To Overlay or to Customize?
Revisiting Architectural Choices in Heterogeneous Systems

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Brown University; Wayne State University*

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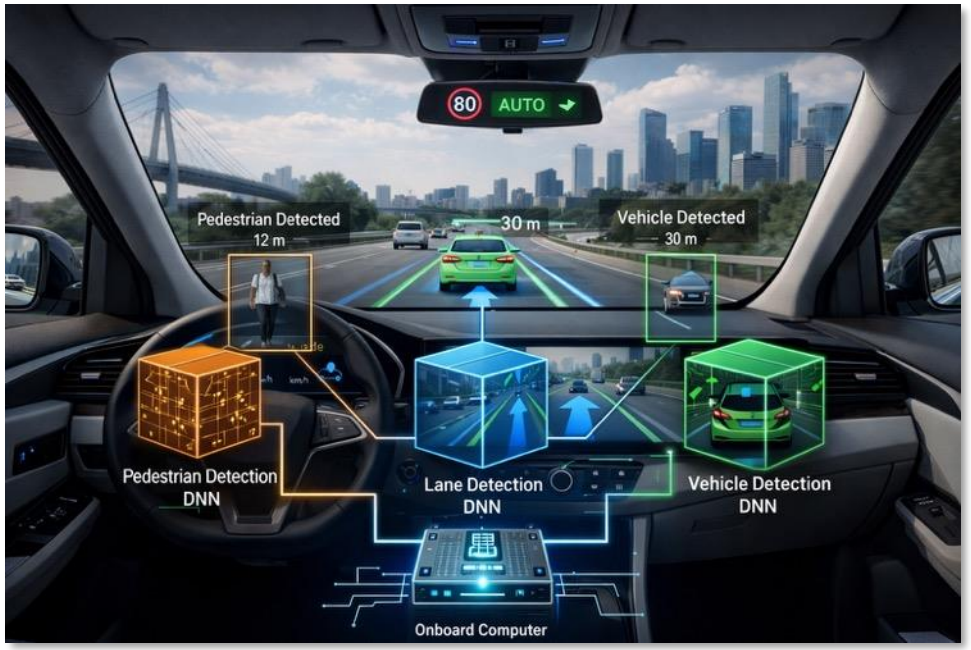
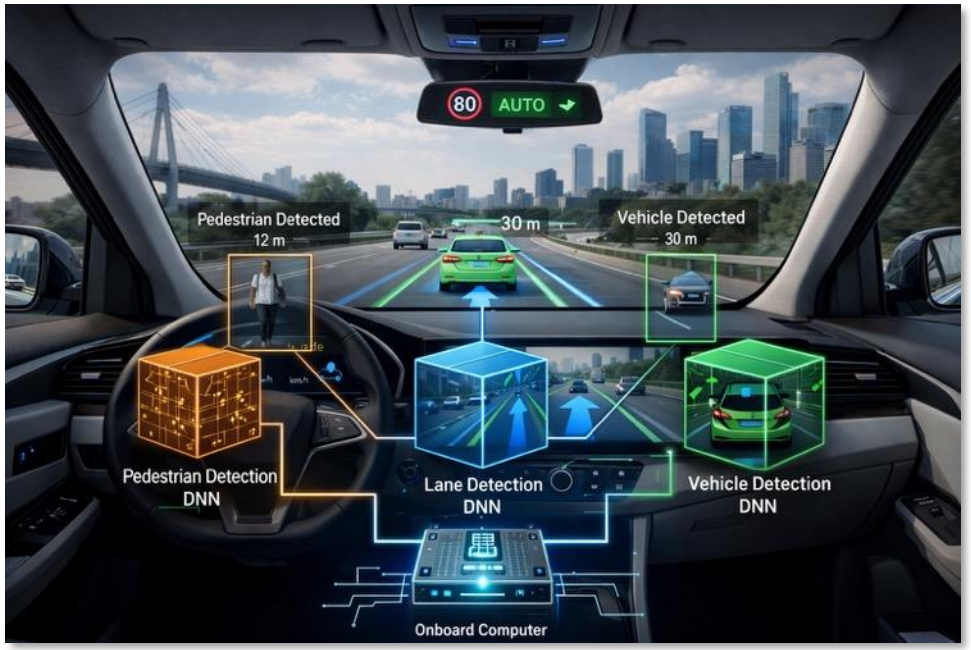
https://peipeizhou-eecs.github.io/


80
AUTO
Pedestrian Detected
12 m
30 m
Vehicle Detected
30 m
Pedestrian Detection
DNN
Lane Detection
DNN
Vehicle Detection
DNN
Onboard Computer



Tasks behind modern autonomous driving systems.

Design Choices

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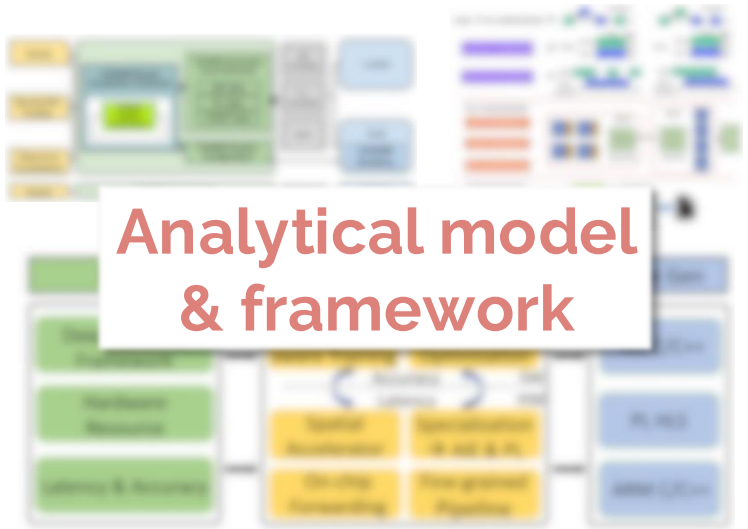

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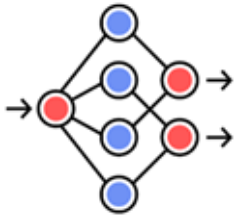
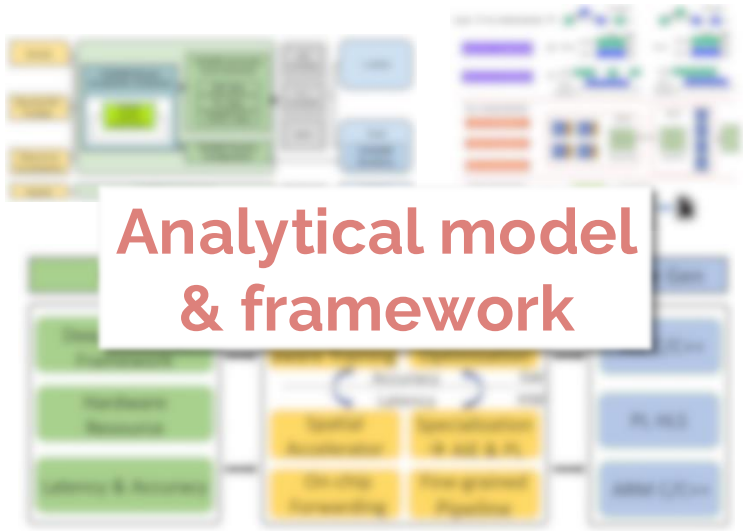


DNN model 1



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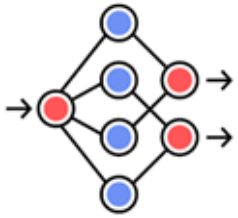

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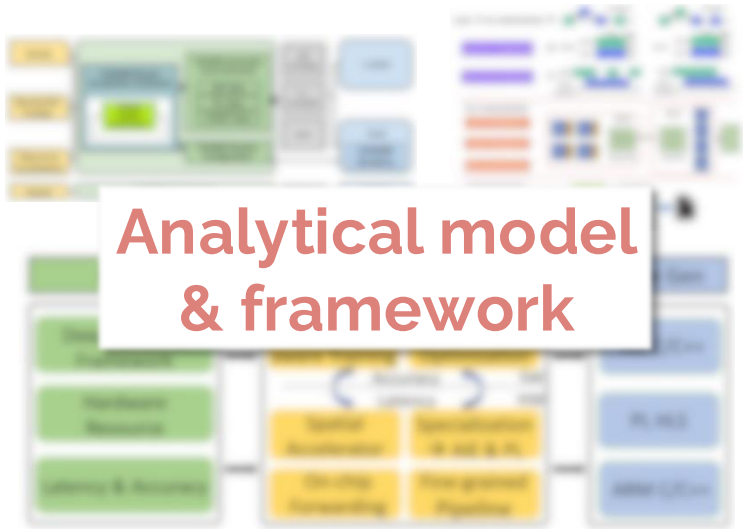

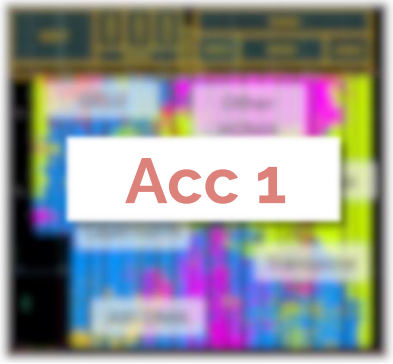

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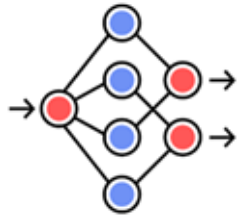

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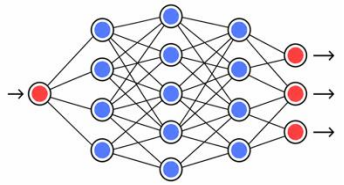
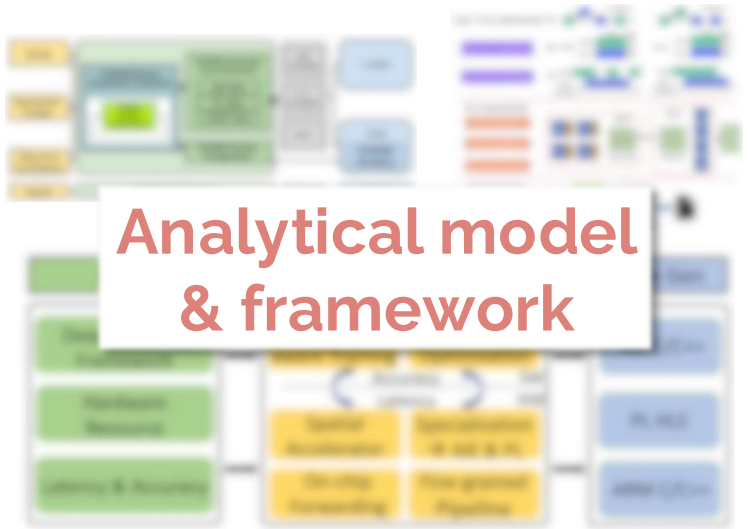


DNN model 2



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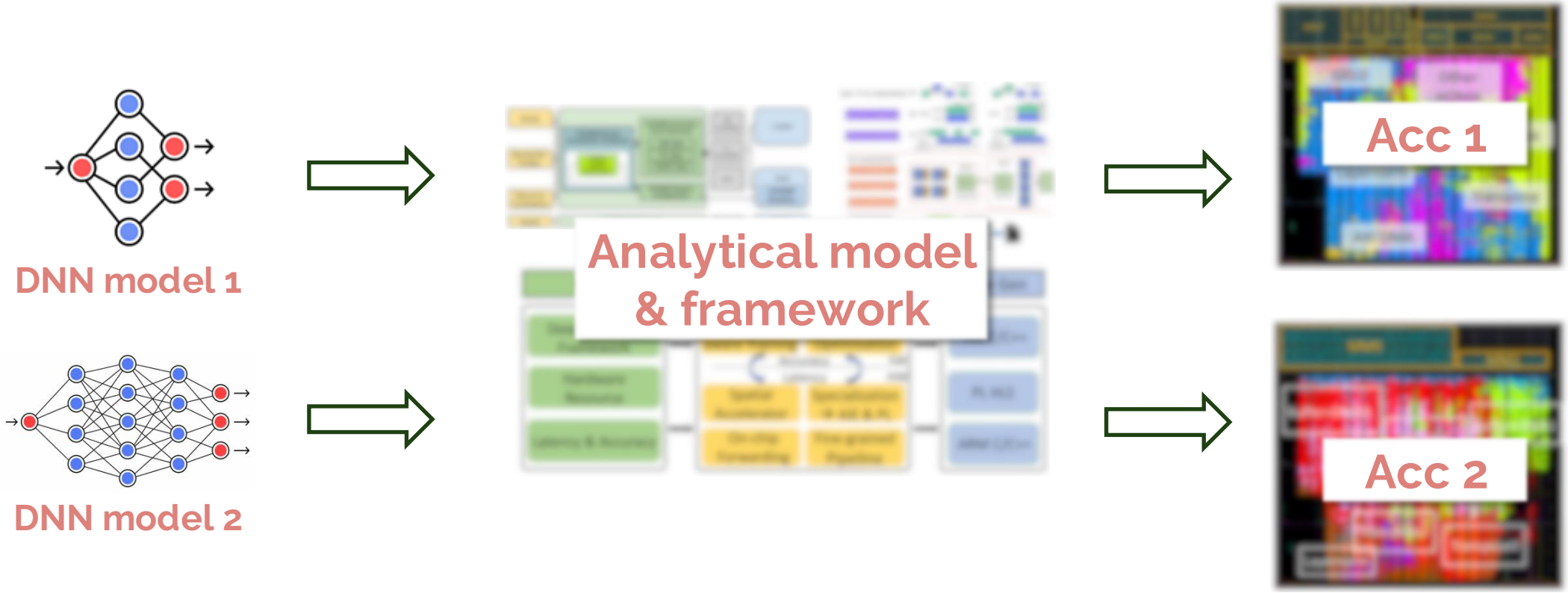

