeDisplay. Not all of the images in those paths are used.

The independent sprite PNG files can be any size so long as it fits within the width and height of the display (184x96). The images may be colored, or in gray scale with an alpha channel. If the sprite is grey-scale, it will be colourized with the current eye colour setting, using the gray scale for the pixel brightness level.

105.6. SPRITE SEQUENCES

sprite sequences

Sprite sequences are PNG files that are displayed sequentially– each PNG makes up each frame of the animation. These image files are held in folder with the same name as the sprite sequence name. The sprite sequence folders are held in:

```
/anki/data/assets/cozmo_resources/assets/sprites/spriteSequences
/anki/data/assets/cozmo_resources/config/sprites/spriteSequences
```

and

```
/anki/data/assets/cozmo_resources/config/devOnlySprites/spriteSequences
```

These paths are hardcoded into libcozmo_engine. Note: the folder name may have a different case than the sprite sequence name used by the SpriteMapBox or the animation; the name should be matched in a case insensitive manner.

The sprite sequence PNG files are sized to fill the display. The images *must* match the width and height of the sprite box they are displayed in, or the display (184x96) if they are employed by a binary animation file. The images may be colored, or in gray scale with an alpha channel. If the sprite is grey-scale, it will be colourized with the current eye colour setting, using the gray scale for the pixel brightness level.

These sprites are displayed as a sequence. The frame number is appended to the file name – range from 2 to 5 digits – starting with 0. The frame rate is computed from the number of images in the sequence (the number of frames) divided by the duration of the animation (given in the animation manifest) that it is associated with.

The images are composited on top of the eye layer. The eyes may haven be turned off, or they may be present.

105.7. DISPLAYING TEXT ON THE SCREEN

When Vector is operating, almost all of the text displayed is composited from image files (sprites). There are two additional procedures that Vector can use to put text on the display:

- drawTextOnScreen() (part of libcozmo_engine)
- OpenCV's putText() (part of OpenCV)

These are procedures are only used in exceptional circumstances. (The typeface is inelegant, if they were something Vector used more frequently; undoubtedly they'd have improved typeface designs.) They are used to display the fault codes (via Vic-faultCodeDisplay), when the system is unable to operate the software; and to display information on the customer care information screen (CCIS) in vic-anim.

106. PROCEDURAL FACE

procedural face

Vector's dynamic, moving eyes are brilliant, forming *the* gateway for an emotion connection. They allow Vector to give eye contact, facial expressions, and his current sentiment. These eyes are drawn by the procedural face manager.

The parameters of the face controls are divided into the overall view of the face and the individual characteristics of each eye:

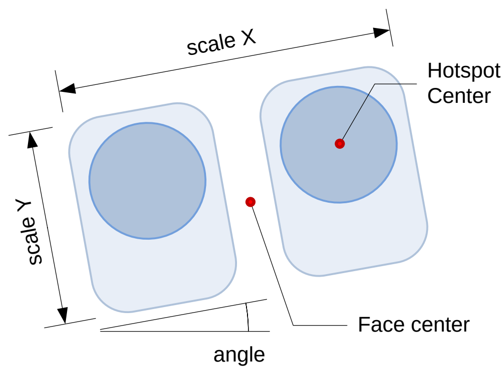

***Figure 102:** Face control points*

face parameters

The high level face animation parameters include:

- The color to draw the eyes in. Vector's eye color is a preference setting, but can be temporarily overridden by the SDK.
- The position of the center of the face
- The angle of the face; tilt (or rotation) of the face gives the impression of tilting the head
- The scaling of the height and width of the face
- The illusion of gaze – the intuition that Vector is looking at something – is achieved by giving each eye a soft spherical rounding effect. The center of the shading, the equivalent of a pupil, may be moved around the eye area. This gives a sense of where Vector is looking – and by moving the center, Vector can appear to be looking around. Coordinated with the face detector, Vector can make (and maintain) direct eye contact.
- The outer shape of the eyes, which gives a sense of the emotions – smiling, frustration, sleep etc.
- There is a *scan line opacity* factor. This controls how much alternating lines are illuminated and darkened. A value of 1.0 has odd and even lines with the same coloring.

Where the eyes are looking is controlled within the procedural face manager, rather than in the animation files. It controls the blink rate, the focus of the eyes and how much the eyes dart around. The manager contributes looking at a face and making eye contact.

106.1. THE RENDERING OF INDIVIDUAL EYES

spherical gradient

The eyes are rendered with a gradient and a shape that is controllable by the animations. These create a soft-face feel, combining the soft glow of the eye, along with rounded eyelids and cheeks.

106.1.1 The Hot spot

The interior of the eye is rendered as a radial gradient from the eyes pupil, with the shape of the eyes forming the clip path. The location of the center of each eye's 'pupil' is called the *hotspot center*:

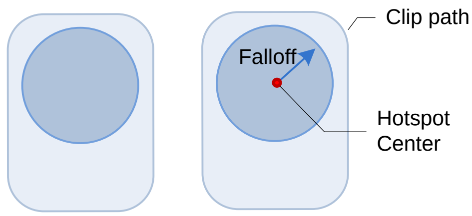

Figure 103: *The hotspot and center*

removing gradient banding

The shape of the eyes is parametrically controlled by the animation engine. An internal configuration variable controls how fast the shading falls off from the center toward the edge. A bit of random noise is added to remove the banding from the spherical gradient, and to give the eyes shading a little texture. This too has an internal configuration variable to control the noise factor.

106.1.2 The eye-shape clip path

Each eye has individual animation parameters that control its shape. These create the rounded eyelids and cheeks by masking off some of the eye pixels. A line is drawn along the outer path to complete the effect.

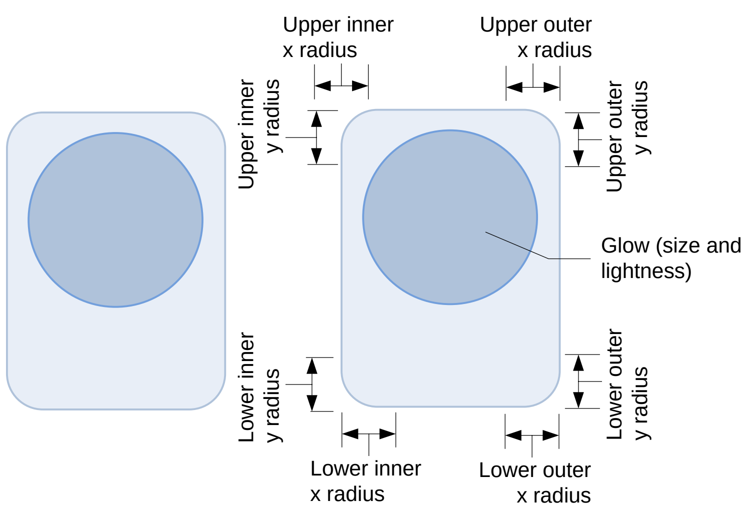

Figure 104: *Basic parameters of an individual eye control*

- The basic shape of the eye is controlled by the roundedness of the corners.
- The position of each eye is controlled by the center of the face;
- The size and width of the eye is created by the face's scaling factors

Each eye has controls for its eyelids (or cheek, depending on your perspective):

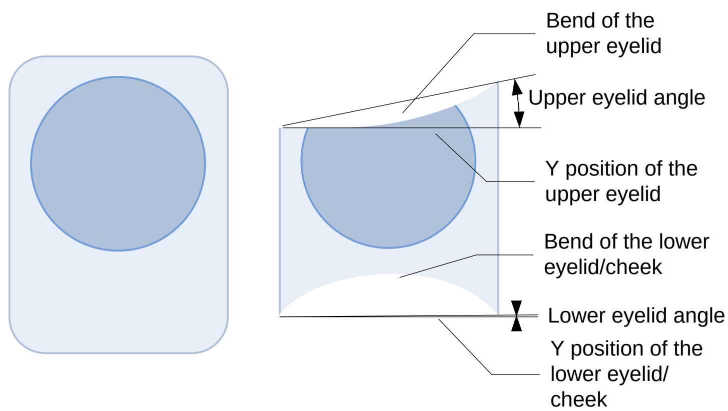

Figure 105: *Parameters of an eyes eyelids (or cheeks)*

- An arc represents the upper eye-lid and erases (or occludes) the upper portion of the eyes; these help create the sleepy, frustrated/angry emotions.
- An arc represents the lower eyelid and cheek, and erases (or occludes) the lower portion of the eyes; these help create the happy emotions

An eye can be made smaller – or to squint – by having no bend to the eyelids, but moving the eyelids position closer to the center.

106.2. THE PROCESS OF DRAWING THE PROCEDURAL FACE

Each eye of the procedural face can be drawn with a process like:

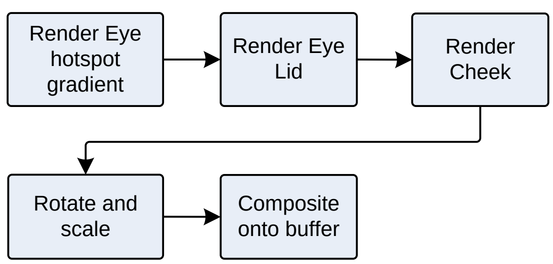

Figure 106: *The functional flow of drawing an eye*

Assuming that a complex clipping path is less efficient, the eye could be render as

1. The eye is rendered as a gradient pattern into a buffer, with the scale
2. The eye lid is drawn, forcing the pixels (of the eye lid area) to become transparent
3. The cheek is drawn, forcing the pixels (of the cheek area) to become transparent
4. The rectangle area where the eye will go is scaled, rotated, and offset for where the eye will go
5. Each pixel in the translated rounded rectangle region is map to one in the eye pixel buffer, and copied to the display buffer

107. COMMANDS

The HTTPS SDK API (Chapter 15) includes commands that affect the display

- Display RGB image (see Chapter 15 section *55.2 Display Image RGB*)

- Mirror display (see Chapter 15 section *55.3 Enable Mirror Mode*)

108. REFERENCES AND RESOURCES

Monson, Nathaniel;Andrew Stein, Daniel Casner, *Reducing Burn-in of Displayed Images*, Anki, US Patent 20372659 A1; 2017 Dec 28

Osipa, Jason, *Stop Staring: Facial Modeling and Animation Done Right*, 3rd Edition, 2010. This "is a wonderful book on rigging eyes for 3D animation... that focuses on setting up eye and face controllers." (Mooly Segal)

https://github.com/juj/fbcp-ili9341
This is an interesting project to study for those who wish to look more into how differential updates can be implemented.

CHAPTER 25

Audio Production

This chapter describes how Vector produces sounds and the audio output system:

- An overview of the audio output
- Text to speech
- Audio Effects

109. SPEAKER

Vector uses sound to convey emotion and activities, to speak, and to play sounds streamed from SDK applications and Alexa's remote servers. There are five sources of sound:

- Sound effects from playing pre-recorded audio files
- Sound effects from parametrically generating audio
- Sound from an audio stream sent by the SDK application to Vector
- Text to speech
- A sound stream from Alexa Voice Services

To support this, Vector includes a sophisticated audio architecture:

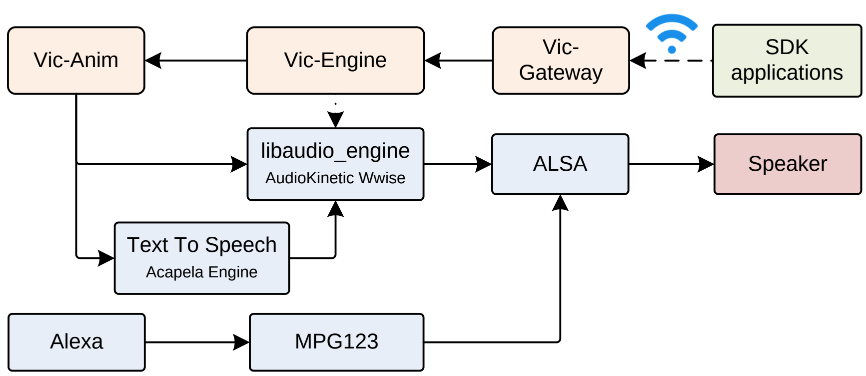

***Figure 107:** The audio output architecture*

Compression is not used to send audio from SDK applications to Vector. The vic-engine passes the received samples to audio engine to mix in its playback.

Some key elements of the audio production are:

Element	Description
ALSA	This is Linux's sound player, which provides the device drivers to allow software access to the speaker.
Alexa Voice Services	These are a set of remote servers that provide an audio stream of Alexa's voice responses, music, and other sounds.
libaudio_engine	This is Vector's sound framework. It is built on AudioKinetic's Wwise framework. It handles audio file loading and playback, sound effects, and others.
MPG123	The MPG123 is used to decode the sound stream sent from Alexa Voice Services servers.
Text to Speech	The text to speech facility is used to convert text (written sentences) to spoken words. This is built on Acapela's speech engine.

Table 509: *The audio systems functional elements*

110. SOUND EFFECTS FROM AUDIO FILES AND PROCEDURES

AudioKinetic Wwise

Vector uses AudioKinetic's Wwise (*WaveWorks Interactive Sound Engine*) toolkit for sound playback. Wwise is one of the most popular high-end game sound frameworks. It has sophisticated composition tools, extensive documentation, and a redistributable player for many platforms. Such a powerful tool seems overkill on device with only one output channel and a tiny speaker. In context, it makes sense.

Wwise was used in Cozmo's mobile application. The application which was designed as a kind of video game, and employs a lot video game design approaches. So it makes senses that an audio tool targeting video games would be used there. In turn, Vector is draws on Cozmo's frameworks– both the mobile application and what ran on the hardware – and creation tools it isn't surprising that the same framework would be employed by Vector.

The key features of Wwise (at least for Vector) are:

- Triggering sound effects, muting sounds, and changing parameters of sound playback (by sending the framework audio events)
- Playing pre-recorded sounds, including looping
- Playing procedural sounds
- Playing music (in the case of Cozmo)
- Sound effects, including fading
- Change the sample rates from different sources to the one played
- Mixing different sound sources together
- Managing a library of files that specify how to respond to audio events, how to create music and sound effects, and can hold pre-recorded sounds.

110.1. SOUND PLUGINS

The Wwise framework provides hooks that allow it to be integrated into the rest of the software system, and given extra functionality. This is accomplished by *plug-in* modules:

plug-ins

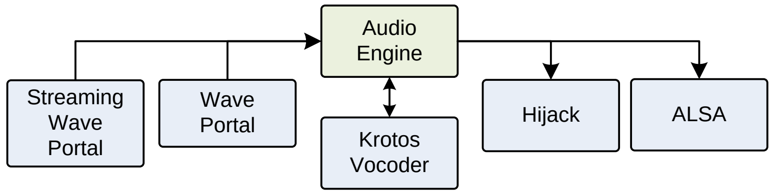

Figure 108: *Plug-ins in the Wwise audio pipeline*

The most import plug-ins are the ones receiving the audio output (aka "sink" plug-ins). This is how the audio sounds are taken from the audio engine and sent to Vectors speaker.

- The ALSA plug-in gathers the audio output and passes it to the "Advanced Linux Sound System" (ALSA) sound handler, which in turn passes it thru to Qualcomm's audio driver.
- The Hijack plug-in is probably unused on Vector, but is used on desktop computers to allow recording of Vector's sounds…? (It may also have been intended to be used as part of the message-recording, with the microphone audio piped thru the audio engine to be filtered/cleaned, and then saved.)

There are two plug-ins allowing audio from external sources to be processed by the audio engine and delivered to Vector's speaker:

- Wave Portal
- Streaming Wave portal. This receives the audio sounds from vic-engine for playback

Finally, there are the sound effects plug-ins:

- The Krotos "Dehumaniser" vocoder is used to give Vector his unique vocal qualities.

110.2. AUDIO PIPELINE

In a sense, Wwise can be thought of having multiple, configurable pipelines to produce sound. Each "game object" –perhaps a character, tool or machine, etc. – have its own pipelines for each kind of sound/sound-effect it would make:

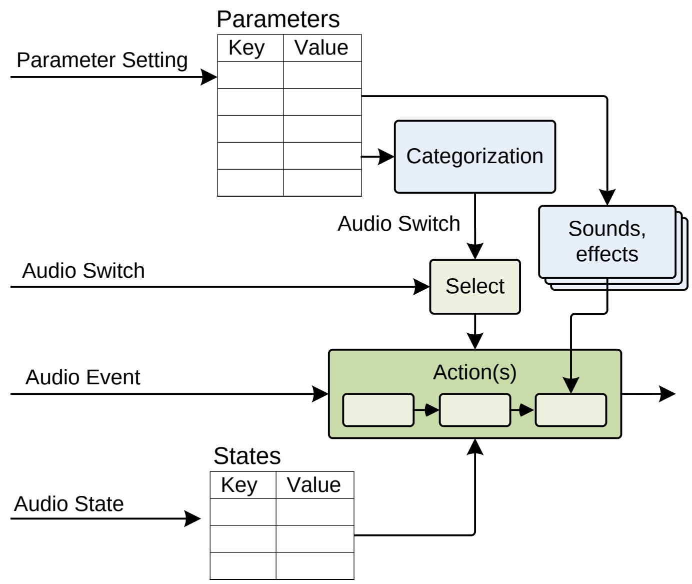

Figure 109: *Overview of the Wwise audio pipline*

audio event

The audio pipeline is driven by *audio events* it receives from the main application. These events are like the animation triggers. The metaphor is that when something occurs in the application (usually a video game), it represents this as an event distributed to a variety of subsystems to respond to, including the audio engine. Typically an event will cause the audio engine to play a sound, but the event system is much more powerful than that. Events trigger an *action,* which is the heart of the pipeline, and it is the action that plays the sound. The actions, in turn, can be configured to change sound parameters, stop playback, and so on:

audio action

> "[Audio] events apply actions to the different sound objects or object groups in your project hierarchy. The actions you select specify whether the Wwise objects will play, stop, pause, .. mute, set volume, enable effect bypass, and so on."

WWise documentation

The Wwise framework employs event ID *numbers* to refer to events. Events can also be referred to using lexical names – as strings. A later section will describe how to translate a string to an event ID.

audio parameter

Audio parameters are settable values used by the actions that control how they sound. Vector mainly uses these to adjust the sounds based on his current mood and activity. Like the action, these parameters are on a per object (within the audio engine) basis.

audio state

An *audio state* is used to set the context for sound system overall, so that the right sounds and effects are used in responding to events, and actions general across all of the game objects.

audio switch

An *audio switch* is similar, but it sets up the context so that the right sound (or sound effect, etc) is used for a particular object or event. AudioKinetic gives an example of foot-step events triggering a footstep sound but the audio switch is set to the kind of surface that is being walked on – selecting walking on grass, gravel, pavement, etc. . A switch can be automatically set by a parameter, if it is set up to use different value thresholds to categorize it into one of the switch states.

110.3. HOW VECTOR USES WWISE

Vector's design uses Wwise features to give a more life-like quality to his sounds. The sounds are triggered in two different ways:

- The binary animation file can trigger sending audio events (by ID), setting parameters, states and switches. See Chapter 27, section 117 for more information.
- The behaviors may emit audio events to convey Vector's emotional state – sadness, approval, etc. See Chapter 28, section *119.8 Audio events* for more information.

To provide variation, when an audio event is received by the audio engine, it does not play just a single, fixed sound file. Instead it triggers a sequence of sounds to play, each step randomly selecting from a set of small sound files. The steps are configured to skip recently played sounds (usually the last 6).

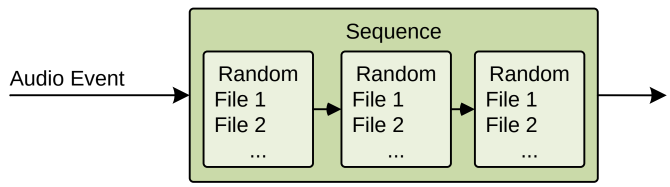

***Figure 110:** Sound sequences with some random variation*

But that is not the full story: Some events have many possible sequences that could be played. The audio engine selects the sequence based primarily on Vector's current level of stimulation.

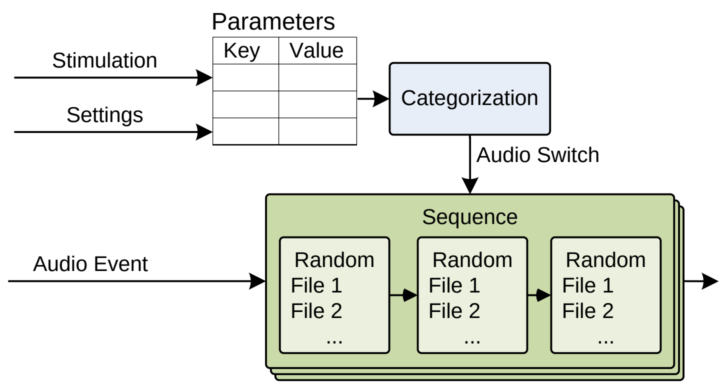

***Figure 111:** Choosing different sound sequences based on stimulation*

The more stimulated Vector is, the more animated his sounds will be. If he is calm and not particularly stimulated, he'll be quieter.

> "This stimulation variable is a distillation of all possible environmental affects Vector experiences. For example, 'hey Vector' or touch automatically triggers a 1.0, getting stuck drop the [stimulation] to about 0.5, etc. .. We adapted the audio system to gradually lower in probability and volume as the stimulation level lowered. The goal being that active Vector users get a more lively sounding robot, and Vectors left on but not being interacted with wouldn't be so chirpy."

Ben Gabaldon

110.3.1 Other Potential Factors

The team at Anki explored selecting the sound sequence based on the current emotional state, mood, activity, and other factors. This gives sounds that convey whether Vector is struggling to do the task, is excited, is frightened, etc.

Wolfrod et al

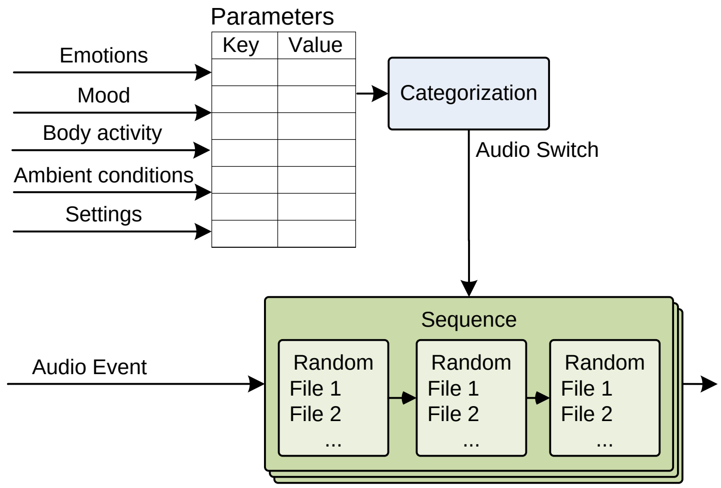

Figure 112: *Choosing different sound sequences based on mood, activity and conditions*

Vector's emotion engine passes the current emotion state and mood to the audio engine. By setting the audio parameters based on the current mood, Vector could give "feedback cues about the robot's emotion state." (See Chapter 29, section *121 Emotions, and Stimulation*.) Different emotions and moods – angry, frightened, trusting – each give can select different sound sequences.

Table 510: *Audio parameters linked to emotion state and mood*

Parameter	Description
Robot_Vic_Confident	This captures the emotion dimension "confidence"
Robot_Vic_Happy	This captures the emotion dimension "happy"
Robot_Vic_Held_Trust	This captures the emotion dimension "trust"
Robot_Vic_Purr_Level	
Robot_Vic_Social	This captures the emotion dimension "social"
Robot_Vic_Stimulation	This captures the emotion dimension "trust"

The motion controller passes the current activity to the audio engine as well. When an action is being performed, the animation may trigger the sound effect, perhaps to "simulate the physical movement" he is making. These would be like *intersectional tones* that people make – grumbles, and grunting.

Table 511: *Audio parameters linked to activity*

Parameter	Description
Robot_Vic_Head_Accelerate	This is how fast the motor controller is accelerating Vector's head movement.
Robot_Vic_Head_Position	This is the position of Vector's head.
Robot_Vic_Head_Speed	This is linked to the speed that Vector's head is moving at, and the direction it is moving in.
Robot_Vic_Lift_Accelerate	This is how fast the motor controller is accelerating Vector's lift movement.
Robot_Vic_Lift_Position	This is the position of the lift.
Robot_Vic_Lift_Speed	This is linked to the speed that the lift is moving at, and the direction it is moving in.
Robot_Vic_Tread_Accelerate	This is how fast the motor controller is accelerating Vector's treads.
Robot_Vic_Tread_Speed	This is linked to the speed that Vector is driving, and the direction it is moving in – at least, when he is not spinning.
Robot_Vic_Tread_Spin_Speed	This is linked to the speed that Vector is rotating at, and which direction.

As interesting as these ideas are, Anki found that the single stimulation level "was a better distillation of all the AI going on." "The behavior system was really difficult to rely on for playing the appropriate sounds with."

Ben Gabaldon

110.3.2 Game Object

The sounds events for these are directed to a special game object just for them. Most of Vectors sounds are driven by the animation, and when they are sent to the audio engine, they are tagged with "Animation" as their game object. For the procedural sound effects, the events are tagged with "Procedural" as their game object.

Table 512: *Game objects*

Game Object Id	Description
Animation	This game object id is for events, settings, sounds and effects from the animation engine.
Procedural	Related to the sounds of moving (mostly treads)…..

110.4. EQUALIZER

The Wwise sound equalizer is used to compensate for some of the distortion of Vectors small speaker. It is also used to "prevent the higher pitches from ever getting very loud" – something that physically is possible despite the speakers small dimensions. The standards for toy sound levels vary by country, but typically are limited to 75-80dB at the ear.

110.5. THE CONFIGURATION

The audio configuration and sound files are located in:

`/anki/data/assets/cozmo_resources/sound`

There are three kinds of files located there: configuration files, sound bank files (which may include sounds), and sound files.

110.5.1 The configuration files

These configuration file is

`/anki/data/assets/cozmo_resources/sound/SoundbankBundleInfo.json`

This file name is hard coded into libaudio_engine. The file is n array of structures, each with the following fields:

Field	Type	Description & Notes
bundle_name	string	A name?
language	string	"SFX" or "English(US)" (It isn't clear how to interpret these.
path	string	The path of the sound bank file, relative to the location of the configuration file.
soundbank_name	string	The name of the sound bank file, without the ".bnk" extension.

Table 513: *The sound bank bundle info JSON structure*

110.6. THE SOUND FILES

The concepts above are held within a network of sound bank and WEM files, starting with the JSON configuration file which specifies the bank files to load:

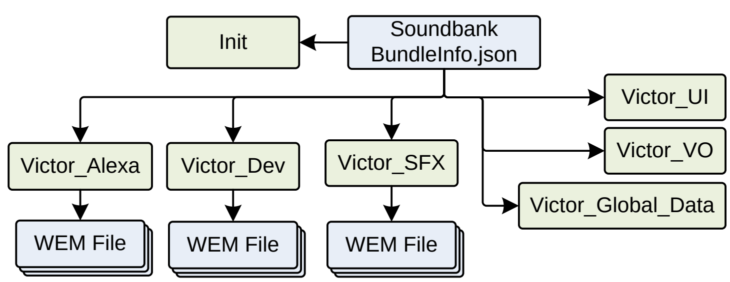

Figure 113: *The relationship between sound banks and WEM files*

110.6.1 Sound Bank Files (BNK)

A sound bank is a binary file, composed of series tagged sections. Some sections are

- The sound bank file has setups for how the sounds flow from files (and other inputs), thru mixers, and other filters to the output. It calls this the *audio bus hierarchy*.
- Sound effects,
- Music compositions to play, (these probably are used heavily in Cozmo, but appear unused in Vector)
- State transition management, how altering the settings of effects during play.

- A map of *audio events* to the actions to carry out when that event occurs, such as playing a sound, stopping other sounds, changing mixer settings, and so on
- The set of other sound bank files to load.
- WEM sound files, either embedded, or a reference to an external file.

Wwise always has an "Init.bnk" sound bank. It is loaded first, since it holds sections that are shared across all of the sound bank files. It does not contain any sounds. The non-init sound banks can define responses to events, etc and refer to external WEM files that provide pre-recorded sounds.

The sound banks loaded later have priority – that is, they get first crack at providing resources. Multiple sound banks can provide resource(s) with the same name, but the higher priority one "wins". This gives us an opportunity to customize the sounds on Vector, by adding new sound banks to the end of the list specified in SoundbankBundleInfo.json.

***Table 514:** The different sound banks used in Vector*

Soundbank	Description
Init.bnk	This bank is mandatory. It holds the definition of WWise "game parameters", and how they become switch group settings, and states transition.
Victor_Alexa.bnk	This bank responds to sound events by playing sound sequences that are specific to Alexa functionality.
Victor_Dev.bnk	This bank responds to sound events by playing sound sequences that are intended for Vector developers, rather than end user use.
Victor_Global_Data.bnk	Unknown. Doesn't have any actual sound references
Victor_SFX.bnk	Has the most of the events (to respond to) and the sound sequences to play. (At least those that are not specific to Alexa, and Vector developer's, and placed into section above)
Victor_UI.bnk	Not used. In Cozmo this had sounds for the application UI.
Victor_VO.bnk	Not used. In conventional games this bank is intended to hold the *voice over* sounds of actors speaking; and different versions of the banks would be localized so that they are spoken in the appropriate language and dialect.

110.6.2 "Wwise Encoded Media" WEM Files

WEM files are sound files. They are considered *containers*, since it is possible for the sound (in the file) to be encoded in different formats, some standard and some custom. The file format is custom to AudioKinetic, and automatically produced by AudioKinetic's WWise tool. Like the BNK file format, a WEM file is organized as tagged sections. The file names are ID numbers with a ".wem" extension. (More on the generation of the ID numbers in the section.)

looping

WEM files also including optional looping parameters. A sound file can be configured to loop indefinitely or a fixed number of times.

In practice, Vector's WEM sound files are usually single channel (mono) but may have two channels. Two different AudioKinetic-specific encoding are used. A modified Vorbis-encoded file. The key changes from a regular Vorbis stream are that they have their own packet wrapper; the information shared across audio files has been separated out to make them smaller.

IMA ADPCM adaptive-differential audio encoding

The second type of encoding used is an AudioKinetic specifc 16-bit little-endian IMA ADPCM files. "IMA ADPCM" is an ugly, confusing acronym, but it is rather simple in practice:

- The decoder produces 16-bit values to feed to a digital to analog converter (DAC) and the amplifier and speaker; that is the *pulse code modulation* (PCM) portion.

- The sound file only has 4 bit values for each sample. Each 4 bit value is used as the index into a pair of look up tables for how much to add to or subtract from the previous 16-bit value for the new output; this is the *adaptive differential* (AD) portion.
- The tables and their interpretation are standardized by a committee, which is the IMA portion.

This approach is easy for the processor, and takes little working memory. It does make for larger files than, say, MP3 or other more sophisticated compression. That is acceptable since the sound segments are all short, and Vector has a large storage area to hold the files.

This approach has one drawback. It uses only 4 bits in each sample to represent the change in the analog waveform. Often this isn't enough; it takes several samples to add or subtract enough for the output to catch up to the desired values (from the source material). At "low" sample rates, this can create audible distortion. The fix is to use a higher sample rate for encoding. First, there is less change between two points closer together in time. Second, the higher rate lets the decoder catch up faster; this effectively makes the distortion at high, inaudible frequencies. The play back can be done with this higher sample rate, or it can be down-sampled again after decoding.

Vector (probably) down-samples many of the sound files (after decoding) during playback. The audio files have sample rates much higher than is supported through the SDK audio channels: many at 30,000 samples/sec, some as high as 44,100 sample/sec.

110.6.3 Wave files

The audio engine includes a facility to load wave files for sound (so long as they are RIFF with PCM data). It likely it was added in preparation for the "messaging" feature. A message from a friend could be recorded, and distributed to a particular Vector. vic-engine could trigger the playback of the audio by vic-anim.

110.7. MAPPING AUDIO EVENT AND SOUND NAMES TO ID NUMBERS

IDs from names
Fowler-Noll-Vo hash

The ID number used to identify the events and audio files is not random or entirely arbitrary. It is formed from the text names used by sound engineers and software developers. The number is automatically made from the text names of the events and sound by the AudioKinetic software[50] using a Fowler-Noll-Vo hash function. (The number is used instead of strings to reduce runtime memory and processing overhead during game play.)

The algorithm to compute the 32-bit hash number:

1. "Start with an initial hash value of FNV offset basis." (Use 16777619 for this offset)
2. "For each [character] in the input,
    a. "multiply [the] hash by the FNV prime," (use 2166136261 for the prime.)
    b. convert the next character to lower case
    c. XOR the hash with the lower case character

[50] https://www.audiokinetic.com/library/edge/?source=SDK&id=_ak_f_n_v_hash_8h_source.html

111. TEXT TO SPEECH

text to speech

Vector includes a text to speech (TTS) facility. The engine is based on Cozmo's text-to-speech subsystem, with the text-to-speech engine from Acapela. The text to speech engine is part of vic-anim, with some components in libcozmo_engine. Vector treats the process of speaking as a type of animation, one with just an audio track. The audio for the speech is generated, and then handled by the animation manager.[51]

The text-to-speech voices are stored in

```
/anki/data/assets/cozmo_resources/tts
```

The voice files include:

- co-French-Bruno-22khz
- co-German-Klaus-22khz
- co-Japanese-Sakura-22khz
- co-USEnglish-Bendnn-22khz

111.1. THAT DISTINCT ROBOTIC VOICE QUALITY

Duhmaniser vocoder

The text to speech engine produces human-sounding speech… so how does it get to be Vector's *robotic* voice? The audio is pumped through a vocoder (the Krotos Dehumaniser) in the sound engine to give it a distinct sound.

Figure 114: *High-level vocoder functional flow*

The exact implementation isn't known, but there are common techniques. A typical vocoder works by estimating the pitch of the text-to-speech voice every 30ms, and then adjusting the gains settings on a multi-band equalizer.

111.1.1 Pitch tracker

pitch tracking

Krotos' pitch detection – or pitch tracker – can be configured to use one five different algorithms:

1. Autocorrelation
2. Cepstrum
3. McLeod pitch detection method (MPM)
4. Frequency spectrum-based
5. YIN

[51] https://forums.anki.com/t/multiple-actions-possibility-for-sdk/104

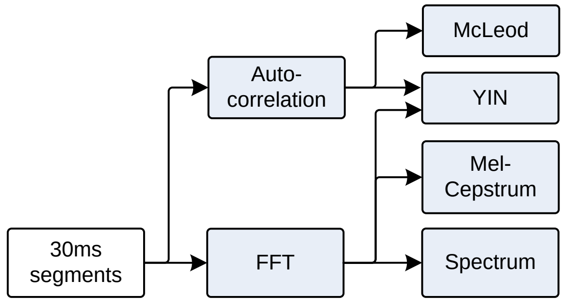

Figure 115: *Pitch tracking methods*

All there are distinctions between these methods, there are far more similarities. They all build on basic techniques like autocorrelation, and *fast-fourier transform* (FFTs). An FFT computes a spectrograph, giving the strength of each frequency. The simplest (or naive) approach is to find the strong frequency and call it a pitch. This approach is easily fooled. A variety of other techniques have been developed to work around this.

