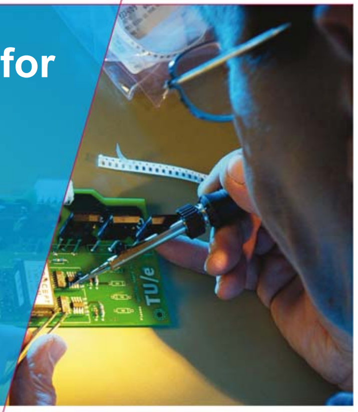
Performance Engineering for High-Tech Systems: Crossing Boundaries



Twan Basten
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TNO Embedded Systems Innovation

Joint work with many others

Funding:
- Artemis – EMC2, Almarvi
- STW – Robust CPS program
- Min. of Economic Affairs, Océ – Octo+ program
- Min. of Economic Affairs, ASML – CARM2G program

TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

Performance Engineering for High-Tech Systems: Crossing Boundaries

... between academia and industry, between disciplines, and across layers of abstraction.

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Industrial challenges inspiring research

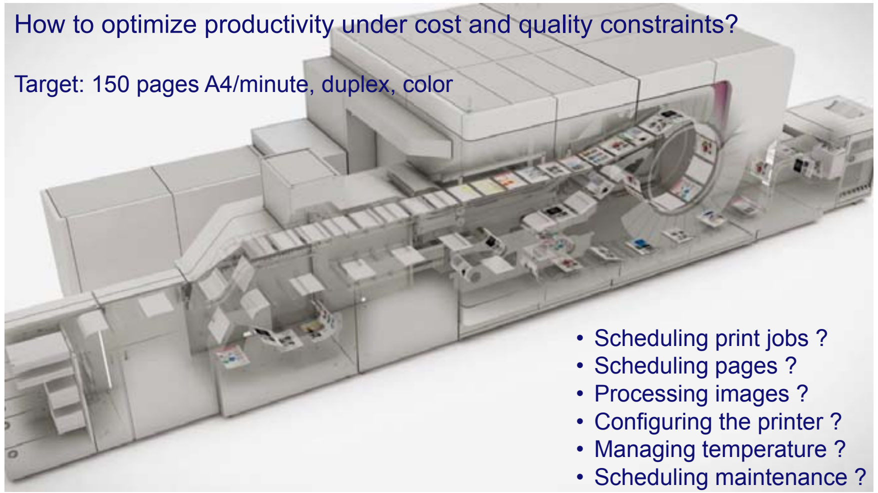
3 The challenge

océ

Image processing and paper handling in production printing

How to optimize productivity under cost and quality constraints?

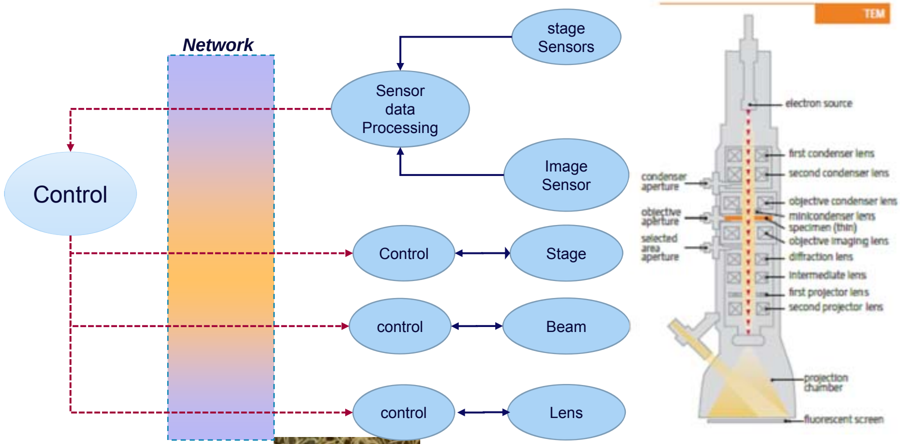
Target: 150 pages A4/minute, duplex, color



- Scheduling print jobs ?
- Scheduling pages ?
- Processing images ?
- Configuring the printer ?
- Managing temperature ?
- Scheduling maintenance ?
- Optimizing topology ?

4 The challenge

Controlling an electron microscope – data-intensive control



mosquito eyes

- Maximizing data processing throughput ?
- Coping with processing & communication latencies ?

5 The challenge

Data processing and motion control in interventional x-ray

- Resource sharing ?
- Virtualization ?
- Real-time processing ?
- Safety ?

