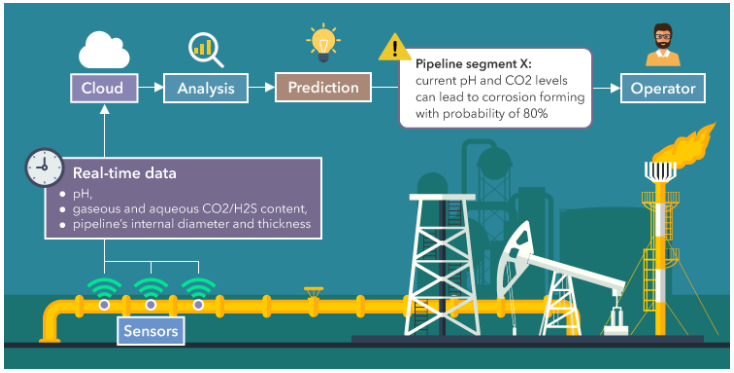
Towards Wireless Environment Cognizance Through Incremental Learning

Aniqua Baset, Christopher Becker, Kurt Derr, Samuel Ramirez, Sneha Kasera, and Aditya Bhaskara

Increasing use of wireless devices in modern infrastructures

Manufacturing

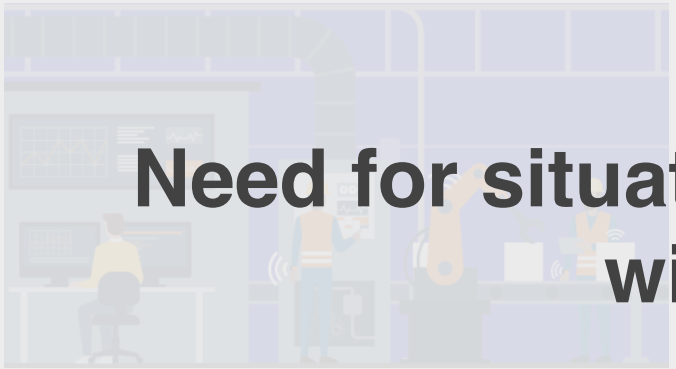
Power plant

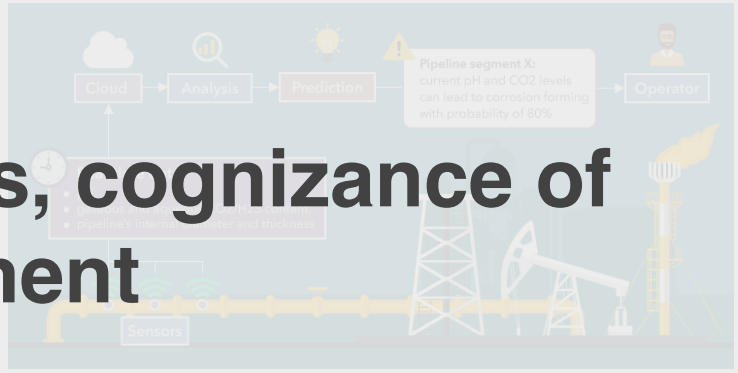


Oil & gas refineries

Interferences, malfunctions, … → Downtime, safety hazards, …

Increasing use of wireless devices
in modern infrastructures





Need for situational awareness, cognizance of wireless environment

Manufacturing

Power plant

Oil & gas refineries

Interferences, malfunctions, … → Downtime, safety hazards, …

Our work

Our work

- Classify known/expected signals
- Detect new/unknown signals

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- Classify known/expected signals
- Detect new/unknown signals
- Incremental learning
  - adapt to dynamic environments
  - learn deviations in deployed environment

Our system overview

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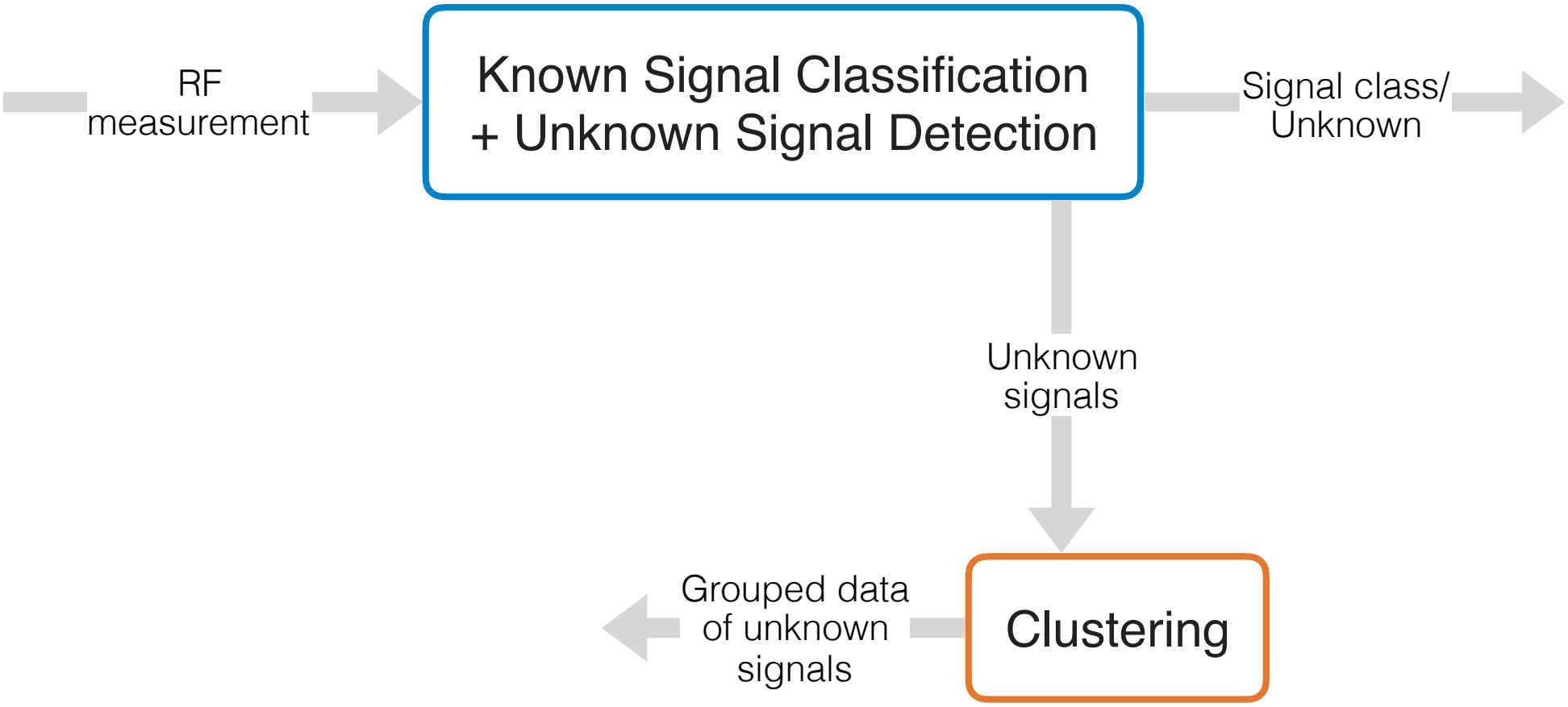

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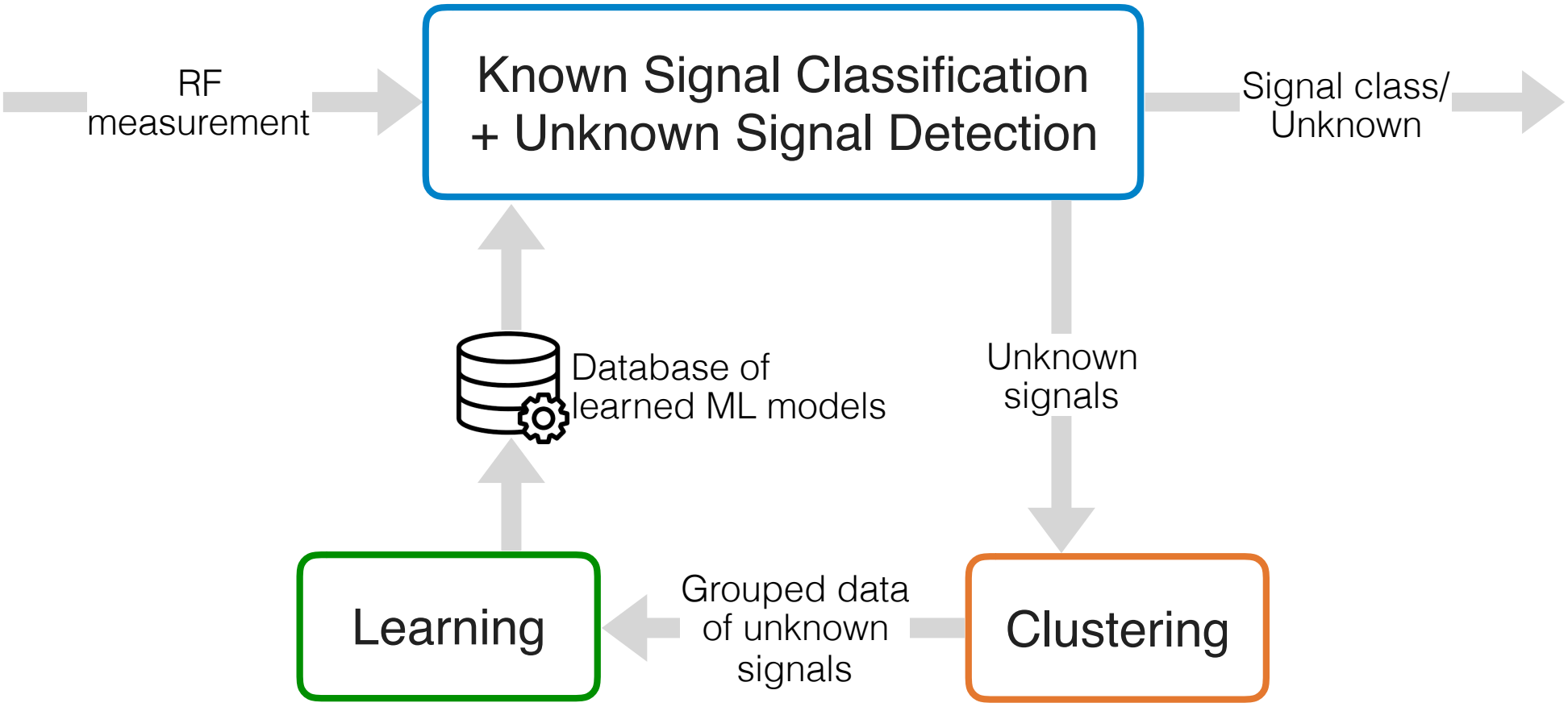

