

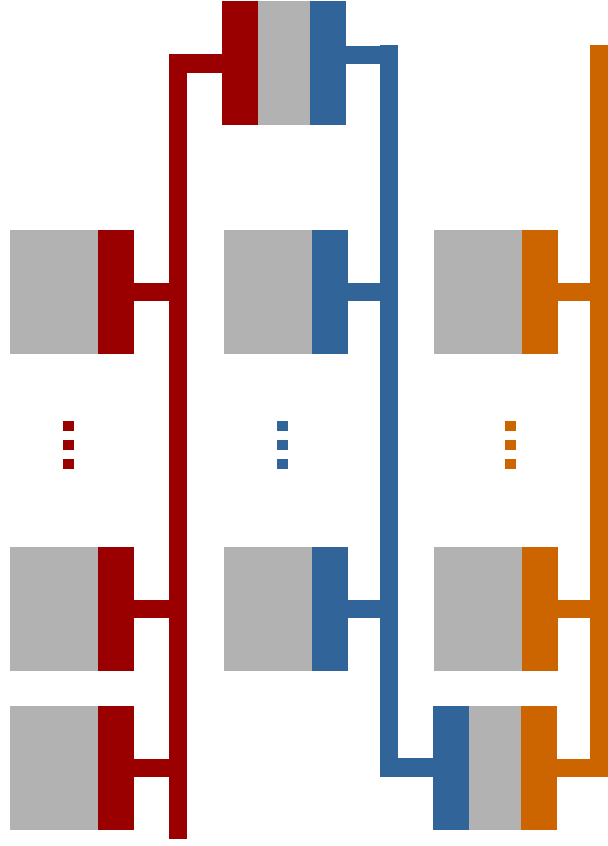
Schedulability-Driven Partitioning and Mapping for **Multi-Cluster Real-Time Systems**

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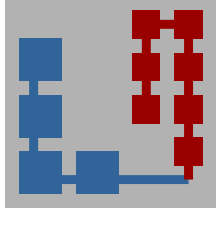
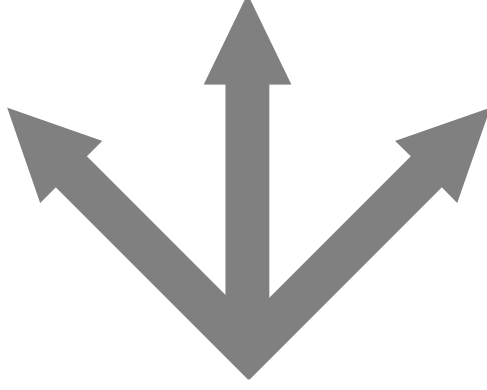


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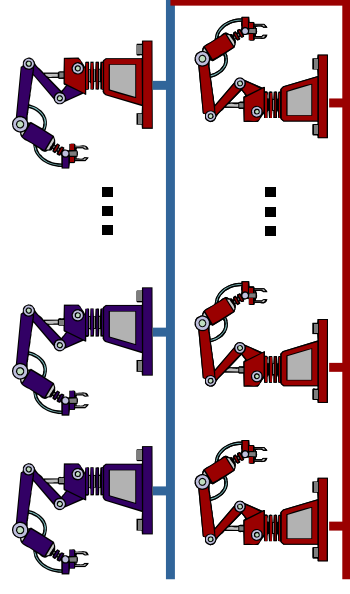
Heterogeneous Networks



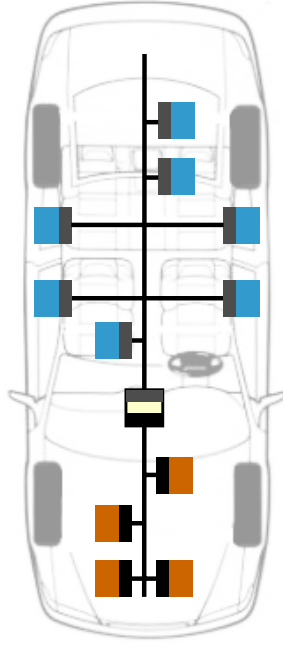
Heterogeneous Networks
Multi-Cluster Systems



