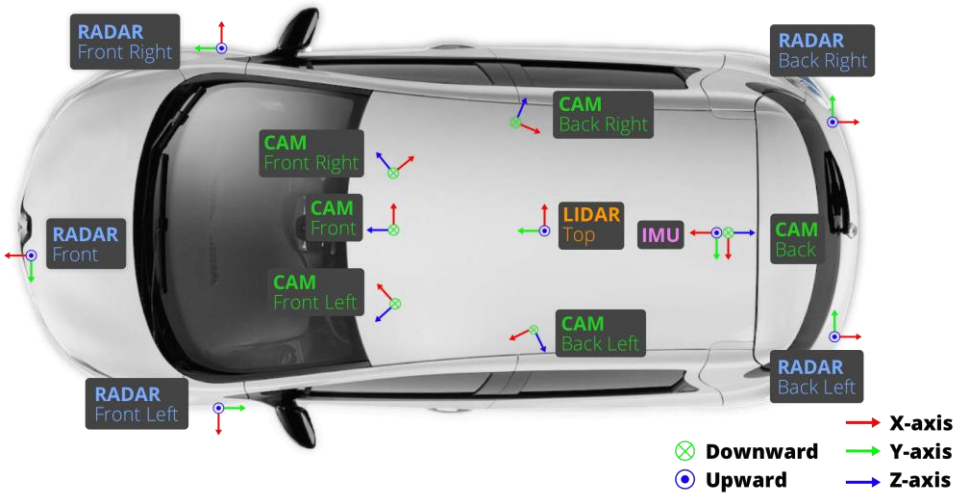
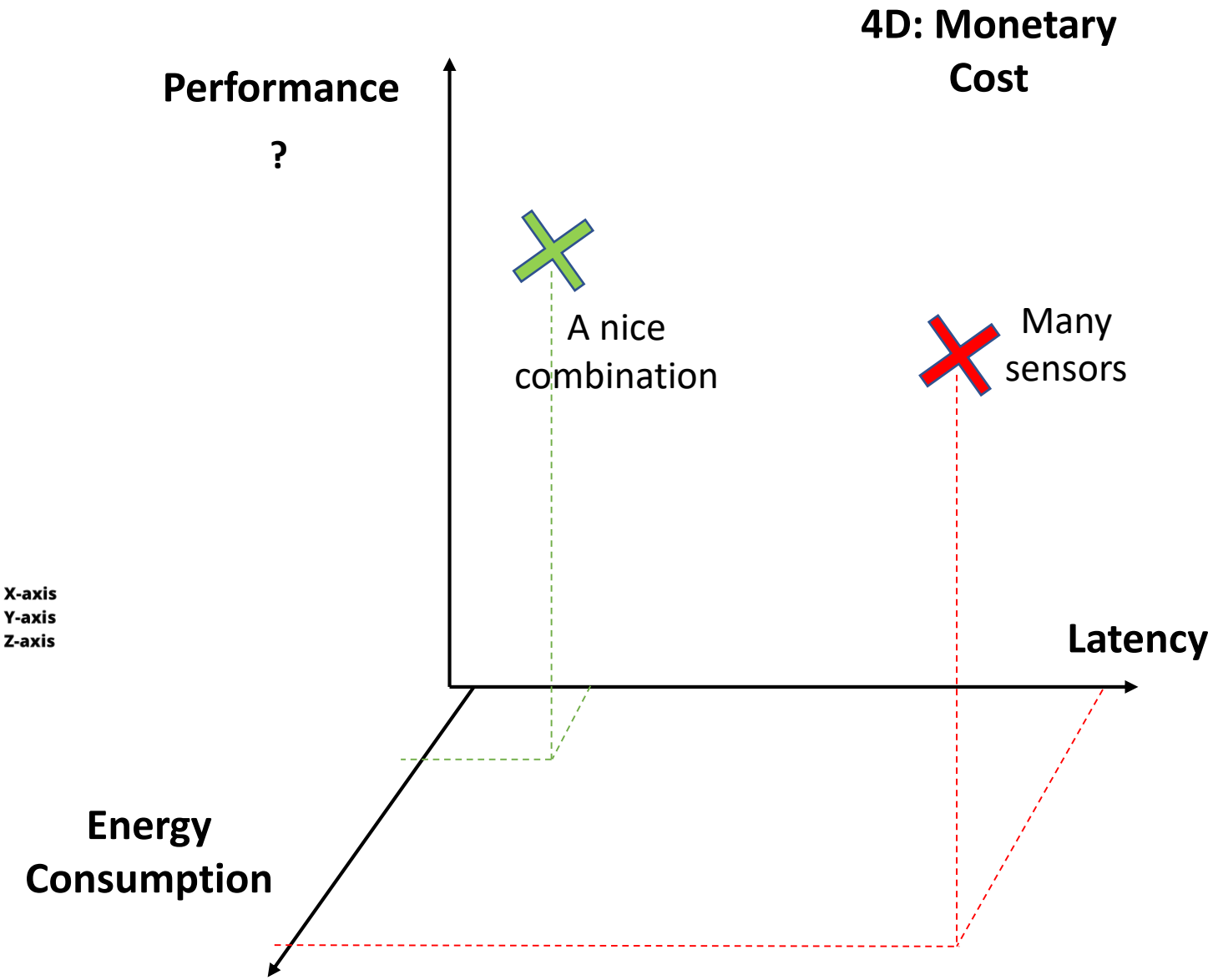
A Multiobjective Systems Architecture Model for Sensor Selection in Autonomous Vehicle Navigation

Anne Collin, Afreen Siddiqi, Yuto Imanishi, Yukti Matta, Taisetsu Tanimichi, and Olivier de Weck

Sensor Trade-offs



From nuScenes.org



Motivation

My thesis research

Evaluate and **find** “good” hardware architectures for autonomous vehicles.

