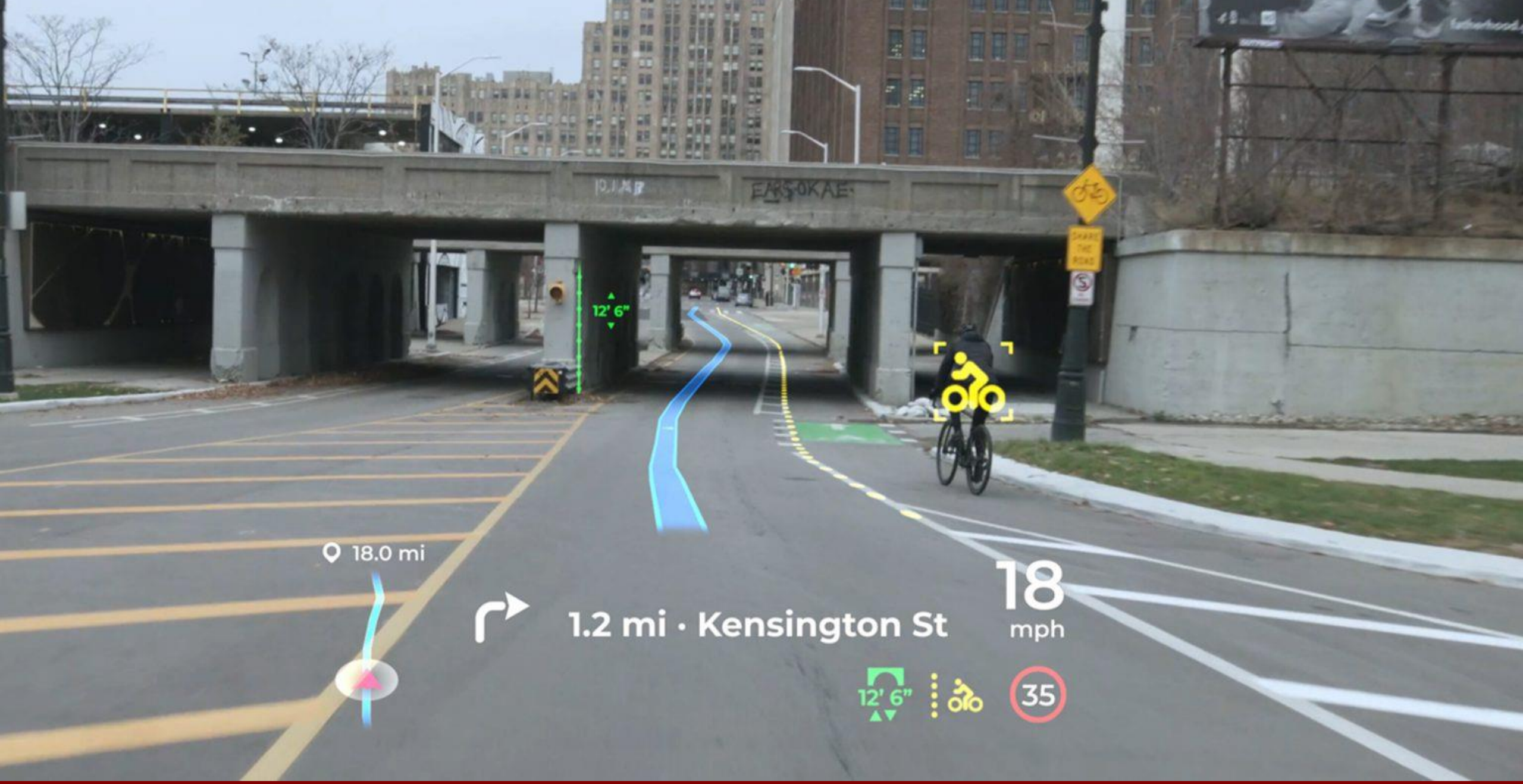
Elastic Scheduling for the ARM Augmented Reality Heads-Up Display

Marion Sudvarg, Ao Li, Chris Gill, Ning Zhang

Thursday, 11 July, 2024

ECRTS 2024 Industrial Challenge

Washington University in St. Louis
James McKelvey School of Engineering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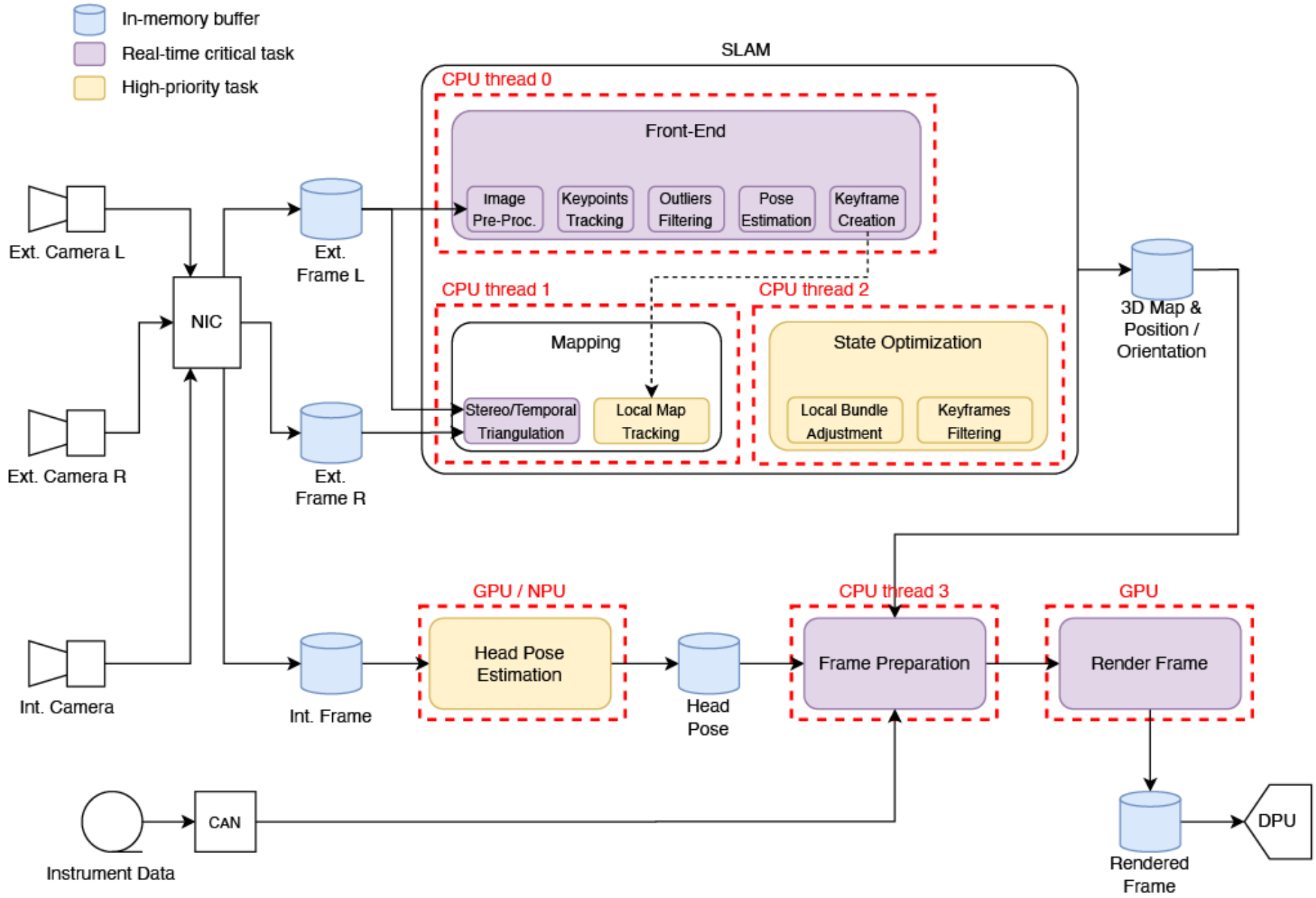
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High-priority task
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Front-End
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Render Frame
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Instrument Data
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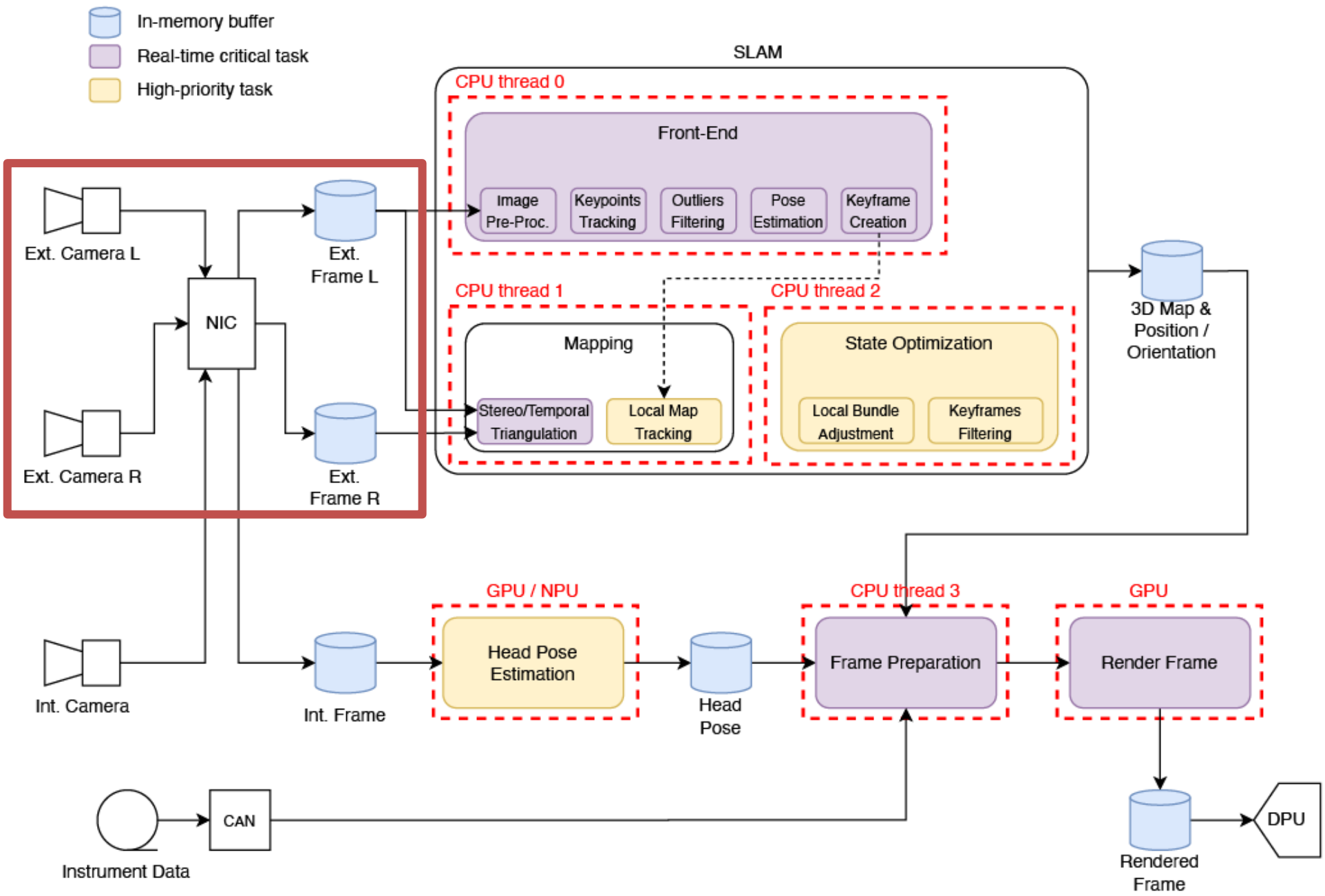
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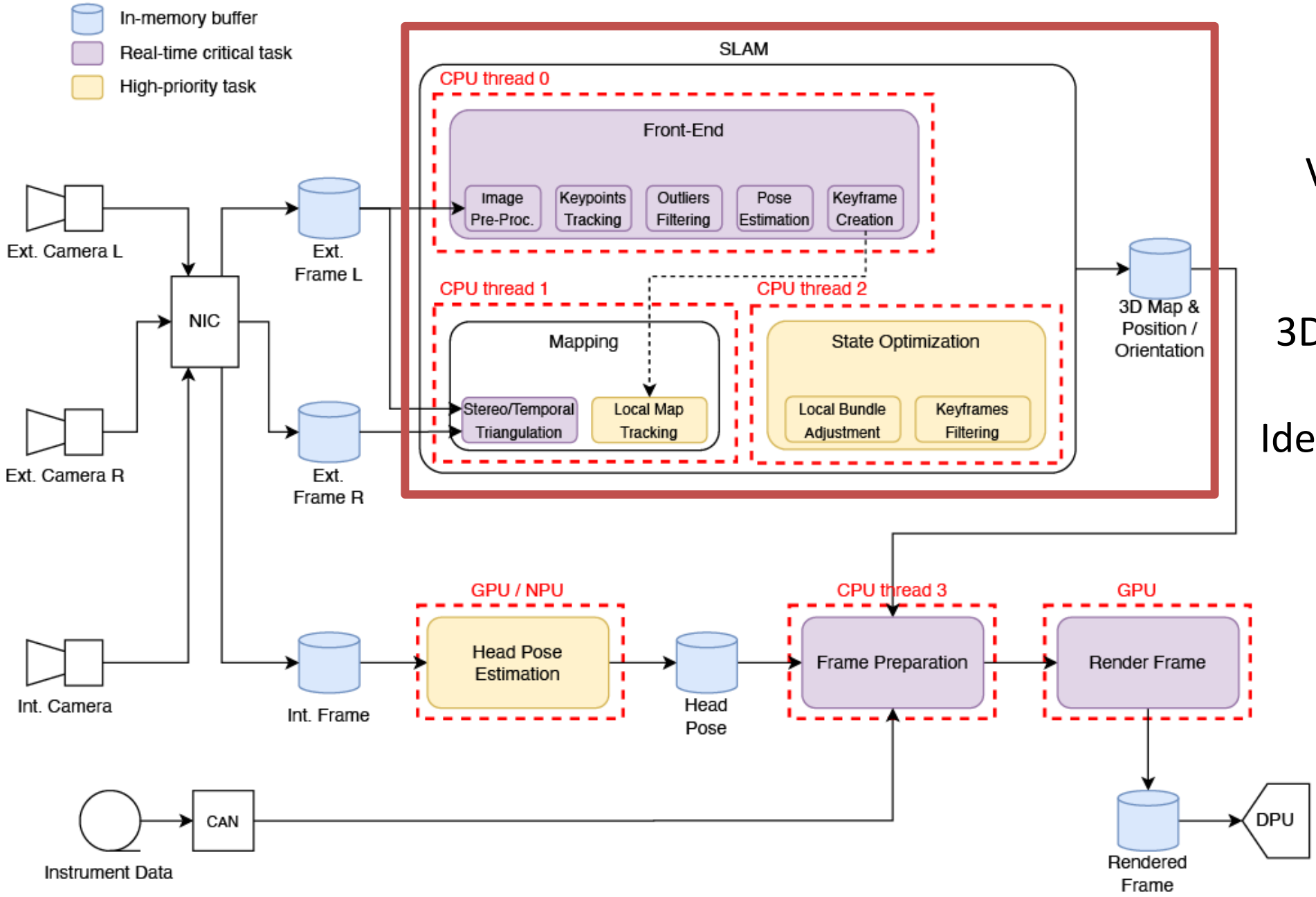