NoCs

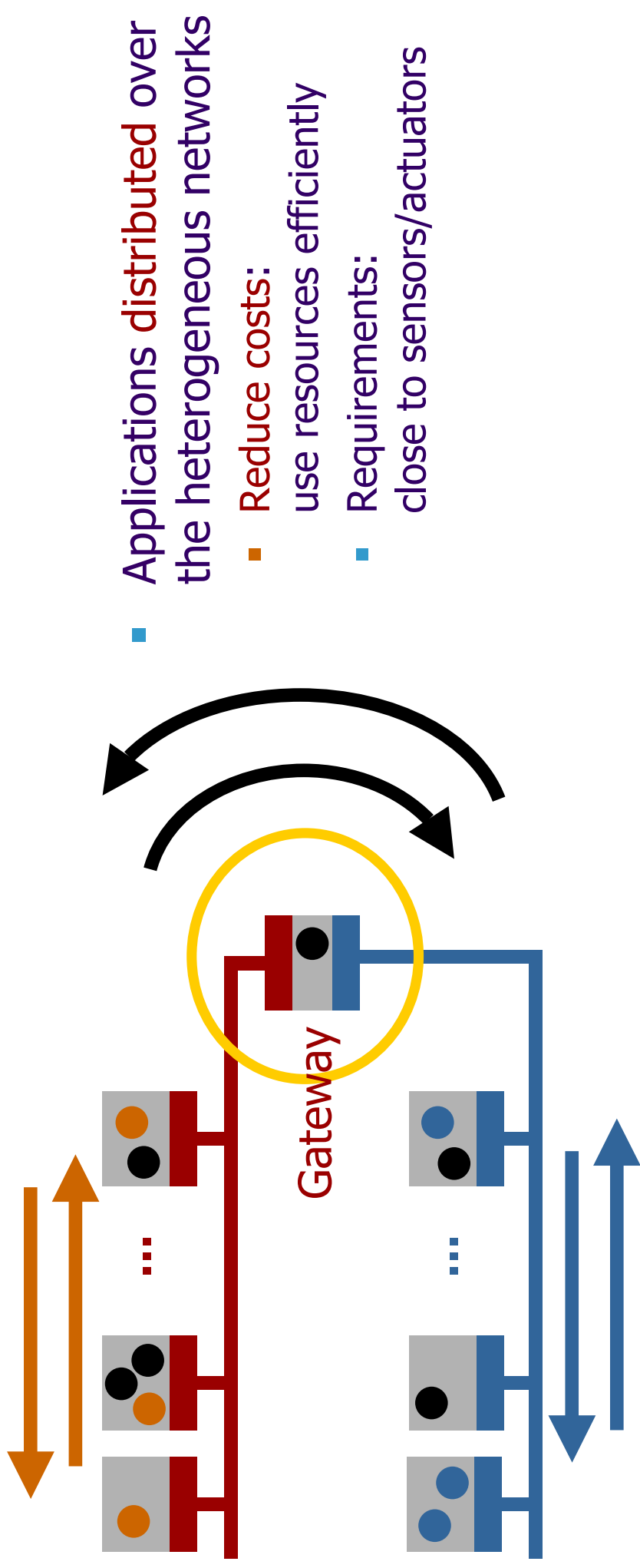


Factory Systems



Automotive Electronics

Distributed Safety-Critical Applications

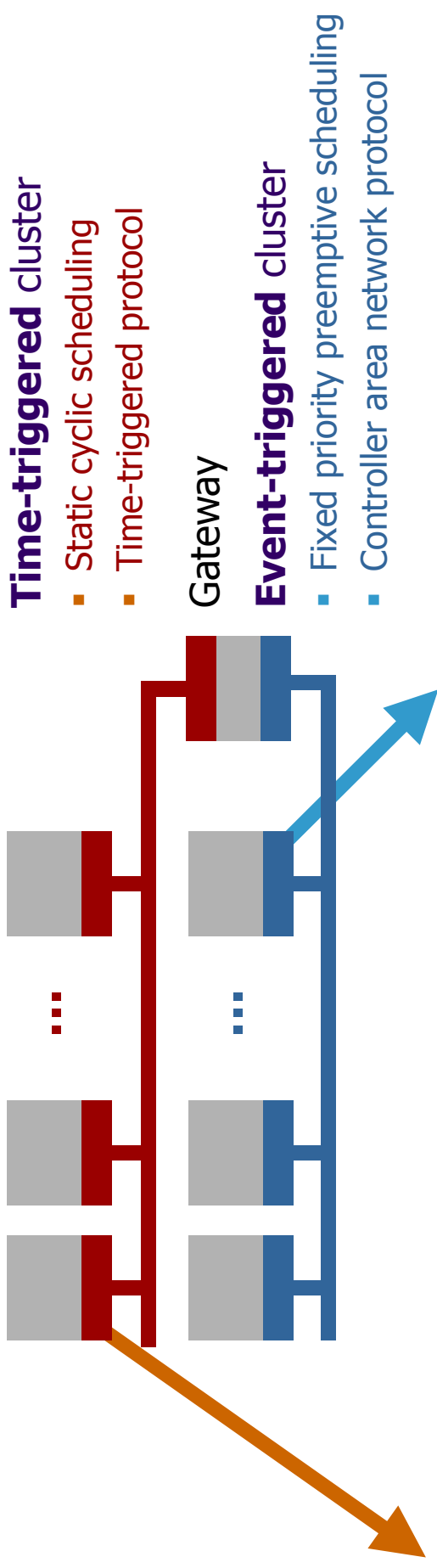


- Applications distributed over the heterogeneous networks
 - Reduce costs: use resources efficiently
 - Requirements: close to sensors/actuators

- Applications distributed over heterogeneous networks are difficult to...
 - **Analyze** (guaranteeing timing constraints)  [DATE'03]
 - **Design** (partitioning, mapping, bus access optimization)  **This paper!**

- Motivation
- ➔ System architecture and application model
- Scheduling for multi-clusters [DATE'03]
- Design optimization problems
 - Partitioning
 - Mapping
 - Bus access optimization
- Branch and bound optimization strategy
- Experimental results
- Contributions and Message

Hardware Architecture



Time-triggered cluster

- Static cyclic scheduling
- Time-triggered protocol

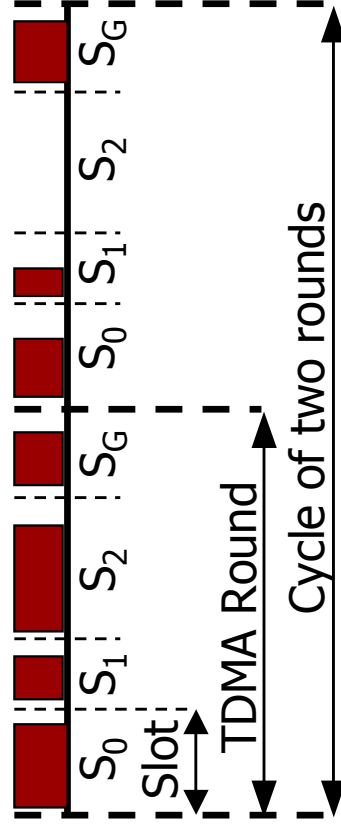
Gateway

Event-triggered cluster

- Fixed priority preemptive scheduling
- Controller area network protocol

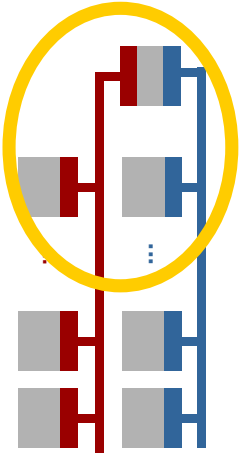
Time Triggered Protocol (TTP)

- Bus access scheme: time-division multiple-access (TDMA)
- Schedule table located in each TTP controller: message descriptor list (MEDL)

