CC-Log: Drastically Reducing Storage Requirements for Robots Using Classification and Compression

Santiago Gonzalez, Vijay Chidambaram,
Jivko Sinapov, and Peter Stone

University of Texas at Austin

TEXAS
The University of Texas at Austin

The Problem

- Robots have a growing number of increasingly sophisticated sensors
- Roboticists want to leverage this data to gain insights into system behavior
- High sampling rates and limited storage
- Storing everything is infeasible
  - Have to let something go

Can we build a system to log only the data we need?

Can we build a system to log only the data we need?

+ figure out what data we need?

CC-Log

A modular, event-centric logging solution for ROS.

- Uses ML to decide whether saving data is required
- Greatly reduced logging storage requirements
- Lossless; fine grained sampling for logged events
- Fits into ROS’s modular architecture

Outline

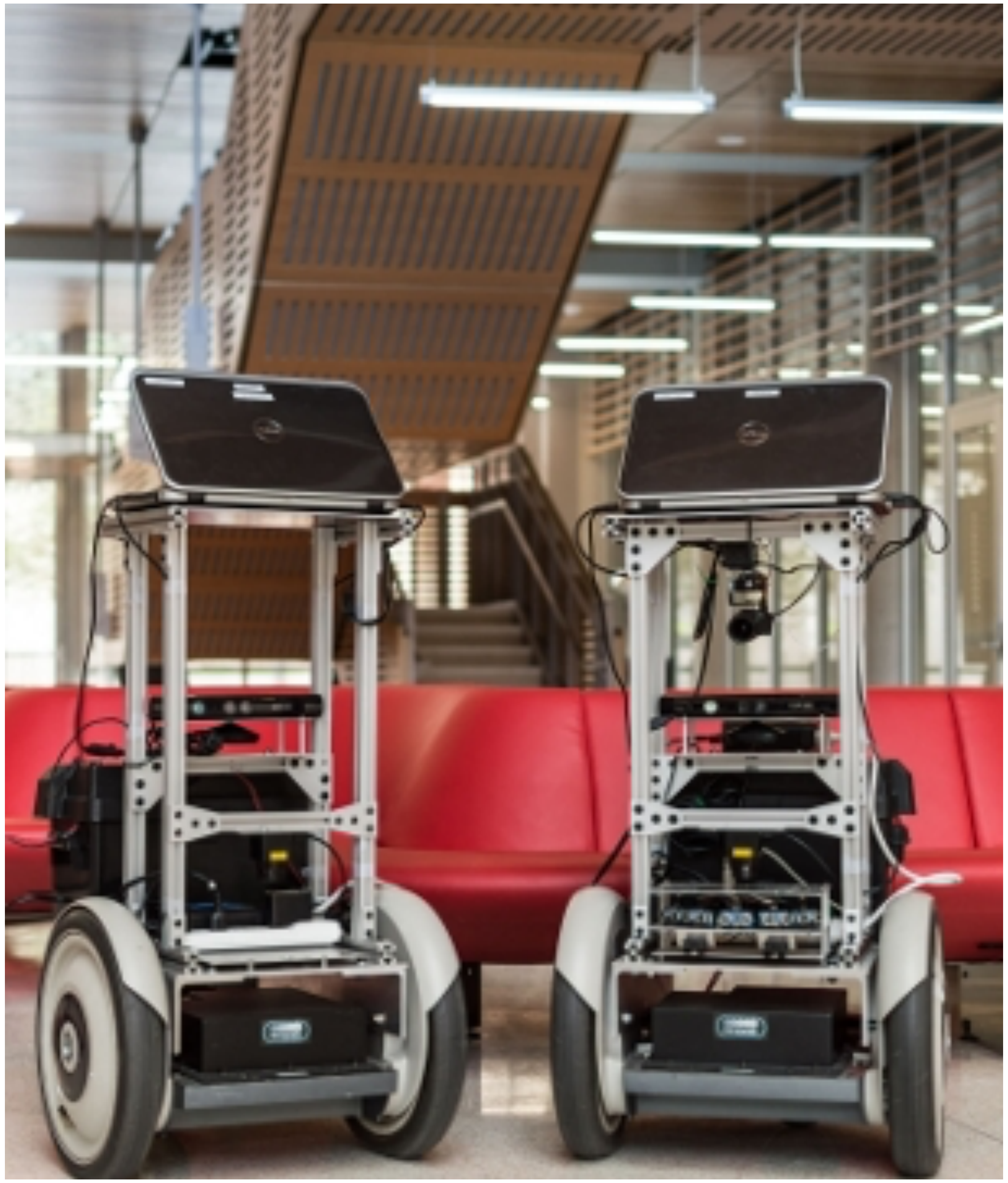
- Background
- The CC-Log system
- Evaluation
- Systems challenges in robotics
- Concluding remarks

Outline

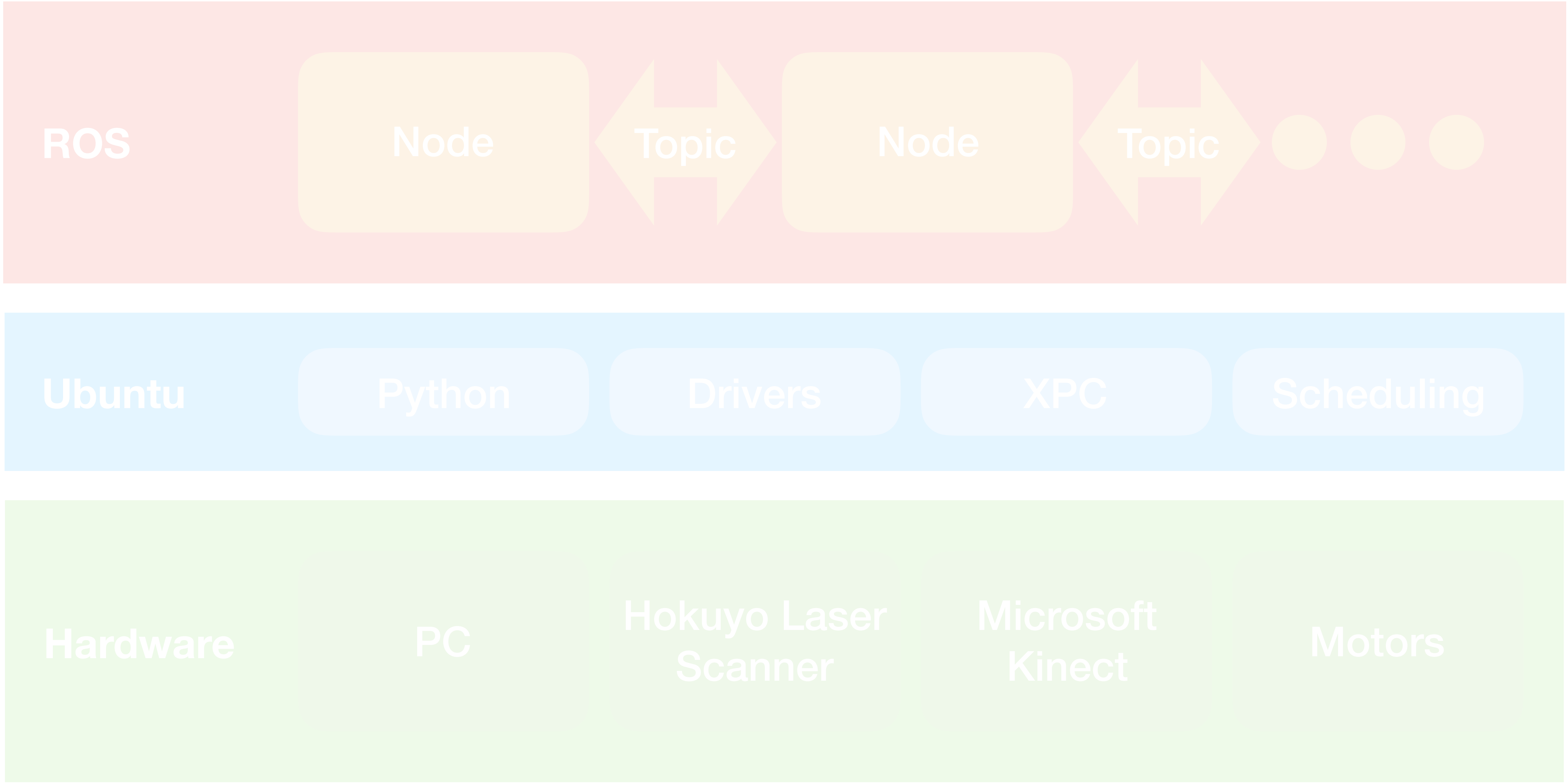
- Background
- The CC-Log system
- Evaluation
- Systems challenges in robotics
- Concluding remarks

BWIBot

- Building-Wide Intelligence
- Autonomous, mobile robots
- Roam for hours on a single charge
- Controlled by a PC running ROS (Robot Operating System)



Robot Operating System (ROS)

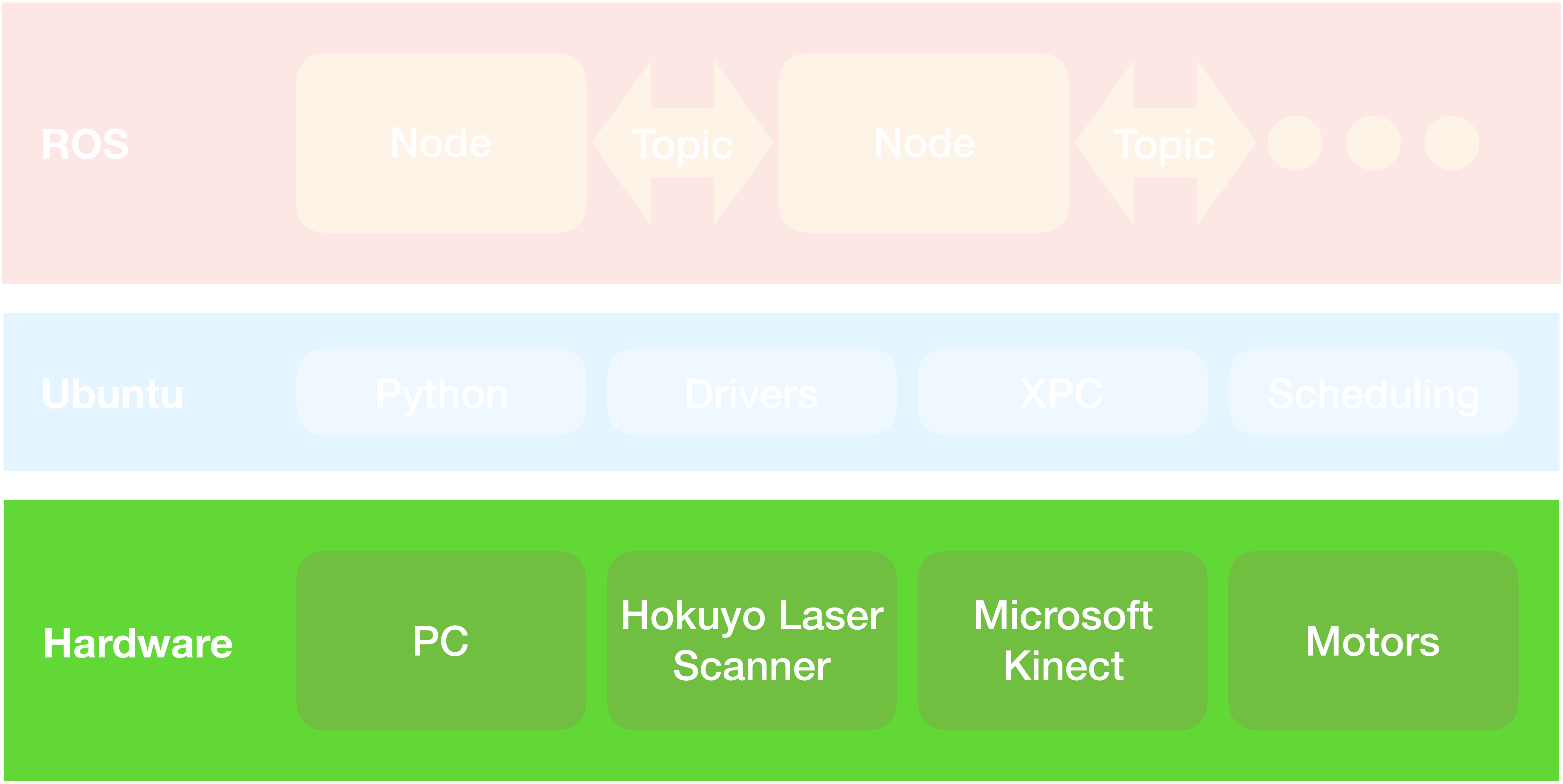


ROS
Node
Topic
Node
Topic

Ubuntu
Python
Drivers
XPC
Scheduling

Hardware
PC
Hokuyo Laser Scanner
Microsoft Kinect
Motors

Robot Operating System (ROS)