111.1.2 Autocorrelation

autocorrelation

Autocorrelation is a slow, brute-force algorithm for finding the pitch. It works by shifting the signal in slight amounts until the shifted signal best matches the original one. The core algorithm looks something like:

```
for each sample offset (1... to big number)
   sum = 0
   for each sample index 0...num samples
      diff = samples[sampleIdx+sampleOfs] - samples[sampleIdx];
      sum += diff*diff

   keep track of the sample offsets with the smallest sums.
```

Example 7: *Autocorrelation pseudo-code*

It does this compute the difference between each of the samples in the shifted waveform and the waveform, square that difference, and then summing it up. The shift offset with the smallest offset is the best match, and used to compute the pitch. Note: It only needs to try the offsets that cover the first few kHz at the given sample rate.

This approach is an expensive way to find the pitch: Every audio sample must be scanned a huge number of times.

111.1.3 YIN detection

YIN detection

YIN is uses auto-correlation and adds a few more "polishing" steps to improve its estimate: it weights the different offsets, and blends together a few of the offsets that are close to the best one.

111.1.4 McLeod Pitch Method (MPM)

McLeod pitch method

McLeod's pitch tracker (named for its author) improves on YIN in two ways. First is that it can be implemented using a FFT to perform the autocorrelation step, and to estimate the pitch. (It can still use the brute force method, if an FFT isn't available.) This FFT autocorrelation is done by

1. Performing an FFT on the sample window.
2. Compute the square magnitude of each complex value – that is, multiply each complex number by its complex conjugate. (Or, for those not steeped in the jargon, *real*real*+imag*imag*, ignore the part where multiplying two imaginary numbers becomes negative)
3. Compute the inverse FFT of this to compute the power vs frequency

4. Identify the frequency with the highest power associated with it

McLeod's method, adds a few more polishing steps as well to clean this up and mix together a few of the best results to get a better one.

111.1.5 Mel Cepstrum

Mel Cepstrum

The Mel Cepstrum method is similar to the FFT-base auto correlation, but tweaked to take into account the psychology of pitch:

1. Performing an FFT on the sample window.
2. Compute the square magnitude of each complex value
3. Change from frequency (Hz) to "mel scale",' which is a perceptual scale for pitch
4. Compute the logs of all of those numbers on this scale
5. Compute a discrete cosine transform of this to compute the amplitude vs frequency
6. Identify the frequency with the highest amplitude associated with it

111.2. THE CONFIGURATION AND LOCALIZATION FILES

The configuration file for the text to speech engine is located at:

/anki/data/assets/cozmo_resources/config/engine/tts_config.json

(This path is hardcoded into vic-anim.) This file is organized as dictionary whose key is the operating system. The "vicos" key is the one relevant for Vector.[52] This dereferences to a dictionary whose key is the language base: "de", "en", "fr", or "ja". The language dereferences to a structure with the following fields:

***Table 515:** The JSON structure*

Field	Type	Description & Notes
pitch	float	This is a pitch setting field. This is not supported by all voices / platforms. (The comment says that this is Acapela TTS SDK.) "Pitch… adjustment is actually performed by audio layer." *Optional.*
shaping		optional
speed	float	
speedTraits	speedTraits[]	Array of speed traits structures (see below). *Optional*
voice	string	a path to the ini file within the [assets/cozmo_resources/tts] folder

Each speedTraits structure has the following fields:

***Table 516:** The speedTraits JSON structure*

Field	Type	Description & Notes
rangeMax	uint	
rangeMin	uint	
textLengthMax	uint	
textLengthMin	uint	

[52] The other OS key is "osx" which suggests that Vector's software was development on an OS X platform.

111.2.1 Localization

Vector internally has support for German, French, and Japanese, but the application-level language settings only really support US, UK, and Australian dialects of English. The files for non-English localization were not completed.

The localization files for feature stores its text strings (to be spoken) in

/anki/data/assets/cozmo_resources/LocalizedStrings

This path is not present in versions before v1.6. The folder holds sub-folders based on the language:

de-DE en-US fr-FR

Note: there is no ja-JA, but it may be possible to create.

Inside of each are three files intended to provide the strings, for a behaviour, in the locale:

- BehaviorStrings.json
- BlackJackStrings.json
- FaceEnrollmentStrings.json

Each JSON file is a dictionary with the following fields:

Field	Type	Description & Notes
smartling[53]	structure	see below to the structure below. Note all smarting structures examined are the same.

Table 517: *The JSON structure*

The dictionary also includes keys, such as "BehaviorDisplayWeather.Rain" that map to a locale specific string. These have the following fields:

Field	Type	Description & Notes
translation	string	The text in the given locale. The string may have placeholders, such as {0}, where text is substituted in.

Table 518: *The JSON structure*

Each smartling structure has the following fields:

Field	Type	Description & Notes
placeholder_format_custom	array of strings	An array of patterns that represent possible placeholder patterns.
source_key_paths	array of strings	"/{*}" Strings are path of a JSON key?
translate_paths	array of strings	"*/translation" Strings are path of a JSON key?
translate_mode	string	"custom"
variants_enabled	boolean	

Table 519: *The JSON structure*

This is handled by libcozmo_engine, including the key strings.

[53] it really has this key.

WEATHER FILES

The weather behaviour stores its text strings (to be spoken) in

`/anki/data/assets/cozmo_resources/config/engine/behaviorComponent/weather/condition_to_tts.json`

This path is hardcoded into `libcozmo_engine`. The JSON file is an array of structures. Each structure has the following fields:[54]

Field	Type	Description & Notes
Condition	string	e.g. "Cloudy", "Cold"
Say	string	The key used in the `BehaviorStrings.json` file to look up the localized test. (In previous versions, this was the text to say, in English.)

***Table 520:** The JSON structure*

111.3. CUSTOMIZATION

Vector's voice files are from Acapela. Acapela sells language packs for book readers, but the format appears different and likely very difficult to modify or create.

Cozmo's employs a different English voice (in the Cozmo APK). This likely could be extracted and used on Vector. (In turn, Vectors voice could probably be used with Cozmo.)

Customization of the Localization TTS would give Vector a bit more personality.

112. COMMANDS

The HTTPS SDK API (Chapter 15) includes commands that affect the sounds

- Audio stream commands (see Chapter 15 section *50.6 External Audio Stream Playback*)
- Text to speech (see Chapter 15 section *50.8 Say Text*) An external application can direct Vector to speak using the Say Text command. The response(s) provide status of where Vector is in the speaking process.
- Vector's volume can be set as a setting using the `UpdateSettings` command (see Chapter 15 section *66.2 Update Settings*) and the `RobotSettingsConfig` structure (see chapter 31), or using the Master Volume command (see Chapter 15 section *50.7 Master Volume*). Note: the volume levels using settings doesn't fully match those in the master volume command.

Note: can also trigger animations which play sounds effects as well.

113. REFERENCES AND RESOURCES

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[54] That this file (and many others) is a simple 1:1 transform lends the suspicion that the localization process is needlessly complex.

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Wolford, Jason; Ben Gabaldon, Jordan Rivas, Brian Min *Condition-Based Robots Audio Techniques*, Anki , USPTO Pub.No: US2019/0308327A1, 2018 Apr 6

Xentax, *Wwise SoundBank (*.bnk)*, 2012 Dec 6
http://wiki.xentax.com/index.php/Wwise_SoundBank_(*.bnk)

This site provides a wealth of information on the format of the Sound Bank files. Unfortunately not all sections of the file have been documented, and there are sections in Vector's Sound Bank files that were not known when this page was written

Some example code for YIN and McLeod pitch tracking
https://github.com/ashokfernandez/Yin-Pitch-Tracking
https://github.com/adamski/pitch_detector/blob/master/source/PitchMPM.h
https://github.com/sevagh/pitch-detection/blob/master/src/mpm.cpp

CHAPTER 26

Motion Control

This chapter describes the motion control subsystem:

- The control of the motors
- Performing head and lift movements
- Moving along paths in a smooth and controlled fashion

Note: the motion control is implemented in vic-robot (except where stated otherwise, of course)

114. MOTION CONTROL

The motion control is designed to take a path of movements from the path planner or the animation systems. The path consists of arc, line, and turn (in place) movement commands. These can be coordinated with the head and lift, by the animation system.

Note: the animation system is described in chapter 22

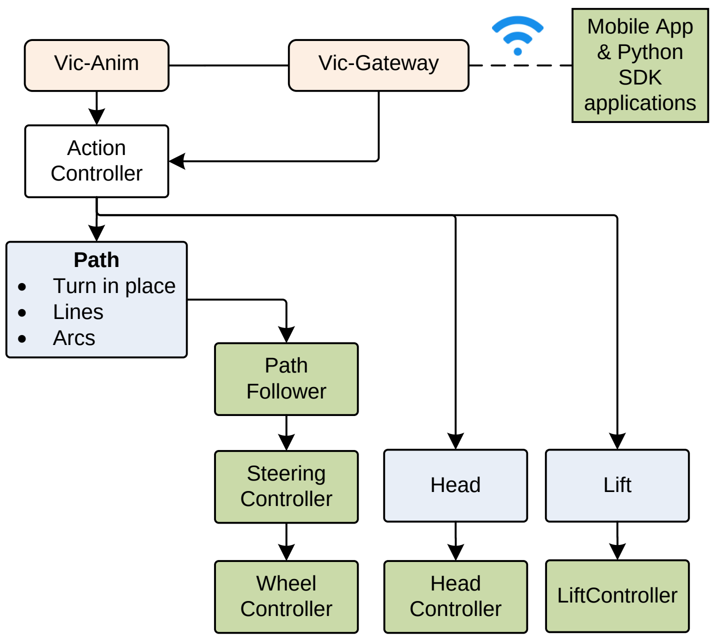

***Figure 116:** Motion controller*

The individual motors have controllers to calibrate, move, prevent motor burnout, and perform any special movements.

114.1. PATHS

The path planner thinks of the world and robot coordinates within it in terms of x,y and θ (theta) coordinates. The θ being the direction angle that Vector is facing at the time. It builds a list of straight line segments, arcs, and point turns. Each of the motors is independently driven and controlled, with the steering controller coordinating the driving actions.

The PathFollower carries out the driving plan. It receives a list of driving segments. Each segment has an associated speed, acceleration, and deceleration to drive at. The three kinds of segments are:

- Drive in a straight line
- Drive arcs
- Turn in place

When it receives the list, it checks that certain rules are followed.

- The list is not too long
- That each segment type is known
- That the path is continuous: the end-point of one segment must be the same as the starting point of the next segment.

114.2. FEEDBACK

The motion controller may take position and orientation feedback from

- The linear speed can be estimated from the motors shaft rotation speed (and some estimated tread slip), merged with IMU information
- The speed that the robot is rotating can be measured by the IMU and the vision system.
- The navigation and localization subsystem, which employs a sophisticated Kalman filter on all of the above position.

114.3. MOTOR CONTROL

Vector's small, light frame and powerful (for their size) motors allow him to make quick actions representing his emotions and little tantrums, as well as drive about smoothly. A typical speed and position controller for the brushed DC motors is a set of PID control loops. (Although the "d" – derivative – term is often small or unneeded.)

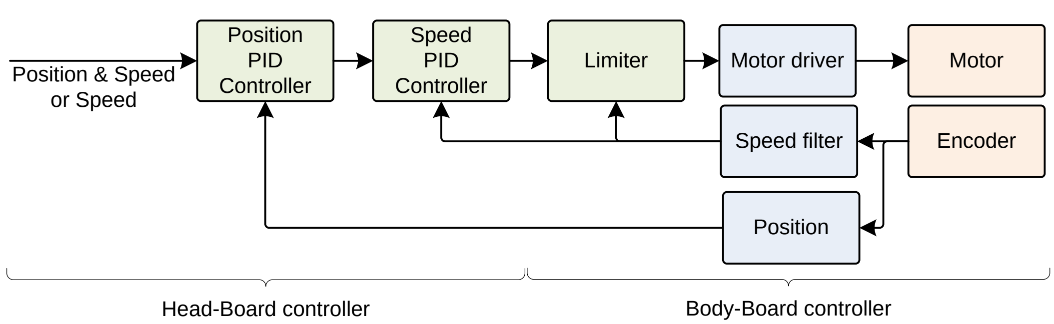

Figure 117: *A typical motor control loops, as they might appear in Vector*

The motor control loops are implemented in the head-board. They are implemented using floating point (rather than the fixed point[55] that the body-board's M0 microcontroller would require), and

[55] Although both approaches work, fixed point (using integers and scaling factors rather than floating point) takes a bit more effort to tune, as small but important parts of the feedback signals are dropped… this can introduce effects like jerkiness, stutter or motor noise from.

are updated 200 times per second. The body-board is responsible for driving the motors and sampling the encoder. It is also responsible for protecting the motors in case of a stall.

The lift and head motors are position-controlled. The motors can be commanded to travel to an encoder position at a speed (given in radians/sec). The position – the cumulative number of radians that that the shaft has turned – can be computed by counting the encoder events, with the expected direction that the motor has turned.

The speed of rotation is also computed from the encoder count. One typical approach is to regularly take a derivative of the position (say once every millisecond), and filter it. Since the encoder is discrete, at slow speeds its update rate will produce false measures of shaft speed.

114.4. BURN OUT PROTECTION

The body-board is responsible for protecting the motors. It monitors the speed of the motors. If a stall is detected, it limits the current to the motor (by limiting the duty-cycle). The motor is still driven, but at such a low power that burn out is not a risk. This lets the head and lift hold position. In case the hand or other obstruction is removed, the motor can sense the change (the encoder will show that they are able to turn again) and resume.

> Luckily, those motors can't overheat instantaneously – it takes at least 15 seconds of being stalled at full power before you risk permanent damage. The firmware in the body board watches the encoders on all 4 motors, and turns down the power on stalled channels. It never turns the power down to 0, since it doesn't have to. All 4 motors can push continuously (gently) without stalling.
>
> So if you drive a motor toward the limit but someone is pulling on it the other way, it might push hard at first, then quickly “relax” to a voltage that's safe for continuous use, but never stop pushing just in case you let go.

114.5. NO PINCHING FINGERS!

The motors can also be “unlocked” – allowed to be spun by external forces. This allows a person to raise and lower the lift, as well as raise and lower the head. Both of these are used as inputs to enter diagnostic modes.

The software control loops can also detect when a person is playing with Vectors lift (or head or tracks), and then unlock the motors.

> the PID controller violently fights your attempt to pull the lift, smacking your fingers and oscillating and otherwise causing trouble. The PID controller is pretty feisty, because it has to operate across a huge range of forces – between flipping or lifting the robot's entire weight and delicately setting down or lifting cubes without flinging them.

114.6. GETTING THE LIFT AND HEAD POSITIONS JUST RIGHT

The head and lift motors need to have their positions calibrated.

> Both head and lift angle must be known exactly, since we need to know exactly where the tongs (on the lift) are relative to what the camera sees. Otherwise we couldn't engage (lift) and disengage (pull out) the block.

At startup Vector performs a calibration procedure, “which is just an animation that pushes the head/lift to [their] hard stop.” Both the lift and head have hard stops at their most downward position, which serves a well-defined starting point. When these motors reach the end of travel, the measured speed will fall below a threshold, and the software knows to zero estimated position.

Vector's software has two backups in case the position is wrong. This can happen if the calibration was wrong – something, perhaps a block or impatient human companion – prevented the head or lift from moving further. Or if someone moved his lifts or head (since the position encoder is single step, Vector won't be able to tell which direction they were moved).

1. The body-board firmware has motor burnout prevent features. This quickly drops the power applied to the motor if there is a stall.
2. If a motor is stalled unexpectedly or the motor isn't stopped (by the hard stop) within 5% of where it should, Vector schedules another calibration procedure. (This is handled by the `ReactToUncalibratedHeadAndLift` behavior.)

114.7. DIFFERENTIAL DRIVE KINEMATICS

Under ideal circumstances, these motions are straight-forward to accomplish:

- To turn in place, the treads turn at the same rate, but in opposite directions. The speed of the turn is proportional to the speed of treads
- To drive straight, both treads turn at the same speed. The speed of motion is proportional to the speed of the treads.
- To drive in an arc is done by driving the treads at two different speeds.

To drive in an arc, the left and right treads are driven speeds:

$$v_{left} = \omega\left(radius + \tfrac{1}{2}width\right)$$
$$v_{right} = \omega\left(radius + \tfrac{1}{2}width\right)$$

Equation 3: *Tread speeds based on arc radius*

Where

- *width* is Vector's body width
- ω is the angular velocity, i.e. speed to drive around the arc
- *radius* is the distance from the center of the arc to the center of Vector's body:

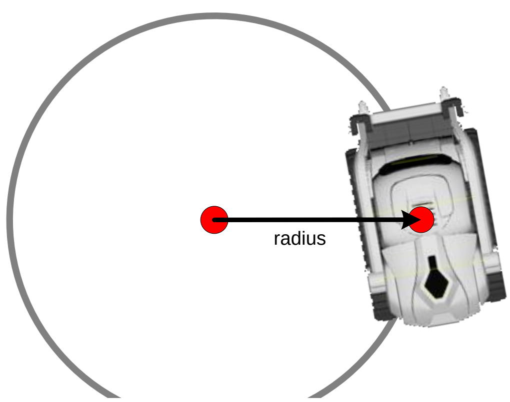

Figure 118: *Radius of arc measurement*

114.7.1 Slip

In practice, Vector's actual movement won't quite match what he attempted to do. Mainly this will come from how the treads slip a bit (especially while trying to push an object), and some variation in how driving the motors maps to actual motion.

115. MOTION CONTROL COMMANDS

The HTTPS SDK API (Chapter 15) includes commands to control the motors, and to initiate driving actions. The lower level commands, below the action processor are:

- *Drive Wheels*
- *Move Head*
- *Move Lift*
- *Stop All Motors*

The higher level commands, part of the action system are:

- *Drive Straight*
- *Stop All Motors*
- *Turn In Place*
- *Set Head Angle*
- *Set Lift Height*
- *Go to Pose*
- *Turn Towards face*
- *Go To Object*

CHAPTER 27

Animation File Format

The binary animation files are the most significant of Vector's animation files. The file format provides for coordinating the display, motion, and sound responses.

- Animation file format overview
- Structures in the file

116. ANIMATION BINARY FILE FORMAT

The schema and format of the animation binary file is given as a flatbuffer specification. This specification is located at:

`/anki/data/assets/cozmo_resources/config/cozmo_anim.fbs`

Note: this file is not read by any program in Vector. A compatible parser is compiled in.

116.1. OVERVIEW OF THE FILE FORMAT

The animation file contains one or more named animation "clips." Each clip has one or more tracks that represent the scripted motions (and lights & sounds) that Vector should perform. There are tracks for moving Vector's head, lift, driving, modifying his facial expressions, displaying images on the LCD, audio effects, and controlling the backpack lights.

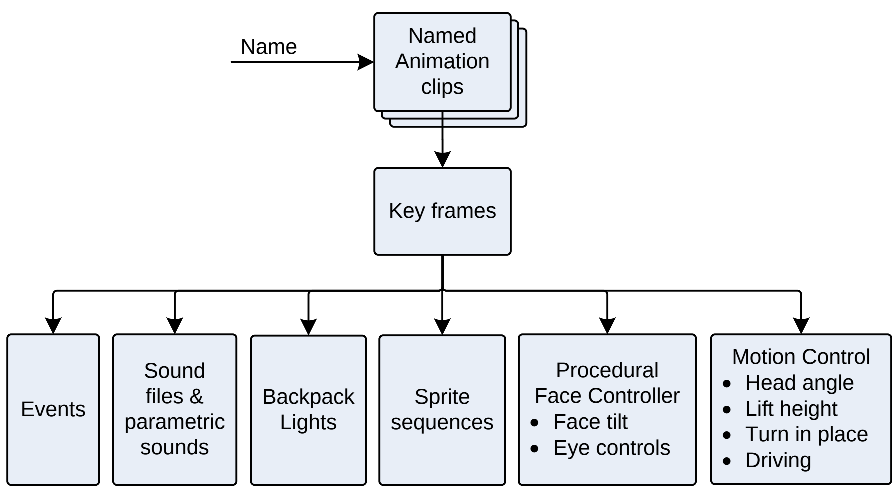

Figure 119: *The animation file structure*

Each of the tracks within the clip is composed of key frames (with settings for each of the relevant tracks) that are triggered at different points in time.

116.2. RELATIONSHIP WITH COZMO

Vector's file format for animations is derived from the file format used with Cozmo. This presents the possibility of adapting Cozmo's animation files to Vector, and vice-versa. The code generated by Google's flatbuffer tools ignores extra fields, and assigns default values to missing ones. This makes it possible to use a Cozmo animation file with Vector – accepting that some areas, such as the sounds, won't link up fully. The key differences between Cozmo and Vector's formats are that Vector includes audio tracks, plus some minor extra fields, and fewer backlight LEDs.

The PyCozmo project has the (experimental) ability extract Cozmo's animations, and may be useful for this transcoding and adjustment to Vector's aesthetic.

117. STRUCTURES

The animation file starts with an AnimClips structure. Unless specified otherwise, each structure is the same as in Cozmo.

By default, all fields are optional unless specified otherwise.

117.1. ANIMCLIPS

The AnimClips structure is the "root" type for the file. It provides one or more animation "clips" in the file. Each clip has one or more tracks. The structure following fields:

Table 521: *AnimClips structure*

Field	Type	Description
clips	AnimClip[]	An array of animation clips

117.2. ANIMCLIP

The AnimClip is a named animation that can be played. This structure has the following fields:

Table 522: *AnimClip structure*

Field	Type	Description
Name	string	The name of the animation clip; this is also called the *animation trigger name*.
keyframes	Keyframes	The key frames for each of the tracks for this animation clip

117.3. AUDIOEVENTGROUP

The AudioEventGroup structure is used to randomly select an audio event (and volume), and send it to the audio subsystem. See Chapter 25, section *110.2 Audio Pipeline* for a description of audio events. This structure has the following fields:

Table 523: *AudioEventGroup structure*

Field	Type	Units	Description
eventIds	uint[]		The audio event IDs, weighted by a probability.
volumes	float[]		The volume to play the selected audio at.
probabilities	float[]	*(0..1]*	The probability weight that a given event will be selected.

This structure is new to Vector.

117.4. AUDIOPARAMETER

The AudioParameter structure is used to set one of the sound parameters in the AudioKinetic Wwise subsystem. See Chapter 25, section *110.2 Audio* Pipeline for a description of audio parameters. This structure has the following fields:

Table 524: *AudioParameter structure*

Field	Type	Units	Description
parameterId	uint		The identifier of the parameter to set. Default: 0
value	float		The value to set the parameter to. Default: 0
time_ms	uint	*ms*	The time at which the parameter should be set. Default: 0
curveType	ubyte		default: 0

This structure is new to Vector.

117.5. AUDIOSTATE

The AudioState structure is used to put the audio system into a particular state. See Chapter 25, section *110.2 Audio Pipeline* for a description of audio state. This structure has the following fields:

Table 525: *AudioState structure*

Field	Type	Description
stateGroupId	uint	The state group to modify. Default: 0
stateId	uint	The new state to put the group into. Default: 0

This structure is new to Vector.

117.6. AUDIOSWITCH

The AudioSwitch structure is used to put an audio switch into a particular setting. See Chapter 25, section *110.2 Audio Pipeline* for a description of audio switches. This structure has the following fields:

Table 526: *AudioSwitch structure*

Field	Type	Description
switchGroupId	uint	The switch to modify. Default: 0
stateId	uint	The new state to put the switch into. Default: 0

This structure is new to Vector.

117.7. BACKPACKLIGHTS

The BackpackLights structure is used to animate the LEDs on Vector's back. This structure has the following fields:

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	The time at which the backlights animation should begin.
durationTime_ms	uint	*ms*	The duration before a transition to the next backlight setting may begin. During this time the lights should be illuminated with these colors; after this the colors may transition from these to the next colors.
Front	float[4]	*RGBA*	Each color is represented as 4 floats (red, green, blue, and alpha), in the range 0..1. Alpha is always 0 (the value is ignored).
Middle	float[4]	*RGBA*	Each color is represented as 4 floats (red, green, blue, and alpha), in the range 0..1. Alpha is always 0 (the value is ignored).
Back	float[4]	*RGBA*	Each color is represented as 4 floats (red, green, blue, and alpha), in the range 0..1. Alpha is always 0 (the value is ignored).

Table 527: *BackpackLights structure*

see also: Chapter 23 section *27 Backpack lights control* for a similar JSON structure.

Note: Cozmo's animation structure includes a left and right LED animation.

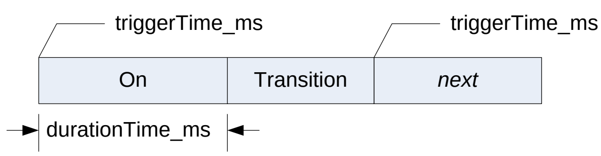

Figure 120: *Time course of the backlight colors*

The best interpretation is that, once a frame is triggered, the LED is set to the given color. The LED won't be changed for at least durationTime_ms. Once that time has expired, the LED color is ramped linearly to the color of the next frame.

117.8. BODYMOTION

The BodyMotion structure is used to specify driving motions for Vector. This structure has the following fields:

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	The time at which the motion should begin
durationTime_ms	uint	*ms*	The duration that the robot should drive.
radius_mm	string	*mm*	
speed	short		The speed at which the robot should move.

Table 528: *BodyMotion structure*

Note: it is possible that the driving should ramp to the speed in the given duration. This is a TBD.

117.9. EVENT

The Event structure is used to pause the animation at the given time code until the event is received or cancelled. When the event is received, the animation resumes the given time code. This structure has the following fields:

Table 529: Event structure

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	When the event occurs it triggers animation to begin at this time.(?) Or, at this time, emit the event?
event_id	string		The name of the event.

The event names include

- CHANGE_EYE_COLOR
- CUBE_LIGHT_TOGGLE
- DANCE_BEAT_SYNC
- DEAL_CARDS_BEGIN
- FLIP_DOWN_BEGIN
- LISTENING_BEGIN
- STRAIGHT
- SWIPE_CARDS_BEGIN
- TAPPED_BLOCK
- TOGGLE_NUMBERS_DISPLAY
- TURN_IN_PLACE

Note: unless otherwise specified the animations are not allowed to have event key frames – the behavior wouldn't expect to send the events to them.

117.10. FACEANIMATION

The FaceAnimation structure is used to specify the JSON file to animation Vector's display. This structure has the following fields:

Table 530: FaceAnimation structure

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	The time at which the motion is triggered.
animName	string		The time at the face animation should begin. See Chapter 24 section *105.6 Sprite Sequences. Required*
scanlineOpacity	float		This is new for Vector. Default: 1.0

The scanlineOpacity is new to support Vector's display. With Cozmo "the screen is displayed interlaced, with only every other line displayed This alternates every time the image is changed (no longer than 30 seconds) to prevent screen burn-in. Therefore to ensure the image looks correct on either scan-line offset we use half the vertical resolution"

Cozmo SDK (Anki)

117.11. HEADANGLE

The HeadAngle structure is used to specify how to move Vector's head. The head should reach the target angle in the duration given, ramping up the movement speed smoothly (with some variability) until it reaches that that point. This structure has the following fields:

Table 531: *HeadAngle structure*

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	The time at which the head motion should begin.
durationTime_ms	uint	*ms*	How long the head motion should last.
angle_deg	ubyte	*deg*	The angle to move the head to. This should be in the range -22.0° to 45.0°.
angleVariability_deg	ubyte	*deg*	The amount of randomness allowed for the target head angle. Default: 0

117.12. LIFTHEIGHT

The LiftHeight structure is used to specify how to move Vector's lift. The lift should reach the target height in the duration given, ramping up the movement speed smoothly (with some variability) until it reaches that. This structure has the following fields:

Table 532: *LiftHeight structure*

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	The time at which the lift should begin motion.
durationTime_ms	uint	*ms*	How long the lift motion should last.
height_mm	ubyte	*mm*	The height to lift the arms to.
heightVariability_mm	ubyte	*mm*	The amount of randomness allowed for the target height. default: 0

117.13. KEYFRAMES

The Keyframes structure provides separate time-coded key frames for each of the possible tracks in the animation. The tracks are optional. There tracks may have different numbers of key frames. The key frames do not need to start at the same time(s).

The KeyFrames structure the following fields:

***Table 533:** KeyFrames structure*

Field	Type	Description
LiftHeightKeyFrame	LiftHeight[]	A series of key frames describing when and how the lift should move.
ProceduralFaceKeyFrame	ProceduralFace[]	A series of key frames describing when and how the eyes should move.
HeadAngleKeyFrame	HeadAngle[]	A series of key frames describing when and how the head should move.
RobotAudioKeyFrame	RobotAudio[]	A series of key frames describing when and how audio should be played.
BackpackLightsKeyFrame	BackpackLights[]	A series of key frames describing when and how the backpack lights should be illuminated.
FaceAnimationKeyFrame	FaceAnimation[]	A series of key frames describing when and how the face should move.
EventKeyFrame	Event[]	Note: many behaviors do not support event key frames; those that do expect a specific event, and number of event keyframes.
BodyMotionKeyFrame	BodyMotion[]	A series of keyframes to drive and turn the body.
RecordHeadingKeyFrame	RecordHeading[]	A series of key frames to record the current heading of the robot so that the animation can return to them later.
TurnToRecordedHeadingKeyFrame	TurnToRecordedHeading[]	A series of key frames use to return the robot to a previously saved heading after a movement.
SpriteBoxKeyFrame	SpriteBox[]	A series of key frames for the visual sprite box animation. *New in version 1.7.*

Note: Each of the structures has a time code. Within each array, the time code(s) must be in ascending order; no two entries in the same array can share the same time code.

117.14. PROCEDURALFACE

The ProceduralFace structure is used squash, stretch and shake Vectors face in cartoonish ways. It does not affect where his eyes are focused. See Chapter 24 section *106 Procedural face* for a description of Vectors face, and how these parameters influence it. The structure has the following fields:

***Table 534:** ProceduralFace structure*

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	The time at which the motion is triggered.
faceAngle	float		default: 0
faceCenterX	float		default: 0
faceCenterY	float		default: 0
faceScaleX	float		default: 1.0
faceScaleY	float		default: 1.0
leftEye	float[]		If present, these describe modifications to the eye – lid, cheeks, and shape of the eye. They have the structure given below.
rightEye	float[]		If present, these describe modifications to the eye – lid, cheeks, and shape of the eye. They have the structure given below.
scanlineOpacity	float		This is new for Vector. default: 1.0

The arrays of floats for each eye in animations for *Cozmo* have been deciphered, and are presumed to be the same for Vector. They are presumed to be the same for Vector:

PyCozmo

Field	Default	Description
lower_inner_radius_x	0.5	
lower_inner_radius_y	0.5	
lower_outer_radius_x	0.5	
lower_outer_radius_y	0.5	
upper_inner_radius_x	0.5	
upper_inner_radius_y	0.5	
upper_outer_radius_x	0.5	
upper_outer_radius_y	0.5	
upper_lid_y	0.0	The vertical position of the upper eye lid (which occludes the eye).
upper_lid_angle	0.0	The angle of the upper eye lid.
upper_lid_bend	0.0	The bend to the upper eye lid.
lower_lid_y	0.0	The vertical position of the lower eye lid / cheek (which occludes the eye).
lower_lid_angle	0.0	The angle of the lower eye lid / cheek.
lower_lid_bend	0.0	The bend to the lower eye lid / cheek.

117.15. RECORDHEADING

The RecordHeading structure has the following fields:

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	The time when the robot should record his heading?

Table 535: *RecordHeading structure*

117.16. ROBOTAUDIO

The RobotAudio structure is used to interact with the audio engine. It is new to Vector; a very different structure with a similar name was used with Cozmo. This structure has the following fields:

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	The time the audio events should be sent, and the parameters should be set.
eventGroups	AudioEventGroup[]		The set of possible audio events to send.
state	AudioState[]		The settings to put different audio states into.
switches	AudioSwitch[]		The configuration of the audio context, setting the audio "switches" to use the right sounds and effects for the circumstances.
parameters	AudioParameter[]		The set of changes to make to the audio playback parameters.

Table 536: *RobotAudio structure*

117.17. SPRITEBOX

The SpriteBox structure defines a rectangular region on the display to draw an image from a file. This structure is new to Vector, introduced in version 1.7 of the software. This structure has the following fields:

Table 537: *SpriteBox structure*

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	The time when Vector should begin to use this sprite box.
spriteBoxName	string		The name of the sprite box. (This name is also defined in vic-anim and libcozmo_engine.) The animation engine may use this to select the procedure(s) in charge managing the layer and sprite boxes. If an image map is available for this animation, the sprite sequence it describes will be displayed in this rectangle. *Required*
layer	string		The name of the layer. (This name is also defined in vic-anim and libcozmo_engine) The animation engine may use this to select the procedure(s) in charge managing the layer and sprite boxes. *Required*
assetName	string		This can be the name of a sprite sequence, independent sprite, or "clear_sprite_box" for an empty image. *Required*
renderMethod	string		"CustomHue" if the PNG images should be converted from gray scale to the colour using the current eye colour setting. "RGBA" if the image should be drawn as is. *Required*
spriteSeqEndType	string		*Required*
alpha	float	*%*	The opacity of the image pixels. Default is 100.0
xPos	int	*pixels*	The x coordinate of the upper left hand corner of the sprite box. The x coordinate can be outside of the display area; only the portion of the image within the display area (0..183) will be shown. This allows an image to slide in. Default: 0
yPos	int	*pixels*	The y coordinate of the upper left hand corner of the sprite box. The y coordinate can be outside of the display area; only the portion of the image within the display area (0..95) will be shown. This allows an image to slide in. Default: 0
width	uint	*pixels*	The width of the sprite box. This should be less than or equal to 96.
height	uint	*pixels*	The height of the sprite box. The width of the sprite box. This should be less than or equal to 184.

The box coordinates and area should smoothly move and change size to the reach the target position and size by the given trigger time.

See also Chapter 24 section *105.3 Layout file* for another method of defining a sprite box.

117.18. TURNTORECORDEDHEADING

The TurnToRecordedHeading is used to specify how Vector should turn to the previously recorded heading. The robot reach the target heading in the duration given, ramping up the movement speed smoothly until it reaches that position (within some tolerance). This structure has the following fields:

Table 538: TurnToRecordedHeading structure

Field	Type	Units	Description
triggerTime_ms	uint	*ms*	The time when Vector should begin to turn to the recorded heading.
durationTime_ms	uint	*ms*	The amount of time to move to the recorded heading.
offset_deg	short	*deg*	default: 0
speed_degPerSec	short	*deg/sec*	The speed that Vector should turn at.
accel_degPerSec2	short	*deg/sec^2*	How fast Vector should accelerate when turning. default: 1000
decel_degPerSec2	short	*deg/sec^2*	How fast Vector should decelerate when turning. default: 1000
tolerance_deg	ushort	*deg*	This specifies how close the actual heading is to the target before considering the movement complete. Default: 2
numHalfRevs	ushort		default: 0
useShortestDir	bool		default: false

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PART VI

High Level AI

This part describes items that are Vector's behaviour function.

- BEHAVIOR. A look at Vectors behaviors, and emotions
- EMOTION MODEL. A look at how Vector emulates emotions
- BEHAVIOR TREES. A look at how the behaviors are selected and their settings

drawing by Steph Dere

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CHAPTER 28

Behavior

This chapter describes Vector's action, behaviour, and emotion system:

- Actions and behaviour queues
- The emotion-behaviour system, and stimulation

118. OVERVIEW

How does Vector get excited from praise, and then decide to go exploring and play? How does he decide it's time to take a nap?