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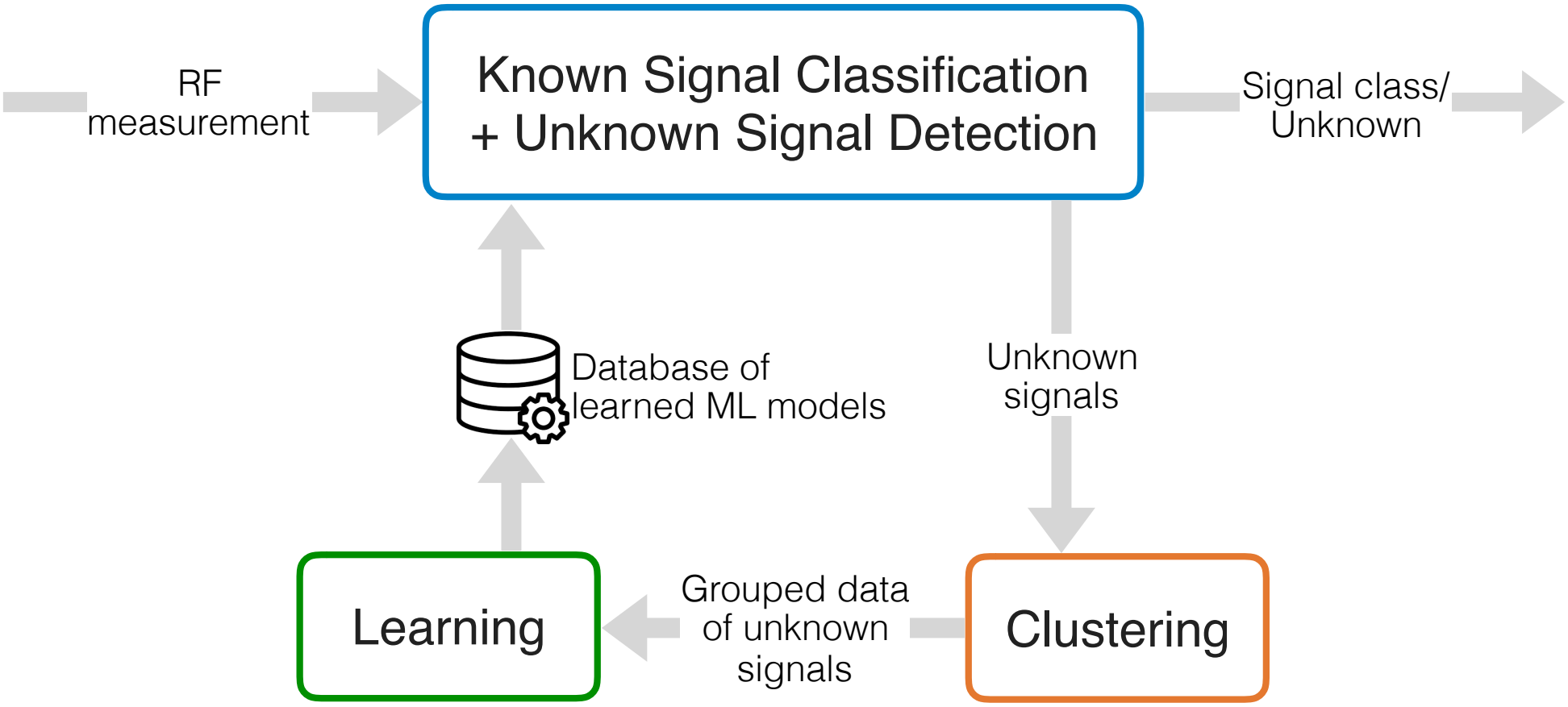
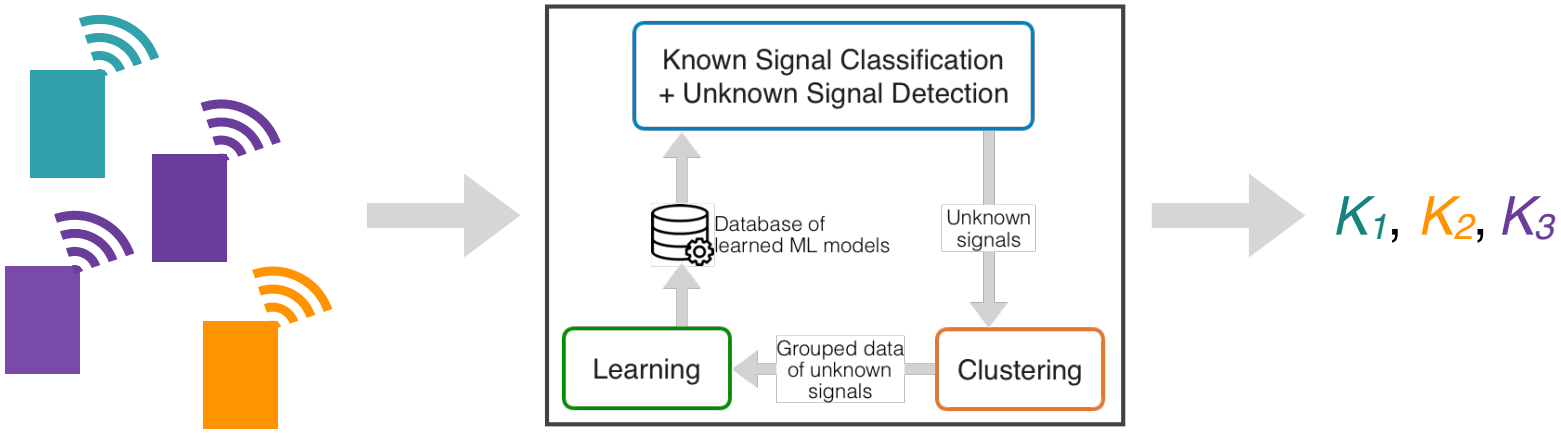
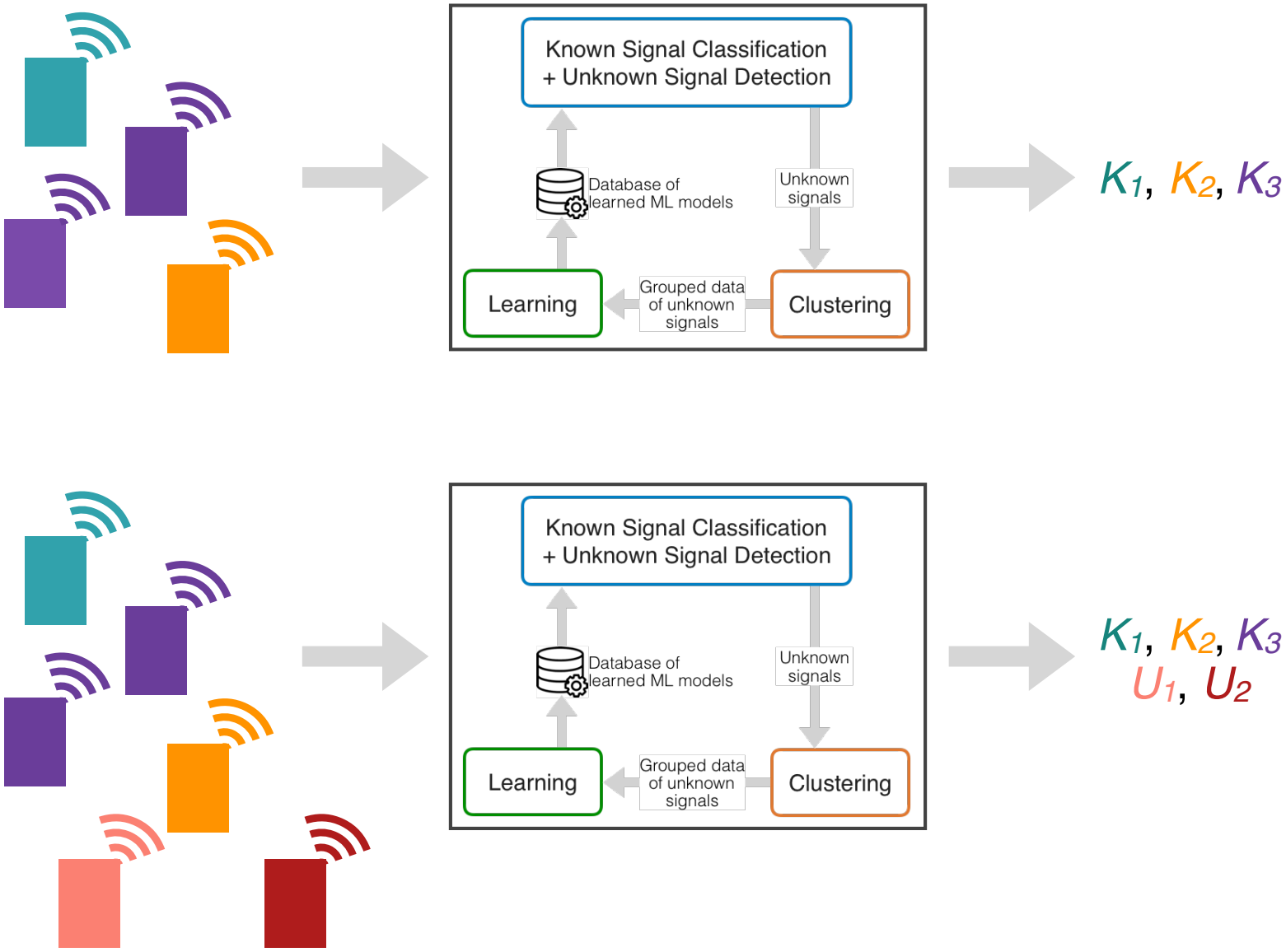


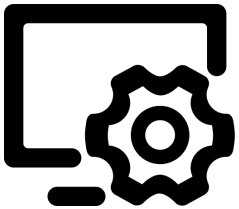
Clustering & Learning → incremental learning