ROS

Node

Topic

Node

Topic

Ubuntu

Python

Drivers

XPC

Scheduling

Hardware

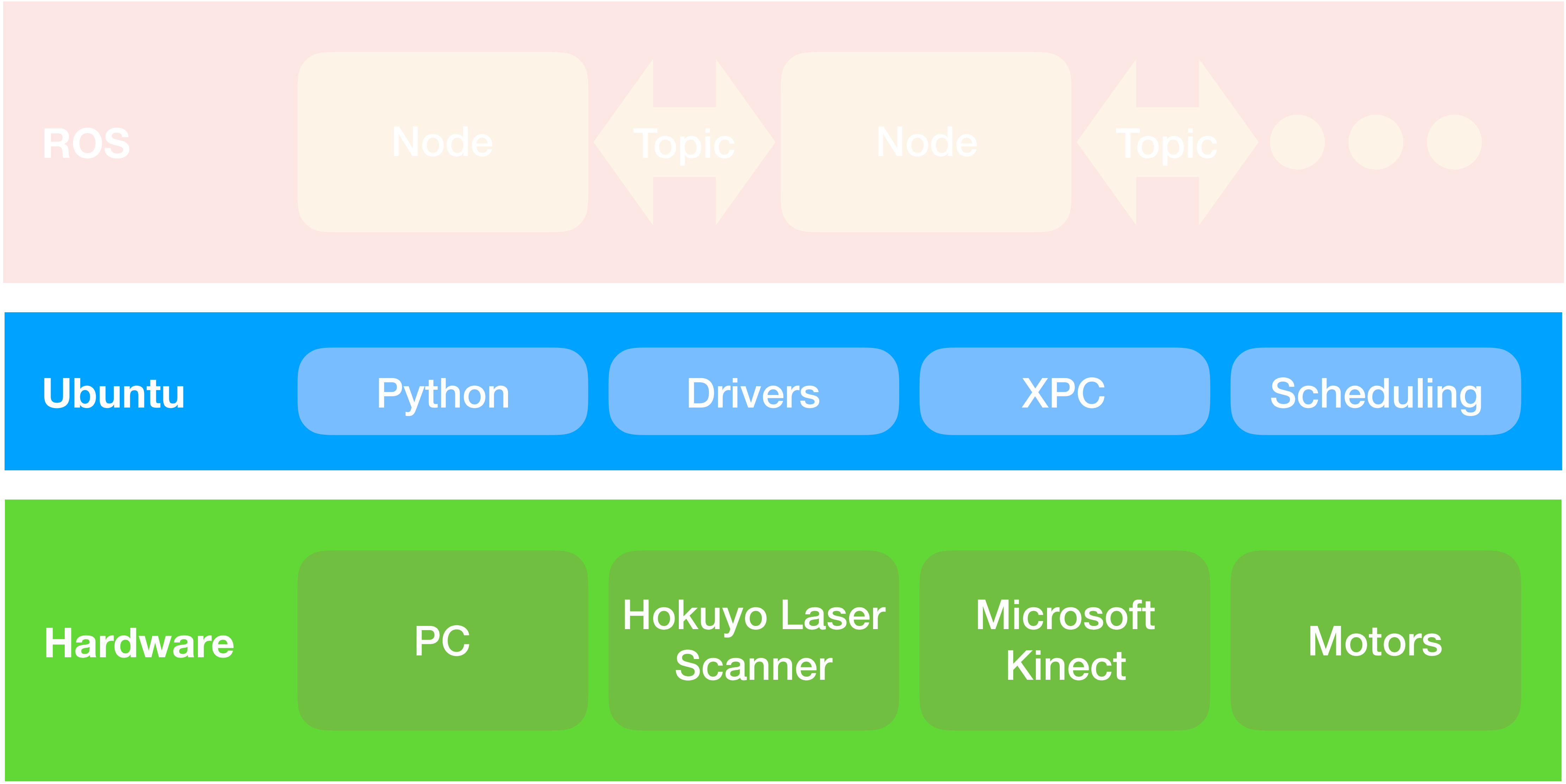
PC

Hokuyo Laser Scanner

Microsoft Kinect

Motors

Robot Operating System (ROS)



ROS

Node

Topic

Node

Topic

Ubuntu

Python

Drivers

XPC

Scheduling

Hardware

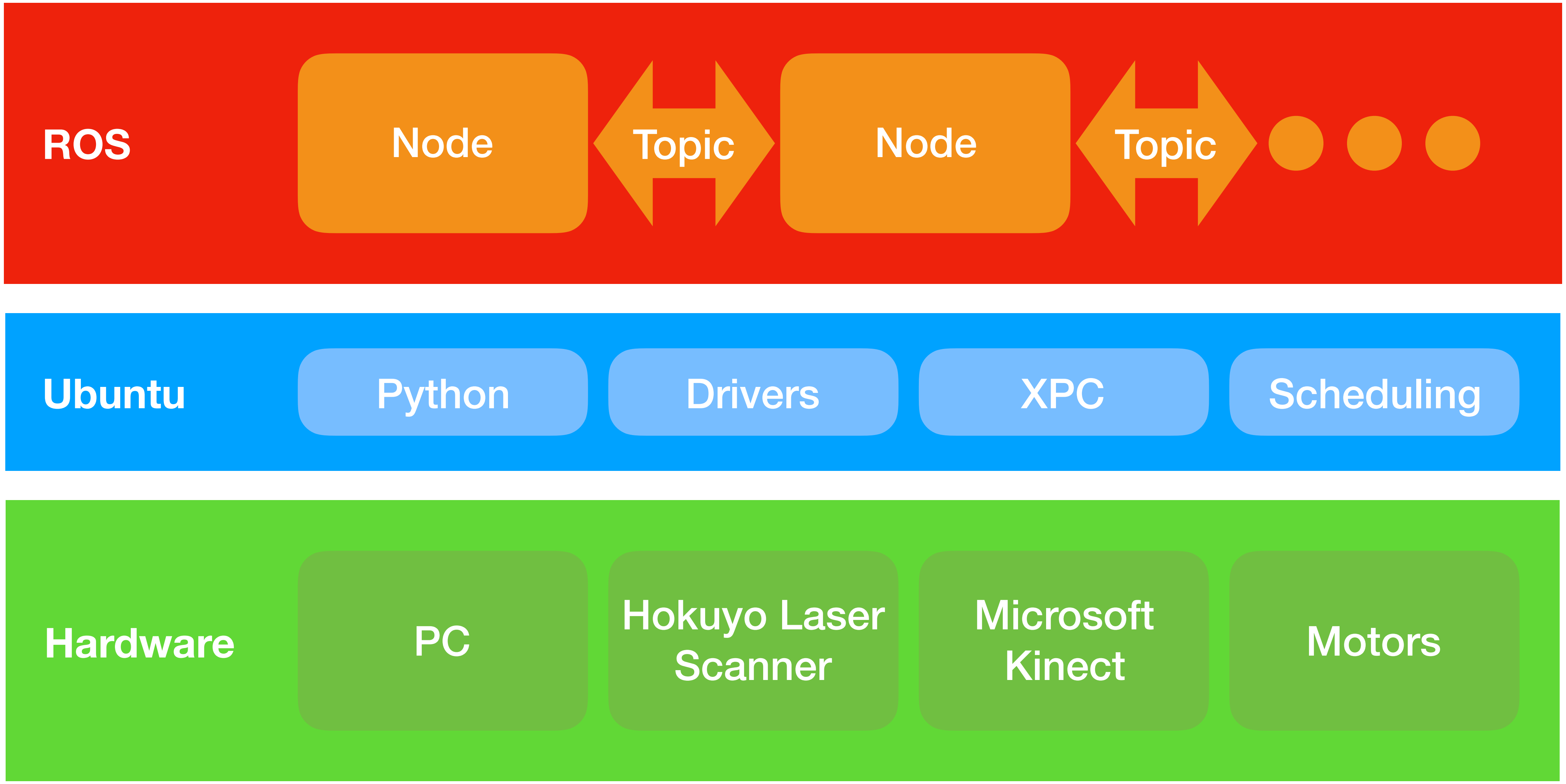
PC

Hokuyo Laser Scanner

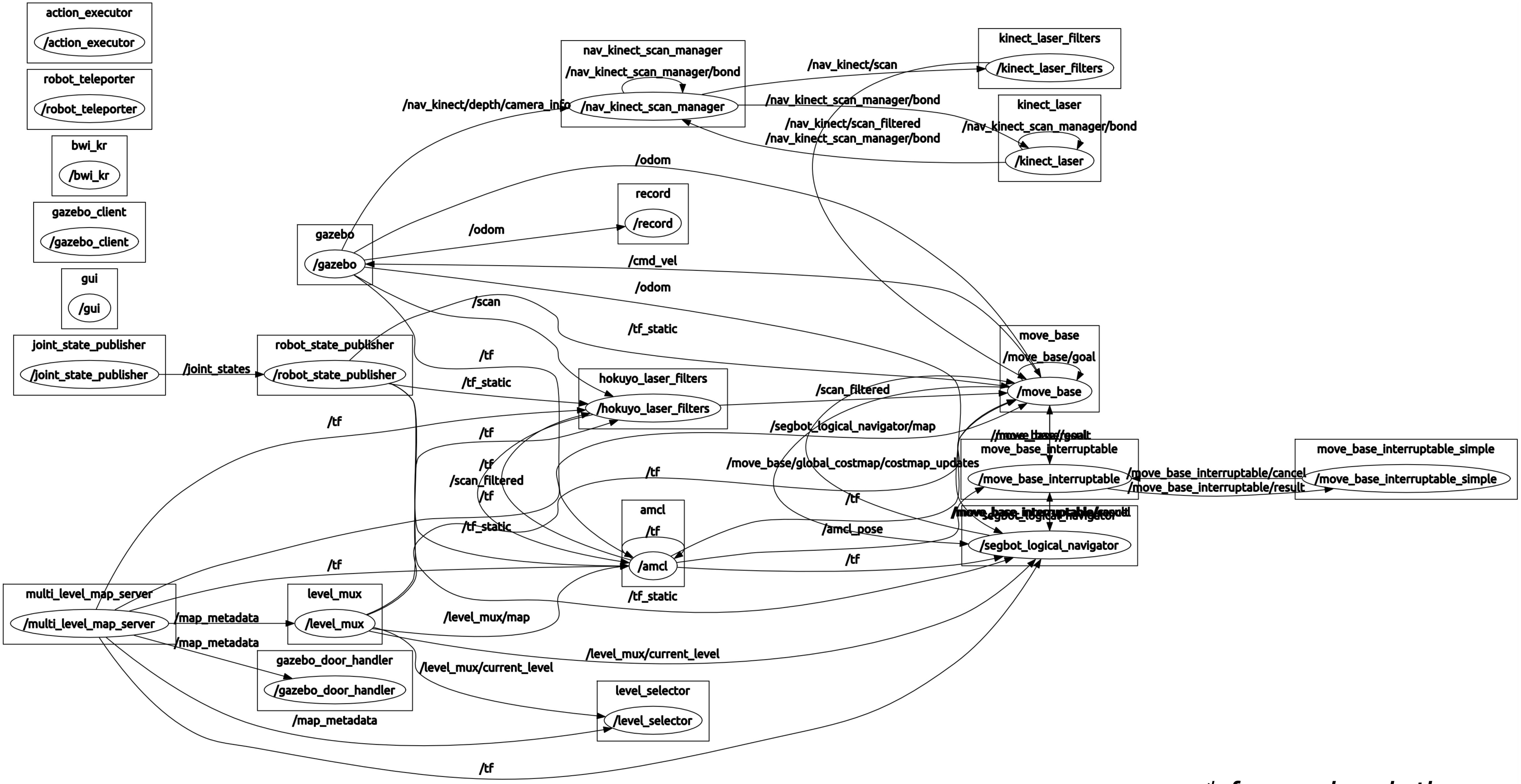
Microsoft Kinect

Motors

Robot Operating System (ROS)



Nodes, topics, and messages?



** from simulation*

What does data look like?