This presentation

What is a “**good**” sensor combination for autonomous vehicles localization and mapping? How can we **find** it?

Sensor Library

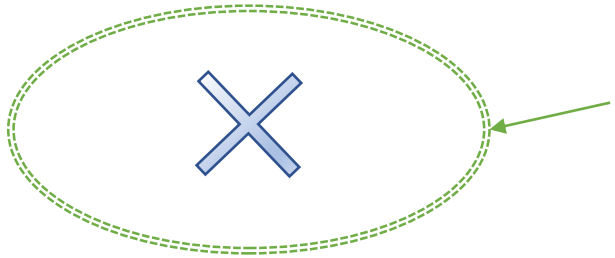
Sensor	**Range** (m)	**FOV*** (rad)	σ_{range} (m)	$\sigma_{bearing}$ (rad)	**Cost** ($)	**Passive Energy Consumption (W)**
Long-range Radar	250	0.0698	0.013	0.00175	1,493	6.6
Mid-Range Radar	160	0.1	0.04	0.00175	2,830	4.5
Long Range LiDAR	120	2π	0.084	0.00110	100,000	60
Mid-Range LiDAR	100	2π	0.03	0.00524	4,000	8

Stereo Camera	**Range** (m)	**FOV *** (rad)	**Baseline** (m)	**Focal Length** (pixels)	**Cost** ($)	**Passive Energy Consumption** (W)
Wide angle	50	$\pi/2$	0.5371	721.5377	2,990	5
HD2K	20	1.33	0.120	1400	449	2
Low resolution	20	1.52	0.120	350	449	2

**Field Of View*

SLAM Evaluation Metric

Precision



Uncertainty Ellipse around Estimated Position

$$\log\det(\boldsymbol{\Sigma})$$

Covariance matrix

$$\boldsymbol{\Sigma}^{-1} = \mathbf{I}$$

Information matrix

$$\begin{aligned}\log\det(\mathbf{I}) &= \log\det(\mathbf{A}^{\mathbf{T}}\mathbf{A}) \\ &= \log\det(\mathbf{R}^{\mathbf{T}}\mathbf{R}) \\ &= 2\sum_i \log(R_{ii})\end{aligned}$$

R is an easily accessible upper triangular matrix, already used for the inference

(Carrillo 2012), (Pukelsheim 2006), (Kaess 2012)

Evaluation Methods

- **Performance**: SLAM precision
- **Energy Consumption**:
  - Sensor passive energy consumption
  - Energy for data storage
  - Energy for cooling inside the car (memory banks)
- **Cost**: linear addition of sensor costs
- **Latency**: RAM usage and Clock Cycle

Tradespace Exploration

- Evolutionary algorithms:
  - Computationally expensive
  - Difficult to validate for lack of other models of AV sensor selection
- Constraint-satisfaction methods
  - No constraints
- Problem formulation

