Machine ballets don't need conductors

Towards scheduling-based service choreographies in a real-time SOA for industrial automation

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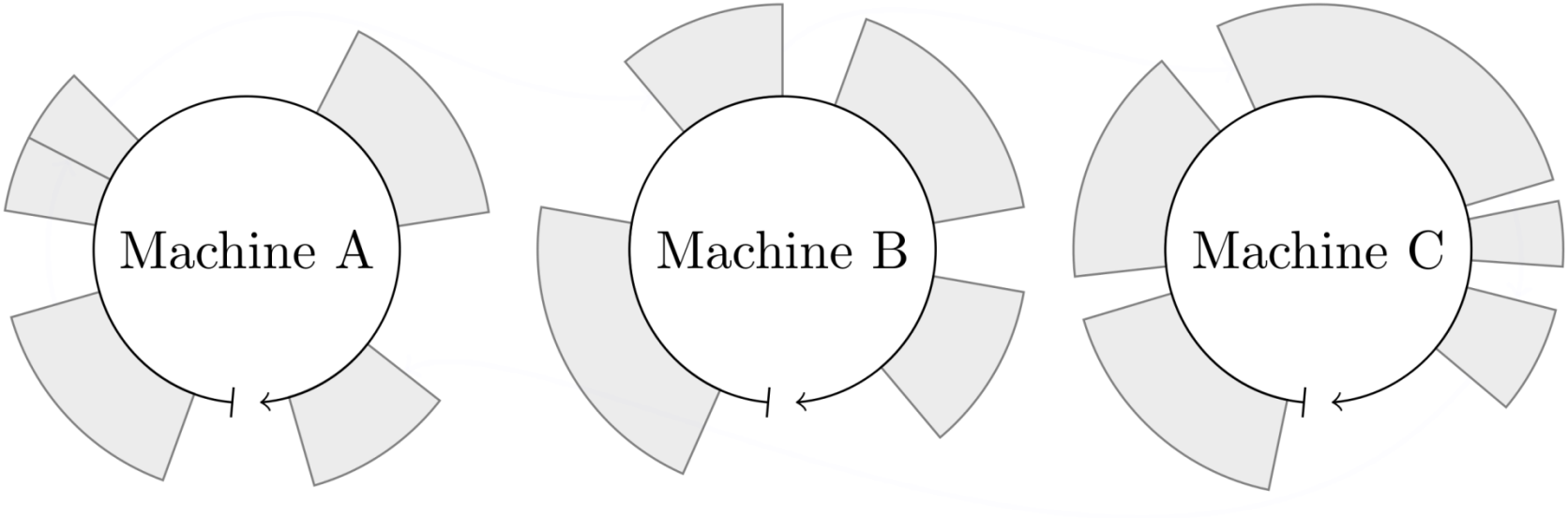
Motivation

- Monolithic, scan-based control systems are inflexible
- Hardware side of automation is already changing
  - Industrial Ethernet is gaining traction
  - Smart embedded devices are performing more and more tasks
- SOA as the emerging design paradigm down to the hard real-time control cycle

→ Goal: Global cooperation without central coordination

A distributed workflow example



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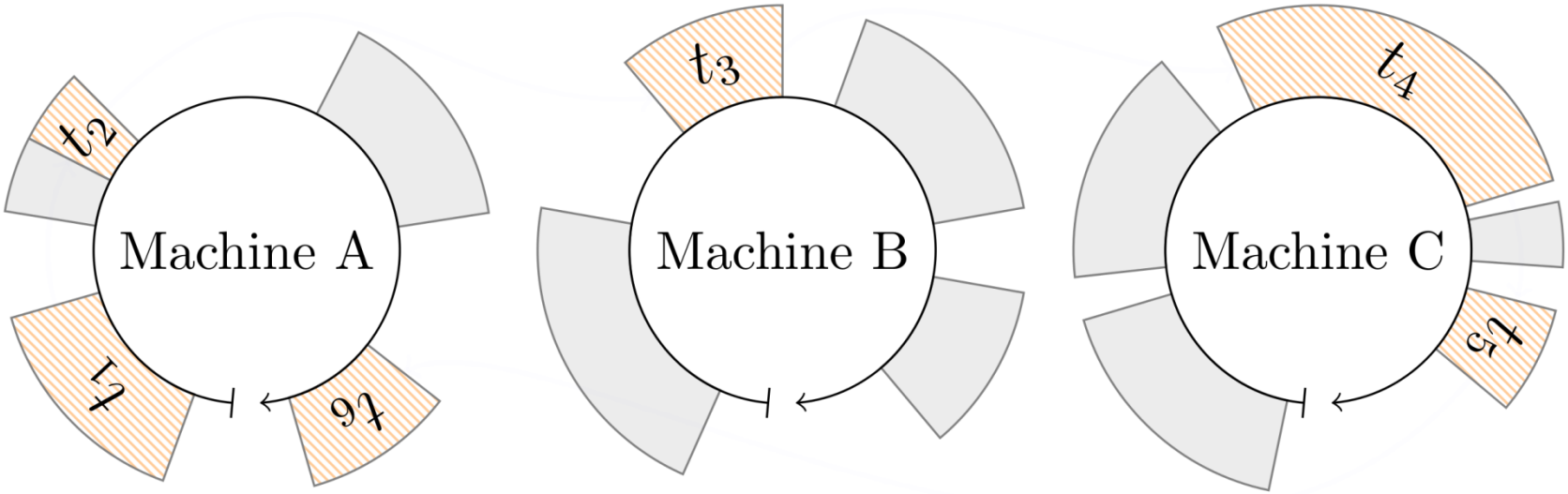