ROS /odom topic

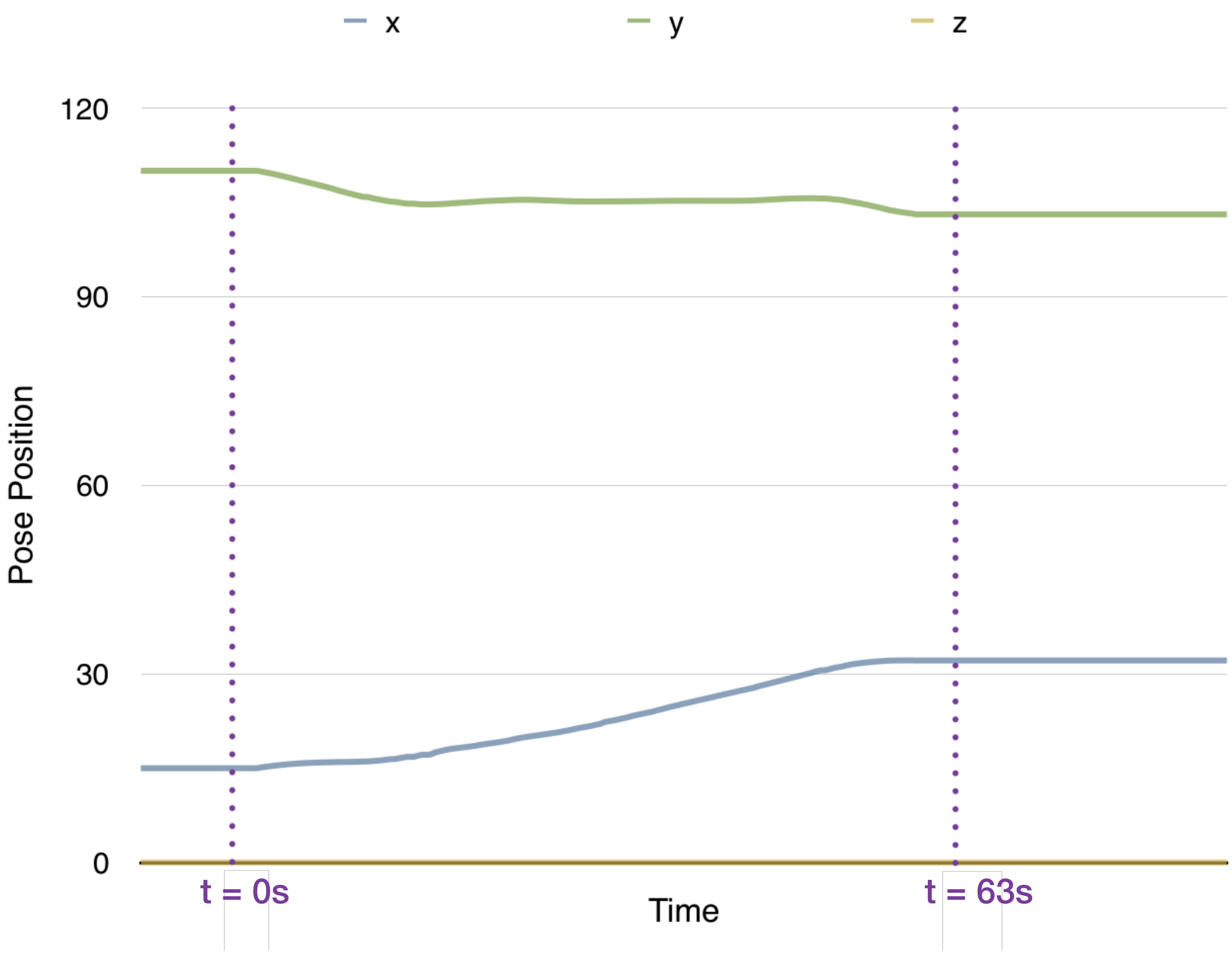
```
header:
  seq: 5229
  stamp:
    secs: 57
    nsecs: 530000000
  frame_id: odom
child_frame_id: base_footprint
pose:
  pose:
    position:
      x: 14.9999999995
      y: 110.0
      z: 0.0
    orientation:
      x: -3.50379416134e-07
      y: -2.89561146542e-05
      z: 7.86406532897e-09
      w: 0.999999999581
  covariance: [1e-05, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1e-05, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
1000000000000.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1000000000000.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
1000000000000.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.001]
twist:
  twist:
    linear:
      x: -3.55271378053e-12
      y: -6.45947936005e-12
      z: 0.0
    angular:
      x: 0.0
      y: 0.0
      z: 1.08357767203e-10
  covariance: [0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0]
```

What does data look like?

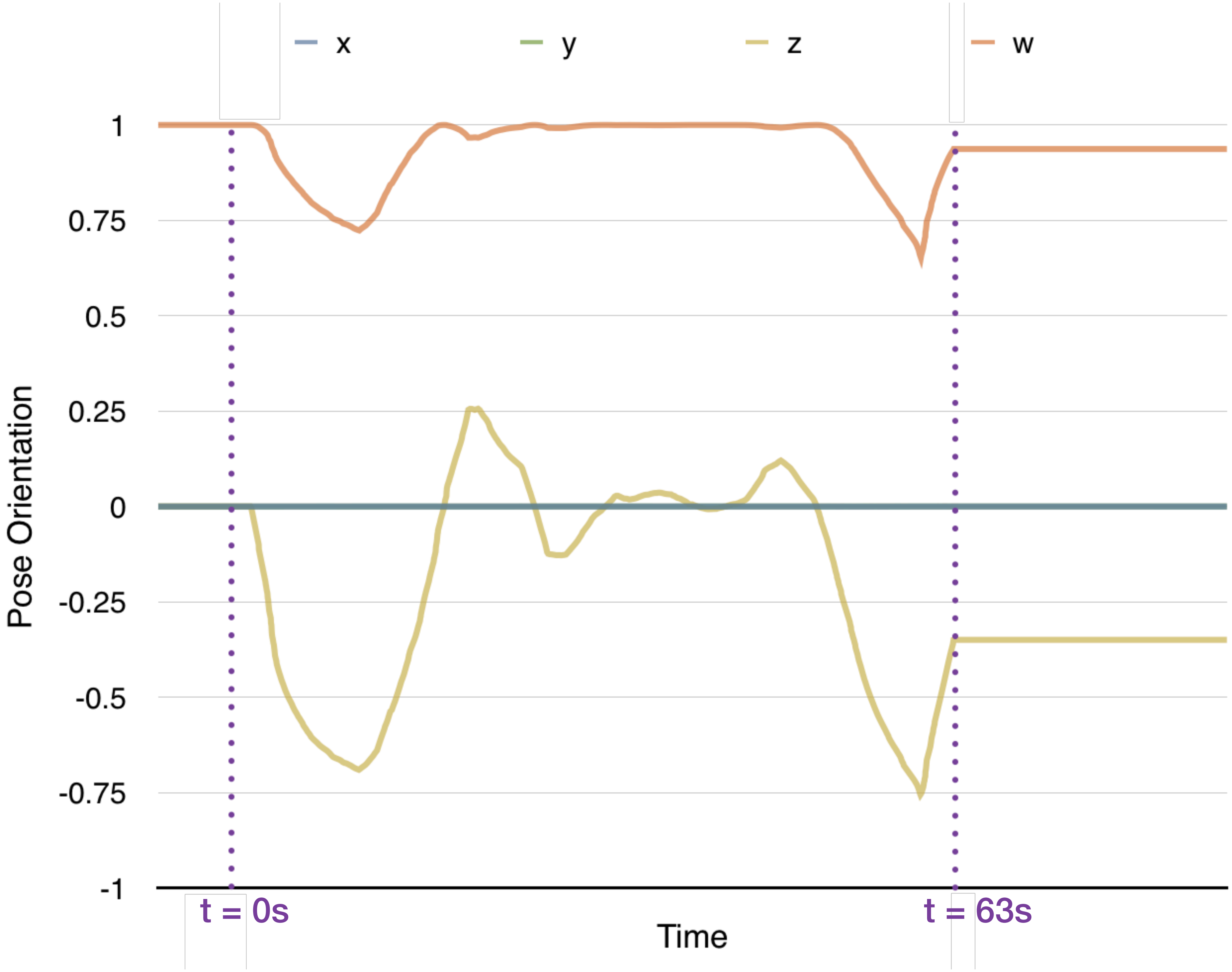
ROS /odom topic

{"twist": {"twist": {"linear": {"y": -5.167583477804464e-12, "x":
-3.5527137587950676e-12, "z": 0.0}, "angular": {"y": 0.0, "x": 0.0, "z":
1.114260199260157e-10}}, "covariance": [0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0]},
"header": {"secs": 55, "nsecs": 84000000, "seq": 5007}, "pose":
{"pose": {"position": {"y": 109.99999999973956, "x":
14.999999999504467, "z": 0.0}, "orientation": {"y":
-2.8818053449111213e-05, "x": -3.4870814337234784e-07, "z":
7.729987484413655e-09, "w": 0.99999999995846992}}, "covariance":
[1e-05, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1e-05, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
1000000000000.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 1000000000000.0, 0.0,
0.0, 0.0, 0.0, 0.0, 0.0, 1000000000000.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
0.001]}}