$$\max_{x_1,\ldots,x_k \in S} \log\det I(x_1,..,x_k) \quad s.t.$$

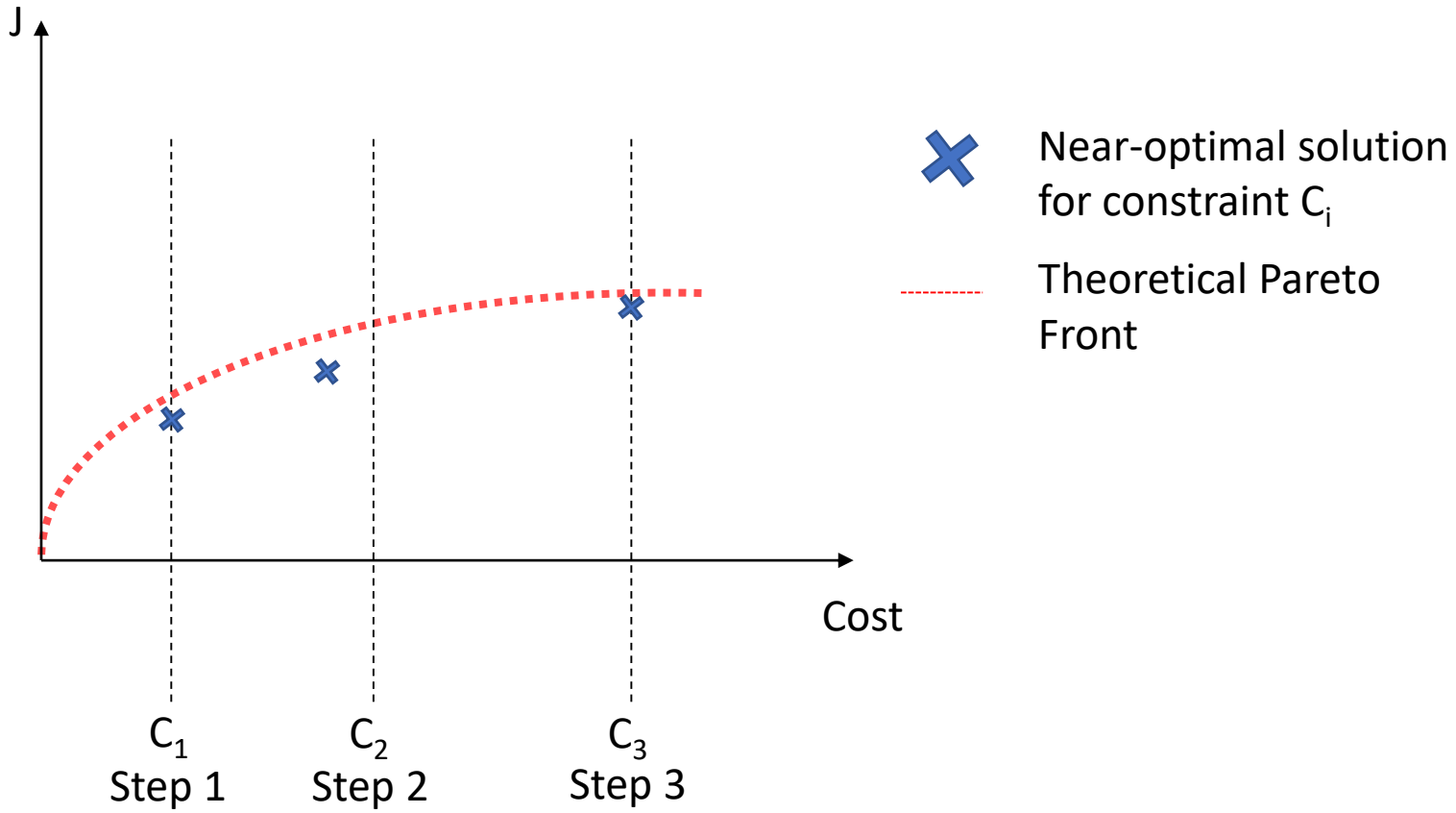
$$\mathcal{R}(x_1,...,x_k) \leq R, R \in \mathbb{R}$$

$$\mathcal{C}l(x_1,...,x_k) \leq C_l, C_l \in \mathbb{R}$$

$$\mathcal{E}(x_1,...,x_k) \leq E, E \in \mathbb{R}$$

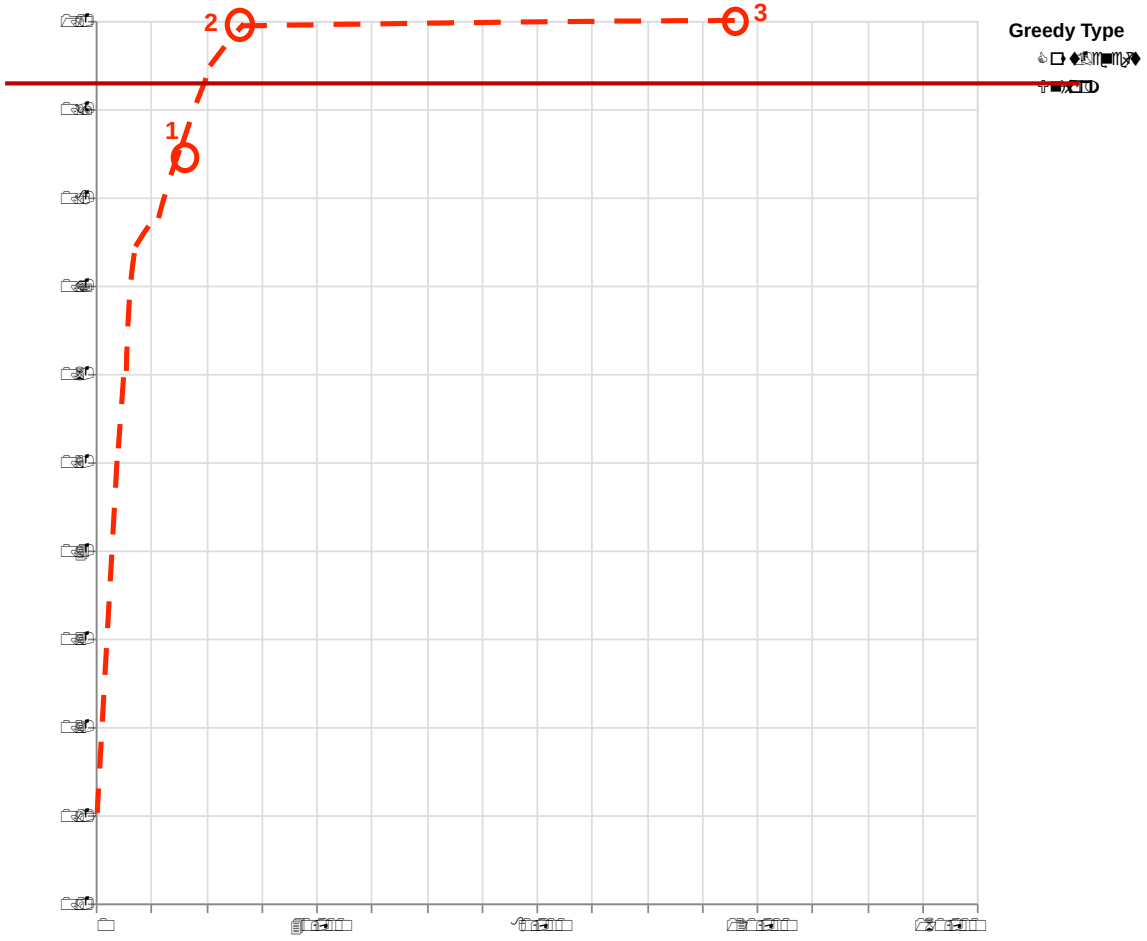
$$\mathcal{C}(x_1,...,x_k) \leq C, C \in \mathbb{R}$$