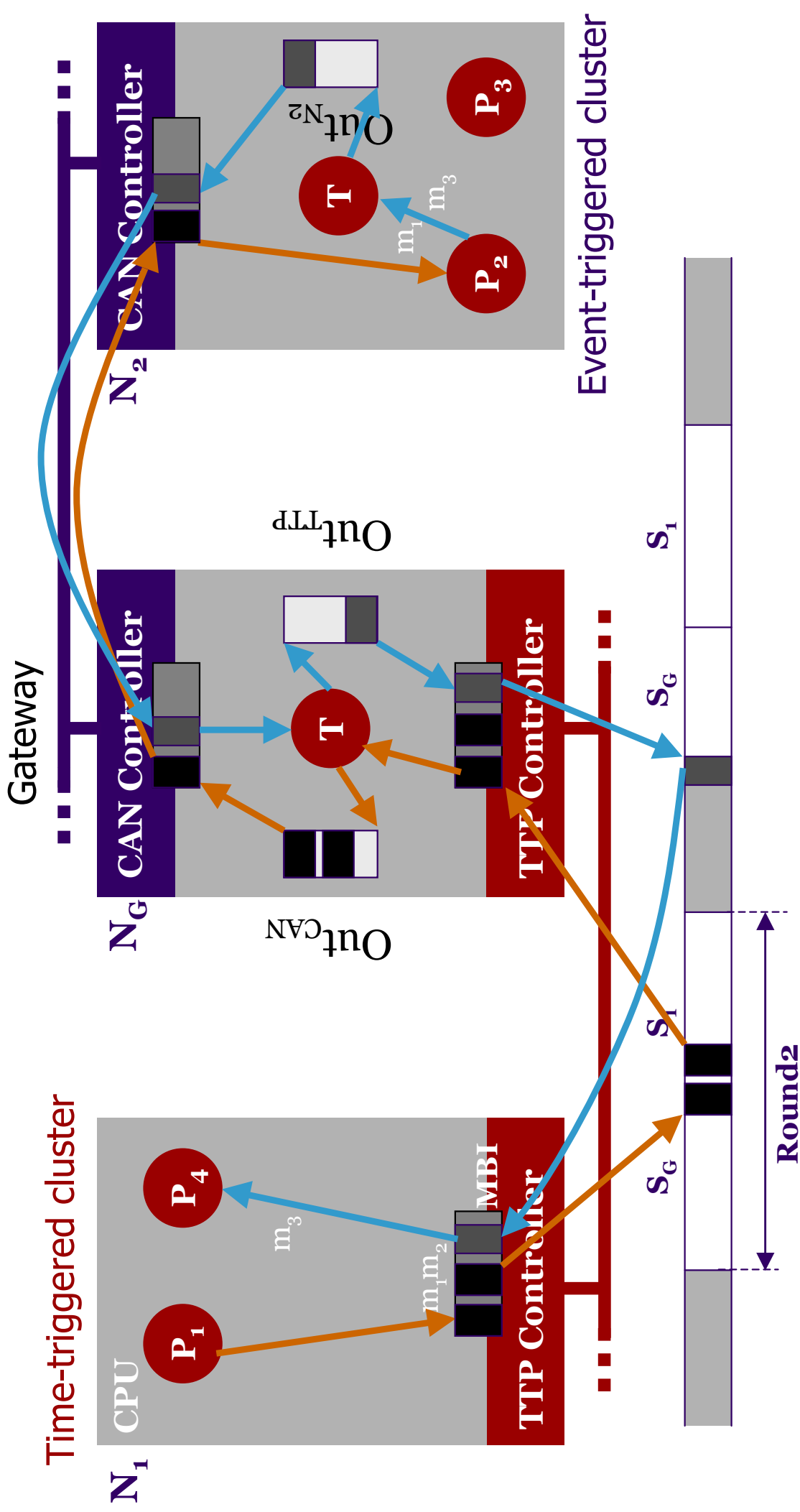


Controller Area Network (CAN)

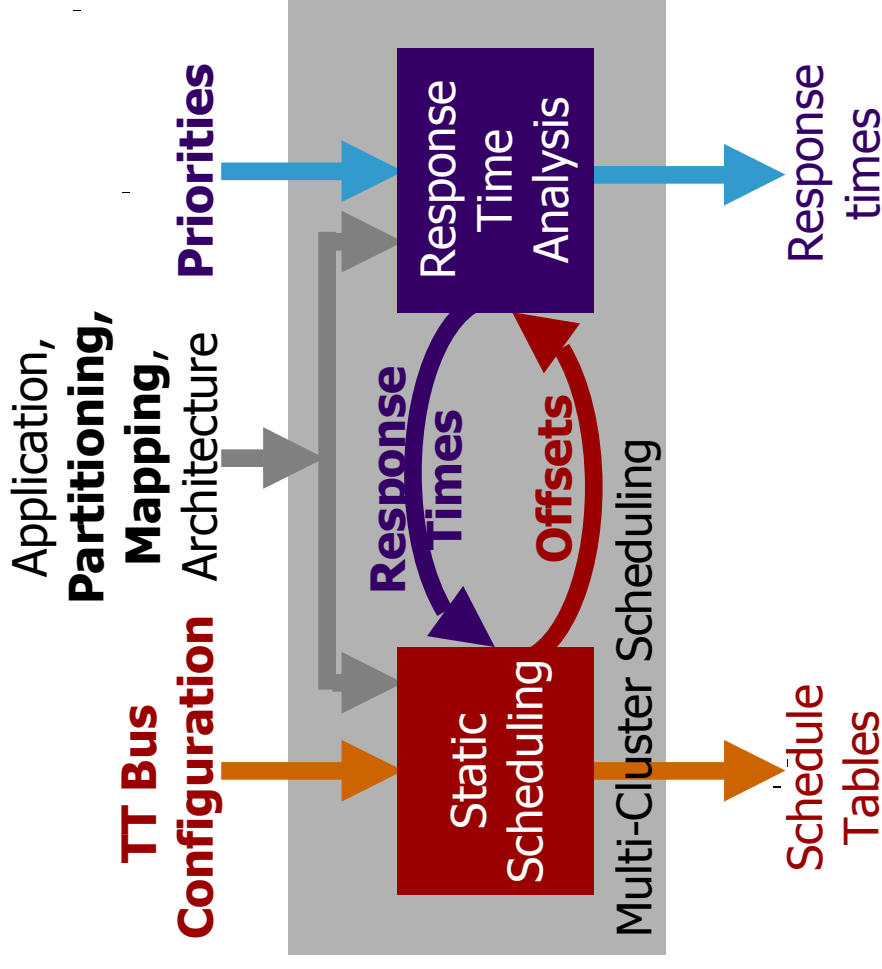
- Priority bus, collision avoidance
- Highest priority message wins the contention
- Priorities encoded in the frame identifier



Software Architecture



Multi-Cluster Scheduling [DATE'03]



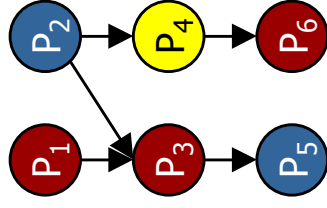
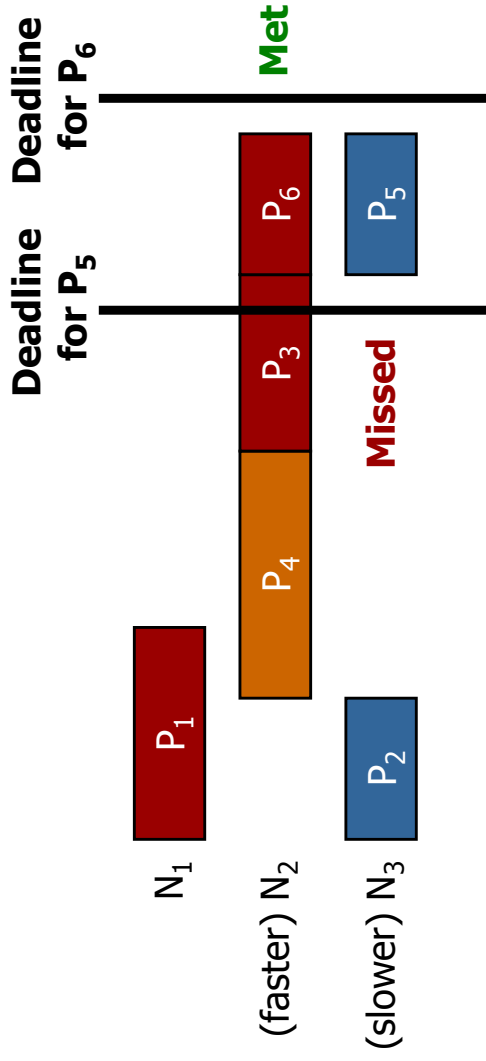
- MultiClusterScheduling algorithm
 - Schedulability analysis: communication delays through the gateway
 - Scheduling: cannot be addressed separately for each cluster

Problem Formulation

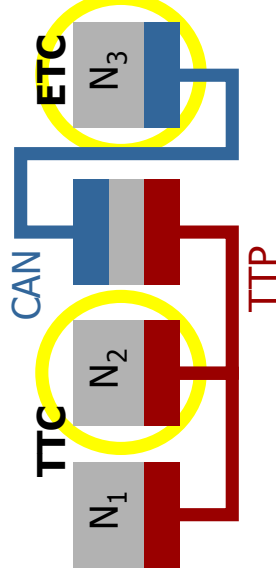
- Input
 - System architecture
 - Application
 - **Partial** partitioning and mapping, based on the designer's experience
- Output
 - **Design implementation** such that the application is schedulable
 - Partitioning for each un-partitioned process
 - Mapping for each un-mapped process
 - Priorities for ET messages
 - TDMA slot sequence and sizes for the TT bus
 - Priorities for ET processes
 - Schedule table for TT messages
 - Partitioning and mapping
 - Communication infrastructure
 - Scheduling information

Motivational Example #1

In which cluster to place process P₄?