Vector's high-level AI – his emotions, sense of the environment and himself, and behaviors – are a key part of how he creates a compelling character. He has an emotional state that is seen in his affect – his facial expression, head and arm posture – how he behaves and responds, as well as the actions he initiates.

119. ACTIONS AND BEHAVIORS

Actions and "behaviors represent a complex task which requires Vector's internal logic to determine how long it will take. This may include combinations of animation, path planning or other functionality." Anki SDK

119.1. ACTIONS AND THE ACTION QUEUES

Animations can be submitted with which tracks of the animation to disable. This allows multiple actions can be run at the same time. If the action requires a track that is already in use, the action isn't run, and returns an error. Actions can automatically retry if a problem was encountered.

Actions can have associated "tag" used to refer to that running instance. The client can cancel the action.

119.2. BEHAVIORS

Unlike actions, only one behavior can be active at a time. The others are waiting in a stack. A behavior is submitted (to be run) with a priority; if its priority is higher priority the current one, it is run instead. The old behavior is pushed down in the stack. When a behavior completes, the next high priority one is resumed.

119.2.1 Priority Levels

The behaviors requested by Vector's internal AI are submitted to the stack with a priority based on that behavior. If the SDK has requested control, the behaviors it requests are submitted with the priority level set when control was requested. As long as the SDK is connected and has control, behaviors submitted at a lower priority will not activate, even if the SDK is not currently running a behavior. The SDK can lose control if a higher priority is submitted (e.g. "like returning to the charger due to low battery"), gives up control or closes the connection.

The priority levels are organized with lower numbers being higher priority (and larger numbers being lower priority). The built in behaviors have different associate priority levels:

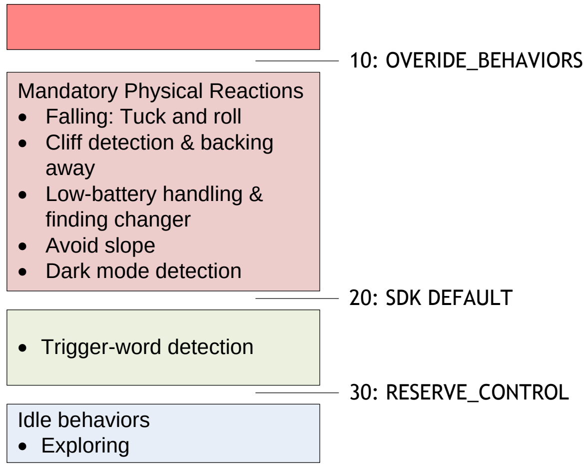


Figure 121: *The behaviour priorities*

The behaviors are grouped, from the highest priority to the least, into the following categories:

- MandatoryPhysicalReactions
- TriggerWordDetected
- SDKDefault (the behaviors submitted via the SDK if the default priority was used)
- SingletonWallTimeCoordinator
- TimerUtilityCoordinator
- WeatherResponses
- TakeAPhotoCoordinator
- ReactToRobotShaken
- ReactToTouchPetting
- BasicVoiceCommands (“simple voice commands that we want to ignore obstacles”)
- ReactToObstacle
- InterruptingVoiceReactions
- ChangeEyeColor
- ReactToUnclaimedIntent
- HeldInPalmDispatcher
- WhileInAirDispatcher
- ReactToPutDown
- ReactToDarkness
- GreetAfterLongTime
- ReactToUncalibratedHeadAndLift
- DanceToTheBeatCoordinator
- StayOnChargerUntilCharged
- ReactToSoundAwake
- ConfirmHabitat

- HighLevelAI

119.2.2 Other properties of a behavior

Besides a priority, a behavior has other properties:

- They have a string identifier
- A given behavior is an instance of a class
- It can have conditions (usually on the current executing environment) that must be met before the behavior can be activated, and other conditions that they must be met to keep running.
- A behavior can have a cool down period associated with it – a period of time after the end of its last use before it can be run again.
- A behavior can trigger animations or actions when it is activated (referred to as the "get in" animations), and when it stops running (the "get out" animations)
- A behavior can submit other behaviors to be run

119.3. PATH PLANNING AND OTHER SMART THINGS TO SUPPORT US

For some commands, "Vector uses path planning, which refers to the problem of navigating the robot from point A to B without collisions. Vector loads known obstacles from his map, creates a path to navigate around those objects, [and] then starts following the path. If a new obstacle is found while following the path, a new plan may be created."

Anki SDK

> "For commands such as go_to_pose, drive_on_charger and dock_with_cube, Vector uses path planning, which refers to the problem of navigating the robot from point A to B without collisions. Vector loads known obstacles from his map, creates a path to navigate around those objects, and then starts following the path. If a new obstacle is found while following the path, a new plan may be created."

119.4. DECIDING ON THE BEHAVIOR TO USE

A behavior can be initiated in two different ways. The libcozmo engine can on startup or based on internal state or events, choose a behavior to submit to run. The other is that the *behavior tree* can decide which behavior should be submitted to run:

Captain 2018 quoting Brad Neuman

> Vector's behavior follows a hierarchy. "The highest level is what kind of things should the robot be doing right now – Should he be quiet? Should he be engaging? Should he be sleeping? Is his battery super-low, and he needs to recharge?" Different behaviors flow from these high-level states, in response to events and the states of his Emotion Engine.

The behavior tree works by allowing the currently executing behavior to submit other behaviors behaviors to run; but those behaviors can have sophisticated rules (and priorities) that govern whether can run, or should stop running. The details of the behavior tree will be examined in the next chapter.

119.5. INITIATING THE BEHAVIOR

In both cases, the identifier (a text string) of the behavior is passed to the behavior engine, along with a priority to run at. The engine checks to see if this is a lower priority (higher number) than the current priority level. If so, the behavior is rejected. . The engine also checks that the behavior is not already on the stack; if so, the behavior is rejected. Otherwise, the behavior id is used to look up (in a table) the relevant behavior node:

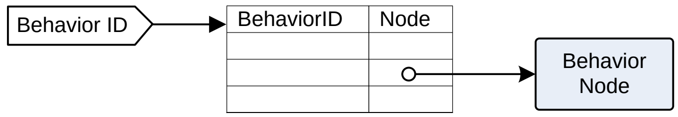


Figure 122: *Mapping a behavior identifier to the behavior tree node*

starting a behavior

A working instance of the behavior is created from the behavior node – the node specifies the class, and its configuration, but the state is not preserved between uses. Then:

1. The behavior is given a preliminary check: can the behavior run?
    a. Is the behavior still in a cool down period? If so, the behavior is rejected
    b. A behavior node can have optional conditions attached to it that say whether or not it can run. Have these conditions been met? If not, the behavior is rejected
2. Next, the active behavior is suspended
3. The stats for behavior activation are updated
4. The new behavior is pushed on to the stack
5. The behaviors associated AI Feature is tracked, to aid in debugging and statistics of usage
6. If the behavior has an emotion event (emotionEventOnActivated) associated, it is posted to the Mood Manager to update Vector's emotional state.
7. The behaviors "get in" activities are carried out – those animations and other actions that are done when the behavior is activated.

119.6. MANAGING THE ACTIVE AND PAUSED BEHAVIORS

The behavior engine regularly checks the behaviors on the stack. It checks that the top most behavior can still run; if not, the behavior is cancelled: its "get out" animation is started, and the behavior is removed from the stack. Perhaps all behaviors on the stack are checked to see if they can still run, and (if not) they and their children are removed from the stack; with the suspended behaviors not running their "get out" animation.

Then the top most behavior carries out any updates to its activities and state. The behavior may also choose to cancel itself, or to initiate another behavior.

If a behavior exits – or is cancelled – the next one on the stack is resumed.

119.7. BEHAVIOR CONTROLLERS

Several behaviors have multiple steps (and behavior classes) used in the interaction. These can be coordinated with a shared entity called a controller. The controller brings together the information from the cloud's intent response, as well as its internal state and logic. These are used for the weather, timers & time, and games like blackjack and cube spinner.

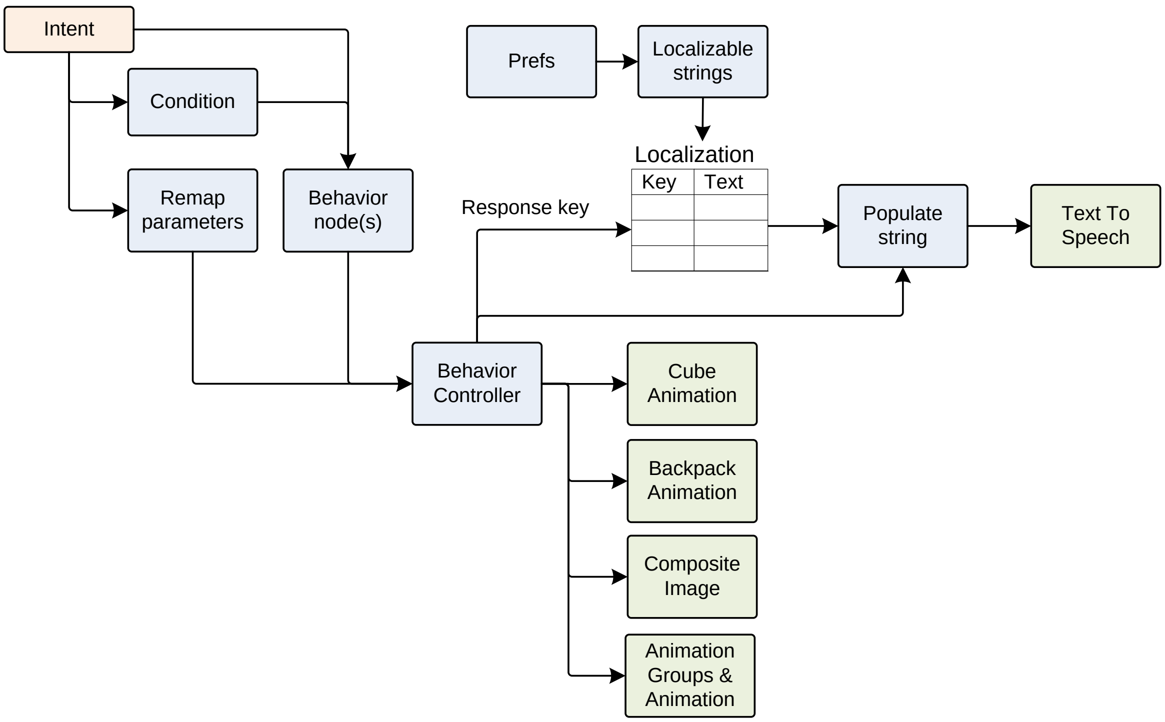


***Figure 123:** The behavior controller links together multiple intents, and responses*

While each controller is unique, in general a controller can:

- Construct the text to be spoken, from templates and parameters. The parameters are from the cloud and within the controller.
- Select cube and backpack light animations, as well as other animations to play. Some of these animations are called out in the behavior node.
- Update the sprites to use in the composite image sprite boxes
- Manage internal timers and state

119.8. AUDIO EVENTS

Many of the behavior JSON files emit audio events; the JSON field names typically look like:

- postAudioEvent
- earConAudioEventNeutral
- earConAudioEventSuccess
- earConAudioEventBegin

CHAPTER 29

Emotion Model

This chapter describes Vector's action, behaviour, and emotion system:

- Actions and behaviour queues
- The emotion-behaviour system, and stimulation

120. OVERVIEW

How does Vector get excited from praise? Vector has an emotional state that is seen in his affect – his facial expression, head and arm posture – how he behaves and responds, as well as the actions he initiates.

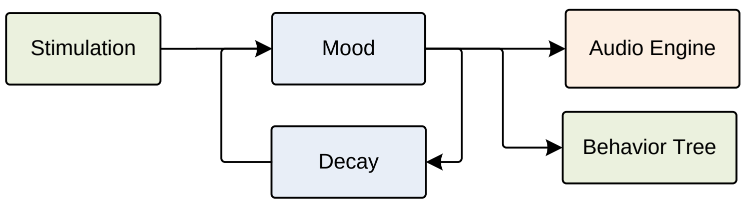


Figure 124: *The functional flow of the mood*

Vectors mood is affected by external stimulation, and his feedback on his successes (and failures) in his activities. His current mode affects the choices he makes and the behaviors he takes, including those in response to events and stimulation. His emotional state is also reflected in how the audio engine modulates its effects, even potentially choosing other effects or sounds. Vectors' emotions are transitory though: heightened emotions decay, based on the stimulus and behavior that drove them.

This emotion model and coupling their effects with other systems is managed by the "MoodManager."

121. EMOTIONS, AND STIMULATION

It's thru stimulation of these emotions that Vector responds to praise. The label "emotion" shouldn't be taken too seriously, as it doesn't model psychological moods, and other concepts. It does just enough to convey character.

121.1. STIMULATION

Vector uses a concept of a stimulation level to guide how much he should initiate

> "When stimulation is low, the robot is chill,".. Vector is studiously observing but not acting out. "Then if you start making noise, or make eye contact with the robot, and certainly if you say 'Hey Vector,' that spikes [stimulation] way up..." But Vector also picks up subtler actions–peripheral movement and noises, for instance, or the room lights turning on and off. "If he gets stimulated enough, he'll drive off his charger and start to socialize with you, … say your name, greet you, give you a fist-bump, potentially."

Captain 2018 quoting Brad Neuman

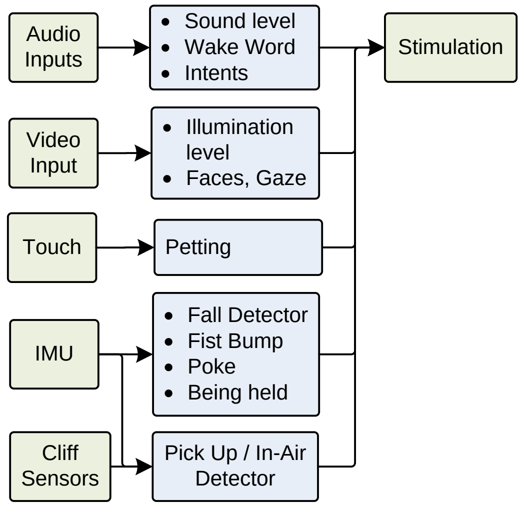


***Figure 125:** The stimulation from sensations*

121.2. THE EMOTION MODEL

Stimulation is just one of the dimensions in Vector's emotional model. Some dimensions are influenced by the kind stimulation he is receiving, but others are from internal feedback Vectors behaviors. Altogether he has five dimensions to his emotional state.

- Stimulated (or the stimulation level) is from those sensory experiences described earlier;
- Social, or "how eager [he] is to interact with users generally." "Hearing his name stimulates Vector, for instance, but it also makes him more social." Wolford et al, 2018 Captain 2018
- Confident: "Vector's confidence is affected by his success in the real world. The hooks on his arms sometimes don't line up with those on his cube, for instance, and he can't pick it up. Sometime he gets stuck while driving around. These failures make him feel less confident, while successes make him more confident and more happy."
- Happy. This is Vectors sense that, overall, things are going well.
- Trust[56]

Overall, Vector possesses just enough dimensions/aspects to his emotion model to drive responses and his goal-driven behaviour, giving him a personality. When more dimensions are used, it is harder to get them right, and the less convincing the character is when they aren't.

121.3. SIMPLE MOODS

The emotions reflect short-term values across the 5 dimensions that arise as a result of stimuli. Vector also has a *simple mood* that is distinguished from emotion by changing at a much slower rate. A simple mood is a name that maps to some emotion value ranges. These are built into the libcozmo_engine. The simple moods include:

- Default
- Frustrated
- HighStim
- LowStim

[56] Trust was added in version 1.6. Vector initially only had the first four. Cozmo had nine, so it seems plausible that Vector would have developed more dimensions over time.

- MedStim

It is not known how the mood interacts with the emotions.

121.4. INTERACTION WITH THE BEHAVIOR ENGINE

The behavior engine receives the stimulation events, and using a behavior tree, posts *emotion event* to the mood manager. (The engine may base its decision what to post on the current mood.) An emotion event is just an identifier string. The mood manager maps the emotion event to an *emotion affector*. This is the emotion dimensions impacted by the event, values describing *how much* the event impacts those emotion dimensions, and a decay graph that describes how the heighten emotion fades away toward a neutral state.

emotion event

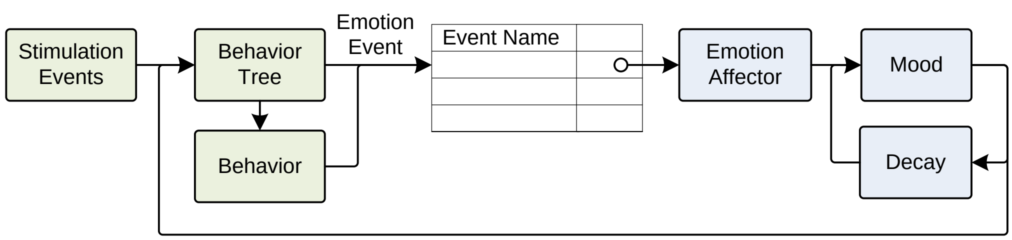


Figure 126: *Mapping an emotion event to how it impacts the emotion model*

The active behaviors (which are also selected by the behavior tree) may post emotion events to the mood manager as well.

121.5. MOOD MANAGER CONFIGURATION

At start up, the mood manager scans the configuration files building a table mapping the emotion event names to the emotion affector.

The configuration files for the mood manager are located in a folder at:

/anki/data/assets/cozmo_resources/config/engine/emotionevents

This is path hardcoded into libcozmo_engine. It is a folder that contains a set of JSON files, all with the same structure. Each of these files is loaded. Each is a structure containing the following fields:

Field	Type	Description
emotionEvents	EmotionEvent[]	An array emotion event structures (see below).

Table 539: *CheckUpdateStatusResponse JSON structure*

The EmotionEvent describes how the emotions respond to an event. It has the following structure:

Field	Type	Description
name	string	The name of the event (see appendix K, *Table 641: The emotion event names*)
emotionAffectors	EmotionAffector[]	The impact on the emotion state.
repetitionPenalty	RepetitionPenalty	This is a "time ratio" describing how the value decays. *Optional.*

Table 540: *EmotionEvent JSON structure*

The EmotionAffector describes how an emotion dimension should be modified:

Field	Type	Description
emotionType	string	The dimension or type of emotion ("Happy", "Confident", "Stimulated", "Social", or "Trust")
value	float	The value to add to the emotional state. The range is usually -1 to 1

Table 541: *EmotionAffector JSON structure*

Altogether, the files respond to the following "emotion event" names. Some are external stimuli, some are events in general, some are events regarding whether or not a behaviour succeeded, or failed (failed with retry, failed with abort).

121.5.1 The RepetitionPenalty

The RepititionPenalty structure contains the following fields:

Field	Type	Description
nodes	XY[]	This is a "time ratio" describing how the value decays with time.

Table 542: *RepititionPenalty structure*

121.5.2 The XY decay graph

The XY structure is used to define how a value (often the value associated with an emotion dimension) should decay with time. This structure contains the following fields:

Field	Type	Description
x	float	With time graphs, this is "the time in seconds since the most recent event (which changed the emotion by more than some delta)." With value slopes, this is "the emotion value."
y	float	With time graphs, this is "the ratio of the original value that should be reached by the given time." With value slopes, this is "the amount it decays (towards zero) per *minute* as a fixed amount (not a ratio)." The value never goes below zero.

Table 543: *XY structure*

121.6. MOOD CONFIGURATION

A mood configuration files is located at:

/anki/data/assets/cozmo_resources/config/engine/mood_config.json

This is path hardcoded into libcozmo_engine.

The file is a structure containing the following fields:

Field	Type	Description
actionResultEmotionEvents	TBD struct	
audioParameterMap	struct	This is a structure that maps an emotion type to an audio parameter's string name. The audio parameter is set to current emotion type's value. *Optional*
decayGraphs	DecayGraph[]	This describes how an emotion decays.
defaultRepetitionPenalty	RepetitionPenalty	This is a "time ratio" describing how the value decays. *Optional.*
eventMapper	struct	
simpleMoodAudioParameters	struct	*Optional*
valueRanges	ValueRange[]	The allowed value ranges for given emotion types. Note: this need not exhaustively define the range for all emotion types. Values not listed should be assumed to have a range of -1..1

Table 544: *Mood config JSON structure*

The DecayGraph structure contains the following fields:

Field	Type	Description
emotionType	string	The dimension or type of emotion ("Happy", "Confident", "Stimulated", "Social", or "Trust"). "default" also matches
graphType	string	"TimeRatio" or "ValueSlope" . The default is "TimeRatio".
nodes	XY[]	Array of structures describing how the value decays with time.

Table 545: *DecayGraph structure*

The ValueRange structure contains the following fields:

Field	Type	Description
emotionType	string	The dimension or type of emotion ("Happy", "Confident", "Stimulated", "Social", or "Trust")
max	float	The maximum value for the emotion type
min	float	The minimum value for the emotion type

Table 546: *ValueRange structure*

122. REFERENCES & RESOURCES

Captain, Sean; *Can emotional AI make Anki's new robot into a lovable companion?* , Fast Company, 2018-8-8 https://www.fastcompany.com/90179055/can-emotional-ai-make-ankis-new-robot-into-a-lovable-companion

CHAPTER 30

Behavior Tree

This chapter describes Vector's behaviour tree and how behaviors are configured:

- Behavior trees, parameters for behaviors, conditions that allow a behavior or stop a behavior
- Cube spinner event mapping.

123. OVERVIEW

Behaviors are why Vector wants to shove stuff off of the desk.

Vector employs a *behavior tree* that decides if a behavior can run or can no longer run. It doesn't take it to the extreme a detailed decision tree scripting every action and response. Most of the behavior tree is is focused on ensuring that transition between behaviors isn't too abrupt, and provides the settings (or preferences) for the behavior.

The fields and structures of the behavior tree are pretty ad hoc though. This seems to be the norm in the video game industry

> The "design principles" listed in this paper are a rather transparent attempt to impose a structure on what might otherwise appear to be a random grab-bag of ideas – interesting, perhaps, in and of themselves but not terribly cohesive as a whole.

Isla 2005

124. BEHAVIOR TREE

behavior tree nodes

The behavior tree is composed of nodes in JSON files. Each of the behavior nodes has a unique identifier, called behaviorID. This is a way to make the records unique so that they can be looked up. It is unlikely that it links to any special code or modules within libcozmo_engine.

The nodes also have a field – behaviorClass – that says how to interpret the node parameters, if the behavior is activated. This class name links to code/modules within libcozmo_engine. There are 86 different behaviour classes.

Behavior nodes can initiate other behaviors. The identity of the behavior they launch may be called out in the configuration of the node, or be hardcoded internally. To prevent loops, the chain of the nodes must be *acyclic.* The concern is that a behavior node kicks off another (and so on), eventually to a child node initiate another copy of the first node, leading to an infinite loop of behaviors being started on pushed onto the stack. Not only doesn't it give expected results, eventually the software will run out of memory, and crash.

libcozmo_engine kicks off the initial behavior that forms the root of the tree. Vector, at the top level, has 7 broad states:

- PR demo
- Factory test (e.g. the playpen tests)
- Acoustic testing
- On-boarding

- Normal
- Developer
- Post on-boarding

These states are mapped to initial behavior identifier. Some have the mapping built-in to the software (hardcode), the others this mapping is in the above JSON configuration file (in the `victor_behavior_config.json` file; more on this below). In normal operation, this is the "`InitNormalOperation`" behavior.

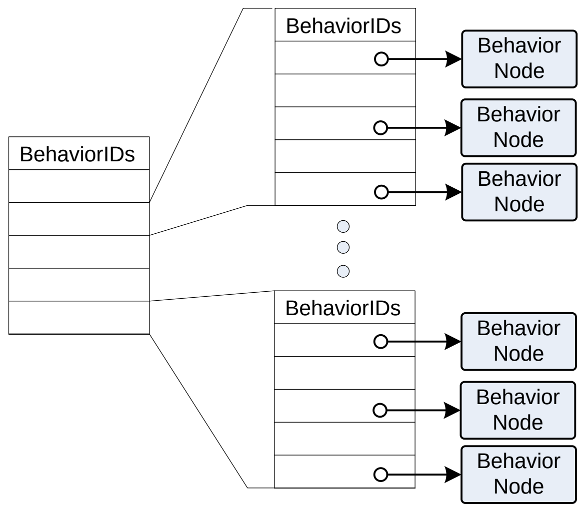


Figure 127: *The behavior tree fan out*

It is built on the `DispatcherStrictPriority` behavior class, listing behaviors to sequentially check to see if they can be run. The top node only refers to behaviors that in a list of a behaviors to invoke sequentially. The behaviors listed at that second level in turn reference behaviors that carry out actual AI features.

The decision tree logic is called out with the nodes. There is a portion of the logic that is used to check to see if the behavior *can be run*. This logic can be used to delay running the behavior until some clean or stabilization of other stuff has occurred. And there is a portion of the logic that is used to check to see if the behavior should be cancelled.

124.1. TIMERS

Behaviors can have an associated timer, similar to an animations cool down timer. This prevents the behavior from re-engaging too quickly. These timers can be used as part of the conditional rules that enable or disable a behavior.

Table 547: *Behavior timers*

Timer	Description
FistBump	
ObservingOffChager	
ObservingOnCharger	
ReactToIllumination	
ReactToJoltInPalm	

The timers are handled by `BehaviorTimerManager()`.

124.2. CONFIGURATION

The configuration files for the behavior tree are located:

/anki/data/assets/cozmo_resources/config/engine/behaviorComponent/victor_behavior_config.json

This is path hardcoded into libcozmo_engine.

Note: most of the names of the structures in this chapter are arbitrary. They were made up to ease readability and documentation. The files do not reference any such structure names.

124.3. BEHAVIOR NODE

The following fields are common to all behavior nodes:

Table 548: *Behavior JSON structure*

Field	Type	Description
animationName	string	The name of an animation to play {note not a trigger name}.
anonymousBehaviors	Behavior[]	A list of behaviors that are executed. *Optional*
associatedActiveFeature	string	Note: this is the high level AI feature, not the feature gate. *Optional*
behaviors	string[]	Array of behavior names, in order; these behaviorName are in the anonymousBehaviors array. Can also be in…? *Optional*
behaviorClass	string	Often these are the same
behaviorID	string	
behaviorName		
behaviors	string	If it is a string, this is the behaviorID of the behavior to run.
	string[]	If it is an array of strings, this is one or more behaviors to run to in sequence. That is, the fist behavior is initiated, and the current behavior node is paused until the new completes. Then the next one in the sequence is initiated, and so on in order.
	BehaviorConfig[]	If it is an array of structures, this is a set of possible behaviors to run; they are picked randomly. based on weight.
behaviorStatToIncrement	string	*Optional*
delegateID	string	
driveOffChargerBehavior		
emotionEventOnActivated	string	e.g. RespondToShortVoiceCommand or DanceToTheBeat. *Optional.*
faceSelectionPenalties		
getInAnimation	string	The animation trigger name of the animation to play when starting the behavior. *Optional*
getOutAnimation	string	The animation trigger name of the animation to play when exiting the behavior. *Optional*

headAngle_deg	float	*Optional*
postBehaviorSuggestion	string	*Optional*
resetTimers		
respondToUserIntents	TBD[]	*Optional*. Only key is "type" (with a value such greeting_goodbye) The intent string is the *User Intent* (see table in appendix J)
wantsToBeActivatedCondition	Condition	If the condition is false, the rest of the behavior is skipped. Some of the conditions are used to wait until the robot is in a state that he can carry out the behavior (and past stuff that could cause false triggers are behind us) *Optional*
wantsToCancelSelfCondition	Condition	If the condition is true, the rest of the behavior is skipped. *Optional*

BehaviorConfig

The BehaviorConfig structure has the following fields:

Table 549: *BehaviorConfig parameters*

Field	Type	Units	Description
behavior	string		The name of a behaviorID. The anonymous behaviors in the current behavior node are checked first to find a behavior node with this id. Then the global table.
cooldown_s	float	*seconds*	The amount of time after this behaviour completes before it can be run again. A value of "-1" means to run the behavior only once – it gives the cooldown timer a value of forever.
weight	float		*Optional*

Note: the weights do not have to sum to 1.0

Given an array of BehaviorConfig structures, the list is prescreened to eliminate behaviors that already running or still in cooldown. A behavior is randomly selected from this list based on its weighting, and launched.

124.4. CONDITION NODES

A condition node is used as part of the behavior tree to determine if a behavior is eligible, or if a running behavior should be cancelled. The interpretation of the condition is (mostly) controlled by the conditionType field. This type defines what other fields will be looked at.

The following are the kinds of condition nodes:

Table 550: *Types of condition nodes*

conditionType	Description
AlexaInteractionActive	This condition is true if Vector's Alexa modules are currently interacting with a person.
BatteryLevel	This type of condition compares the current battery state with a specified state. Although any of the states can be used, the current behavior tree nodes only check for low

	battery.
BeatDetected	This condition is true if a music beat has been detected
BehaviorTimer	This condition is true if
BeingHeld	This condition is true if Vector is being held.
CarryingCube	This condition is true if Vector is currently carrying a cube.
CliffDetected	This type of condition is true if a cliff sensor has detected an edge.
Compound	This type of condition is used for boolean logic. It is the only kind that recurses to other compound structures.
Emotion	This condition is true if the value for the given emotion dimension is above a threshold.
EyeContact	This condition is true if someone is making eye contact with Vector.
FeatureGate	This type of condition is true if a specified AI feature is active or inactive.
HighTemperature	This type of condition is true if Vector's temperature is above an acceptable limit.
InCalmMode	This type of condition is true if Vector is in a calm emotional state.
IsMaintenanceReboot	This type of condition is true if Vector has rebooted for a software update or other maintenance reasons.
IsNightTime	This type of condition is true if Vector [thinks it is night? the illumination level is dark?]
MotionDetected	This type of condition is true if Vector sees some motion in his peripheral vision.
ObjectInitialDetection	This condition is true if
ObjectKnown	This condition is true if
ObstacleDetected	This condition is true if Vector has encountered an obstacle.
OffTreadsState	This type of condition is true if Vector's current state matches a conditions such as on his tread, or has been picked up, is being held, is being put back down, has fallen (on his side). There is a time component to ensure that state is stable, to prevent overreacting.
OnCharger	This condition is true if Vector is currently on his charger (i.e. he is in his dock) and it is providing energy.
OnChargerPlatform	This condition is true if Vector is currently on his charger (i.e. he is in his dock); it may or may not be providing any energy.
ProxInRange	
RobotHeldInPalm	This condition checks whether or not Vector is being held.
RobotInHabitat	This is true if Vector is in his habitat.
RobotPickedUp	This type of condition is true if Vector is picked up – being held. (does "in the air" count?)
RobotPitchInRange	This type of condition is true if Vector's pitch is within a specified range.
RobotPlacedOnSlope	

RobotRollInRange	This type of condition is true if Vector's roll is within a specified range.
RobotShaken	This type of condition is true if Vector has been shaken.
RobotTouched	This type of condition is true if Vector has been touched/petted (for at least a minimum duration).
SalientPointDetected	This condition is true if
StuckOnEdge	This type of condition is true if at least one tread has gone over the edge. Perhaps the cliff sensors on one side show in open space, perhaps Vector can tell that the tread isn't moving the robot?
TimedDedup	This condition is true if
TimerInRange	This condition is true if a specified timer is within a specified value range.
TooHotToCharge	
TriggerWordPending	
TrueCondition	This is condition is always true.
UnexpectedMovement	
UserIsHoldingCube	This is true if the user is holding the cube.

The Condition structure has the following possible fields:

***Table 551:** Condition JSON structure*

Field	Type	Condition Type	Description
and	Condition[]	*Compound*	The condition is true iff all of the sub-conditions are true; false otherwise. The array must contain at least two conditions The array must contain at least two conditions. *Optional*
allowPotentialBeat	boolean	*BeatDetected*	
begin_s	float	*TimerInRange*	Wait for the timer to have been going for at least this number of seconds.
conditionType	string	*(all conditions)*	One of the conditions listed in *Table 550: Types of condition nodes*
cooldown_s	float	*BehaviorTimer*	The minimum duration between behaviors.
dedupInterval_ms	int	*TimedDedup*	
emotion	string	*Emotion*	The name of the emotion dimension to fetch the value for.
expected	boolean	*FeatureGate*	This is compared against the feature toggle value, the FeatureGate condition is true iff they have the same values.
feature	string	*FeatureGate*	The name of the feature toggle, e.g. "HowOldAreYou"
firstTimeOnly	boolean	*ObjectInitialDetection*	
invalidSensorReturn	boolean	*ProxInRange*	If true, matches when the proximal sensor is unable to measure the distance to the object. Default is false. *Optional*
maxAge_ms	int	*ObjectKnown*	

maxPitchThreshold_deg	float	*RobotPitchInRange*	The maximum acceptable pitch reported by the IMU.
maxProxDist_mm	float	*ProxInRange*	The maximum acceptable distance reported by the time of flight sensor.
maxRollThreshold_deg	float	*RobotRollInRange*	The maximum acceptable roll angle reported by the IMU.
maxTimeSinceChange_ms	int	*OffTreadsState*	*Optional*
min		*Emotion*	The minimum acceptable value associated with the given emotion dimension.
minAccelMagnitudeThreshold	uint	*RobotShaken*	The threshold (in milli-g's?) for the vibrations on the accelerometer to be considered a shake event.
minDuration_ms	uint	*CliffDetected*	The minimum amount of time that the cliff sensors have registered an cliff of this condition should be true. *Optional*
minDuration_s	float	*RobotHeldInPalm*	The minimum amount of time that the rest of this condition should be true. *Optional*
minPitchThreshold_deg	float	*RobotPitchInRange*	The minimum acceptable pitch reported by the IMU.
minProxDist_mm	float	*ProxInRange*	The minimum acceptable distance reported by the time of flight sensor.
minRollThreshold_deg	float	*RobotRollInRange*	The minimum acceptable roll angle reported by the IMU.
minTimeSinceChange_ms	int	*OffTreadsState*	*Optional*
minTouchTime	float	*RobotTouched*	The robot must be touched for at least this duration (in seconds) this condition to be true.
motionArea	string	*MotionDetected*	The area of the vision that detected the motion should match this string: "Left", "Right", (potentially "Ground")
motionLevel	string	*MotionDetected*	"High"
not	Condition	*Compound*	The condition is true iff the sub-condition is false; otherwise the condition is false. *Optional*
numCliffDetectionsToTrigger	uint	*CliffDetected*	A count of the number separate cliff sensors that are to trigger before a cliff is considered to have been detected.
objectTypes	string[]	*ObjectInitialDetection ObjectKnown*	The acceptable kinds of object kinds/faces to meet this condition. *Optional*
or	Condition[]	*Compound*	The condition is true if any of the sub-conditions are true; false otherwise. The array must contain at least two conditions. *Optional*
shouldBeHeld	boolean	*BeingHeld*	If true, the condition is true iff the robot is currently being held. If false, the condition is true iff the robot *is not* currently being held.
shouldBeHeldInPalm	boolean	*RobotHeldInPalm*	If true, the condition is true iff the robot is currently being held in the palm of a hand. If false, the condition is true iff the robot *is not* currently being held in the palm of a hand.

shouldDetectNoCliffs	boolean	*CliffDetected*	If true, the condition is true iff a cliff has *not* been detected.
subCondition	Condition	*TimedDedup*	
targetBatteryLevel	string	*BatteryLevel*	e.g. "Low"
targetSalientPoint	string	*SalientPointDetected*	e.g. "Person" This could be other outputs of the neural network matching.
targetState	string	*OffTreadsState*	"Falling", "InAir" , "OnBack", "OnFace", "OnLeftSide", "OnRightSide", "OnTreads"
timerName	string	*BehaviorTimer*	"ReactToIllumination"

125. A LOOK AT SOME INTERESTING BEHAVIORS

There are too many behavior classes to dig into. But a few are particularly fun to look at.