Example scenario

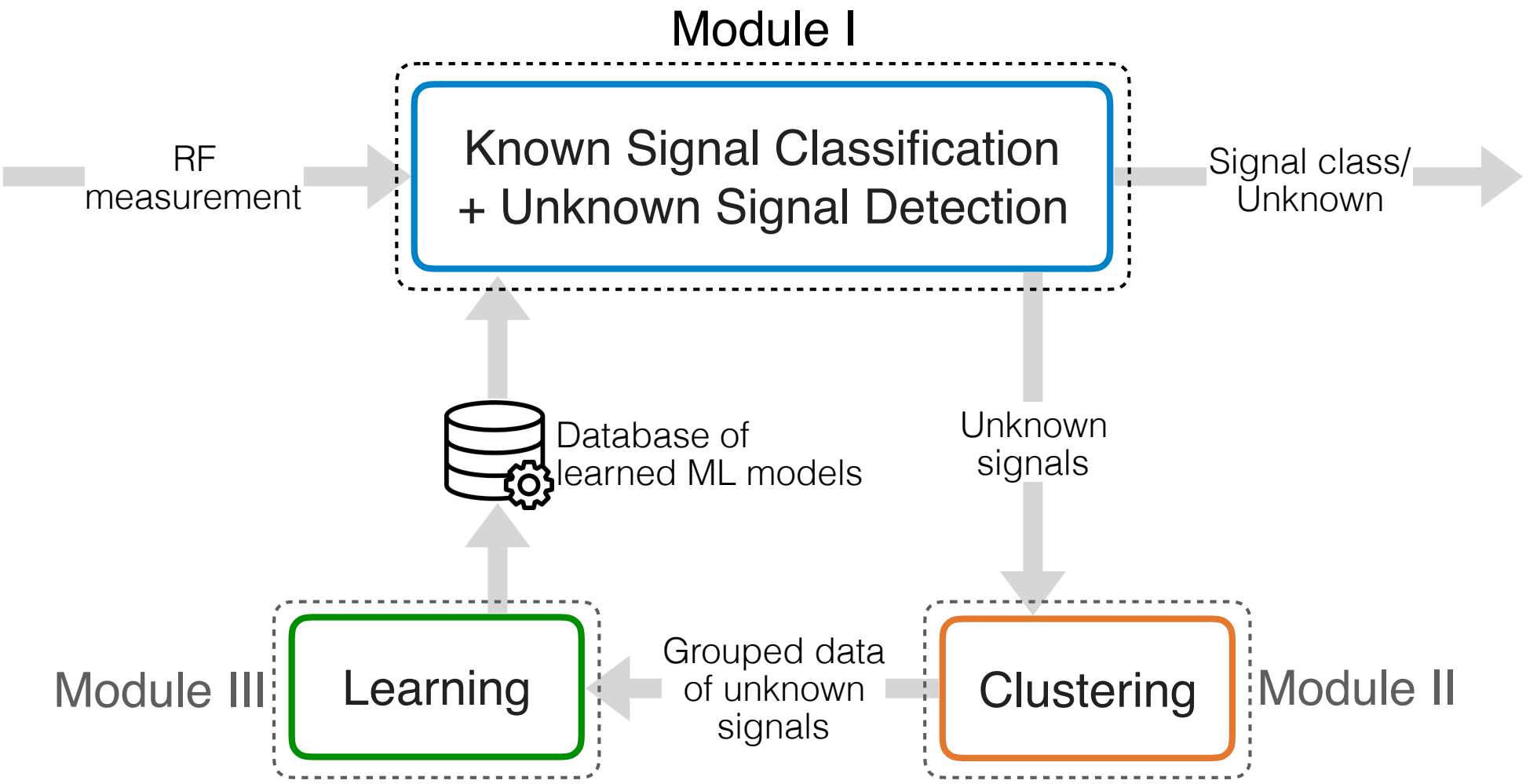


Example scenario





System Details


Module I
RF measurement
Known Signal Classification + Unknown Signal Detection
Signal class/ Unknown
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Unknown signals
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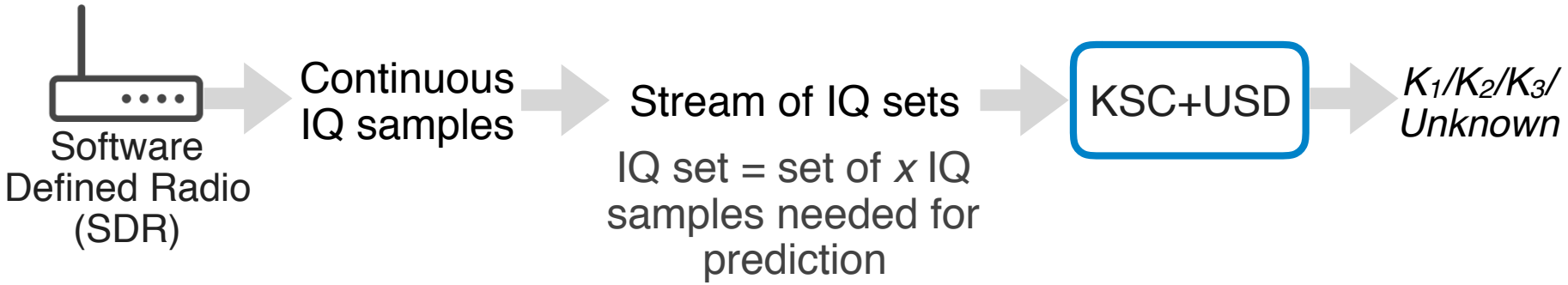
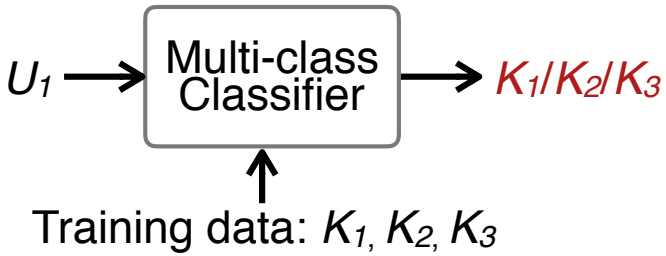
Module I : Known Signal Classification + Unknown Signal Detection (KSC+USD)



Challenge 1: Multi-class classification not enough



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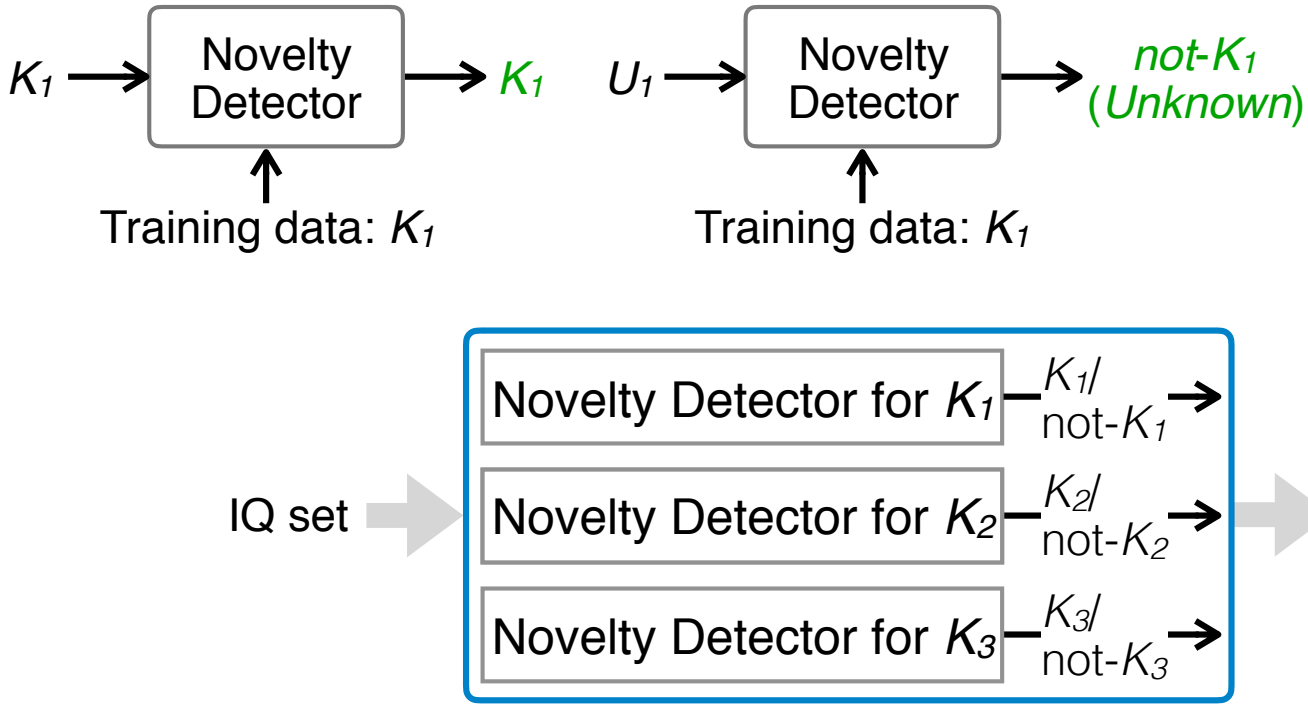

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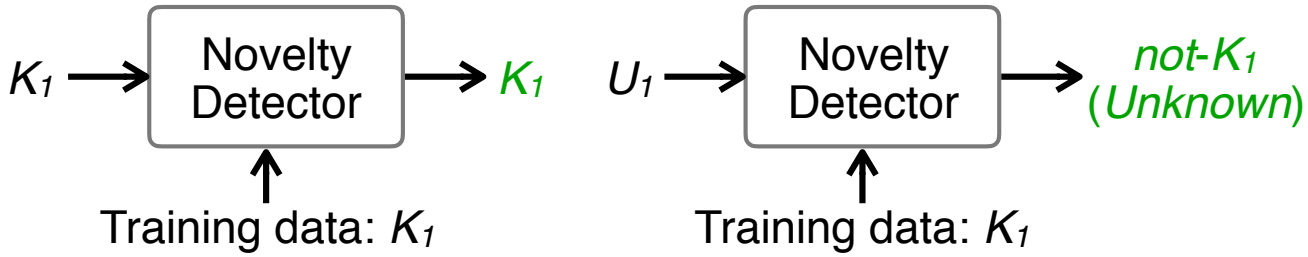
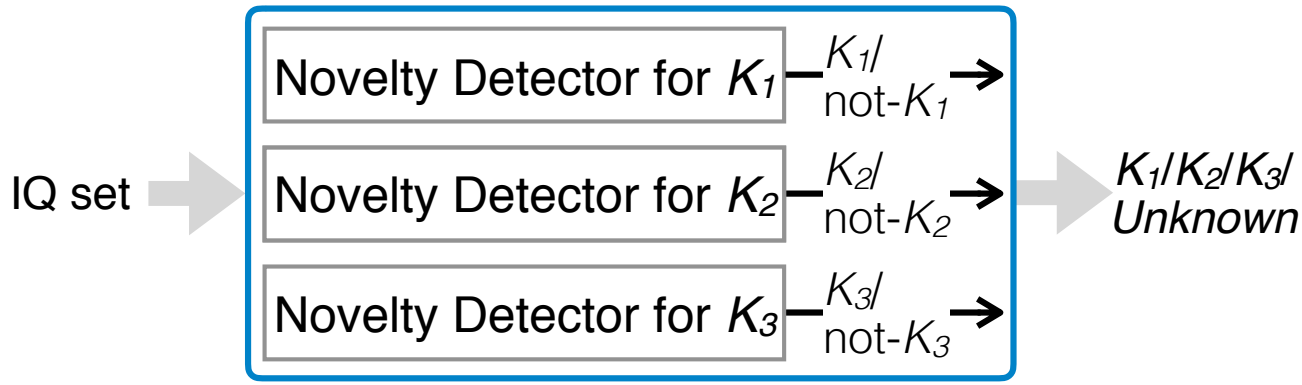
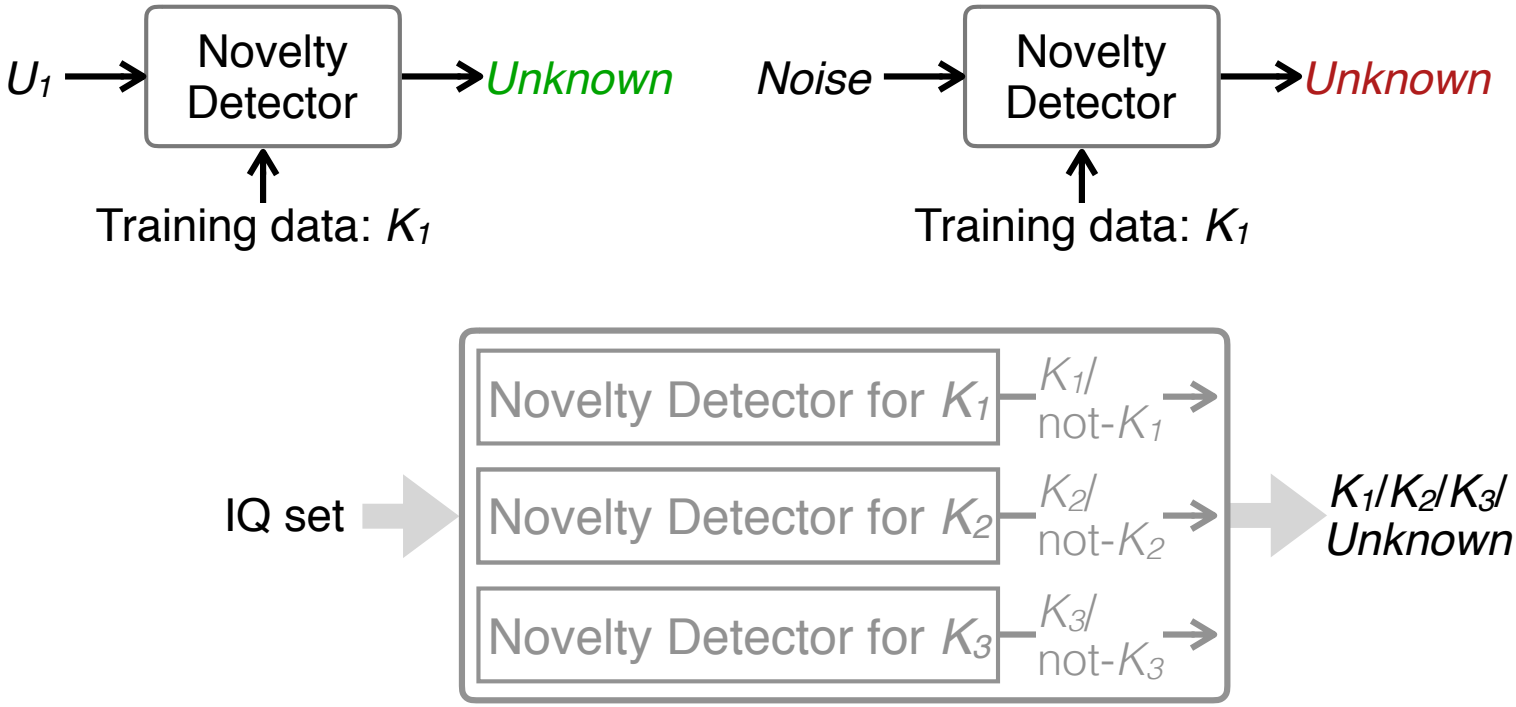




Easily extensible to new signal classes

Challenge 2: *Unknown* signal or just noise?