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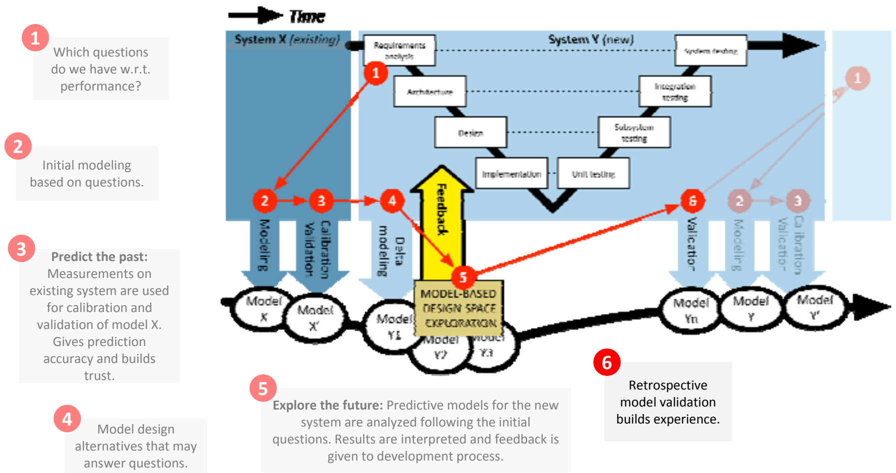
Performance Engineering @ TNO ESI

Model-based performance engineering



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Performance Engineering for High-Tech Systems: Crossing Boundaries

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Interplay between model and implementation

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Production printing: Which CPU for image processing?

Requirements

Reduce cost, while guaranteeing performance

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Production printing: Which CPU for image processing?

Requirements

Parallel code that uses all available CPU cores.

Model existing system

Modeling: Amdahl's law:

$$T(n) = T(1) \cdot (s + \frac{1-s}{n})$$

T(n) – the execution time with n cores
s – the sequential fraction of the code

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Production printing: Which CPU for image processing?

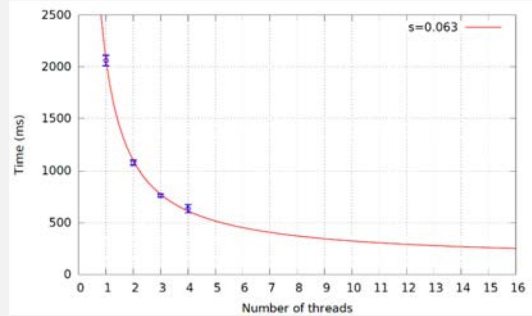
Requirements

Model existing system

Calibration & validation

Calibration using several multi-core CPU platforms

Validation fitting Amdahl's law gives a good fit !



(schematic)

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Production printing: Which CPU for image processing?

- Requirements
- Model existing system
- Calibration & validation
- **Model new system**

$$T(n) = T(1) \cdot \left(s + \frac{1-s}{n}\right)$$

T(1) is estimated by scaling the measurements with the ratio given by a public single-threaded CPU performance benchmark
https://www.cpubenchmark.net/singleThread.html

s is estimated from the measurements

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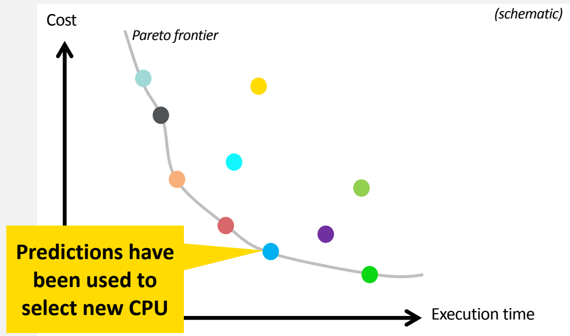
Production printing: Which CPU for image processing?

- Requirements
- Model existing system
- Calibration & validation
- Model new system
- **Prediction**

Prediction model implemented in a spread-sheet



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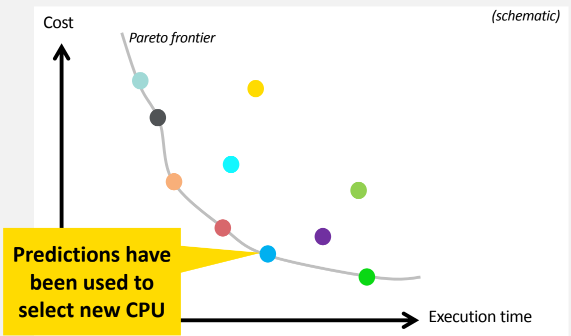
Production printing: Which CPU for image processing?