125.1. SHOVING STUFF OFF OF THE TABLE

The BumpObject class is likely the behavior that drives Vector to shove stuff off of desk. There is only one behavior tree node with this class. It has the id ExploringBumpObject and is held in the file

```
/anki/data/assets/cozmo_resources/config/engine/behaviorComponent/behaviors/victorBehaviorTree/highLevelDelegates/exploring/exploringBumpObject.json
```

The BumpObject class takes the following extra parameters:

Table 552: *BumpObject behavior structure*

Field	Type	Units	Description
maxDist_mm	uint	*mm*	The maximum distance to the potential object to bump.
minDist_mm	uint	*mm*	The minimum distance to the potential object to bump
pBumpWhenEvil	float		Probability of bumping things when being evil?
pBumpWhenNotEvil	float		Probability of bumping things when not being evil?
pEvil	float		Probability of being evil?

125.2. POUNCING

Pouncing is where Vector springs forward to leap on an object, such as a finger.

- Vector detects visual motion, and turns toward that (see motion detection). In this he turns left (or right) to where he detected the motion (the Turn behavior class)
- When he has a distance measurement (from the proximity sensor) (The PounceWithProx behavior class)
- When he is close enough, the animation takes over; he'll make his facial expressions, moves his arms, and tries to pin the object with his arms ("mousetrap"). Note: the animations can't be used to drive toward the target earlier; they aren't linked into the proximity sensors for driving.
- If nothing else is happening, he'll wait for up to 30 seconds before losing interest.

A behavior tree node, using the DispatcherStrictPriority behavior class, coordinates these. The DispatcherStrictPriority class takes the following extra parameters:

Table 553: *DispatcherStrictPriority behavior structure*

Field	Type	Units	Description
interruptActiveBehavior	boolean		

The Turn class takes the following extra parameters:

Table 554: *Turn behavior structure*

Field	Type	Units	Description
shouldTurnClockwise	boolean		True if Vector should turn clockwise; false if he should turn counter clockwise
turnDegrees	int		The number of degrees to turn.

125.3. REACTING TO SOUND

Vector has two related behaviors for reacting to sound – deciding that there is some activity and that he should react, or even play.

The ReactToSound behavior class is used to rouse Vector and respond if there are any sudden noises, or there sounds like activity in the room:

Table 555: *ReactToSound parameters*

Field	Type	Units	Description
micAbsolutePowerThreshold	float		"a mic power above this will always be considered a valid reaction sound" 0…4?
micConfidenceThresholdAtMinPower	float		Used in conjunction with micMinPower? 0…5000
micDirectionReactionBehavior	string		The behavior ID to use for reactions
micMinPowerThreshold	float		"a mic power above this will require a confidence of at least kRTS_ConfidenceThresholdAtMinPower to be considered a valid reaction sound" 0..3 ? 999.9 is considered impossibly high"

The ReactToMicDirection behavior class is used to allow Vector to respond to direction that the sound is coming from. It maps the sound direction to the terms "TwelveOClock", "OneOClock", "ambient", and has conditions like "OnSurface" and "OnCharger".

See Chapter17, section *76.2 Spatial audio processing* for where it the microphone sound is coming from.

125.4. DANCING

Vector can dance to music, making moves in response to the beats. The dancing can be initiated two different ways. The first step is if a beat is detected. The second is if Vector is verbally told to dance.

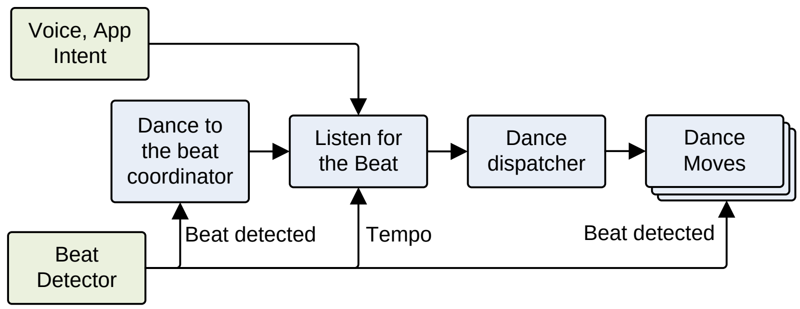


Figure 128: *Flow of the detecting and dancing to music*

The details of the beat detector and tempo measurement are in Chapter 18 section *76.5 Beat Detection*.

125.4.1 Dancing if a beat is detected

A behavior node (of behavior class "DanceToTheBeatCoordinator") is regularly invoked as part of the behavior tree (see section *124 Behavior Tree*). This node has the pre-condition to check that a beat has been detected. This isn't quite the same as reacting sounds, but it is similar. The BeatDetected condition structure has the following parameters:

Table 556: *BeatDetected parameters*

Field	Type	Units	Description
allowPotentialBeat	boolean		Default: false. *Optional*

If a beat has been heard, the DanceToTheBeatCoordinator proceeds in two phases. The first kicks off a helper behavior to listen for music. If it detects music (beats), it then fires off a dance behavior: there are two such behaviors, depending on whether or not it was on the charger. If there is no music detected – or Vector is no longer on his treads – this behavior exits.

The behavior's configuration structure has the following parameter fields:

Table 557: *DanceToTheBeatCoordinator parameters*

Field	Type	Units	Description
listeningBehavior	string	*behaviorID*	The name of a behavior node to invoke.
longListeningBehavior	string	*behaviorID*	The name of a behavior node to invoke.
offChargerDancingBehavior	string	*behaviorID*	The name of a behavior node to invoke.
onChargerDancingBehavior	string	*behaviorID*	The name of a behavior node to invoke.

125.4.2 Dancing by voice command

A behavior node (of behavior class "DanceToTheBeatVoiceCommand") is regularly invoked as part of the behavior tree (see section *124 Behavior Tree*). Part of pre-conditions for being able to execute this node is that someone has given Vector a command to dance. This is done by the "respondToUsersIntents" condition including the "imperative_dance" intent. If there is no such user intent pending, the node is skipped.

Otherwise, the intent is dequeued, Vector drives off of the charger, listen for the music beats, and (if there are any) begins dancing.

125.4.3 Listening for the beat

The `ListenForBeats` behavior class is used to listen for multiple beats and to get the tempo. The behavior exits once music has been heard, or if there is a timeout. Then the behavior node that invoked it is then resumed to initiate the next step.

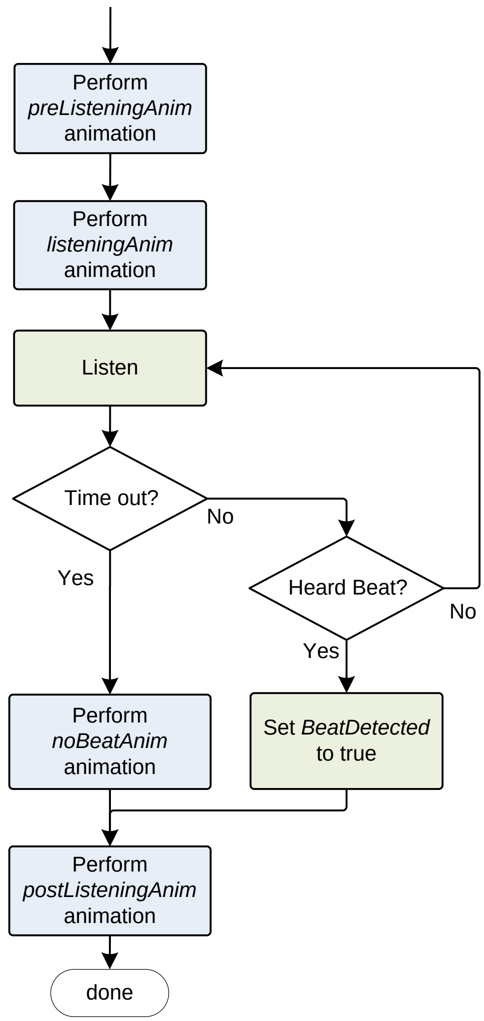


Figure 129: *ListenForBeats behavior function*

The behavior plays animations when it begins, ends, and if it doesn't hear any beats. (If it does hear beats, the dancing behaviors will play their own animations.) It sets the behavior tree variable "`BeatDetected`" to true if it heard beats; otherwise it is set to false.

The behavior's configuration structure has the following parameter fields:

Table 558: ListenForBeats parameters

Field	Type	Units	Description
cancelSelfIfBeatLost	boolean		If true, exits the behavior when the beat has been lost,
listeningAnim	string		The name of an animation trigger that is played while listening for music and getting the tempo.
maxListeningTime_sec	float	*seconds*	The maximum amount of time to listen for music
minListeningTime_sec	float	*seconds*	Listen for at least this amount of time before concluding that there is no music and exiting.
noBeatAnim	string		The name of an animation trigger that is played when the behavior exits because there is no music playing.
postListeningAnim	string		The name of an animation trigger that is played after music has been detected, and is transitioning to the dancing.
preListeningAnim	string		The name of an animation trigger that is played when this behavior is started, before listening for music has fully started.

The dance feature employs multiple instances of these to detect beats.

125.4.4 The Robo-boogie

Once Vector has decided to get his groove on, he chooses a dance from the many kinds of dances of that he knows about. The dances themselves are partly-randomized sequences of dance move animations that are coordinated the beats of the music.

The selection of the dance is performed using a node with the DispatcherRandom behavior class. The different dances (as behaviors nodes) are listed in the "behaviors" array (along with some weighting to help randomize with dance is selected). A new behavior – one that performs the dancing – is randomly selected from this.

A particular dance is an instance of the DanceToTheBeat behavior class. A dance includes the dance moves, whether the back pack lights can play along, and the facial expression.

Table 559: DanceToTheBeat parameters

Field	Type	Description
backpackAnim	string	The backpack animation trigger name to play while dancing.
danceSessions	DanceSession[]	The dance moves that make up the dance.
eyeHoldAnim	string	The animation trigger name to animate the face
getOutAnim	string	The animation trigger name to play when exiting this behavior.
useBackpackLights	boolean	If true, play the backpack lights animation. Default is false(?)

The dance moves – called *dance sessions* – are made up of smaller animated movements called "dance phrases." They can (optionally) be coordinated with the beat of the music. These are captured in the DanceSession structure:

Table 560: *DanceSession parameters*

Field	Type	Description
canListenForBeats	boolean	If true, then the animation (in the dance phrases) will be synchronized with beats with the beat. If false, then the beat events from the beat-detector will be ignored.
dancePhrases	DancePhraseConfig []	The sequence of (randomized) animations. These are played in order.
playGetoutIfInterrupted	boolean	If true, and is interrupted by another animation, it plays the animation specified by getOutAnim (in the containing structure).

The dancing motions– dance phrases – are "made up of one or more possible dance animations … strung together and played on sequential musical beats." The DancePhraseConfig structure "specifies the rules by which dance phrases are generated when the behavior is run." These differ from animation groups: here a random *list* of animations to play is created, rather than selecting just one. This structure has the following fields:

Table 561: *DancePhraseConfig parameters*

Field	Type	Description
anims	string[]	The list of animation names (rather than trigger names) to randomly draw from. There must be at least one animation given.
maxBeats	uint	The animation is played no more than this number of times.
minBeats	uint	The animation is played at least this number of times.
multipleOf	uint	The animation is played is a multiple of this number of times.

"The number of animations that make up the phrase is random, but is always between 'minBeats' and 'maxBeats', and is always a multiple of 'multipleOf'." The "animations are randomly drawn from the [anims] list in accordance with the min/max beats."

If canListenForBeats (in the containing structure) is true, the animation (may) have an event key frame that pauses the animation until a musical beat is heard and a DANCE_BEAT_SYNC event is sent to the animation engine. In this case, the animations must have one event key frame, and the event_id must be "DANCE_BEAT_SYNC".

126. USER CONDITIONS

There is an unusual configuration file that looks like it was intended to allow some user defined behaviors, tuning of behaviours or responses:

```
/anki/data/assets/cozmo_resources/config/engine/userDefinedBehaviorTree/conditionToBehaviorMaps.json
```

This is path hardcoded into libcozmo_engine. It is a configuration that links to a bunch of backpack and cube lights patterns.

127. REFERENCES & RESOURCES

Isla, Damian; *Handling Complexity in the Halo 2 AI*, GDC 2005 Proceeding, 2005 March 11 https://www.gamasutra.com/view/feature/130663/gdc_2005_proceeding_handling_.php

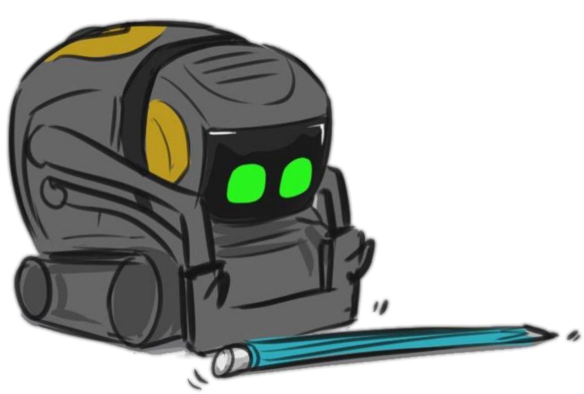
It is said that this presentation kicked off the widespread use of behavior trees in video games.

PART VII

Maintenance

This part describes practical items to support Vector's operation.

- SETTINGS, PREFERENCES, FEATURES AND STATISTICS. A look at how Vector syncs with remote servers
- SOFTWARE UPDATES. How Vector's software updates are applied.
- DIAGNOSTICS & STATS. The diagnostic support built into Vector, including logging and usage statistics



drawing by Steph Dere

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CHAPTER 31

Settings, Preferences, Features, and Statistics

This chapter describes:

- The owner's account settings and entitlements
- The robot's settings (owner preferences)
- The robot's lifetime stats

128. THE ARCHITECTURE

The architecture for setting and storing settings, statistics, account information is:

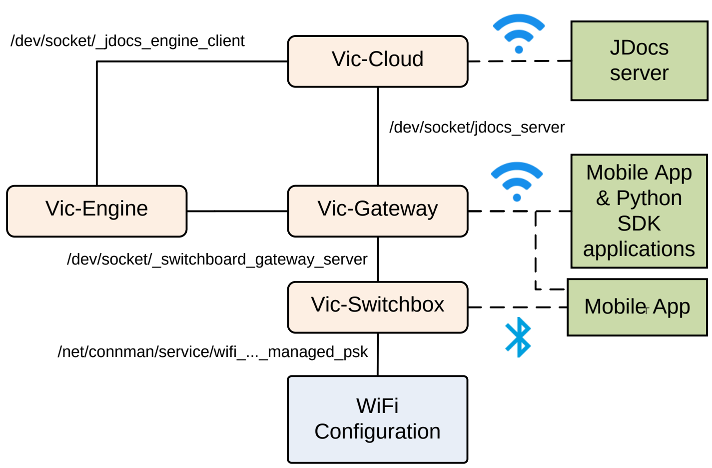

Figure 130: *The architecture for storing preferences, account info, entitlements, and tracking stats*

The Vic-Cloud service accesses information on a remote server.

The Vic-Switchbox interacts with the WiFi subsystem (connman) to allow the mobile App to set the preferred WiFi network to use. The mobile app must use Bluetooth LE to do this.

Vic-Gateway interacts with the mobile App and SDK programs to changes the robot settings.

Vic-Engine receives the preferences from the Vic-Cloud and Vic-Gateway, to carry out an changes in behaviour of Vector.

128.1. STORAGE LOCATION

Many of the settings are stored in the "`/data/`" folder which is located on the modifiable "`userdata`" partition.

The settings in the "`/data/data/com.anki.victor/persistent/jdocs`" folder are all JSON files with the following fields:

Field	Type	Description
client_meta	string	The string is always empty.
cloud_accessed	bool	This is always true
cloud_dirty_remaining_sec	uint	This is always true
cloud_get_time	uint	The time stamp of the cloud settings?
doc_version	uint64	A number used to uniquely identify changes to the setting structure, and be able to tell which one is the more recent settings. Most often this is the number of times that the settings have been changed.
fmt_version	uint64	The version number of the jdoc structure schema; this is always 1.
jdoc	struct	The settings structure for this kind of jdoc. (These will be discussed below.)

Table 562: *Persistent structure JDoc files*

129. WIFI CONFIGURATION

The WiFi configuration (aka settings or preferences) is entirely local to the Vector robot. The information about the WiFi settings is not stored remotely.

The mobile application can configuration the WiFi settings via Vic-Switchbox commands. The WiFi is managed by connman thru the Vic-Switchbox:

- To provide a list of WiFi SSIDs to the mobile app
- To allow the mobile app to select an SSID and provide a password to
- Tell it forget an SSID
- To place the WiFi into Access Point mode

The WIFI configuration is stored in folders located in "/data/lib/connman/" and is managed by connmanctl. The folder names are based on the SSID (stored as a decimal number) and the WiFi security method. Within each folder is s settings file that contains the SSID, the passphrase, and other settings for that WiFi access point.

130. THE OWNER ACCOUNT INFORMATION

The owner account information is sent from the mobile application to Anki servers at time of registration and setting up a Vector. The owner account information includes:[57]

JSON Key	units	Description & Notes
user_id	base64	A base64 token to identify the user
created_by_app_name	string	The name of the mobile application that register the owner. Example: "chewie"
created_by_app_platform	string	The mobile OS version string when the mobile application created the owners account. Example "ios 12.1.2; iPhone8,1
created_by_app_version	string	The version of the mobile application that register the owner. Example: "1.3.1"
deactivation_reason		
dob	YYYY-MM-DD	The owner's date of birth (the one given at time of registration)

Table 563: *The owners account information*

[57] It is not clear why there is so much information, and why this is sent from the Jdocs server in so many cases.

drive_guest_id	GUID	A GUID to identify the owner. This is the same as the "player_id"
email	string	The email address used to register the account; the same as the user name.
email_failure_code		The reason that the email was unable to be verified
email_is_blocked	boolean	
email_is_verified	boolean	True if the email verification has successfully completed. False otherwise.
email_lang	IETF language tag	The IETF language tag of the owner's language preference. example: "en-US"
family_name	string	The surname of the owner; null if not set
gender	string	The gender of the owner; null if not set
given_name	string	The given of the owner; null if not set
is_email_account	boolean	
no_autodelete	boolean	
password_is_complex	boolean	
player_id	GUID	A GUID to identify the owner. This is the same as the "drive_guest_id"
purge_reason		
status	string	Example "active"
time_created	string	The time, in ISO8601 format, that the account was created
user_id	base64	A base64 token to identify the owner
username	string	Same as the email address

131. PREFERENCES & ROBOT SETTINGS

The following settings & preferences are stored in (and retrieved from) the JDoc server. They are set by the mobile app or python SDK program using the HTTPS protocol described in chapter 15. They may also be set (in some cases) by the cloud in response to verbal interaction with the owner, via vic-cloud (e.g. "Hey Vector, set your eye color to teal.").

131.1. ENUMERATIONS

131.1.1 ButtonWakeWord

When Vector's backpack button is pressed once for attention, he acts as if someone has said his wake word. The ButtonWakeWord enumeration describes which wake word is treated as having been said:

***Table 564:** ButtonWakeWord Enumeration*

Name	Value	Description
BUTTON_WAKEWORD_ALEXA	1	When the button is pressed, act as if "Alexa" was said.
BUTTON_WAKEWORD_HEY_VECTOR	0	When the button is pressed, act is "Hey, Vector" was said.

131.1.2 EyeColor

This is the selectable colour to set Vector's eyes to. The JdocType enumeration maps the playful name to the following value used in the RobotSettingsConfig (and vice-versa) and the colour specification:

Name	Value	Hue	Saturation	Description
CONFUSION_MATRIX_GREEN	6	0.30	1.00	
FALSE_POSITIVE_PURPLE	5	0.83	0.76	
NON_LINEAR_LIME	3	0.21	1.00	
OVERFIT_ORANGE	1	0.05	0.95	
SINGULARITY_SAPHIRE	4	0.57	1.00	
TIP_OVER_TEAL	0	0.42	1.00	
UNCANNY_YELLOW	2	0.11	1.00	

Table 565: *EyeColor Enumeration*

The mapping from to enumeration to color values is held in

/anki/assets/cozmo_resources/config/engine/eye_color_config.json

(This path is hardcoded into libcozmo_engine.so.) This JSON configuration file is a hash that maps the EyeColor *name* (not the numeric value) to a structure with the "Hue" and "Saturation" values suitable for the SetEyeColor API command. The structure has the following fields:

Field	Type	Description & Notes
Hue	float	The hue to use for the color
Saturation	float	The saturation to use for the color.

Table 566: *The eye colour JSON structure*

This structure has the same interpretation as the SetEyeColor request, except the first letter of the keys are capitalized here.

The mapping of the number to the JSON key for the eye colours configuration file is embedded in Vic-Gateway. Adding more named colours would likely require successful complete decompilation and modification. Patching the binary is unlikely to be practical. The colours for the existing names can be modified to give custom, permanent eye colours.

131.1.3 Volume

This is the volume to employ when speaking and for sound effects. Note: the MasterVolume API enumeration is slightly different enumeration.

Name	Value	Description
MUTE	0	
LOW	1	
MEDIUM_LOW	2	
MEDIUM	3	
MEDIUM_HIGH	4	
HIGH	5	

Table 567: *Volume Enumeration*

131.2. ROBOTSETTINGSCONFIG

The entitlement settings associated with the user account (as opposed to the per-robot settings) are stored in the cloud. The settings are retrieved and a local copy is located at in:

/data/data/com.anki.victor/persistent/jdocs/vic.RobotSettings.json

The file is specified in the "jdocs_config.json" file (see Chapter 17, section *72 JDocs Server*) by the "docName" key within the "ROBOT_SETTINGS" subsection. The "jdoc" field is a RobotSettingsConfig structure with the following fields:

Field	Type	Description & Notes
button_wakeword	ButtonWakeWord	When the button is pressed, act as if this wake word ("Hey Vector" vs "Alexa") was spoken. default: 0 ("*Hey Vector*")
clock_24_hour	boolean	If false, use a clock with AM and PM and hours that run from 1 to 12. If true, use a clock with hours that run from 1 to 24. default: false
default_location	string	default: "San Francisco, California, United States"
dist_is_metric	boolean	If true, use metric units for distance measures; if false, use imperial units. default: false
eye_color	EyeColor	The colour used for the eyes. The colour is referred to by one of an enumerated set. (Within the SDK, the eyes can be set to a colour by hue and saturation, but this is not permanent.) default: 0 (TIP_OVER_TEAL)
locale	strong	The IETF language tag of the owner's language preference – American English, UK English, Australian English, German, French, Japanese, etc. default: "en-US"
master_volume	Volume	default: 4 (MEDIUM_HIGH)
temp_is_fahrenheit	boolean	If true, use Fahrenheit for temperature units; otherwise use Celsius.[58] default: true
time_zone	string	The "tz database name" for time zone to use for the time and alarms. default: "America/Los_Angeles"

***Table 568:** The RobotSettingsConfig JSON structure*

The default values for each of the settings are held in:

/anki/assets/cozmo_resources/config/engine/settings_config.json

(This path is hardcoded into libcozmo_engine.so.) The file is a JSON structure that maps each of the fields of RobotSettingsConfig to a control structure. Each control structure has the following fields:

[58] Anyone else notice that metric requires a true for distance, but a false for temperature? Parity.

Field	Type	Description & Notes
defaultValue		The value to employ unless one has been given by the operator or other precedent.
updateCloudOnChange	boolean	true if the value is pushed to the colour when it is changed by the operator. False if not. Won't be restored..?

Table 569: The setting control structure

It is implied that the setting value is to be pulled from the Cloud when the robot is restored after clearing.

132. OWNER ENTITLEMENTS

An entitlement is a family of features or resources that the program or owner is allowed to use. It is represented as set of key-value pairs. This is a concept that Anki provided provision for but was not used in practice.

The only entitlement defined in Vector's API (and internal configuration files) is "kickstarter eyes" (JSON key "KICKSTARTER_EYES"). Anki decided not to pursue this, and its feature(s) remain unimplemented.

The entitlement settings associated with the account (as opposed to the per-robot settings) are stored in the cloud. The settings are retrieved and a local copy is located at in:

```
/data/data/com.anki.victor/persistent/jdocs/vic.UserEntitlements.json
```

The file is specified in the "jdocs_config.json" file (see Chapter 17, section *72 JDocs Server*) by the "docName" key within the "ACCOUNT_SETTINGS" subsection. The default entitlement settings are held in

```
/anki/assets/cozmo_resources/config/engine/userEntitlements_config.json
```

(This path is hardcoded into libcozmo_engine.so.) The file is a JSON structure that maps each of the entitlement to a control structure. The control structure is the same as *Table 569: The setting control structure*, used in settings in the previous section.

133. VESTIGAL COZMO SETTINGS

The settings associated with the account (as opposed to the per-robot settings) are stored in the cloud. The settings are retrieved and a local copy is located at in:

```
/data/data/com.anki.victor/persistent/jdocs/vic.AccountSettings.json
```

The file is specified in the "jdocs_config.json" file (see Chapter 17, section *72 JDocs Server*) by the "docName" key within the "ACCOUNT_SETTINGS" subsection. The "jdoc" field is a structure with the following settings:

Field	Type	Description & Notes
APP_LOCALE	string	The IETF language tag of the owner's language preference – American English, UK English, Australian English, German, French, Japanese, etc. default: "en-US"
DATA_COLLECTION	boolean	default: false

Table 570: The Cozmo account settings

The default "account settings" are held in:

/anki/etc/config/engine/accountSettings_config.json

This path is hardcoded into libcozmo_engine.so and these settings are only read (possibly) by vic-gateway. The file is a JSON structure that maps each of the settings to a control structure. The control structure is the same as *Table 569: The setting control structure*, used in settings in an earlier section.

134. FEATURE FLAGS

Vector has granular features that can be enabled and disabled thru the use of feature flags. Feature flags allow the code to be deployed, and selectively enabled. As a software engineering practice, a feature is usually is disabled because the feature is:

- not yet fully developed, or
- specific to a customer, or
- mostly developed and being tested in some groups, or
- only enabled when there is some error occurs or other functionality is not working intended, or
- a special/premium function sold at a cost or reward (like an entitlement).

Many of these possibilities do not apply to Anki. But some do. Many of the disabled features are probably disabled because they are incomplete, do not work, and likely not to work for without further development.

134.1. CONFIGURATION FILE

The features flag configuration file is located at:

/anki/data/assets/cozmo_resources/config/features.json

(This path is hardcoded into libcozmo_engine.so.) This file is organized as an array of structures with the following fields:

Table 571: *The feature flag structure*

Field	Type	Description & Notes
enabled	boolean	True if the feature is enabled, false if not
feature	string	The name of the feature

The set of feature flags and their enabled/disabled state can be found in Appendix I. The features are often used as linking mechanisms of the modules. It is likely modules of behavior / functionality.

134.2. COMMUNICATION INTERFACE TO THE FEATURES

The list of features can be queried with the GetFeatureFlagList command. The status of each individual feature (whether it is enabled or not) can be found with the GetFeatureFlag query. See Chapter 15 section *57 Features & Entitlements* for more details.

135. ROBOT LIFETIME STATISTICS & EVENTS

Vector summarizes his experiences and activities into a set of fun measures. The intent is that they can be shared as attaboys and a novel dashboard. They may also have been used in product planning to prioritize new behaviors and firmware features, and next generation product needs. The lifetime statics are updated by the robot and sent to the server; a local copy is located at in a JSON file:

/data/data/com.anki.victor/persistent/jdocs/vic.RobotLifetimeStats.json

The file is specified in the "jdocs_config.json" file (see Chapter 17, section *72 JDocs Server*) by the "docName" key within the "ROBOT_LIFETIME_STATS" subsection. The "jdoc" field holds a structure with the following fields:

***Table 572:** The robot lifetime stats schema*

Key	units	Description & Notes
Alive.seconds	seconds	Vector's age, since he was given preferences (a factory reset restarts this)
Stim.CumlPosDelta		The lifetime (cumulative) sensory score.
BStat.AnimationPlayed	count	The number of animations played
BStat.BehaviorActivated	count	
BStat.AttemptedFistBump	count	The number of fist bumps (attempted)
BStat.FistBumpSuccess	count	
BStat.PettingBlissIncrease		
BStat.PettingReachedMaxBliss		
BStat.ReactedToCliff	count	
BStat.ReactedToEyeContact	count	
BStat.ReactedToMotion	count	
BStat.ReactedToSound	count	
BStat.ReactedToTriggerWord	count	
Feature.AI.DanceToTheBeat		
Feature.AI.Exploring		
Feature.AI.FistBump		
Feature.AI.GoHome		
Feature.AI.InTheAir		
Feature.AI.InteractWithFaces	count	The number of times recognized / interacted with faces
Feature.AI.Keepaway		
Feature.AI.ListeningForBeats		
Feature.AI.LowBattery		
Feature.AI.Observing		
Feature.AI.ObservingOnCharger		
Feature.AI.Onboarding		
Feature.AI.Sleeping		
Feature.AI.Petting	ms	The amount of time petted

Feature.AI.ReactToCliff		
Feature.AI.StuckOnEdge		
Feature.AI.UnmatchedVoiceIntent		
Feature.Voice.VC_Greeting		
FeatureType.Autonomous		
FeatureType.Failure		
FeatureType.Sleep		
FeatureType.Social		
FeatureType.Play		
FeatureType.Utility	count	The number of utilities used
Odom.LWheel	mm	The left wheel odometer – how far it has driven
Odom.Rwheel	mm	The right wheel odometer – how far it has driven
Odom.Body		
Pet.ms	ms	The cumulative time petted

The statistics are retrievable by the application.

136. REFERENCES & RESOURCES

Wikipedia, *List of tz database time zones*, https://en.wikipedia.org/wiki/List_of_tz_database_time_zones

CHAPTER 32

The Software Update process

This chapter describes Vector's software update process

- The software architecture
- The software update process
- How to extract official program files

137. THE ARCHITECTURE

The architecture for updating Vector's software is:

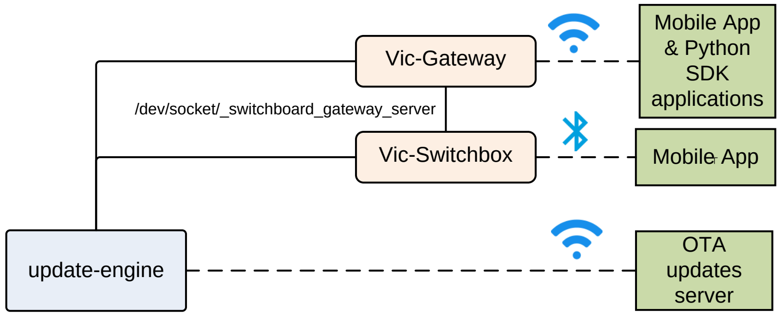

Figure 131: *The architecture for updating Vector's software*

The Vic-Gateway and Vic-Switchbox both may interact with the mobile App and SDK programs to receive software update commands, and to provide update status information. It is their responsibility to ensure that Vector has met any preconditions for an update – that the battery is charger, he is on the charger, the temperature is acceptable, and so on.

The update-engine is responsible for downloading the update, validating it, applying it, and providing status information to Vic-Gateway and Vic-switchbox. The update engine can be initiated by Vic-Switchbox via a Bluetooth LE command, or by HTTP command (see Chapter 15 section *67 Software Updates*). [It isn't known yet how they kick off the update automatically]. The update-engine provides status information in a set of files with the "/run/update-engine" folder.

137.1. BODY-BOARD

The body-board firmware is updated during power on initialization. See Chapter 7 and 12 for a little more information.

137.2. THE COMPANION CUBE FIRMWARE

The cube firmware is updated (or downloaded if not present at all) when the Bluetooth LE subsystem finds a cube. See Chapter 14 for details.

138. THE UPDATE FILE

The update files are TAR files with a suffix "OTA" (*over the air* update). The TAR file has a fixed structure, with some of the files encrypted. There are 3 kinds of update files

- Factory updates. These modify the ABOOT, RECOVERY and RECOVERYFS partitions – the aboot boot-loader, the recovery Linux kernel (and initramfs), and its file system.
- Production updates. These modify the BOOT, and SYSTEM partitions – the main Linux kernel (and initramfs), and the file system.
- Delta updates. These modify the main file system partitions; by sending only the changes to the underlying partitions, the updates can be very compact.

The archive contains 3 to 5 files, and they must be in the following order:

***Table 573:** The contents of an over-the-air update archive file*

file name	Description
manifest.ini	This provides a description of which Vector units this update can be applied to, a list of the update files, including their compression & encryption schemes, and their signature.
manifest.sha256	This is a sha256 digest produced when the manifest is signed with secret OTA key. This is used to ensure that the manifest is valid.
apq8009-robot-delta.bin.gz	This holds the changes to the disk at a block level. This is present only in delta updates. It is optionally encrypted.
apq8009-robot-emmc_appsboot.img.gz	This provides a new ABOOT partition. This is present only in factory updates. To unlock Vectors, making them developer units, the modified (and signed) aboot is provided using this type of updater. It is optionally encrypted.
apq8009-robot-boot.img.gz	In factory updates it will be applied to the RECOVERY partition; otherwise it will be applied to the BOOT partition. This is not present in delta updates. It is optionally encrypted.
apq8009-robot-sysfs.img.gz	In factory updates it will be applied to the RECOVERYFS partition; otherwise it will be applied to the SYSTEM partition. This is not present in delta updates. It is optionally encrypted.

138.1. MANIFEST.INI

The manifest.ini is checked by verifying its signature[59] against manifest.sha256 using a secret key (/anki/etc/ota.pub):

***Example 8:** Checking the manifest.ini signature*

```
openssl dgst \
   -sha256 \
   -verify /anki/etc/ota.pub \
   -signature /run/update-engine/manifest.sha256 \
   /run/update-engine/manifest.ini
```

[59] I'm using the information originally at: https://github.com/GooeyChickenman/victor/tree/master/firmware

Note: the signature check that prevents turning off encryption checks in the manifest below. At this time the signing key is not known.

All forms of update have a [META] section. This section has the following structure:

Table 574: manifest.ini META section

Key	Description
ankidev	0 if production release, 1 if development
manifest_version	Acceptable versions include 0.9.2, 0.9.3, 0.9.4, 0.9.5, or 1.0.0
num_images	The number of img.gz files in the archive. The number must match that of the type of update file it is. 1, 2, or 3
qsn	The Qualcomm Serial Number, it must match the robot's serial number. If there are three images (ABOOT, RECOVERY, RECOVERYFS) present, the software is treated as a factory update. *Optional.*
reboot_after_install	0 or 1. 1 to reboot after installing.
update_version	The version that the system is being upgraded to, e.g. 1.6.0.3331

After the [META] section, there are 1 to 3 sections, depending on the type of update:

- A delta update has a [DELTA] section
- A regular update has a [BOOT], [SYSTEM] sections; both must be present.
- A factory update has [ABOOT], [RECOVERY], and [RECOVERYFS] sections; all 3 must be present.