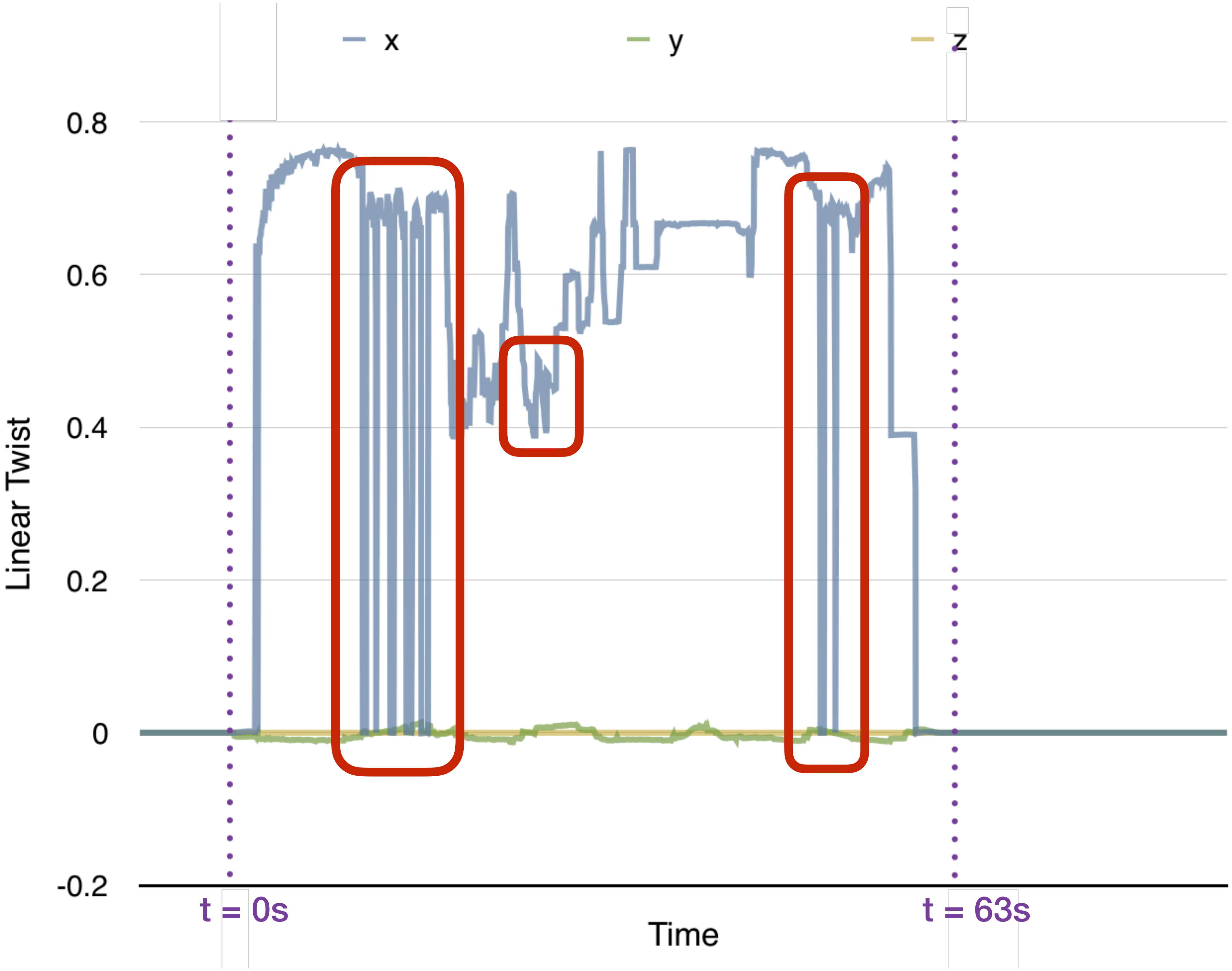
Position Over Time



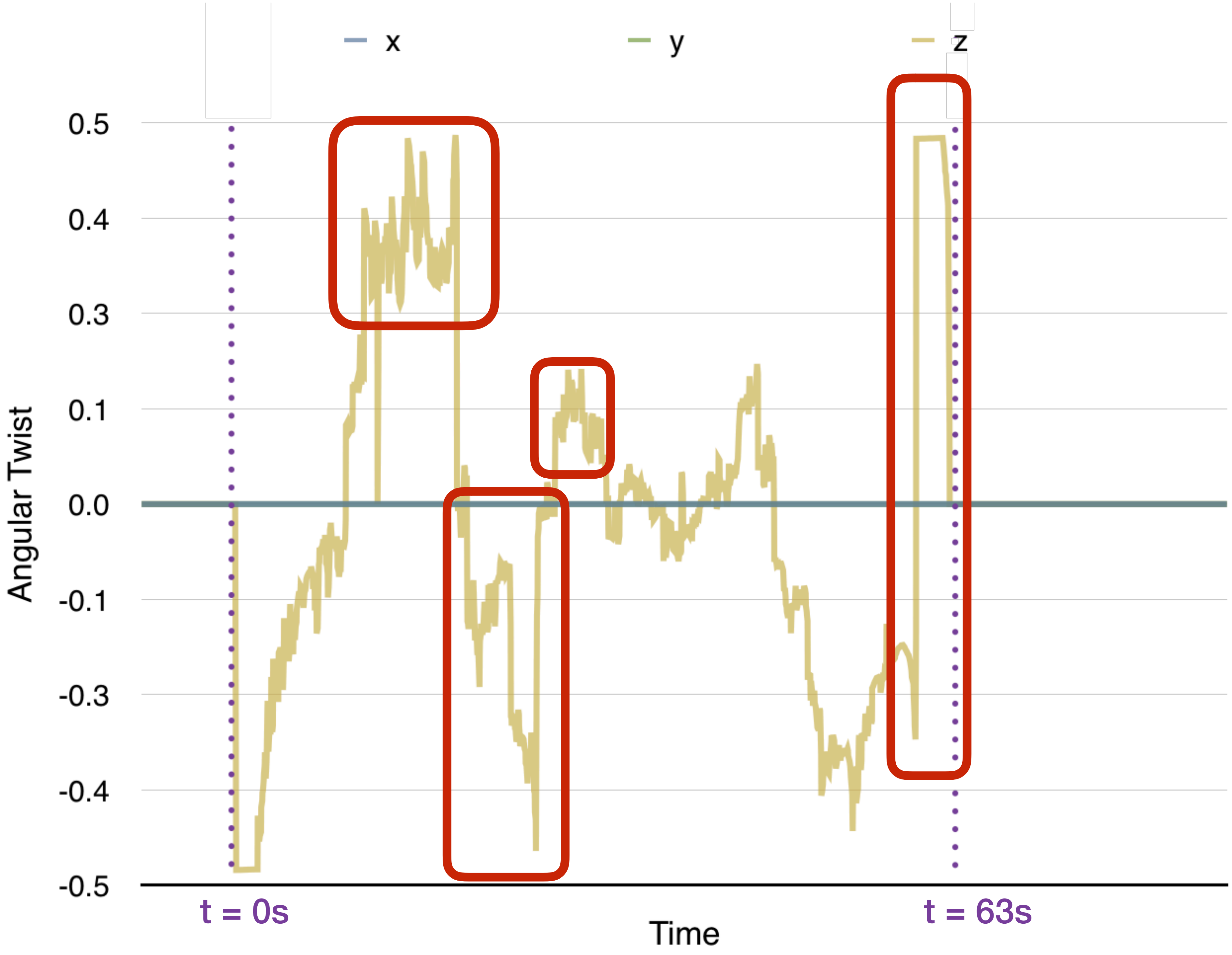
Orientation Over Time



Linear Twist Over Time



Angular Twist Over Time



Outline

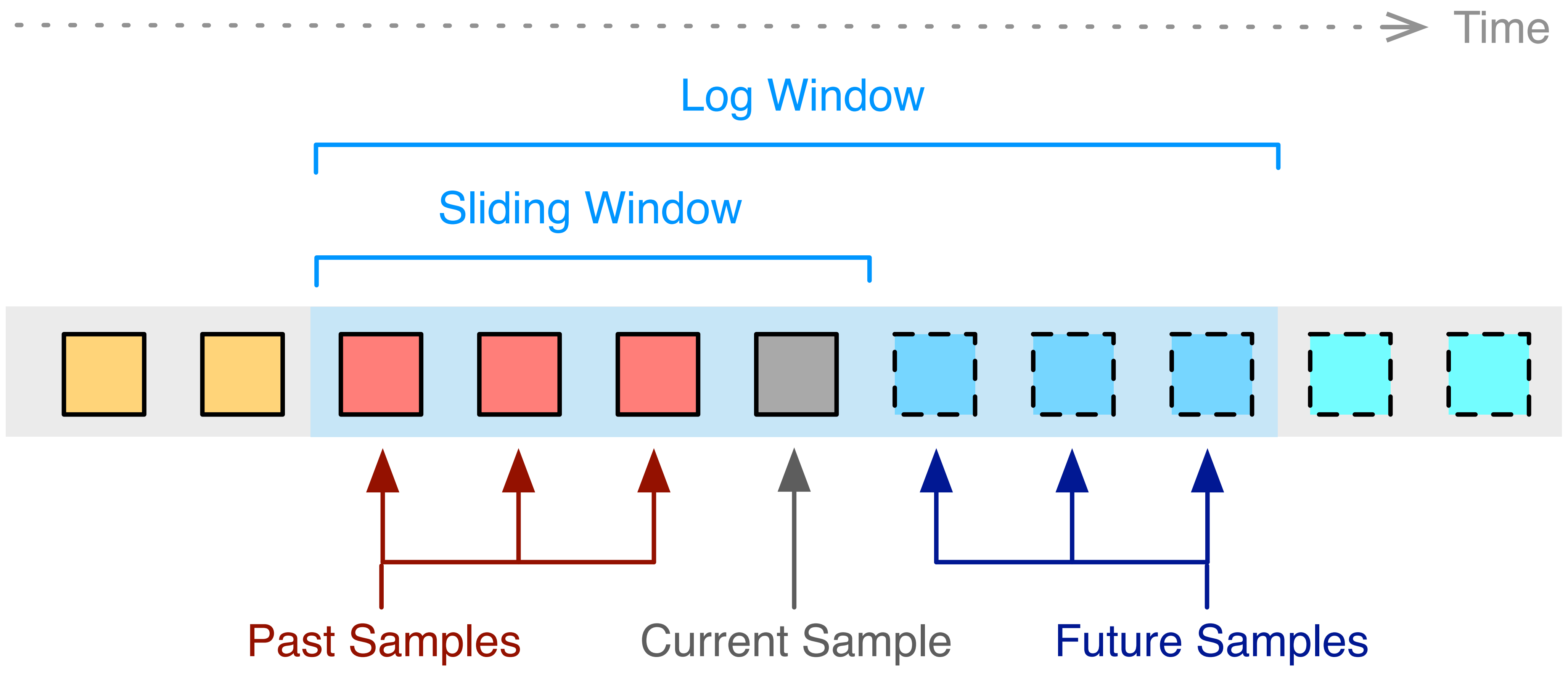
- Background
- The CC-Log system
- Evaluation
- Systems challenges in robotics
- Concluding remarks

CC-Log

Classification and Compression

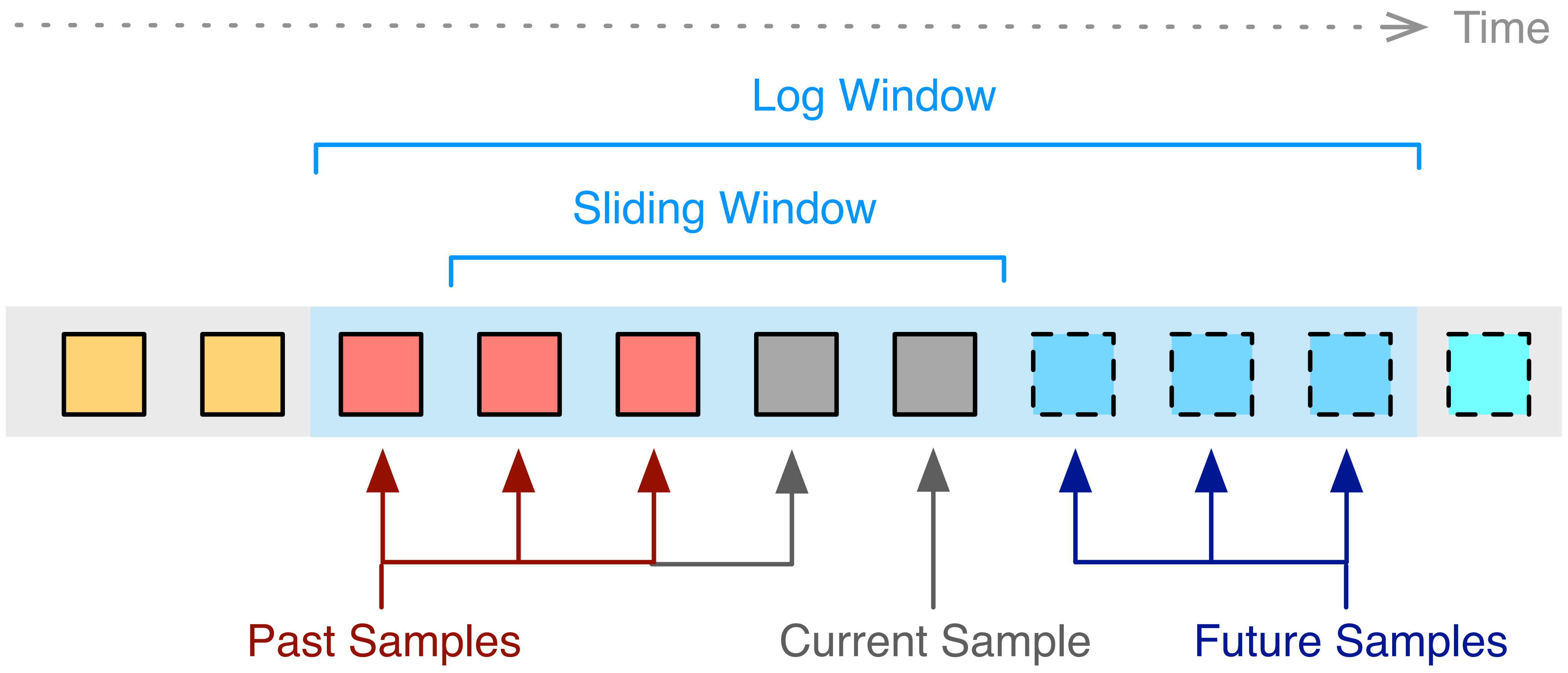
- Use a machine learning classifier to determine whether the system is currently in an anomalous state
- Anomalies trigger logging of a window of data extending into the past and into the future
- Saved data is compressed to achieve further space savings

Window Sampling



- **Log Window** provides **flexible** set of samples to log
- **Sliding Window** provides **fixed** set of samples for analysis

Window Sampling



- Log Window can grow as samples are deemed anomalous using history in Sliding Window