Tradespace Exploration



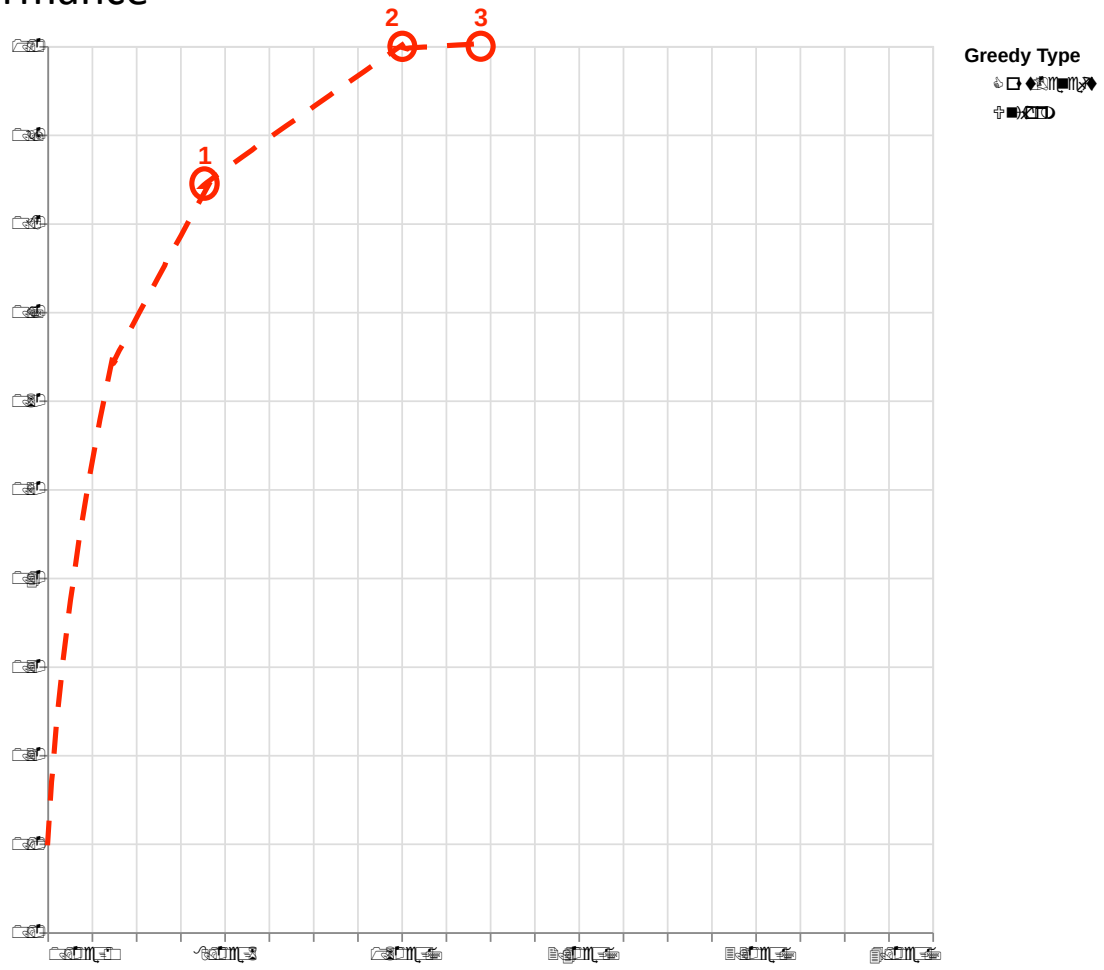
Tradespace Exploration - Results

Performance



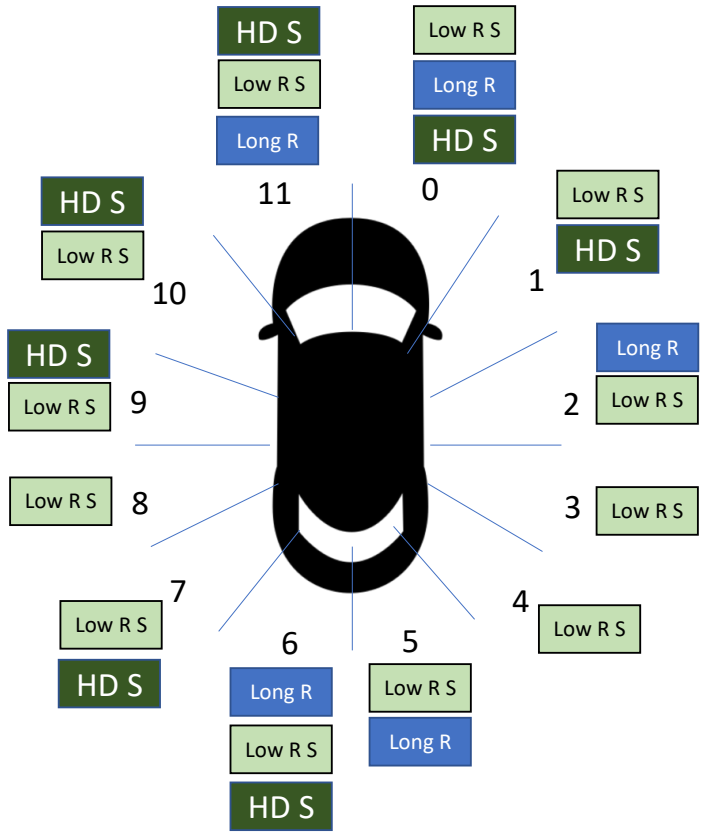
Cost ($)