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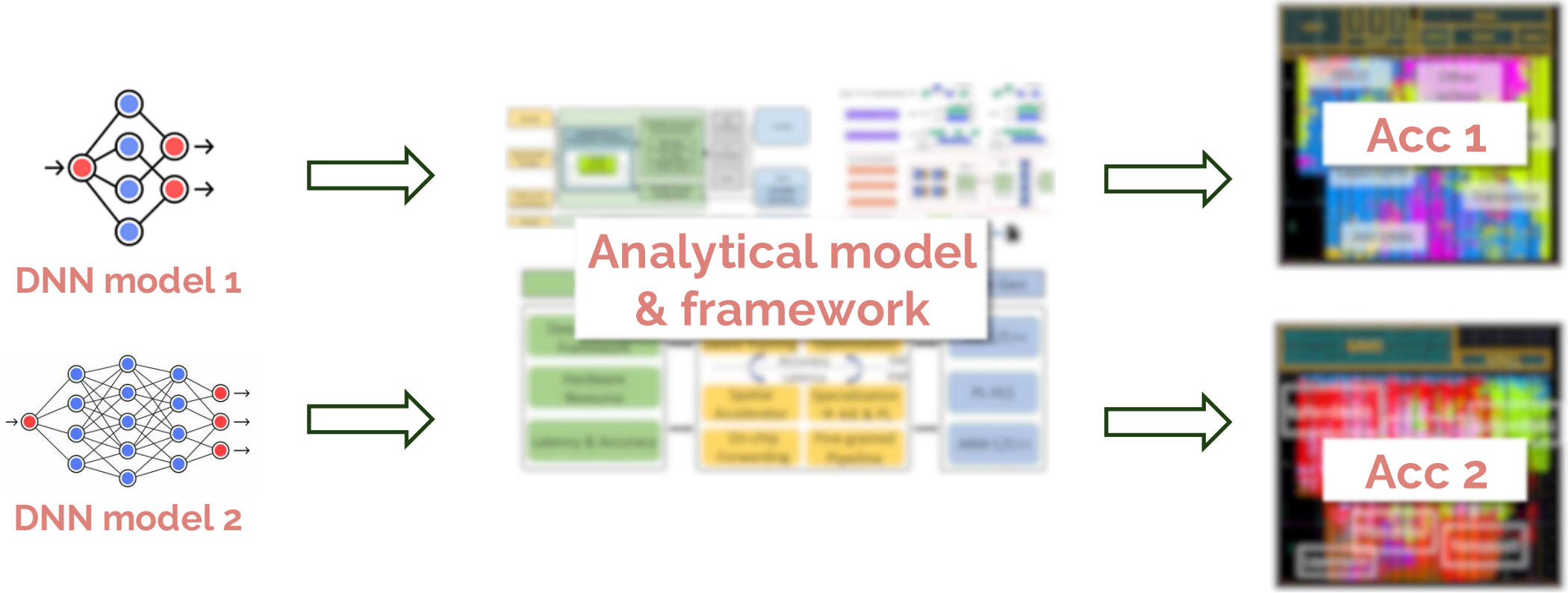

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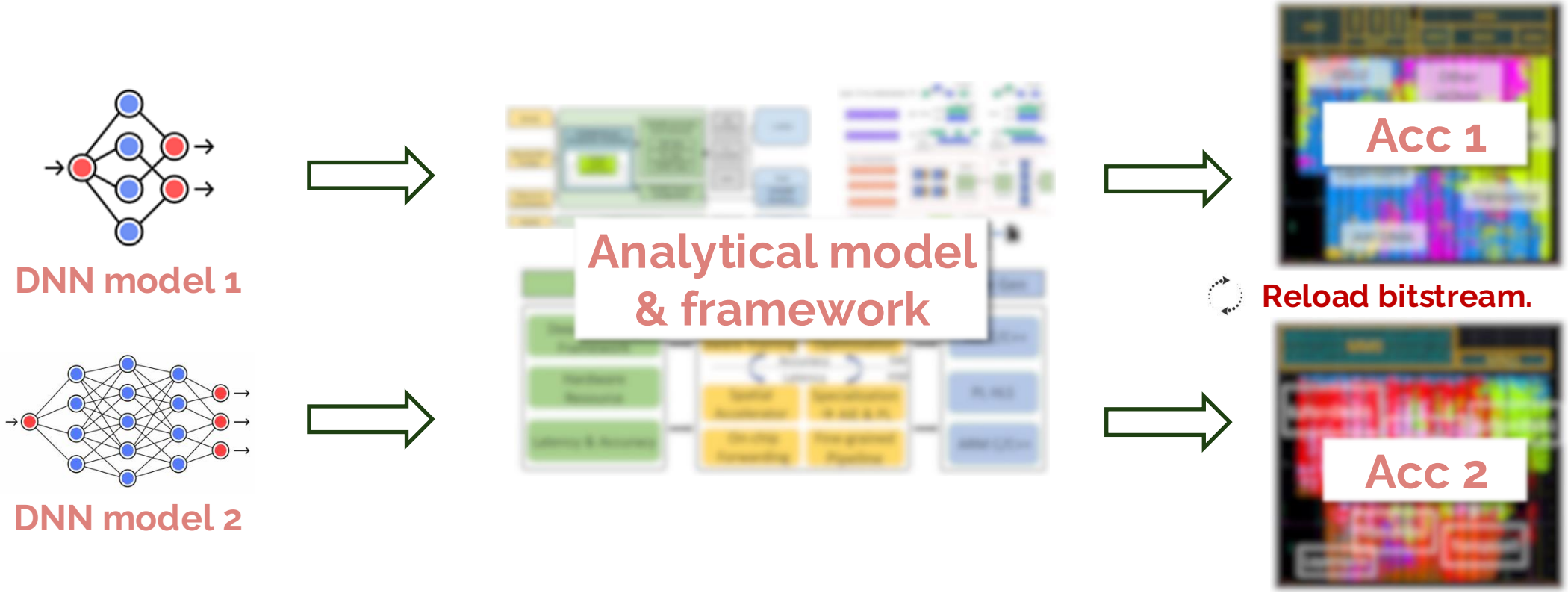

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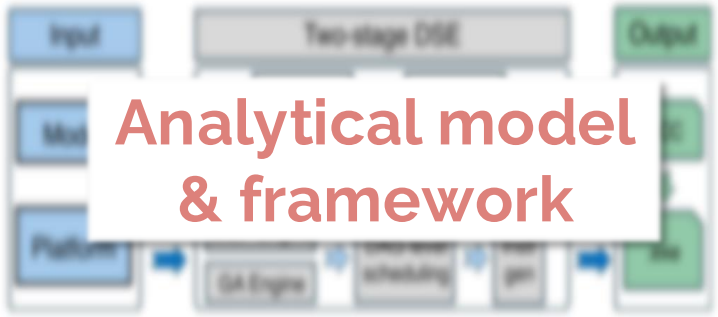

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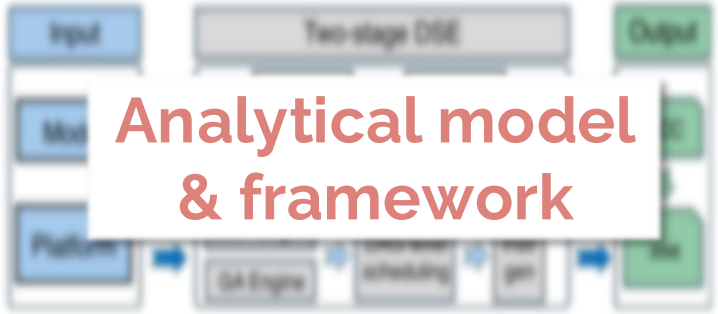

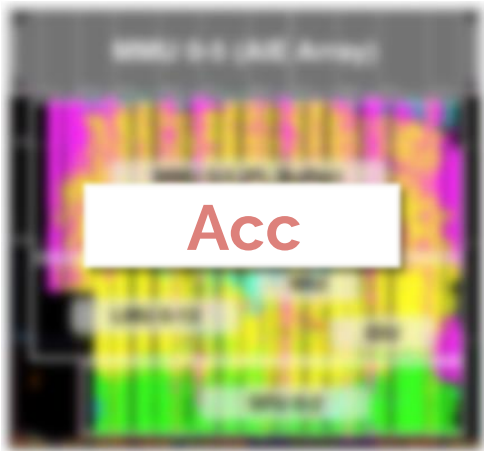

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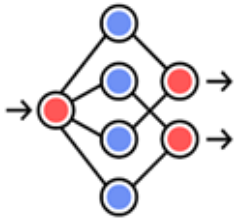

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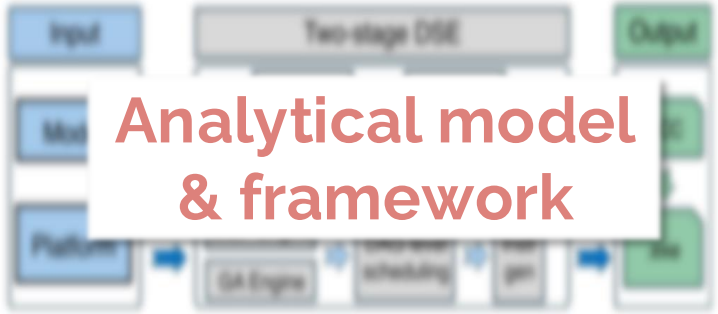

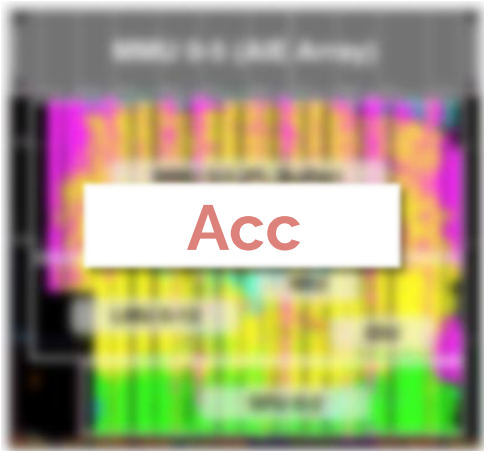

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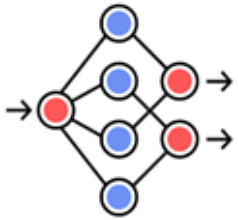

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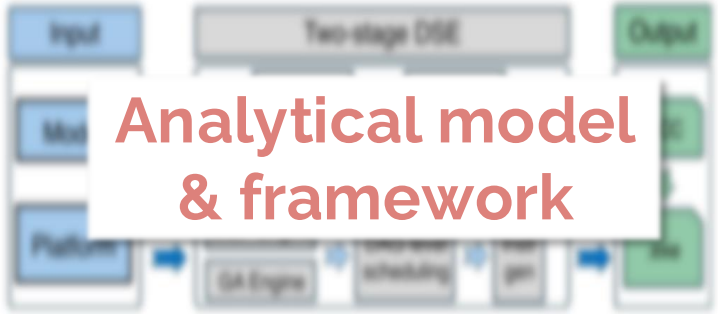
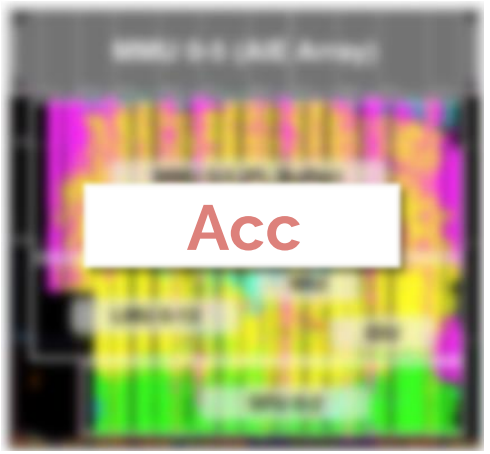


Instruction 1



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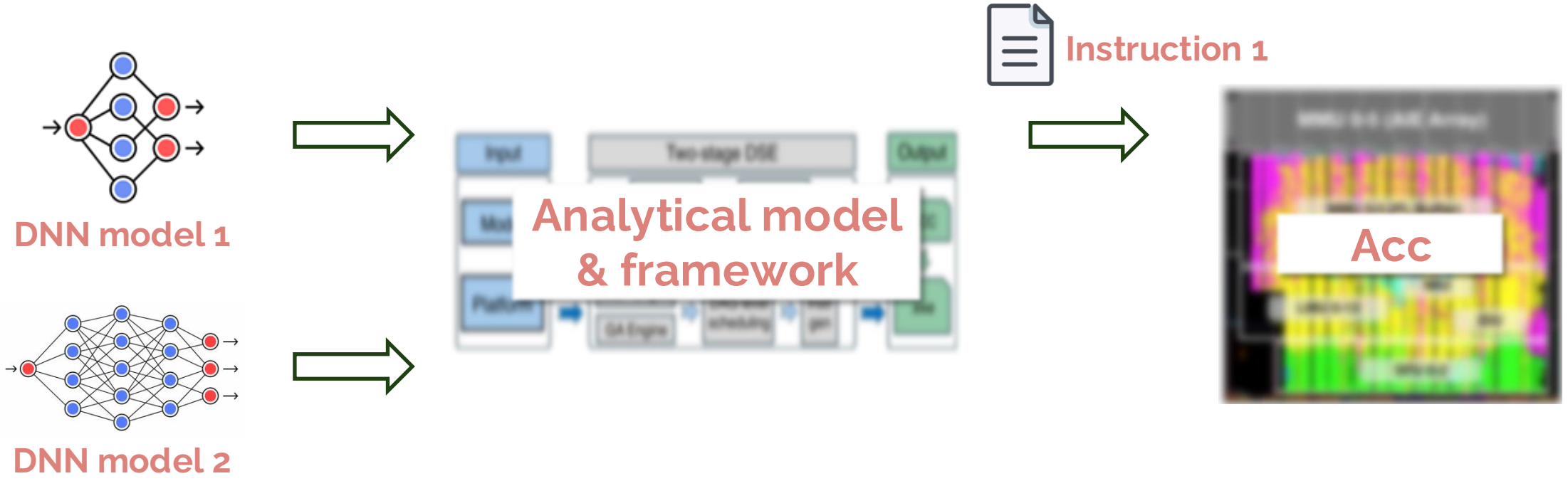