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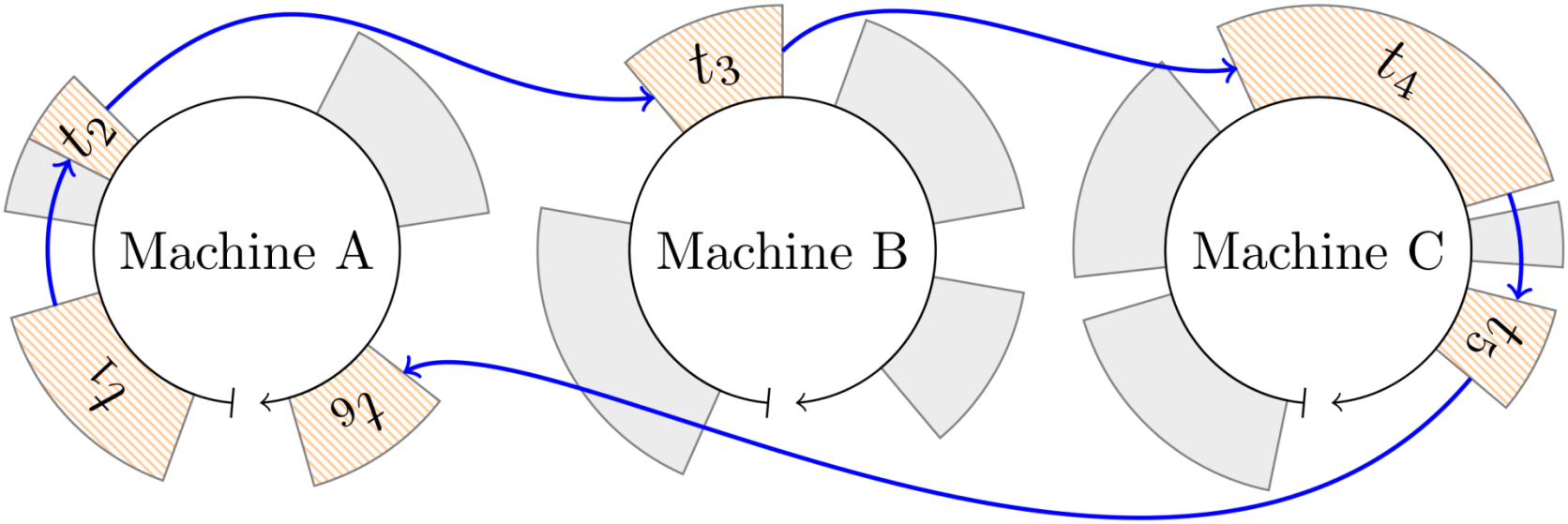

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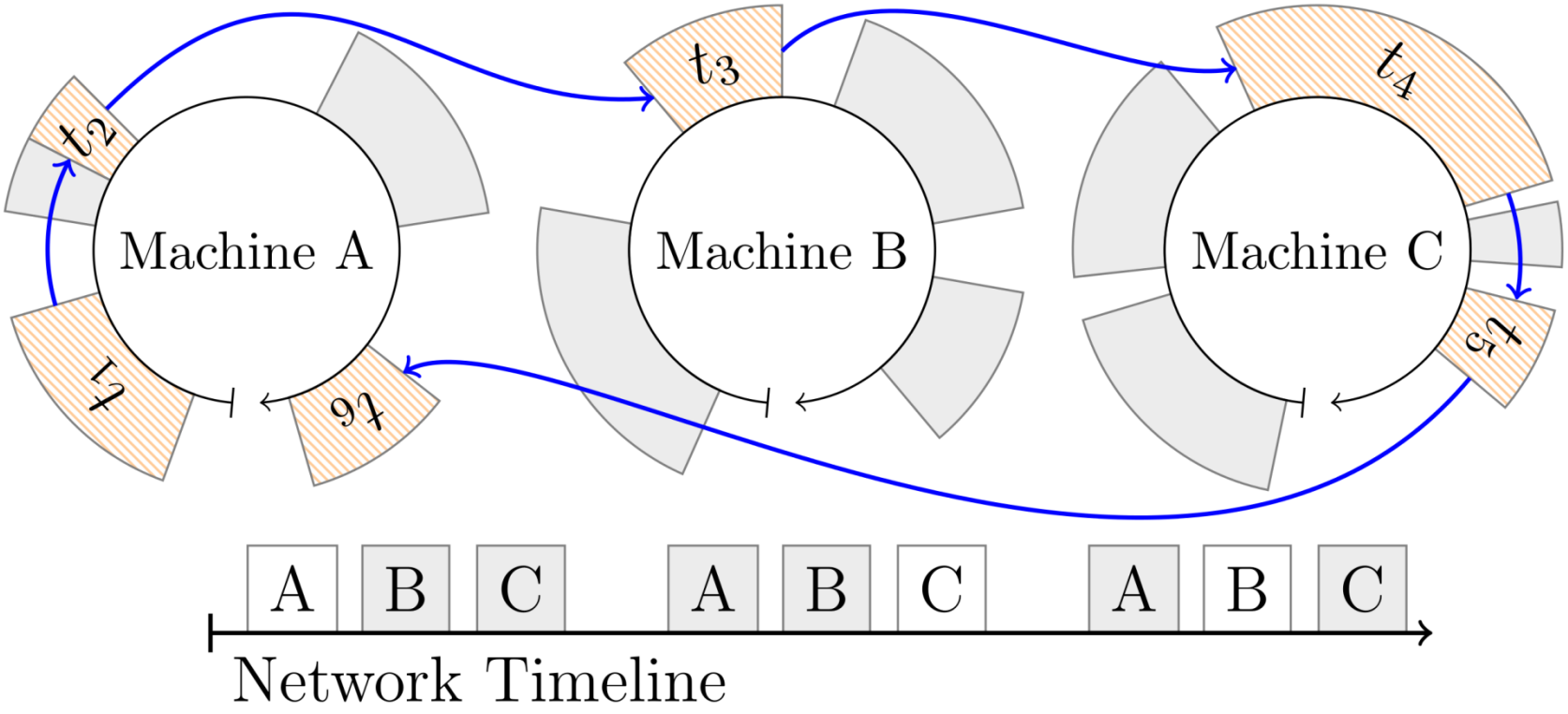