OV²SLAM

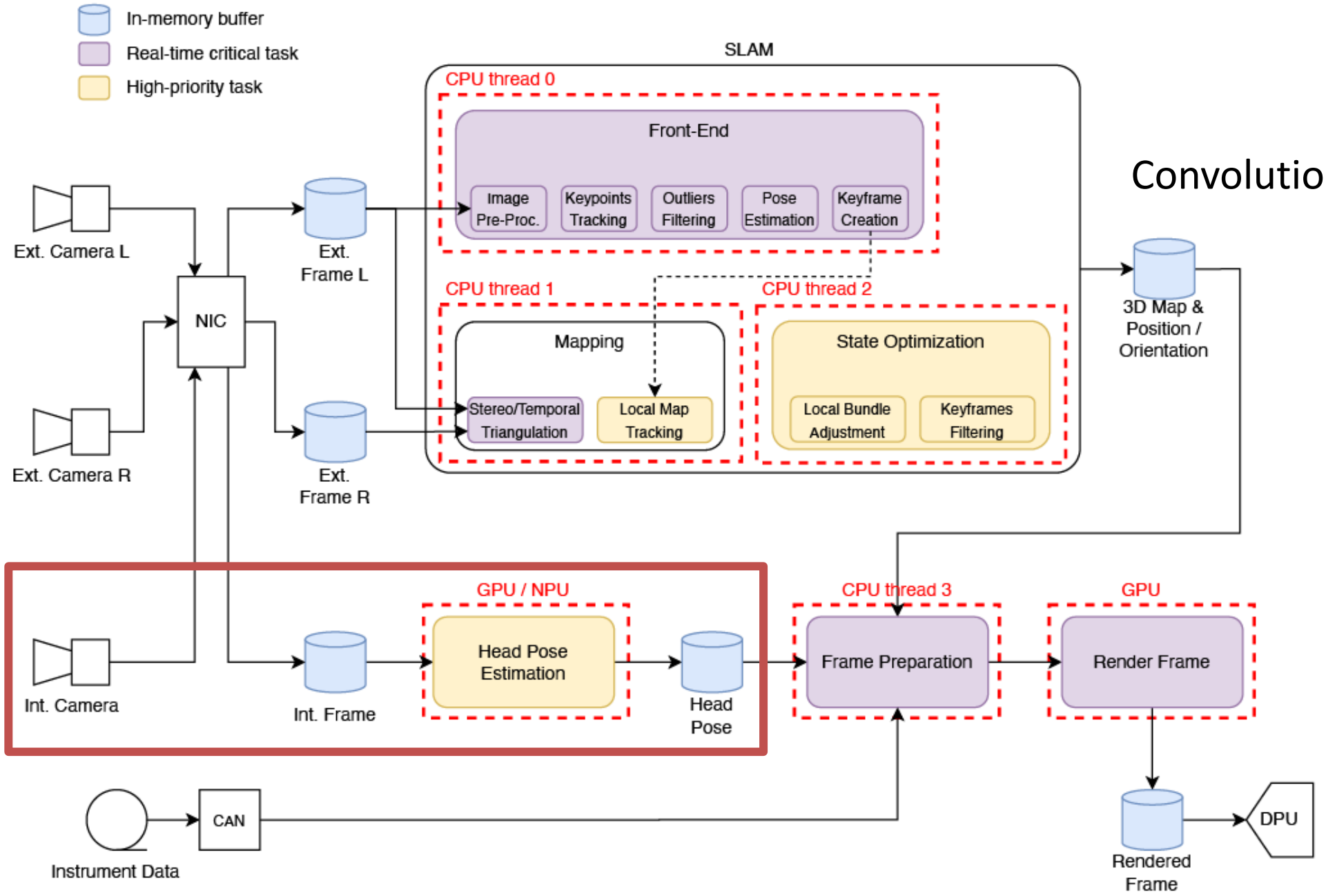
Vehicle orientation + trajectory

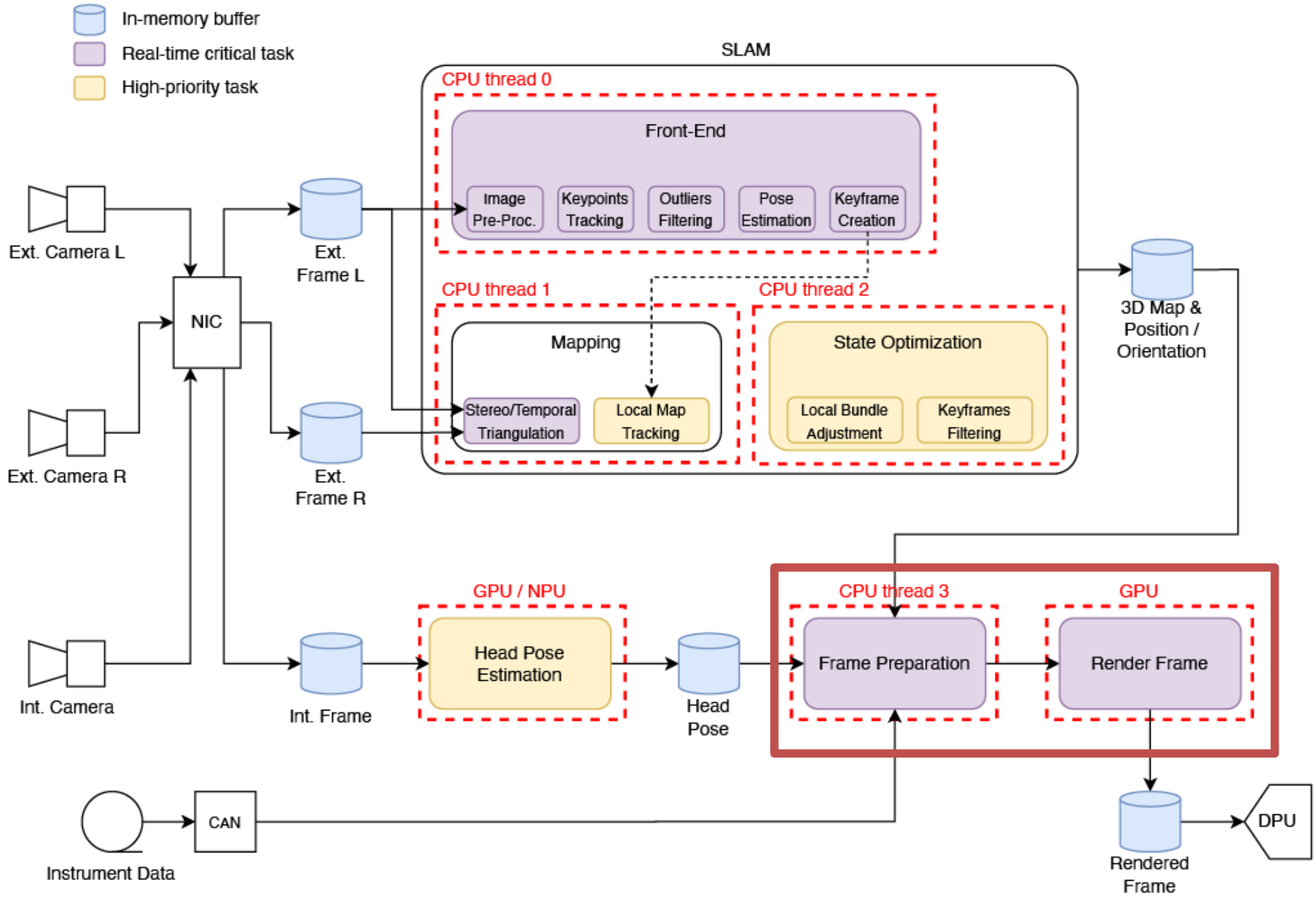
3D map of surroundings

Identify objects / features in map

Hopenet

Convolutional Neural Network

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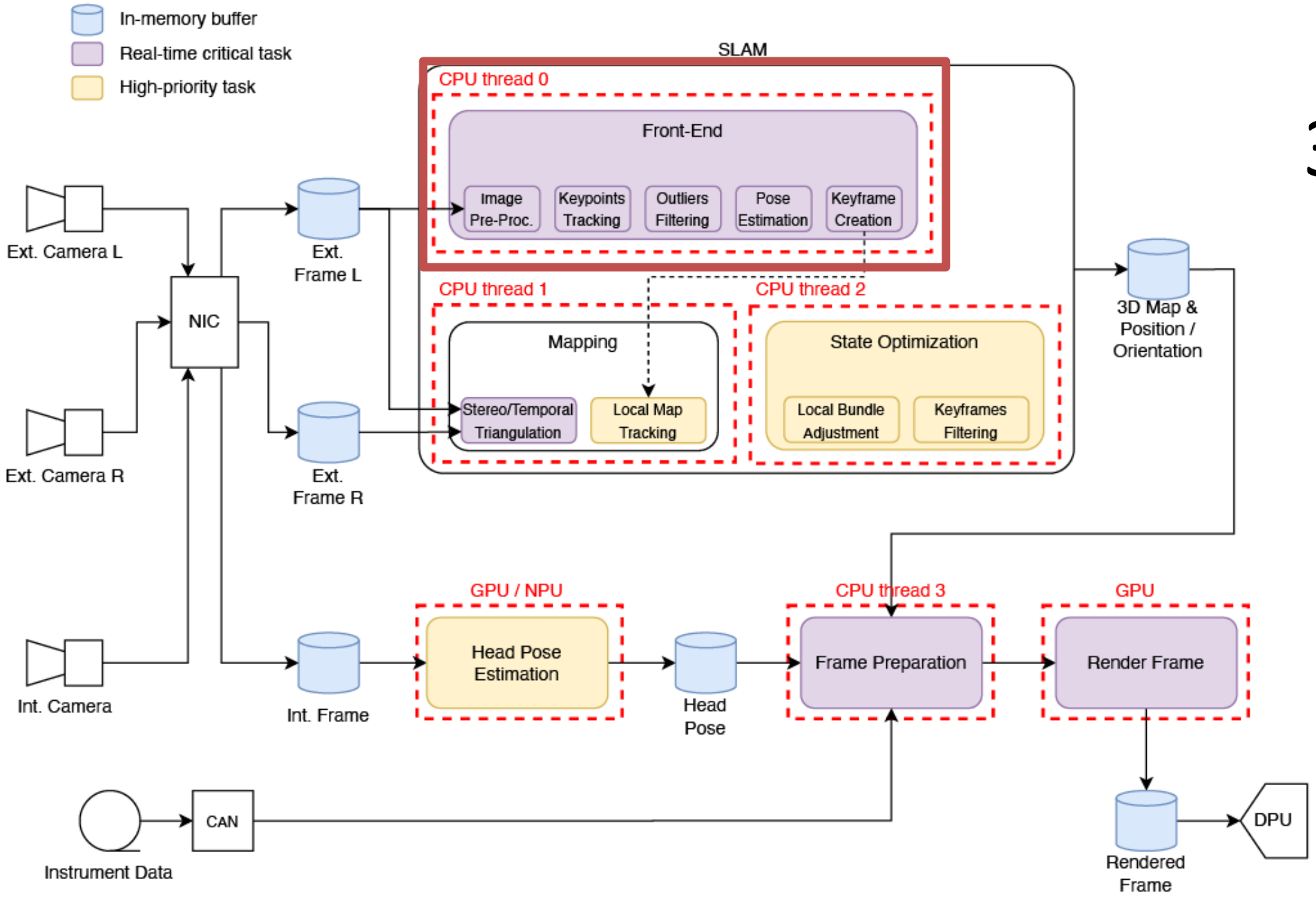
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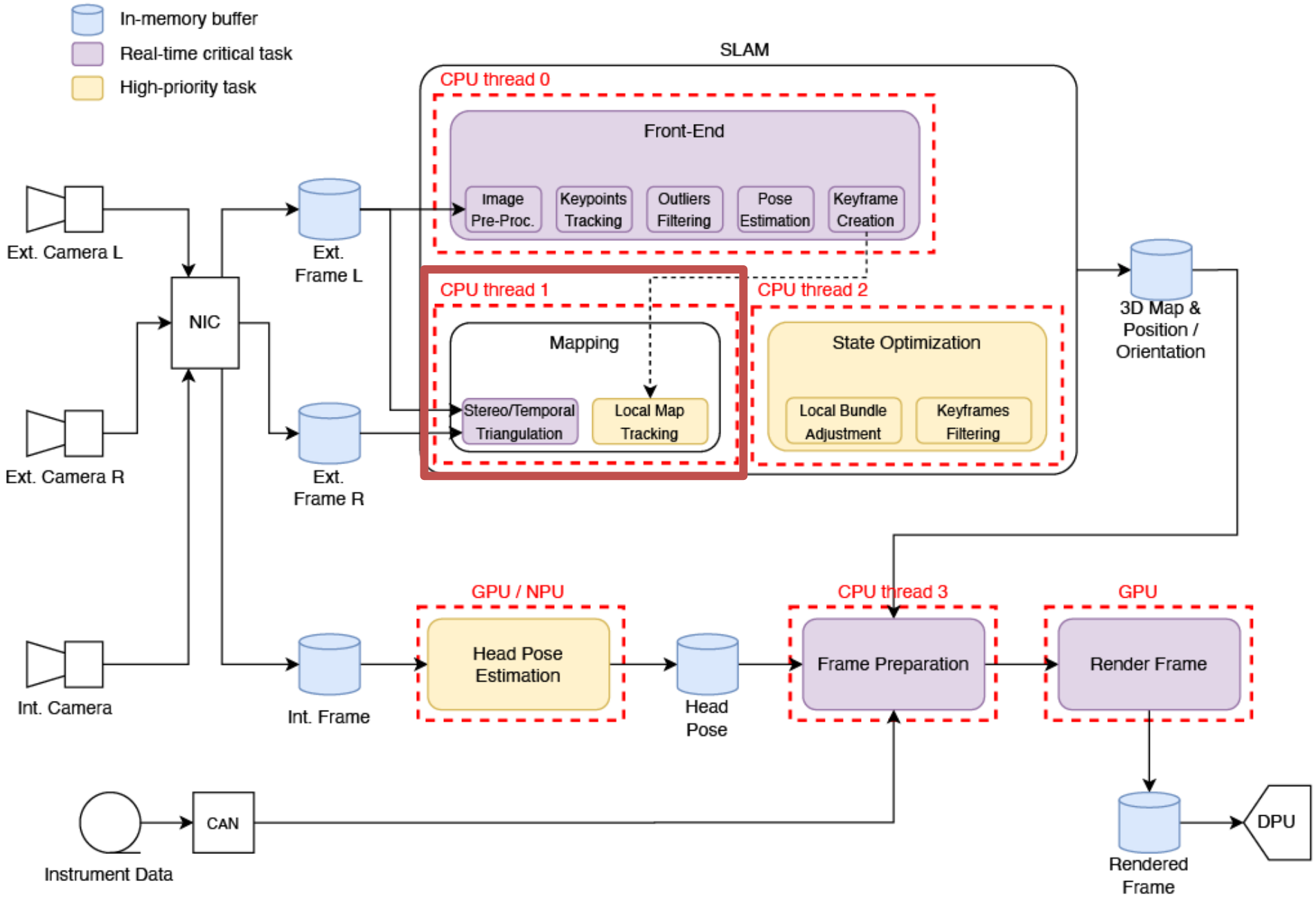