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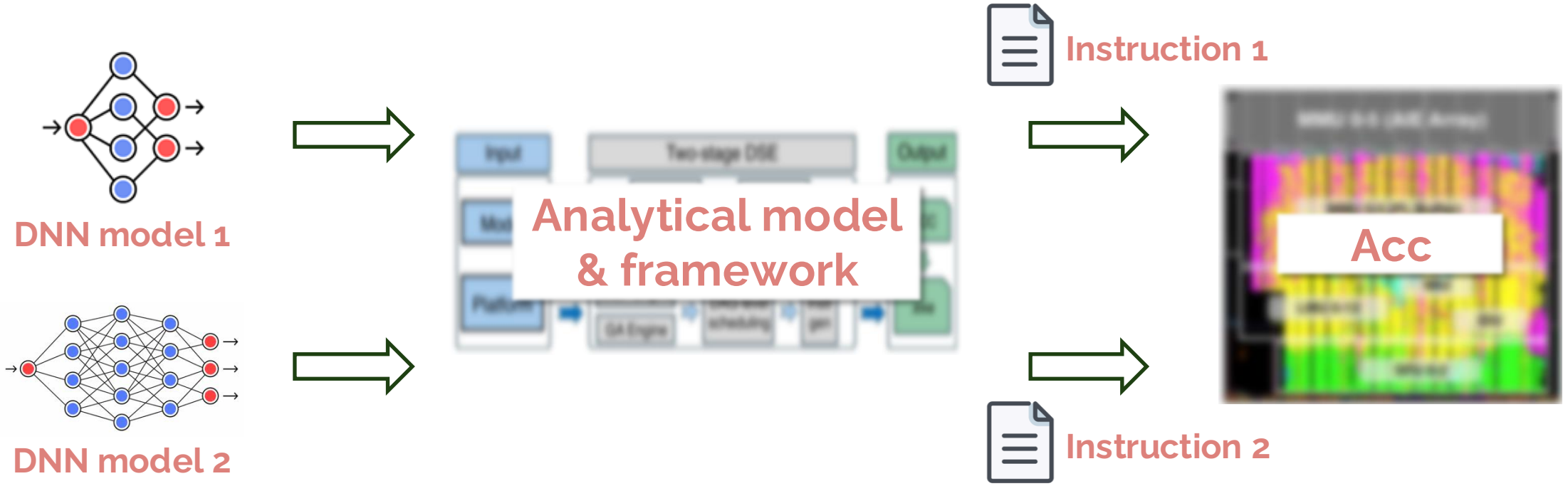

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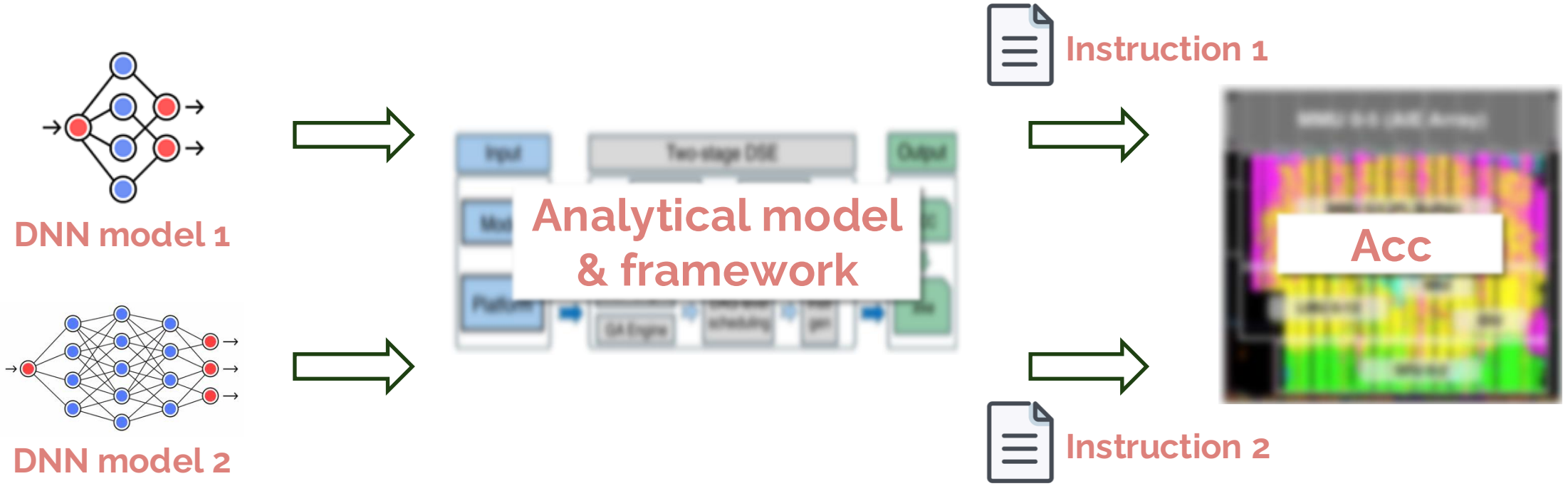

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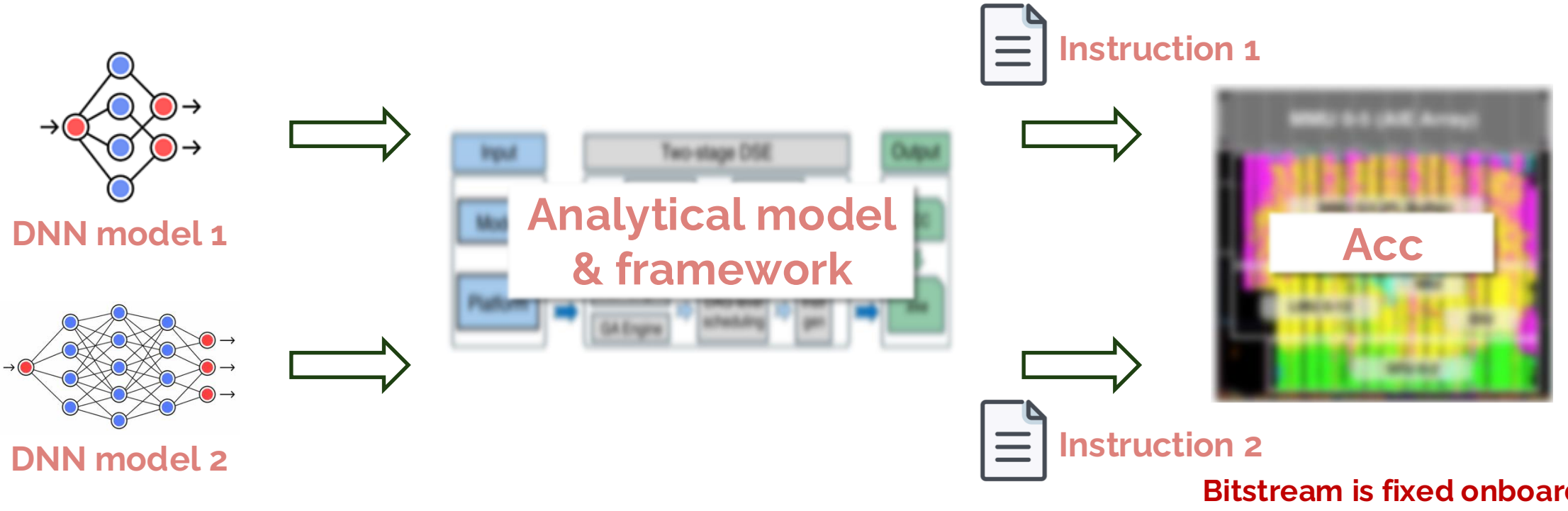

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■ Dedicated customization for specific DNN models. ■ Better efficiency and performance. ■ Worse flexibility and extra overhead.	

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Customization accelerators

- Dedicated customization for specific DNN models.
- Better efficiency and performance.
- Worse flexibility and extra overhead.

Overlay accelerators

- Multiple DNN models share the same architecture.
- Better flexibility and negligible overhead.
- Worse efficiency and performance.

Design Choices

- There exists a trade-off between two design choices.

Customization accelerators	Overlay accelerators
■ Dedicated customized hardware for specific DNN models. ■ Better efficiency and performance. ■ Worse flexibility and extra overhead.	■ Support multiple DNNs of the same architecture. ■ Better flexibility and negligible overhead. ■ Worse efficiency and performance.

To overlay or to Customization?

Real-time Systems

Real-time Systems

- We focus on real-time + autonomous driving systems.

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20Hz,
50ms/frame

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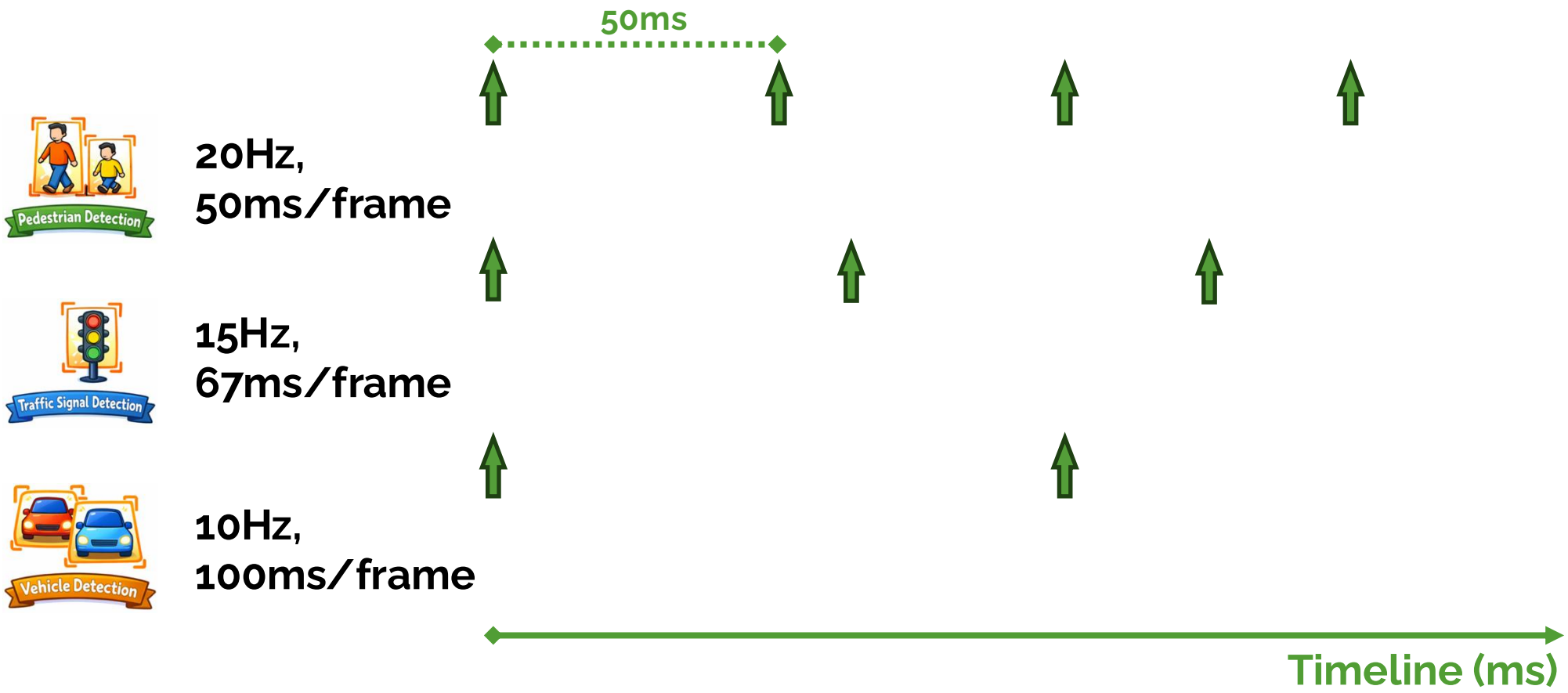

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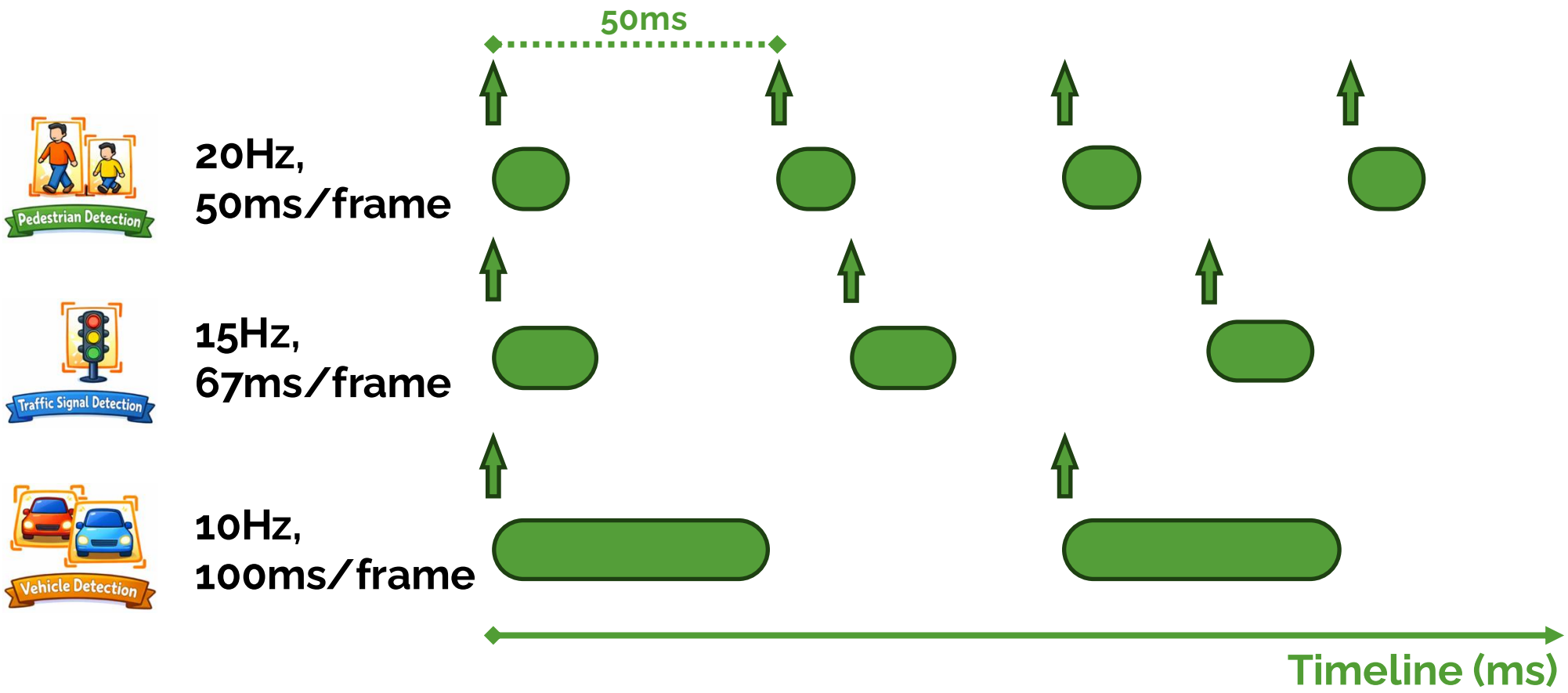