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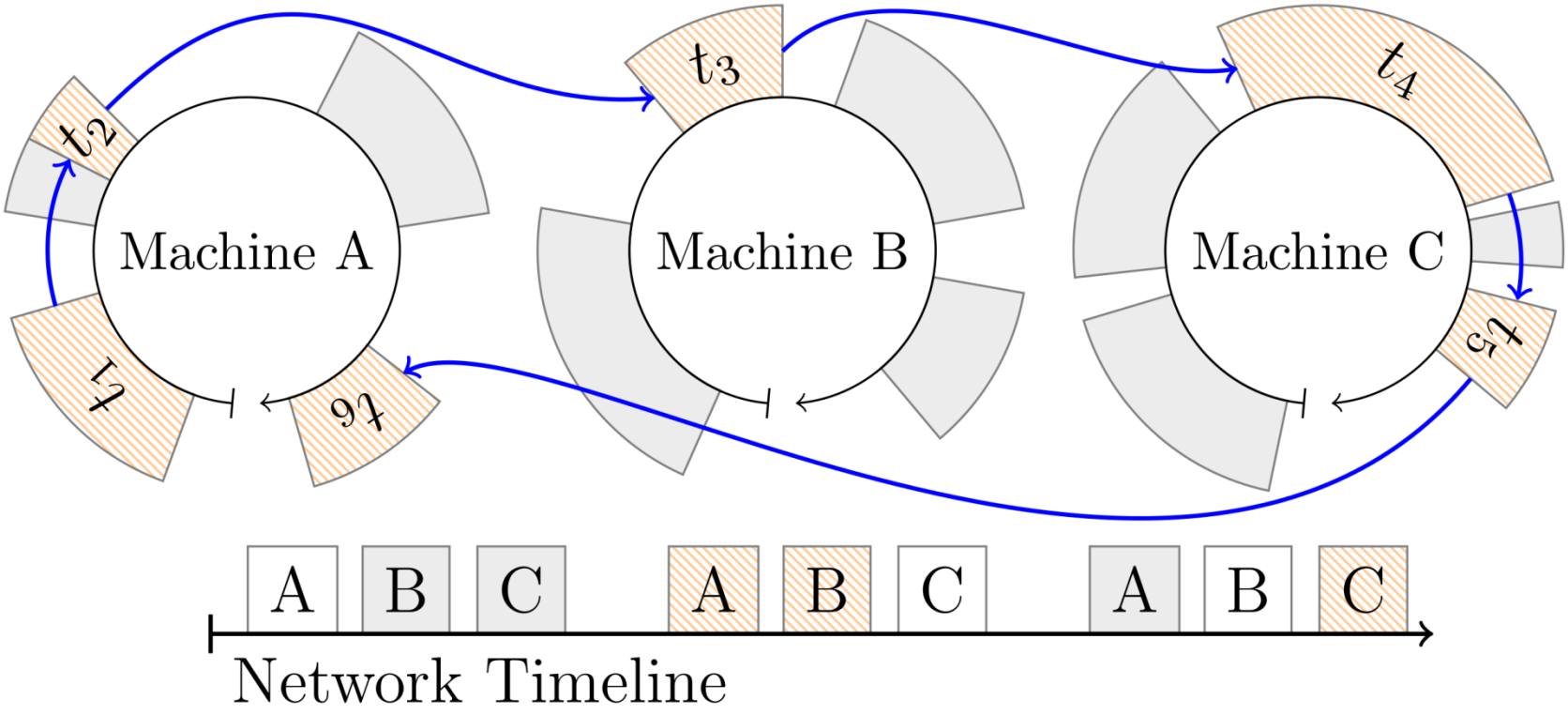
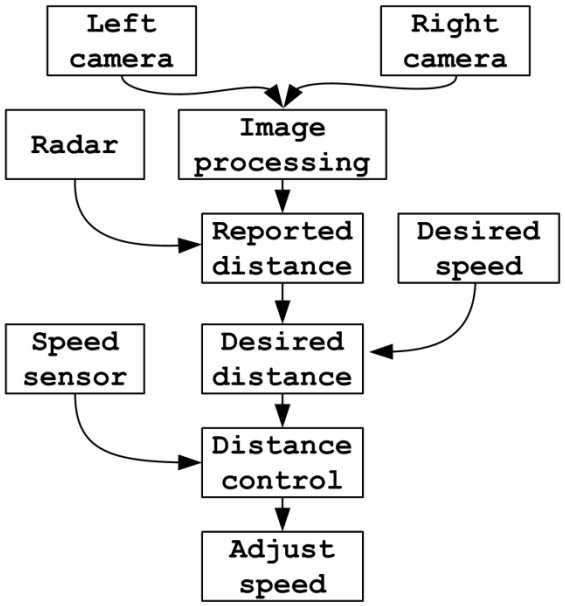
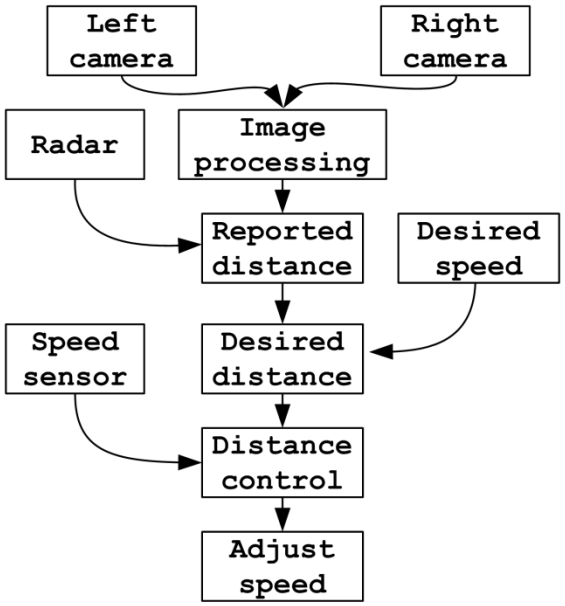


Goals and target environment

- Our target environment
  - Distributed hard real-time systems
  - Automation task modelled as workflow of communicating jobs
    - Workflow constraints: Global deadline, workflow period
  - Devices connected through TDMA network
  - Physical and network properties are inputs to the planner, i.e. network configuration is fixed an not an output parameter
- Our goal
  - Synthesize a cyclic, non-preemptive schedule for each processor in the system
  - Employ heuristics to enable interactive planning and development of large systems