30-60 fps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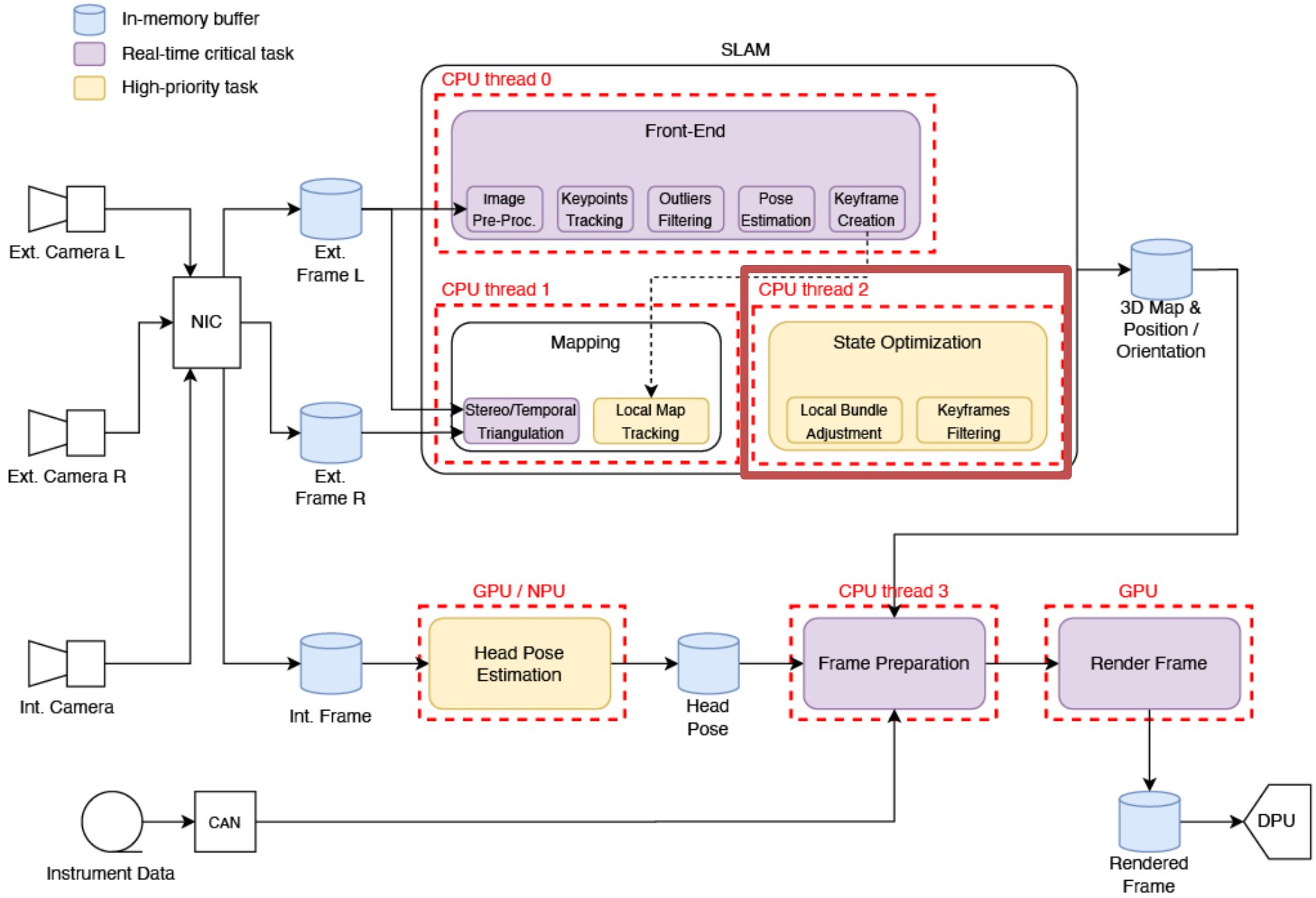
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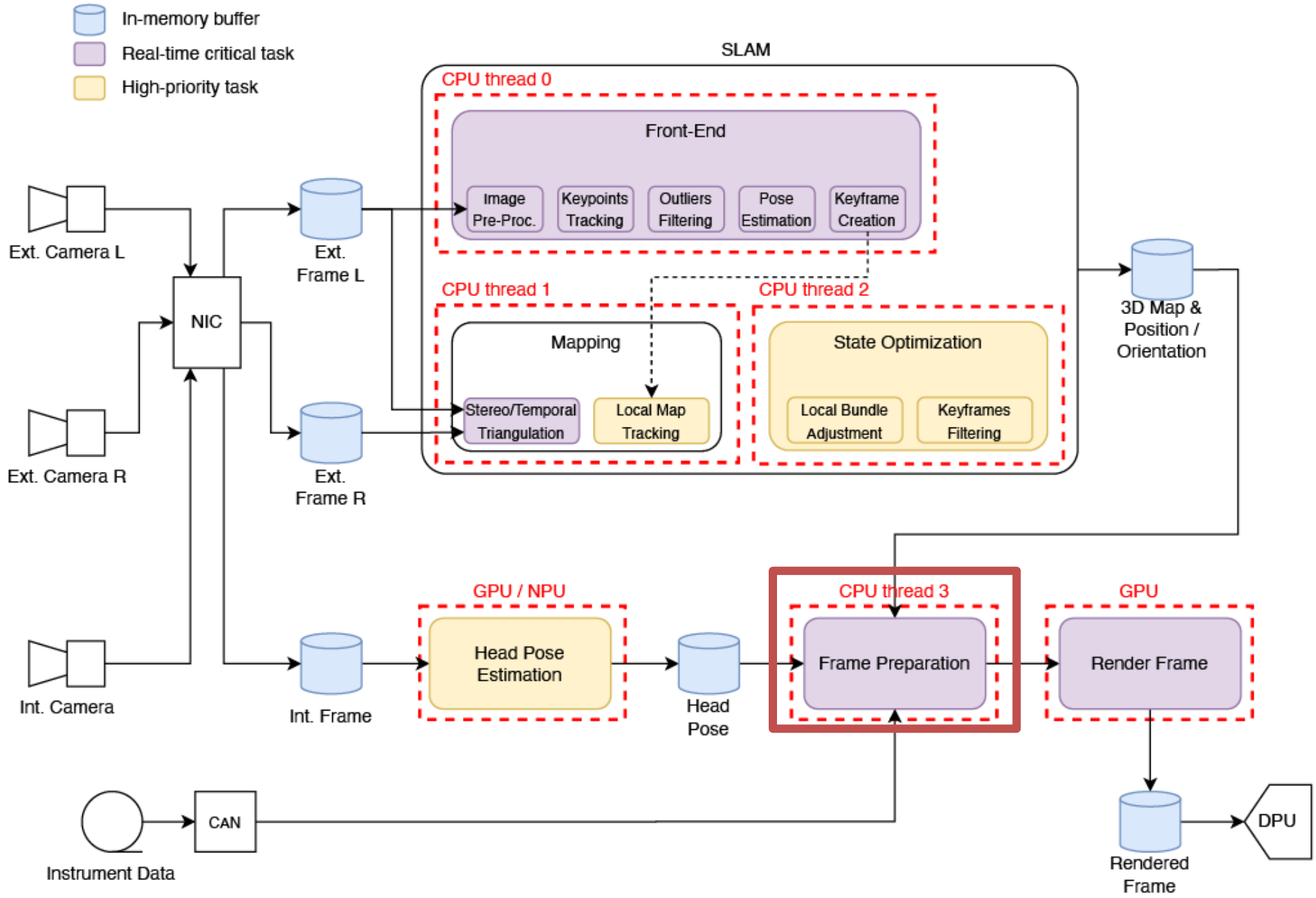
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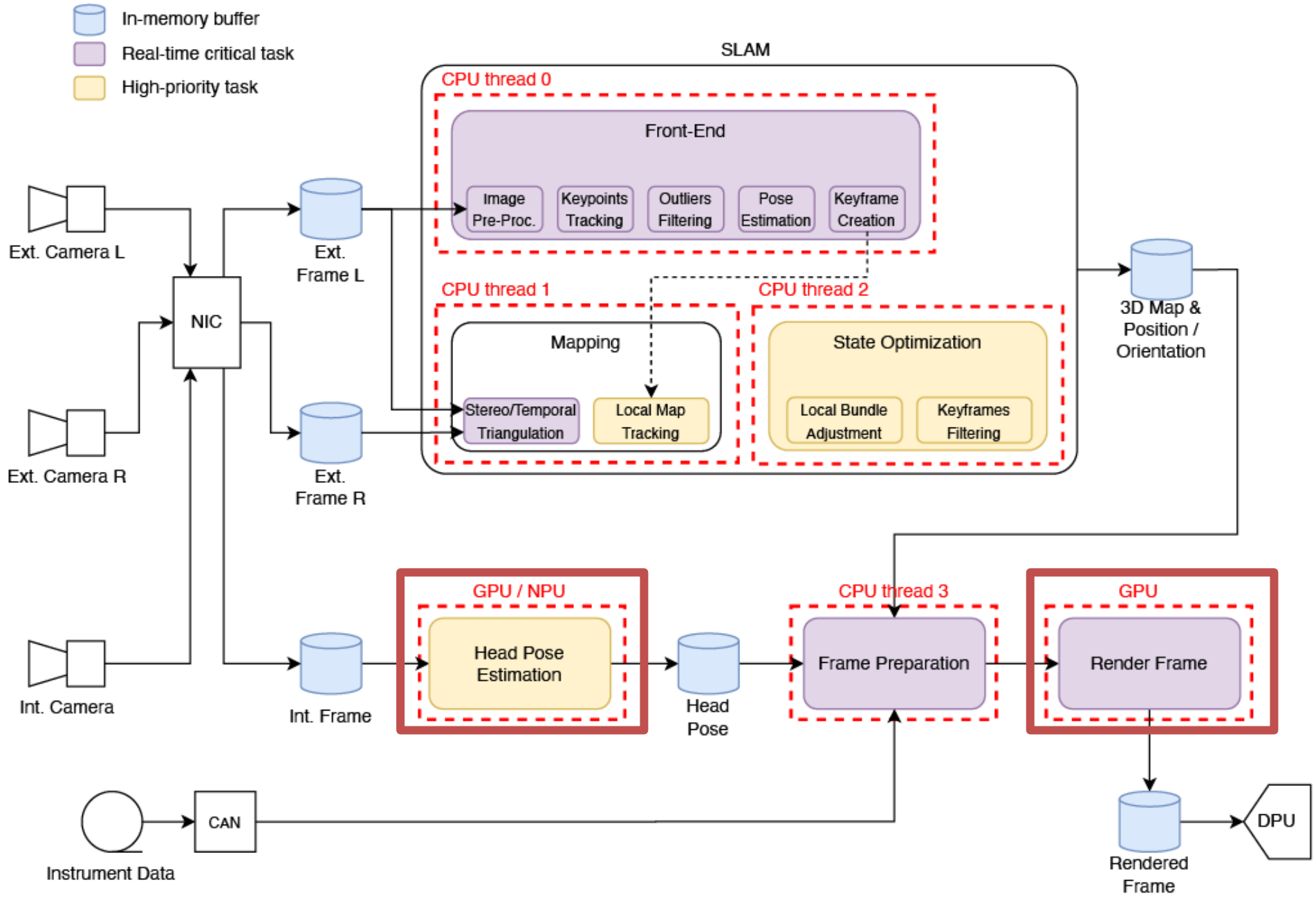
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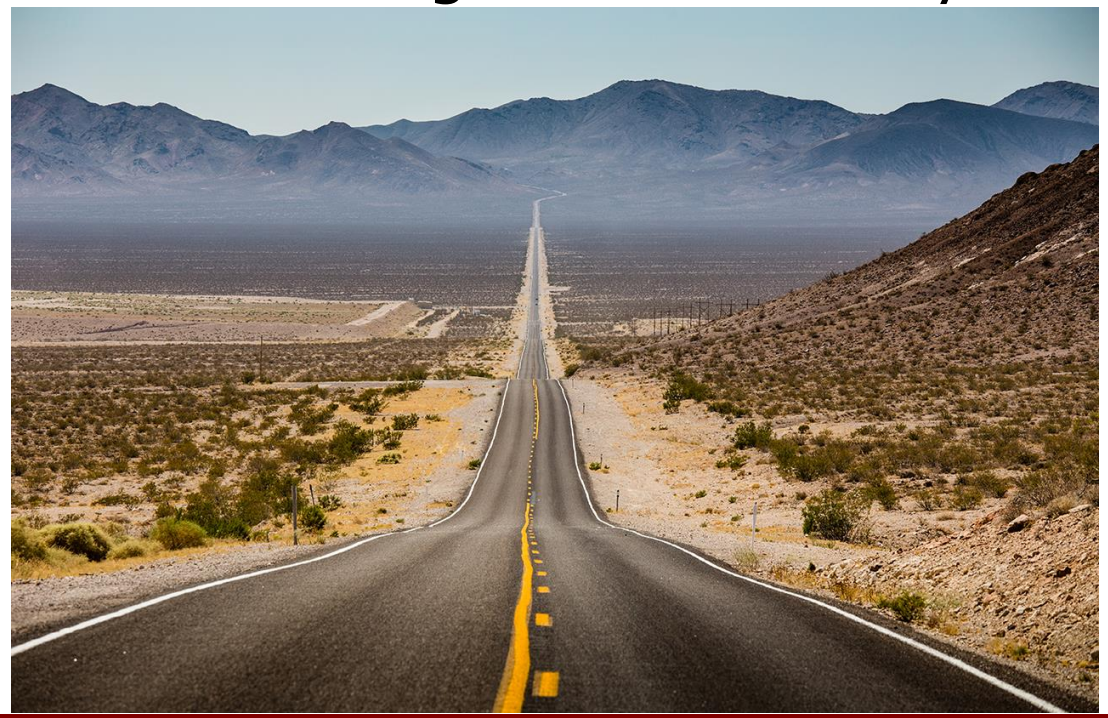
Challenge: Construct a Scheduling Policy