Each of these sections has the same structure:

Table 575: manifest.ini image stream sections

Key	Description
base_version	The version that Vector's software must be at in order to accept this update. Honored only in delta updates. This prevents corrupting a filesystem by ensuring that it has the expected layout.
bytes	The number of bytes in the uncompressed archive
compression	gz (for gzipped). This is the only supported compression type.
delta	1 if this is a delta update; 0 otherwise
encryption	1 if the archive file is encrypted; 0 if the archive file is not encrypted.
sha256	The digest of the decompressed file must match this
wbits	31. Not used by update-engine

138.1.1 Version numbers

When performing version checks on the update file, looks at the number in update_version, the suffix in the update_version and the ankidev field. The update-engine ensures that production Vectors will not install software with the ankidev field set – and that developer Vector's will not install production software. (This is probably because production software won't allow development software to be installed on the unit.)

There are also subtle different kinds of development software. This is indicated in the suffix at the end of the version string – blank, "d" or "ud". The update-engine ensures that a Vector

Wire/Kerigan Creighton

cannot be changed from running software with one kind of suffix to another kind.

Type	anki.dev	suffix	Description
developer	1	*d*	This can include developer tools, such as SCP, SSH, AWK, a web server, and a web-viz browser-based visualization application. It has logging, simulation visualization, microphone processing information, beat detection visualization, cloud intents, CPU usage statistics, etc.
production	0		This is the end-consumer released software. (The boot partition is signed, and dmverity is enabled for the system partition.)
release candidate	1		This is almost identical to the production software releases, and is likely used to test the units.
userdev	1	*ud*	Some have SSH installed, but often do not include web-viz & web-server.

***Table 576:** Different kinds of Vector software updates*[60]

138.2. HOW TO DECRYPT THE OTA UPDATE ARCHIVE FILES[61]

The OTA update archive files can be decrypted by:

```
openssl enc -d -aes-256-ctr -pass file:ota.pas -in apq8009-robot-boot.img.gz -out
apq8009-robot-boot.img.dec.gz
openssl enc -d -aes-256-ctr -pass file:ota.pas -in apq8009-robot-sysfs.img.gz -out
apq8009-robot-sysfs.img.dec.gz
```

***Example 9:** Decrypting the OTA update archives*

To use OpenSSL 1.1.0 or later, add "-md md5" to the command:

```
openssl enc -d -aes-256-ctr -pass file:ota.pas -md md5 -in apq8009-robot-boot.img.gz -
out apq8009-robot-boot.img.dec.gz
openssl enc -d -aes-256-ctr -pass file:ota.pas -md md5 -in apq8009-robot-sysfs.img.gz -
out apq8009-robot-sysfs.img.dec.gz
```

***Example 10:** Decrypting the OTA update archives with Open SSL 1.1.0 and later*

Note: the password on this file is insecure (ota.pas has only a few bytes[62]) and likely intended only to prevent seeing the assets inside of the update file. The security comes from (a) the individual image files are signed (this is checked by the updater), and (b) the file systems that they contain are also signed, and are checked by aboot and the initial kernel load. See Chapter 7 *Startup* for the gory details.

Signing the files is a whole other kettle of fish.

139. THE UPDATE PROCESS

The update process checks for update:

- After 1st getting access to the internet
- On demand, via an HTTPS API command or a Bluetooth LE command
- Random intervals, between a few seconds and 1 hour.
- On demand, via the command line.

The update-engine-oneshot.service is used to initiate the first attempt to update after access to the internet has been restored.

[60] https://docs.google.com/document/d/1KZ93SW7geM0gA-LBXHdt55a9NR1jfKp7UZyqlRuokno/edit
[61] https://groups.google.com/forum/#!searchin/anki-vector-rooting/ota.pas%7Csort:date/anki-vector-rooting/YlYQsX08OD4/fvkAOZ91CgAJ
[62] Opening up the file in a UTF text editor will show Chinese glyphs; google translate reveals that they say "This is a password". This password is a bit of humour to comply with a security consultant.

The /sbin/update-os can be used to initiate the software update process from the command-line on developer units. This acts as if the vic-switchboard had initiated the download and install. Downgrading is automatically enabled. This command is new to version 1.7.

139.1. STATUS DIRECTORY

The update-engine provides its status thru a set of files in the /run/update-engine folder.

***Table 577:** update-engine status file*

File	Description
done	If this file exists, the OTA update process has completed, and the system is preparing "to reboot into the new OS version." This is used to prevent "another OTA download and install in this case."
error	This file is set if there has been an error in the update process. The error code representing why the update failed. See Appendix D, *Table 606: OTA update-engine status codes*. It can also have a value of "Unclean exit" by default.
expected-download-size	The expected file size (the given total size of the OTA file) to download.
expected-size	In non-delta updates, the total number of bytes of the unencrypted image files. This is the sum of the "bytes" field in the sections.
phase	A short label indicating which phase of the update process it is in, e.g "starting", "sleeping", "download", and "done"
progress	Indicates how many of the bytes to download have been completed, or how much of the partitions have been written.

This folder also holds the unencrypted, uncompressed files from the OTA file:

- manifest.ini
- manifest.sha256
- delta.bin
- aboot.img
- boot.img

139.2. PROCESS

The update process works as follows; if there is an error at any step, skips the rest, deletes the bin and img files.

1. Remove everything in the status folder
2. Being downloading the OTA file. It does *not* download the TAR and then unpack it. The file is unpacked as it is received.
3. Copies the manifest.ini to a file in the status folder
4. Copies the manifest.sha256 to a file
5. Verifies the signature of the manifest file
6. Validates that the update to the OTA version is allowed. .
   Note: the software can be downgraded by going into the recovery mode (running factory software). The recovery mode does not check the version number or suffix. These checks

were likely included (in the main software) to prevent any server bugs from accidentally downgrading Vectors – wiping out bug fixes – at home.

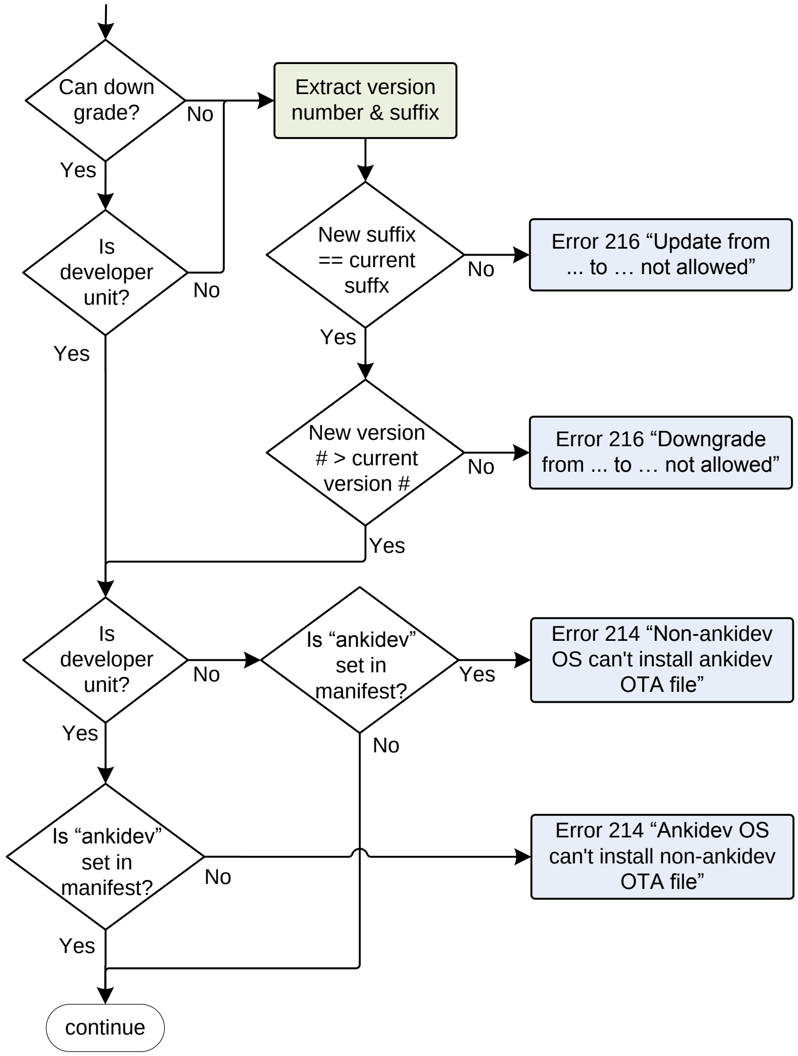

***Figure 132:** The update-engine's version check process*

a) If this is a development Vector (i.e. anki.dev is set on the linux boot command line), and the current software has UPDATE_ENGINE_ALLOW_DOWNGRADE internally set (to true), the next two checks are skipped (until step d). Otherwise,

b) Does the suffix at the end of the version number in the new manifest match the suffix in the currently running software? If not, a 216 error code is produced.

c) Is the new version number in the new manifest greater than the one in the currently running software? If not, a 216 error code is produced.

d) The ankidev variable in the manifest must be set on developer units, and must not be set on production units; otherwise a 214 error code is produced.

7. If this is factory update, it checks that the QSN in the manifest matches Vector's QSN.
8. It marks the target partition slots as unbootable
9. Checks the img and bin contents

a) delta file

b) boot & system archive files

c) If this is a factory update, aboot, recovery, and recoveryfs

10. If this is a factory update:

    a) Creates the file /run/wipe-data. This will trigger erasing all of the user data (the user data partition and the "switchboard" partition) when the system shutdowns down to reboot.[63]

    b) Makes both a and b slots for BOOT and SYSTEM partitions as unbootable

11. If this is not factory update

    a) Sets the new target slot as active

12. Deletes any error file

13. Sets the done file

14. Posts a DAS event robot.ota_download_end to success + next version

15. If the reboot_after_install option was set, reboots the system

139.3. UPDATER CONFIGURATION

The update engine configuration files are located at:

/anki/etc/update-engine.env
/run/ update-engine-oneshot.env
/run/vic-switchboard/update-engine.env

This path is in the start-up /lib/systemd/system/update-engine.service file that starts the fault-codes service. This file can have the following fields (if none are set, the fault-code-handler reverts to these defaults):

***Table 578:** The update-engine configuration variables*

Variable	Default	Description & Notes
UPDATE_ENGINE_ALLOW_DOWNGRADE	false	If true, older versions of the software can be installed thru the updated; if false, they cannot be.
UPDATE_ENGINE_ANKIDEV_BASE_URL		The URL to inquire for new update OTA files on developer units; if set, overrides UPDATE_ENGINE_BASE_URL
UPDATE_ENGINE_BASE_URL		The URL to inquire for new update OTA files, when UPDATE_ENGINE_URL is "auto". The shard id and file request is appended to this.
UPDATE_ENGINE_ENABLED		Does not appear to be used
UPDATE_ENGINE_BASE_URL_LATEST		
UPDATE_ENGINE_DEBUG	false	
UPDATE_ENGINE_OTA_TYPE	diff	
UPDATE_ENGINE_SHARD		
UPDATE_ENGINE_URL	auto	The URL to request an update from. This is overridden by a command line argument.
UPDATE_ENGINE_USE_SHARDING	false	

[63] There is slight race condition here: the file to signal that the user data is in a tmpfs. It is possible that the other partitions could be updated, and the system stops executing – has a kernel panic or loses power – before it gets to the step to wipe the data. This flag will be gone when the system restarts.

139.4. MAINTENANCE REBOOT

Vector has a service – rebooter.service, which launches rebooter.py – to regularly reboot the system, and to check for updates. This chooses a random time within a window (usually between 1 and 5AM) to reboot.

Why reboot so regularly? Vector was a new system with software initially (and hurriedly) ported from mobile phone applications meant to be run only for a few hours. The longer a program runs, the more likely a latent bug will cause it crash. The system software might have:

- Resource leaks: unreclaimed memory, accumulated temporary files, etc
- Race conditions
- Dead-locks

If that happens while being using it, the Vector's applications might crash... or things limp along with mysterious inconsistent behaviors, slowdowns, etc. By rebooting, these issues can be cleared when no one is looking, and Vector can be played with much lower risk of a crash.

139.4.1 The logic to decide when to reboot

The time of the reboot is randomized… not because of what is going on around Vector (presumably the world around him is asleep). The restart also triggers a check for an update to download. By randomizing the reboot, it spreads the load on the OTA servers out over time.

Sanity checks before a reboot:

- It checks that a download of update – or installing one – is not already in progress
- It checks that the robot hasn't rebooted too recently.

Other processes can request the reboot to not reboot by creating one the following files (and removing it when no longer needing to delay):

```
/data/inhibit_reboot
/run/inhibit_reboot
```

Note: no program creates either of these files.

If those files do not exist, it checks to see if the updater has completed applying an update and is waiting for the reboot. It does this be checking if the "/run/update-engine/done" exists. If it does not exist, the robot will also check for the following:

- That processor is in power power-saving state. If not this indicates that it is perhaps active and being used; this will trigger a delay
- If the updater is being run; if it is, this will also delay the reboot.

The reboot can only occur within a configurable time window. If the reboot is delayed until the robot is outside of the time window, the reboot is skipped for the day.

When the reboot does occur, the rebooter creates the file /data/maintenance_reboot to indicate the type of reboot to the start up scripts. The startup moves the file to /run/after_maintenance_reboot

139.4.2 The rebooter configuration file

The rebooter configuration file is located at:

`/data/etc/rebooter.env`

This path is in the start-up `/etc/systemd/system/rebooter.service` file that starts the rebooter service. This file can have the following fields (if none are set, they revert to these defaults):

Table 579: The rebooter configuration variables

Variable	Default	Units	Description
REBOOTER_EARLIEST	3600	*seconds*	The earliest time that a reboot can occur. The time is expressed in seconds after midnight. The default is 1 AM.
REBOOTER_INHIBITOR_DELAY	17	*seconds*	The amount of time
REBOOTER_LATEST	18000	*seconds*	The earliest time that a reboot can occur. The time is expressed in seconds after midnight. The default is 5 AM.
REBOOTER_MINIMUM_UPTIME	14400	*seconds*	The earliest time that a reboot can occur. The time is expressed in seconds. The default is 4 hours.
REBOOTER_VERBOSE_LOGGING	false	*boolean*	If true, extra messages are displayed to stdout.

That the configuration file was located in the user's private file system indicates a potential per robot configuration. The reboot time of day (etc) may have been intended (or at least considered) to be a settable preference in the future.

140. RESOURCES & RESOURCES

https://source.android.com/devices/bootloader/flashing-updating
Describes the a/b process as it applies to android

CHAPTER 33

Diagnostics

This chapter describes the diagnostic support built into Vector

- The customer care information screen
- The logging of regular use
- Crash logs
- Gathering usage, and performance data

141. OVERVIEW

Anki gathers "analytics data to enable and improve the services and enhance your gameplay… Analytics Data enables us to analyze crashes, fix bugs, and personalize or develop new features and services." There are many services that accomplish the analytics services. This data is roughly: logs, crash dumps and "DAS manager"

Logging and diagnostic messages are typically not presented to the owner, neither in use with Vector or thru the mobile application... nor even in the SDK.

The exception is gross failures that are displayed with a 3-digit error code. This is intended to be very exceptional.

Diagnostic and logging information is available thru undocumented interfaces.[64]

141.1. THE SOFTWARE INVOLVED

There are many different programs and libraries used in the diagnostic and logging area. The table below summarizes of them:

***Table 580:** Vector diagnostic & logging software*

Program / Library	Description
animfail	This program is started by the animfail service.
anki-crash-log	Copies the last 500 system messages and the crash dump passed to the command line to a given log file. This is called by vic-cloud, vic-dasmgr, vic-engine, vic-gateway, vic-log-kernel-panic, vic-log-upload, vic-robot, vic-switchboard, and the anki-crash-log service.
ankitrace	This program wraps the Linux tracing toolkit (LTTng). This program is not present in Vector's file system. This is called by fault-code-handler.
cti_vision_debayer	This is not called.
diagnostics-logger	Bundles together several log and configuration states into a compressed tar file. This is called by vic-switchboard, in a response to a Bluetooth LE log command.
displayFaultCode	Displays error fault codes on the LCD. This is not called; see vic-faultCodeDisplay.

[64] The lack of documentation indicates that this was not intended to be supported and employed by the public... at least not until other areas had been resolved.

fault-code-clear	This clears any pending or displayed faults (by deleting the relevant files). This allows new fault code to be displayed. This is called by vic-init.sh. Located in /bin
fault-code-handler	This is called by the fault-code service. It listens for a fault code, initiates capturing crash logs, and calls vic-faultCode to display the fault code. Located in /bin
librobotLogUploader.so	Sends logs to cloud. This library is employed by libcozmo_engine, vic-gateway and vic-log-upload.
libosState	Used to profile the CPU temperature, frequency, load; the WiFi statistics, and etc. This is used by libvictor_web_library, vic-anim, and vic-dasmgr.
libwhiskeyToF	This unusually named library[65] has lots of time of flight sensor diagnostics. This is present only in version 1.6 and later. This library is employed by libcozmo_engine.
rampost	This performs initial communication and version check of the firmware on the body-board (syscon). This exists within the initial RAM disk, and is called by init.
vic-anim	Includes the support for the Customer Care Information Screen. This is started by the vic-anim service.
vic-crashuploader-init	Removes empty crash files, renames the files ending in ".dmp~" to ".dmp". This is called by the vic-crashuploader service.
vic-crashuploader	A script that sends crash mini-dump files to backtrace.io. This is called by the vic-crashuploader service.
vic-dasmgr	This is started by the vic-dasmgr service.
vic-faultCodeDisplay	Displays error fault codes on the LCD. This is called by fault-code-handler.
vic-init.sh	Takes the log messages from rampost and places then into the system log, forwards any kernel panics. This is started by the vic-init service.
vic-log-cat	Used to concatenate the logs from /var/log/messages.1.gz and /var/log/messages
vic-log-event	A program that is passed an event code in the command line. This is called by TBD.
vic-log-forward	This is called by vic-init.sh
vic-log-kernel-panic	This is called by vic-init.sh
vic-log-upload	This is called by vic-log-uploader
vic-log-uploader	"This script runs as a background to periodically check for outgoing files and attempt to upload them by calling 'vic-log-upload'." This is started by the vic-log-uploader service.
vic-logmgr-upload	"This script collects a snapshot of recent log data" into a compressed (gzip) file, then uploads the file" and software revision "to an Anki Blobstore bucket." This is not called.
vic-on-exit	Called by systemd after any service stops. This script posts the fault code associated with the service (if another fault code is not pending) to fault-code-handler for handling and display.
vic-powerstatus.sh	Record every 10 seconds the CPU frequency, temperature and the CPU & memory usage of the "vic-" processes. This is not called.

(Quotes from Anki scripts.) Support programs are located in /bin, /anki/bin, and /usr/bin

[65] Anki has taken great care for squeaky-clean image, even throughout the internal files, so it was a surprise to see one that might appear named after a rude acronym (WTF). The name is a result of the internal product codes: *Whiskey* was the code name for a new generation of Cozmo in development. This was its time of flight (ToF) sensor library, using a modified Vector (called "Spiderface") as a development prototype. On Whiskey, the time of flight sensor would connect directly to the main processor.

142. SPECIAL SCREENS AND MODES

Vector has 3 special screens and two special modes. The screens are

- A Customer Care Info Screen (CCIS) that can display sensor values and other internal measures,
- A debug screen used to display Vector's serial number (ESN) and IP address, and
- The fault code display which is used to display a 3-digit fault code when there is an internal failure (this screen is only displayed if there is a fault, and can't be initiated by an operator.)

Vector has two special modes

- Entering recovery mode, to force Vector use factory software and download replacement firmware. (This mode doesn't delete any user data.)
- "Factory reset" which erases all user data, and Vector's robot name

142.1. CUSTOMER CARE INFORMATION SCREEN

Customer Care Info Screen (CCIS). It has a series of screens that display sensor values and other readings.

See https://www.kinvert.com/anki-vector-customer-care-info-screen-ccis/ for a walk thru

142.2. VECTORS' DEBUG SCREEN (TO GET INFO FOR USE WITH THE SDK)

Steps to enter the debug screen

1. Place Vector on the charger,
2. Double-click his backpack button,
3. Move the arms up and down

This will display his ESN (serial number) and IP address. The font is much smaller than normal, and may be hard to read.

142.3. DISPLAYING FAULT CODES FOR ABNORMAL SYSTEM SERVICE EXIT / HANG

If there is a problem while the system is starting or running – such as one of the services exits early (e.g. crashes) , or it encounters an internal error – a fault code associated with that service is displayed , and crash information is gathered for later analysis. See Appendix D for fault codes. The implementation details will be discussed in section *145.6 Fault Code Handler* below.

142.4. RECOVERY MODE

Vector includes a *recovery mode* that is used to force Vector to boot using factory software. The recovery mode will not delete any user data or software that had previously been installed via Over-The-Air (OTA) update.

The recovery mode is intended to help with issues such as Vector failing to boot up using the regular firmware. He may have been unable to charge (indicated by teal Back Lights), or encountered other software bugs[66].

The application in the recovery mode attempts to download and reinstall the latest software. This is likely done under the assumption that the firmware may be corrupted, or not the latest, and that a check for corruption isn't possible with the read-only filesystems of production software.

142.5. "FACTORY RESET"

Choosing the "Clear User Data" option in Vector's CCIS erases all user data, including pictures, faces, and API certificates & tokens. This also clears out the robot name. The Vector will be given a new robot name when he is set up again.

The menu is implemented in the `vic-anim` program. When the Clear User Data menu option is selected and confirmed, triggers the erasing all of the user data when the system shutdowns down to reboot. First, it creates the file `/run/wipe-data` and then begins the shutdown and reboot process. During the system shutdown, the mount-data service will detect the existence of the `/run/wipe-data` file and erase the user data (/data) and the switchboard board partitions.

The name "factory reset" is slightly controversial, as this does not truly place Vector into an identical software state as robot in the factory.

143. BACKPACK LIGHTS

The lights on the backpack are primarily set by `Vic-robot`, but driven by the body-board. If the body-board firmware (`syscon`) is unable to communicate with `Vic-robot`, the body-board will set the lights on its own.

144. DIAGNOSTIC COMMANDS

There are several HTTPS commands that are useful for diagnosing errors:

- The connectivity with the cloud can be checked to see if the servers can be reached, if the authentication (i.e. username and password) is valid, if the server certificate is valid. See Chapter 15, section *54.1 Check Cloud Connection*
- The debug logs can be requested to be sent to the server for analysis. See the Upload Debug Logs command in Chapter 15, section *54.2 Upload Debug Logs*

145. LOGS

Acquiring Logs

- Logs can be downloaded to a PC or mobile application using the Bluetooth LE API
- The logs can be sent to the server using the Upload Debug Logs API command. See Chapter 15 section *54.2 Upload Debug Logs*
- Logs are gathered when a fault-code is raised
- Logs are gathered when an Anki program crashes

[66] The web page says that are "indicated by a blank screen. If you get a status code between 200-219, recovery mode will also help."

145.1. GATHERING LOGS, ON DEMAND

The logs can be requested by issuing a log fetch command via Bluetooth LE. Vic-switchboard handles the request, delegating the preparation of the log files to diagnostics-logger.

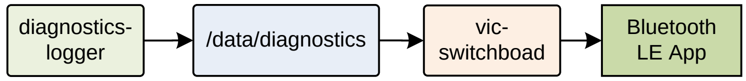

Figure 133: *The Bluetooth LE based diagnostics-logger process*

This utility gathers the following files, archives and compresses them:

Table 581: *Files in the diagnostics log archive*

File	Description
connman-services.txt	connmanctl services
dmesg.txt	Executes dmesg and captures the standard output.
ifconfig.txt	Executes ifconfig wlan0 and captures the standard output.
iwconfig.txt	Executes iwconfig wlan0 and captures the standard output.
log.txt	Concatenates /var/log/messages.1.gz (uncompressed) and /var/log/messages
netstat-ptlnu.txt	Executes netstat -ptlnu and captures the standard output.
ping-anki.txt	Ping's anki.com for connectivity and latency.
ping-gateway.txt	Looks up the IP address (using netstat) of the gateway that Vector is using and pings it for connectivity and latency.
ps.txt	Process stats (ps) of Anki's "Vic" processes
top.txt	Executes top -n 1 and captures the standard output.

This utility is triggered by:

- Vic-switchboard when issued a log fetch command (via Bluetooth LE).
- Vic-gateway when the upload log command is issued
- Other

145.2. VIC-LOGMGR-UPLOAD

The vic-logmgr-upload script is not used, but it instructive to examine. When called it copies all of the messages from /var/log/messages.1.gz and /var/log/messages then sends the compressed result to the URL given on the command line.

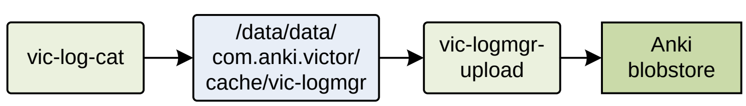

Figure 134: *The vic-logmgr-upload log uploader*

145.3. GATHERING LOGS, REGULARLY

The vic-log-uploader service regularly checks for log files to send to a server. The fault code and crash handlers may place log files into an outgoing folder to be uploaded. The outgoing folder is in non-volatile memory, so they can be waiting for a reboot before they are sent, if the robot loses power, has a serious fault, or network access isn't available.

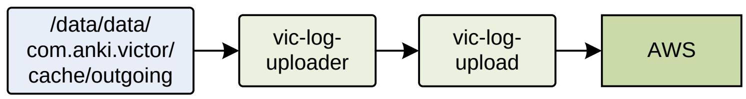

***Figure 135:** The vic-log-uploader log upload pipeline*

The log uploader configuration file is located at:

`/anki/etc/vic-log-uploader.env`

This path is in the start-up /lib/systemd/system/vic-log-uploader.service file that starts the log uploader service. This file can have the following fields (if none are set, the log uploader reverts to these defaults):

Variable	Default	Description & Notes
VERBOSE	0	If set to 1, extra debugging messages are logged.
VIC_LOG_UPLOADER_FOLDER		The path on the local file system to store the logs until they can be uploaded.
VIC_LOG_UPLOADER_QUOTA_MB	10	The maximum allowed total size of the log files to leave in the upload folder; the oldest files are removed until the total size is less than (or equal) to this.
VIC_LOG_UPLOADER_SLEEP_SEC	30	The amount of time between checks for log files.

***Table 582:** The log uploader configuration variables*

145.4. OPTING INTO (AND OUT OF) UPLOADING LOGS AND DAS EVENTS

The fault handler and crash uploader also checks for the existence of the following file before passing logs to vic-log-uploader:

`/run/das_allow_upload`

This file is intended to indicate – to only exist – if the user accepts uploading diagnostic information, and to not exist if they have opted out of data collection. If this exists, the crash minidump traces and log files are captured by fault-crash-handler and the log files are captured vic-crashuploader, and passed to be uploaded. If it does not exist, the log files are not captured or uploaded. (vic-crashuploader uploads the crash minidumps either way, but will only included the logs files allowed.)

This file is created by the DAS-manager (more on its event collection later).

`/data/data/com.anki.victor/persistent/dasGlobals.json`

This path is specified by the DASConfig.json (more on that in a later section).

This JSON file is a structure with a single key: "dasGlobals". This in turn dereferences to a structure with the following fields:

Variable	Type	Description & Notes
allow_upload	boolean	If true, the file will be created, and uploads are allowed

***Table 583:** The DAS preferences variables*

profile_id	string	The Base-64 identifier for the account. If there is no account, it is an identifier that is made by other means.

This file appears to be downloaded from the JDocs store.

145.5. KERNEL ACTIVITY TRACING (LTTNG)

Vector 1.7 started the use of the Linux Trace Toolkit NG (LTTng). LTTng is configured by the ankitrace.service to record a variety of events – syscalls, kernel switch, CPU frequency, IRQ's, kernel memory management, custom events emitted by Anki programs, and so on. The Anki applications also register a few probes to add to the traces as they execute.

When a fault occurs, the record of activity is saved for later examination.

Both the service to start the tracing, and to record (on demand) a snapshot of the trace are handled by the ankitrace script.

145.6. FAULT CODE HANDLER

A fault code can be posted to the fault code handler by a service, based on errors it detects. More often, a fault code is sent by systemd if one of the service processes it started exits unexpectedly. The fault code handler receives this code, captures diagnostic information to pass on to Anki developers to prevent further problems in the future, and invokes vic-faultCodeDisplay to display the 3 digit code. It then (optionally) restarts the Vic services, or allows the body-board to turn the system power off, after giving enough time for a person to read the code.

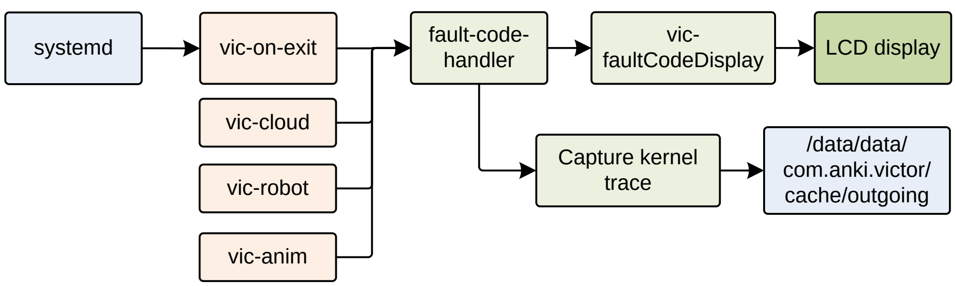

Figure 136: *The fault-code-handler process*

The fault code is sent by writing a string with the fault code to the FIFO file located at:

/run/fault_code

The fault code handler configuration file is located at:

/anki/etc/fault-code-handler.env

This path is in the start-up /lib/systemd/system/fault-code.service file that starts the fault-codes service.

This configuration file can have the following fields (if none are set, the fault-code-handler reverts to these defaults):

Table 584: *The fault code handler configuration variables*

Variable	Default	Description & Notes
FAULT_RESTART_COUNT	0	The default count for the number of restarts. The count of

		restarts is loaded from the /run/fault_restart_count file.
FAULT_RESTART_LIMIT	2	Automatic restarts are allowed only if the restart count is less than this.
FAULT_RESTART_LIMIT_SEC	60	The restart count is cleared after this amount of time has passed. the /run/fault_restart_count
ON_FAULT_RESTART	0	If set to 1, "Vector will restart" is displayed. Then Vector will restart (if it hasn't restarted too many times recently)
ON_FAULT_UPLOAD_LOG	0	If greater than 0, the log data is captured. If this is a developer build, the log is left on disk; if it isn't the log is compressed and placed in the outgoing path.
ON_FAULT_UPLOAD_TRACE	0	If greater than 0, the trace data is captured. If this is a developer build, the log is left on disk; if it isn't the log is compressed and placed in the outgoing path.
TIMEOUT_SIGTERM_SEC	3	This is the period of time to wait for services to stop before sending them a SIGTERM signal.
TIMEOUT_RESTART_SEC	5	If restarting, wait this number of seconds before initiating the system restart command.
VERBOSE	0	If set to 1, extra debugging messages are logged.

The fault-code-handler process works as follows:

1. The /run/fault_code FIFO is created by the fault-code.socket service.
2. When there is any input on the FIFO, systemd launches the corresponding fault-code.service. This launches fault-code-handler with its stdin set to read from the FIFO.
3. Then a line of text is read from the /run/fault_code FIFO, and cleaned up to only contain only digits. If there are no digits – or the fault code is 0 – it exits.
4. The handler checks to see if the /run/fault_code.pending exists. If so, it exits. This file is used to tell if the fault-code-handler still handling a fault, possibly while waiting for the system to be powered off by the body-board.
5. It begins the process of capturing diagnostic traces, and logs for later analysis of the fault;
6. The system services are stopped; depending on the classification of the fault, this may stop all, or just a few.
7. Updates the counts of restarts, and checks the limit
8. The handler checks to see if /run/fault_code.showing exists. If the /run/fault_code.showing file exists, the fault display is already showing and another will not be shown. Otherwise,
    a. Then the vic-faultCodeDisplay is executed to display the fault code. The fault code is passed on the command line.
    b. The fault code is placed into /run/fault_code.showing
9. If uploading is enabled, the fault report and diagnostic LTTng traces are copied to the outgoing queue area.
10. It also takes care to clear out the FIFO.
11. Attempt to restart the system services, after a delay – if that is allowed with this fault classification, and there have not been too many restarts in an attempt to clear the error.

The handler counts the number of restarts (of the system services) within a time window; if there have too many restarts, another one is not performed.

a. If a restart is not allowed, the body-board will eventually power off the system.

12. The /run/fault_code.pending file is removed.

The following files are employed by the fault code handler:

File	Description
/run/fault_code.pending	The "pending" file allows a second fault – a second attempt to run fault-code-handler after it has already displayed a fault, but not been cleared by the restart of the system services. It will still trap the trace of diagnosticsevents, and may trigger further restarting of services – or stopping them, forcing the body-board to eventually remove power.
/run/fault_code.showing	The existence of this file is used to allow only a single fault code to be displayed. It is set to the fault code being displayed.
/run/fault_restart_count	This is incremented with each restart, and cleared by a reboot.
/run/fault_restart_uptime	This captures the time of the last restart of system services. It is used to tell if enough time has passed to reset the restart counter.

***Table 585:** Fault code handler files.*

145.7. CRASH LOGS

The Anki applications are set up to produce small information files when the application crashes. This is done by the applications using Google breakpad toolkit, which hooks several of the applications emergency exit signals. When the application crashes, the toolkit captures the key information in minidump files, which are optionally sent to backtrace.io for analysis.

The vic-crashuploader service regularly checks for log files to send to a server. The outgoing logs are in non-volatile memory, so they can be waiting for a reboot before they are sent, if the robot loses power, has a serious fault, or network access isn't available.

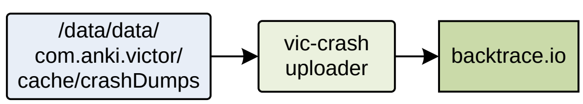

***Figure 137:** The vic-crashuploader pipeline*

The vic-crashuploader configuration file is located at:

/anki/etc/vic-crashuploader.env

This path is in the start-up /lib/systemd/system/vic-crashuploader.service file that starts the fault-codes service.

This file can have the following fields (if none are set, the crash uploader reverts to these defaults):

Variable	Default	Description & Notes
VIC_CRASH_FOLDER		The path to store crash dump files in
VIC_CRASH_SCRAPE_PERIOD_SEC	30	The number of seconds to sleep between cycles of looking for crash files to upload.
VIC_CRASH_UPLOADER_KEEP_LATEST	30	The maximum number of crash files to retain; older files are deleted.

***Table 586:** The crash uploader configuration variables*

VIC_CRASH_UPLOAD_LOG	0	If greater than zero, the log files are also uploaded.
VIC_CRASH_UPLOAD_URL		The URL to upload the crash dump files to

The anki-crash-log process works as follows:

1. The anki-crash-log.socket service creates a FIFO file called:

   /run/anki-crash-log

2. The anki-crashuploader.service removes old files from the VIC_CRASH_FOLDER and launches vic-crashuploader.

3. When an Anki application crashes, the breakpad toolkit creates a minidump file in the VIC_CRASH_FOLDER., then it posts the path to the FIFO file

4. When there is any input on the FIFO, systemd launches the corresponding anki-crash-log.service. This launches anki-crash-log script with its stdin set to read from the FIFO.

5. This script reads a line of text from the /run/anki-crash-log FIFO, and copies the last 400 messages the system log to file in the same directory.