Left camera
Right camera
Radar
Image processing
Reported distance
Desired speed
Speed sensor
Desired distance
Distance control
Adjust speed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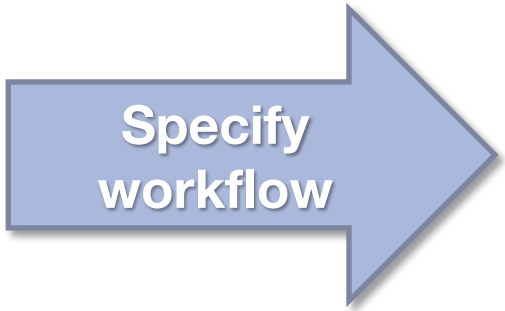
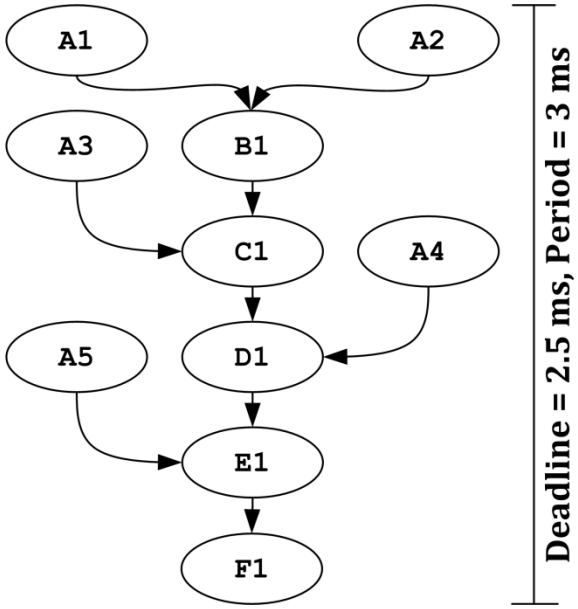
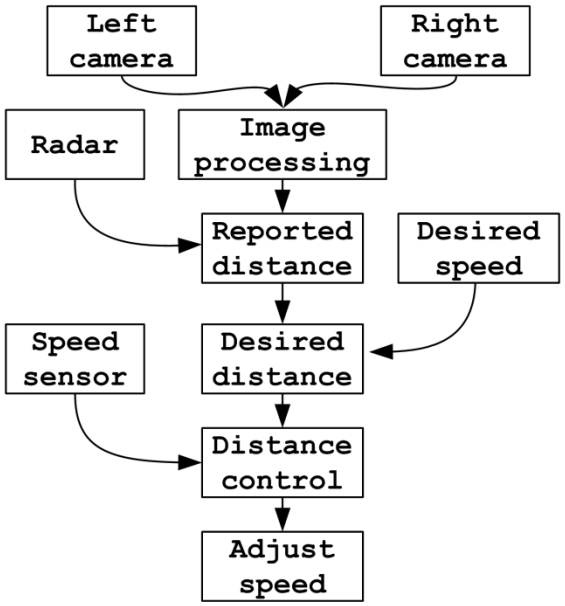

Specify workflow


A1
A2
A3
B1
C1
A4
A5
D1
E1
F1
Deadline = 2.5 ms, Period = 3 ms



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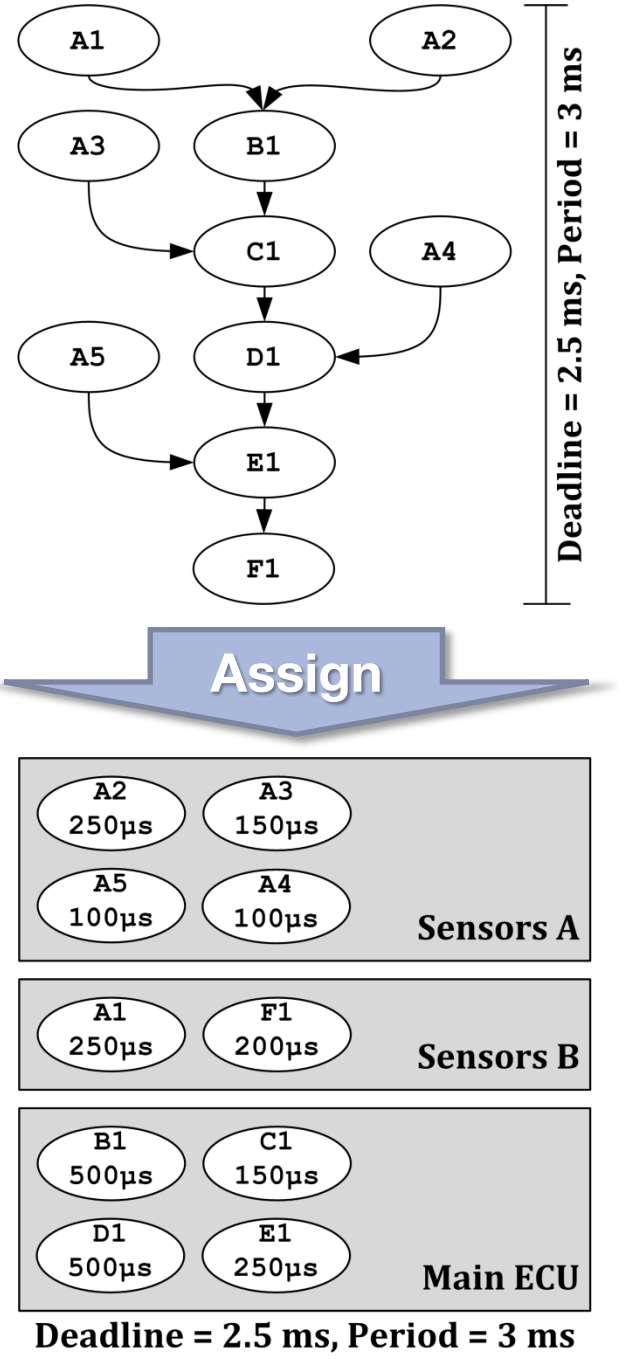