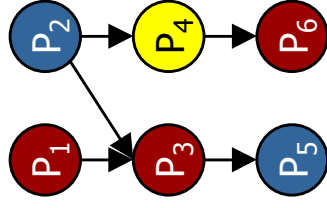
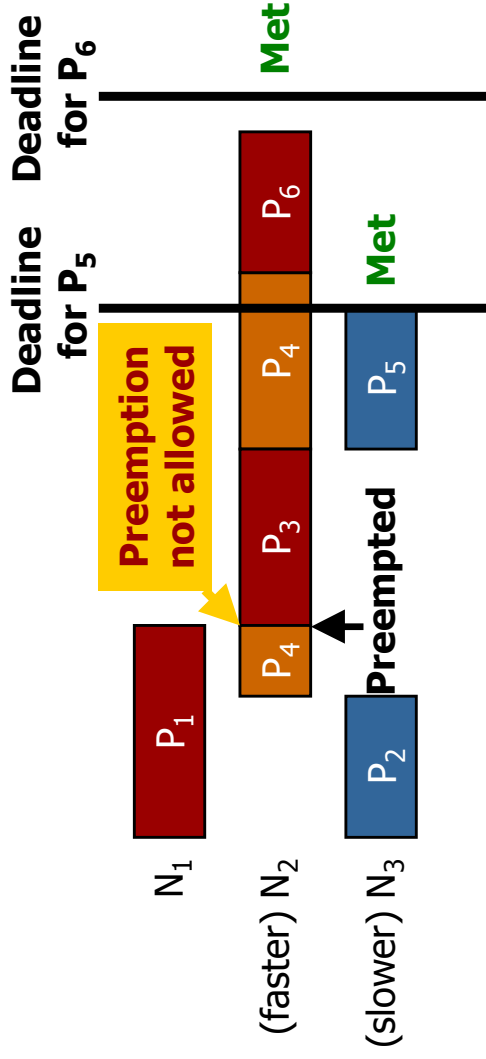


	N ₁	N ₂	N ₃
P ₁	70	X	X
P ₂	X	X	40
P ₃	X	50	X
P ₄	X	70	90
P ₅	X	X	40
P ₆	X	X	40

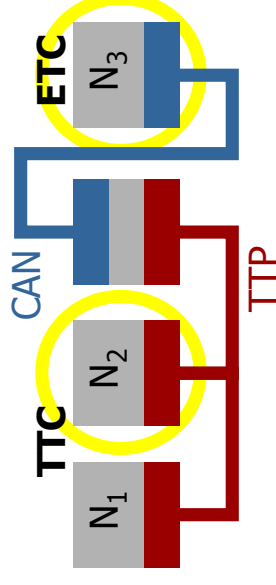


Motivational Example #1, Cont.

In which cluster to place process P₄?

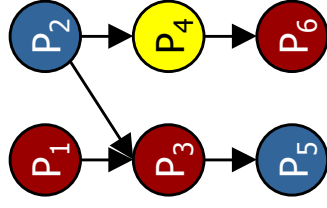
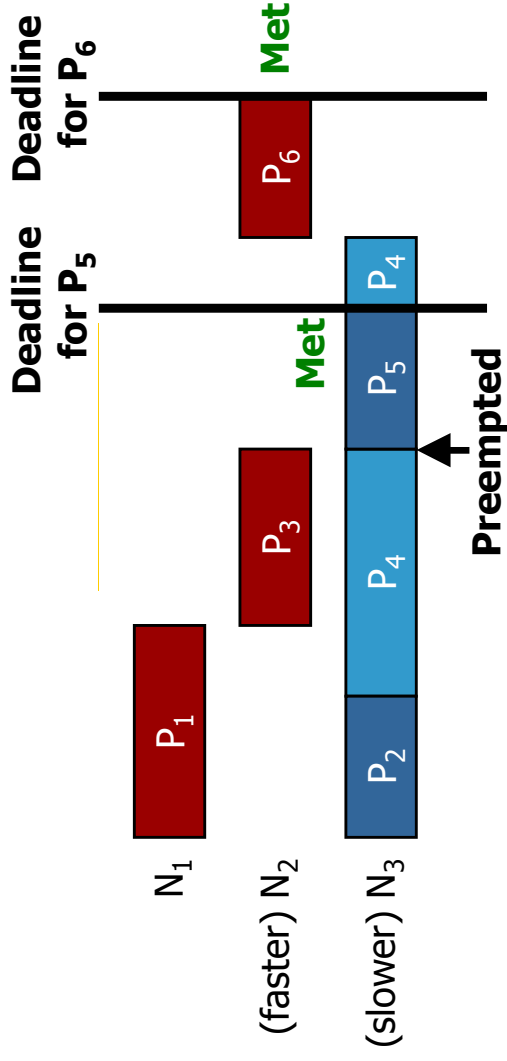


	N ₁	N ₂	N ₃
P ₁	70	X	X
P ₂	X	X	40
P ₃	X	50	X
P ₄	X	70	90
P ₅	X	X	40
P ₆	X	X	40

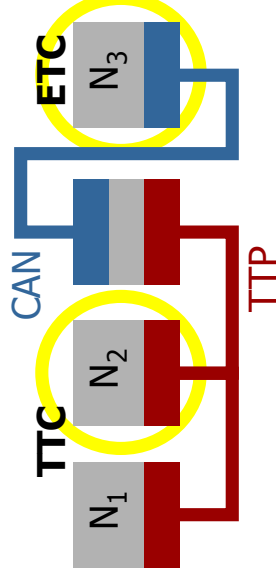


Motivational Example #1, Cont.

In which cluster to place process P₄?