Challenge 2: *Unknown* signal or just noise?

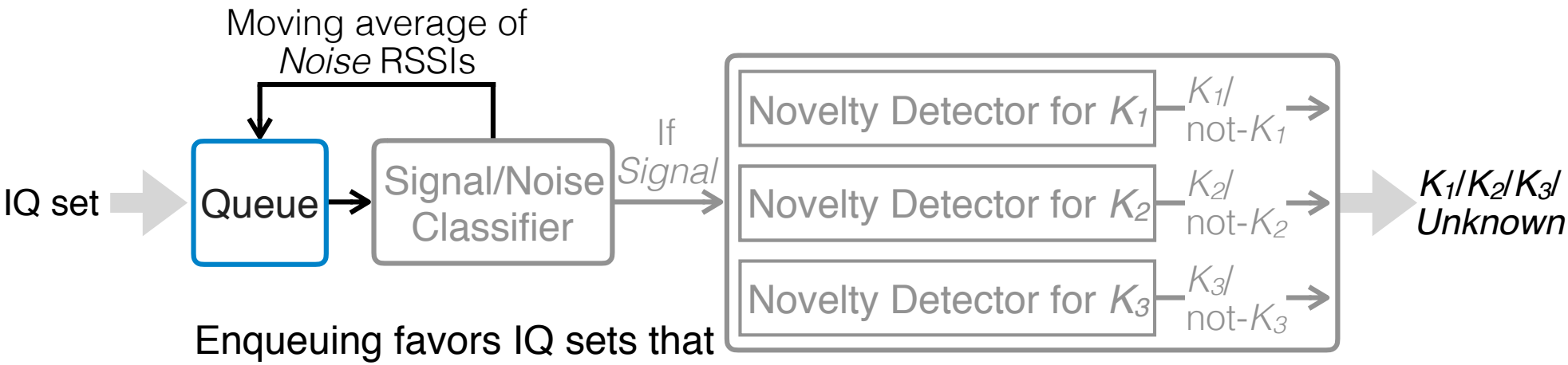
Challenge 3: How to keep up with high sample rate?

USRP X310

25 million samples/sec

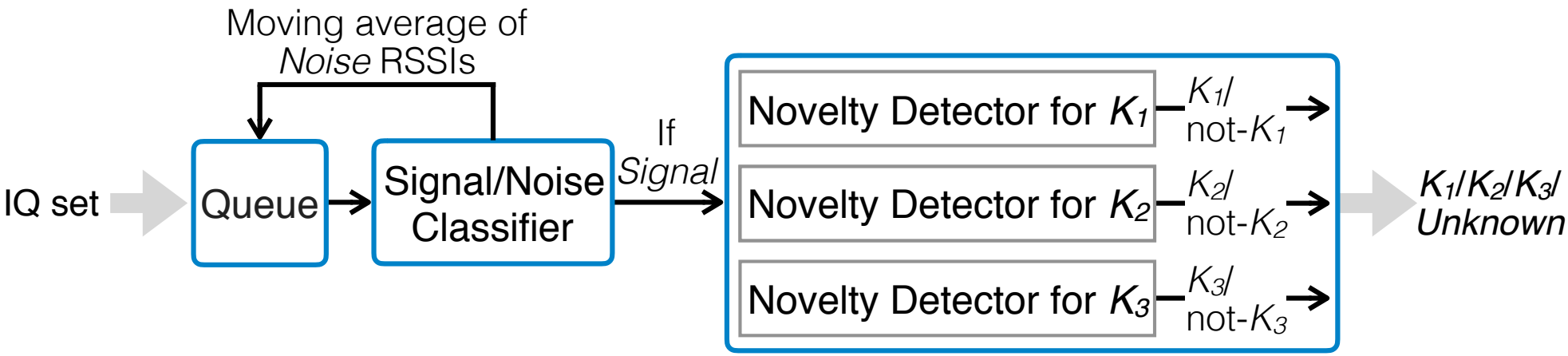
Slow data processing leads to unstable state

Challenge 3: How to keep up with high sample rate?

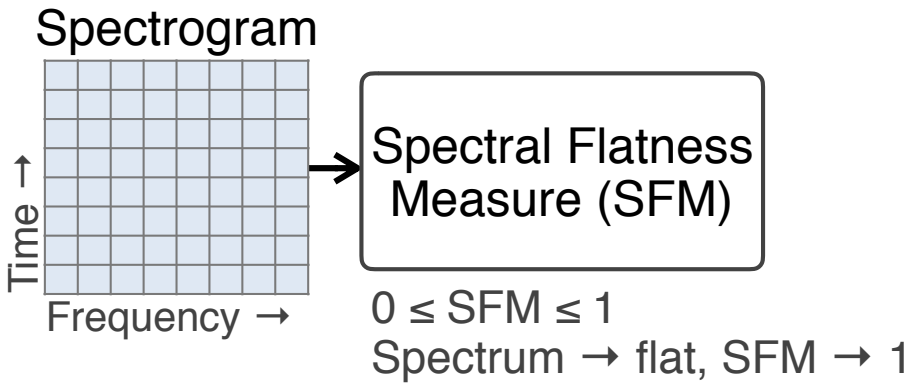


Enqueuing favors IQ sets that are more likely to contain signal over noise

Module I: KSC+USD



Methodology for Signal/Noise Classifier



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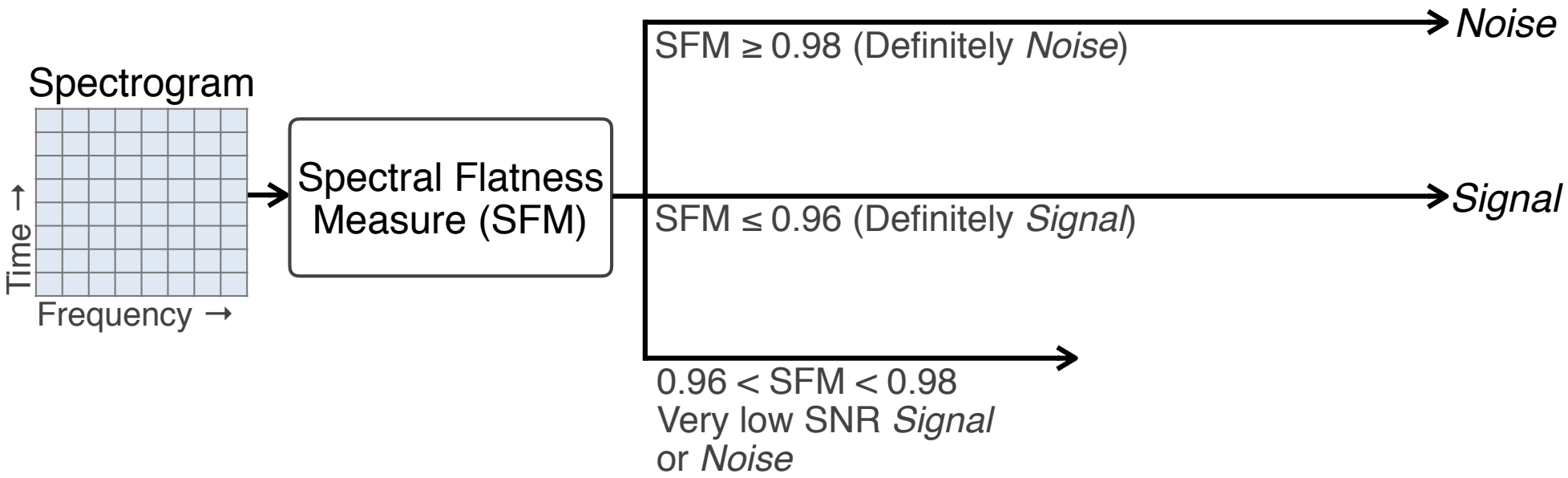

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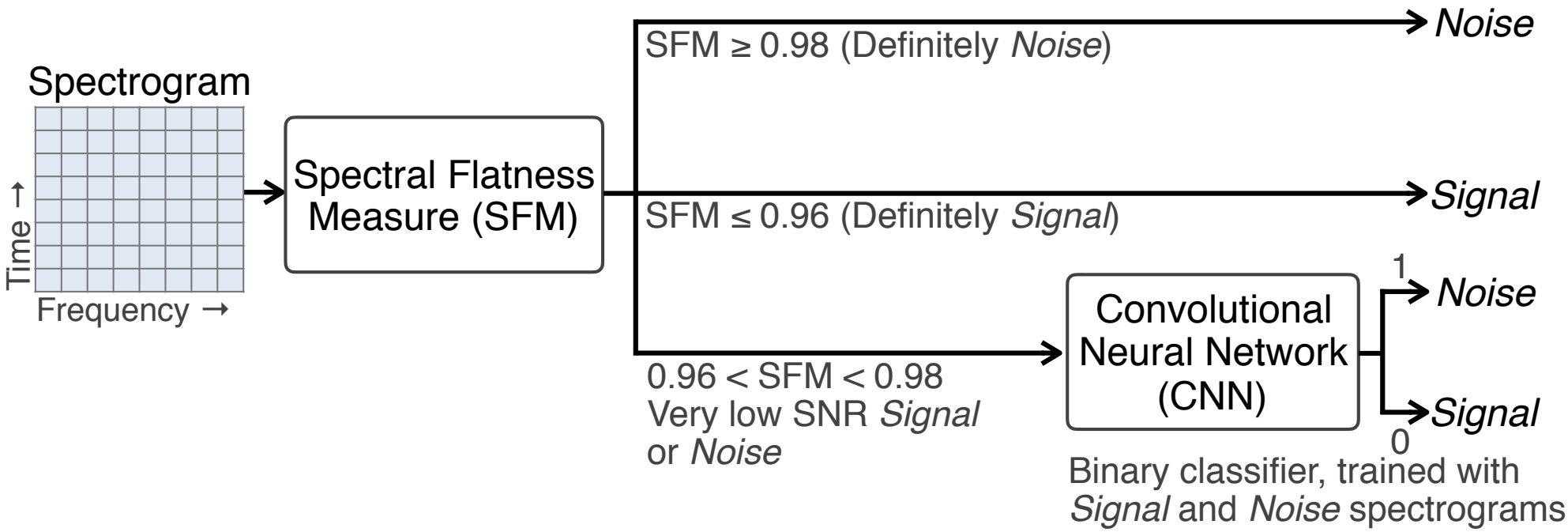
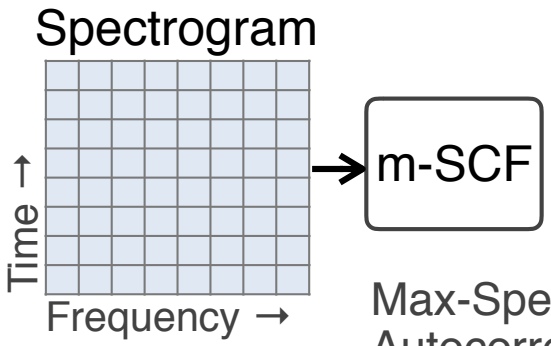
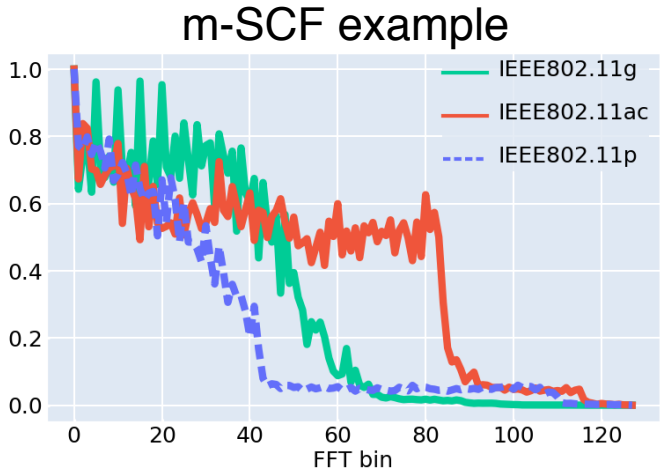