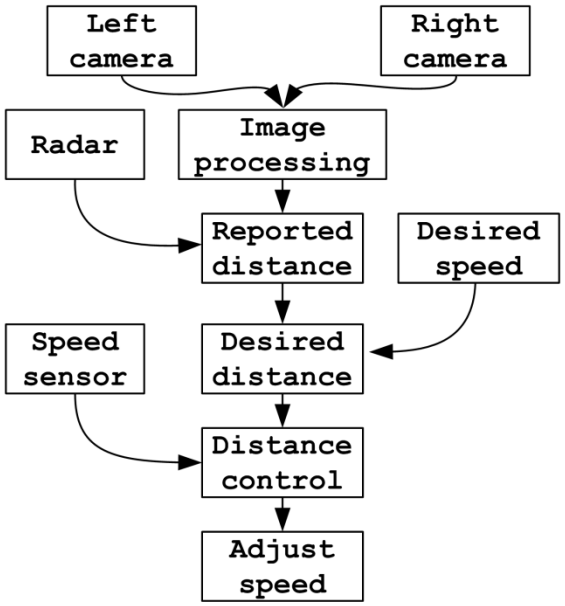

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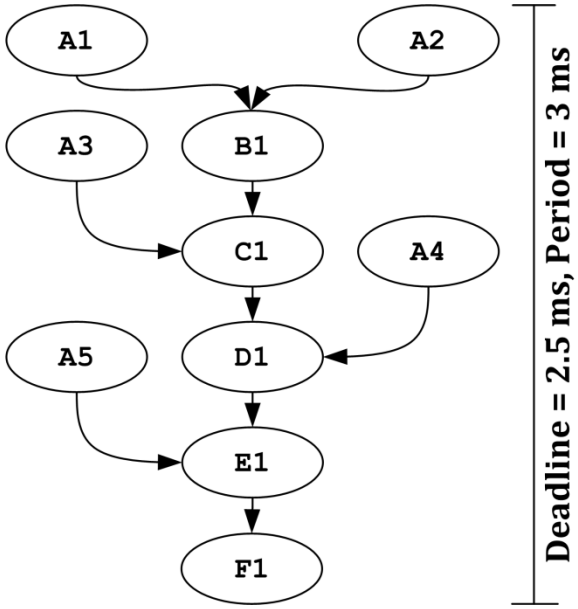
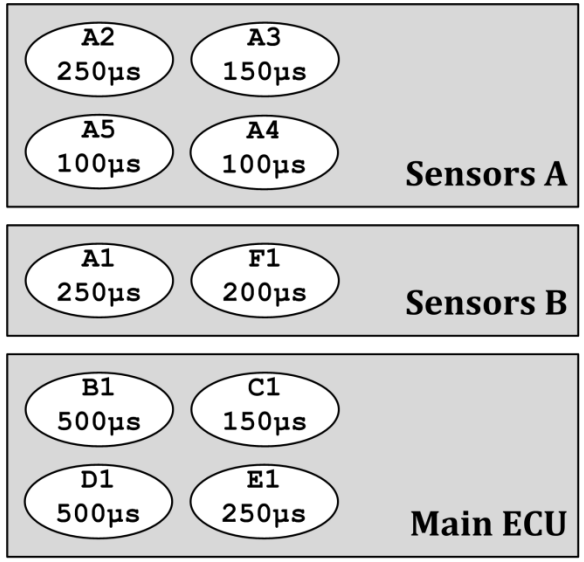
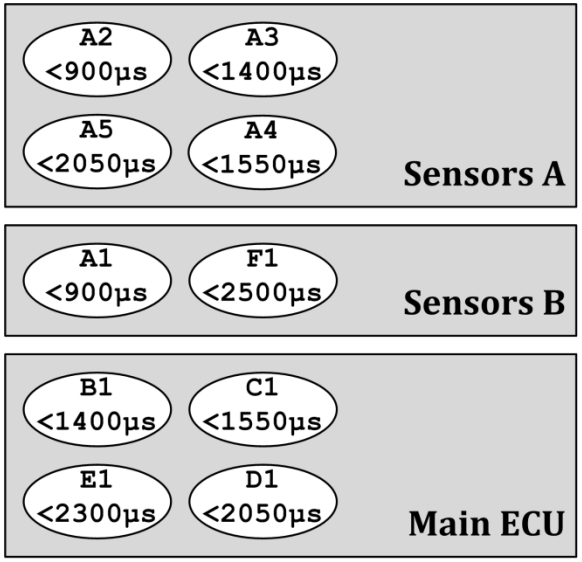


Assign



Deadline = 2.5 ms, Period = 3 ms

Assign local constraints



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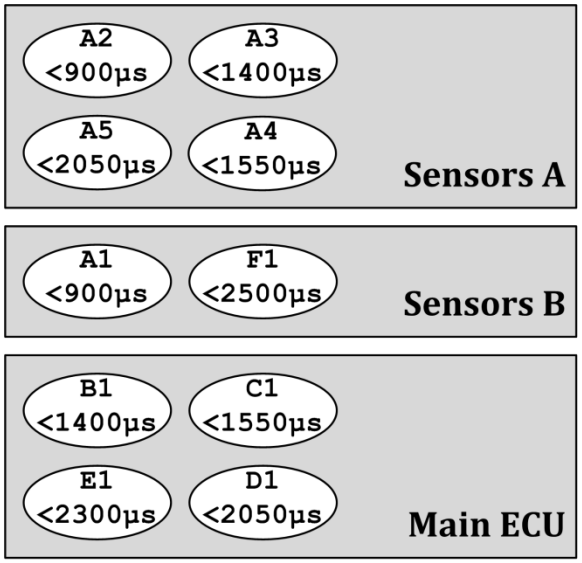
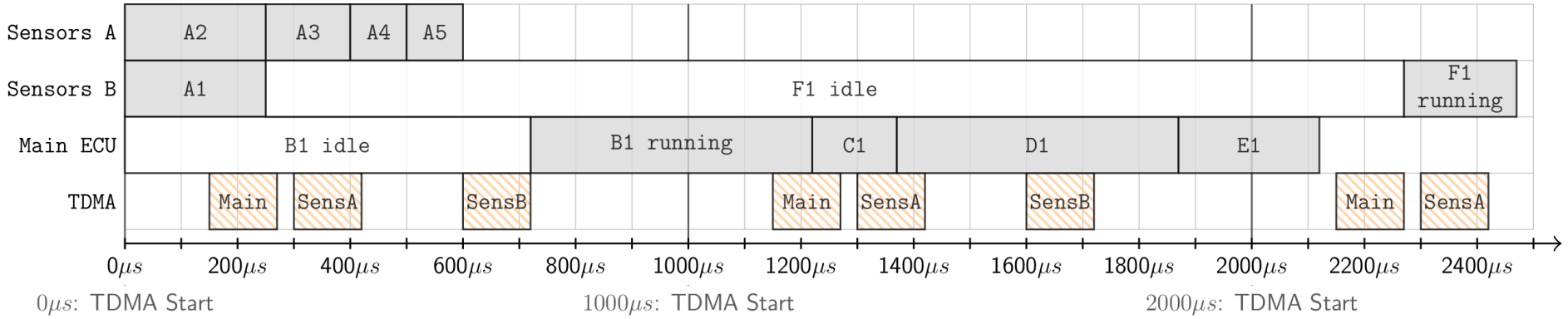