Performance

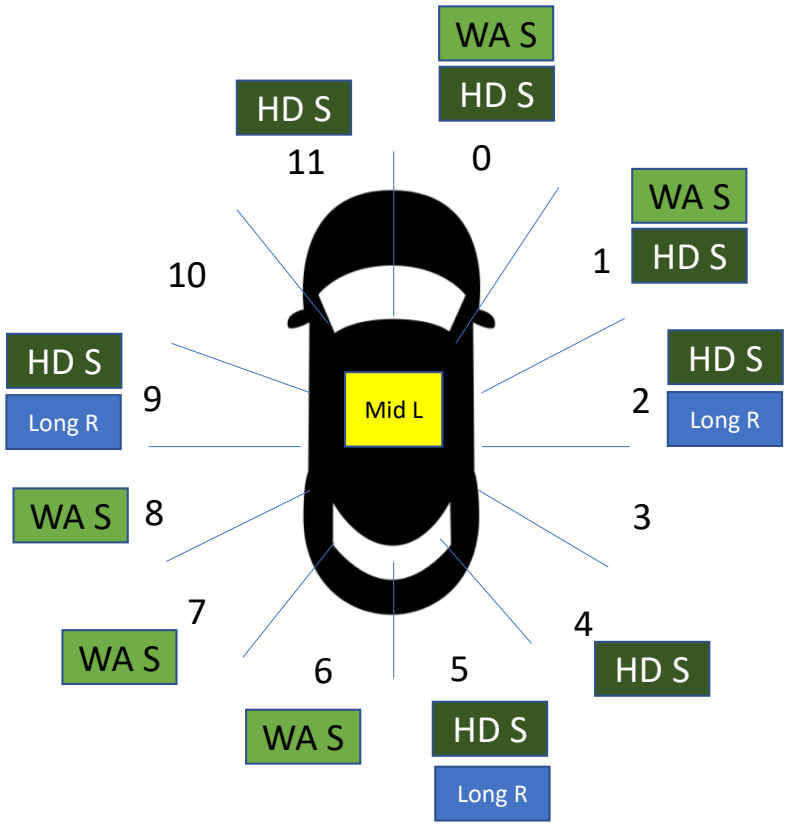


Clock Cycle (-)