- Requirements
- Model existing system
- Calibration & validation
- Model new system
- Prediction
- **Validation**

Prediction: model implemented in a spread-sheet



Measurements on the new CPU confirm accuracy

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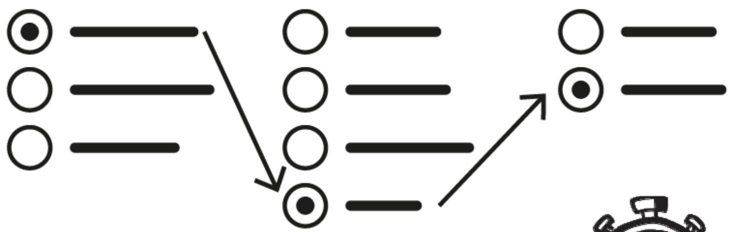
- Combinatorial optimization
- Embedded computing

16 Print job scheduling

- Simultaneous sequencing (job order) and selection (print mode)

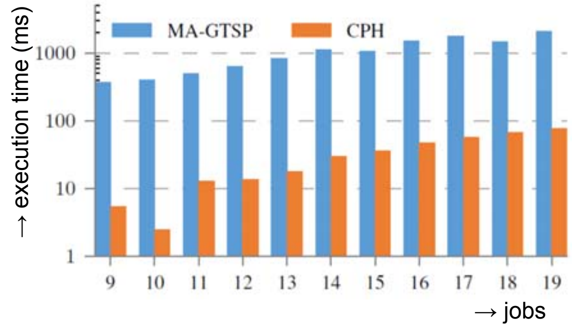


- On-line – timing constraints

- Compositional – to cope with new jobs

> - Generalized Traveling Salesman Problem
> - Compositional Pareto-algebraic Heuristic – CPH

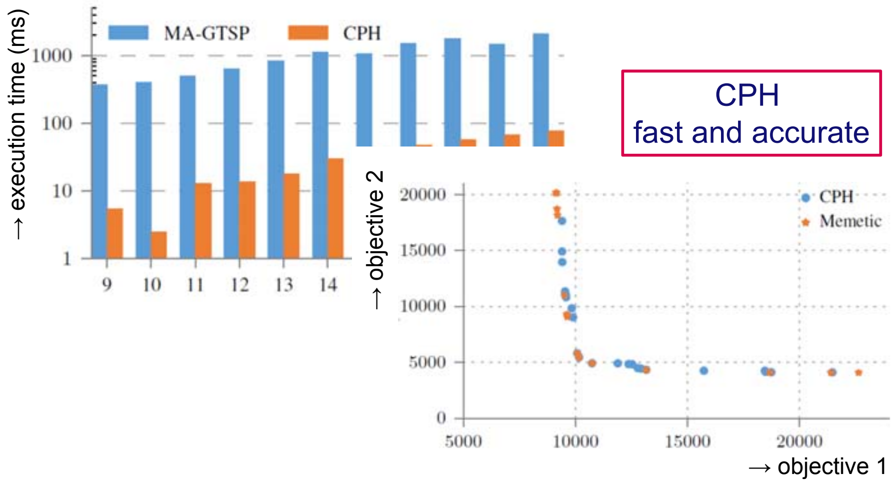
17 Print job scheduling – synthetic benchmark



> CPH
> fast and accurate

> - Generalized Traveling Salesman Problem
> - Compositional Pareto-algebraic Heuristic – CPH