Deadline = 2.5 ms, Period = 3 ms

Schedule



$0\mu s$: TDMA Start $1000\mu s$: TDMA Start $2000\mu s$: TDMA Start

Heuristics for Scheduling

Scheduling Heuristics

- Earliest Release time First (ERF)
  - Map precedence constraints to release times:
    $\forall j_i, j_k \epsilon \mathcal{J} \cup \Omega : j_i \prec j_k \implies r'_k = max\{r_k, r_i + wcet_i\}$
  - Sort tasks according to their release time

- Earliest Deadline First (EDF)
  - Map precedence constraints deadlines:
    $\forall j_i, j_k \epsilon \mathcal{J} \cup \Omega : j_i \prec j_k \implies d'_i = min\{d_i, d_k - wcet_k\}$
  - Schedule task with earliest release time if it does not violate earliest deadline

Scheduling Heuristics

- BLOCK heuristic
  - Setup schedule through ERF
  - Divide schedule into consecutive blocks of jobs
  - If invalid, move jobs with higher deadline towards end of block

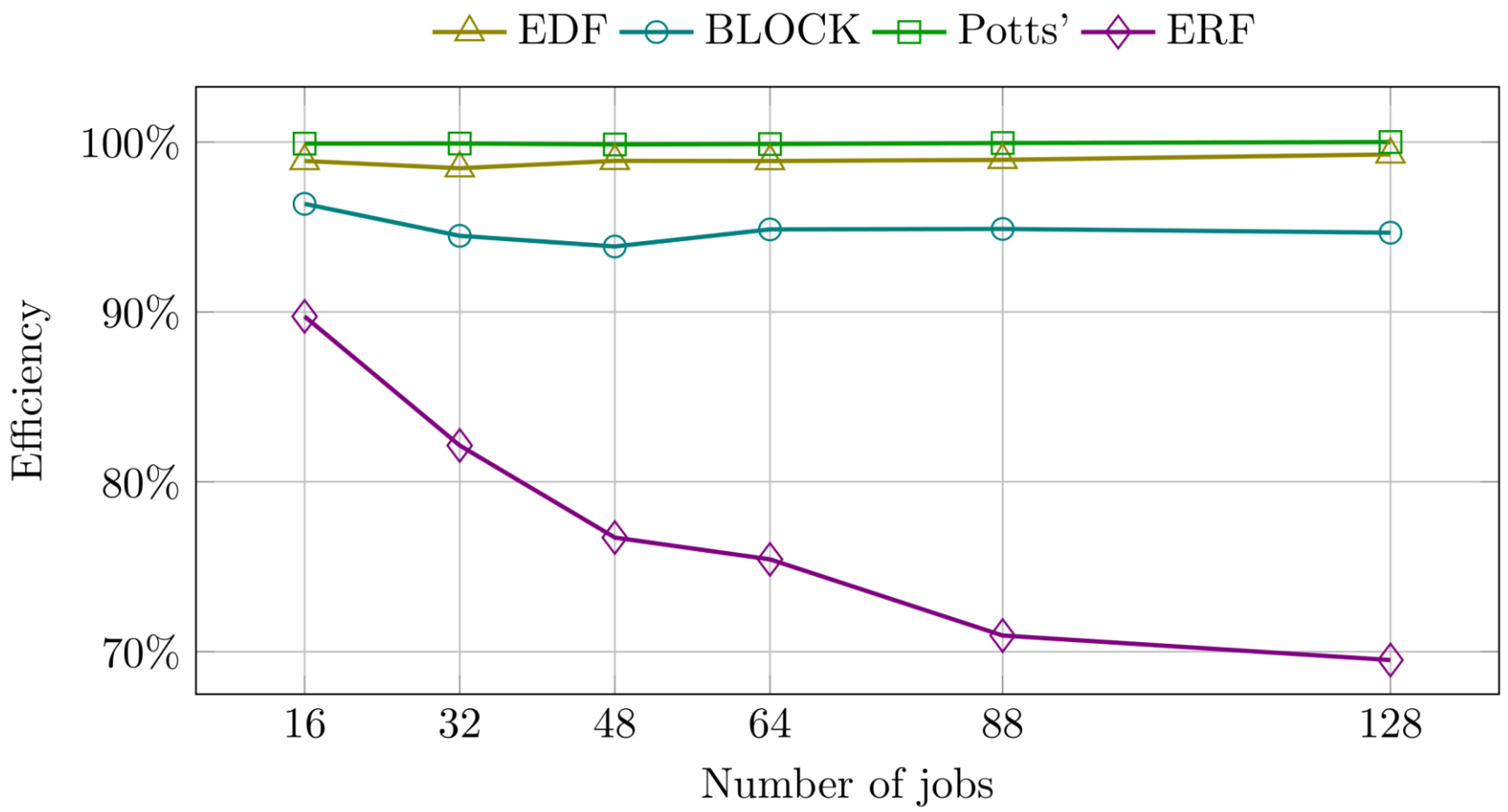
- Pott‘s algorithm
  - Setup by sorting jobs by deadline in topological order
  - If invalid, analyze critical sequence and identify critical job (missing its deadline) and interference job (before critical job)
  - Move interference job behind critical job