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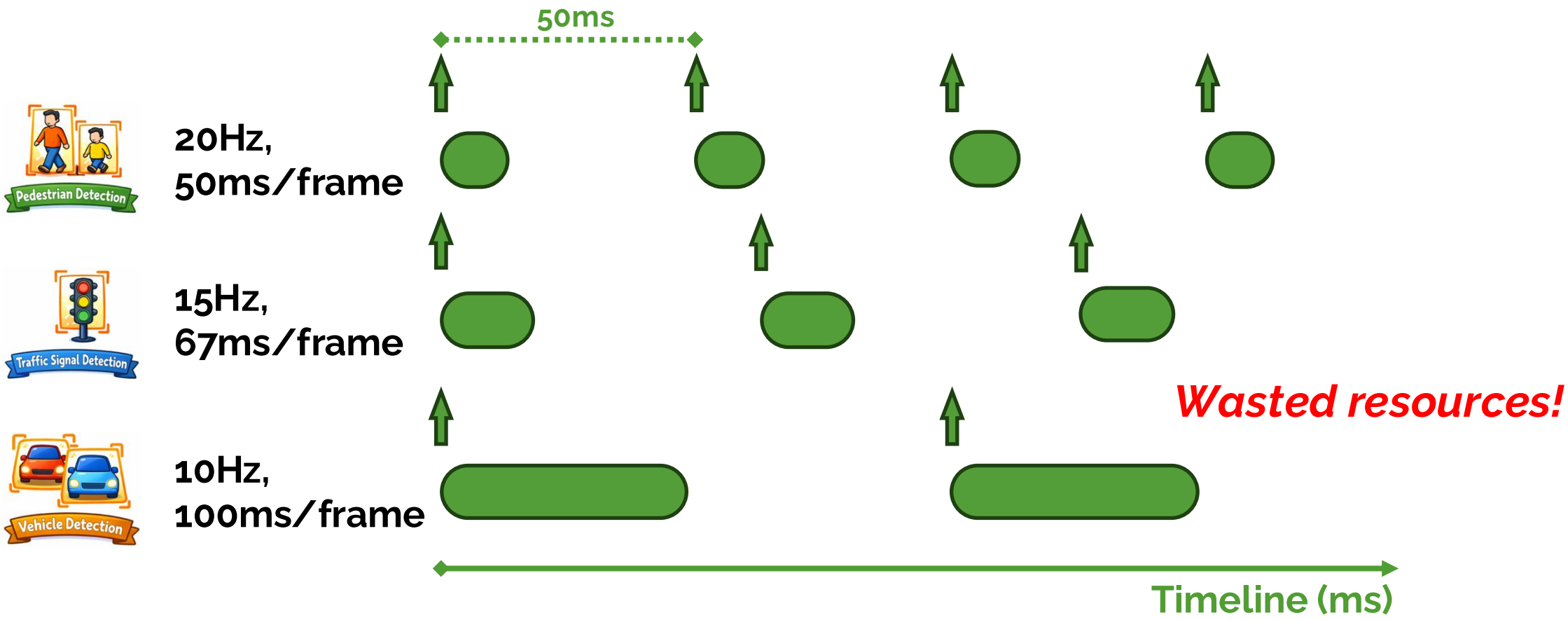

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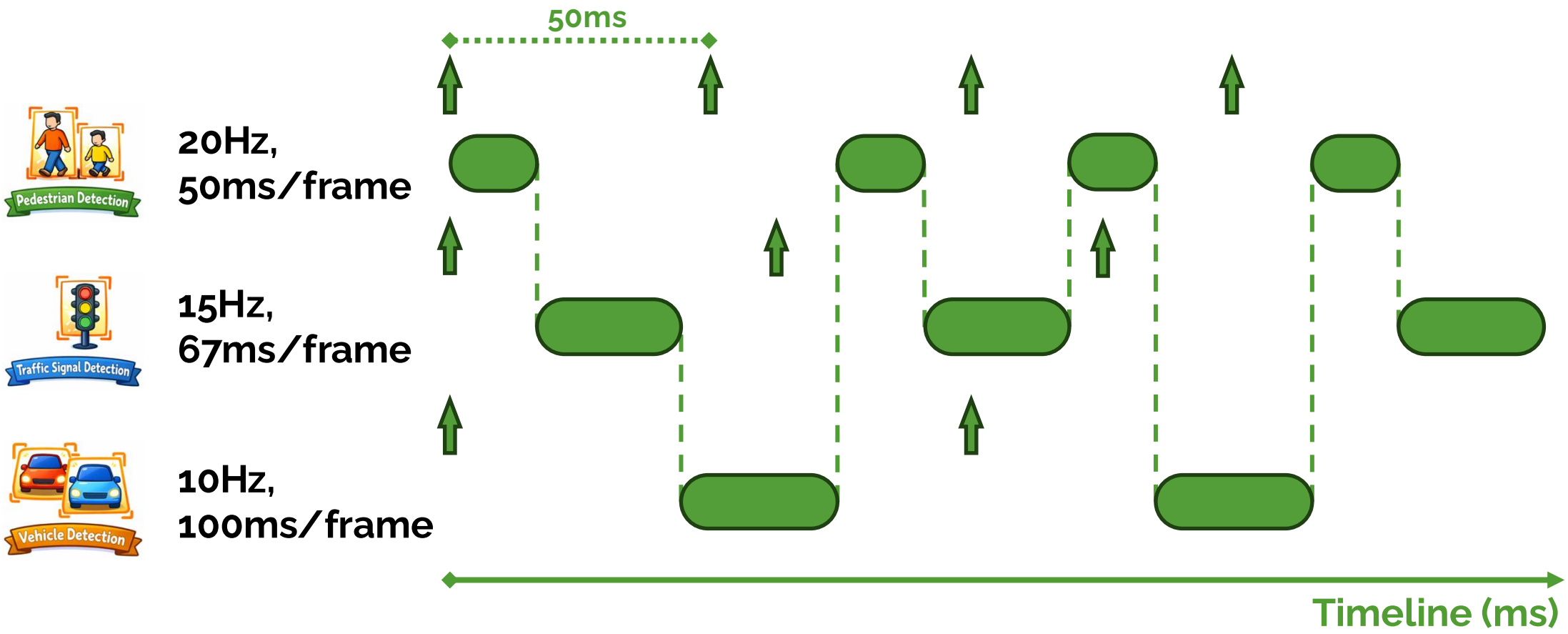

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Revisiting Architectural Choices in Heterogeneous Systems

Challenges

Solutions

To Overlay or to Customize?

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Challenges	Solutions
▪ The system requires periodic execution of multiple tasks.	▪ Integrate real-time systems into modeling.
▪ Diverse scenarios, complicated hardware, and flexible objectives.	▪ Build an analysis tool that takes safety and resources as constraints, and determines the optimal choices.
▪ Technique improvements may flip the design choices.	▪ Explore improvements in terms of key features.

Experimental Setup

Experimental Setup

- ADS Setup: Periodic tasks with hard deadline constraints.

Periodic tasks models

Experimental Setup

- **ADS Setup**: Periodic tasks with hard deadline constraints.
- **Applications Setup**: DeiT[1], MLP-Mixer[2], PointNet[3].

Periodic tasks models

	DeiT-S	DeiT-L	MLP-Mixer-S	MLP-Mixer-L	PointNet-S	PointNet-L
Setup A		20Hz		15Hz		10Hz
Setup B	20Hz			15Hz		10Hz
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Representative applications

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State-of-the-art Accs.

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- **Evaluation Metric**: Busy ratio.

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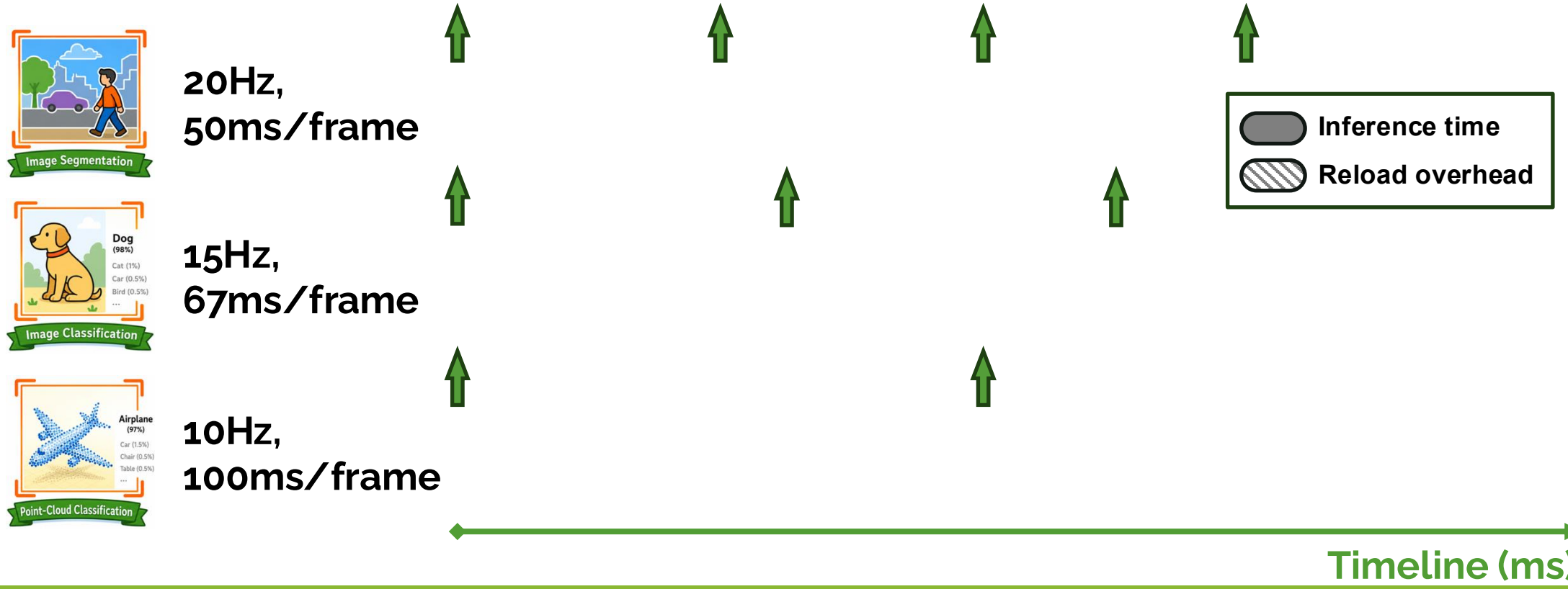

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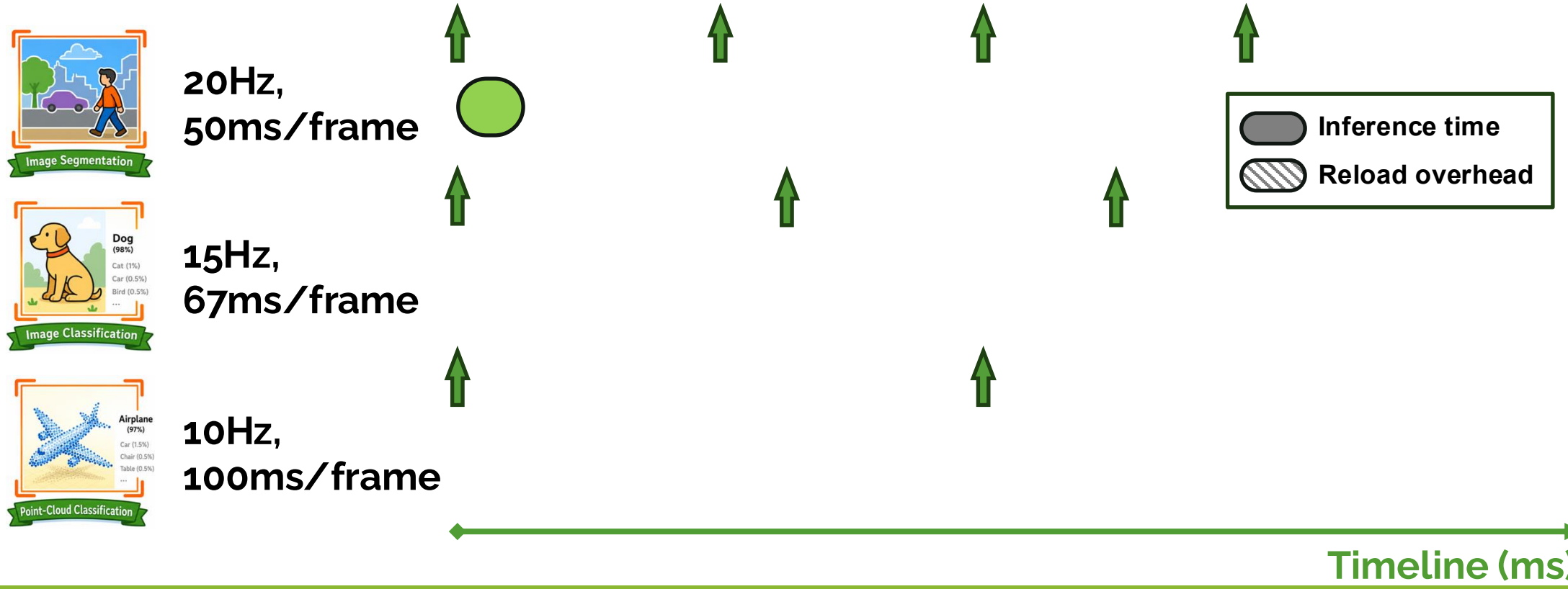