18 Print job scheduling – synthetic benchmark



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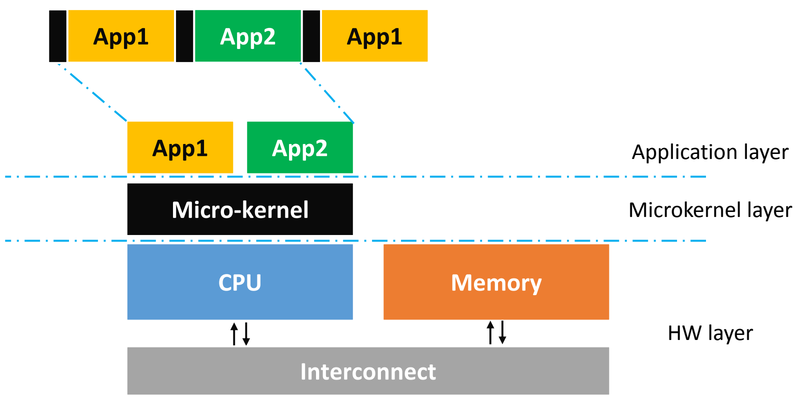
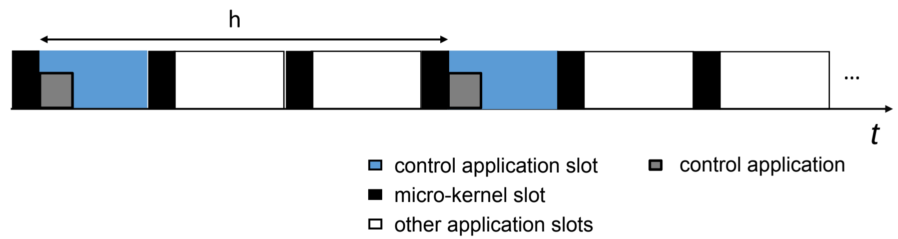
> - Feedback control
> - Embedded computing