6. Periodically anki-crashuploader wakes (every VIC_CRASH_SCRAPE_PERIOD_SEC seconds) and, if upload is allowed, TBD, uploads the file to VIC_CRASH_UPLOAD_URL. (See chapter 17 for more details.)

7. All but the newest VIC_CRASH_UPLOADER_KEEP_LATEST crash files are removed.

146. CONSOLE FILTER

The logging by functional blocks (primarily in Vic-engine) can be configured. The logging configuration file is located at:

/anki/data/assets/cozmo_resources/config/engine/console_filter_config.json

This file is organized as dictionary whose key is the host operating system. The "vicos" key is the one relevant for Vector.[67] It dereferences to a structure with the following fields:

Table 587: *The console filter channel structure*

Field	Type	Description & Notes
channels	array	An array of the channel logging enable structures
levels	array	An array of logging level enable structures

This "channels" is as an array of structures with the following fields:

Table 588: *The channel logging enable structure*

Field	Type	Description & Notes
channel	string	The name of the channel
enabled	boolean	True if should log information from the channel, false if not.

[67] The other OS key is "osx" which suggests that Vector's software was development on an OS X platform.

This "levels" is an array of structures with the following fields:

Table 589: The logging level enable structure

Field	Type	Description & Notes
enabled	boolean	True if should log information at that level, false if not.
level	string	"event" or "debug"

The features are used as linking mechanisms of the modules. It is likely modules of behavior / functionality. It is not clear how it all ties together.

Table 590: The channels

Channel	enabled	Description & Notes
Actions	false	
AIWhiteboard	false	
Alexa	false	
Audio	false	
Behaviors	false	
BlockPool	false	
BlockWorld	false	
CpuProfiler	true	
FaceRecognizer	false	
FaceWorld	false	
JdocsManager	true	
MessageProfiler	true	
Microphones	false	
NeuralNets	false	
PerfMetric	true	
SpeechRecognizer	false	
VisionComponent	false	
VisionSystem	false	
*	false	

147. USAGE STUDIES AND PROFILING DATA

Anki had ambitions to perform engagement studies and experiments with device settings:

> "The Services collect gameplay data such as scores, achievements, and feature usage. The Services also automatically keep track of information such as events or failures within them. In addition, we may collect your device make and model, an Anki-generated randomized device ID for the mobile device on which you run our apps, robot/vehicle ID of your Anki device, ZIP-code level data about your location (obtained from your IP address), operating system version, and other device-related information like battery level (collectively, "Analytics Data")."

The DAS manager protocol's version identifier dates to the development of Overdrive. One patent on their "Adaptive Data Analytics Service" is quite an ambitious plan to tune an improve systems.

> "A closed-loop service, referred to as an Adaptive Data Analytics Service (ADAS), characterizes the performance of a system or systems by providing information describing how users or agents are operating the system, how the system components interact, and how these respond to external influences and factors. The ADAS then builds models and/or defines relationships that can be used to optimize performance and/or to predict the results of changes made to the system(s). Subsequently, this learning provides the basis for administering, maintaining, and/or adjusting the system(s) under study. Measurement can be ongoing, even after the operating parameters or controls of a system under the administration or monitoring of the ADAS have been adjusted, so that the impact of such adjustments can be determined. This recursive process of observation, analysis, and adjustment provides a closed-loop system that affords adaptability to changing operating conditions and facilitates self-regulation and self-adjustment of systems."

There is no information on whether this was actually accomplished, or that these techniques were used in Cozmo or Vector. Anki developed "both batch and real-time dashboards to gain insights over device and user behavior," according to their Elemental toolkit literature.

147.1. EVENT TRACING

The DAS manager on Vector and the mobile application posts event such as when an activity begins, key milestones along the way, and when the activity ends. The events can include extra parameters such as text and values. In the case of the mobile application, this is the name of each button pressed, screen displayed, error encountered, and so forth.

Speculated purpose:

- To identify how far people got in a process, or what their flow thru an interaction is
- To estimate durations of activities, such as onboarding, how long Vector can play between charge cycles, and how long a charge cycle is.
- To identify unusual events (such as errors).
- May allow detailed reconstruction of the setup, configuration and interaction

The event naming pattern is [*module name*].[*some arbitrary name*]. When these are logged in Vector's text log files they are prefixed with an '@' symbol.[68] For examples of DAS events, see Appendix L.

The vic-dasmgr configuration file is located at:

`/anki/data/assets/cozmo_resources/config/DASConfig.json`

This path is in the vic-dasmgr executable. This file can have the following fields:

Variable	Default	Description & Notes
backup_path		
backup_quota	10000000	
file_threshold_size	1000000	
flush_interval	600	
persistent_globals_path		
storage_path	/run/das Logs	
storage_quota	5000000	
transient_globals_path		
url		The URL to upload the DAS files to

Table 591: *The DAS manager configuration variables*

147.2. DAS

The DAS engine uploads JSON files. Each file holds an array of structures with the following fields:

Field	Type	Description & Notes
boot_id	string	
event	string	The name of the event/error that occurred, or the type of stats loggedy. Sometimes the event is generic – as with "log.error" – so the s1 field needs to be examined. Spaces should be trimmed from the start and end of the field. Some event names are accidentally logged with a trailing space (e.g. "rampost.dfu.desired_version").
feature_run_id	string	
feature_type	string	
i1	int64	Extra information, in integer format. Note, for at least one kind of entry the value domain is 64-bits.
i2	int	Extra information, in integer format.
i3	int	Extra information, in integer format.
i4	int	Extra information, in integer format.
level	string	"info", "warning", "error", etc.
profile_id	string	The account profile id... probably tied to jdocs, and token

Table 592: *The DAS event JSON structure*

[68] This is a very helpful feature

		manager; "unless you create an account and log in, Analytics Data is stored under a unique ID and not connected to you."
robot_id	string	The robot's electronic serial number.
robot_version	string	The software version.
s1	string	Extra information, in string format.
s2	string	Extra information, in string format.
s3	string	Extra information, in string format.
s4	string	Extra information, in string format.
seq	int	The event sequence number. It appears that each event on the robot increments this number. This can be helpful for spotting missing events.
source	string	The module that submitted the event... e.g. vic-engine
ts	uint64	Time stamp, in milliseconds since 1970 Jan 1 (the start of the epoch)
uptime_ms	int	How long it's been since the operating system has rebooted.

This record is generic enough that it can hold each of the events in this form. Not every field is used every time, and not necessarily used in the same way.

147.3. PROFIILING AND LIBOSSTATE

The tools in Vector gather a variety of diagnostic information about:

- Basic information about the robot – the version of software it is running, and what the robot's identifier/serial number is.
- Whether Vector is booted into recovery mode when it is sending the information.
- The uptime – how long Vector has been running since the last reboot or power on.
- The WiFi performance, to understand the connectivity at home since Vector depends so heavily on cloud connectivity for his voice interactions.
- The CPU temperature profile, to find the balance between overheating and AI performance. Some versions and features of Vector can cause faults due to the processor overheating. Anki probably wanted to identify unusual temperatures and whether their revised settings addressed it.
- The CPU and memory usage statistics for the "vic-" application services. Anki probably sought to identify typical and on unusual processing loads and heavy use cases.
- The condition of the storage system – information about the flash size & partitions, whether the user space is "secure", and whether the EMR is valid.

Speculated purpose: To identify typical and on unusual processing loads and temperatures. The heavy uses cases are likely undesired and would be something to identify.

The data gather in Vector for these is primarily based in a library called `libosState`.

147.3.1 WiFi Stats

libosState gathers the following information about the WiFi network:

- The WiFi MAC address
- The WiFi SSID (and flagged if it isn't valid)
- The assigned IP Address (and flagged if it isn't valid)
- The number of bytes received and sent
- The number of transmission and receive errors

The key files employed to access this information:

***Table 593:** The WiFi related stats /proc files*

File	Description
/sys/class/net/wlan0/address	The IP address assigned to Vector
/sys/class/net/wlan0/statistics/rx_bytes	The number of bytes received
/sys/class/net/wlan0/statistics/rx_errors	The number of receive errors
/sys/class/net/wlan0/statistics/tx_bytes	The number of transmit errors
/sys/class/net/wlan0/statistics/tx_errors	The number of bytes sent

How this is used: to get a sense of WiFi connectivity in the home, and rooms where Vector is used. Anki's internal research showed that rooms in a home can have a wide range of connectivity characteristics.

Jane Fraser, 2019

147.3.2 CPU stats

libosState gathers the following information about the CPU temperature:

- The CPU temperature
- The CPU target and actual frequency
- Whether the CPU is being throttled
- The limits set on the CPU frequency

The key files employed to access this information:

***Table 594:** Named device and control files*

File	Description
/sys/devices/system/cpu/cpu0/cpufreq/cpuinfo_cur_freq	The current frequency of the CPU.
/sys/devices/system/cpu/cpu0/cpufreq/scaling_max_freq	The maximum frequency the CPU is allowed to run at.
/sys/devices/system/cpu/cpu0/cpufreq/scaling_governor	
/sys/devices/system/cpu/cpu0/cpufreq/scaling_setspeed	
/sys/devices/virtual/thermal/thermal_zone3/temp	The current temperature of the CPU.

How this is used: This information was probably intended to find the balance between overheating and AI performance.

147.4. EXPERIMENTS

There is an experiments file; this is in libcozmo-engine as well. Cozmo's APK has a file with the same structure. The file has the following high-level structure:

Field	Type	Description & Notes
meta	meta structure	A structure that describes what project the experiment applies to and the versioning info of the structure.
experiments	array of experiment structures	An array of experiments, each with their own conditions and parameters.

Table 595: *The experiments TBD structure*

The meta structure has the following fields:

Field	Type	Description & Notes
project_id	string	"cozmo"[69]
revision	int	1
version	int	2

Table 596: *The meta JSON structure*

The experiment can be run for a bounded period of time, with an optional period that the experiment is paused (perhaps for holidays). An experiment structure has the following fields:

Field	Type	Description & Notes
activation_mode	string	"automatic"
audience_tags	array of TBD	
forced_variations	array of TBD	
key	string	"report_test_auto"
pop_frac_pct	int	Portion of the population, as a percentage, that will take part in this experiment.
pause_time_utc_iso8601	string	The time at which to pause the experiment.
resume_time_utc_iso8601	string	The time at which to resume the experiment after pausing.
start_time_utc_iso8601	string	The date and time that the experiment will commence.
stopt_time_utc_iso8601	string	The date and time that the experiment will end.
variations	array of variation	
version	int	0

Table 597: *The experiment JSON structure*

A variation structure has the following fields:

Field	Type	Description & Notes
key	string	One of at least two populations subject to the test: "control" or "treatment"
pop_fract_pct	int	Portion of the population, as a percentage, that will be in this subject group.

Table 598: *The variation JSON structure*

[69] I suspect that this would have changed once experiments were initiated with Vector

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Built on — extending slightly — the mini dump format developed by Microsoft

os-release — Operating system identification
https://www.freedesktop.org/software/systemd/man/os-release.html

Describes the `/etc/os-version` and `/etc/os-version-rev` files

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References & Resources

Note: most references appear in the margins, significant references will appear at the end of their respective chapter.

149. CREDITS

Credit and thanks to Anki who made Vector possible; C0RE, Melanie T for access to the flash partitions, file-systems, decode keys, board shots, unusual LED codes, information on the electronics, and OTA URLs. Wire/Kerigan Creighton for board shots, the Project Victor website & public relations, finding the web-visualization tool, OTA URLs, identifying the valuable OTA versions, checking the compatibility with Cozmo animations and fun with boot animations. Fictiv for board shots. (The board shots helped identify parts on the board and inter-connection on the board.) GooeyChickenman for the github repository. Cyril Peponet for aboot analysis, finding OTA v1.7, and pointing me valuable past discord postings. Alexander Entinger for body-board connector signal information. Paul Brett for Cube Bluetooth LE information. HSReina for Vector Bluetooth LE protocol information. Wayne Venables for crafting a C# version of the SDK. Silvarius/Silvarius613 & nammo for info on the other Anki products that were under development. nammo for information on error codes, shaft encoders, battery life, signal processing, and much more. Ben Gabaldon for information on Wwise craftsmanship. Mike Huller for catching several typos. Thanks to Mike Corlett for helping me understand more of the token passing scheme.

Several drawings were adapted from Steph Dere, and Jesse Easley's twitter & instagram.

Thank-you Frien and Wire for posting JSON intents, and keeping the communities together. Cyke for alerting people to interesting updates.

Thank-you to Digital Dream Labs (DDL) for continuing support for Vector; DDL and Drew Zhrodague for providing error tables and cloud information.

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Sriram, Swetha, *Anki Vector Robot Teardown*, Fictiv, 2019 Aug 6
https://www.fictiv.com/blog/anki-vector-robot-teardown

Tenchov, Kaloyan; *PyCozmo*
https://github.com/zayfod/pycozmo/tree/master/pycozmo

Venable, Wayne; *Anki.Vector.SDK*
https://github.com/codaris/Anki.Vector.SDK
https://github.com/codaris/Anki.Vector.Samples
https://weekendrobot.com/

Zaks, Mazim *FlatBuffers Explained*, 2016-Jan-30
https://github.com/mzaks/FlatBuffersSwift/wiki/FlatBuffers-Explained

150.3. QUALCOMM

Although detailed documentation isn't available for the Qualcomm APQ8009, there is documentation available for the sibling APQ8016 processor.

Qualcomm, *APQ8016E Application Processor Tools & Resources*,
https://developer.qualcomm.com/hardware/apq-8016e/tools

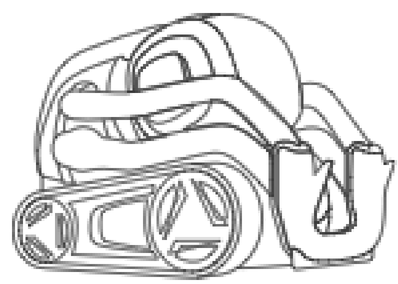
Qualcomm, *DragonBoard™ 410c based on Qualcomm® Snapdragon™ 410E processor ADB Debugging Commands Guide*, LM80-P0436-11, Rev C, 2016 Sep
lm80-p0436-11_adb_commands.pdf

Qualcomm, *DragonBoard™ 410c based on Qualcomm® Snapdragon™ 410E processor Software Build and Installation Guide, Linux Android*, LM80-P0436-2, Rev J, 2016 Dec
lm80-p0436-2_sw-build-and-install_gd_linux_android_dec2016.pdf

Appendices

Robots enjoy large, properly-formatted data files (and flowers from their sweetie). We can't replicate large files here but we can give large, well-formatted tables telling where to find those large data files, and consolidating other useful details – details that would distract from the main narrative.

- ABBREVIATIONS, ACRONYMS, & GLOSSARY. This appendix provides a gloss of terms, abbreviations, and acronyms.
- TOOL CHAIN. This appendix lists the tools known or suspected to have been used by Anki to create, and customize the Vector, and for the servers. Tools that can be used to analyze Vector.
- ALEXA MODULES. This appendix describes the modules used by the Alexa client
- FAULT AND STATUS CODES. This appendix provides describes the system fault codes, and update status codes.
- BODY-BOARD CONNECTOR AND PIN MAP. This appendix lists the electrical connections on the body-board.
- FILE SYSTEM. This appendix lists the key files that are baked into the system.
- BLUETOOTH LE SERVICES & CHARACTERISTICS. This appendix provides information on the Bluetooth LE interface GUIDs to the companion Cube, and to Anki Vector.
- SERVERS. This appendix provides the servers that the Anki Vector and App contacts
- FEATURES. This appendix enumerates the Vector OS "features" that can be enabled and disabled; and the AI behavior's called "features."
- PHRASES. This appendix reproduces the phrases that the Vector keys off of.
- EMOTION EVENTS. This appendix provides a list of the emotion events that Vector internally responds to.
- DAS EVENTS. This appendix describes the identified DAS events
- PLEO. This appendix gives a brief overview of the Pleo animatronic dinosaur, an antecedent with many similarities.



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APPENDIX A

Abbreviations, Acronyms, Glossary

***Table 599:** Common acronyms and abbreviations*

Abbreviation / Acronym	Phrase
ADC	analog to digital converter
AG	animation group
ALSA	advanced Linux sound architecture
APQ	application processor Qualcomm (used when there is no modem in the processor module)
ASR	automatic speech recognition
AVS	Alexa Voice Service
BIN	binary file
BMS	battery management system
BNK	AudioKinetic sound bank file
CCIS	customer care information screen
CLAD	C-like abstract data structures
CLAHE	contrast-limited adaptive histogram equalization
CNN	convolution neural network
CRC	cyclic redundancy check
CSI	Camera serial interface
DAS	*unknown (diagnostic/data analytics service?)*
DFU	device firmware upgrade
DTTB	Dance to the beat
DVT	design validation test
EEPROM	electrical-erasable programmable read-only memory
EMR	electronic medical record
ESD	electro-static discharge
ESN	electronic serial number
EVT	engineering validation test
FBS	flat buffers
FDE	full disc encryption
FFT	fast Fourier transform

GPIO	general purpose IO
gRPC	Google remote procedure call
GUID	globally unique identifier (effectively same as UUID)
HLAI	high-level AI
I2C	inter-IC communication
IMA ADPCM	interactive multimedia association adaptive pulse-code modulation
IMU	inertial measurement unit
IR	infrared
JDocs	JSON Documents
JSON	JavaScript Object Notation
JTAG	Joint Test Action Group
JWT	JSON web token
LCD	liquid crystal display
LED	light emitting diode
LUKS	Linux unified key setup
MCU	microcontroller
mDNS	multicast domain name service (DNS)
MEMS	micro-electromechanical systems
MIPI	mobile industry processor interface
MISO	master-in, slave-out
MOSI	master-out, slave-in
MPM	McLeod pitch detection method
MPU	microprocessor
MSM	mobile station modem, the APC processor and a modem.
MSRP	manufacturer’s suggest retail price
OLED	organic light-emitting diode display
OTA	over the air updates
PCB	printed circuit board
PCBA	printed circuit board assembly (PCB with the components attached)
PCM	pulse-code modulation
PDM	pulse-density modulation
PMIC	power management IC
PNG	portable network graphics; an image file format
PWM	pulse width modulation
PVT	production validation test
QSN	Qualcomm serial number
ROI	region of interest
RPM	resource power management

RRT	rapidly-expanding random tree
RSSI	received signal strength indicator
SCLK	(I2C) serial clock
SDA	(I2C) serial data
SDK	software development kit
SHK	silicon-based hardware key
SLAM	simultaneous localization and mapping
SOC	system on a chip
SPAD	single photon avalanche diode
SPI	serial-peripheral interface
SSH	secure shell
SSID	service set identifier (the name of the Wifi network)
STM32	A microcontroller family from ST Microelectronics
SWD	single wire debug
SYSCON	system controller
TAR	tape archive file
TTS	text to speech
UART	universal asynchronous receiver/transmitter
USB	universal serial bus
UUID	universally unique identifier (effectively same as GUID)
vic	short for Victor (Vector's working name)
WEM	AudioKinetic Wwise Encoded Media. (a type of sound file)

Table 600: *Glossary of common terms and phrases*

Phrase	**Description**
*A**	A path finding algorithm
aboot	The Android boot-loader used to launch Vector's linux system.
accelerometer	A sensor used to measure the angle of Vector's head, and acceleration (change in velocity).
animation	A scripted "sequence of highly coordinated movements, faces, lights, and sounds … to demonstrate an emotion or reaction."
animation trigger name	An identifier of a group of related animations; Vector "pick[s] .. [an] actual animations to play based on Vector's mood or emotion, or with random weighting. Thus playing the same trigger twice may not result in the exact same underlying animation playing twice."
attitude	Vector's orientation, esp relative to the direction of travel
autocorrelation	A technique to find how repetitive a signal is; it works by finding how much one has to shift version of the signal before it (mostly) matches the original signal again.
backpack board	The circuit board in Vectors head with lights, push button, microphones and touch sensor

beam forming	A technique using multiple microphones to listen to a single speaker by selectively paying attention to sound only coming from that direction.
behavior	Behaviors represent a complex task [that] may include combinations of animation, path planning or other functionality. Examples include" driving to the charger, set the lift height, etc.
behavior tree	A decision tree that decides if a behavior can run or can no longer run, which related behaviors to start, and the parameter settings to run the behavior with.
body board	The circuit board in Vector's belly that manages the battery and drives the motors
boot loader	A piece of software used to load and launch the application software.
C-like abstract data structure (CLAD)	Anki's phrase for how they pack information into fields and values with a defined binary format. "Any data [passed] over the wire, [is] define[d with] enums, structures and messages in ".clad" files.. [with a] syntax [that] looks a lot like C structs. [A tool] auto-generate[s] Python, C++ and C# code for each of these structures, along with code to serialize and deserialize to efficiently packed byte streams of data."[70] (FlatBuffers are used for the same purpose, but were not available when CLAD was developed.)
capacitive touch	A type of sensing where light contact, such as touch, is detected without requiring pressing a mechanism.
cascade	Applies a series of fast to compute filters and classifiers to detect low-level features and identify things like faces.
cepstrum	A way of using the frequency spectrum to analyze a voice.
certificate	Vector generates an SSL certificate that can be used for the secure communications.
characteristic (Bluetooth LE)	A key (or slot) that holds a value in the services key-value table. A characteristic is uniquely identified by its UUID.
client token	A string token provided by Vector that is passed with each SDK command.
control	Responsible for motors and forces to move where and how it is told to. (smooth arcs)
cooldown	A period of time after an action, animation, or behavior has run before it can be run again. see also *hold-off timer*
D-lite*	A path-finding algorithm
decimation	The amount (or ratio) that something is down sampled by.
delocalization	"Whenever Vector no longer knows where he is – e.g. when he's picked up," or falls.
device mapper verity (dm-verity)	A feature of the Linux kernel that checks the boot and RAM file systems for alteration, using signed keys
electronic medical record	A software record of Vector's serial number, model, lot code, manufacturing & test dates, and other information. This is stored in flash.
electronic serial number	Vector's serial number, but the copy that is in his *electronic medical record.*
entitlement	An entitlement is a family of features or resources that the program or owner is allowed to use.
face detection	The ability to realize that there is a face in the image, and where it is
face recognition	The ability to know the identity of a face seen.
feature flags *aka feature toggle*	A setting that enables and disables features, especially those still in development. This allows developing the code and integrating its structure before the module or function is completely ready. Otherwise it is very difficult to keep the different

[70] https://forums.anki.com/t/what-is-the-clad-tool/102/3

	branches of development in sync and merge them when the feature is ready.
field of view	How wide of an area in the world that the camera can see
firmware	A type of software held (and usually executed from) in ROM or flash. It may have a (minimal) operating system, but often does not.
flash	A type of persistent (non-volatile) storage media.
guidance	Builds the desired path
gyroscope	A sensor that is used to measure how fast Vector is turning (the angular velocity) along its x, y, and z axes.
Haar feature	Facial features picked out using Haar wavelets
Haar wavelet	A fast, low-cost that can used to pick out (or recognize) simple features in an image.
habitat	A small area for Vector to drive around in while alone, without accidentally driving off the edge or getting lost. Sold as "Vector Space"
head board	The circuit board in Vector's head with the main processor, WiFi (and Bluetooth LE), camera, speaker, etc.
hold-off timer	a timer that prevents another trigger or event for a period of time (after the previous one). *see also cool down.*
hotword	aka *wake word*
inertial measurement unit	The combination of an accelerometer and gyroscope to measure linear acceleration and rotational velocity.
inner node	A node in a tree data structure that does links to other nodes below it. Often it does not hold any other information.
intent	An intent is an internal code (and accompanying structure) that is used to represent the how to respond to the question or other phrases spoken by a person. It may represent the action requested, an answer to a query, or an action that emotionally responds to what was said.
JSON web token[71]	A compressed, encoded JSON structure that hold a small amount of data (like a cookie), and some meta-information about how long the token is valid for.
Kalman filter	Used to merge two or more noisy signals together to estimate a proper signal.
leaf node	A node in a tree data structure that does not link to any other nodes below it. It holds the information that was being looked up.
navigation	Knowing where it is in the map
nonce	An initially random number, incremented after each use.
odometry	Estimate motion – displacement and rotation – from inertial measurement units and wheel & track rotation.
path planning	Forms smooth arcs and line segments to move in around an environment to avoid collisions, blocked paths, and cliffs. This is often used to navigate from point A to point B.
playpen	The playpen is a testing area with ramps, barriers, camera targets at a variety of angles, cube and a charging station.
playpen test	The playpen test is a check of the robots sensors, camera calibration, motor function, microphone and a check over his overall functions. During testing, Vector's is checked for correct function: that he can correctly navigate, detect cliffs, see markers (getting their type and size correct), dock, and charge.
pose	The position and orientation of an object relative to a coordinate system

[71] https://en.wikipedia.org/wiki/JSON_Web_Token

power source	Where the electric energy used to power Vector comes from.
quad-tree	A way of compressing a 2D map down into regions.
rapidly-expanding random tree	A path-finding algorithm
recovery mode	A separate, independent operating system that Vector can boot into for purposes of downloading software to replace a damaged partition.
robot name	Vector's robot name looks like "Vector-E5S6". It is "Vector-" followed by a 4 letters and numbers.
serial number	A unique number that is stamped on Vector's hardware (on the bottom) and in his *electronic medical record.*
service (Bluetooth LE)	A key-value table grouped together for a common purpose. A service is uniquely identified by its UUID.
session token	A string token provided by the Anki servers that is passed to Vector to authenticate with him and create a *client token.*
silicon-based hardware key	This is a key that is unique to each processor – it is programmed by blowing fuses during manufacture – and is used to check the signing by secure boot and TrustZone functions.
simultaneous localization and mapping	A vision-based technique for building a map of the immediate world for purposes of positioning oneself within it and detecting relative movements.
software	Software is distinct from firmware in that is often loaded from external storage to be run in RAM, and is based on dynamic linking, allowing the use of other (replaceable) software elements. It does not access hardware directly; instead it employs sophisticated features of the operating system.
system controller (syscon)	The name of the body-board microcontroller, and the firmware program running on it.
tempo	The pace of music, in beast per second
text to speech	A process of reading aloud a word, phrase, sentence, etc.
trigger word	aka *wake word*
Trust Zone	A security mode on ARM processor where privileged/special code is run. This includes access to encryption/decryption keys.
universally unique identifier (UUID)	A 128bit number that is unique. (effectively same as GUID)
vocoder	A sound effect that analyzes and transforms a voice; in this case to give Vector his unique vocal sound.
wake word	The phrase ("Hey, Vector") used to activate Vector so that he will respond to spoken interaction.

Quotes are from Anki SDK.

APPENDIX B

Tool chain

This appendix tries to capture the tools that Anki is known or suspected to have used for the Anki Vector and its cloud server.

Table 601: *Tools used by Anki*

Tool	Description
Acapela	Vector uses Acapela's text to speech synthesizer, and the Ben voice. https://www.acapela-group.com/
Advanced Linux Sound Architecture (alsa)	The audio system https://www.alsa-project.org
Amazon Alexa	A set of software tools that allows Vector to integrate Alexa voice commands, probably in the AMAZONLITE distribution https://github.com/anki/avs-device-sdk https://developer.amazon.com/alexa-voice-service/sdk
Amazon Simple Queue Service (SQS)	Vector employs Amazon's SQS for its DAS functions.
Amazon Simple Storage Service (S3)	Vector's cloud interface uses Amazon's AWS go module to interact with Amazon's service: https://docs.aws.amazon.com/sdk-for-go/api/service/s3/ https://docs.aws.amazon.com/AmazonS3/latest/API/API_Operations_Amazon_Simple_Storage_Service.html
Amazon Web services	used on the server https://aws.amazon.com/
android boot-loader	Vector uses the Android Boot-loader; the code can be found in the earlier archive.
ARM NN	ARM's neural network support https://github.com/ARM-software/armnn
AudioKinetic Wwise[72]	Used to craft the parametric sound effects, and play pre-recorded effects. https://www.audiokinetic.com/products/wwise/
Backtrace.io	A service that receives uploaded minidumps from applications in the field and provides tools to analyze them. https://backtrace.io
clang	A C/C++ compiler, part of the LLVM family https://clang.llvm.org
bluez v5	Bluetooth LE support http://www.bluez.org/
busybox	The shell on the Anki Vector linux https://busybox.net
chromium update	?
civetweb	The embedded webserver that allows Mobile apps and the python SDK to communicate

[72] https://blog.audiokinetic.com/interactive-audio-brings-cozmo-to-life/

	with Vector. https://github.com/civetweb/civetweb
connman	Connection manager for WiFi https://01.org/connman
Eigen	A linear algebra library http://eigen.tuxfamily.org/
gemmlowp	A low-precision general matrix multiplication library https://github.com/google/gemmlowp
GNU C Compiler (gcc)	GCC version 4.9.3 was used to compile the kernel
golang	Go is used on the server applications, and (reported) some of Vector's internal software.
Google Breakpad	Google Breakpad is used to generate tracebacks and mini-dump files of programs that crash. Results are sent to htttp://backtrace.io https://chromium.googlesource.com/breakpad/breakpad
Google FlatBuffers	Google FlatBuffers is used to encode the animation data structures. "It is similar to protocol buffers, but the primary difference is that FlatBuffers does not need a parsing/unpacking step to a secondary representation before you can access data, often coupled with per-object memory allocation. Also, the code footprint of FlatBuffers is an order of magnitude smaller than protocol buffers"[73] https://github.com/google/flatbuffers
Google Protobuf	Google's Protobuf interface-description language is used to describe the format/encoding of data sent over gRPC to and from Vector. This is used by mobile and python SDK, as well as on the server. https://developers.google.com/protocol-buffers
Google RPC (gRPC)	A "remote procedure call" standard, that allows mobile apps and the python SDK to communicate with Vector. https://grpc.io/docs/quickstart/cpp/
hdr-histogram	This is a library used to support gathering histograms over a potentially wide range. It is most likely used when gathering stats about internet access speeds, and equalizing images from the camera. https://github.com/HdrHistogram/HdrHistogram
libsodium	Cryptography library suitable for the small packet size in Bluetooth LE connections. Used to encrypt the mobile applications Bluetooth LE connection with Vector. https://github.com/jedisct1/libsodium
linux, yocto[74]	The family of linux distribution used for the Anki Vector (v3.18.66)
linux unified key storage (LUKS)	This is used to protect the private keys and user data.
Maya	A character animation tool set, used to design the look and movements of Cozmo and Vector. The tool emitted the animation scripts.
mpg123	A MPEG audio decoder and player. This is needed by Alexa; other uses are unknown. https://www.mpg123.de/index.shtml
ogg vorbis	Audio codec https://xiph.org/vorbis
Omron OKAO Vision	Vector uses the Omron Okao Vision library for face recognition and tracking. https://plus-sensing.omron.com/technology/position/index.html
open CV	Used for the first-level image processing – to locate faces, hands, and possibly accessory symbols. https://opencv.org/

[73] https://nlp.gitbook.io/book/tensorflow/tensorflow-lite
[74] https://www.designnews.com/electronics-test/lessons-after-failure-anki-robotics/140103493460822

openssl	used to validate the software update signature https://www.openssl.org
opkg	Package manager, from yocto https://git.yoctoproject.org/cgit/cgit.cgi/opkg/
Opus codec	Audio codec; to encode speech sent to servers http://opus-codec.org/
perl	A programming language, on Victor https://www.perl.org
Pretty Fast FFT pffft	Julien Pommier's FFT implementation for single precision, 1D signals https://bitbucket.org/jpommier/pffft
Pryon, Inc	The recognition for the Alexa keyword at least the file system includes the same model as distributed in AMAZONLITE https://www.pryon.com/company/
python	A programming language and framework used with desktop tools to communicate with Vector. Vector has python installed. Probably used on the server as well. https://www.python.org
Qualcomm	Qualcomm's device drivers, camera support and other kit are used.
Segger ICD	A high-end ARM compatible in-circuit debugging probe. Rumoured to have been used by Anki engineers, probably with the STM32F030 https://www.segger.com/products/debug-probes/j-link/
Sensory TrulyHandsFree	Vectors recognition for "Hey Vector" and Alexa wake word is done by Sensory, Inc's TrulyHandsfree SDK 4.4.23 (c 2008) https://www.sensory.com/products/technologies/trulyhandsfree/ https://en.wikipedia.org/wiki/Sensory,_Inc.
Signal Essence	Designed the microphone array, and the low-level signal processing of audio input. https://signalessence.com/
Sound Hound, inc Houndify	Vector's Q&A "knowledge graph" is done by Sound Hound, using their Houndify product https://blog.soundhound.com/hey-vector-i-have-a-question-3c174ef226fb https://www.houndify.com/
SQLite	This is needed by Alexa; other uses are unknown https://www.sqlite.org/index.html
systemd	Used by Vector to launch the internal services https://www.freedesktop.org/software/systemd/
tensor flow lite (TFLite)	TensorFlow lite is used to recognize hands, the desk surface, and was intended to support recognizing pets and common objects. https://www.tensorflow.org/lite/microcontrollers/get_started

151. REFERENCES & RESOURCES

Several of the tools have licenses requiring Anki to post that the tools was listed and/or to post their versions of the tools, and their modification. The following archives of the open source tools are listed in the "acknowledgements" section of the mobile application:[75]

https://anki-vic-pubfiles.anki.com/license/prod/1.0.0/licences/OStarball.v160.tgz
https://anki-vic-pubfiles.anki.com/license/prod/1.0.0/licences/engineTarball.v160.tgz

[75] You can only read the acknowledgements in the mobile application if you are connected to a robot.