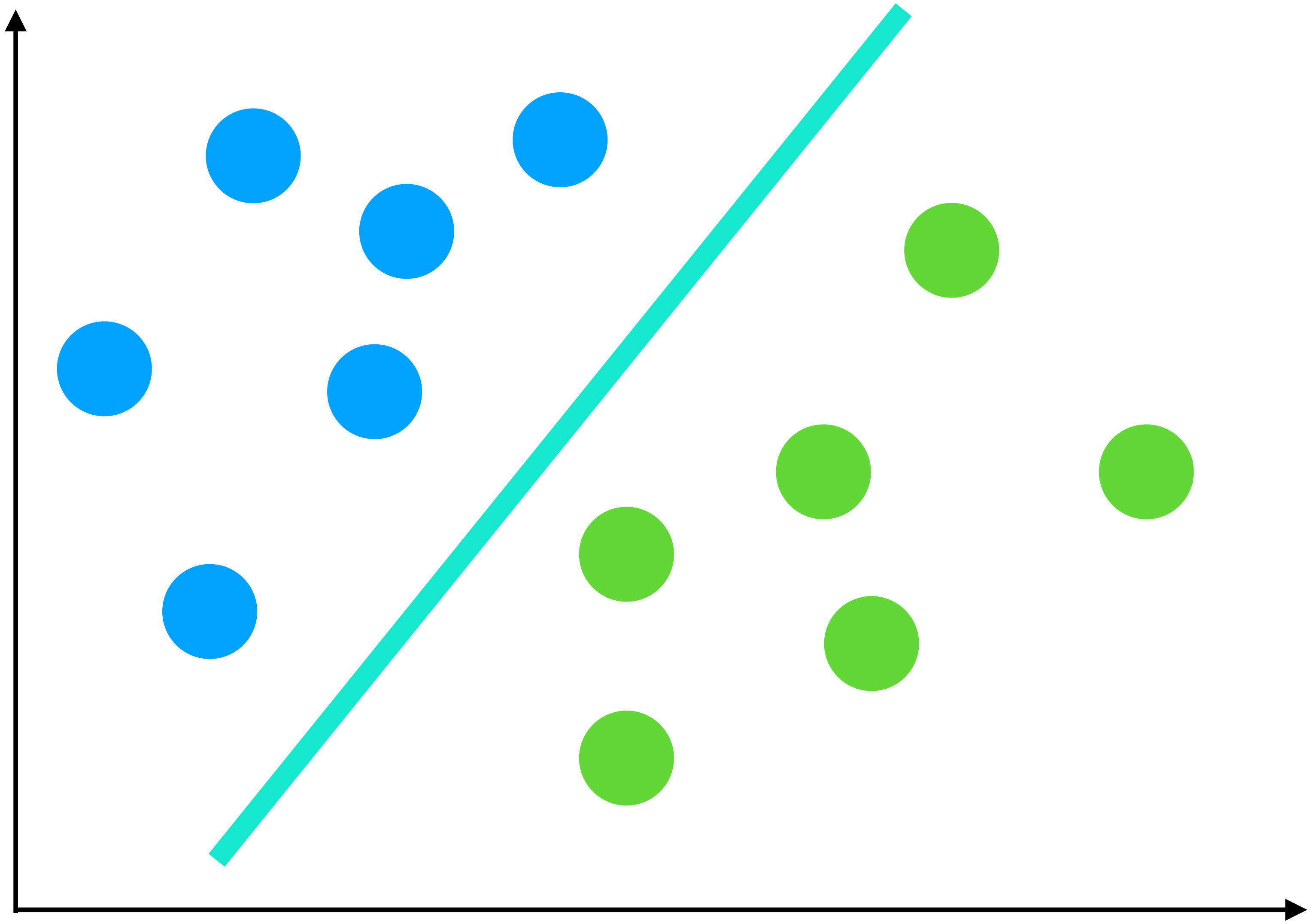
- How do we know if a sample is anomalous?

Anomaly Classifier

- Want to determine if a datapoint is an outlier along a set of dimensions
    - 100s to 1,000s of dimensions
- Anomaly detection has been used to great effect in numerous areas (e.g., structural integrity monitoring)
- CC-Log uses a **1-class RBF-SVM**

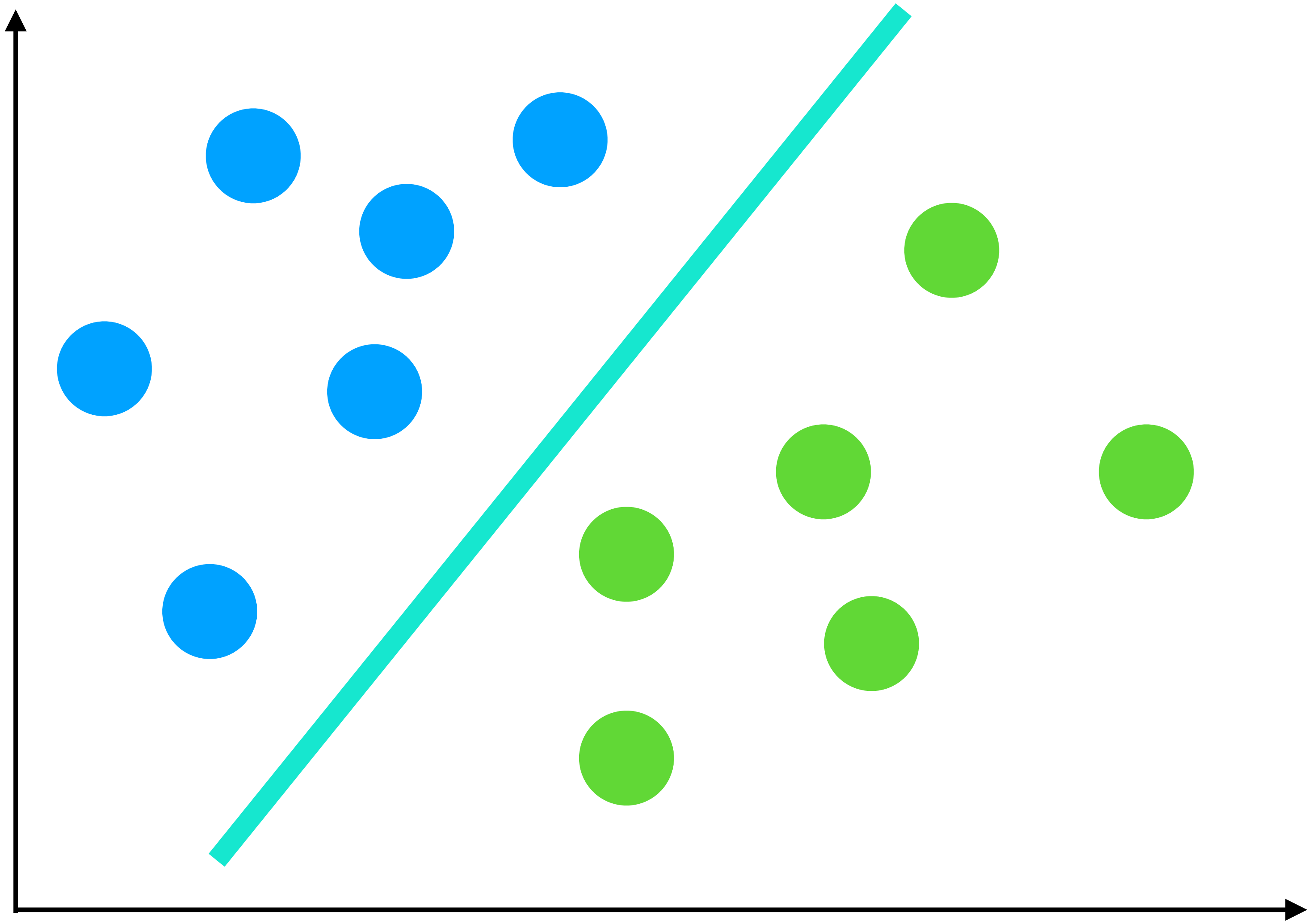
Support Vector Machine (SVM)

- Find a maximally separating hyperplane between two sets of linearly separable data



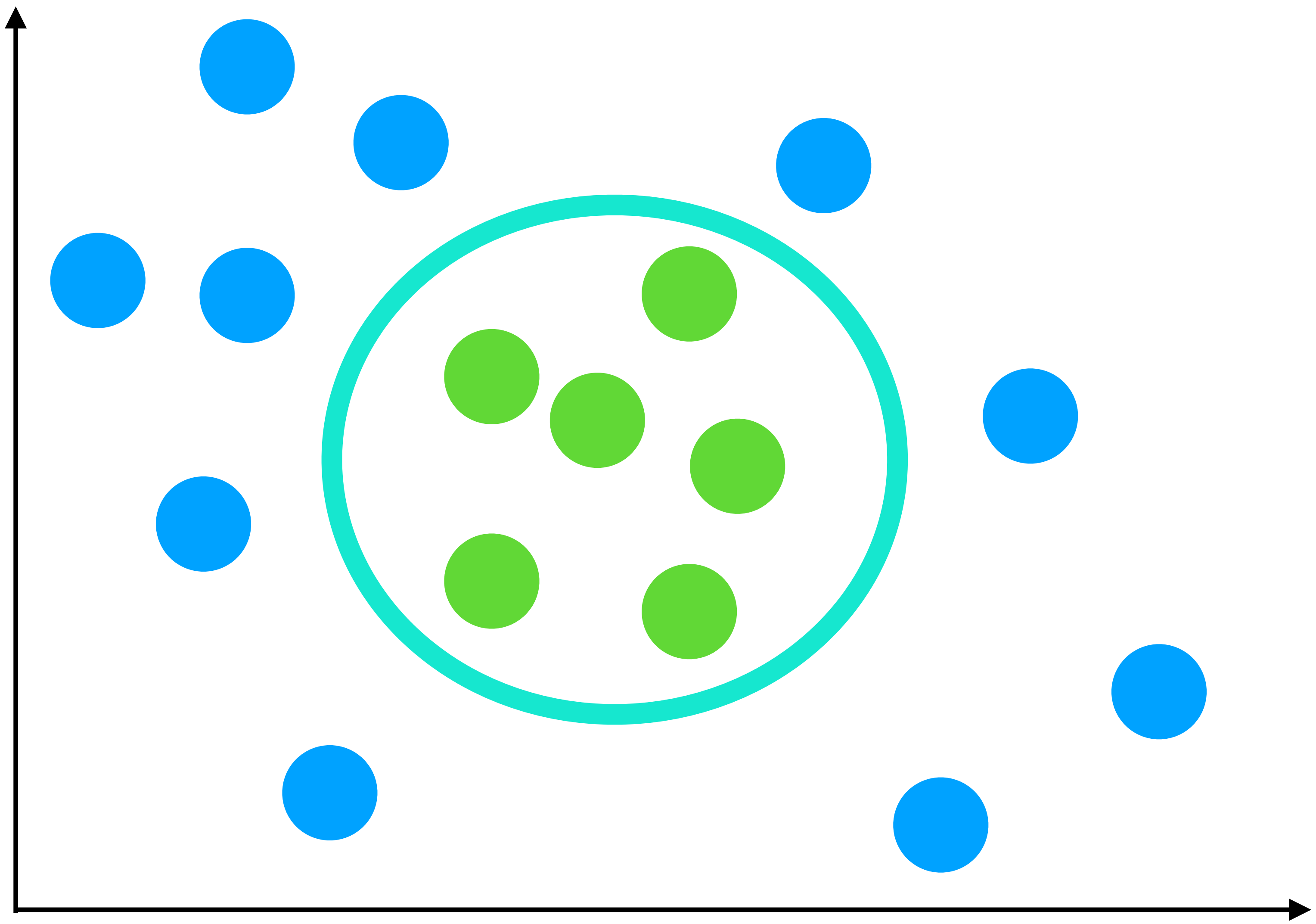
Support Vector Machine (SVM)

- Find a maximally separating hyperplane between two sets of linearly separable data