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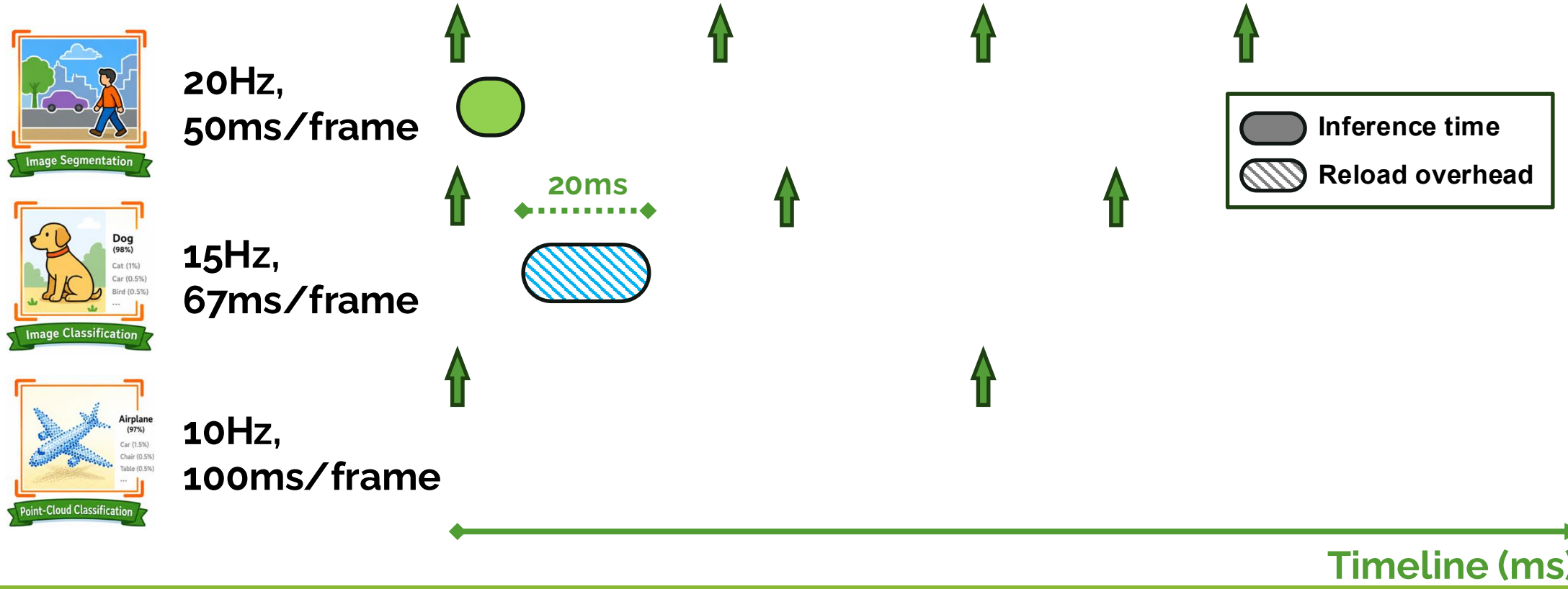

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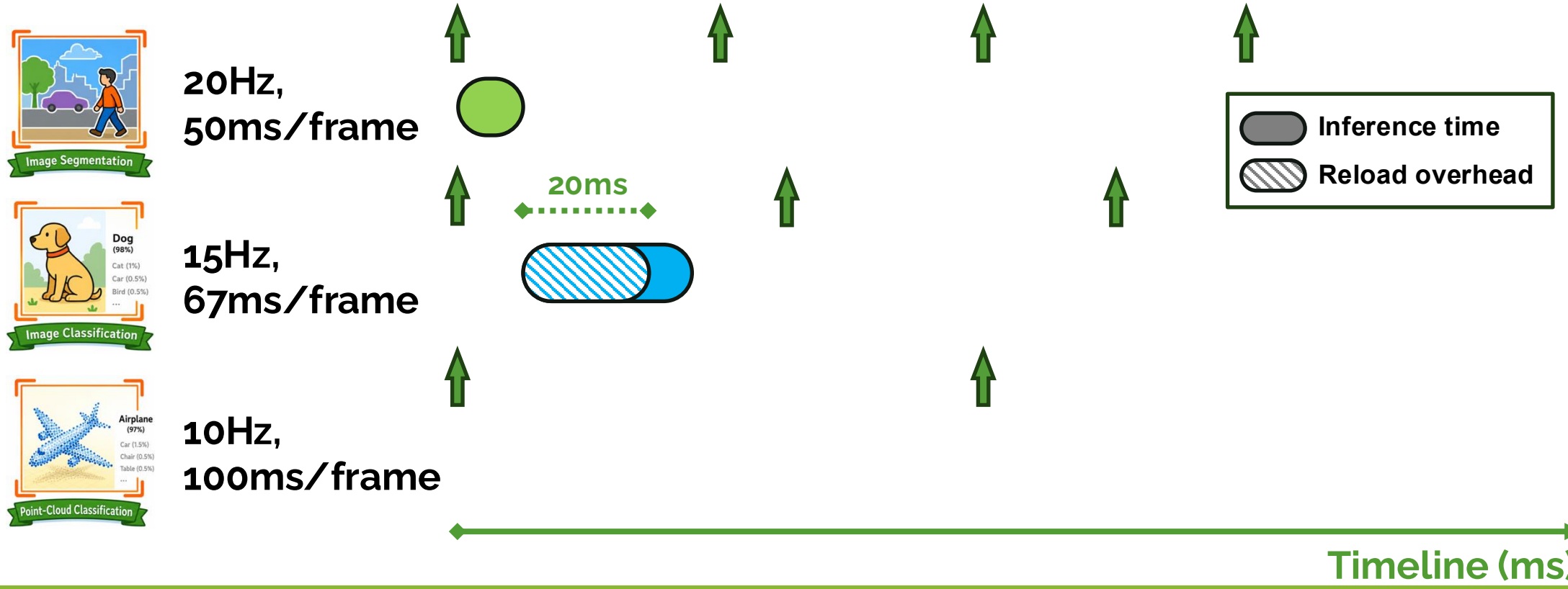

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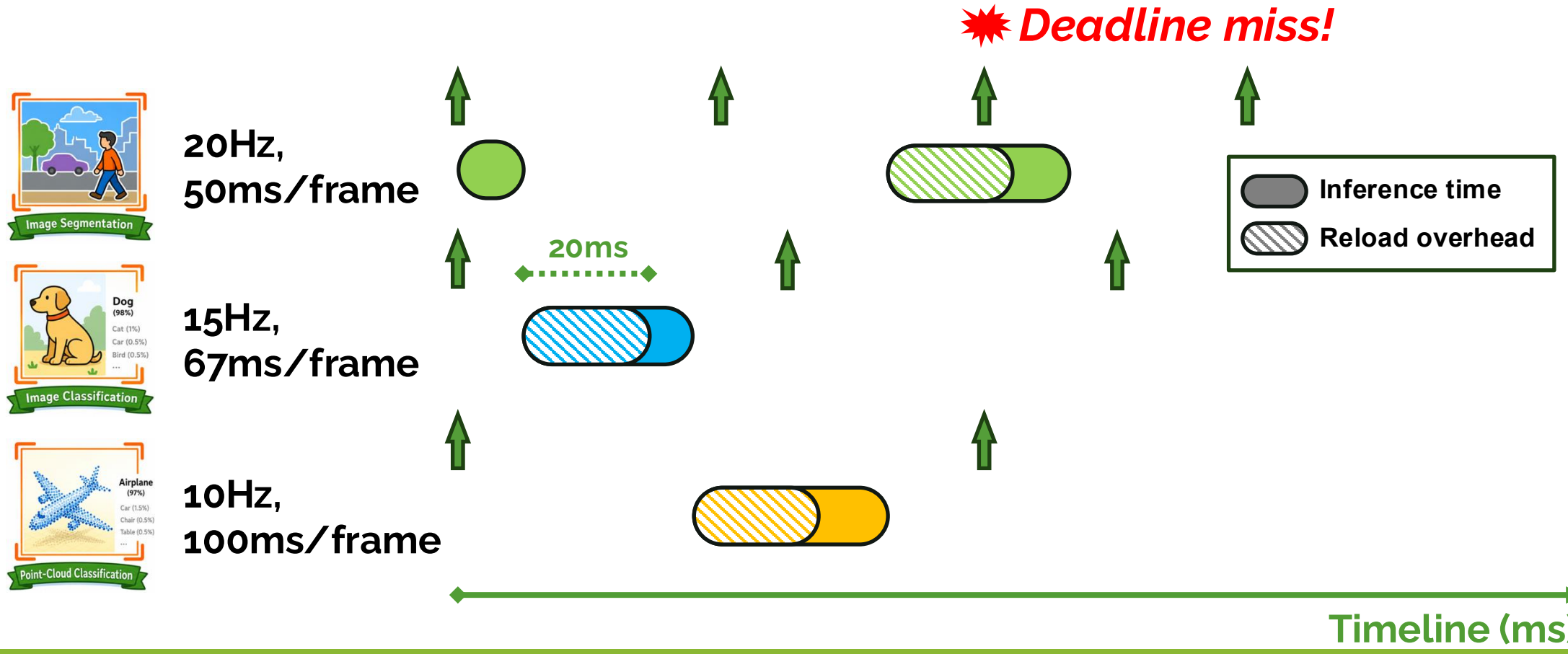

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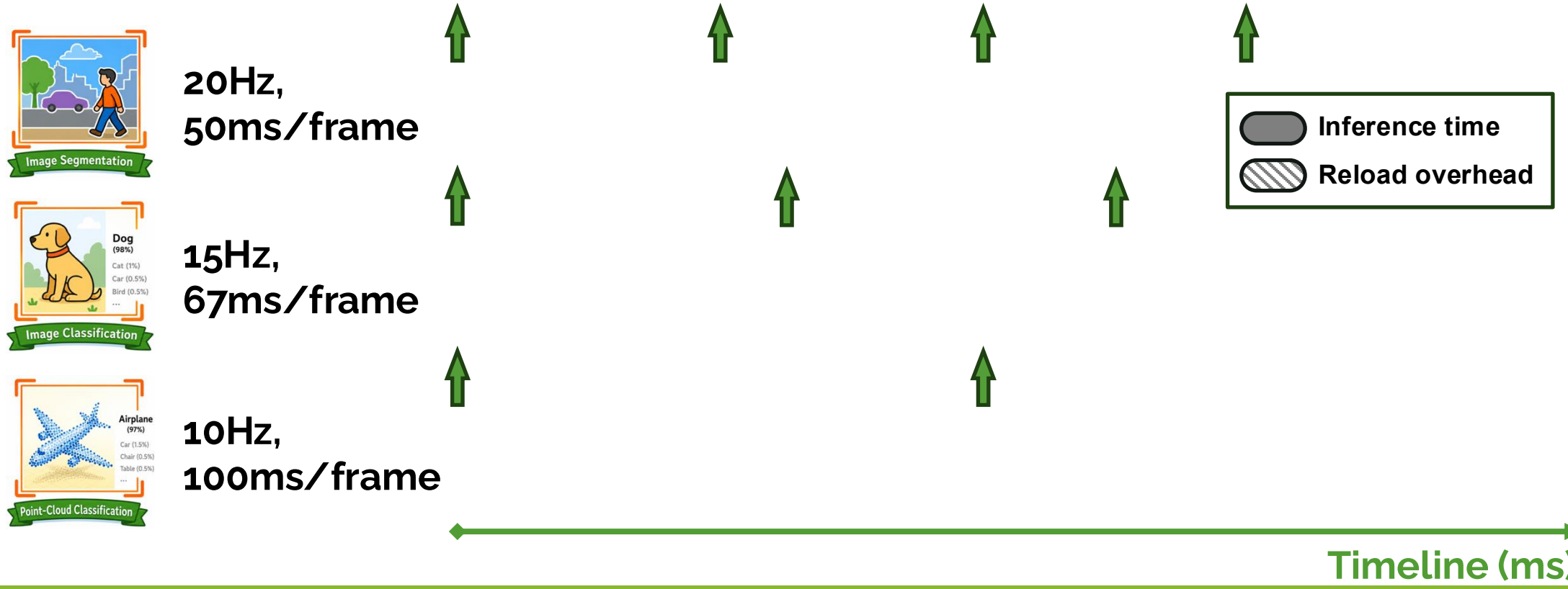