APPENDIX C

Alexa modules

This Appendix outlines the modules used by the Alexa client built into Vector (using the Alexa Client SDK). Alexa's modules connect together like so:

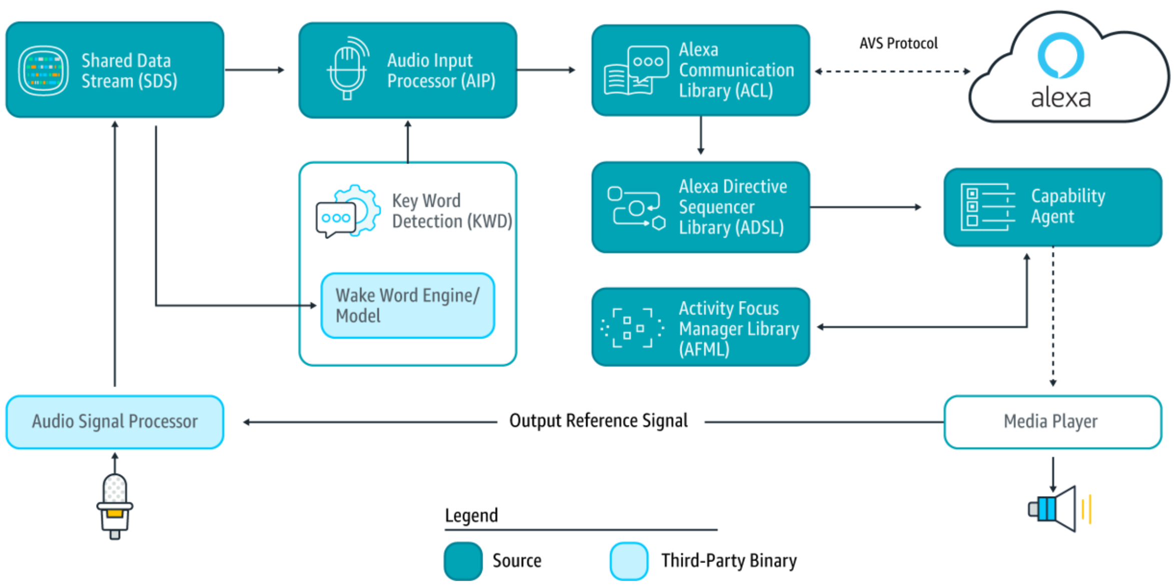

***Figure 138:** Alexa's function blocks* (image courtesy Amazon)

Alexa's modules include:

***Table 602:** Alexa files*

Library	Description & Notes
libACL.so	Alexa Communication Library. "Serves as the main communications channel between the device and the Alexa Voice Service."
libAIP.so	Audio Input Processor. "Handles the audio input to Alexa Voice Service from on-device microphones, remote microphones and other audio input sources."
libADSL.so	Alexa Directive Sequencer Library (Directive Router, Processor, Sequencer; Message Interpreter).
libAFML.so	Activity Focus Manager Library, including Audio Activity Tracker, Visual Activity tracker. "Prioritizes the channel inputs and outputs as specified by the AVS Interaction Model"
libAlerts.so	Alexa alert scheduler; "The interface for setting, stopping, and deleting timers and alarms."
libAudioPlayer.so	Alexa's audio player. "The interface for managing and controlling audio playback."

libAudioResources.so	Alexa's audio resources, including calls
libAVSCommon.so	Alexa's voice service support
libAVSSystem.so	Alexa's voice service support
libCapabilitiesDelegate.so	Alexa capabilities. "Handles Alexa-driven interactions; specifically, directives and events. Each capability agent corresponds to a specific interface exposed by the AVS API."
libCBLAuthDelegate.so	Alexa Authorization
libCertifiedSender.so	Alexa certified sender
libContextManager.so	Alexa's context manager
libESP.so	Alexa ESP, Dummy ESP
libInteractionModel.so	"This interface allows a client to support complex interactions initiated by Alexa, such as Alexa Routines."
libNotifications.so	Alexa Notifications. "The interface for displaying notifications indicators." Uses SQLite
libPlaybackController.so	"The interface for navigating a playback queue via GUI or buttons."
libPlaylistParser.so	Alexa playlist
libRegistrationManager.so	Alexa's registration manager
libSettings.so	Alexa's settings & preferences module
libSpeakerManager.so	
libSpeechSynthesizer.so	"The interface for Alexa speech output."

Note: quotes from Amazon Alexa Voice Services SDK documentation

APPENDIX D

Fault and status codes

The following are system status codes that may be produced during startup (*Quotes from "Anki Vector Error Codes")*:

Table 603: *The system fault codes*

Code	Meaning
1..10	Systemd failed…?
1	"Switchboard: unknown status"
2	"Switchboard: [Over the Air Update is] in progress "
3	"Switchboard: [Over the Air Update has] completed"
4	"Switchboard: rebooting"
5	"Switchboard: other [Over the Air Update] error"
10	"OS: Unknown system error"
001-099	Playpen
100-199	Error related to the body-board (syscon)
200-219	Software update status codes, see table below
220-299	Error codes in the range of 220-299 refer to problems from the software processes within Vector's OS
300-799	Error codes in the range of 300-799 refer to problems expected during factory tests.
700	The robot was shutdown because the button was pressed.
701	The gyroscope sensor is out of range or failed (it wasn't able to calibrate), so the robot shutdown.
702	The robot was shutdown because the battery voltage was too low.
703-704	Internal sensor out of range or failed.
705	The robot was shutdown because the battery was too hot to safely operate.
800-999	Error codes in the range of 800-999 refer to "power on self check" failures.
800	Vic-anim was unable to start or crashed.
801	The process to update the cube firmware failed.
840	The camera calibration is missing.
850	There is a problem with the cloud certificate
851	There is a problem with the cloud token store
852	There is a problem reading the cloud electronic serial number (ESN).
870	The front right MEMS microphone failed during power-on self test.
871	The front left MEMS microphone failed during power-on self test.
872	The back right MEMS microphone failed during power-on self test.
873	The back left MEMS microphone failed during power-on self test.
890	The front right cliff sensor failed during power-on self test.
891	The front left cliff sensor failed during power-on self test.
892	The back right cliff sensor failed during power-on self test.

893	The back left cliff sensor failed during power-on self test.
894	The time-of-flight distance sensor failed during power-on self test.
895	The touch sensor failed (during power-on self test?)
898	The main board is unable to communicate with the body-board. The cable between boards may be disconnected. This also appears as a software bug in version 1.6.
899	"No Body" This may mean that the main board is unable to communicate with the body-board. The cable between boards may be disconnected. This also appears as a software bug in version 1.6.
911	The audio system (hardware or software?) is not working properly.
913	Vic-switchboard was unable to start or crashed
914	Vic-engine was unable to start or crashed. "This was what zombie 915 was (915 on the screen, robot still drove around)" If vic-engine can't read some part of the behavior tree, this will appear.
915	Vic-engine stopped responding.
916	Vic-robot was unable to start or crashed
917	Vic-anim stopped responding (Or Vic-robot stopped responding.)
919	systemd is not working properly
920	Vic-gateway-cert was unable to generate a x509 certificate for vic-gateway
921	Vic-gateway was unable to start or crashed
923	Vic-cloud was unable to start or crashed
960	The IMU (accelerometer and gyroscope) has failed, or is not communicating properly.
919	
970	The WiFI hardware has failed.
980	"These codes indicate issues with the camera. These issues are typically caused by mm-anki-camera hanging when we try to stop the camera stream on vic-engine stop. We have to manually kill it and start it again."
981	The camera stopped responding. "These codes indicate issues with the camera. These issues are typically caused by mm-anki-camera hanging when we try to stop the camera stream on vic-engine stop. We have to manually kill it and start it again."
990	The LCD display is not communicating properly with the processor.

The following are the Playpen Failure codes. These overlap some of the error number ranges for other status codes:

Table 604: Playpen Failure codes

Status	Meaning
0	Unknown: "Not possible"
1	Success: "Passed playpen"
2	There was a problem with one of the CLAD data structures. This error should not happen.
3	The lift or head failed. This error should not happen.
4	The "robot not detecting charger/ not charging. Make sure charger is plugged in; Check charge, contacts/charge circuit"
5	The charger is unavailable. This error should not happen.
6	The charger is not connected. This error should not happen.
7	The IMU is faulty or not communicating. The IMU is faulty. "Check/replace IMU. Maybe robot is shaking/moved while on charger."
8	Still on charger. This error should not happen.
9	Failed to go to the calibration pose. This error should not happen.
10	The "robot saw a cliff and then stopped seeing it. Check cliff sensors; Check cliff slot in playpen; Check playpen surface for dirt"
11	The "robot detected a cliff" where there is none. "Check cliff sensors; Check playpen surface for dirt."
12	The robot is not in the calibration pose. This error should not happen.
13	The calibration has failed. The "robot is seeing the calibration target but calibration [is] taking too long." "Check calibration target; Check camera position and lens"
14	The "camera calibrated but the calibration is outside normal range. Check camera position and lens"
15	"Failed to write [camera calibration] data to [the] robot [non-volatile storage]. Should never happen"
16	"Failed to write [camera calibration image] data to [the] robot [non-volatile storage]. Should never happen"
17	"Failed to write [calibration pose] data to [the] robot [non-volatile storage]. Should never happen"
18	"Too many calibration images. Not possible."
19	"Calibration pose failed. Not possible."
20	"Read tool code failed. Not possible."
21	"Tool code positions [out of range]. Not possible"
22	"Tool code write failed. Not possible."
23	"Goto pre pickup pose action failed. Not possible."
24	"Not in pre pickup pose. Not possible."
25	"Not seeing cube to pickup. Check [that the] cube is in correct spot; Check [the] camera; Check [the] wheels if robot is not facing the cube"
26	"Seeing cube to pickup but robot thinks the cube is somewhere else. Check [that the] cube is in correct spot; Check [the] camera position."
27	"Failed to pickup cube. Check [the] cube position; check [the] lift motor/gearbox."
28	"Failed to place cube. Check [the] lift motor/gearbox."

29	"Unexpected observed object. Not possible."
30	"Goto pre mount charger pose action failed. Not possible"
31	The charger was not found. "Not possible"
32	The charger dock failed. "Not possible"
33	Queue action failed. "Not possible."
34	"A motor randomly calibrated. Check for issue with all motors: Sticky gearbox? Encoder problem?"
35	"Failed to write [test result] data to [the] robot [non-volatile storage]. Should never happen"
36	A test timed out. "Some step of playpen took too long and never completed. Try rerunning"
37	The test was cancelled. "Not possible"
38	The "robot detected being picked up. Was the robot picked up during the test or lifted off the ground in some way? Check cliff sensors; Check IMU"
39	"Tool code images write failed. Not possible."
40	The "touch sensor readings [are] not stable, [too noisy]. Check touch sensor"
41	"Failed to write [cube pose] data to [the] robot [non-volatile storage]. Should never happen"
42	The "lift motor randomly calibrated. Check lift motor/gearbox"
43	The "head motor randomly calibrated. Check head motor/gearbox"
44	"Touch sensor readings [are] too small or [too] large. Check touch sensor"
45	The robot "rid not pass all previous fixtures. Run robot through previous fixtures"
46	The robot has not been tested. "Not possible."
47	The "head/lift motor failed to calibrate. Check head/lift motor/gearbox"
48	"Failed to write [birth certificate] data to [the] robot [non-volatile storage]. Should never happen"
49	"Failed to write data to [the] robot [non-volatile storage]. Should never happen"
50	"Failed to write data to [the] robot [non-volatile storage]. Should never happen"
51	There are "too many tool code images. Not possible."
52	"Failed to write [calibration meta information] data to robot. [This] should never happen."
53	"Failed to write [IMU] data to robot. [This] should never happen."
54	"No [Bluetooth LE] advertising packet [was received] from a cube. Check battery of cube; Check [Bluetooth LE] radio on robot."
55	"Touch sensor readings [standard deviation is] too large. Check [the] touch sensor."
56	Failed to computer the camera pose. "Not possible."
57	The camera pose is out of range. "Not possible."
58	Failed to play sound. "Not possible."
59	Was unable to read the results of the previous test. "Not possible."
60	The wrong firmware version. "Not possible."
61	A cliff sensor value is too high. "Not possible."
62	A cliff sensor value is too low. "Not possible."
63	The "robot did not backup straight while picking up the cube. Check wheel treads/motors/gearboxes"

64	The “battery is too low. Check battery; Leave robot on a charger for a couple of minutes to charge”
65	No IMU data. “Not possible.”
66	The “robot did not backup straight after picking up the cube. Check [the] wheel treads/motors/gearboxes”
67	The wrong body hardware version. This error should not happen.
68	There is no body hardware version information. This error should not happen.
69	The non-volatile storage erase operation failed. “Not possible.”
70	Was unable to parse the header of [??]. “Not possible.”
71	“No WiFi [access points were] found. Check [the] radio on [the] robot”
72	“Unknown body color. Not possible.”
73	“Failed to write data to robot. [This] should never happen”
74	The behavior is not runnable. “Software bug. Try rerunning.”
75	The “robot [is] not seeing [the] camera calibration target. Check camera position and lens”
76	The “robot detected being on a charger randomly. Check charge contacts/circuit”
77	“Head motor randomly disabled. Check head motor/gearbox”
78	“Lift motor randomly disabled. Check lift motor/gearbox”
79	“Some motor randomly disabled. Check all motors/gearboxes”
80	The “robot detected unexpected movement. [It] probably ran into something in playpen. Check wheels; Check IMU”
81	“Some action [that] the robot was trying to do failed.
82	The “robot failed to detect front cliffs. Check [the] front two cliff sensors.”
83	The “robot failed to detect back cliffs. Check [the] back two cliff sensors.”
84	The “robot failed to undetect front cliffs after detecting them. Check [the] front two cliff sensors.”
85	The “robot failed to undetect back cliffs after detecting them. Check [the] back two cliff sensors.”
86	The “robot thinks [that the] cube [is too] low in the ground. Check [the] cube position; Check camera position/rotation”
87	The “robot thinks [that the] cube [is too] high above the ground. Check [the] cube position; Check camera position/rotation”
88	The “camera calibrated but the calibration is outside normal range. Check camera position and lens.”
89	The “robot [is] not seeing [the] distance sensor marker. Check [the] robot[s] position at [the] time of failure, why wasn't it seeing the marker. Check [the] distance sensor marker.”
90	The “robot [is] seeing [the] distance sensor marker [too] close or far away. [The] robot is too far or close to [the] distance sensor marker; check [the] wheels.”
91	The “front right [microphone is] not working. Check [the] front right [microphone].”
92	The “front left [microphone is] not working. Check [the] front left [microphone].”
93	The “back right [microphone is] not working. Check [the] back right [microphone].”
94	The “back left [microphone is] not working. Check [the] back left [microphone].”
95	“Either [the] speaker [is] not working or all [of the microphones are] not

	working. If [the] robot played [a] sound, check all [of the microphones, otherwise] check [the] speaker."
96	"Never received FFT result from [the microphone] check."
97	The "touch sensor reporting unexpected [out of range] values. Check [the] touch sensor."
98	The time-of-flight "distance sensor reporting incorrect values. Check [the] distance sensor."
99	The certificates were checked but have been found to be invalid. "Invalid [certificates] written by previous fixture. Run robot through previous fixtures"

The following are the RAMPOST DFU error codes. (These are not the fault status code):

***Table 605:** RAMPOST DFU status codes*

Status	Meaning
16	Couldn't get version from syscon
17	Failed to erase
18	couldn't send data to download
19	App failed verification check or could not be verified

The following are the update-engine status codes that may be produced during the update process:

Table 606: OTA update-engine status codes

Status	Meaning
200	The TAR contents did not follow the expected order.
201	Unhandled section format for expansion, or The manifest version is not supported, or The OTA has the wrong number of images for the type, or The OTA is missing a BOOT or SYSTEM image, or The manifest configuration is not understood
202	Could not mark target, a, or b slot unbootable, or Could not set target slot as active
203	Unable to construct automatic update URL, or The URL for the update could not be opened
204	The file (from the update URL) wasn't a valid TAR file, or is corrupt
205	The compression scheme is not supported, or Decompression failed, the file may be corrupt
206	"Block error" (*Note: this error code is not present in Vector's update software, and may be reserved.)*
207	Delta payload error
208	Couldn't sync OS images to disk, or Disk error while transferring OTA file.
209	The manifest failed signature validation; or the aboot, boot image, system image, or delta.bin hash doesn't match signed manifest
210	The encryption scheme is not supported.
211	Vector's current version doesn't match the baseline for a delta update.
212	The decompression engine had an unexpected, undefined error.
213	The processor serial number (QSN) doesn't match the one in the manifest
214	There is a mismatch: development Vectors can't install release OTA software, and release Vectors can't install development OTA software.
215	OTA transfer failed, due to timeout. (There may be poor network connectivity)
216	OS version name in the update file doesn't follow an acceptable pattern (the version suffixes – for production, release candidate, userdev, and development – must match the already installed software), or it is not allowed to upgrade or downgrade from the current version to the new version.
219	Other unexpected, undefined error while transferring OTA file.

152. REFERENCES AND RESOURCES

Anki Vector Error Codes, 2020-2-26
https://documents.project-victor.org/Release-Anki-Vector-error-codes-20200226.pdf
https://github.com/GooeyChickenman/victor/blob/master/documentation/Anki-Vector-error-codes%20-%2020200226.pdf

APPENDIX E

Body Board Connectors, Pin Map

This appendix covers:

- The body-board connectors
- The microcontroller peripheral allocation
- The microcontroller pin maps

153. BODY-BOARD CONNECTORS

Alexander Entinger

The body-board has the following connectors:

- Connector to the head-board
- Connector to the head motor & encoder
- Connector to the lift motor & encoder
- Connector to the time of flight sensor
- Connector to the backpack board

153.1.1 The head-motor connector

The P1 Head motor connector (P1) has the following functions for its pins:

***Table 607:** Head Motor Connector (P1) pin map*

Pin#	Label	Test point	Cable Color	Description
1	CAI	HENCK	Brown	Head encoder emitter on/off (low is on)
2	E2	HENCB	Yellow	Head encoder output B
3	E1	HENCA	Green	Head encoder output A
4	V_{DD}		White	Head encoder voltage source
5	Motor -		Black	Motor connection
6	Motor +		Red	Motor connection

153.1.2 The lift-motor connector

The lift motor connector (P2) has the following functions for its pins:

Table 608: *Lift Motor Connector (P2) pin map*

Pin#	Label	Test point	Cable Color	Description
1	CAI	LENCK	Brown	Lift encoder emitter on/off (low is on)
2	E2	B	Yellow	Lift encoder output B
3	E1	A	Green	Lift encoder output A
4	V_{DD}		White	Lift encoder voltage source
5	Motor -		Black	Motor connection
6	Motor +		Red	Motor connection

153.1.3 The time of flight connector

The front (Time of Flight) sensor connector has the following functions for its pins:

Table 609: *Front Sensor (time of flight) Connector pin map*

Pin#	Label	Test point	Cable Color	Description
1	V_{DD}	V_{DD} (TP)	Red	Sensor voltage source
2	SCL1		Yellow	I^2C serial clock
3	SDA1		Green	I^2C serial data in/out
4	GND	GND (DC)	Black	Sensor ground reference

153.1.4 Backpack connector

The flat-pack connector (P4) to the back-pack has the following functions for its pins:

Table 610: *Backpack Connector pin map*

Pin#	Label	Description
1		goes to Q17
2		has a 24M to head board power supply
3	MOSI	has
4	MISO1	
5	MISO2	
6	VMAIN	
7	PWR_B	Power to the button
8	BAT_B	Batter to the button
10	V_{DD}	Power for the microphones, LEDs, and logic
11		
12		
13	Touch	

153.1.5 The debug connector

The PCBA debug pads, connector employs the following pins and functions:

Table 611: Debug Connector pin map

Pin#	Label	Description
1	VX	External power supply (connected with charger connector positive.)
2	BAI	Internal power supply for head
3	TX	UART transmit; connects to STM32F030C8T6 Pin #12 (PA2 = USART2_TX)
4	SWCLK	Single wire debug clock signal
5	SWDIO	Single wire debug bi-directional data signal
6	NRST	Processor reset (reset is transition from low to high).
7	GND	Ground

153.1.6 Other body-board test points

The remaining PCBA test points, connector employs the following pins and functions:

Table 612: PCBA test points

Test Point	Layer	Description
V_{dd}	Bottom	Body board MCU power supply
BODY_TX	Bottom	RS232 sent from the body board's MCU
SCL2	Top	I^2C serial clock
SDA2	Top	I^2C serial data in/out

154. MICROCONTROLLER PIN MAPS AND RESOURCES

This section outlines the microcontroller pin maps and internal peripherals that are used.

- The allocation of DMA channels
- The allocation of timer channels
- The allocation of ADC channels
- Power control signals
- UART-related communication pins
- Microphone related pin allocation
- Cliff sensor and time of flight pin and function allocation
- LED driver pin allocation
- Motor driver pin and function allocation

The DMA channels are allocated for the following functions:

DMA Channel	Function
1	Used to regularly sample all of the ADC channels
2	Used to received the data from the microphones on SPI1
3	Used by USART TX to send data, the microcontroller lists this as USART1 RX, but it uses the receive signal to drive sending the data.
4	Used to received the data from the microphones on SPI2
5	Used to receive USART1 data from the head board

Table 613: *DMA channel usage*

The internal hardware timers are allocated for the following functions:

Timer	Function
1	Used to PWM the motors
3	Used to PWM the motors
6	
14	used to drive internal events processing
15	The input (SPI clock) to divide the clock down for the microphones
16	The divided the SPI clock for the microphones
17	Probably used to clock out the stuff to the LCD

Table 614: *Timer usage*

154.1.1 ADC inputs

The ADC module employs the following pins and functions:

Pin	Function	Test point	Description
PA2	ADC		Charger input. Note: this pin is shared with the charger USART communication.
PA4	ADC	VBat	Battery measurement.
PA3	ADC		Unknown.
PA6	ADC		Touch sense.

Table 615: *UART communication pin map*

154.1.2 Power control, management

The power control employs the following pins and functions:

Pin	Function	Test point	Description
PA3	digital	out	Power to head board?
PA12	digital	out	Power enable to back pack? To R34 (100K) the to Q14, gate
PB9	digital	out	Power enable to the body board from the MP charger.

Table 616: *Power control pin map*

Note: see also the encoders section for their power control.

154.1.3 External Communication

The UART communication employs the following pins and functions:

Table 617: *UART communication pin map*

Pin	Function	Test point		Description
PA2	USART2 TX, RX	TX	in/out	USART to charger port 1-wire communication. The USART is put into half-duplex operation, so it employs the same pin for RX and RX. *Note: this pin is shared with the charger ADC measurement.*
PB6	USART1 TX	BODY_TX	out	USART to the head board.
PB7	USART1 RX		in	USART from the head board

154.1.4 Microphone related pin map

The microphone interface employs the following pins and functions:

Table 618: *Microphone related pin map*

Pin	Function	Test point		Description
PA5	SPI1 Clock		out	Clock from SPI1. May be fed into TIM15 CH2
PB4	SPI1 MISO		in	Data in from the microphones for SPI1
PB8	TIM16_CH1			The clock used to drive all of the microphones; derived from scaling down an SPI clock.
PB13	SPI2 Clock		out	Clock from SPI2. May be fed into TIM15 CH2
PB14	SP12 MISO		in	Data in from the microphones for SPI2
PB15	TIM15 CH2		out	The SPI clock probably goes into here for division

154.1.5 Proximity sensors: Cliff, and Time of flight

The cliff and time of flight proximity sensors employ the following pins and functions:

Table 619: *Proximity sensor pin map*

Pin	Function	Test point		Description
PB10	I2C2 Clock		out	I2C clock to the peripherals. This is alternated with PF6 to access different peripherals.
PB11	I2C2 Data		in/out	I2C data to/from the peripherals. This is alternated with PF7 to access different peripherals.
PF6	I2C2 Clock	SCL2	out	I2C clock to the peripherals. This is alternated with PB10 to access different peripherals.
PF7	I2C2 Data	SDA2	in/out	I2C data to/from the peripherals. This is alternated with PB11 to access different peripherals.

154.1.6 LEDs

The LED controller employs the following pins:

Table 620: *Back-pack LED logic pin map*

Pin	Function	Test point		Description
PA13	digital		out	The bits to be sent to the 74HC164. Note this pin also serves as SWDIO.
PA14	digital		out	The clock for the bits sent to 74HC164. Note this pin also serves as SWCLK.

154.1.7 Motor driver and encoders

The motor drivers use the following pins and functions:

Table 621: *Motor driver pin map*

Pin	Function	Test point		Description
PA7	TIM1_CH1N		out	Motor 3 (Head), -, Q6,p1
PA8	TIM1_CH1		out	Motor 3 (Head), +, Q2 p1
PA9	TIM1_CH2		out	
PA10	TIM1_CH3		out	Motor 0 (), +, Q1P1
PA11	TIM1_CH4		out	Motor 2 (Lift), +, Q4p1,
PA15	digital		out	Motor 0 (), +, Q1P3. Note: configured as open drain output.
PB0	TIM1_CH2N		out	Motor 0 (), -, Q5P1
PB1	TIM3_CH4		out	Motor 1 (), -, Q7P1
PB5	TIM3_CH2		out	Motor 1 (), +, Q3P1
PB12	digital		out	Motor 3 (Head), +, Q2P3. Note: configured as open drain output.
PF0	digital		out	Motor 2 (Lift), +, Q4P3. Note: configured as open drain output.
PF1	digital		out	Motor 1 (), +, Q3P3. Note: configured as open drain output.

The motor encoders use the following pins and functions:

Table 622: *Motor encoder pin map*

Pin	Function	Test point		Description
PA0	digital	HENCA	in	Head encoder output A
PA1	digital	HENCB	in	Head encoder output B
PB2	digital	A	in	Lift encoder output B
PB3	digital	B	in	Lift encoder output A
PC13	digital		out	Power control for the encoders. Low is on, otherwise off
PC14	digital	RTENC	in	Right motor encoder.
PC15	digital	LTENC	in	Left tread encoder.

APPENDIX F

File system

This Appendix describes the file systems on Vector's flash. As the Vector uses the Android boot-loader, it reuses – or at least reserves – many of the Android partitions[76] and file systems. Many are probably not used. Quotes are from Android documentation.

The file system table tells us where they are stored in the partitions, and if they are non-volatile.

Table 623: The file system mount table

Mount point	Partition name	Description & Notes
/	BOOT_A	The primary linux kernel and initramfs
/data[77]	USERDATA	The data created for the specific robot (and user) that customizes it. A factory reset wipes out this user data. This portion of the file system is encrypted using "Linux Unified Key Setup" (LUKS).
/firmware	MODEM	The firmware for the WiFi/Bluetooth radio, and TrustZone modules (trustlets). These modules are signed with the processor's key.
/factory	OEM	Keys and configurations assigned to the individual robot at the factory, and some logs.
/persist	PERSIST	Device specific "data which shouldn't be changed after the device is shipped, e.g. DRM related files, sensor reg file (sns.reg) and calibration data of chips; wifi, bluetooth, camera etc."
/run		Internal temporary file system; holding commands for the updating setting, state of update processes, the fault codes, etc.
/media/ram /var/volatile /dev/sm		Internal temporary file systems; holds temporary files, interprocess communication

The partition table[78] found on the Vector:

Table 624: The partition table adapted from Melanie T

Partition name	Size	Description & Notes
ABOOT ABOOTBAK	1 MB 1 MB	The primary and backup Android boot loader, which may load the kernel, recovery, or fastboot. This is in the format of a signed, statically linked ELF binary.
BOOT_A BOOT_B	32 MB 32 MB	These are the primary and backup linux kernel and initramfs. Updates modify the non-active partition, and then swap which one is active.
CONFIG	512 KB	This partition is not employed by Vector. It is zero'd out.
DDR	32 KB	Configuration of the DDR RAM.
DEVINFO	1 MB	This partition is not read by Vector. It is zero'd out. In typical aboot implementations this partition is used to hold "device information including: is_unlocked (aboot), is_tampered, is_verified, charger_screen_enabled, display_panel, bootloader_version, radio_version etc.

[76] https://forum.xda-developers.com/android/general/info-android-device-partitions-basic-t3586565
[77] This is mounted by "mount-data.service" The file has a lot of information on how it unbricks
[78] Much information from: https://source.android.com/devices/bootloader/partitions-images

		Contents of this partition are displayed by “fastboot oem device-info” command in human readable format. Before loading boot.img or recovery.img, [the] boot loader verifies the locked state from this partition.” Vector’s aboot will write to this partition to indicate tampering when it finds that the boot image does not pass integrity checks.
EMR	16 MB	This is Vectors “Electronic Medical Record.” It holds Vector’s Model, Serial Number, and such. It is a binary data structure, rather than a file system.
FSC	1KB	“Modem FileSystem Cookies”
FSG	1.5 MB	Golden backup copy of MODEMST1, used to restore it in the event of error
KEYSTORE	512 KB	“Related to [USERDATA] Full Disk Encryption (FDE)”
MISC	1MB	This is “a tiny partition used by recovery to communicate with boot-loader store away some information about what it's doing in case the device is restarted while the OTA package is being applied. It is a boot mode selector used to pass data among various stages of the boot chain (boot into recovery mode, fastboot etc.). e.g. if it is empty (all zero), system boots normally. If it contains recovery mode selector, system boots into recovery mode.”
MODEM	64 MB	Binary “blob” for the WiFi/Bluetooth radio firmware, and TrustZone trustlets. These are signed by Anki, and the processor key.
MODEMST1 MODEMST2	1.5MB 1.5MB	A FAT file-system holding executables and binary “blobs” for the WiFi/Bluetooth radio firmware, and TrustZone trustlets. These are signed by Anki, and the processor key. Includes a lot of test code, probably for emissions testing.
OEM	16MB	A modifiable ext2/4 file system that holds the logs, robot name, some calibration info, and SDK TLS certificates.
PAD	1MB	“related to OEM”
PERSIST	64MB	This partition is not employed by Vector. It is zero’d out.
RECOVERY	32 MB	An alternate partition holding kernel and initial RAM filesystem that allows the system boot into a mode that can download a new system. Often used to wipe out the updates.
RECOVERYFS	640 MB	An alternate partition holding systems applications and libraries that let the application boot into a mode that can download a new system. Often used to wipe out the updates. This partition holds v0.90 of the Anki software.
RPM RPMBAK	512KB 512KB	The primary and backup partitions for resource and power management. This is in the format of a signed, statically linked ELF binary.
SBL1 SBL1BAK	512KB 512KB	The primary and back up partitions for the secondary boot-loader. Responsible for loading aboot; has an “Emergency” download (EDL) mode using Qualcomm’s Sahara protocol. This is in the format of a signed, statically linked ELF binary.
SEC	16KB	The secure boot fuse settings, OEM settings, signed-boot-loader stuff
SSD	8KB	“Secure software download” for secure storage, encrypted RSA keys, etc
SYSTEM_A SYSTEM_B	896MB 896MB	The primary and backup system applications and libraries with application specific code. Updates modify the non-active partition, and then swap which one is active.
SWITCHBOARD	16 MB	This is a modifiable data area used by Vic-switchboard to hold persistent communication tokens. This appears to be a binary data structure, rather than a file system.
TZ TZBAK	768KB 768KB	The primary and backup TrustZone. This is in the format of a signed, statically linked ELF binary. This code is executed with special privileges to allow encrypting and decrypting key-value pairs without any other modules (or debuggers) having access to the secrets.

USERDATA	768MB	The data created for the specific robot (and user) that customizes it. A factory reset wipes out this user data. This partition is encrypted using "Linux Unified Key Setup" (LUKS).

The following files are employed in the Vector binaries and scripts:

Table 625: *Files*

File	Description
/anki/etc/revision	Contains the robot revision number
/anki/etc/version	Contains the robot version number
/data/data/com.anki.victor	This folder is used to hold outgoing logging information and the preferences.
/data/data/com.anki.victor/cache/crashDumps	This folder is used to hold the minidump files produced when a program crashes.
/data/data/com.anki.victor/cache/outgoing	This folder is used to hold outgoing logs.
/data/data/com.anki.victor/cache/vic-logmgr	A folder used to hold the log files while constructing the compressed archive file that will be uploaded.
/data/diagnostics/	This folder is to holder outgoing logging information as it is prepared to be sent over Bluetooth LE.
/data/etc/localtime	The time zone
/data/etc/robot.pem	The robot's secret key that it used to generate the vic-gateway public key. This file is created by mount-data.
/data/fault-reports	This folder is used to hold the LTTng trace files and copy of the log; an archive is made from these and placed into the outgoing logs folder above.
/data/lib/connman/	The WiFi settings (managed by connman) are copied here.
/data/maintenance_reboot	This is set when the system has rebooted for maintenance reasons (e.g. updates)
/data/misc/bluetooth	A folder to hold communication structures for the Bluetooth LE stack.
/data/misc/bluetooth/abtd.socket	The IPC socket interface to Anki's Bluetooth LE service
/data/misc/bluetooth/btprop	The IPC socket interface to BlueZ Bluetooth LE service.
/data/misc/camera	
/data/panics	
/data/data/com.anki.victor/persistent/switchboard/sessions	Used by Vic-switchboard to hold persistent session information, e.g. tokens
/data/usb	
/data/vic-gateway	This folder holds the x509 certificate used by SDK & mobile app, as well as a table of API tokens used to ensure that the SDK & mobile app have been authenticated to use the bot.
/dev/block/bootdevice/by-name/emr	File system access to the manufacturing records, including serial number
/dev/block/bootdevice/by-name/switchboard	File system access to switchboards persistent data.
/dev/rampost_error	The status of the rampost checks of the body board.
*/dev/socket/_anim_robot_server_*	The IPC socket with Vector's animation controller
*/dev/socket/_engine_gateway_server_*	The IPC socket interface to Vector's Gateway [TBD] server

*/dev/socket/_engine_gateway_proto_server_*	The IPC socket interface to Vector's Gateway [TBD] server
*/dev/socket/_engine_switch_server_*	The IPC socket interface to Vector's Switchbox [TBD] server
/etc/os-version	Contains the OS (linux) version string.
/etc/os-version-rev	Contains the OS (linux) revision string.
/proc/sys/kernel/random/boot_id	A random identifier, created each boot
/sys/devices/system/cpu/possible[79] */sys/devices/system/cpu/present*	The number of CPUs and whether they can be used.
/run/after_maintenance_reboot	This is set to indicate to Vectors services that the system was rebooted for maintenance reasons, and they should take appropriate action. This will be set, on boot, if `/data/maintenance_reboot` had been set.
/run/fake-hwclock-cmd[80]	Sets the fake time to the time file (Vector doesn't have a clock)
/tmp/vision/neural_nets	

Key named device files employed in Vector binaries:

Table 626: *Named device and control files*

File	Description
/dev/fb0	The display frame-buffer for the kernel-based driver. Used prior to version 1.0.
/dev/spidev0.0	The SPI channel to communicate with the IMU
/dev/spidev1.0	The SPI channel to communicate with the LCD
/dev/ttyHS0	Serial connection with the body-board
/dev/ttyHSL0	Console log
/sys/class/android_usb/android0/iSerial	Set to Vector's serial number
/sys/class/gpio/gpio83	Used to control the camera power
/sys/class/leds/face-backlight-left/brightness	LCD left backlight control
/sys/class/leds/face-backlight-right/brightness	LCD right backlight control
/sys/devices/platform/soc/1000000.pinctrl/gpio/gpiochip0/base	LCD backlight enable (left or right?) GPIO config
/sys/devices/system/cpu/cpu0/cpufreq/scaling_max_freq	The maximum frequency that the CPU can run at. Initially set to 533MHz
/sys/kernel/debug/msm_otg/bus_voting	Disabled to prevent the USB from pinning RAM to 400MHz.
/sys/kernel/debug/rpm_send_msg/message	Used to control the RAM controller. The RAM is set to a maximum of 400MHz.
/sys/devices/soc/1000000.pinctrl/gpio/gpiochip0/base	LCD backlight enable (left or right?) GPIO config
/sys/devices/soc.0/1000000.pinctrl/gpio/gpiochip911/base	LCD backlight enable (left or right?) GPIO config
/sys/module/spidev/parameters/bufsiz	The buffer size for SPI transfers. This is set to the size of the LCD frame (184 pixels × 96 pixels × 2 bytes/pixel).

79 https://www.kernel.org/doc/Documentation/ABI/testing/sysfs-devices-system-cpu
80 https://manpages.debian.org/jessie/fake-hwclock/fake-hwclock.8.en.html

APPENDIX G

Bluetooth LE Services & Characteristics

This Appendix describes the configuration of the Bluetooth LE services – and the data access they provide – for the accessory cube and for Vector.

155. CUBE SERVICES

The basic Bluetooth LE services:

Service	UUID[81]	Description & Notes
Device Info Service[82]	$180A_{16}$	Provides device and unit specific info –it's manufacturer, model number, hardware and firmware versions
Generic Access Profile[83]	1800_{16}	The device name, and preferred connection parameters.
Generic Attribute Transport[84]	1801_{16}	Provides access to the services.
Cube's Service	C6F6C70F-D219-598B-FB4C-308E1F22F830$_{16}$	Service custom to the cube, reporting battery, accelerometer and date of manufacture

Table 627: *The Bluetooth LE services*

Note: It appears that there isn't a battery service on the Cube. When in over-the-air update mode, there may be other services present (i.e. by a boot-loader)

Element	Value
Device Name (Default)	"Vector Cube"
Firmware Revision	"v_5.0.4"
Manufacturer Name	"Anki"
Model Number	"Production"
Software Revision	"2.0.0"

Table 628: *The Cube's Device info settings*

[81] All values are a little endian, per the Bluetooth 4.0 GATT specification
[82] http://developer.bluetooth.org/gatt/services/Pages/ServiceViewer.aspx?u=org.bluetooth.service.device_information.xml
[83] http://developer.bluetooth.org/gatt/services/Pages/ServiceViewer.aspx?u=org.bluetooth.service.generic_access.xml
[84] http://developer.bluetooth.org/gatt/services/Pages/ServiceViewer.aspx?u=org.bluetooth.service.generic_attribute.xml

155.1. CUBE'S SERVICES

Values are little-endian, except where otherwise stated.