- Meet the desired timing semantics of the application
- Critical tasks at 30-60fps
- Non-critical tasks can accommodate some dropped frames
- Maintain guarantees with “aggressor” workloads
- Maintain guarantees in dynamic environments



Dropping frames is wasted work

Why not adapt (extend) task ***periods*** to maintain schedulability?

Elastic Scheduling

Giorgio Buttazzo, Giuseppe Lipari, and Luca Abeni. "Elastic task model for adaptive rate control." RTSS 1998

Elastic Scheduling

Tasks are characterized by:

- Minimum period 60fps ⟶ 16.7 ms
- Maximum period

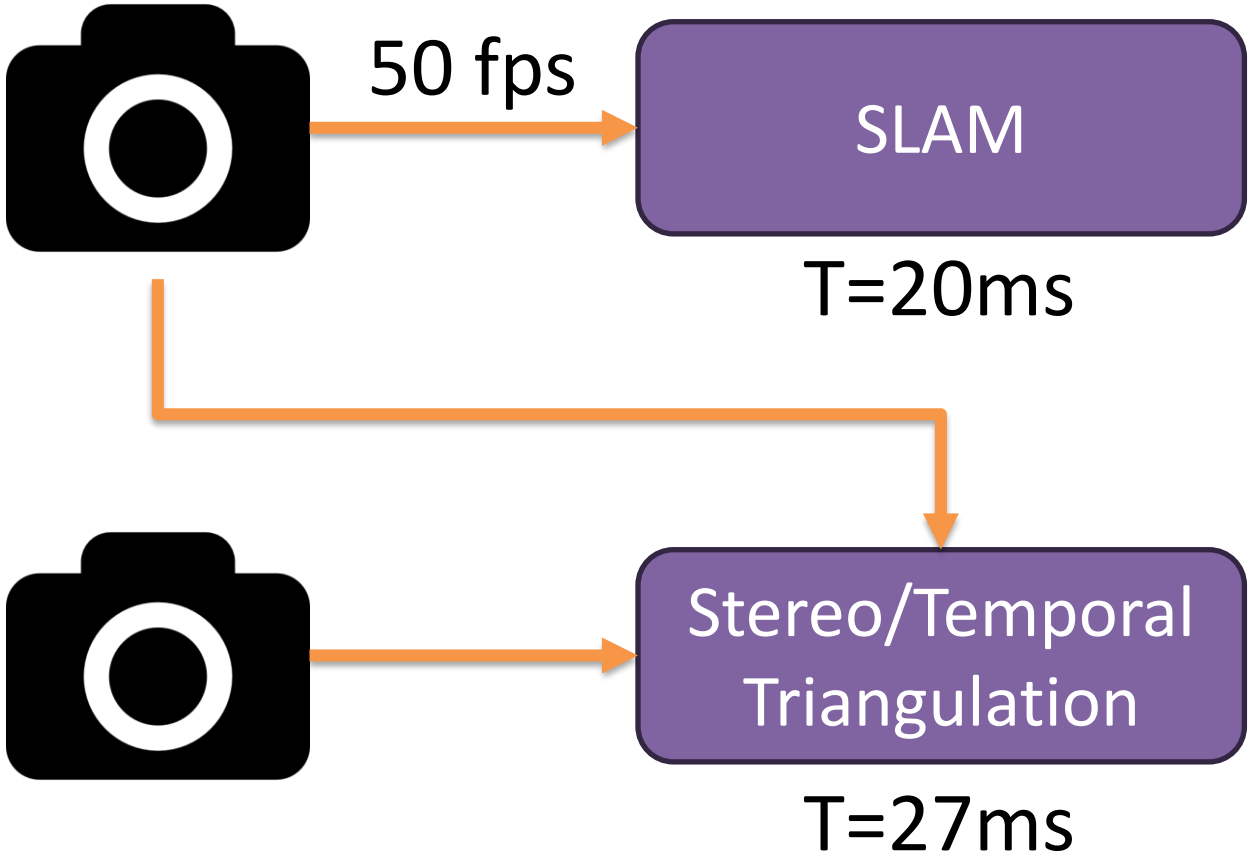
SLAM front-end	Frame Prep	Bundle Adj.
30fps ⟶ 33.3 ms	100 ms	500 ms

- Elasticity (adaptability)

Utilizations compressed from max *proportionally to elasticity* (stopping at min) until system schedulable

Giorgio Buttazzo, Giuseppe Lipari, and Luca Abeni. "Elastic task model for adaptive rate control." RTSS 1998

Dataflow Imposes Harmonic Period Constraints



Elastic Scheduling of Implicit-Deadline Tasks with ***Harmonic*** Periods

Marion Sudvarg, Ao Li, Daisy Wang, Sanjoy Baruah, Jeremy Buhler, Chris Gill, Ning Zhang, Pontus Ekberg.
"Elastic Scheduling for Harmonic Task Systems." RTAS 2024.

Remainder of this Proposal

- Brief overview of harmonic elastic scheduling
- Results for ORB-SLAM3
- Model extensions needed for ARM HUD challenge

Problem

Proportional compression may not maintain the harmonic period relationships

Solution

Use equivalent constrained optimization

$$\min_{\{U_i\}} \quad \sum_{i=1}^{N} \frac{1}{E_i} \left(U_i^{max} - U_i\right)^2$$

$$\text{s.t.} \quad \sum_{i=1}^{N} U_i \leq U_D$$

$$\forall_i, \quad U_i^{min} \leq U_i \leq U_i^{max}$$

$$\forall_{i,j}, \quad \frac{T_i}{T_j} \in \mathbb{N} \text{ or } \frac{T_j}{T_i} \in \mathbb{N}$$

Thidapat (Tam) Chantem, Xiaobo (Sharon) Hu, and Michael D. Lemmon. "Generalized Elastic Scheduling." RTSS 2006

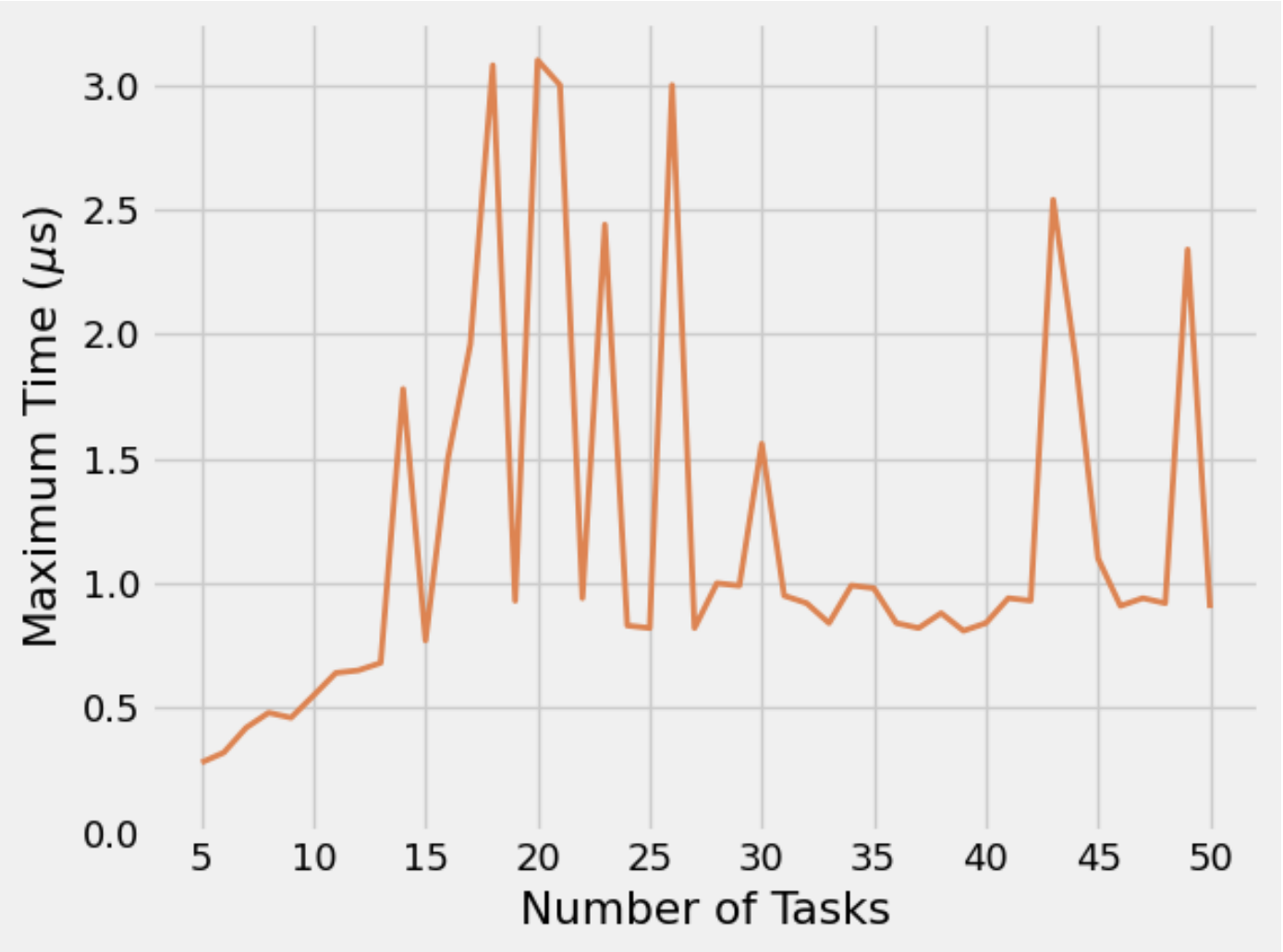
Problem

Solving this constrained-optimization problem is NP-hard

Build a lookup table *offline*

to enable polynomial-time *online* compression in response to changes in available utilization