Methodology for Novelty Detector



Max-Spectral Correlation Function (m-SCF)
Autocorrelation on spectrums



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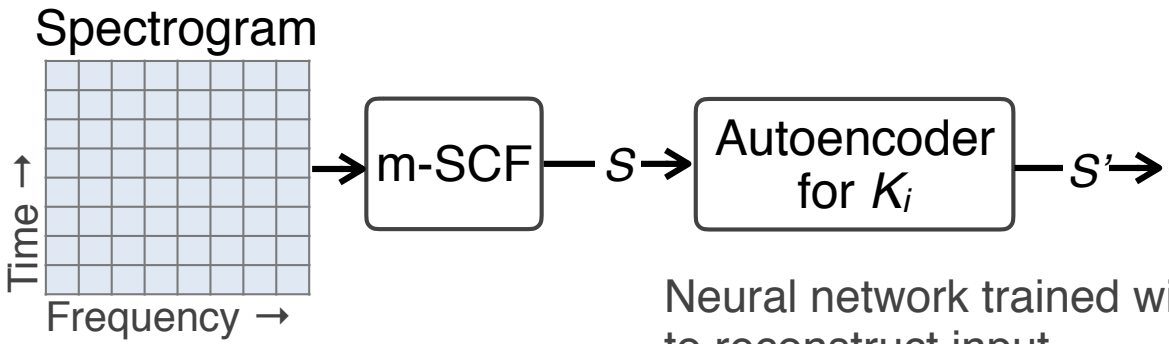
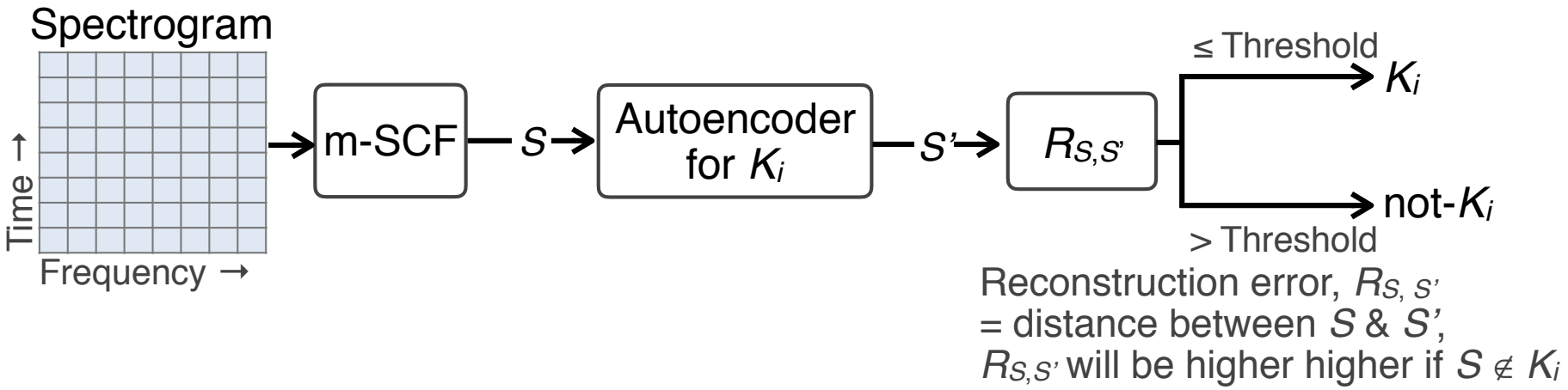
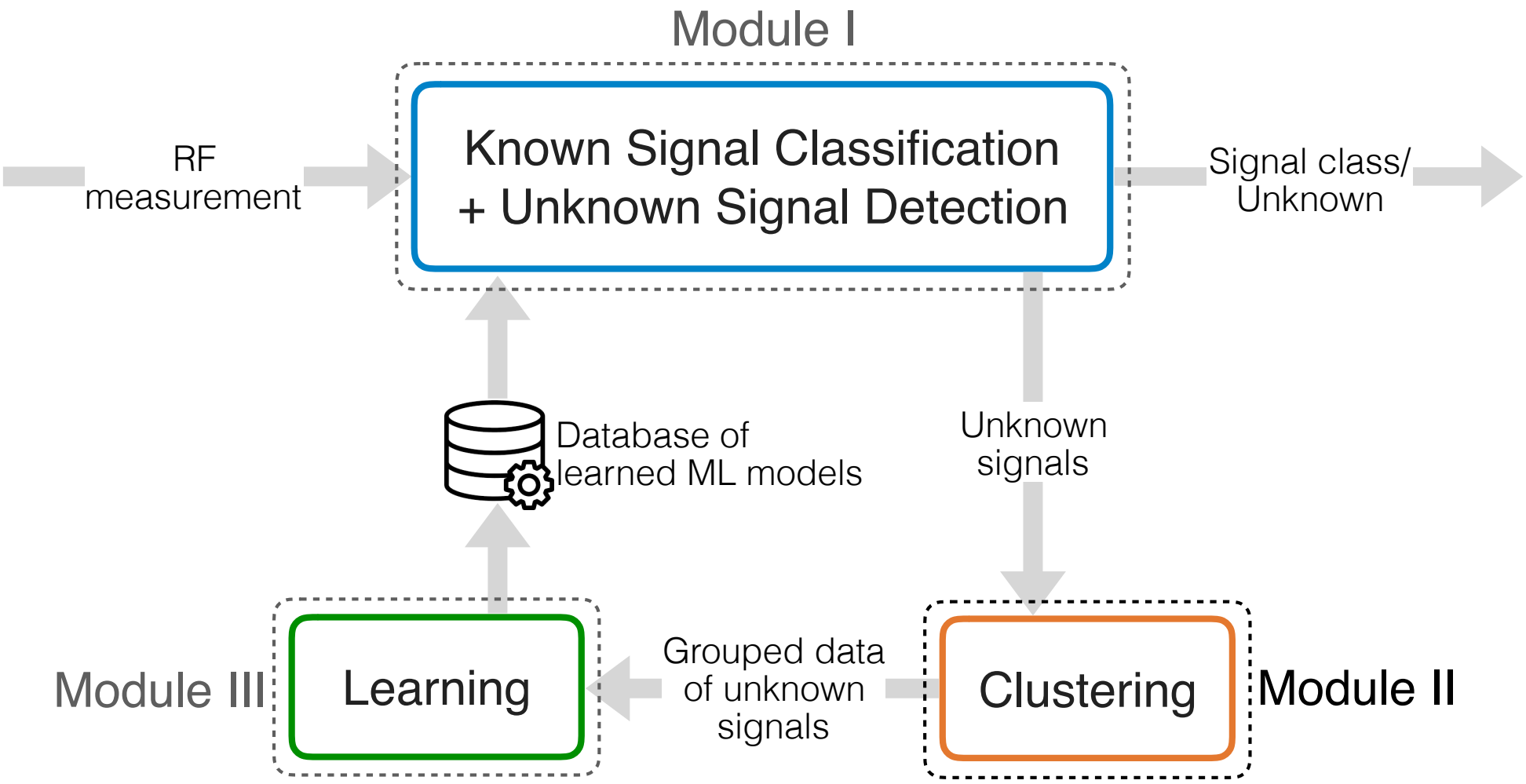


Neural network trained with m-SCF of K_i to reconstruct input

Methodology for Novelty Detector



Reconstruction error, $R_{S, S'}$
= distance between S & S',
$R_{S,S'}$ will be higher higher if $S \notin K_i$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Module II: Clustering