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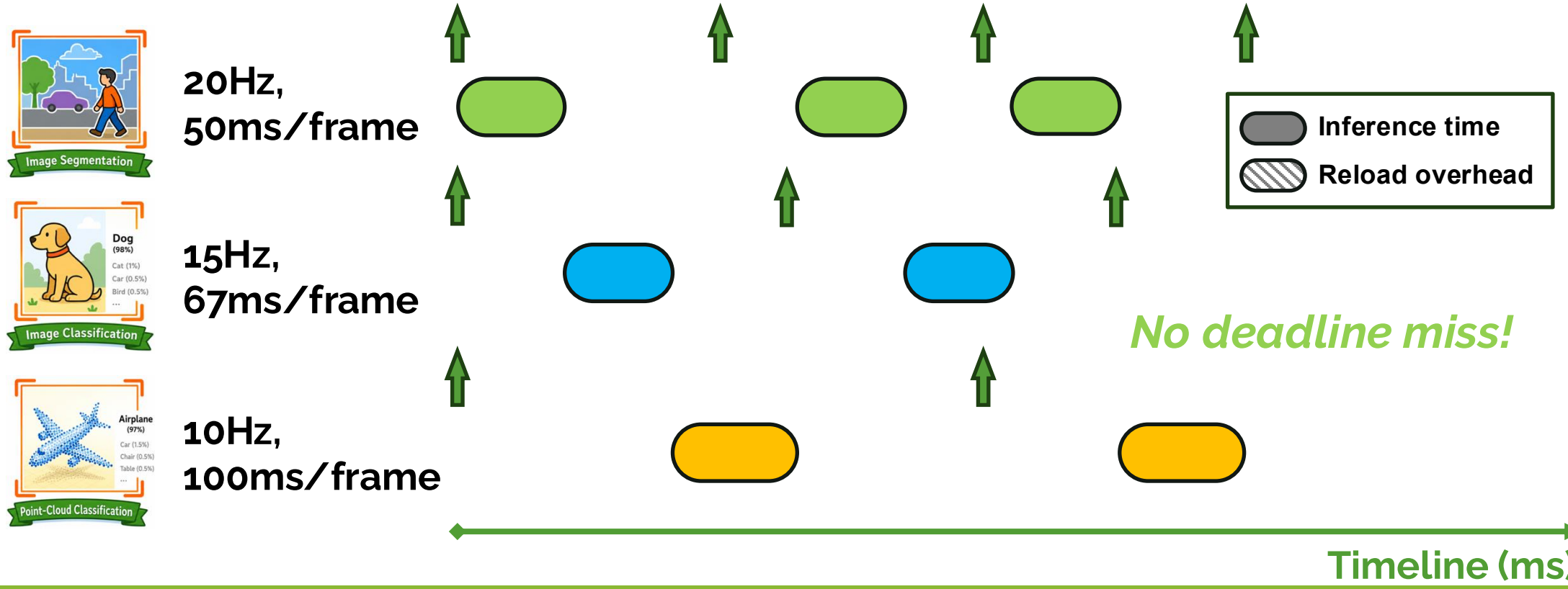

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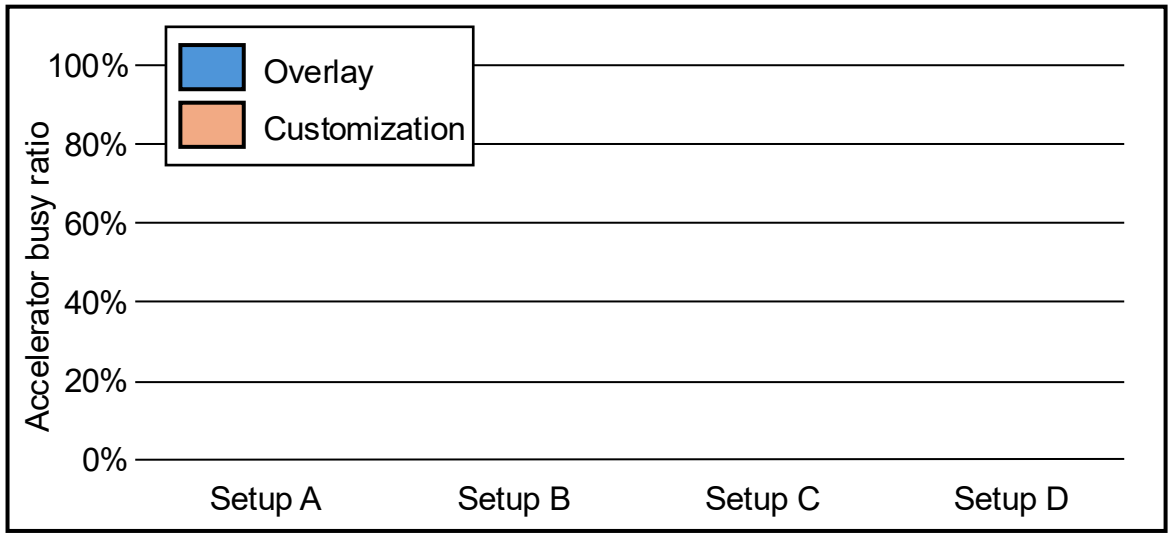
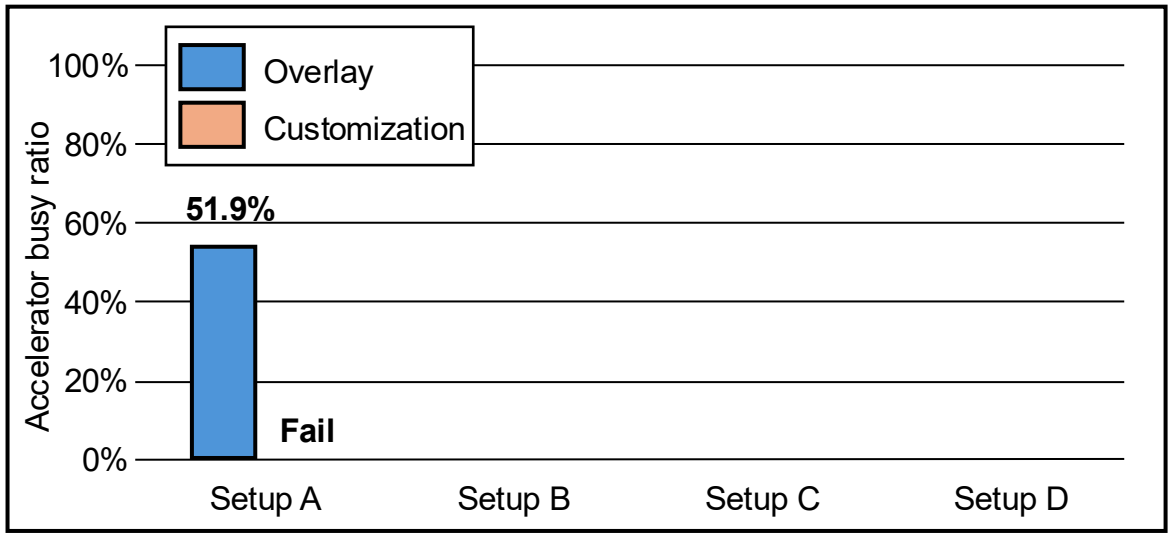


Trade-off with state-of-the-art techniques

- **Setup A: Customization choice fails with deadline miss.**



Trade-off with state-of-the-art techniques

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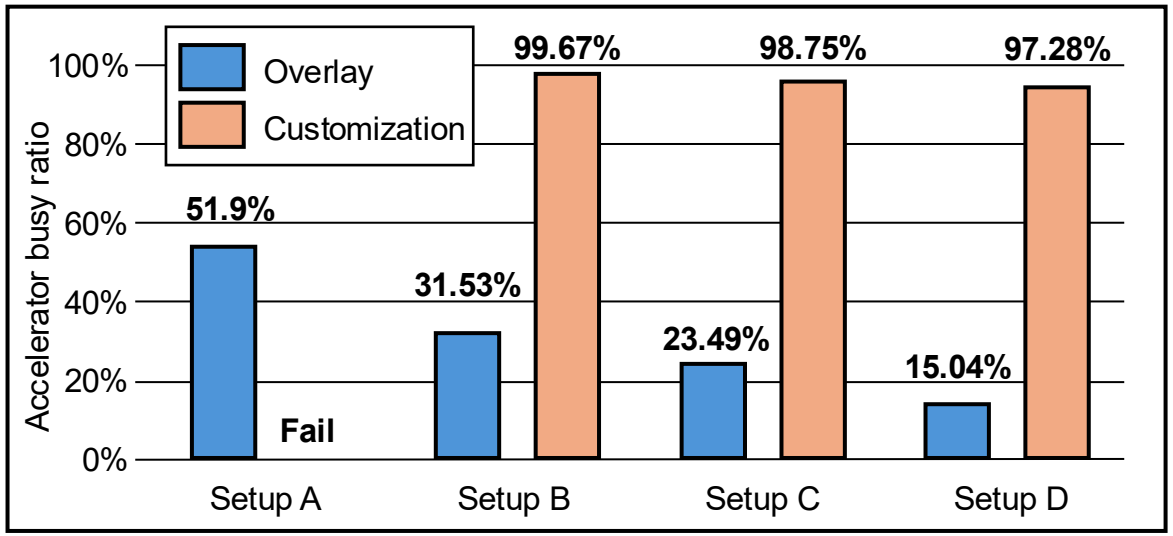

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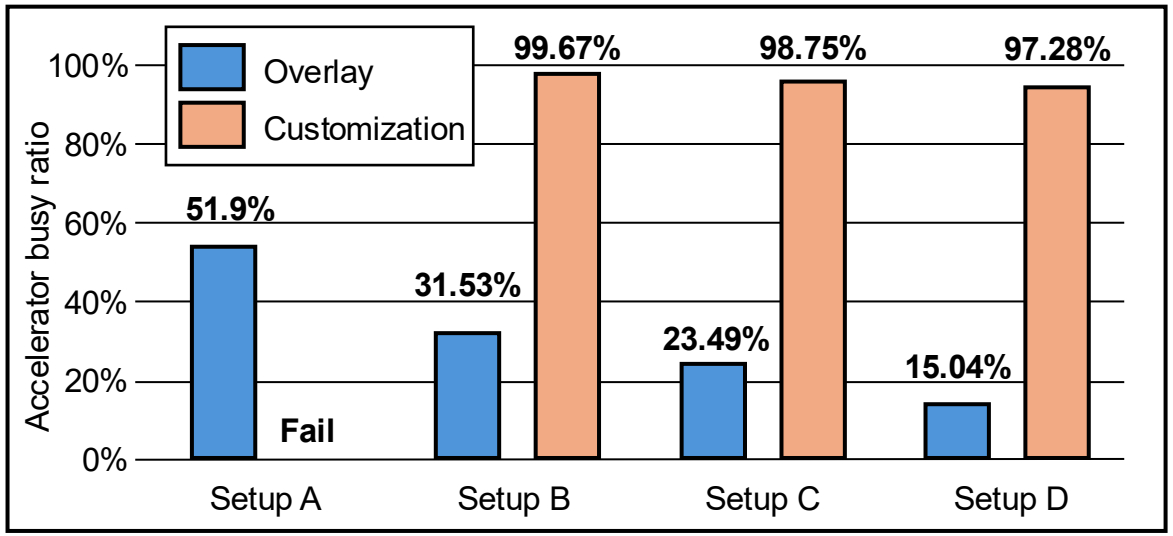

- Under current techniques, overlay usually outperforms customization in frequent switch scenarios.

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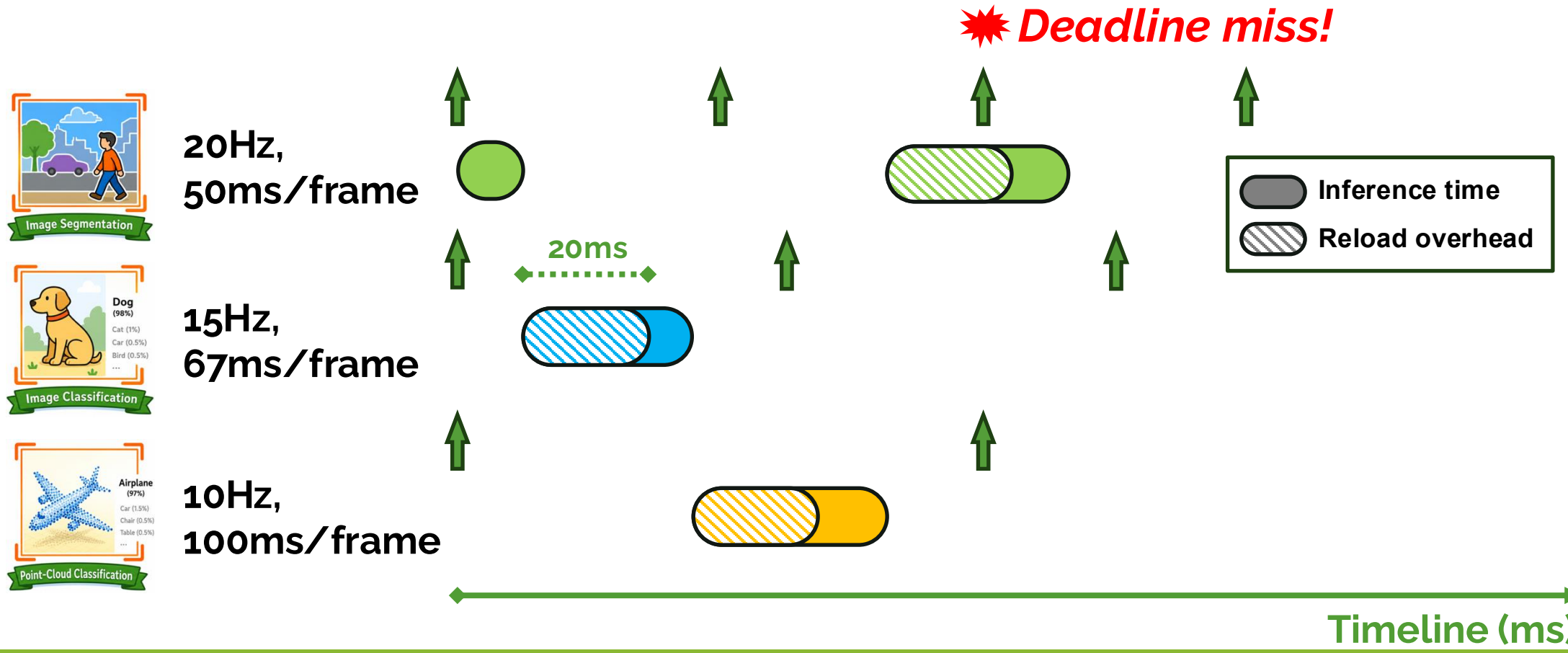