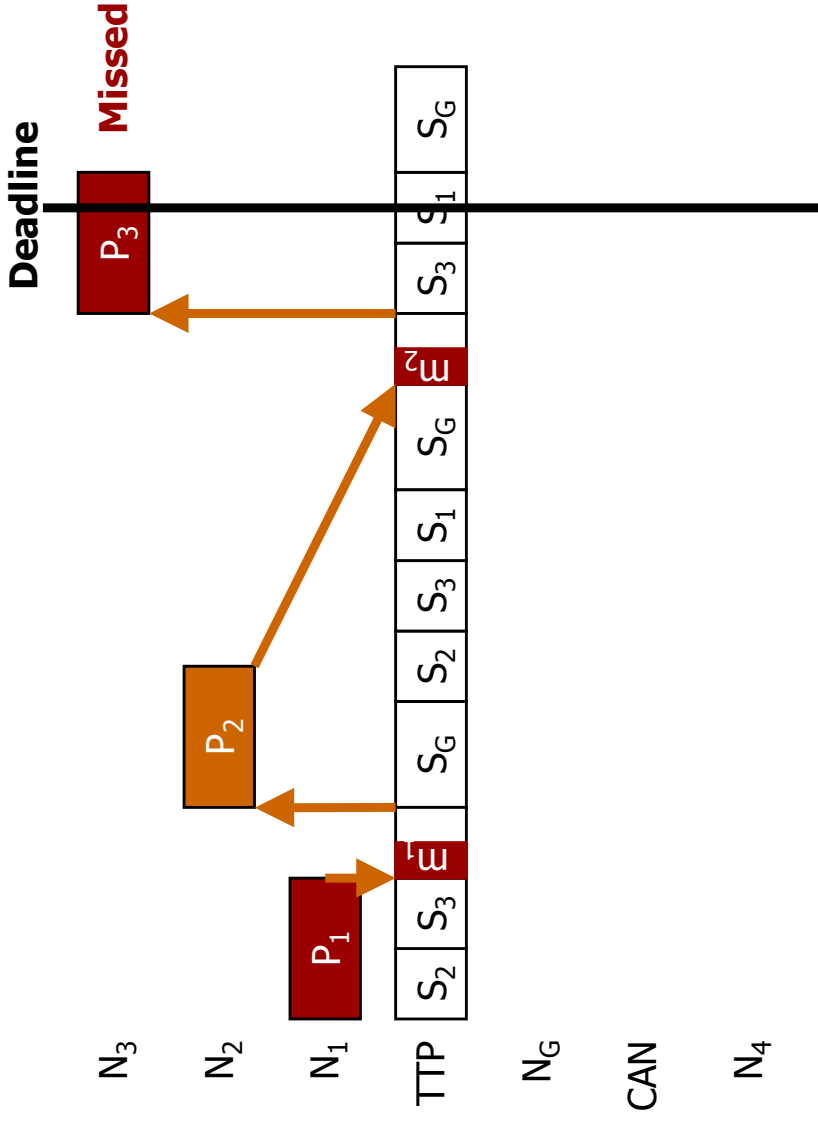


	N ₁	N ₂	N ₃
P ₁	70	X	X
P ₂	X	X	40
P ₃	X	50	X
P ₄	X	70	90
P ₅	X	X	40
P ₆	X	X	40

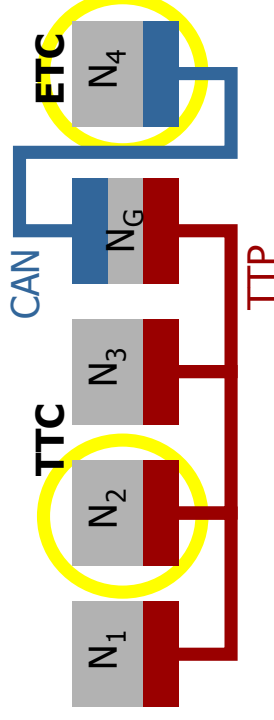


Motivational Example #2

Where to map process P₂?

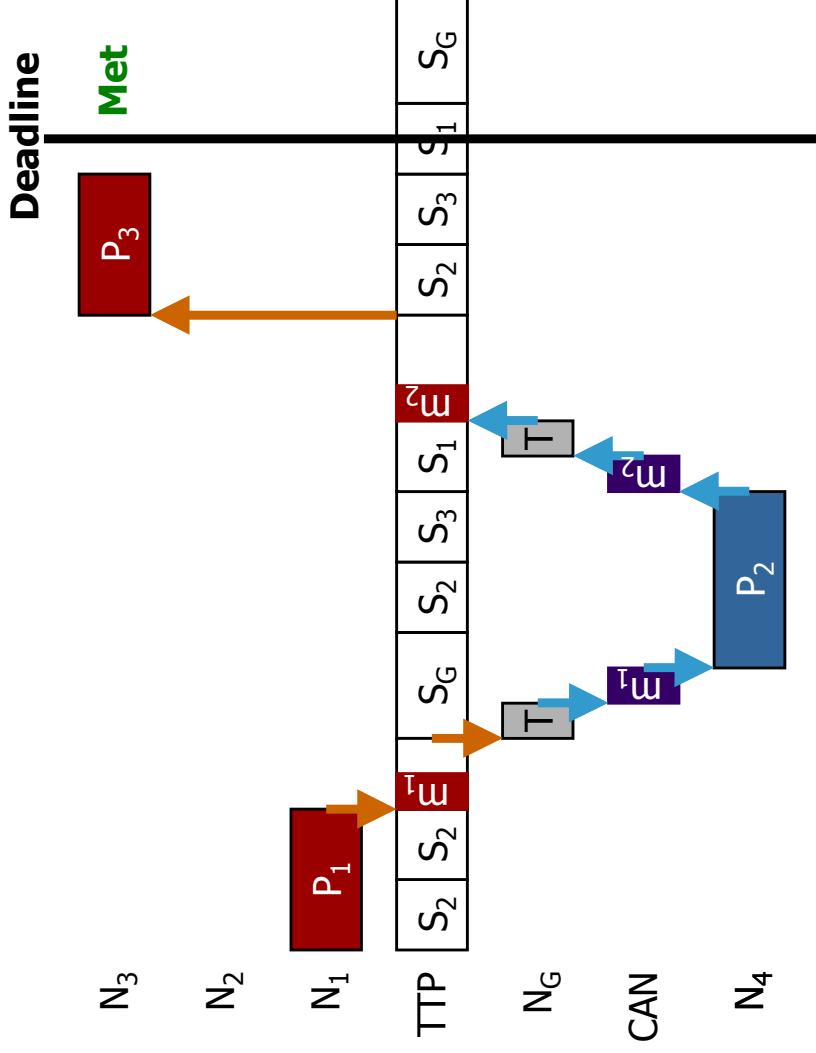


	N ₁	N ₂	N ₃	N ₄
P ₁	20	X	X	X
P ₂	X	40	X	50
P ₃	X	X	20	X

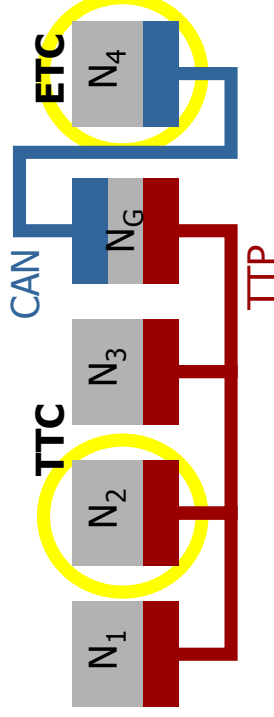


Motivational Example #2, Cont.

Where to map process P₂?