Offline

Online

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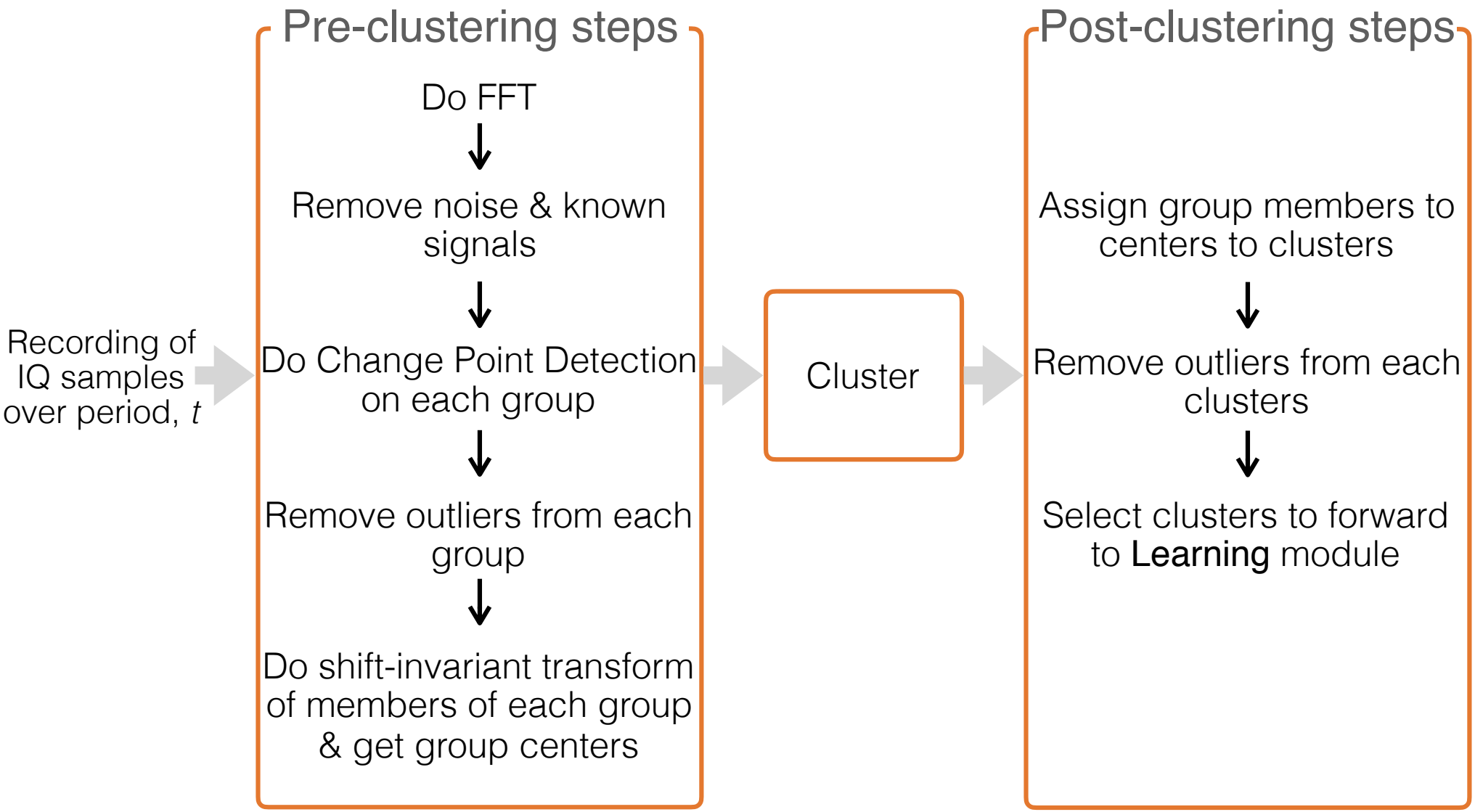
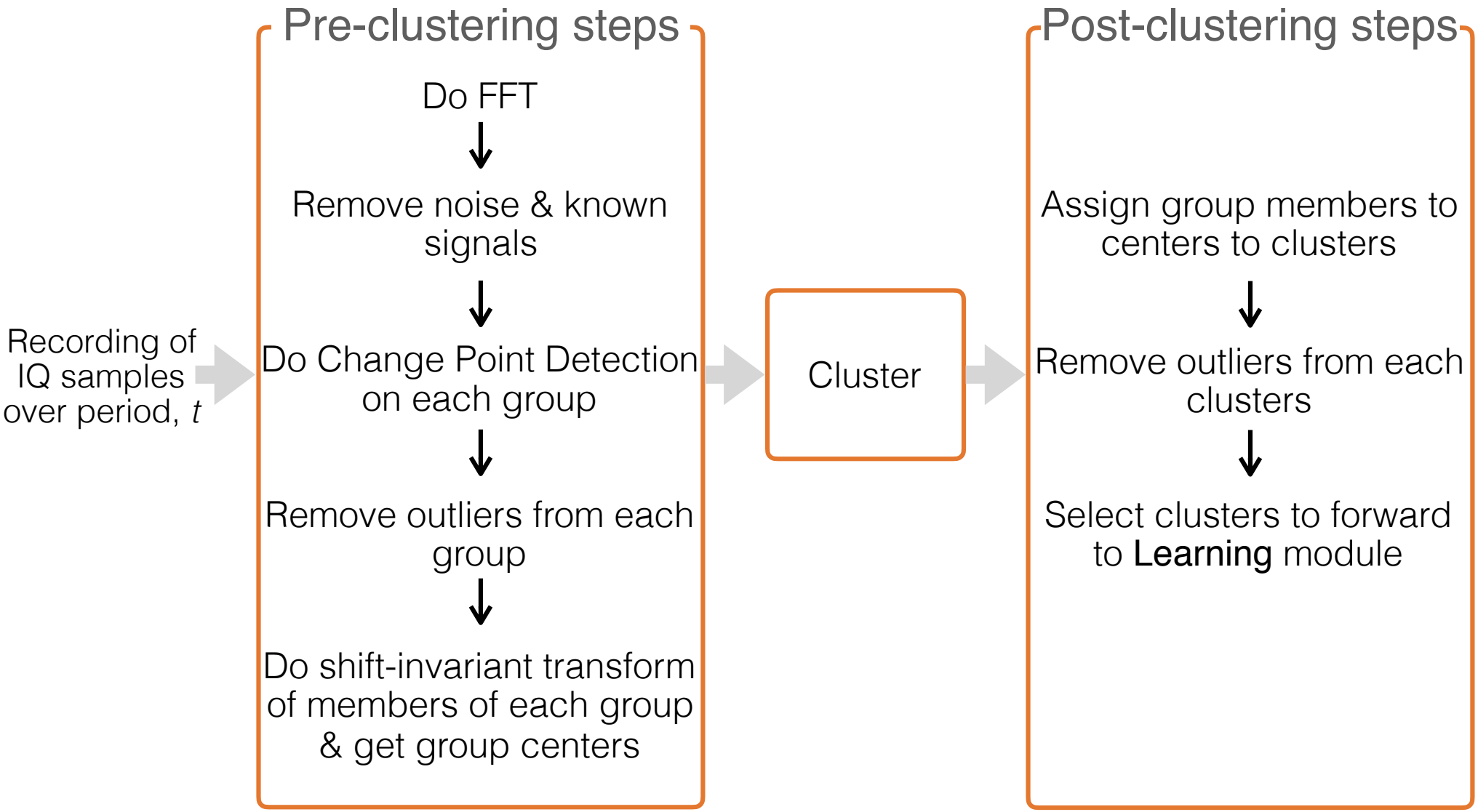
Workflow of offline module



Workflow of offline module



Greatly reduce # of data points to cluster

Challenge 1: Different channels but same signal class should be in same cluster

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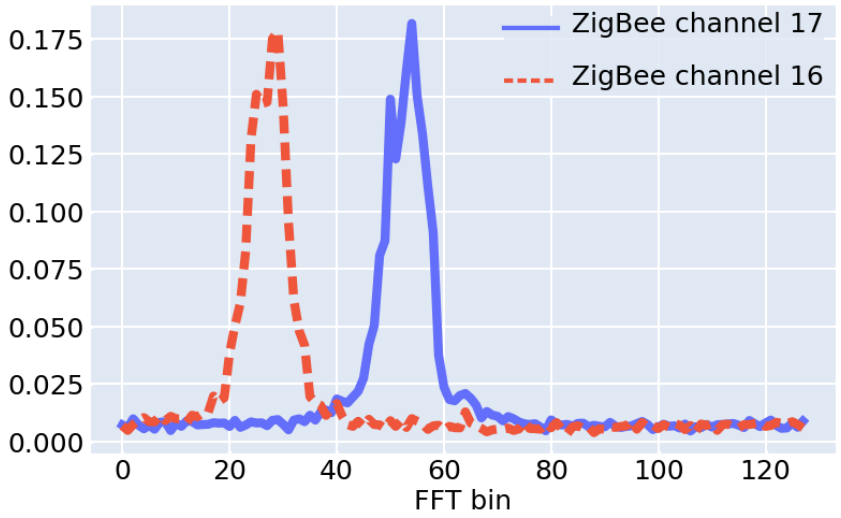
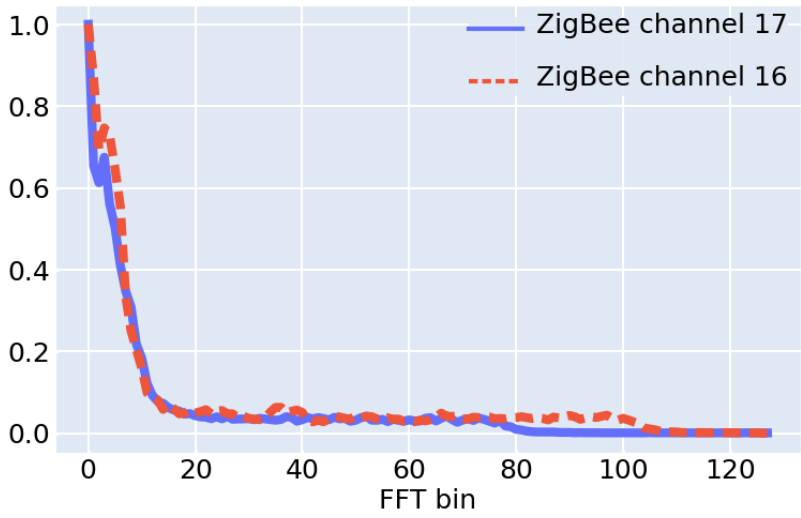
m-SCF shift-invariant