Overhead of Task Period Reassignment



Case Study: ORB-SLAM3

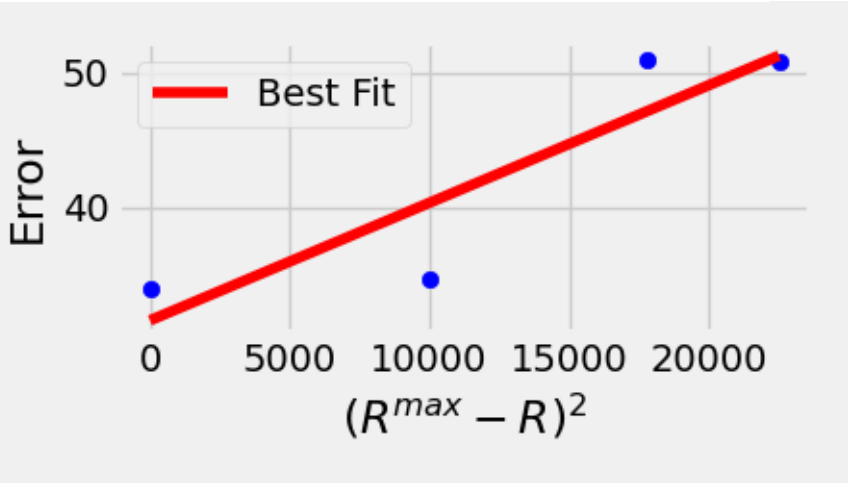
Selecting elastic constants to ***minimize result error*** within the constraints of schedulability

$$\min_{\{U_i\}} \sum_{i=1}^{N} \frac{1}{E_i} \left(U_i^{max} - U_i\right)^2$$

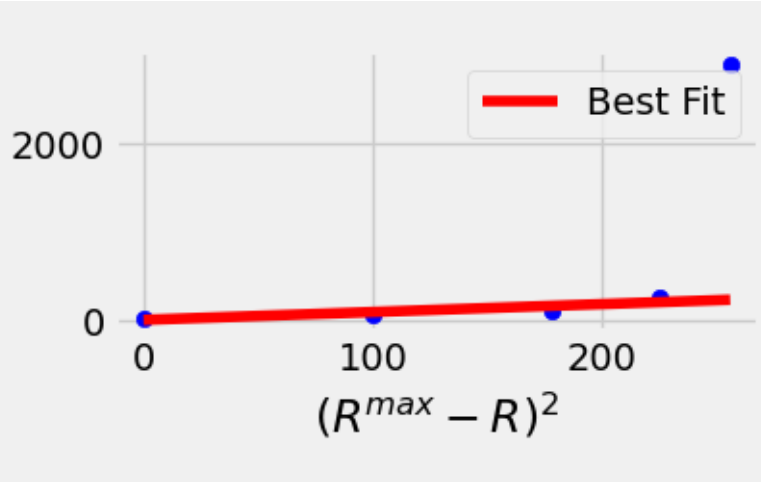
$$\min_{\{R_i\}} \sum_{i=1}^{N} \frac{C_i^2}{E_i} \left(R_i^{max} - R_i\right)^2$$

Error = 10^4 × Relative Translational Error

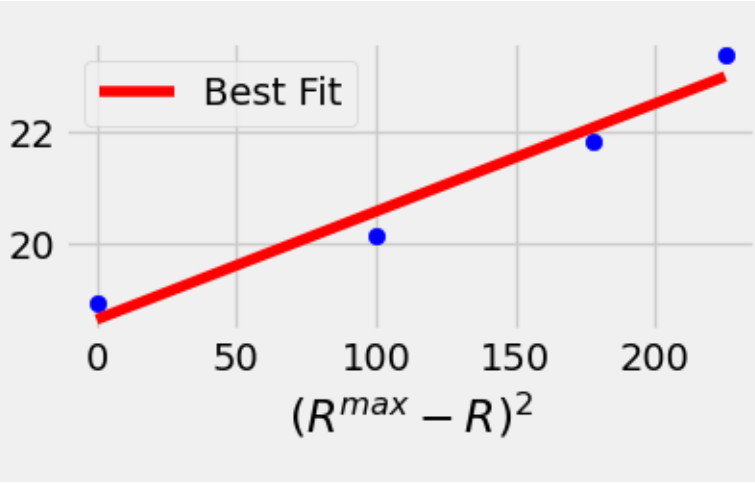
IMU



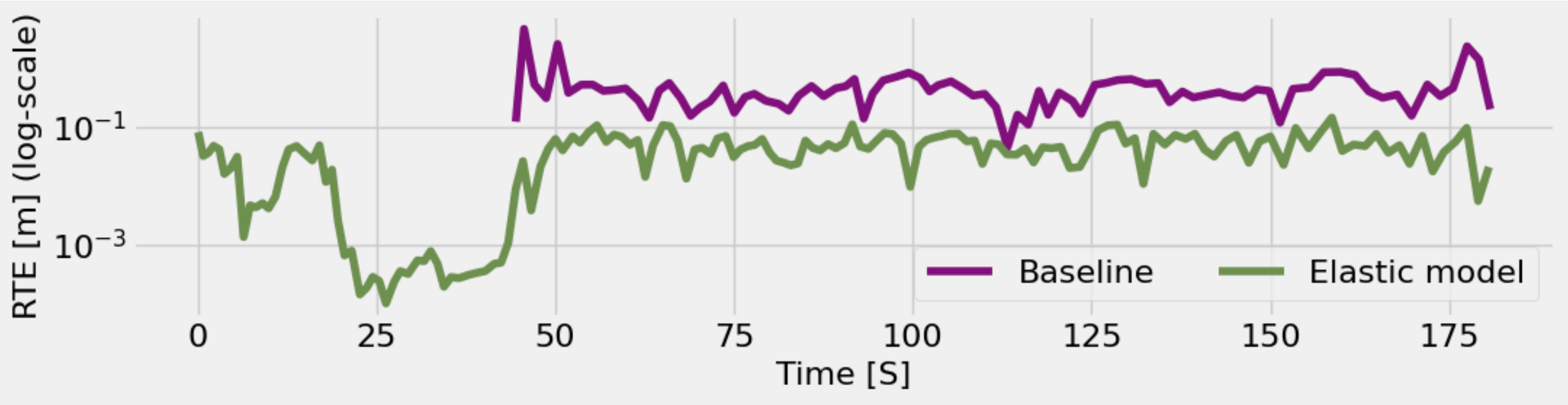
Camera



Mapping



Quality of Produced Map



Extensions Needed for Online Adaptation in ARM AR HUD

Multicore Scheduling

Assume m processors

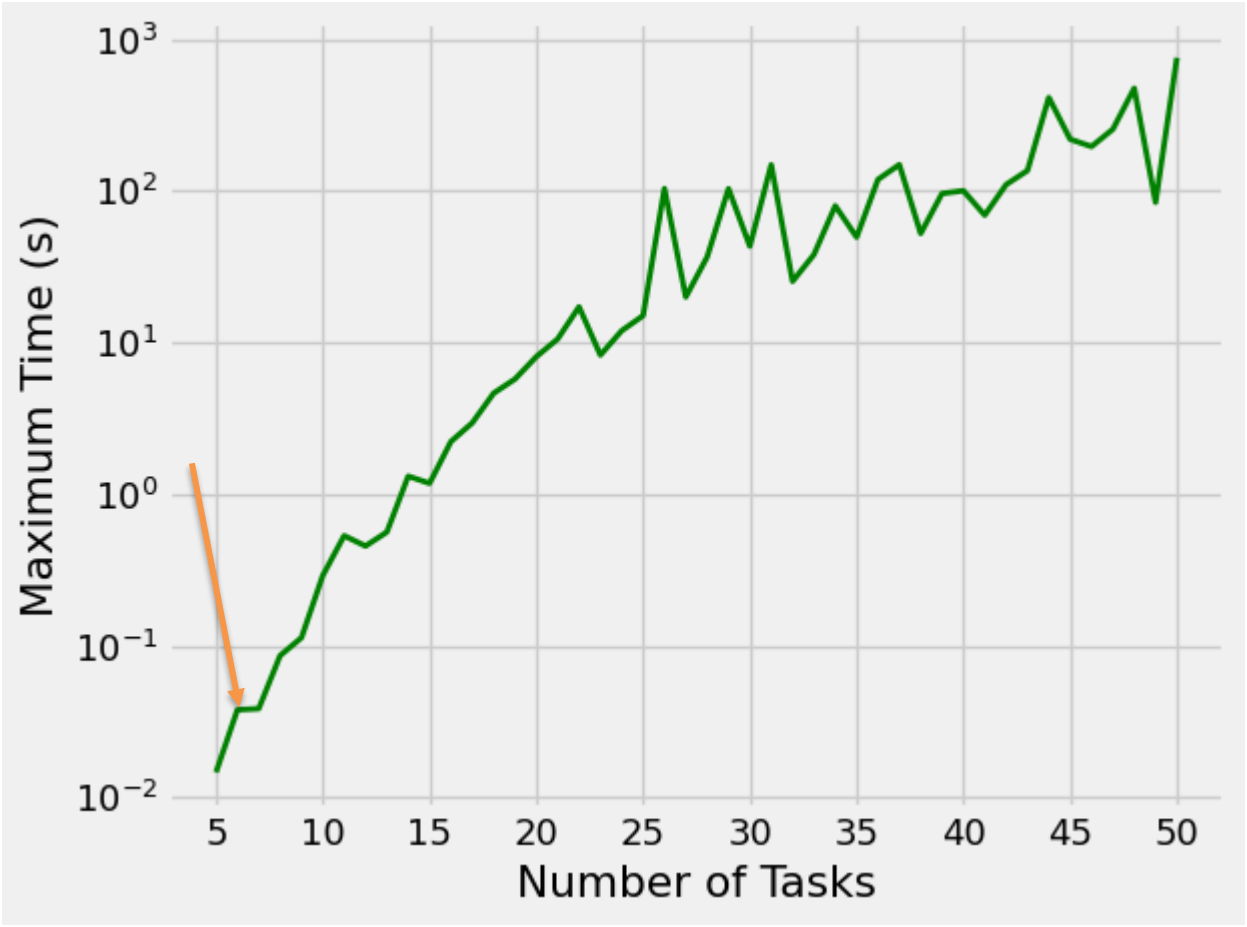
Fluid scheduling $\sum_i U_i \leq m$

Global EDF $\sum_i U_i \leq m - (m-1) \cdot \max_{\tau_i \in \Gamma} \{U_i\}$

Partitioned EDF $\sum_i U_i \leq \frac{m+1}{2}$

Dynamic Execution Times

- Workloads depend on environment
- Execution times vary with resource contention
- Algorithm still inefficient in these scenarios
- Up to 38 ms for 6 tasks



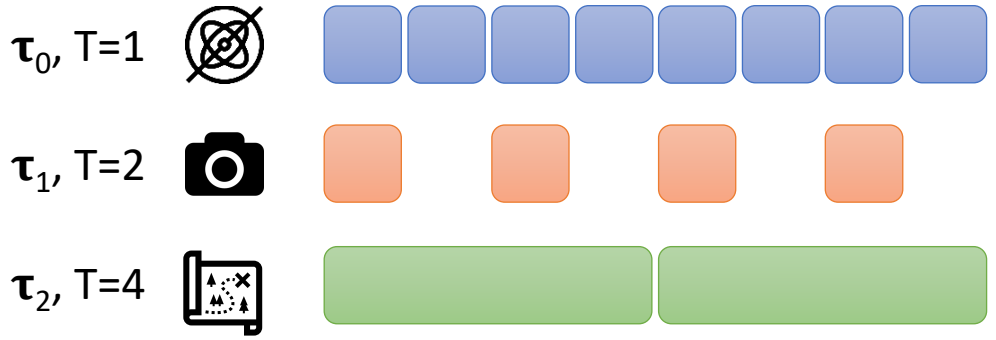
Takeaway Message

- ARM's AR HUD presents several challenges
- We focus on designing a dynamic scheduling policy
- We propose to apply elastic scheduling for harmonic tasks
- Needs to be extended to multiprocessor
- Must consider dynamic execution times