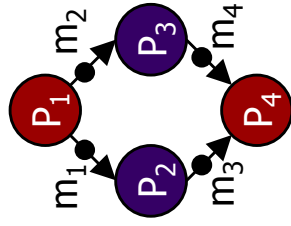
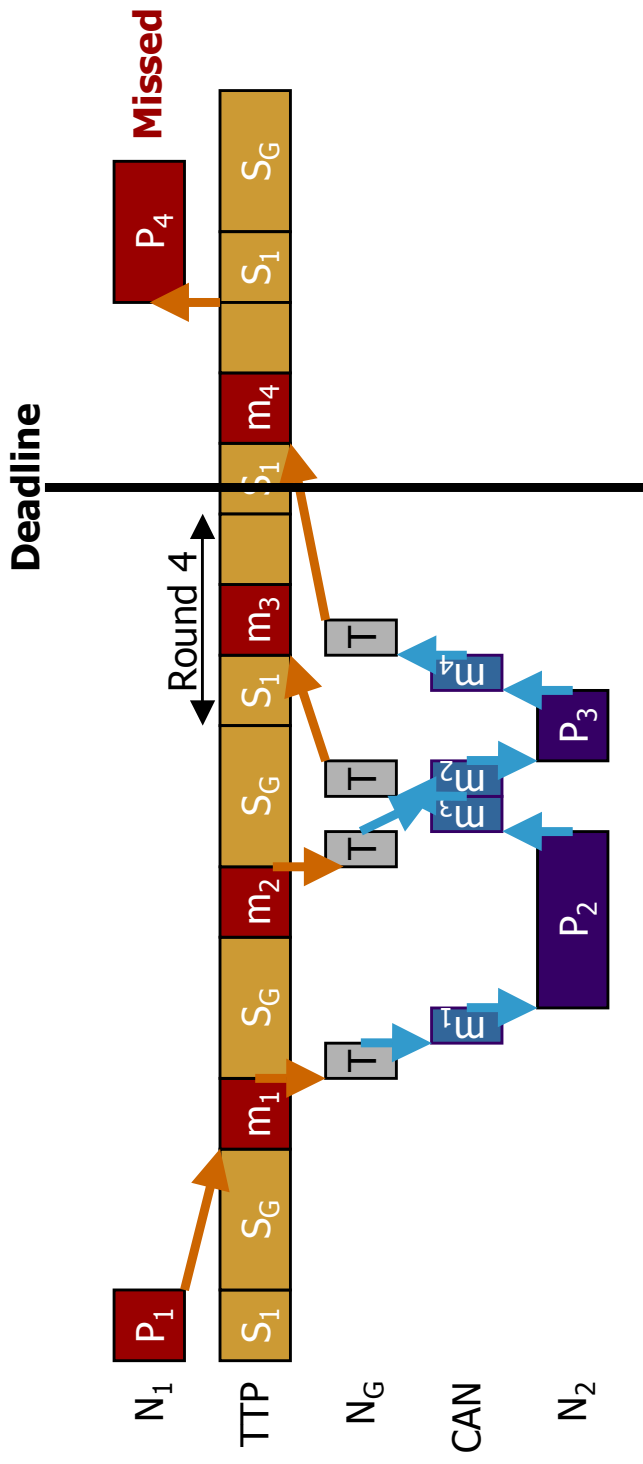


	N ₁	N ₂	N ₃	N ₄
P ₁	20	X	X	X
P ₂	X	40	X	50
P ₃	X	X	20	X

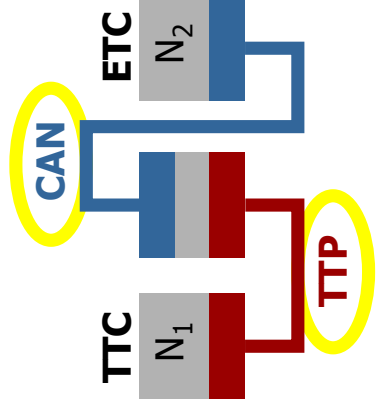


Motivational Example #3

What are the priorities on ETC?
Which slot should come first on the TTC?

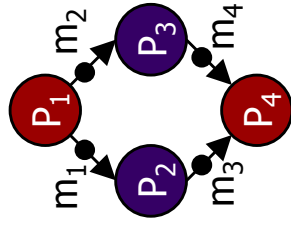
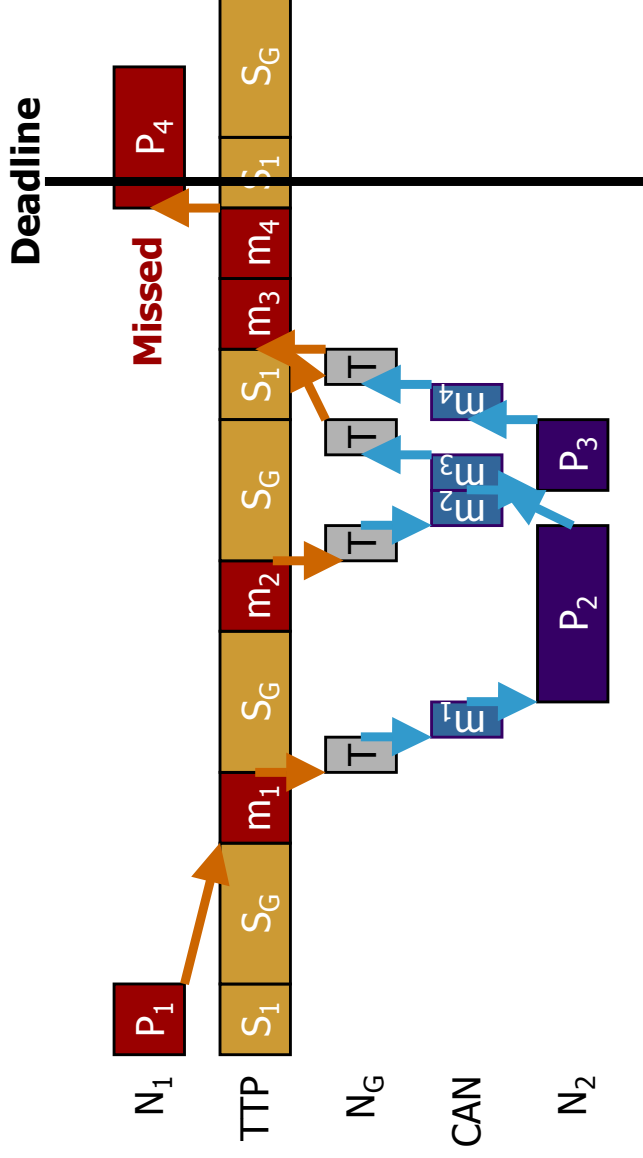


	N ₁	N ₂
P ₁	20	X
P ₂	X	40
P ₃	X	20
P ₄	40	X

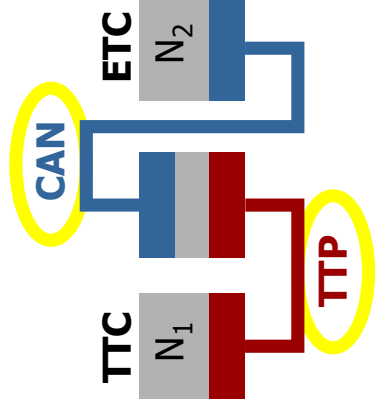


Motivational Example #3, Cont.

What are the priorities on ETC?
Which slot should come first on the TTC?