Power spectrum



m-SCF

Challenge 2: # unknown clusters

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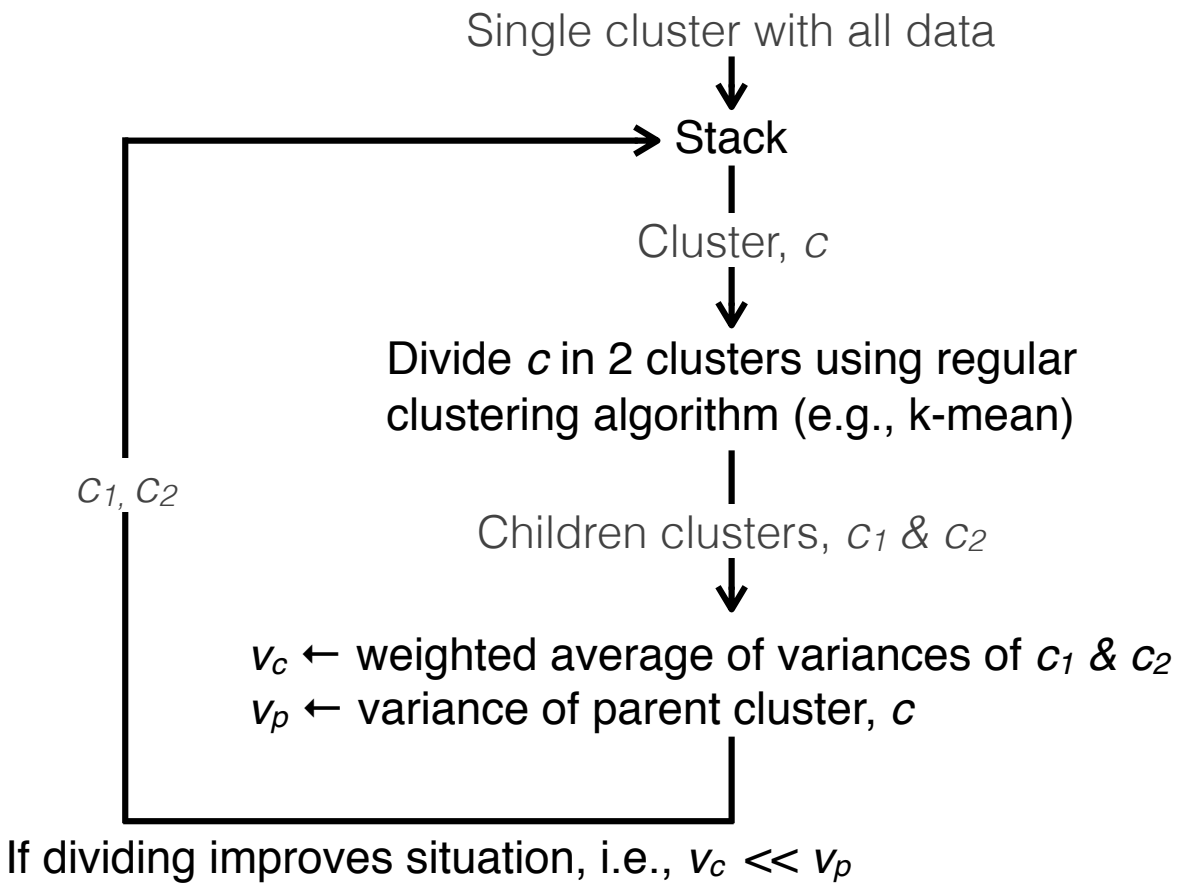
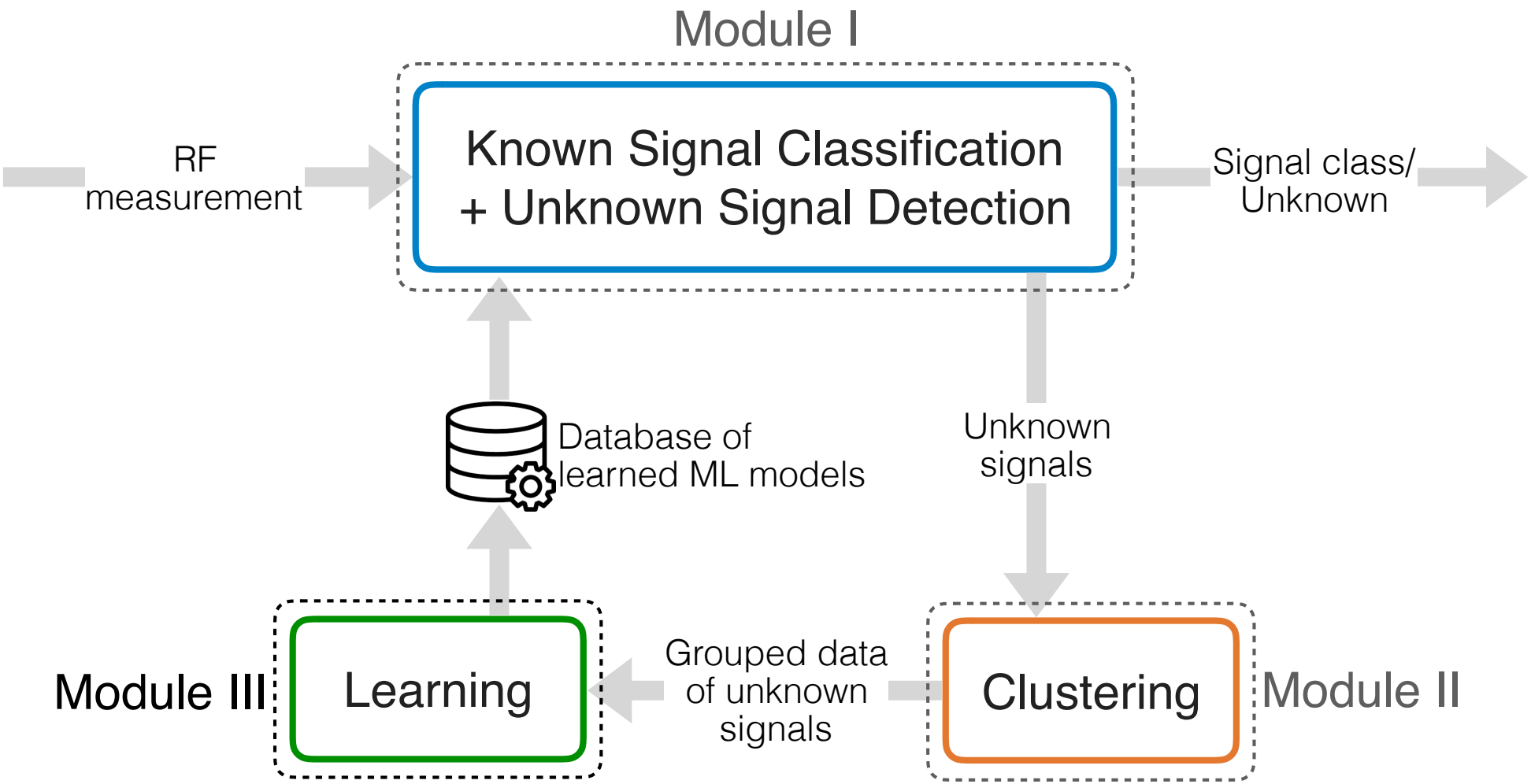
HIER-CLUST: our custom divisive hierarchical clustering algorithm

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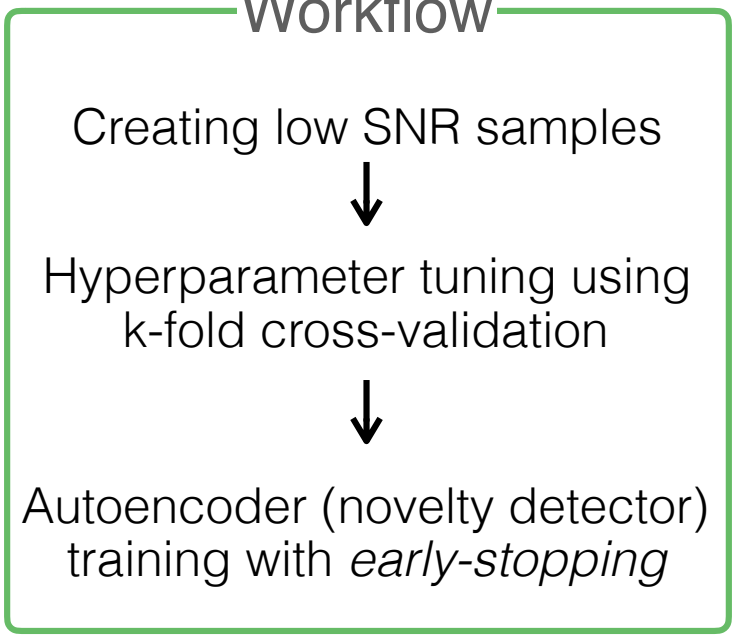


Evaluation

Implementation

KSC+USD module

- Standalone C++ application

Clustering module

- Multiple Python scripts for offline version

Learning module

- Multiple Python scripts
- CNN & Autoencoder: keras with Tensorflow backend

Evaluating real-time performance

Evaluation Setup

USRP X310

25 million samples/sec
25 MHz bandwidth

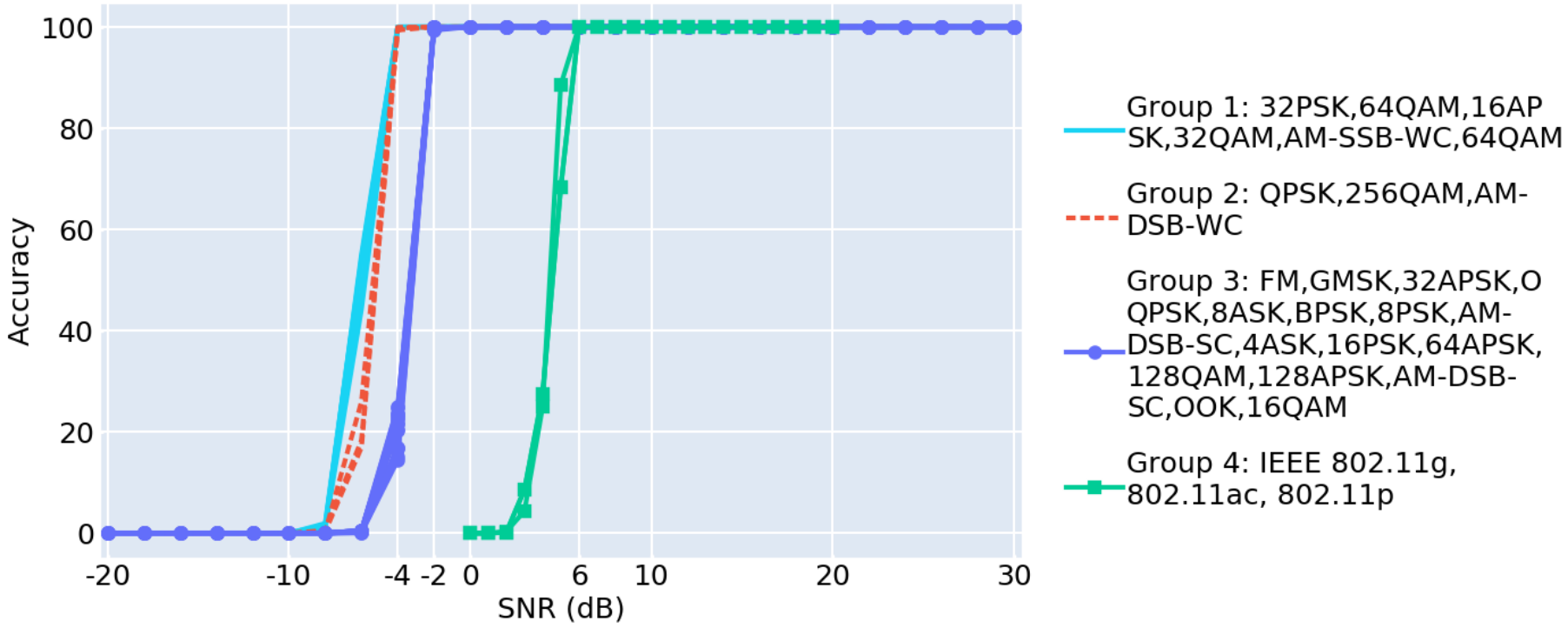
C++ application of
KSC+USD module

4-core 64-bit Intel i7-4810MQ
2.8GHz processor, 32GB RAM

Results

- No overflow in X310 in 2 hours run
- One prediction: ~4.6ms

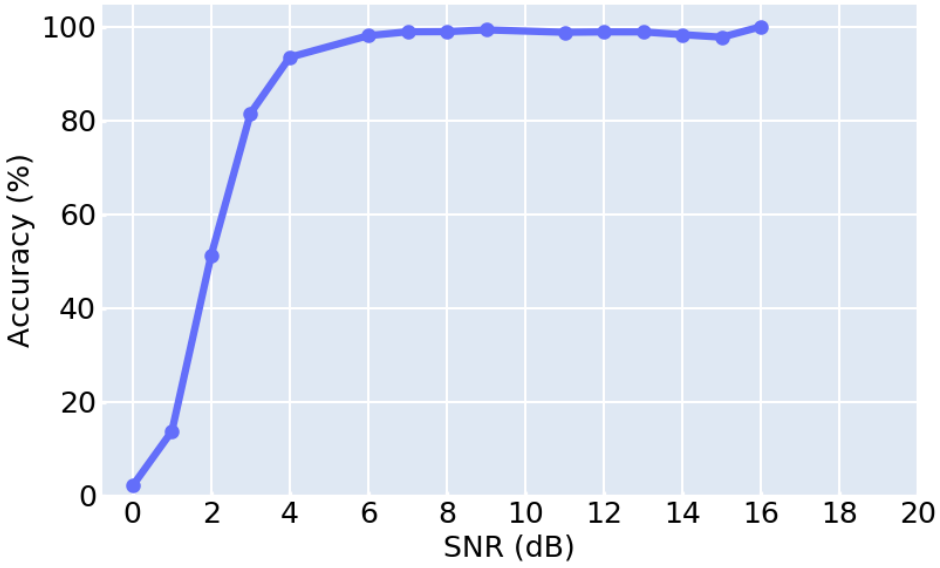
SNR vs. Signal/Noise Classifier accuracy



Groups 1-3: RADIOML 2018.01 dataset from DEEPSIG
Group 4: Our custom dataset with over-the-air (OTA) recordings