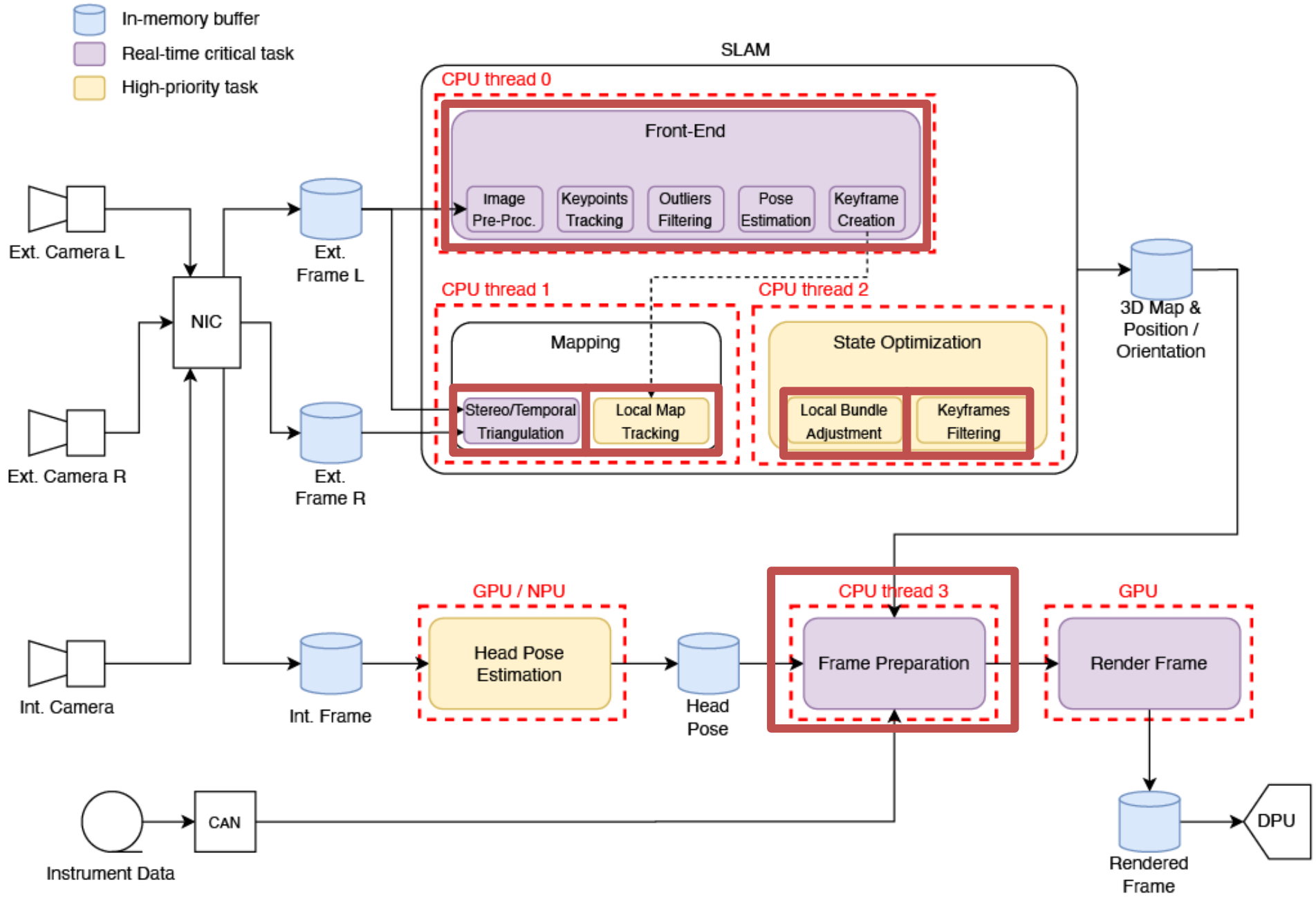
SLAM systems synchronize frames from multiple input sources

Visual **Inertial** **Lidar**

ORB-SLAM3



Harmonic Periods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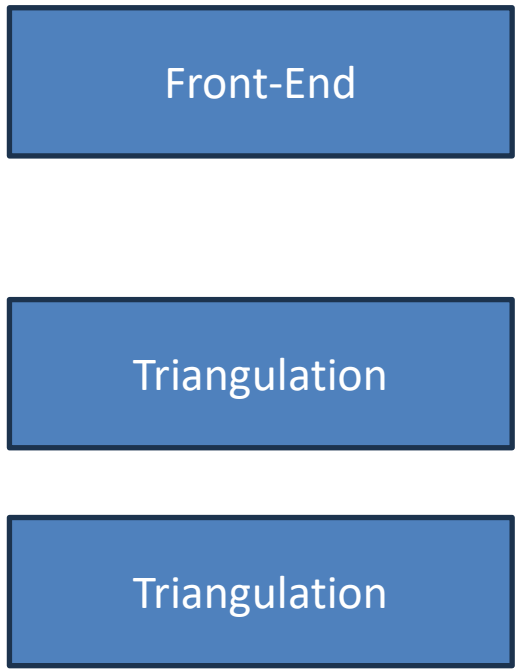
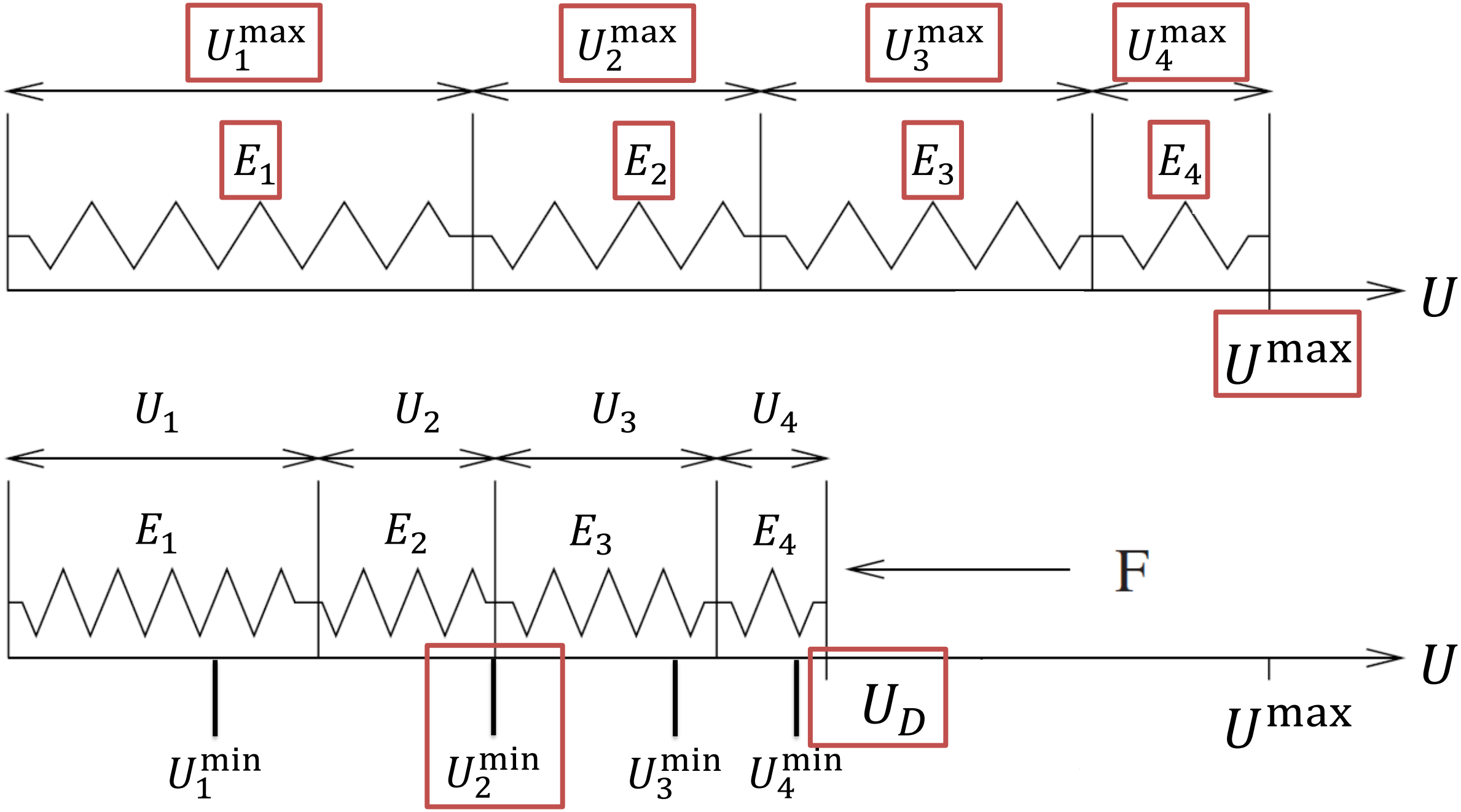
Harmonic Chains




U_1^{max}
U_2^{max}
U_3^{max}
U_4^{max}
E_1
E_2
E_3
E_4
U
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U_2
U_3
U_4
E_1
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E_3
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U_D
U^{max}
U_1^{min}
U_2^{min}
U_3^{min}
U_4^{min}

Elastic Scheduling of Implicit-Deadline Tasks with ***Harmonic*** Periods

This Talk

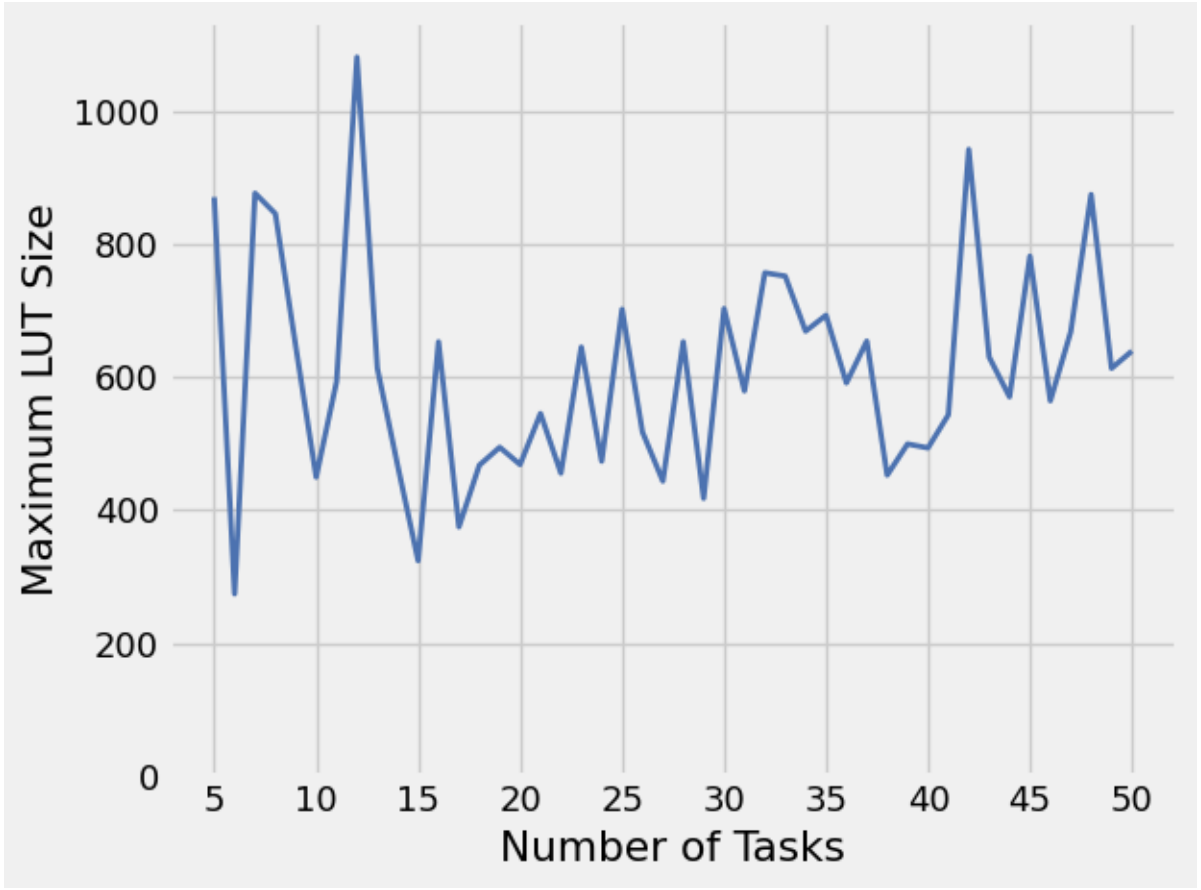
1. Selecting harmonic periods
2. Elastic scheduling with harmonic periods
3. Case study: atmospheric aerosol sampling
4. Case study: ORB-SLAM3
5. Open questions in computational complexity