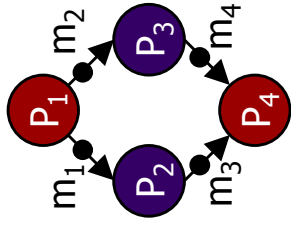
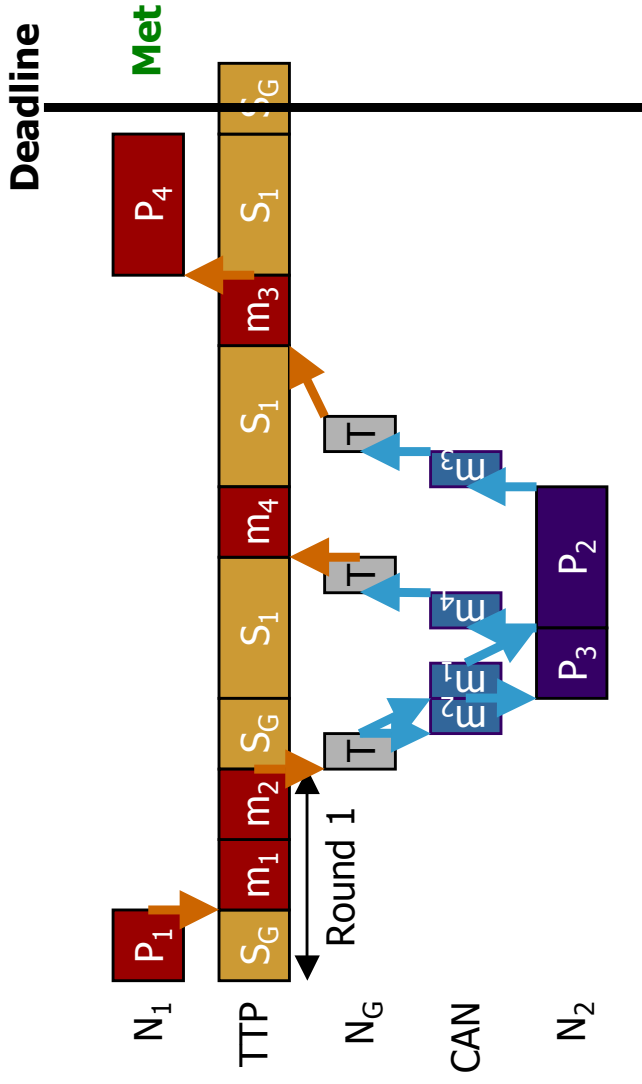
	N ₁	N ₂
P ₁	20	X
P ₂	X	40
P ₃	X	20
P ₄	40	X



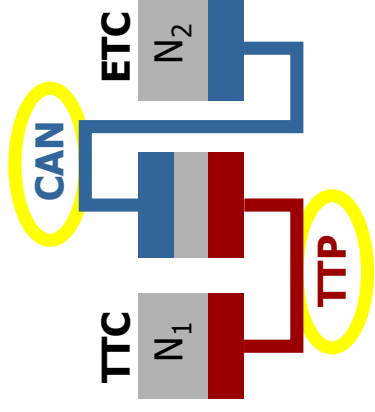
Motivational Example #3, Cont.

What are the priorities on ETC?

Which slot should come first on the TTC?



	N ₁	N ₂
P ₁	20	X
P ₂	X	40
P ₃	X	20
P ₄	40	X



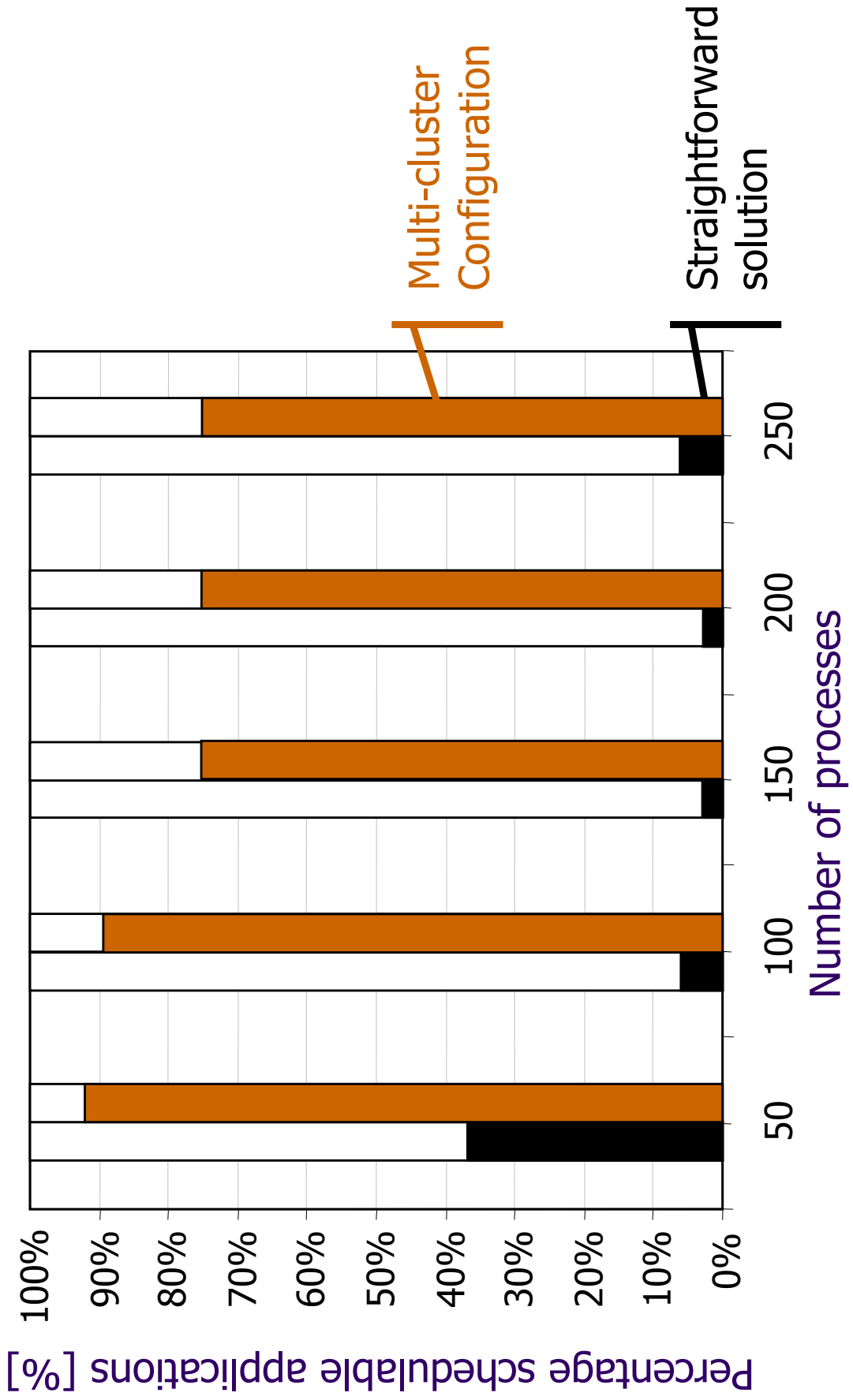
Optimization Strategy

- **Multi-Cluster Configuration**
- **1. Branch and Bound Partitioning and Mapping**
 - Branching rule
 - Selection rule
 - Bounding rule: **lower bound**
- **2. Bus Access Optimization**
 - Determines the slot sequence and lengths on the TTC, message priorities on the ETC
 - Greedy optimization heuristic
- **Straightforward solution**
 - Partitioning and mapping that balances the utilization of processors and buses
 - Could be produced by a designer without optimization tools