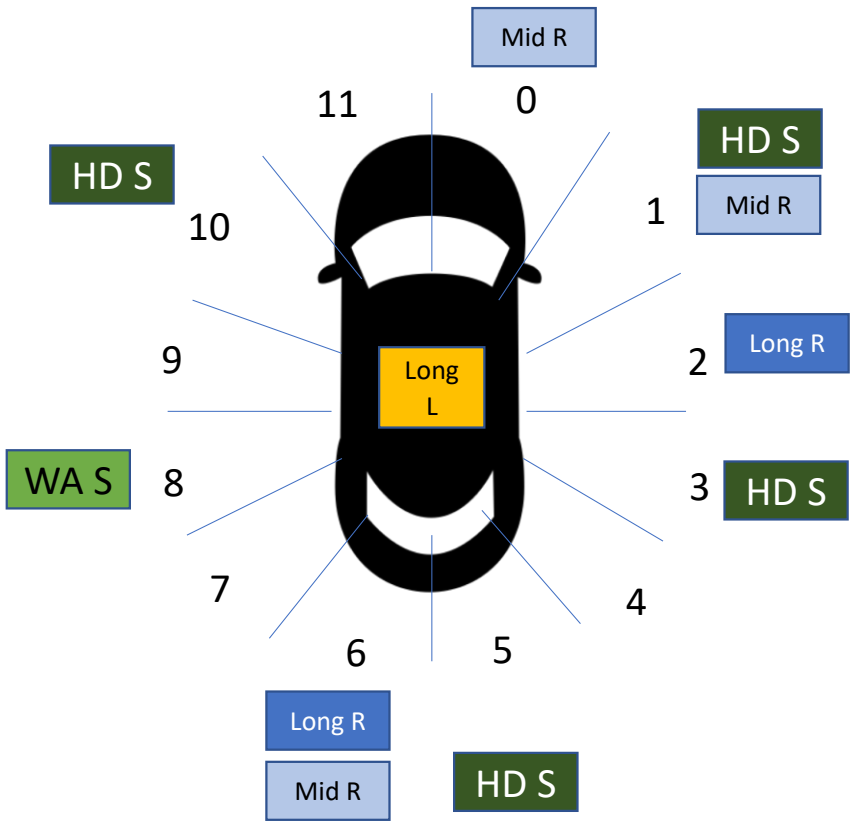
Conclusion - Architecture comparison



1



2



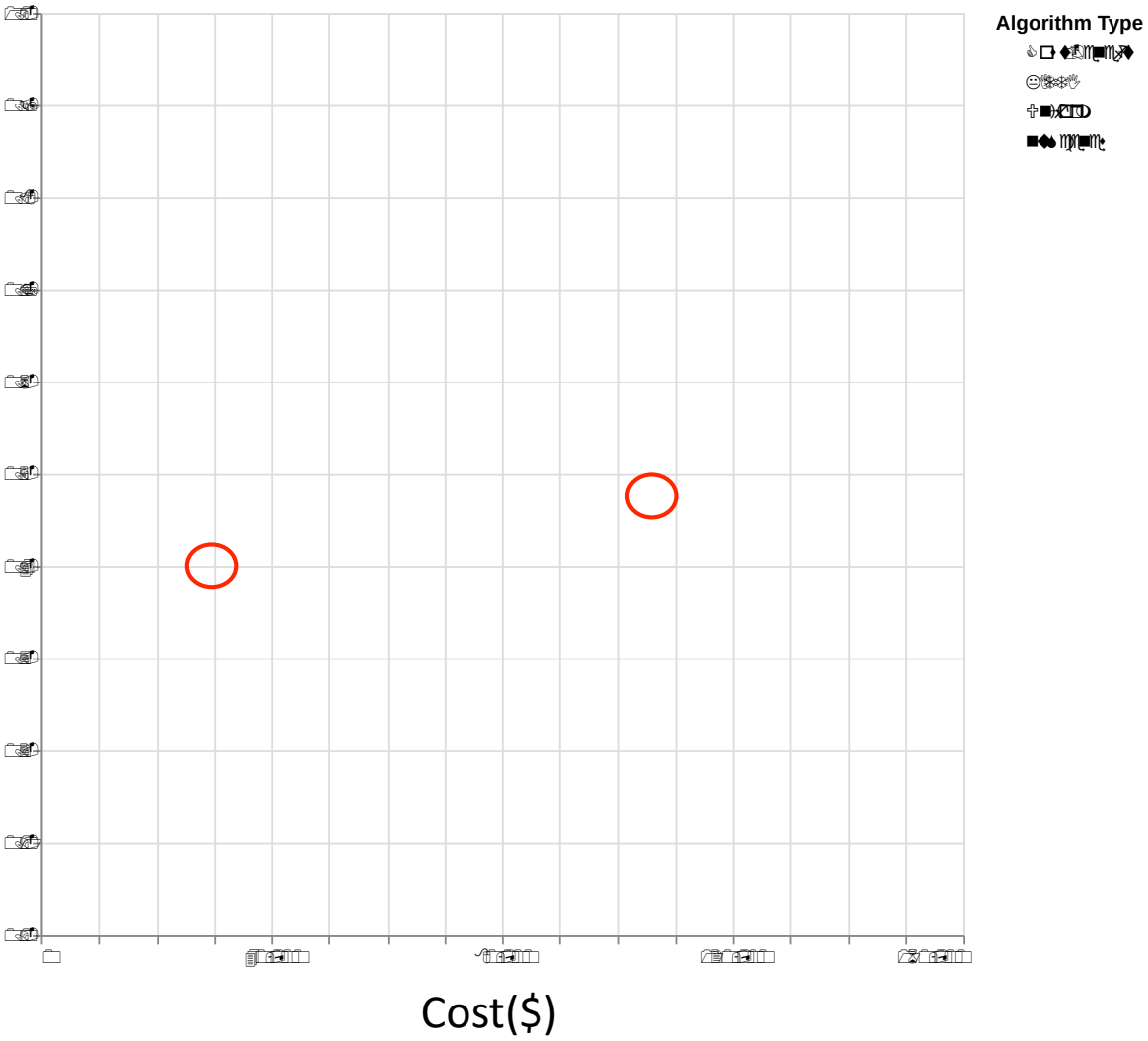
3

These three architectures are on the Pareto Fronts