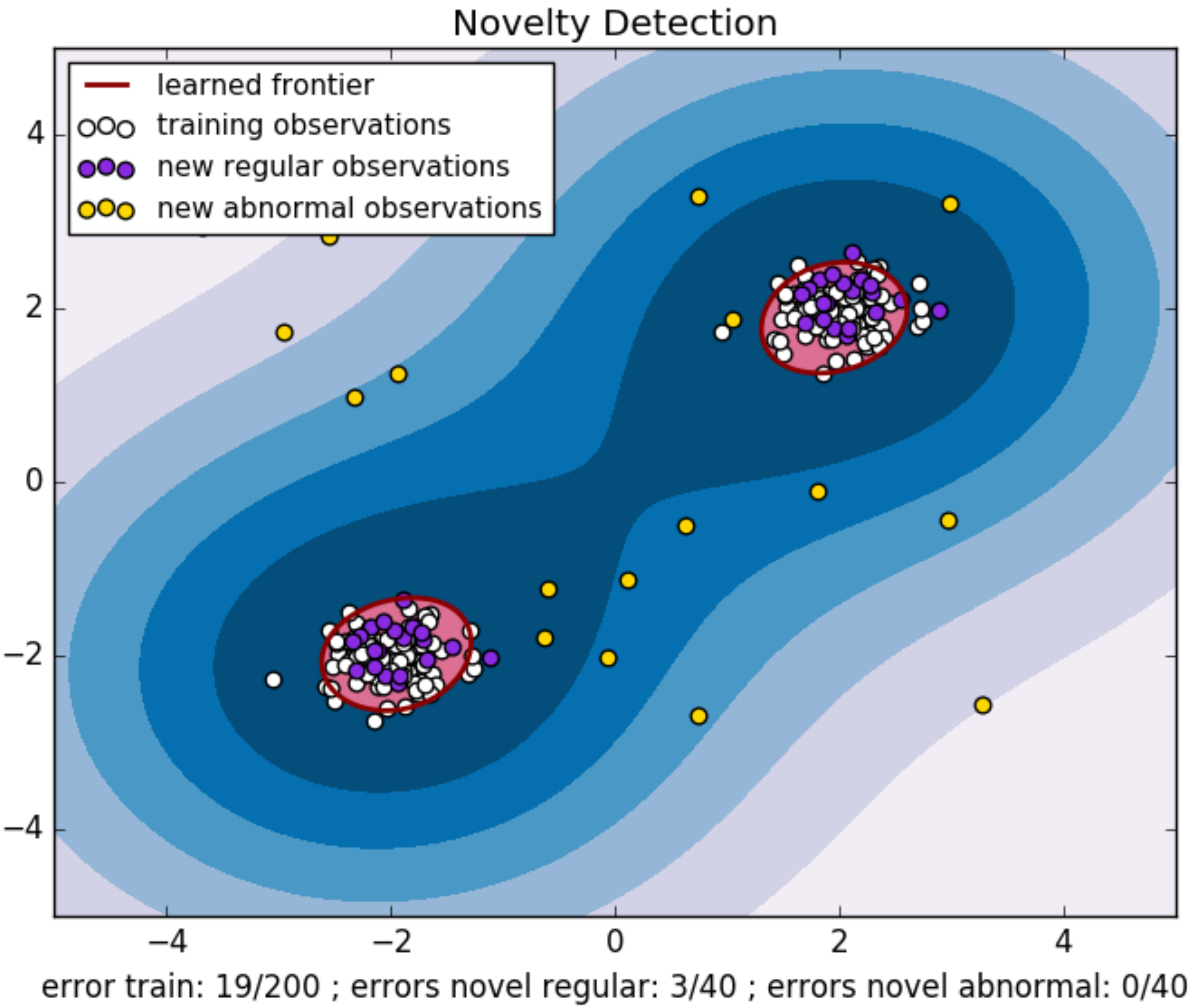


Radial Basis Function (RBF) SVM

- **The Kernel Trick:** Find a separating surface between two sets of data by embedding into a higher dimensional implicit feature space