Experimental Results

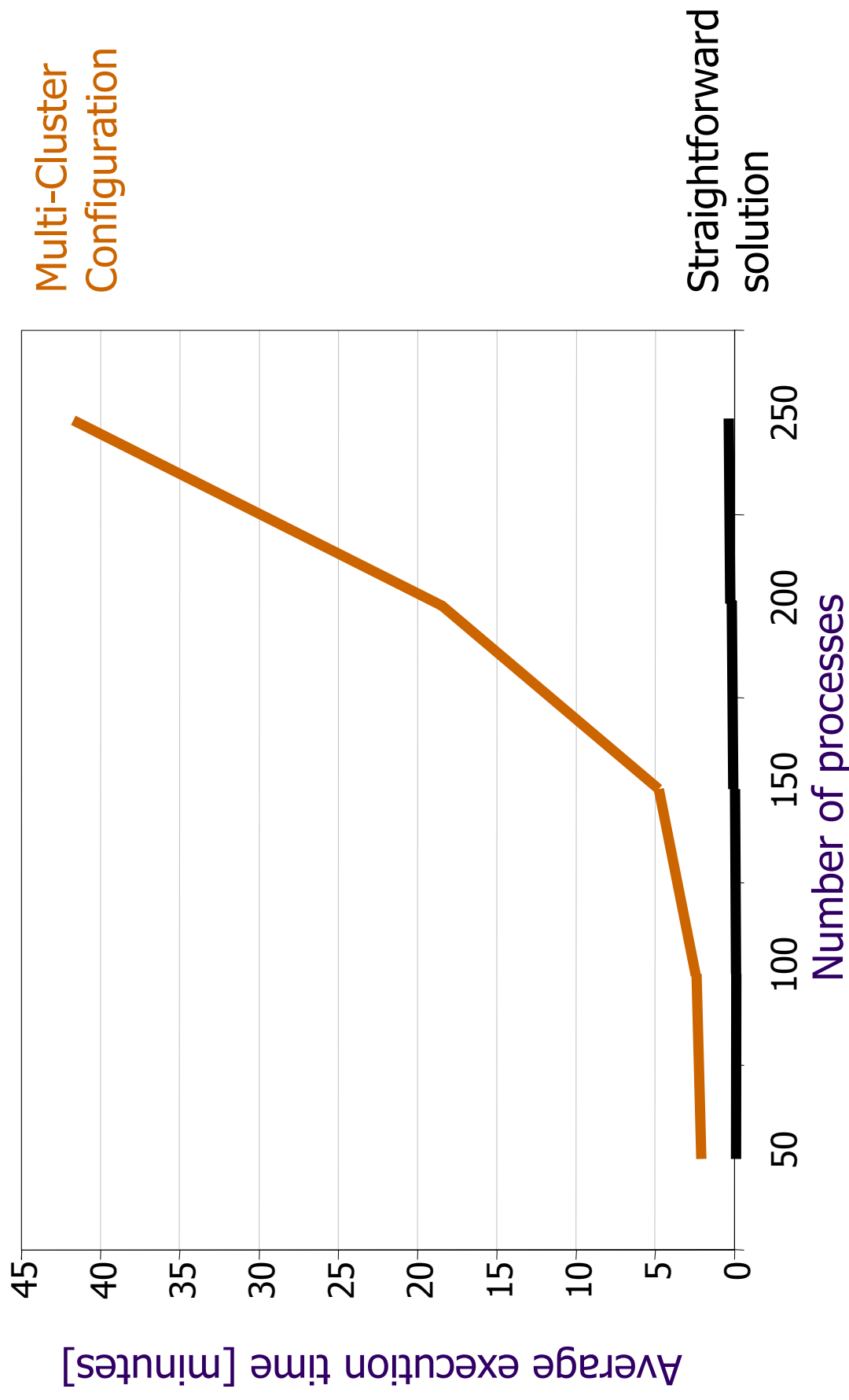


Can we increase the number of schedulable applications?



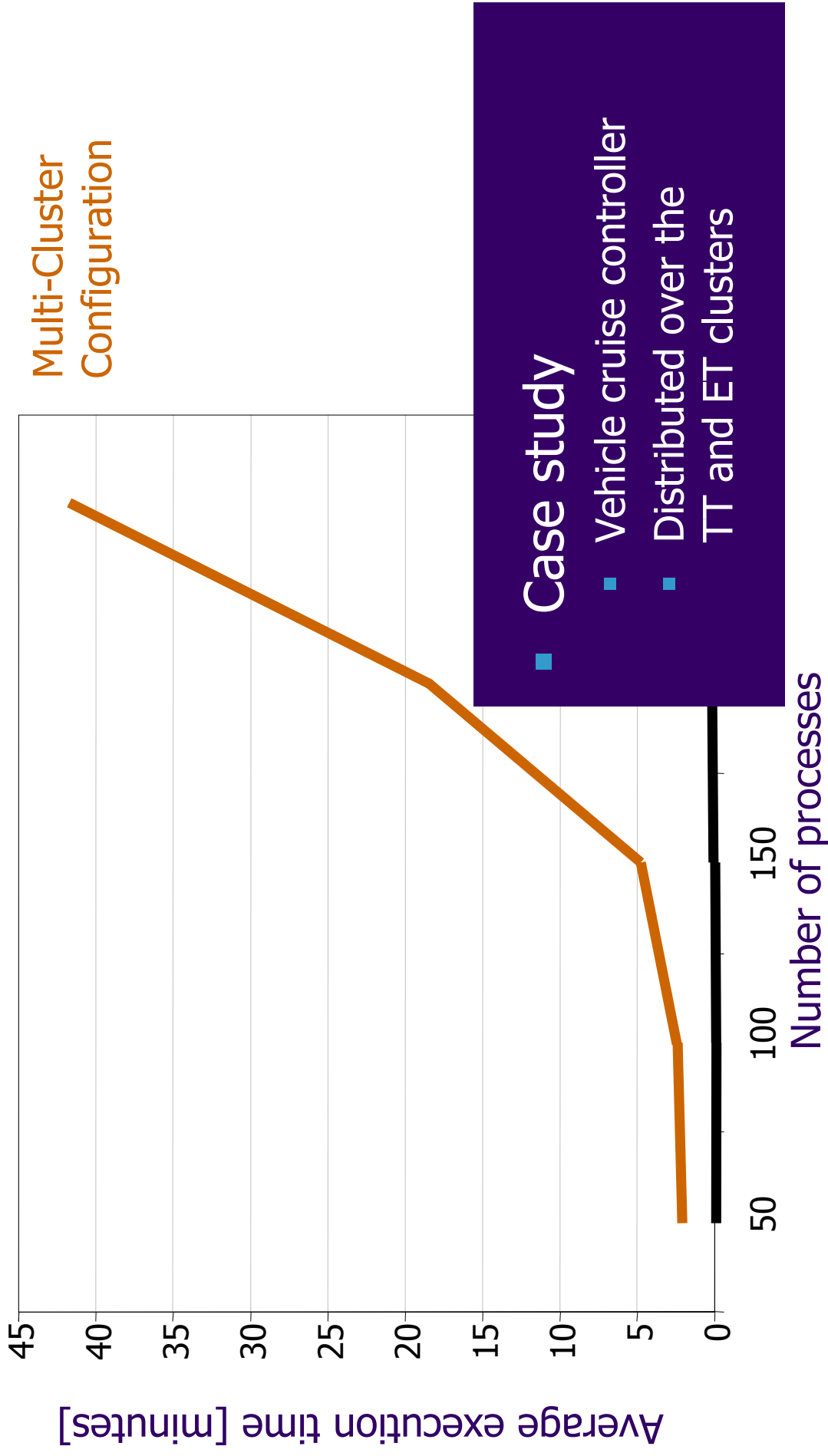
Experimental Results, Cont.

How time-consuming is our optimization strategy?



Experimental Results, Cont.

How time-consuming is our optimization strategy?



Contributions and Message

- Contributions
 - Addressed design problems characteristic to **multi-clusters**
 - Partitioning
 - Mapping
 - Bus Access Optimization
 - Proposed a **branch and bound** approach for optimization

Analysis and optimization methods are needed for the efficient implementation of applications distributed over interconnected **heterogeneous networks.**