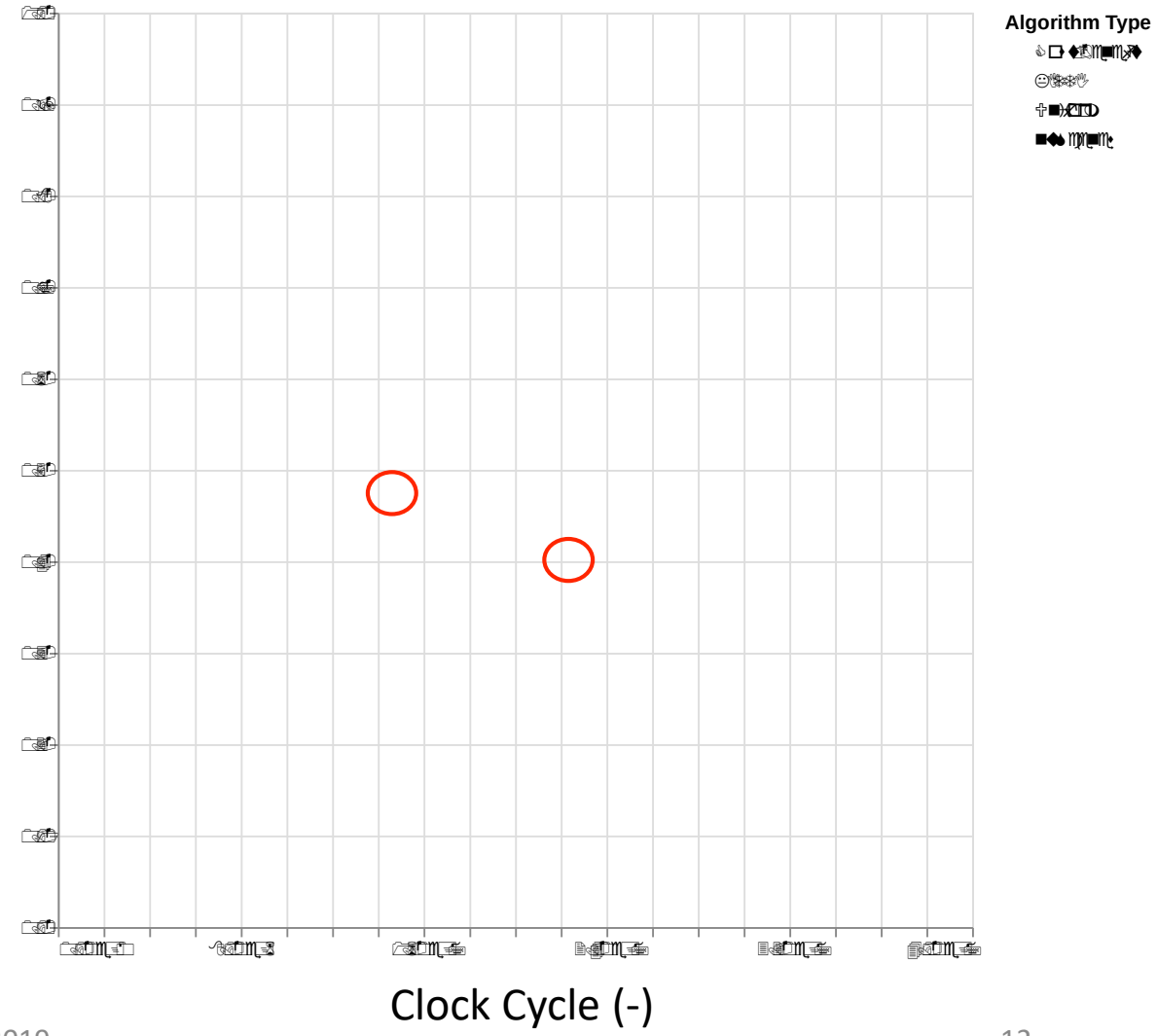
Bonus Slides

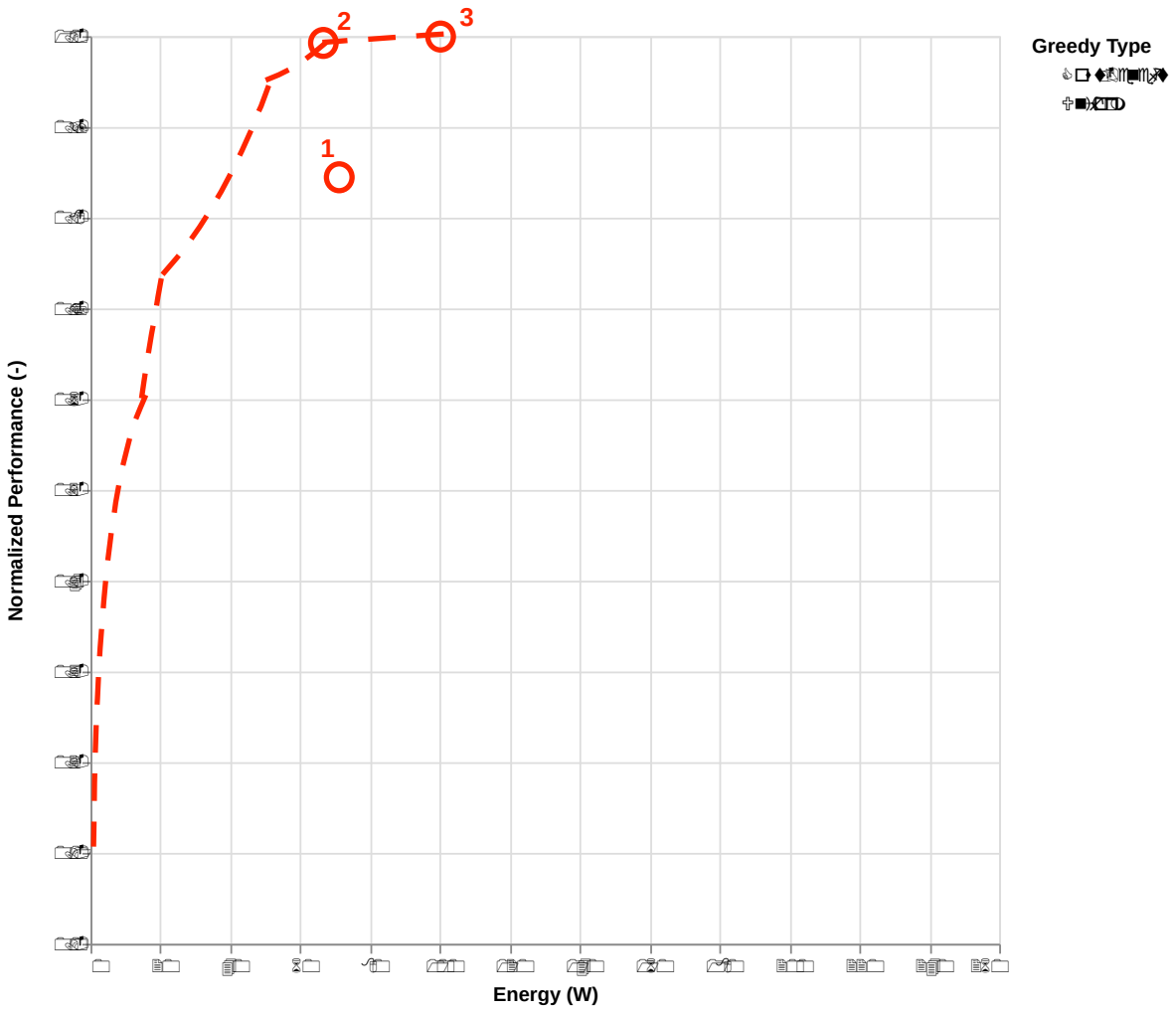
Tradespace Exploration - Validation

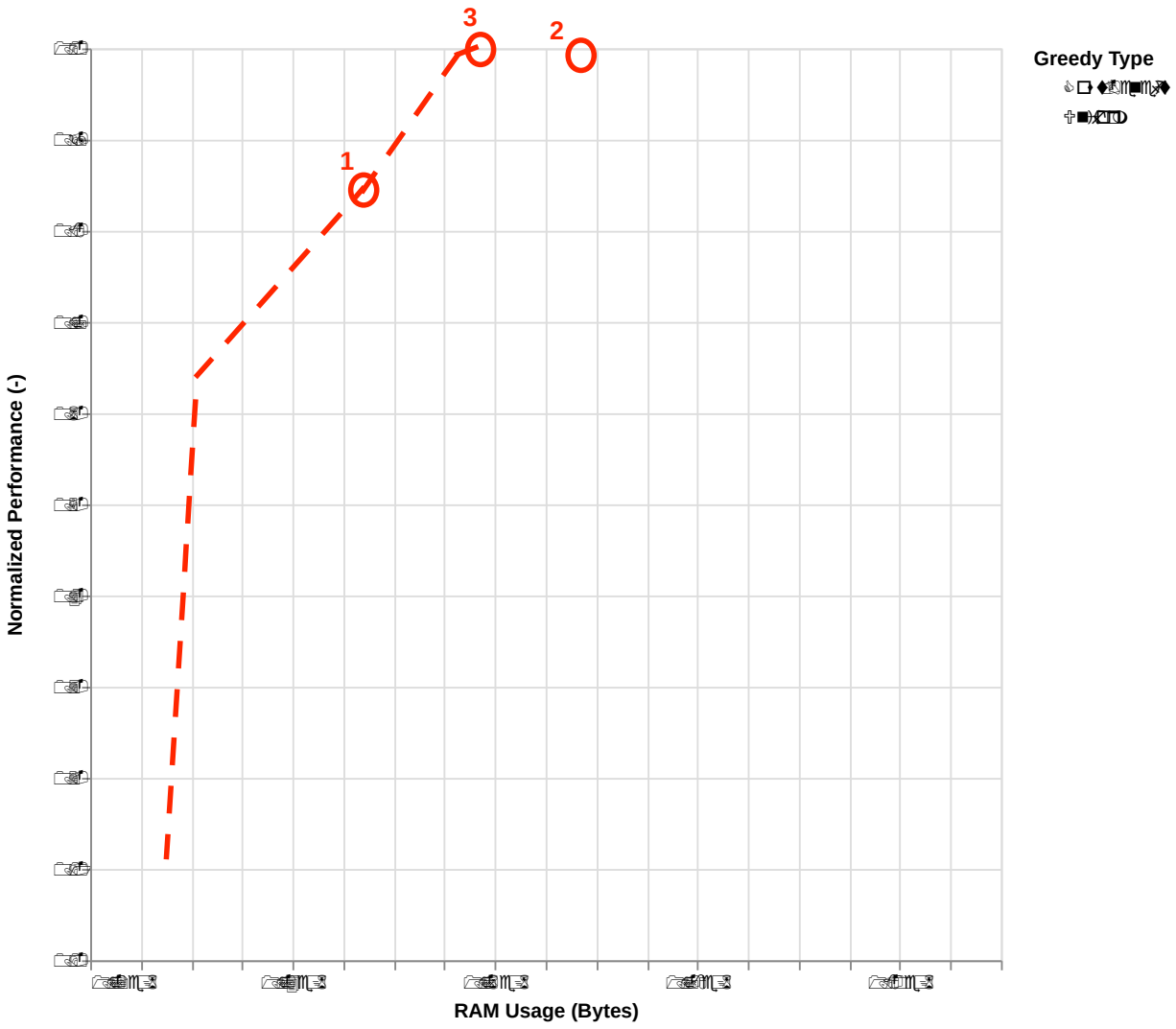
Performance



Performance




Normalized Performance (-)
Energy (W)
Greedy Type
1
2
3


Normalized Performance (-)
RAM Usage (Bytes)
Greedy Type
1
2
3