Evaluation of scheduling heuristics

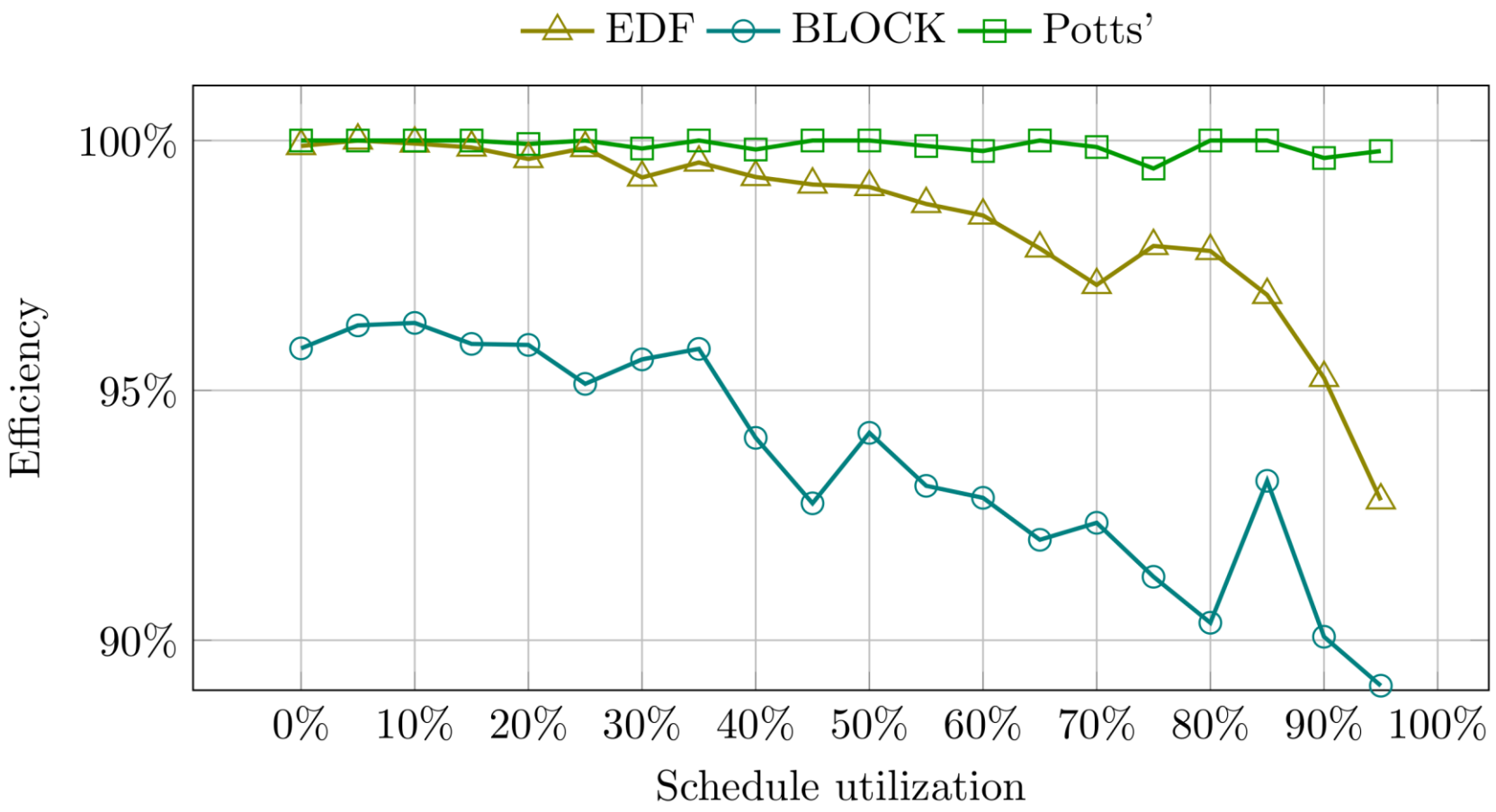
- 20 500 feasible random in-tree test cases
  - Verified through linear program solver
  - Test case size between 16 and 128 jobs
  - Jobs have to be scheduled before a global deadline

- Evaluation for efficiency
  - Which percentage of all feasible test cases are solved?
  - Makespan, max lateness, etc. not relevant
  - All or nothing scoring: one late job invalidates the schedule