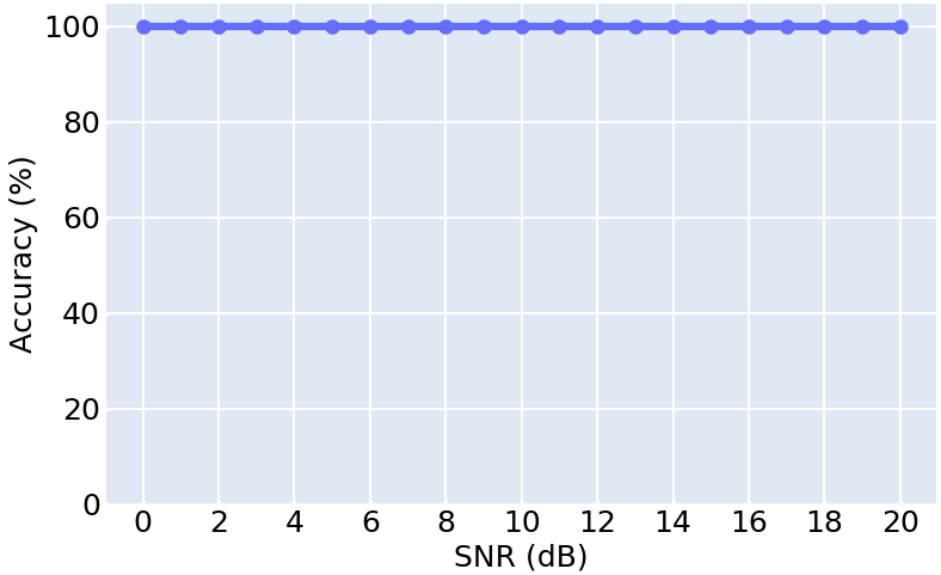
SNR vs. Novelty Detector accuracy

Known signal detection



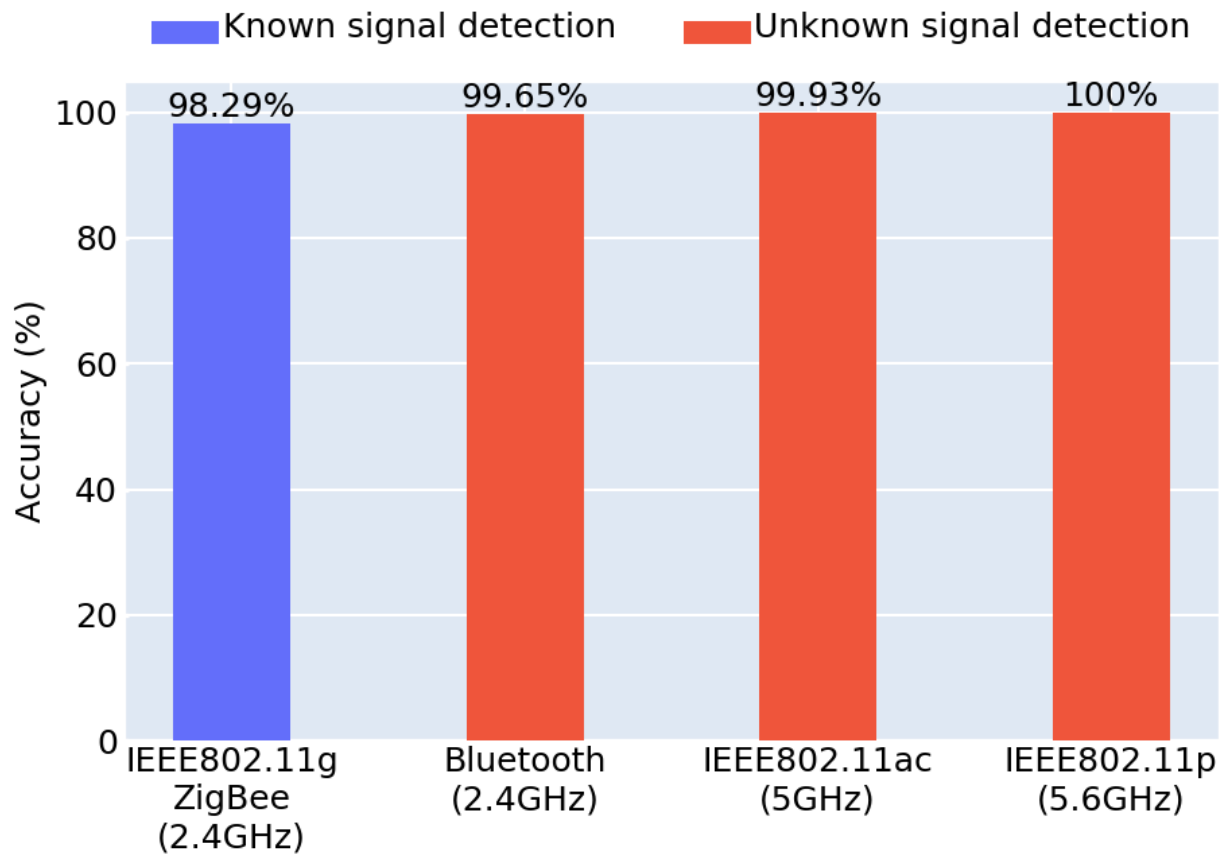
OTA recordings of IEEE 802.11g

Unknown signal detection



OTA recordings of IEEE 802.11p & IEEE 802.11ac

Novelty Detector accuracy for different signals



HIER-CLUST performance for class imbalanced dataset

Ratio of # of data points in largest to smallest class		20	10	5
# of classes		5	2	4
HIER-CLUST	# of clusters found	8	2	5
	Normalized Mutual Information (NMI)	0.9609	1.0	0.9298

Labeled signal data from OTA recording in 2.4GHz band

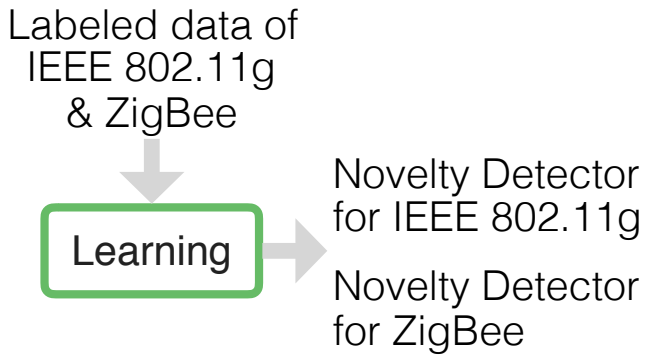
Normalized Mutual Information (NMI)
$0 \leq NMI \leq 1$, values close to 1 indicate good clustering

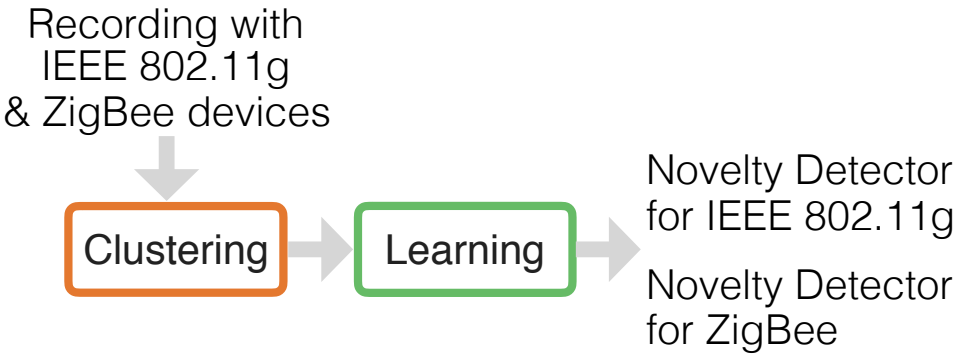
HIER-CLUST performance for different environment dataset

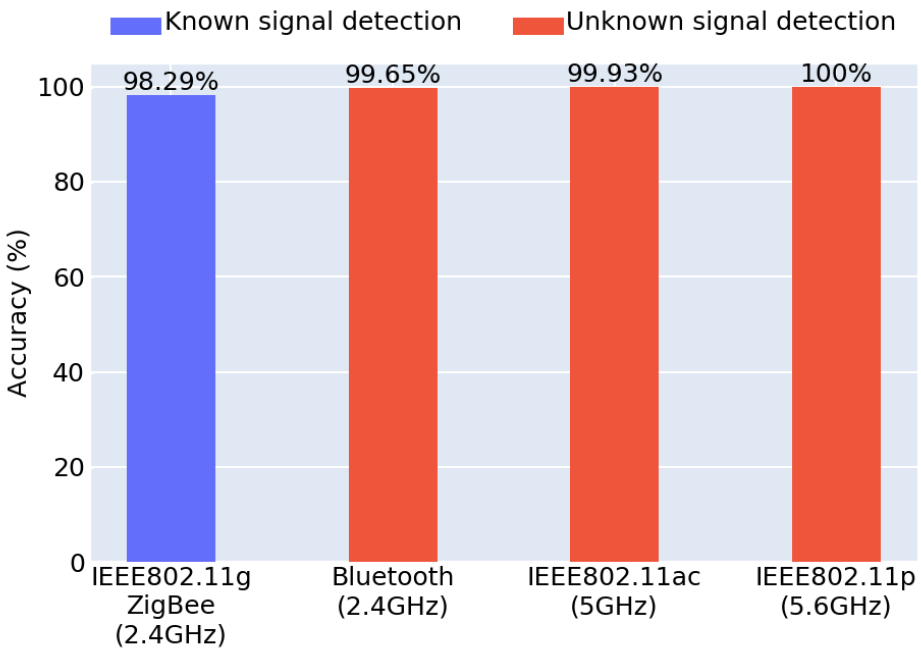
Frequency band		5.6 GHz	2.4GHz in anechoic chamber
Device type		IEEE802.11p	Bluetooth
# of expected signal classes		1	1
HIER-CLUST	# of clusters found	2	3
	Cluster details	Cluster 1: IEEE802.11p Cluster 2: noise from some wide-band signal	Cluster 1: Bluetooth Clusters 2, 3: Bluetooth mixed with DC offset spikes at center frequency

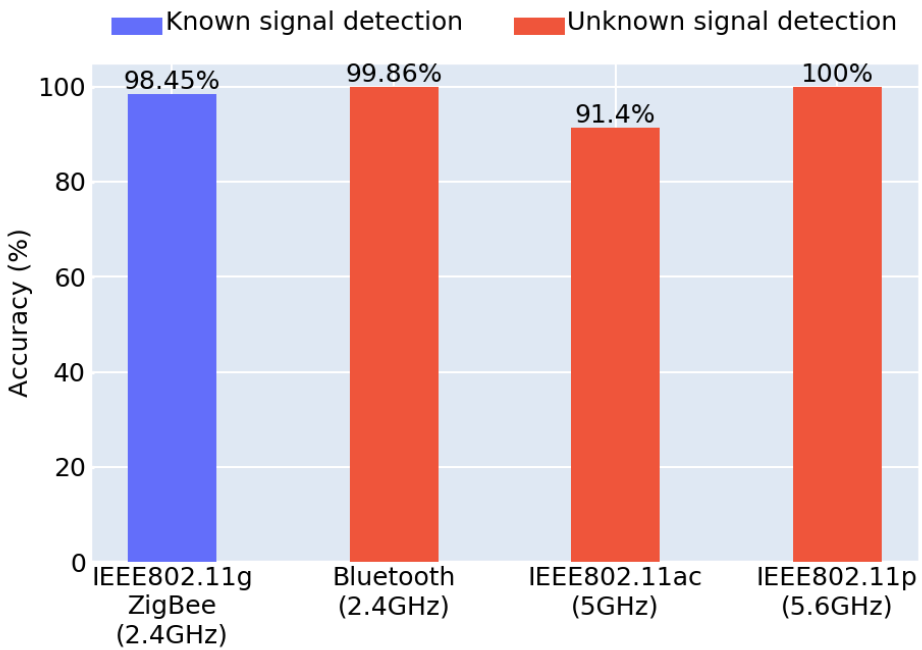
Evaluating incremental learning capability

Novelty Detector from labeled data vs clustering









Summary

- Wireless-environment Cognizance System
  - Adaptive & robust against changes in deployed environment, hardware, computing resources

- Thorough evaluation for several OTA scenarios

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