1-class RBF-SVM

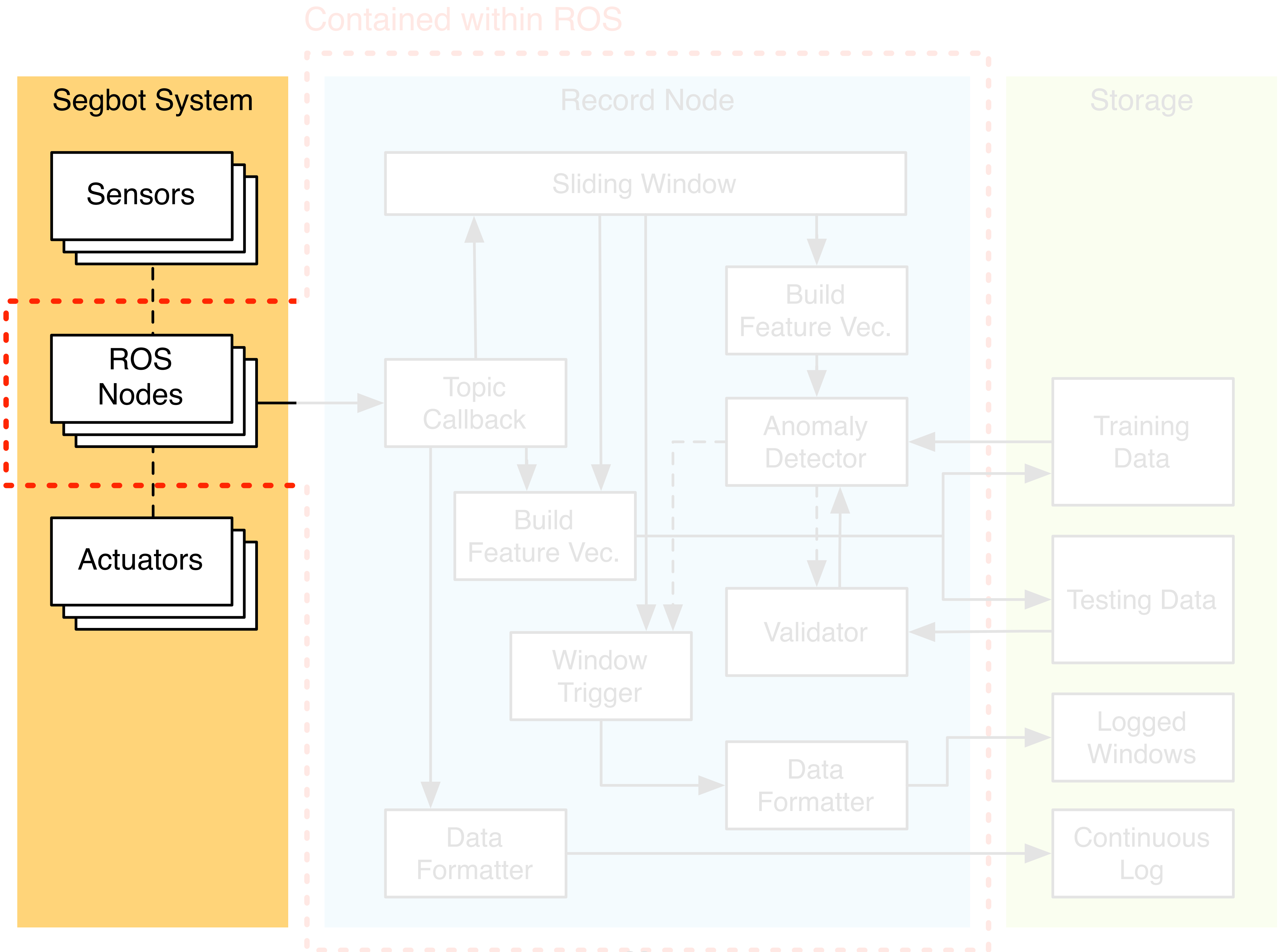


graphic from Scikit-learn

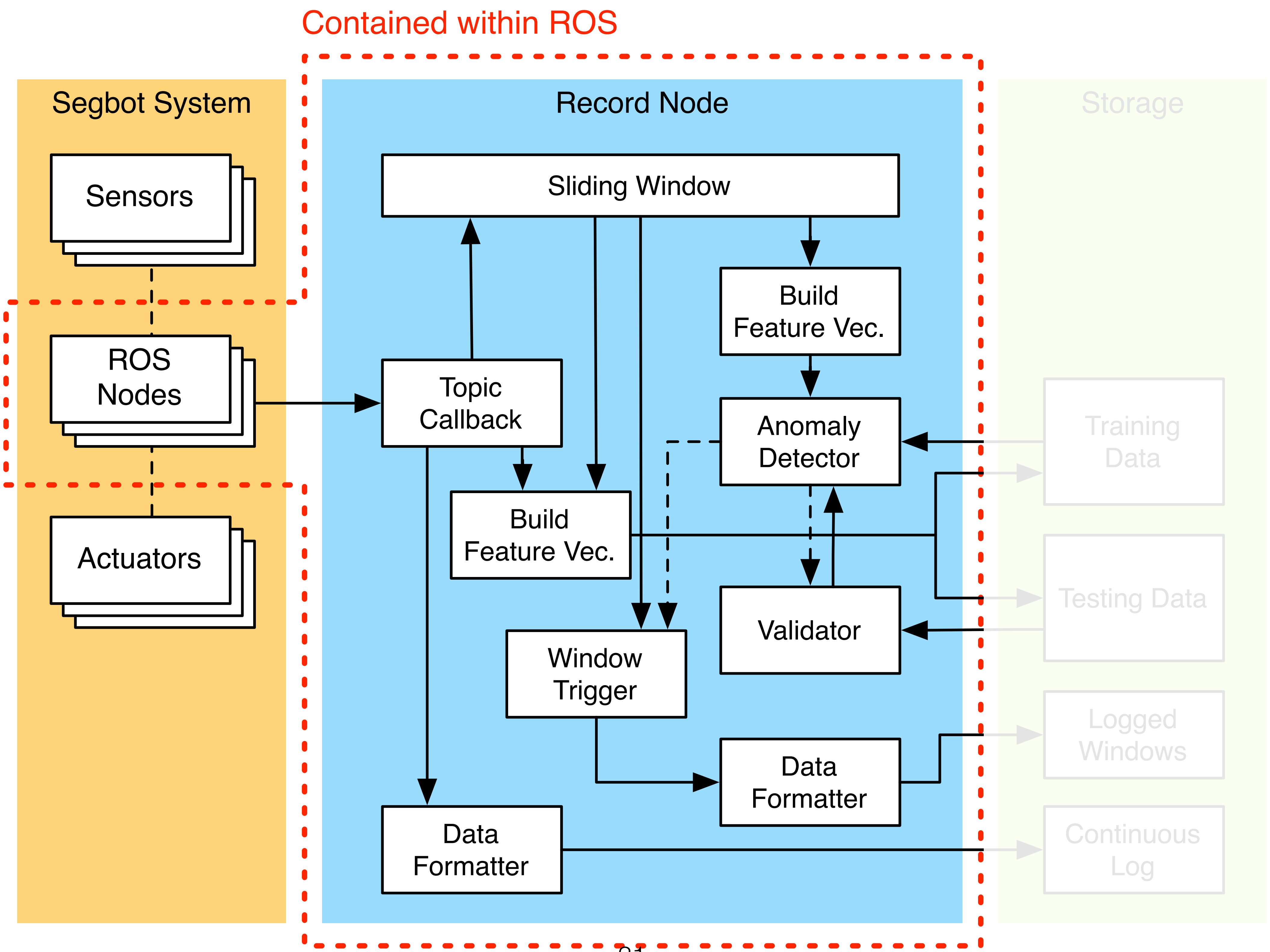
CC-Log Operation

1. Full logging
2. Offline learning
3. Intelligent logging

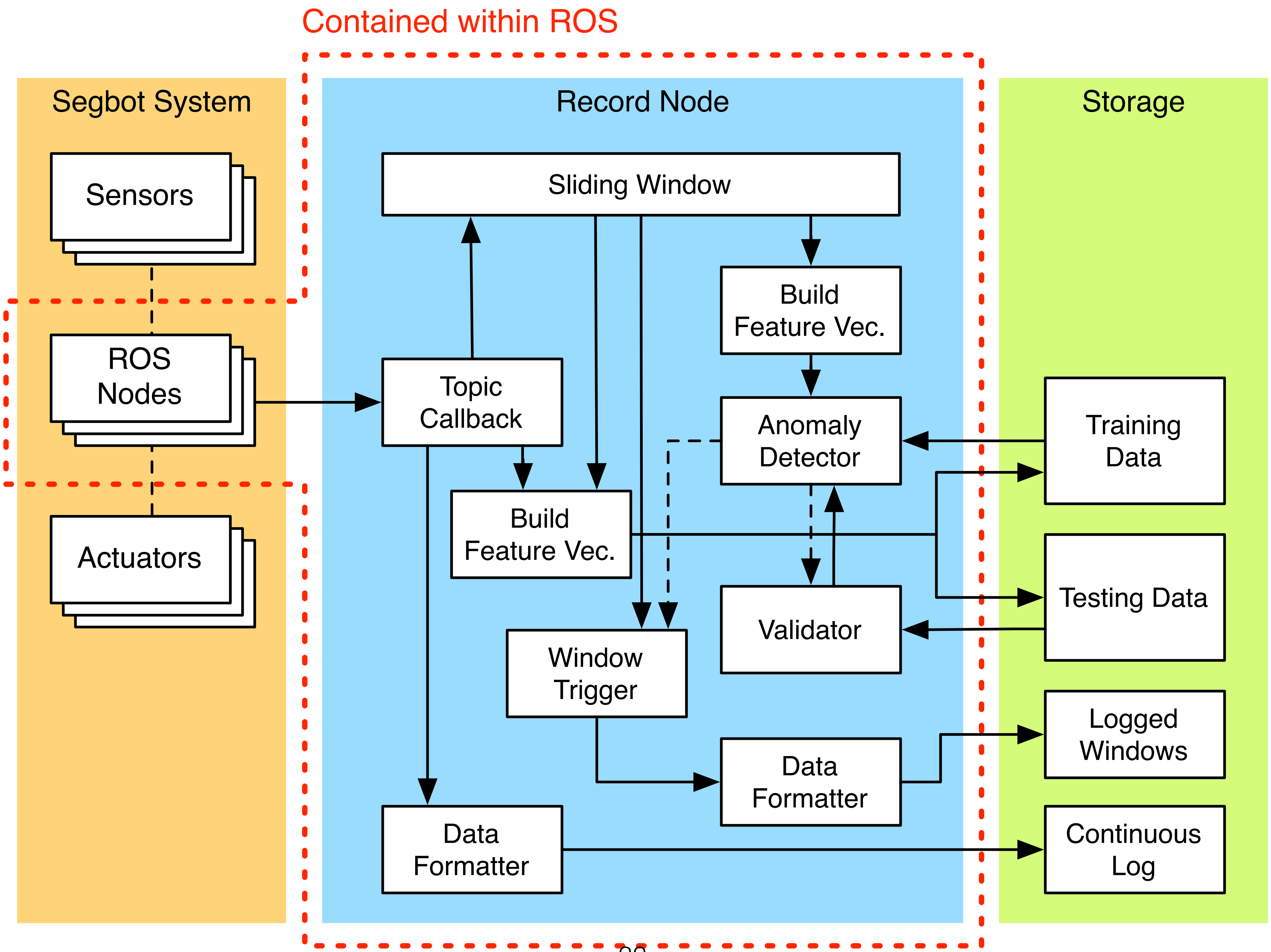
CC-Log Architecture



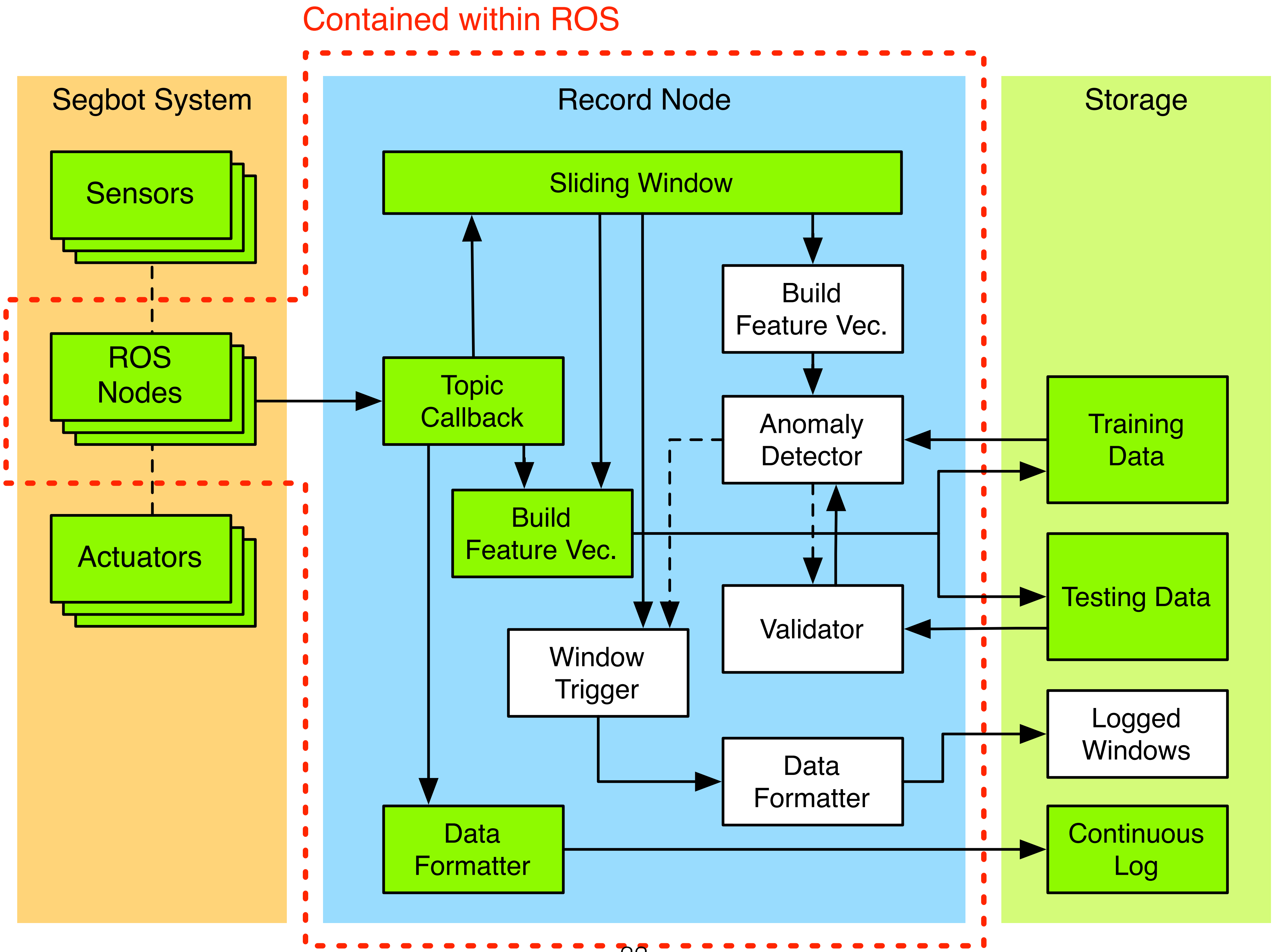
CC-Log Architecture



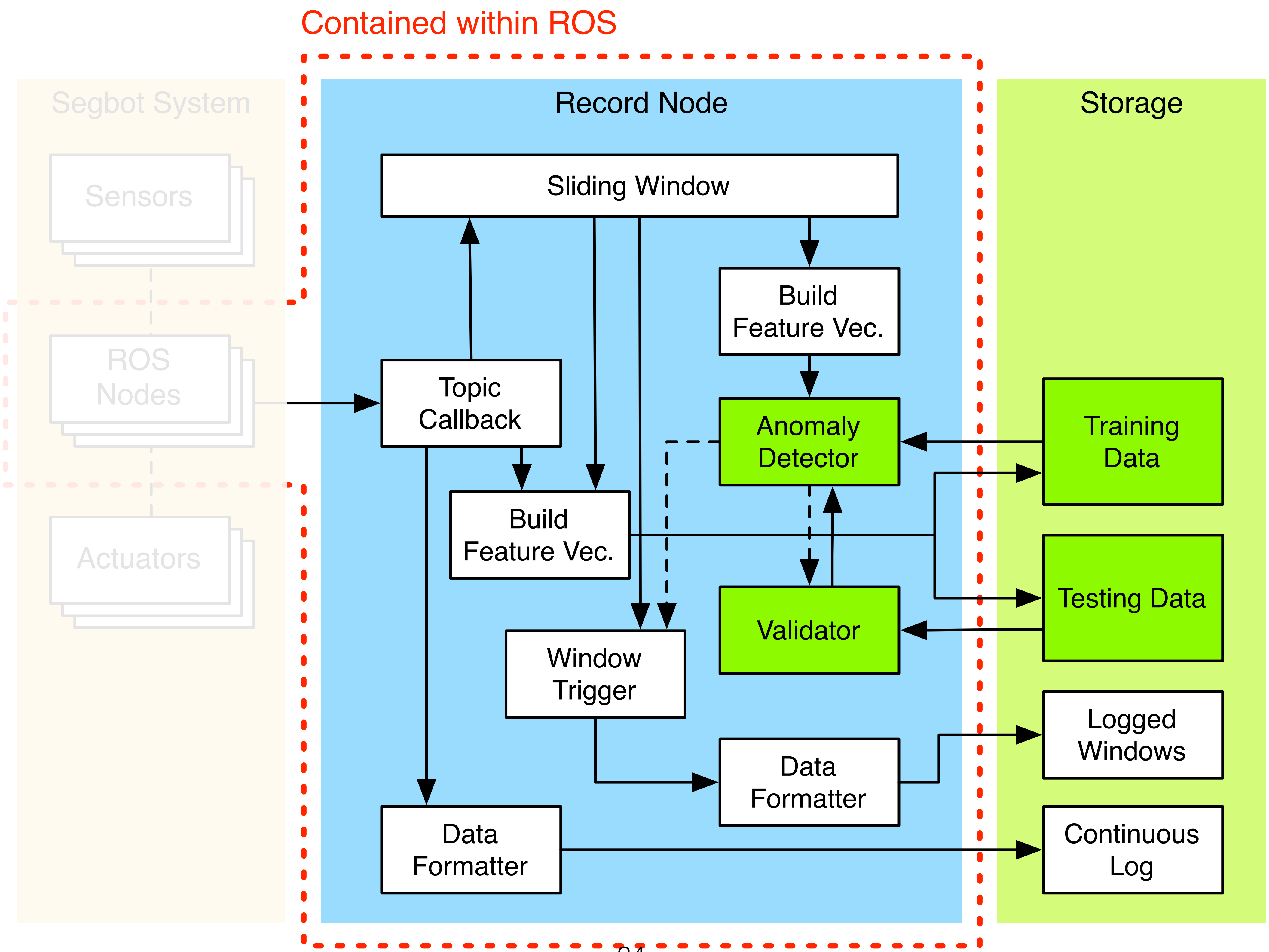
CC-Log Architecture



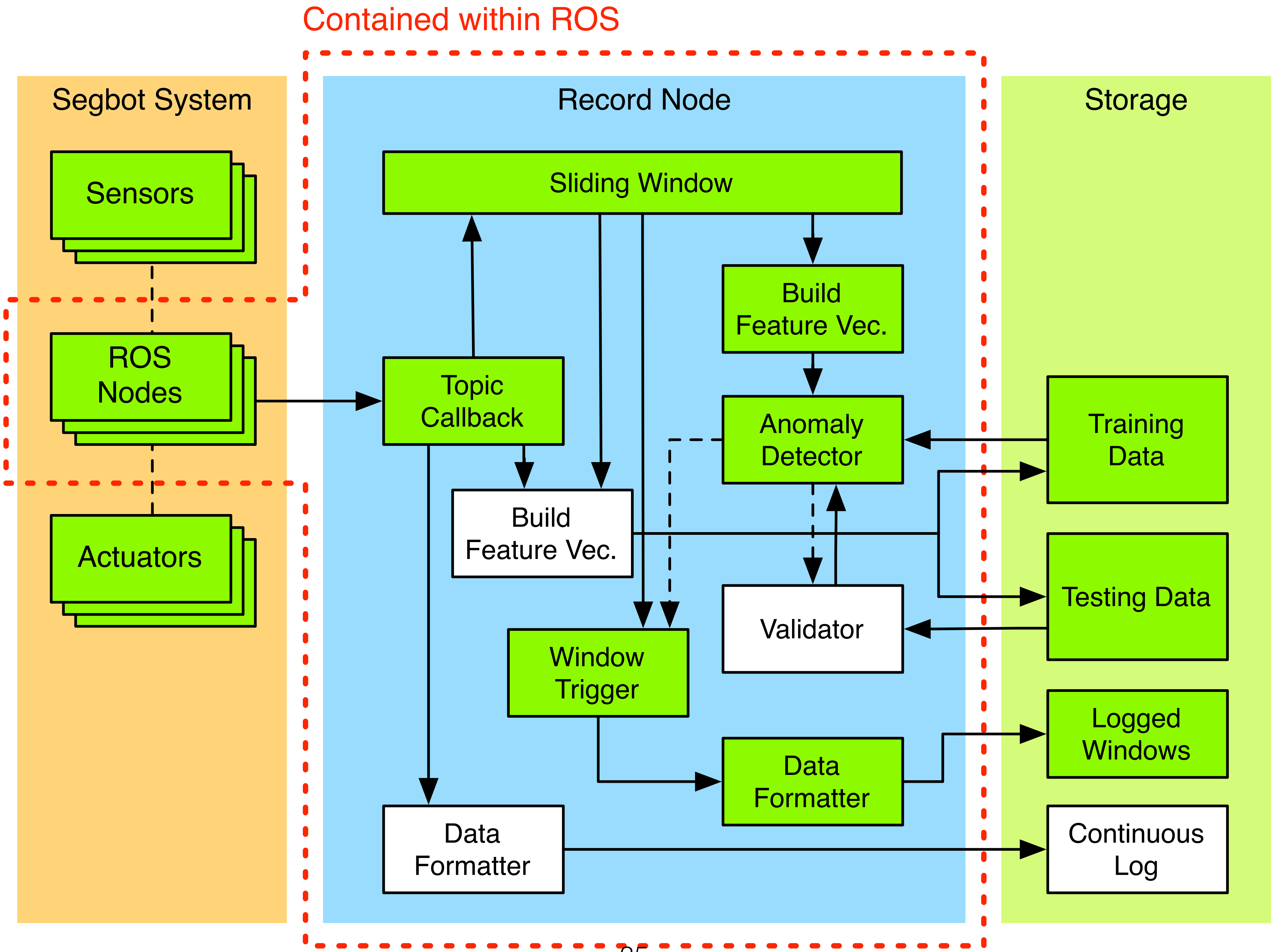
1 Full logging



2 Offline learning



3 Intelligent logging



Implementation

- Dependency and setup challenges
- VM used extensively
- Tricky to get system fully integrated into ROS
- Collecting data proved to be arduous