The Harmonic Elastic Problem

For n tasks, table size at most

$$k(n-1)^{2\lfloor \log k \rfloor}$$

1000 sets each, $k \leq 1000$



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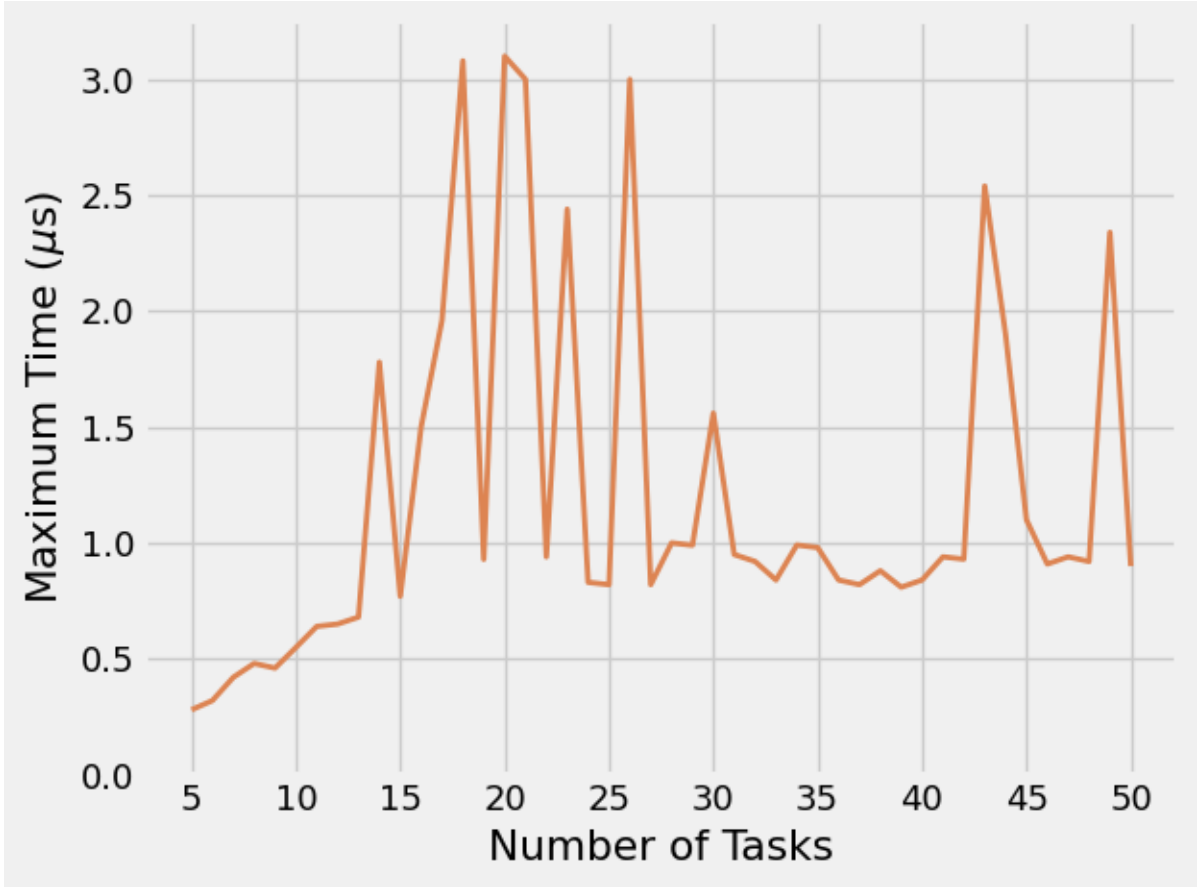
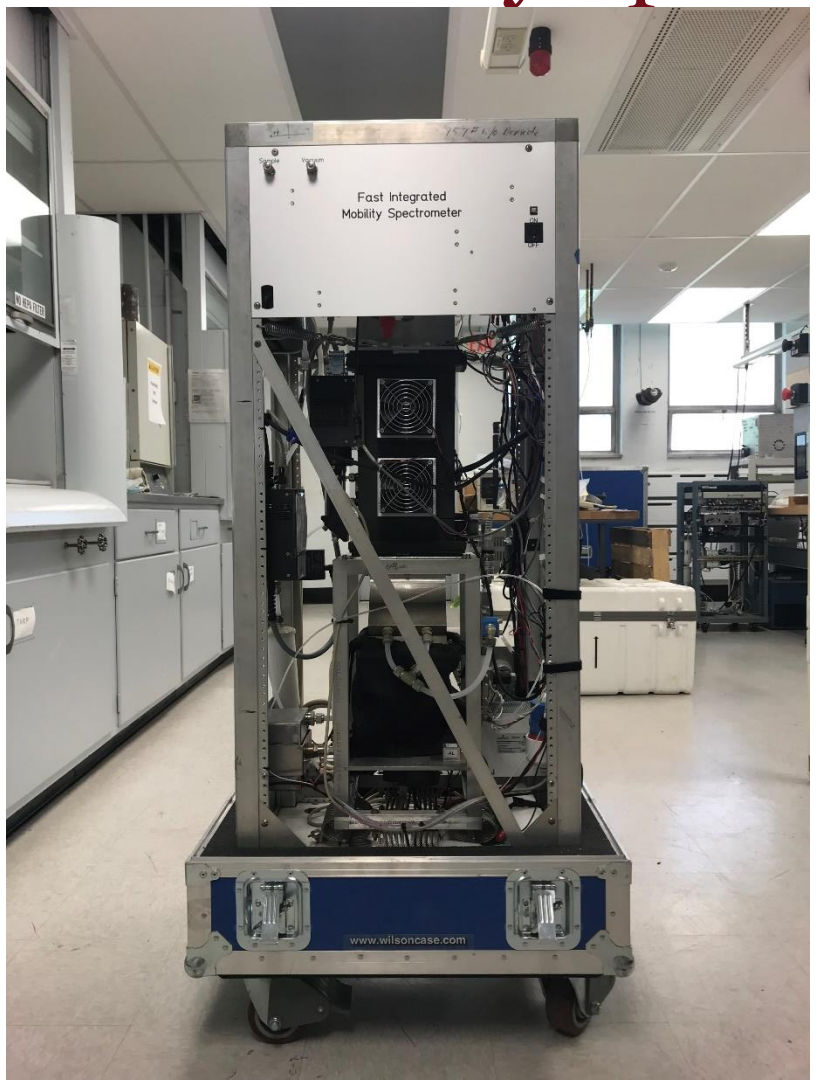


Case Studies

The Fast Integrated Mobility Spectrometer (FIMS)



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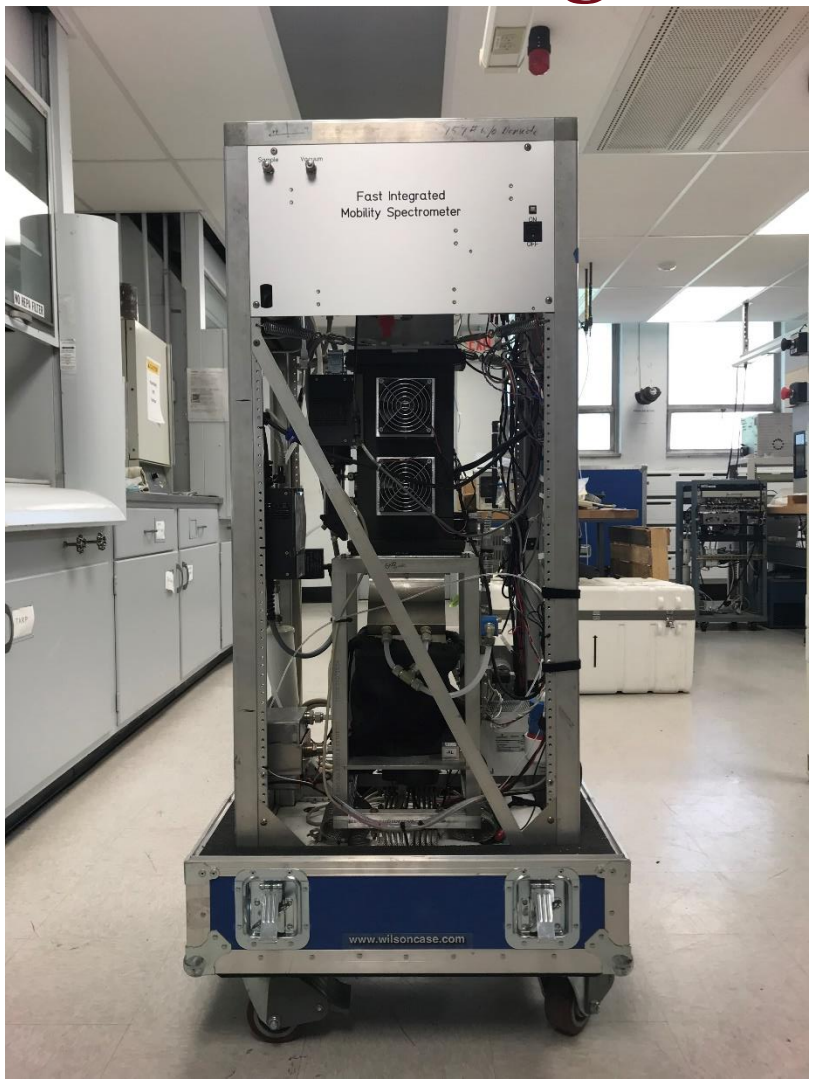

Image courtesy https://www.seilergeodrones.com/shop/dji-matrice-300-rtk/

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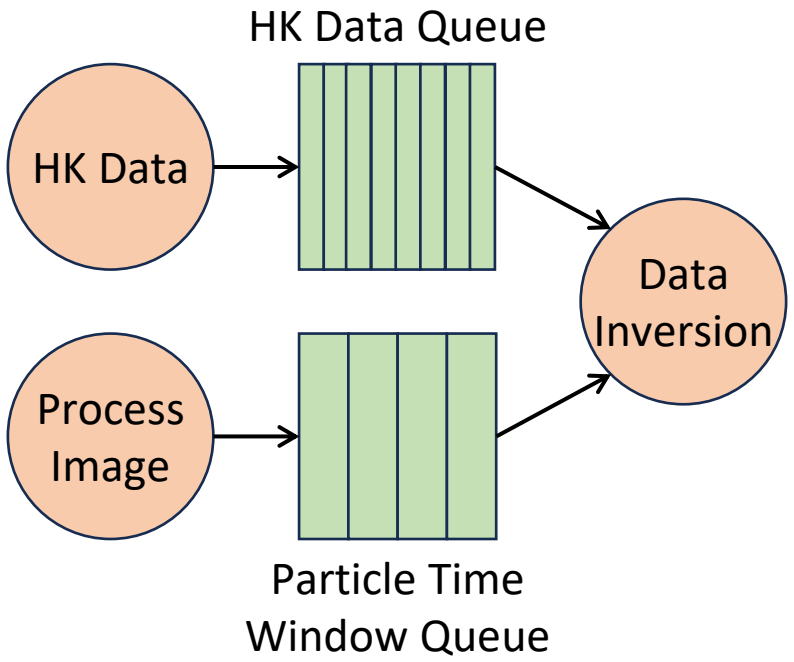
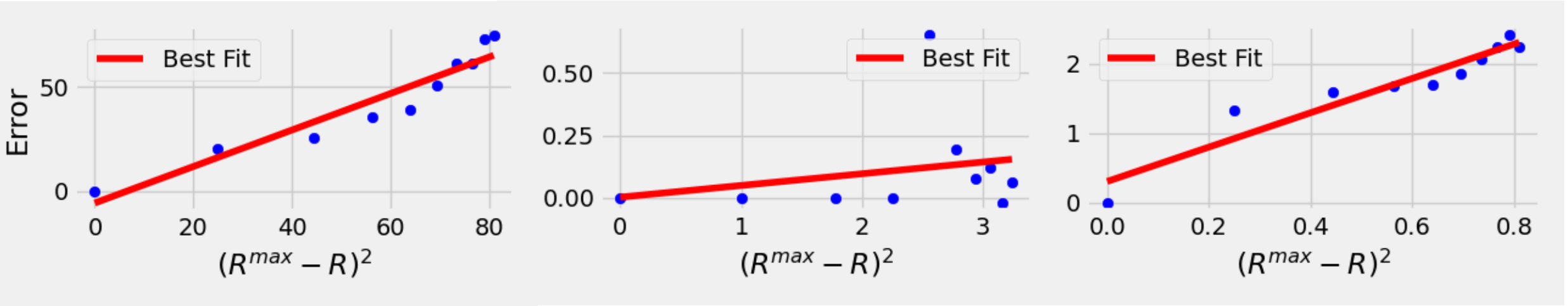


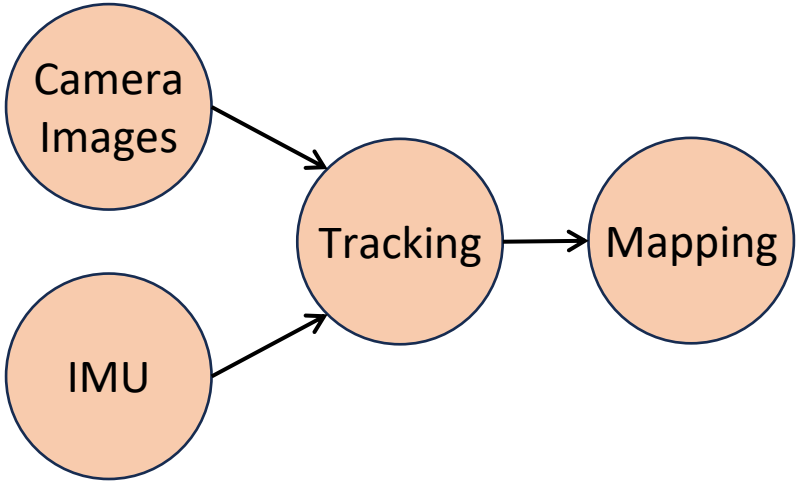
$$\text{Error} = 1000 \times (1 - \theta)$$