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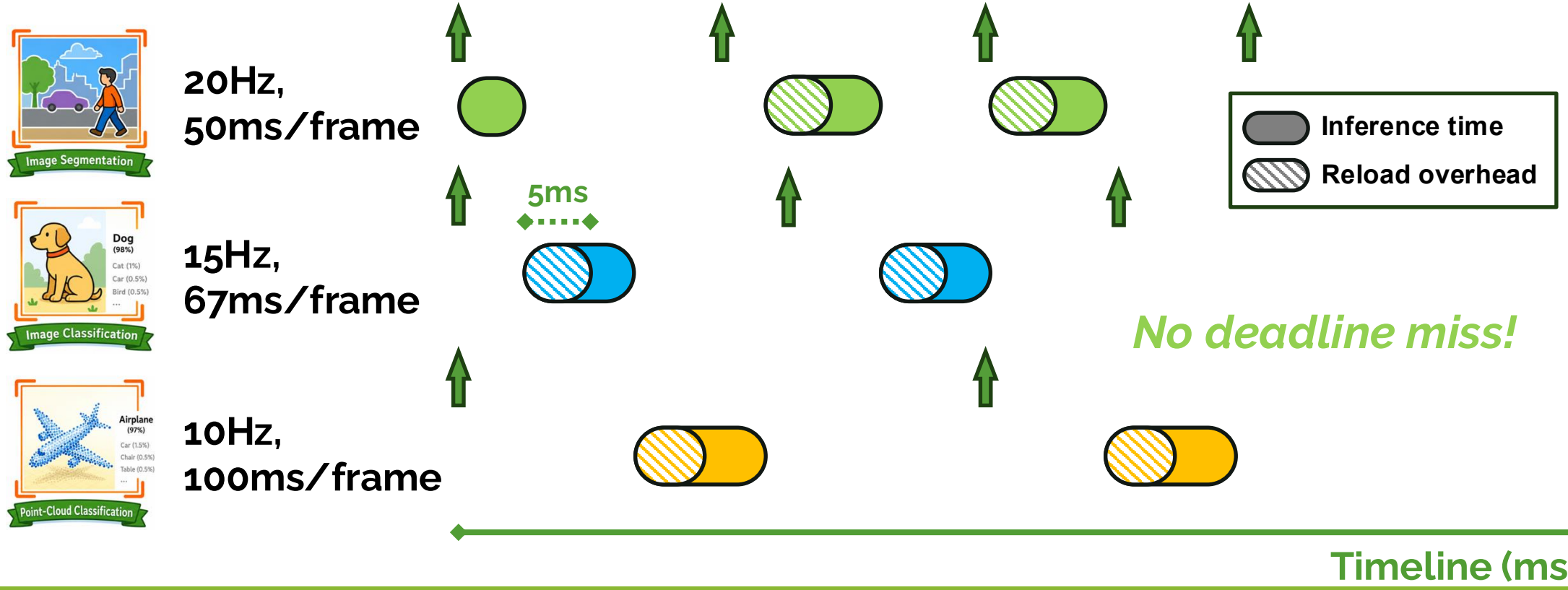

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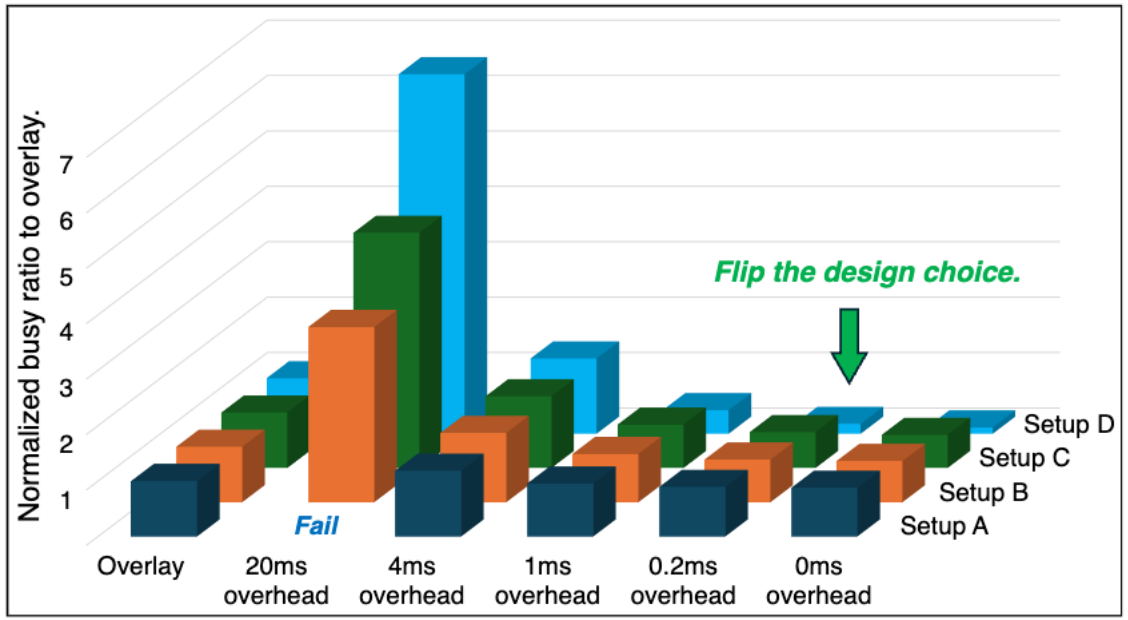
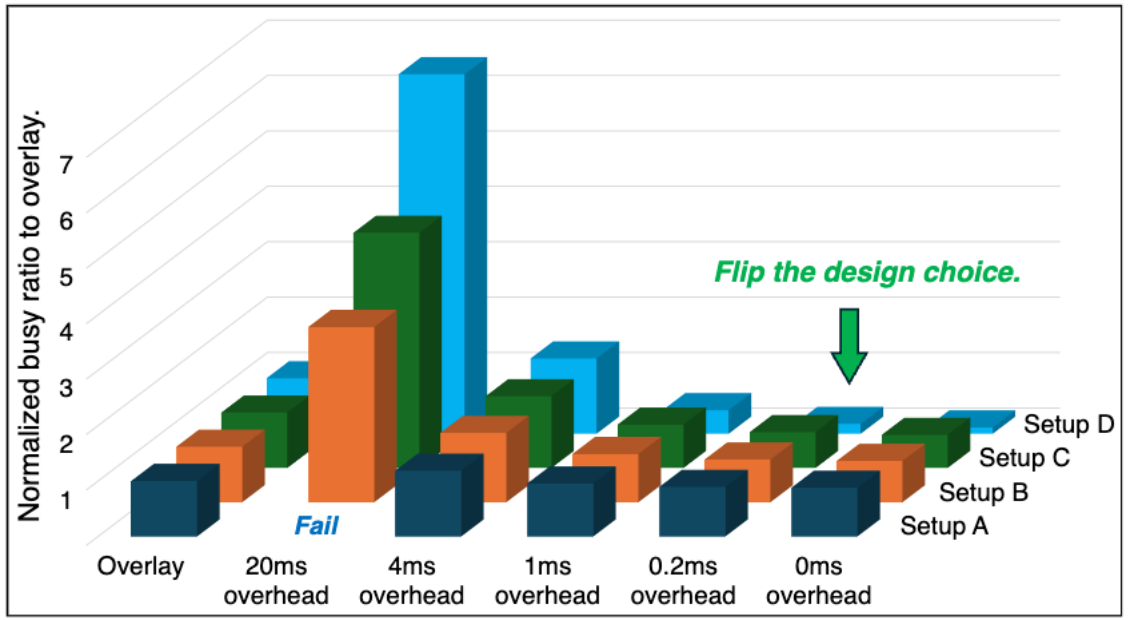


Comparison under advanced reconfiguration techniques.

Trade-off with advanced reconfiguration

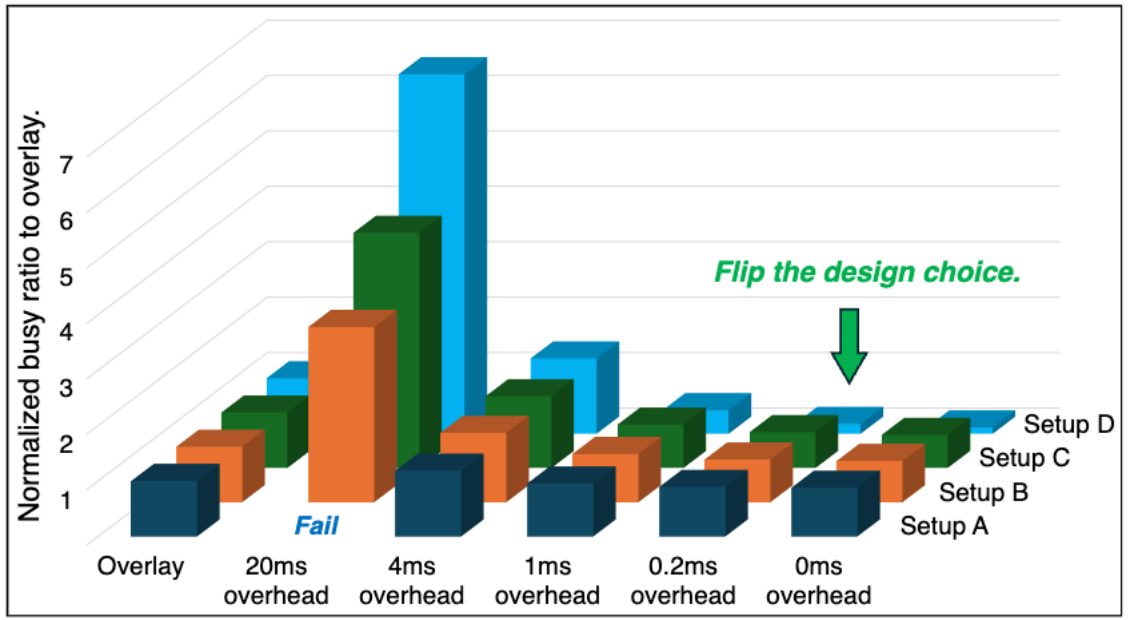
- Experiments on further advanced reconfiguration assumption.
- In current ADS scenarios, faster reconfiguration can reduce the busy ratio.



Comparison under advanced reconfiguration techniques.

Trade-off with advanced reconfiguration

- Experiments on further advanced reconfiguration assumption.
- In current ADS scenarios, faster reconfiguration can reduce the busy ratio.
- 0.2ms reconfiguration latency will flip the design choices.



Comparison under advanced reconfiguration techniques.

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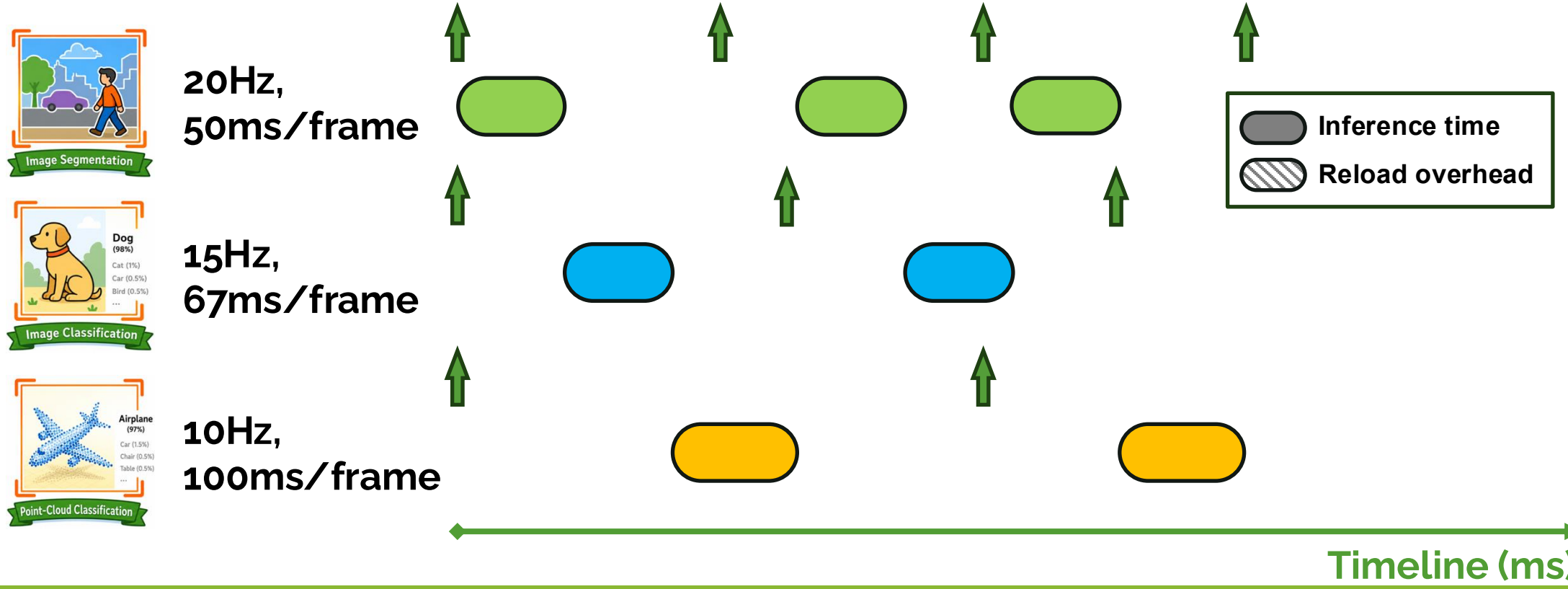