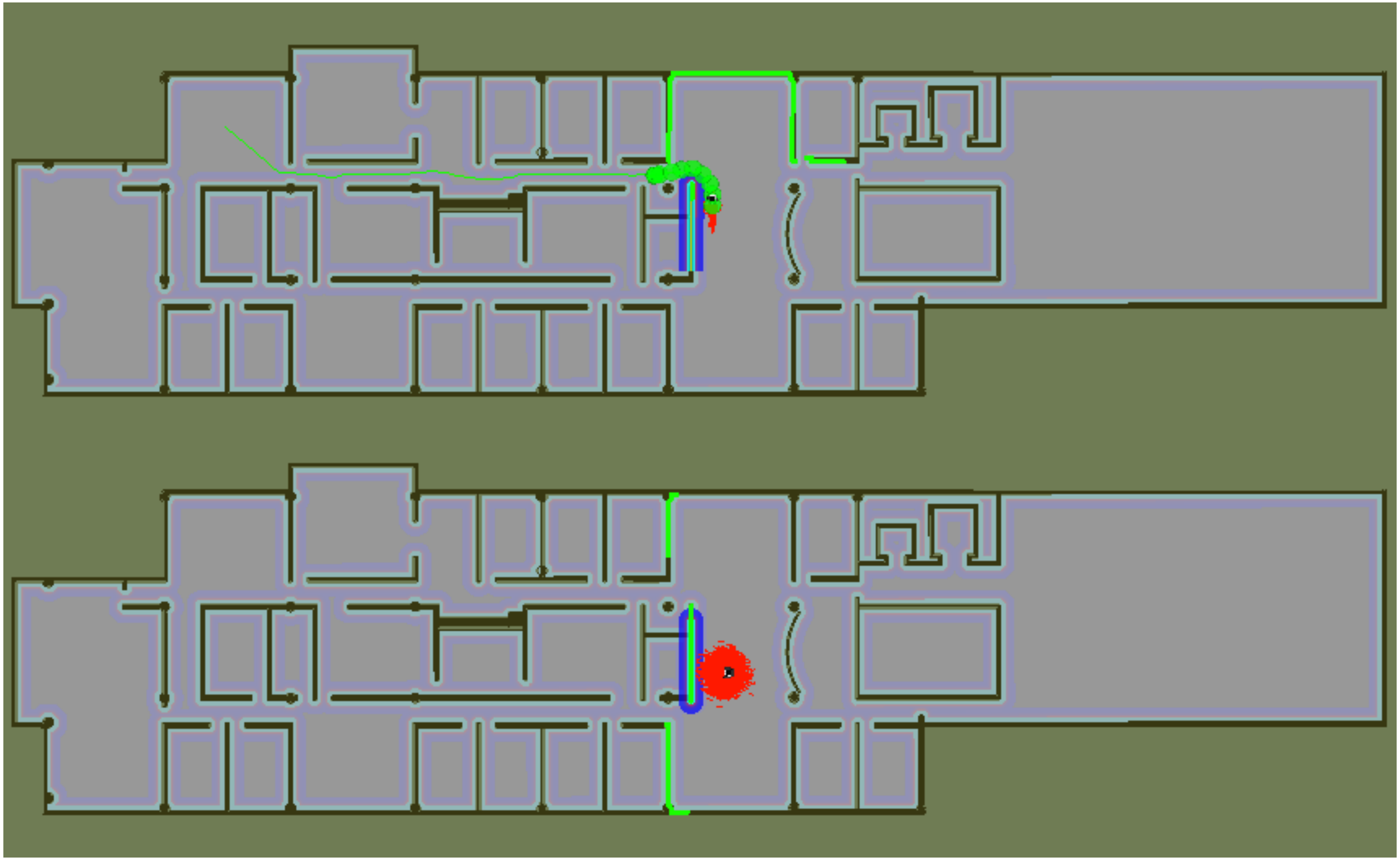
Outline

- Background
- The CC-Log system
- Evaluation
- Systems challenges in robotics
- Concluding remarks

Simulation

- Robot is shared resource, need lots of data
- Full featured simulation within ROS, based on Gazebo
- Different notions of nominal behavior, subset of reality
- Can’t simply train in simulation and test on physical robot
    - Domain adaptation outside of project scope

Simulation



In Silico Classifier Accuracy

Training: **983** **nominal**

Testing: **492** **nominal**, **20** **anomalous**

In Silico Classifier Accuracy

Training: **983 nominal**

Testing: **492 nominal, 20 anomalous**

In Silico Classifier Accuracy

Training: **983 nominal**

Testing: **492 nominal, 20 anomalous**

Total Events	**512**
True Positives	20
False Positives	183
False Negatives	0
True Negatives	309

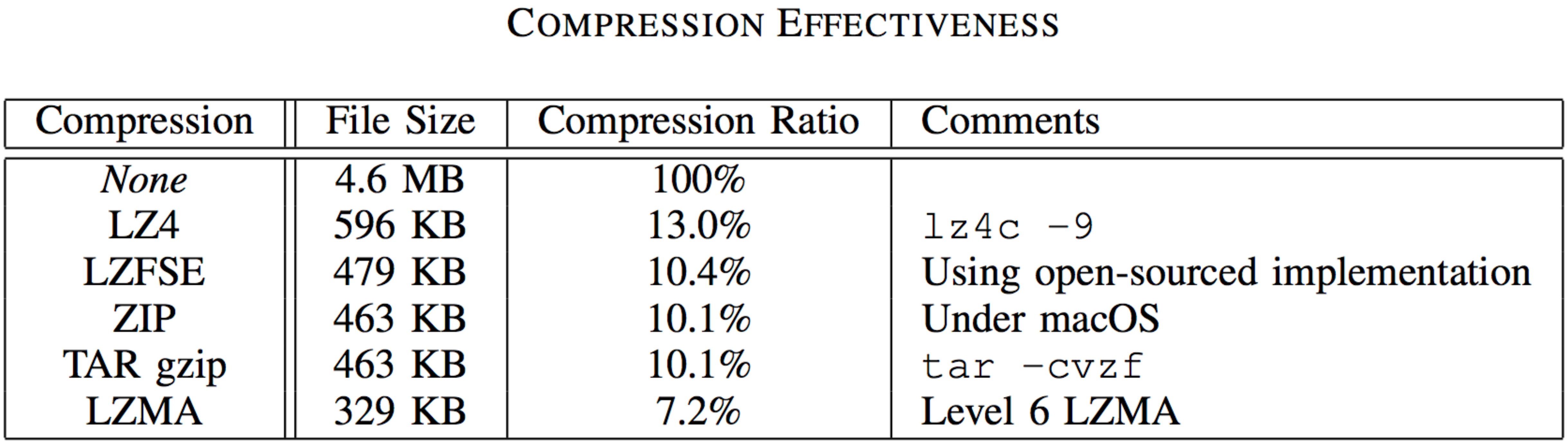
In Silico Classifier Accuracy

Training: **983 nominal**

Testing: **492 nominal, 20 anomalous**

Total Events	**512**
True Positives	20
False Positives	183
False Negatives	**0**
True Negatives	309

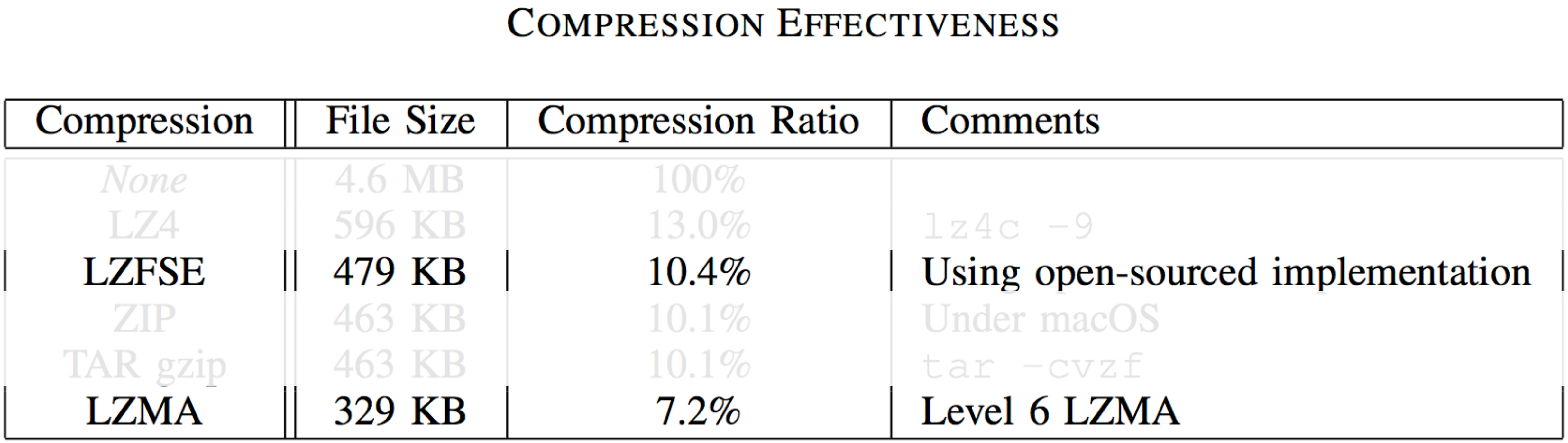
Compression Schemes



COMPRESSION EFFECTIVENESS

Compression	File Size	Compression Ratio	Comments
None	4.6 MB	100%	
LZ4	596 KB	13.0%	`lz4c -9`
LZFSE	479 KB	10.4%	Using open-sourced implementation
ZIP	463 KB	10.1%	Under macOS
TAR gzip	463 KB	10.1%	`tar -cvzf`
LZMA	329 KB	7.2%	Level 6 LZMA

Compression Schemes



COMPRESSION EFFECTIVENESS

Compression	File Size	Compression Ratio	Comments
None	4.6 MB	100%	
LZ4	596 KB	13.0%	`lz4c -9`
LZFSE	479 KB	10.4%	Using open-sourced implementation
ZIP	463 KB	10.1%	Under macOS
TAR gzip	463 KB	10.1%	`tar -cvzf`
LZMA	329 KB	7.2%	Level 6 LZMA

Limitations

- Currently tailored for odometry data
- Adapting to real robot requires lots of clean running data
- Cannot capture aggregate data
- Simple classifier cannot fully capture certain intricacies
  - Need more data
  - Could be better served by HMM or LSTM based model

Future Work

- Collect more data and fine tune the classifier
- Incorporate more types of data into the system
- Course-grained continuous logging
- Integrate compressive sampling, such as RTV

Outline

- Background
- The CC-Log system
- Evaluation
- Systems challenges in robotics
- Concluding remarks

Scheduling

- Robots require more nuanced scheduling
- Data generated at different speeds
- Different nodes need to process data at different rates
- ROS has very primitive scheduling

Lightweight Processes

- BWIBot has sluggish performance after some time
    - Many concurrent ROS nodes
- Each ROS node is a process
- ROS nodes are too heavy for long-running processes

Storage

- CC-Log solves one facet of the storage problem
- Other use cases may require stratified sampling to get aggregate statistics
- Security and privacy

Continuous Learning

- Want robots to be able to train models “on-the-go”
- Continuous learning poses unique challenges
  - Data requirements change over time
  - How much data is enough data?

Retrospective

- Tackled a problem in robotics from a systems perspective
- Simple techniques can be very powerful
- Robotics / systems collaborations are great
- Building a working system end-to-end in ROS is somewhat difficult, collaboration should ameliorate this

Q&A

Santiago Gonzalez
slgonzalez@utexas.edu