Process Image **HK Data** **Data Inversion**



With utilization limited to 0.1-0.5 by a high-priority interfering task,
no FIMS tasks missed their deadlines

ORB-SLAM3



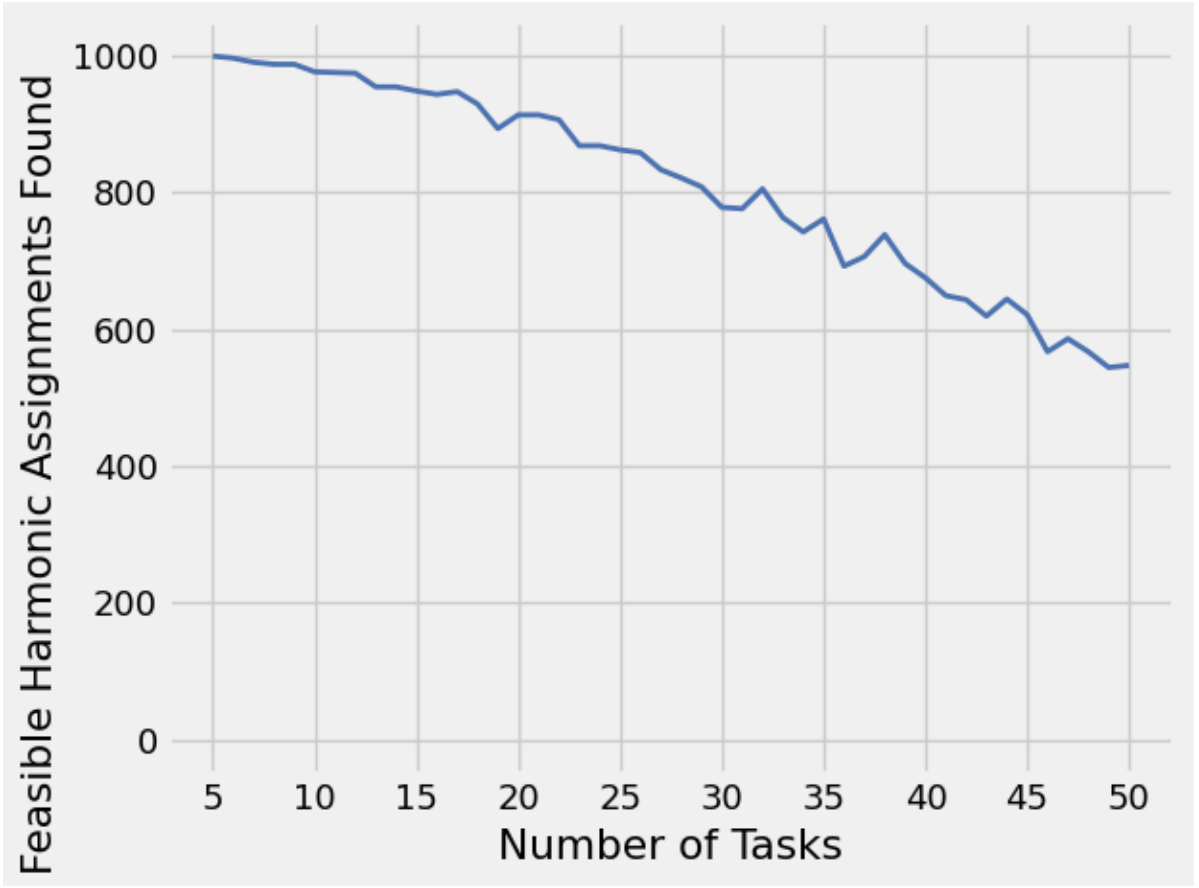






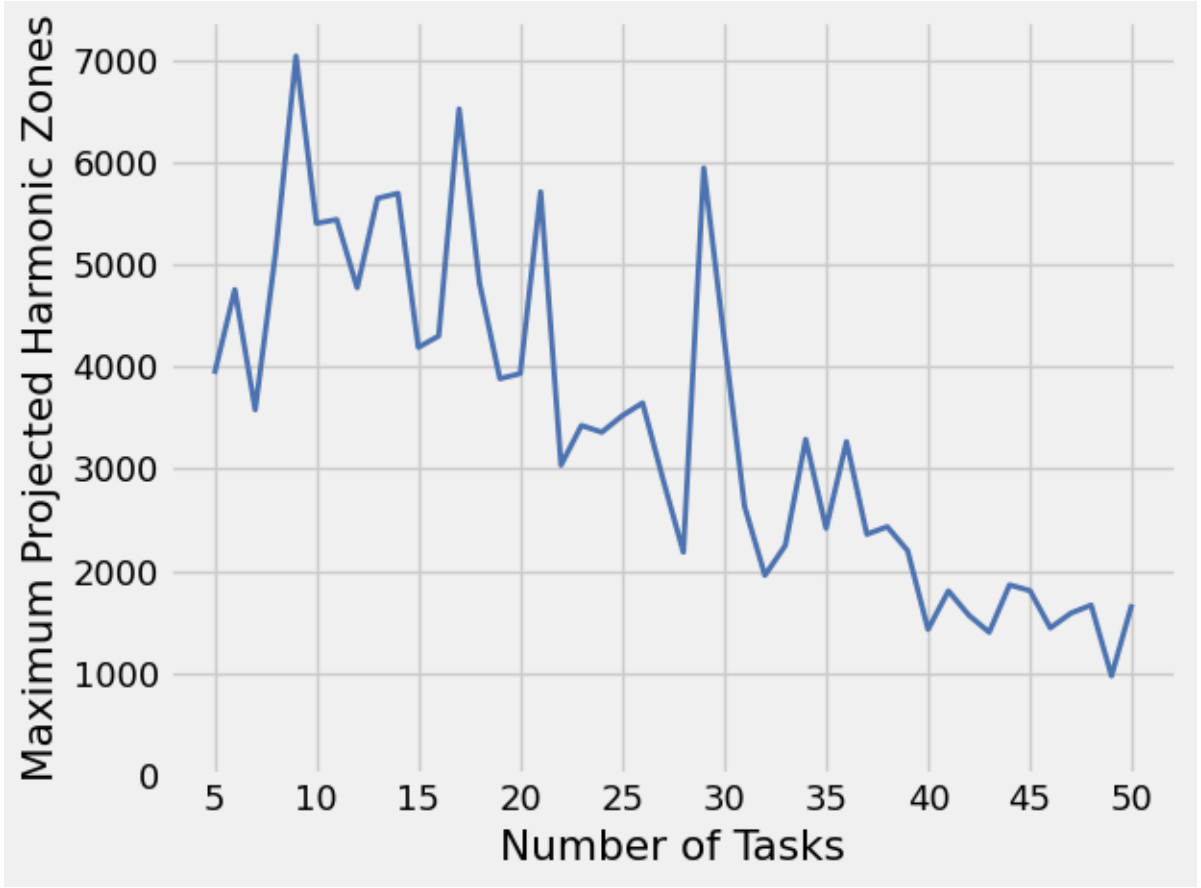
Synthetic Task Sets

1000 sets each, $k \leq 1000$



Number of projected harmonic zones on last task at most k^2

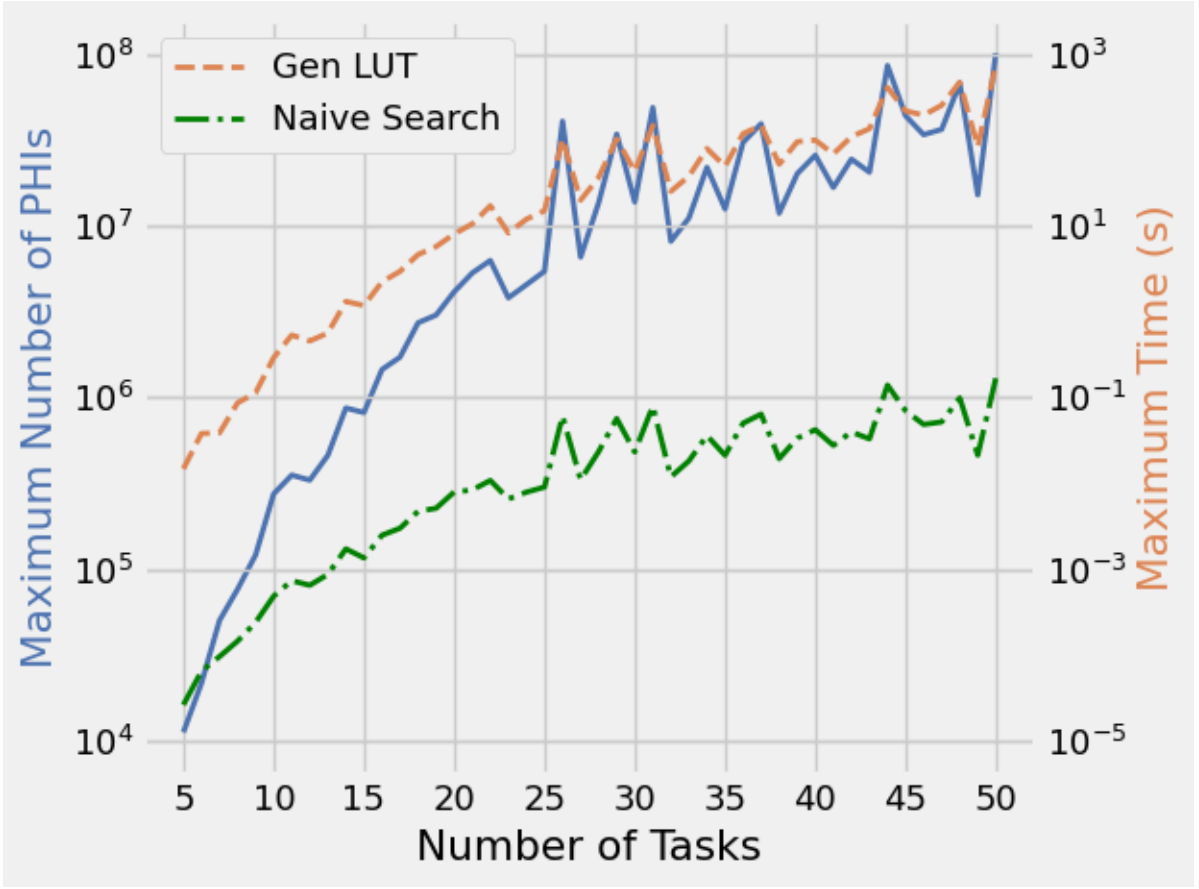
1000 sets each, $k \leq 1000$

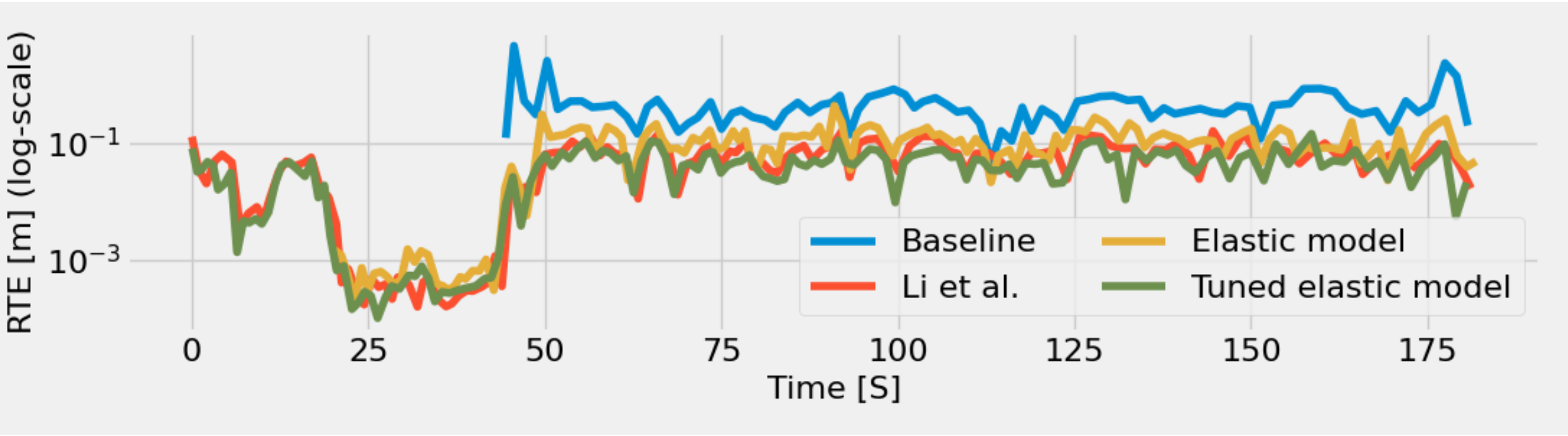


For n tasks, table size at most

$$k(n-1)^{2\lfloor \log k \rfloor}$$

1000 sets each, $k \leq 1000$




RTE [m] (log-scale)
10^{-1}
10^{-3}
0
25
50
75
100
125
150
175
Time [S]
Baseline
Li et al.
Elastic model
Tuned elastic model

Problem

Solving this constrained-optimization problem is NP-hard

Number Partitioning

Can a set of integers $\{a_1,a_2,\ldots,a_n\}$ be partitioned into subsets S_1 and S_2 so that the sum of integers in each subset are equal?

Construct a set of tasks $\{\tau_1, \tau_2,\ldots, \tau_n\}$

Periods may be selected from [1,2]

A dummy task τ_{n+1} has period 1

Tasks are partitioned into sets of periods 1 and 2