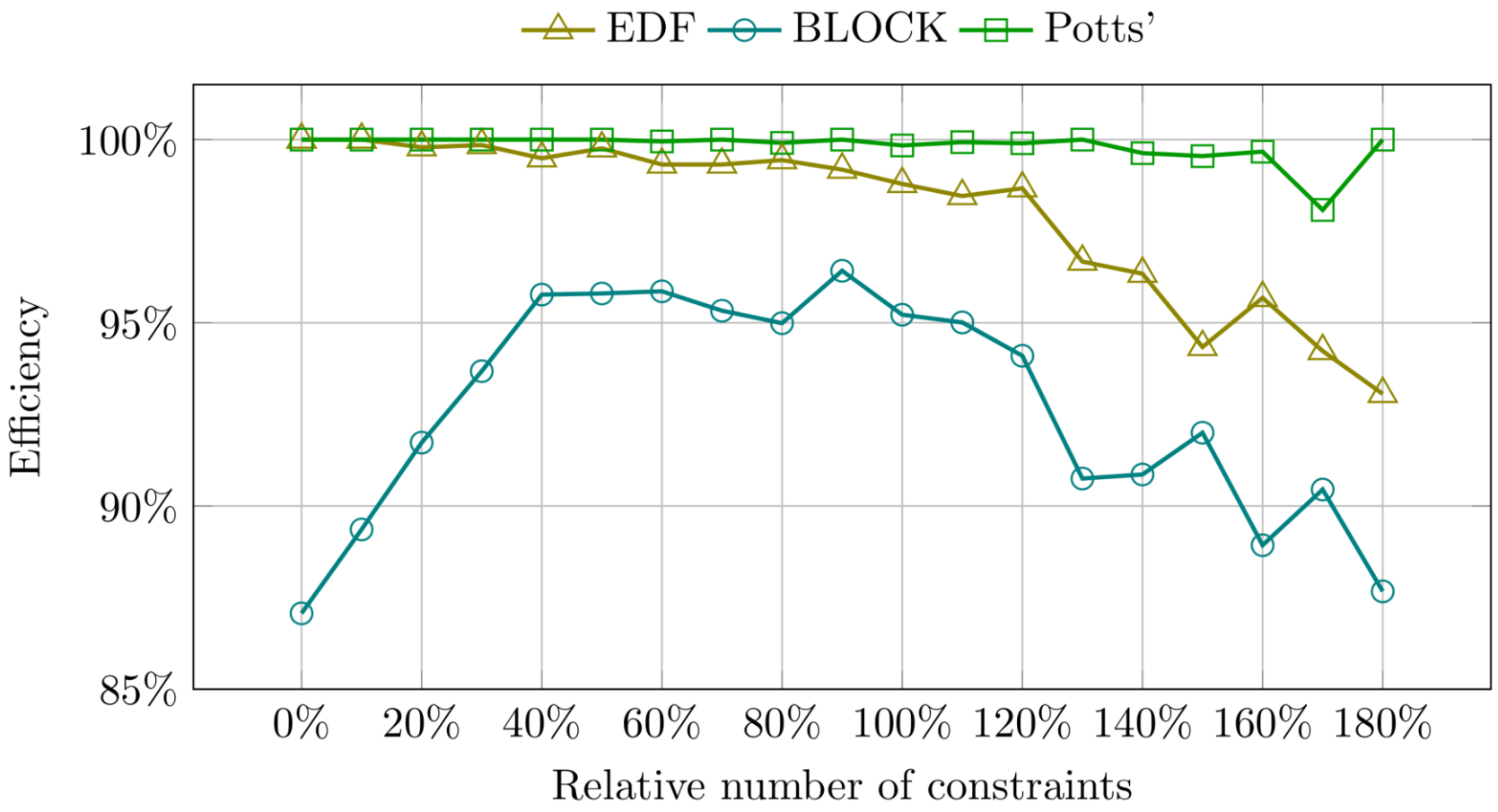
Heuristics: Efficiency



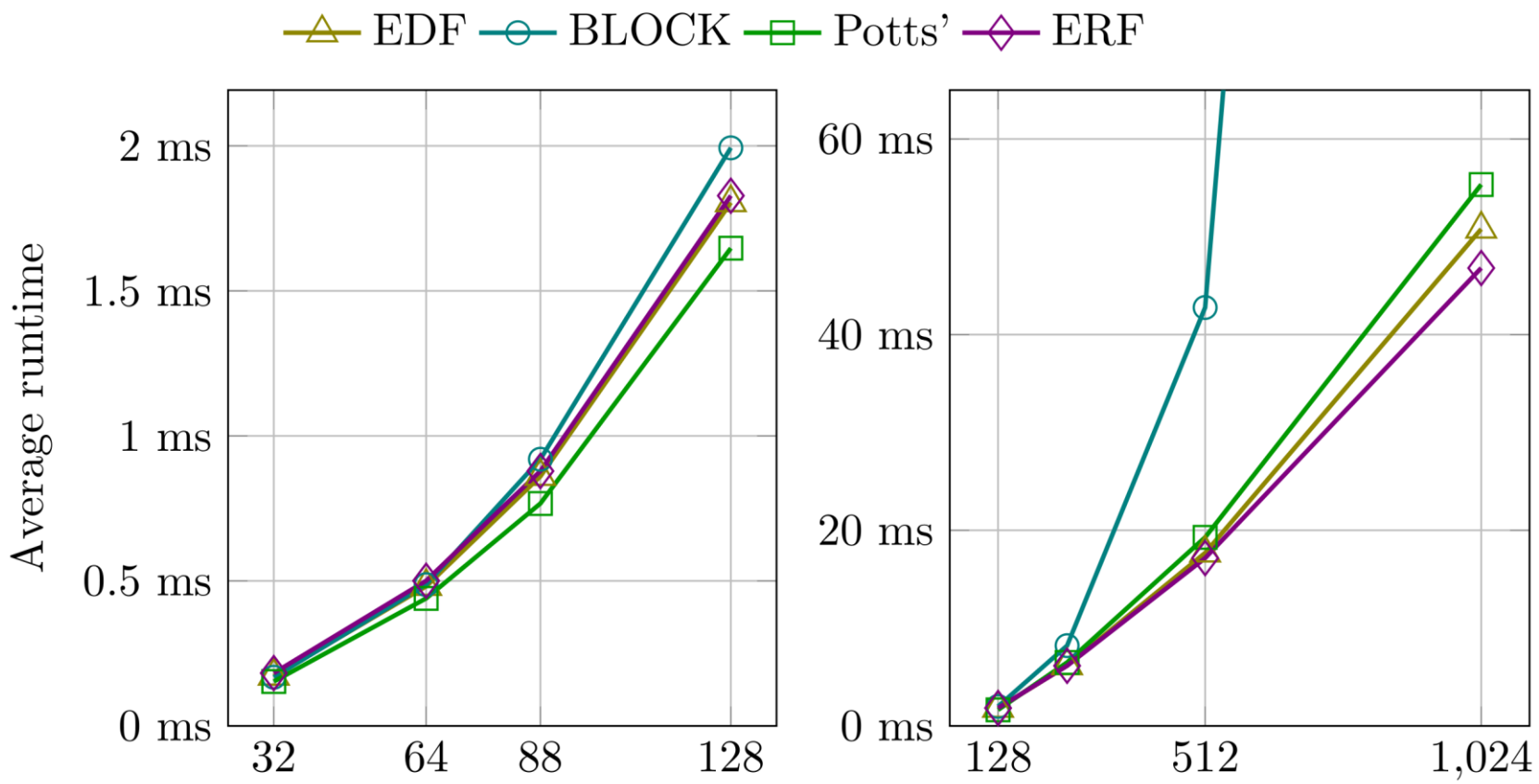
Heuristics: Efficiency vs. Utilization



Heuristics: Efficiency vs. Constraints



Heuristics: Runtime



Conclusions and future work

Three steps for schedule-based service choreographies:

1. Task assignment
2. Deriving local constraints
3. Scheduling

Conclusions and future work

Three steps for schedule-based service choreographies:

1. Task assignment → Performed by skilled engineer ✓
2. Deriving local constraints → Ongoing research ⊘
3. Scheduling → Existing heuristics are up to the task ✓

Thank you for your attention!