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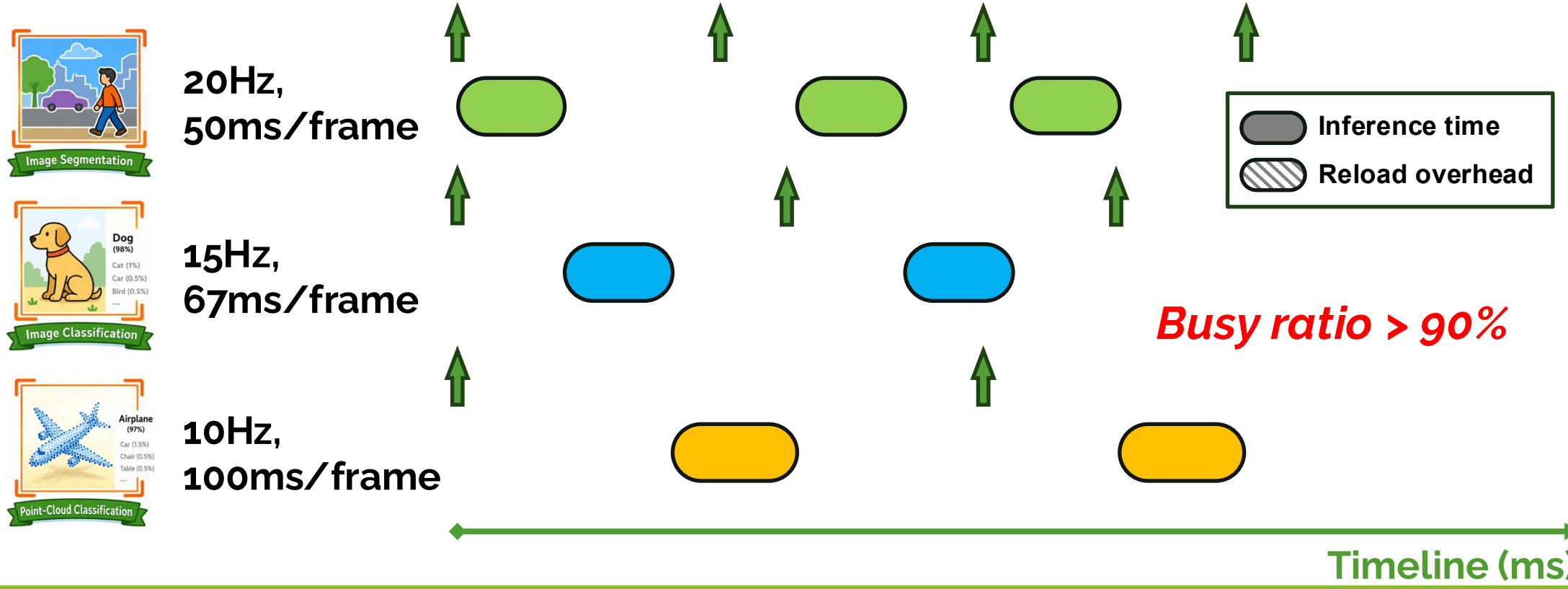

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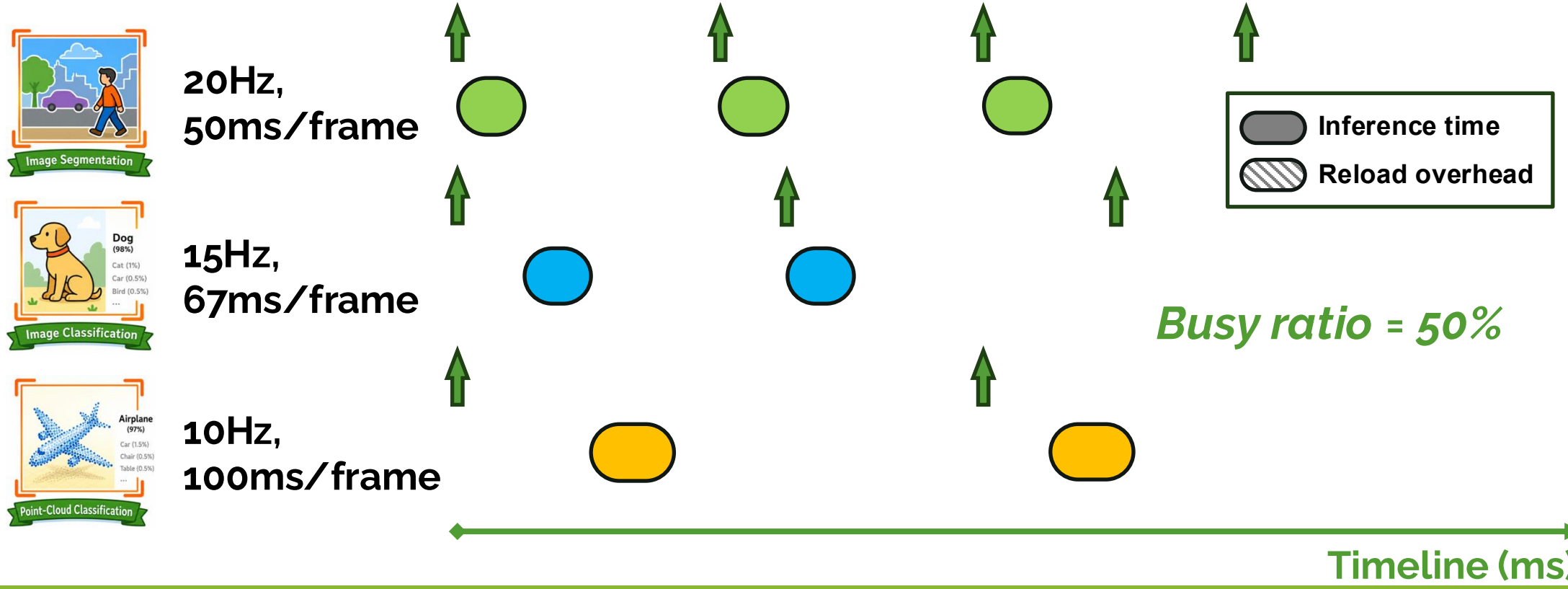

Trade-off with advanced overlay architecture

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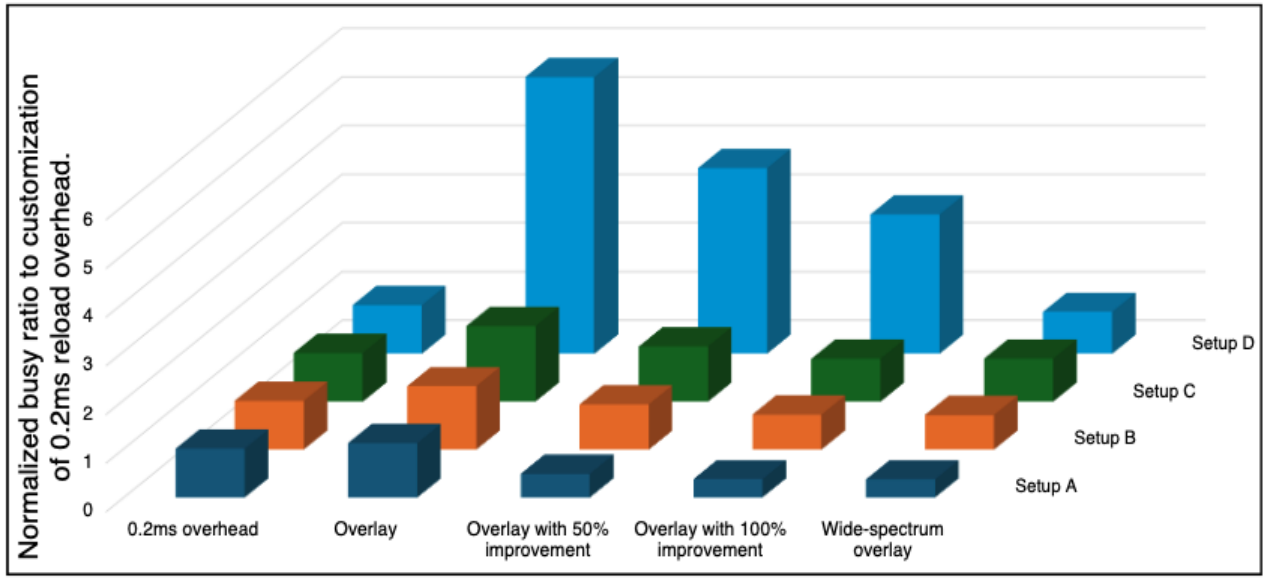

Comparison under advanced overlay accelerators.

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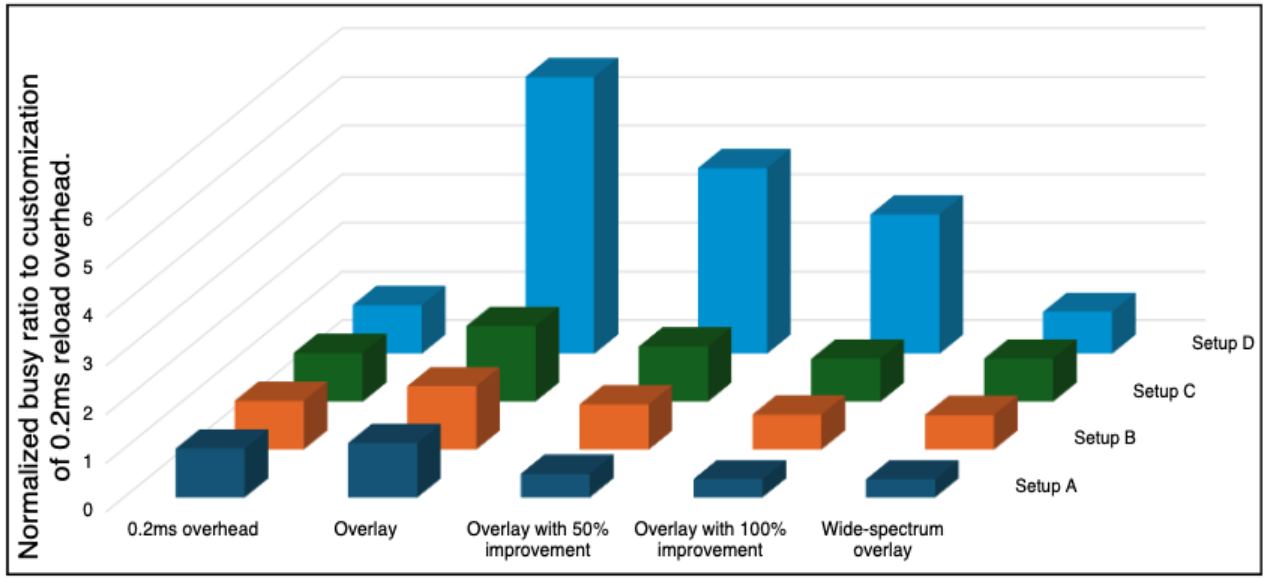
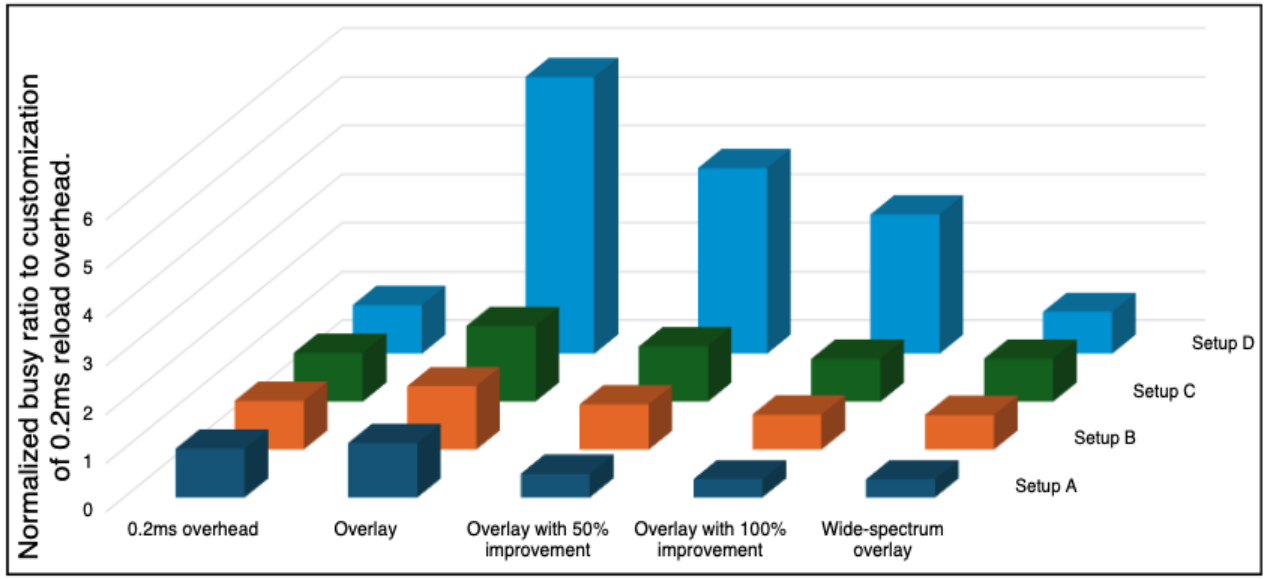
- Experiments on further advanced overlay assumption.
- Current overlay acc struggles on diverse workload scenarios.



Comparison under advanced overlay accelerators.

Trade-off with advanced overlay architecture

- Experiments on further advanced overlay assumption.
- Current overlay acc struggles on diverse workload scenarios.
- Wide-spectrum overlay that covers entire range of workload diversity is necessary.



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- Optimal architecture for one task is not necessarily the best for the whole ADS system.
- Reconfiguration overhead is a significant factor. Even a few milliseconds' reduction affects a lot.
- Customized architectures become attractive when bitstream reload overhead is sufficiently reduced.
- Advanced overlays can reverse the trend again.

Thank You & Welcome to questions!

To Overlay or to Customize?
Revisiting Architectural Choices in Heterogeneous Systems

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