UUID	Access	Description & Notes
0EA75290-6759-A58D-7948-598C4E02D94A$_{16}$	Write	Sets the LED patterns
450AA175-8D85-16A6-9148-D50E2EB7B79E$_{16}$	Read	The version string of the application firmware. This is also the date and time of the firmware build.
43EF14AF-5FB1-7B81-3647-2A9477824CAB$_{16}$	Read, Notify, Indicate	Reads the battery and accelerometer. Subscribing to this will stream the accelerometer data.
9590BA9C-5140-92B5-1844-5F9D681557A4$_{16}$	Write	OTA update. This is used to send the application firmware to the Cube.

Table 629: *Cube's accelerometer service characteristics*

See chapter 14 for a description of the commands that go over this service.

156. VECTOR SERVICES

Times and other feature parameters:

Service	UUID[85]	Description & Notes
Generic Access Profile	1800_{16}	The device name, and preferred connection parameters
Generic Attribute Transport	1801_{16}	Provides access to the services.
Vector's Serial Service	$FEE3_{16}$	The service with which we can talk to Vector.

Table 630: *Vector's Bluetooth LE services*

It appears that there isn't a battery service on the Vector.

Element	Value
Device Name (Default)	"Vector" followed by his serial number

Table 631: *The Vector's Device info settings*

156.1. VECTOR'S SERIAL SERVICE

UUID	Access	Format	Notes
30619F2D-0F54-41BD-A65A-7588D8C85B45$_{16}$	Read, Notify,Indicate		
7D2A4BDA-D29B-4152-B725-2491478C5CD7$_{16}$	write		

Table 632: *Vector's serial service characteristics*

See chapter 13 for a description of the commands that go over this service.

[85] All values are a little endian, per the Bluetooth 4.0 GATT specification

APPENDIX H

Servers & Data Schema

This Appendix describes the servers that Vector contacts[86]

Server	Description & Notes
chipper.api.anki.com:443	The speech recognition engine is contacted thru this server.
chipper-dev.api.anki.com:443	Development Vectors contact this speech recognition engine server.
conncheck.global.anki-services.com/ok	This server is used to check to see if Vector can connect to Anki.
conncheck.global.anki-dev-services.com/ok	This server is used to check to see if development Vectors can connect to Anki.
jdocs.api.anki.com:443	Server used to store of some of preferences, usage stats.
jdocs-dev.api.anki.com:443	Server used by development Vectors to store of some of preferences, usage stats.
s3://anki-device-logs-dev/victor	Development Vectors send their log files here.
token.api.anki.com:443	This server is used to provide the API certificate.[87]
token-dev.api.anki.com:443	This server is used to provide the API certificate for development Vectors.
https://anki.sp.backtrace.io:6098/post?format=minidump&token=6fd2bd053e8dd542ee97c05903b1ea068f090d37c7f6bbfa873c5f3b9c40b1d9	Vector posts crashes (linux minidumps) to this server. This is hard coded in anki-crashuploader
https://sqs.us-west-2.amazonaws.com/792379844846/DasProd-dasprodSqs-1845FTIME3RHN	This is used to synchronize with data analytics services.
https://ota.global.anki-services.com/vic/prod/	Server used to check for updates
https://ota.global.anki-dev-services.com/vic/rc/lo8awreh23498sf/	For the Developer branch
amazon.com/code	

***Table 633:** The servers that Vector contacts.*

[86] Todo: sync up with info at: https://github.com/anki-community/vector-archive
[87] Project Victor had a write up, reference that.

The mobile application contacts the following servers:

Server	Description & Notes
https://locations.api.anki.com/1/locations	This is used to provide a list of locations to the mobile application that the Chipper servers will recognize. Without this, you cannot change Vector's location in the mobile application

Table 634: The servers that the mobile application contacts.

The Alexa modules contact the following servers:

Server	Description & Notes
https://api.amazon.com/auth/O2/	Used to authenticate the account for the Alexa device.
https://avs-alexa-na.amazon.com	The Alexa Voice Service that accepts the spoken audio and returns a rich intent. Amazon changed preferred URLs on 2019 May 22, and this is considered legacy.[88]

Table 635: The Amazon Alexa Voice Service servers that Vector contacts.

[88] https://developer.amazon.com/docs/alexa-voice-service/api-overview.html

APPENDIX I

Features

The following is the set of application-level feature flags and whether they are enabled (i.e. sufficiently developed to be used) in Vector:

***Table 636:** The features*

Feature	enabled	Description & Notes
ActiveIntentFeedback	true	
Alexa	true	The ability to use Alexa
Alexa_AU	true	The ability to use Alexa, localized for Australia
Alexa_UK	true	The ability to use Alexa, localized for the UK
AttentionTransfer	false	
CubeSpinner	false	
Dancing	true	The ability for Vector to dance to music.
Exploring	true	The ability for Vector to explore his area
EyeColorVC	true	The ability to set Vector's eye color through a voice command
FetchCube	true	The ability for Vector to fetch his cube
FindCube	true	The ability for Vector to find his cube
GazeDirection	false	
GreetAfterLongTime	true	
HandDetection	true	The ability for Vector to spot hands
HeldInPalm	true	
HowOldAreYou	true	The ability for Vector to track how long it has been since he was activated (his age) and use that info to respond to the question "How old are you?"
Invalid	false	
Keepaway	true	
KnowledgeGraph	true	The ability for Vector to answer a question when asked "Hey Vector, I have a question…"
Laser	false	
Messaging	false	
MoveCube	true	
PopAWheelie	true	The ability for Vector pop a wheelie using his cube
PRDemo	false	
ReactToHeldCube	true	
ReactToIllumination	true	
RollCube	true	The ability for Vector to drive up and roll his cube

StayOnChargerUntilCharged	true	
TestFeature	false	
Volume	true	The ability to set Vector's volume by voice command.

The following is the set of AI features (related to, but the same as the feature flags), which identify an active behavior:

Table 637: *The AI behaviour features*

Feature	Description & Notes
Alexa	This behavior is used to perform Alexa-based interaction.
AskForHelp	? Is Vector asking for help?
BasicVoiceCommand	Vector is responding to a wake word and intent.
BeQuiet	Vector is responding to the intent TBD to be quiet (make no sounds and not move).
Blackjack	Vector is playing a game of Blackjack.
CantDoThat	
ComeHere	Vector is going to the speaker.
CubeSpinner	
DanceToTheBeat	Vector is dancing to music.
Exploring	Vector is driving and exploring his area.
FetchCube	Vector is fetching his cube.
FindCube	Vector is looking for his cube. This is done prior to fetching a cube, if Vector doesn't know where it is.
FindHome	Vector is looking for his home (the charger). This is done if Vector needs to charger, and doesn't know where the charger is.
FistBump	If Vector has received a fist bump. Note this can be a result of the shaking of lifting the cube, driving with the cube, or putting it down.
Frustrated	Vector is frustrated and throwing a little tantrum.
GoHome	Vector is driving home to his charger, often in response to a low battery.
HeldInPalm	Vector is held in the palm of a hand; he may coo or throw a little tantrum.
HowOldAreYou	Vector has been asked how long it has been since he was activated (his age) and telling his human.
InteractWithFaces	
InTheAir	Vector has detected that his in the air. If he thinks he is falling, he may engage in "tuck and roll" where lowers his lift, and tilts his head down.
KeepAway	
KnowledgeGraph	Vector has been ask to answer a question ("Hey Vector, I have a question…") and this behaviour is used to perform the rest of the interaction.
ListeningForBeats	Vector thinks that music may be playing and is listening for the beat of the music to dance to. (He may follow this with the *DanceToTheBeat* feature).
LookAtMe	Vector is looking for a person face, to look into their gaze.

LowBattery	Vector's battery level is low and he needs to begin looking for the charger.
MeetVictor	Vector is performing the on-boarding steps.
MoveCube	
MovementBackward	
MovementForward	
MovementLeft	
MovementRight	
MovementTurnAround	
NoFeature	When Vector's mind isn't doing anything and his mind is blank… he'll probably pick exploring, observing, or sleeping as his next activity.
Observing	Vector is looking around.
ObservingOnCharger	Vector is looking around while on his charger.
Petting	Vector is being petting.
PlayingMessage	*The messaging features are not yet support.*
PopAWheelie	Vector is attempting to pop a wheelie using his cube.
ReactToAbuse	Vector is responding to verbally abusive statements (represented as an intent).
ReactToAffirmative	Vector is responding to verbal complements (represented as an intent).
ReactToApology	Vector is responding to an apology (represented as an intent).
ReactToCliff	Vector has detected a cliff while driving, and is reacting to it.
ReactToGazeDirection	Vector has detected a face looking at him (the gaze) and is reacting to it.
ReactToGoodBye	Vector is responding to a verbal goodbye (represented as an intent).
ReactToGoodMorning	Vector is responding to a verbal good morning (represented as an intent).
ReactToHand	Vector has seen a hand and is reacting to it.
ReactToHello	Vector is responding to a verbal hello (represented as an intent).
ReactToLove	Vector is responding to a verbal statement of affection (represented as an intent).
ReactToNegative	Vector is responding to verbal abuse.
ReactToRobotOnSide	Vector has fallen (possibly from driving off the edge of his area) and is on his side.
RecordingMessage	*The messaging features are not yet support.*
RequestCharger	Vector is asking his human to help him by putting him on his charger. This happens if Vector can't get to his charger – he is stuck or doesn't know where it is.
RobotShaken	Vector has detected being shaken, like a snow globe
RollBlock	The ability for Vector to drive up and roll his cube
SDK	
SeasonalHappyHoliday	Vector is animating a little celebration video suitable for Christmas and other holidays.

SeasonalHappyNewYear	Vector is animating a little celebration video suitable for New Years.
ShutUp	
Sleeping	Vector is sleeping, usually on his charging, and waiting for stimulation.
StuckOnEdge	Vector has driven at least one of
TakeAPhoto	Vector is taking a photo.
TimerCanceled	Vector is cancelling the timer, as part of the timer behavior
TimerChecked	Vector is answering "how long is left on the timer", as part of the timer behavior.
TimerReminder	
TimerRinging	Vector is playing the timer ring (i.e. the timer has expired) animation as part of the timer behavior.
TimerSet	
UnmatchedVoiceIntent	The cloud wasn't able to identify an intent based on what was said (if anything) after the *Hey Vector* wake word.
VolumeAdjustment	Vector's volume was adjusted by a voice command.
Weather	Vector is looking up the weather (from the cloud) and animating the results.
WhatsMyName	Vector is looking for a face and identifying it.

APPENDIX J

Phrases and their Intent

This Appendix maps the published phrases that Vector responds to and their intent:

Table 638: *The "Hey Vector" phrases*

Intent	Enumeration	Phrase
movement_backward	23	Back up
imperative_scold	18	Bad robot
imperative_quiet		Be quiet
global_stop	3	Cancel the timer
		Change/set your eye color to [blue, green, lime, orange, purple, sapphire, teal, yellow].
check_timer	1	Check the timer
imperative_come	10	Come here
imperative_dance	11	Dance.
play_popawheelie	34	Do a wheelstand
imperative_fetchcube	12	Fetch your cube
imperative_findcube	13	Find your cube
play_fistbump	32	Fist Bump
play_fistbump	32	Give me a Fist Bump
movement_backward	23	Go backward
explore_start	2	Go explore
movement_forward	22	Go forward.
movement_turnleft	24	Go left
movement_turnright	25	Go right
system_sleep		Go to sleep
system_charger		Go to your charger
		Good afternoon
greeting_goodbye	4	Goodbye
		Good evening
greeting_goodnight		Good night
greeting_goodmorning	5	Good morning
imperative_praise	16	Good robot

seasonal_happyholidays	36	Happy Holidays
seasonal_happynewyear	37	Happy New Year
greeting_hello	6	Hello
		He's behind you
character_age	0	How old are you
imperative_abuse	7	I hate you.
knowledge_question	27	I have a question …
imperative_love	15	I love you.
imperative_apology	9	I'm sorry.
play_blackjack	31	Let's play Blackjack
		Listen to music
imperative_lookatme	14	Look at me
		Look behind you
		My name is [Your Name]
imperative_negative	17	No
play_pickupcube	33	Pick up your cube.
play_anygame	29	Play a game
play_anytrick	30	Play a trick
play_blackjack	31	Play Blackjack
play_popawheelie	34	Pop a wheelie.
play_rollcube	35	Roll your Cube
imperative_quiet		Quiet down
		Run
set_timer	38	Set a timer for [length of time]
imperative_shutup		Shut up
explore_start	2	Start Exploring
		Stop Exploring
global_stop	3	Stop the timer
take_a_photo	40	Take a picture of [me/us]
take_a_photo	40	Take a picture
take_a_photo	40	Take a selfie
movement_turnaround	26	Turn around
movement_turnleft	24	Turn left
{same as be quiet }		Turn off
movement_turnright	25	Turn right
imperative_volumelevel	19	Volume [number].
imperative_volumedown	21	Volume down
imperative_volumeup	20	Volume up.
		Volume maximum

names_ask	28	What's my name?
weather_response	41	What's the weather in [City Name]?
weather_response	41	What's the weather report?
show_clock	39	What time is it?
blackjack_hit		
blackjack_playagain		
blackjack_stand		
global_delete		
imperative_lookoverthere		
knowledge_response		
knowledge_unknown		
meet_victor		
message_playback		
message_record		
silence		
status_feeling		
imperative_affirmative	8	Yes

Note: Vector's NLP server doesn't recognize "home" ..

Questions

Table 639: *The Vector questions phrases*

Subject	**Example Phrase**
Current conversion	What's 1000 Yen in US Dollars?
Flight status	What is the status of American Airlines Flight 100?
Equation solver	What is the square root of 144?
General knowledge	What is the tallest building?
places	What is the distance between London and New York?
People	Who is Jarvis?
Nutrition	How many calories are in an avocado?
Sports	Who won the World Series?
Stock market	How is the stock market?
Time zone	What time is it in Hong Kong?
Unit conversion	How fast is a knot?
Word definition	What is the definition of Artificial Intelligence?

Table 640: Mapping of different intent names

User Intent	Cloud Intent	App Intent	Feature Flag
amazon_signin	intent_amazon_signin		
amazon_signout	intent_amazon_signout		
blackjack_hit	intent_blackjack_hit		
blackjack_playagain	intent_blackjack_playagain		
blackjack_stand	intent_blackjack_stand		
character_age	intent_character_age		HowOldAreYou
check_timer	intent_clock_checktimer		
explore_start	intent_explore_start	explore_start	Exploring
global_delete	intent_global_delete_extend		
global_stop	intent_global_stop_extend		
greeting_goodbye	intent_greeting_goodbye		
greeting_hello	intent_greeting_hello		
greeting_goodmorning	intent_greeting_goodmorning		
greeting_goodnight	intent_greeting_goodnight		
imperative_abuse	intent_imperative_abuse		
imperative_affirmative	intent_imperative_affirmative		
imperative_apology	intent_imperative_apologize		
imperative_come	intent_imperative_come	intent_imperative_come	
imperative_dance	intent_imperative_dance	intent_imperative_dance	
imperative_eyecolor	intent_imperative_eyecolor		EyeColorVC
imperative_eyecolor_specific	intent_imperative_eyecolor_specific_extend		EyeColorVC
imperative_fetchcube	intent_imperative_fetchcube	intent_imperative_fetchcube	FetchCube
imperative_findcube	intent_imperative_findcube	intent_imperative_findcube	FindCube
imperative_lookatme	intent_imperative_lookatme	intent_imperative_lookatme	
imperative_lookoverthere	intent_imperative_lookoverthere	intent_imperative_lookoverthere	GazeDirection
imperative_love	intent_imperative_love		
imperative_negative	intent_imperative_negative		
imperative_praise	intent_imperative_praise		
imperative_scold	intent_imperative_scold		
imperative_quiet	intent_imperative_quiet	intent_imperative_quiet	
imperative_shutup	intent_imperative_shutup	intent_imperative_shutup	
imperative_volumedown	intent_imperative_volumedown		Volume
imperative_volumelevel	intent_imperative_volumelevel_extend		Volume
imperative_volumeup	intent_imperative_volumeup		Volume
knowledge_question	intent_knowledge_promptquestion	knowledge_question	KnowledgeGraph
knowledge_response	intent_knowledge_response_extend	knowledge_response	KnowledgeGraph
knowledge_unknown	intent_knowledge_no_response	knowledge_unknown	KnowledgeGraph
meet_victor	intent_names_username_extend	intent_meet_victor	
message_playback	intent_message_playmessage_extend	intent_message_playmessage	Messaging
message_record	intent_message_recordmessage_extend	intent_message_recordmessage	Messaging
movement_backward	intent_imperative_backup		

movement_forward	intent_imperative_forward	
movement_turnaround	intent_imperative_turnaround	
movement_turnleft	intent_imperative_turnleft	
movement_turnright	intent_imperative_turnright	
names_ask	intent_names_ask	intent_names_ask
play_anygame	intent_play_anygame	
play_anytrick	intent_play_anytrick	
play_blackjack	intent_play_blackjack	
play_fistbump	intent_play_fistbump	
play_pickupcube	intent_play_pickupcube	
play_popawheelie	intent_play_popawheelie	
play_rollcube	intent_play_rollcube	
play_specific	intent_play_specific_extend	intent_play_specific
seasonal_happyholidays	intent_seasonal_happyholidays	
seasonal_happynewyear	intent_seasonal_happynewyear	
set_timer	intent_clock_settimer_extend	intent_clock_settimer
show_clock	intent_clock_time	
silence	intent_system_noaudio	
status_feeling	intent_status_feeling	
system_charger	intent_system_charger	intent_system_charger
system_sleep	intent_system_sleep	intent_system_sleep
take_a_photo	intent_photo_take_extend	
unmatched_intent		
weather_response	intent_weather_extend	

APPENDIX K

Emotion Events

The following is the set of emotion names used by Vector's mood manager. Some are from external events. Many whether or not a behavior or action succeeded, or failed (failed with retry, failed with abort).

Table 641: *The emotion event names*

	Emotion Name	Description and notes
Ambient light	ReactToDark	
Charger	DriveOffCharger	Vector was able to drive off of the charger.
	MountChargerSuccess	Vector was able to drive onto of the charger successfully.
	PlacedOnCharger	Vector was place on the charger.
Cube	CubeSpinner	
	KeepawayPounce	
	KeepawayStarted	
	PickingOrPlacingActionFailedWithAbort	Vector was unable to pick up his cube or to place it successfully, and the action was aborted.
	PickingOrPlacingActionFailedWithRetry	Vector was unable to pick up his cube or to place it successfully, even with retries.
	PickupSucceeded	Vector picked up his cube successfully.
	RollSucceeded	Vector rolled his cube successfully.
Driving	CliffReact	Vector encountered a cliff and reacted.
	DrivingActionFailedWithAbort	Vector was unable to drive to his target successfully, and the action was aborted.
	DrivingActionFailedWithRetry	Vector was unable to drive to his target successfully, even with retries.
	DrivingActionSucceeded	Vector was able to drive to his target successfully.
	ExploringExamineObstacle	Vector found an obstacle (possibly a marked object) to look at while exploring.
	FoundObservedObject	Vector found an object he knows about.
	ReactToObstacle	Vector is reacting to the obstacle he encountered while driving,
Faces	DrivingToFace	Vector is driving to a face.
	DriveToFaceSuccess	Vector was able to drive to a face successfully.
	EnrolledNewFace	Vector associated a new face with a name.
	EyeContactReaction	Vector detected the gaze of someone looking at him.
	GreetingSayName	Vector said the name of someone he recognized.
	InteractWithFaceRetry	

	InteractWithNamedFace	Vector is looking at the face of someone he knows.
	InteractWithUnnamedFace	Vector is looking at the face of someone he doesn't know.
	LookAtFaceVerified	
Intents	BeQuietVoiceCommand	Vector was told to be quiet.
	FistBumpLeftHanging	Vector attempted a fist bump, but no one gave him one.
	FistBumpSuccess	Vector received a fist bump.
	NoValidVoiceIntent	The wake word was sent, but an intent was either unable to be identified, or the returned intent is not recognized.
	OnboardingStarted	Vector has started the process of on boarding his human companion.
	ReactToTriggerWord	The wake word was said, and Vector has reacted to it.
	RespondToGoodNight	Vector responded to a verbal goodnight (represented as an intent)
	RespondToShortVoiceCommand	Vector responded to an intent that didn't trigger a more complex behavior interaction.
Motion sensing	ReactToMotion	
	ReactToPickedUp	Vector has been picked up and has reacted to it.
	ReactToUnexpectedMovement	
	RobotShaken	Vector was shaken.
Power State	Asleep	Vector is asleep
	Sleeping	Vector is sleeping
Petting	PettingBlissLevelIncrease	Vector is being petted.
	PettingReachedMaxBliss	Vector is being petted.
	PettingStarted	Vector is being petted.
Sound	DanceToTheBeat	Vector is dancing to music that he hears (he may be the only one to hear it)
	ReactToSoundAsleep	Vector heard some noise while asleep or sleeping.
	ReactToSoundAwake	Vector heard some noise (but wasn't asleep)
Timer	TimerRinging	Vector's timer has expired and is ringing.

APPENDIX L

DAS Tracked Events and Statistics

This Appendix captures the events and statistics that are posted to Anki's the diagnostics / analytics services (see Chapter 33)

157. DAS TRACKED EVENTS AND STATISTICS

157.1. BASIC INFORMATION

157.1.1 Version Information

The following are version-information related events that are posted to the diagnostic logger:

Table 642: Version info, posted to DAS

Event	Description & Notes
hal.body_version	
robot.boot_info	
robot.cpu_info	
robot.disk_info	
robot.memory_info	

157.1.2 Crashes, Faults and other error information

The following are crash, fault and other error related entries:

Table 643: Crash, fault and error related DAS events

Event	Description & Notes
dasmgr.upload.failed	The DAS manager was unable to contact or successfully upload the DAS events.
log.error	There was an error with the logging system, including errors with DAS manager uploads.
robot.crash	The robot software crashed
robot.fault_code	The robot fault code explaining which processes exited or task failed; the same as the one displayed.
robot.imu_failure	There was a problem communicating with or calibrating the IMU
vectorbot.main_cycle_too_late	
vectorbot.main_cycle_too_long	

Note: see the IMU section for events related to IMU

157.1.3 Start-up Information not described elsewhere

The following are start-up events that are posted to the diagnostic logger:

Event	Description & Notes
das.allow_upload	
ntp.timesync	
profile_id.start	
profile_id.stop	
rampost.lcd_check	
random_generator.seed	The random number generator was initialized.
robot.engine_ready	
robot.init.time_spent_ms	
robot.maintenance_reboot	Whether or not a maintenance reboot was able to be performed and, if not, why; or indicates that it is proceeding.
switchboard.hello	
vic.cloud.hello.world	

Table 644: *Start up information, posted to DAS*

Note: other startup events are covered elsewhere with their functional groups.

157.2. POWER MANAGEMENT EVENTS AND STATISTICS

The power management posts the following set of related events:

Event	Description & Notes
behavior.sleeping.falling_asleep	
behavior.sleeping.wake_up	
engine.power_save.end	
engine.power_save.start	
hal.active_power_mode	
robot.power_off	
robot.power_on	
vectorbot.prep_for_shutdown	

Table 645: *Power management events, posted to DAS*

157.2.1 Battery Statistics and Events

The battery management posts the following battery related events and state information:

Event	Description & Notes
battery.battery_level_changed	This is set when the battery level has changed from the previous event posting.
battery.encoder_power_stats	Information about when the motor encoders were turned on and off.
battery.fully_charged_voltage	The battery voltage seen when the charger reported the battery to be fully charged.
battery.periodic_log	
battery.voltage_reset	
battery.voltage_stats	Information about the range of battery voltages that have been observed; e.g. min/max, average, etc.
rampost.battery_flags	
rampost.battery_level	

Table 646: *Battery level events and statistics*

157.2.2 Charger Statistics and Events

The charging function of the battery management system posts the following events and state information:

Event	Description & Notes
battery.is_charging_changed	This is set when the state of charging has changed from event posting.
battery.on_charger_changed	
battery.saturation_charging	
robot.off_charger	
robot.on_charger	

Table 647: *Charger statistics and events, posted to DAS*

Event	Description & Notes
battery.cooldown	Indicates that Vector is or needed to pause charging and activity to let the battery cool down.
battery.temp_crossed_threshold	The battery – or body-board – got too hot.
battery.temperature_stats	Information about the range of battery temperatures that have been observed; e.g. min/max, average, etc.
cpu.temperature_stats	
rampost.battery_temperature	

Table 648: *Thermal management statistics and events, posted to DAS*

157.3. SENSOR STATISTICS AND EVENTS

157.3.1 IMU Events

The IMU and navigation subsystem posts the following events and statistics:

Event	Description & Notes
gyro.bias_detected	
gyro.drift_detected	
imu_filter.fall_impact_event	
imu_filter.falling_event	
imu_filter.gyro_calibrated	

***Table 649:** IMU, navigation events*

157.3.2 Microphone & Sound Events

The system posts the following events and state information related to Vector's microphones:

Event	Description & Notes
behavior.trigger_word.dropped	
behavior.voice_command.dropped	
mic_data_system.speech_trigger_recognized	
robot.microphone_on	
robot.reacted_to_sound	
robot. stuck_mic_bit	
wakeword.triggered	
wakeword.vad	

***Table 650:** Microphone statistics and events, posted to DAS*

157.3.3 Proximity Sensor Statistics and Events

The system posts the following events and state information related to Vector's proximity sensors:

Event	Description & Notes
hal.invalid_prox_reading_report	
hal.severe_invalid_prox_reading_report	
robot.cliff_detected	
robot.bad_prox_data	

***Table 651:** Proximity sensor statistics and events, posted to DAS*

157.3.4 Touch Sensor Statistics and Events

The system posts the following touch-related events and state information:

Event	Description & Notes
touch_sensor.activate_charger_mode_check	

***Table 652:** Touch sensor statistics and events, posted to DAS*

touch_sensor.baseline_fast_calibration_finished	
touch_sensor.baseline_reading_difference_monitor_too_low	
touch_sensor.charger_mode_check.baseline_changed	
touch_sensor.charger_mode_check.no_baseline_change	

157.4. MOTOR STATISTICS AND EVENTS

The motor controllers post the following events and statistics:

Event	Description & Notes
calibrate_motors	
head_motor_calibrated	
head_motor_uncalibrated	
lift_motor_calibrated	
lift_motor_uncalibrated	

***Table 653:** Motor events*

157.5. COMMUNICATION RELATED EVENTS POSTED TO DAS

157.5.1 Body-Board / Spine Related Events Posted to DAS

The communication with the body-board controller posts the following events:

Event	Description & Notes
rampost.dfu.desired_version	
rampost.dfu.open_file	
rampost.dfu.installed_version	
rampost.dfu.request_version	
rampost.rampost.exit	The rampost has completed and exited.
rampost.spine.configure_serial_port	The rampost program was successful in configuring the serial port to communicate with the body-board.
rampost.spine.open_serial	The rampost was able to open the serial port to communicate with the body-board.
rampost.spine.select_timeout	There was a timeout in communicating with rampost the body-board.

***Table 654:** Body-board / spine related DAS events*

Note: see the updates section for events related to updating the body-board firmware

157.5.2 Bluetooth LE / WiFi Related Events Posted to DAS

The wireless communication posts the following events:

Table 655: Bluetooth LE, WiFi related DAS events

Event	Description & Notes
ble.connection	
ble_conn_id.start	
ble_conn_id.stop	
ble.disconnection	
dasmgr.upload.stats	
dasmgr.upload.failed	
robot.cloud_response_failed	
robot.wifi_info	
robot.sdk_wrong_version	
wifi_conn_id.start	
wifi_conn_id.stop	
wifi.connection	
wifi.disconnection	
wifi.initial_state	

157.5.3 Accessory-Related Events Posted to DAS

The communication with the mobile application and SDK posts the following events:

Table 656: Accessory cube related DAS events

Event	Description & Notes
cube.battery_voltage	The cube's battery voltage
cube.connected	Vector was able to connect to his accessory companion cube.
cube.connection_failed	Vector was unable to connect to his accessory companion cube.
cube_connection_coordinator.connection_requested	
cube_connection_coordinator.disconnect_requested	
cube_connection_coordinator.unexpected_disconnect	
cube.disconnected	Vector lost the connection with his accessory companion cube.
cube.firmware_mismatch	Vector is unable to use his accessory companion cube as is, since the firmware version is not compatible.
cube.low_battery	
cube.scan_result	
cube.unexpected_connect_disconnect	

Note: see the updates section for events related to updating the cube firmware

157.6. SETTINGS AND PREFERENCES EVENTS

The following are settings and preference related events that are posted to the diagnostic logger:

Table 657: Settings and preferences events posted to DAS

Event	Description & Notes
das.allow_upload	Whether or not the account owner – Vector's human – has opted in (true) or opted out (false) of data gathering, allowing the DAS events to be uploaded to the servers.
dasmgr.upload.stats	
engine.language_locale	The IETF language tag of the human companion's language preference – American English, UK English, Australian English, German, French, Japanese, etc. default: "en-US"
robot.cleared_user_data	
robot.locale	The IETF language tag of the human companion's language preference – American English, UK English, Australian English, German, French, Japanese, etc. default: "en-US"
robot.settings.passed_to_cloud_jdoc	
robot.settings.updated	
robot.settings.volume	
robot.timezone	The "tz database name" for time zone to use for the time and alarms. default: "America/Los_Angeles"
sdk.activate	

157.7. UPDATE-RELATED EVENTS POSTED TO DAS

The following are events are posted by the update subsystem:

Table 658: Update events

Event	Description & Notes
cube.firmware_flash_success	True if the cube's firmware was successfully updated.
rampost.dfu.desired_version	The version of firmware desired for the body-board.
rampost.dfu.installed_version	The version of firmware presently on the body-board.
rampost.dfu.open_file	Opening the body-board firmware update file.
rampost.dfu.request_version	
robot.ota_download_end	On success the parameters include the new version; on failure the parameters include the version identifier, error code, and some explanatory text.
robot.ota_download_stalled	The OTA update engine download process has gotten stuck.
robot.ota_download_start	The OTA update engine has started the process of downloading an OTA file.

157.8. VISION & NAVIGATION RELATED EVENTS POSTED TO DAS

The vision, mapping, and navigation subsystem posts the following events and statistics:

Table 659: Vision, mapping, navigation events

Event	Description & Notes
robot.docking.status	
robot.delocalized	
robot.delocalized_map_info	
robot.dock_action_completed	
robot.fallback_planner_used	
robot_impl_messaging.handle_robot_stopped	
robot.object_located	
robot.obstacle_detected	
robot.offtreadsstatechanged	
robot.plan_complete	
robot.planner_selected	
robot.too_long_in_air	
robot.vision.image_quality	
robot.vision.profiler.	

Events related to the charger posts the following events and statistics:

Table 660: *Home & charger events*

Event	Description & Notes
find_home.result	
behavior.find_home.invalid_turn_angle	
go_home.charger_not_visible	
go_home.result	
robust_observe_charger.stats	

The face recognition subsystem posts the following events and statistics:

Table 661: *Face recognition events*

Event	Description & Notes
behavior.findfaceduration	
robot.vision.detected_pet	
robot.vision.face_recognition.immediate_recognition	
robot.vision.face_recognition.persistent_session_only	
robot.vision.loaded_face_enrollment_entry	
robot.vision.remove_unobserved_session_only_face	
robot.vision.update_face_id	
turn_towards_face.might_say_name	
turn_towards_face.recognition_timeout	

157.9. BEHAVIOUR, FEATURE, MOOD, AND ENGINE RELATED EVENTS POSTED TO DAS

The engine/animation controller posts the following behavior-related events:

Table 662: Behaviour, feature, mood and engine related DAS events

Event	Description & Notes
action.play_animation	The specified animation will be played
AkAlsaSink	
behavior.cliffreaction	
behavior.cycle_detected	
behavior.exploring.end	
behavior.exploring.poke	
behavior.feature.end	A behavior has completed. (s1 has the name of the behavior that ended)
behavior.feature.pre_start	The behaviour for specified feature will begin.
behavior.feature.start	The behaviour for specified feature has begun.
behavior.hlai.change	There was a change in the high-level AI state. Some possible supplemental parameters include "ObservingOnCharger"
Behavior.PutDownReaction	
engine.state	
mood.event	
mood.simple_mood_transition	
robot.dizzy_reaction	

Table 663: Dance to the beat related DAS events

Event	Description & Notes
dttb.activated	The "dance to the beat" feature has been activated.
dttb.cancel_beat_lost	
dttb.coord_activated	The "dance to the beat" coordinator has been started and is trying to synchronize with the beat of the music.
dttb.coord_no_beat	
dttb.end	

APPENDIX M

Pleo

The Pleo, sold in 2007 – a decade prior to Vector – has many similarities. The Pleo was a soft-skinned animatronic baby dinosaur created by Caleb Chung, John Sosuka and their team at Ugobe. Ugobe went bankrupt in 2009, and the rights were bought by Innvo Labs which introduced a second generation in 2010. This appendix is mostly adapted from the Wikipedia article and reference manual.

Sensing for interacting with a person

- Two microphones, could do beat detection allowing Pleo to dance to music. The second generation (2010) could localize the sound and turn towards the source.
- 12 touch sensors (head, chin, shoulders, back, feet) to detect when petted,

Environmental sensors

- Camera-based vision system (for light detection and navigation). The first generation treated the image as gray-scale, the second generation could recognize colors and patterns.
- Four ground foot sensors to detect the ground. The second generation could prevent falling by detecting drop-offs
- Fourteen force-feedback sensors, one per joint
- Orientation tilt sensor for body position
- Infrared mouth sensor for object detection into mouth, in the first generation. The second generation could sense accessories with an RFID system.
- Infrared detection of objects
- Two-way infrared communication with other Pleos
- The second generation include a temperature sensor

Annuciators and Actuators

- 2 speakers, to give it sounds
- 14 motors
- Steel wires to move the neck and tail (these tended to break in the first generation)

The processing

- Atmel ARM7 microprocessor was the main processor.
- An NXP ARM7 processor handle the camera system, audio input
- Low-level motor control was handled by four 8-bit processors

A developers kit – originally intended to be released at the same time as the first Pleo – was released ~2010. The design included a virtual machine intended to allow "for user programming of new behaviors."[89]

157.10. SALES

Pleo's original MSRP was $350, "the wholesale cost of Pleo was $195, and the cost to manufacture each one was $140" sold ~100,000 units, ~$20 million in sales[90]

The second generation (Pleo Reborn) had an MSRP of $469

157.11. RESOURCES

Wikipedia article. https://en.wikipedia.org/wiki/Pleo

iFixit's teardown. https://www.ifixit.com/Teardown/Pleo+Teardown/597

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