20 Platform virtualization & resource sharing

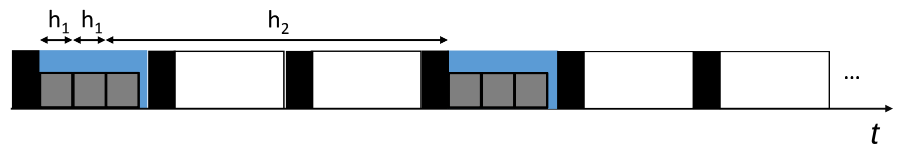


21 Embedded control

- Periodic sampling

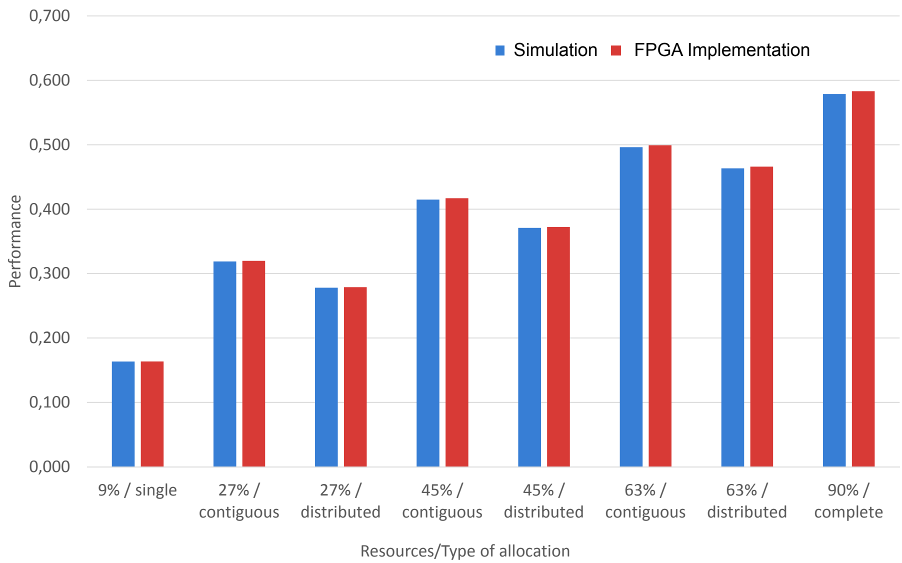


- Multi-periodic sampling



Switched linear systems

22 Embedded control – cost / performance trade offs



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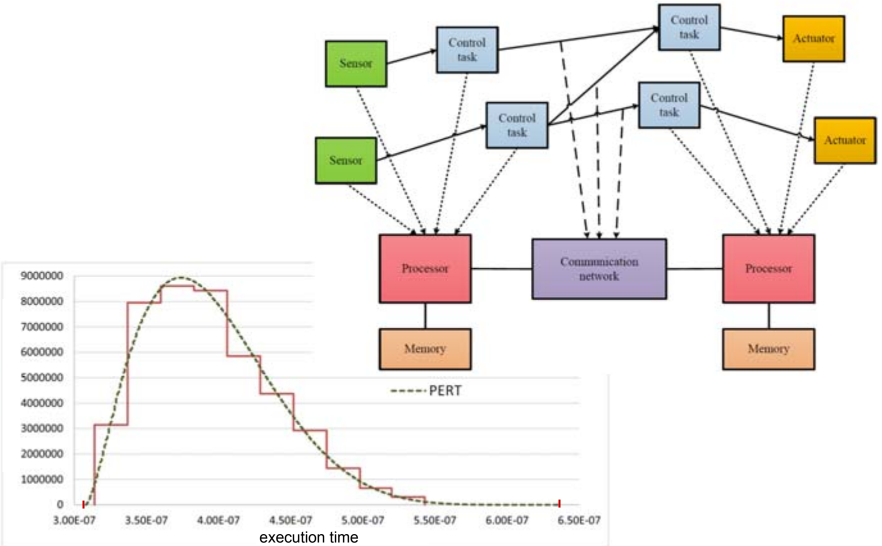
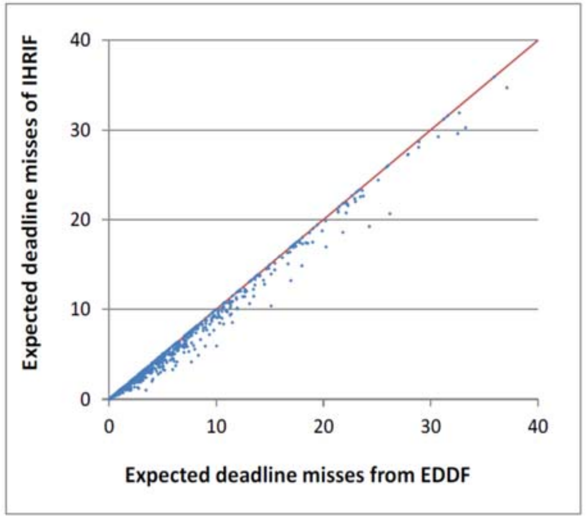
- Feedback control
- Embedded computing

24 Robust scheduling of control applications



25 Robust scheduling of control applications



Stochastic robustness analysis in a list scheduler

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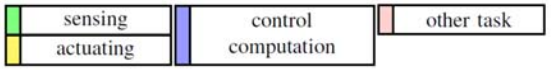
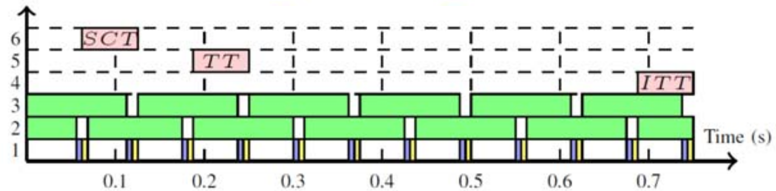
- Feedback control
- Embedded computing

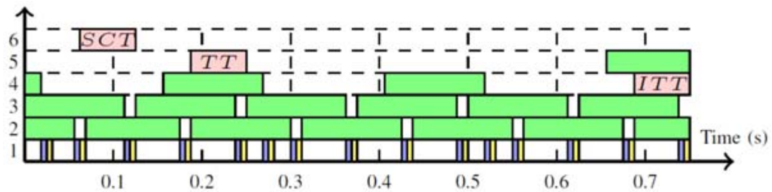
27 Multi-core pipelined sensing in image-based control

- Static pipelined control



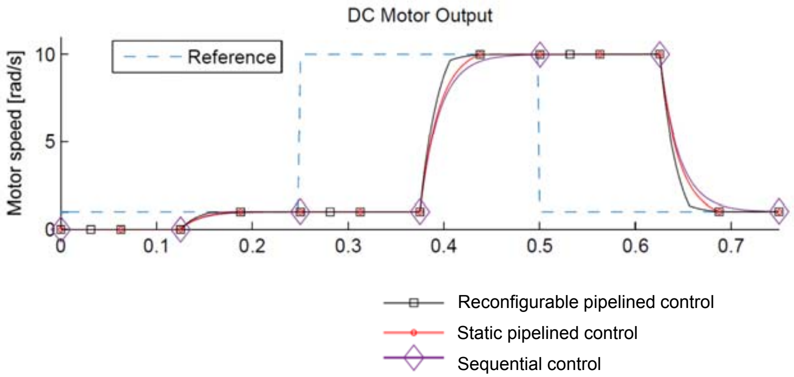


- Dynamically reconfigurable pipelined control



Switched linear systems

28 Multi-core pipelined sensing in image-based control



Reconfigurable pipelined control performs best !

Switched linear systems

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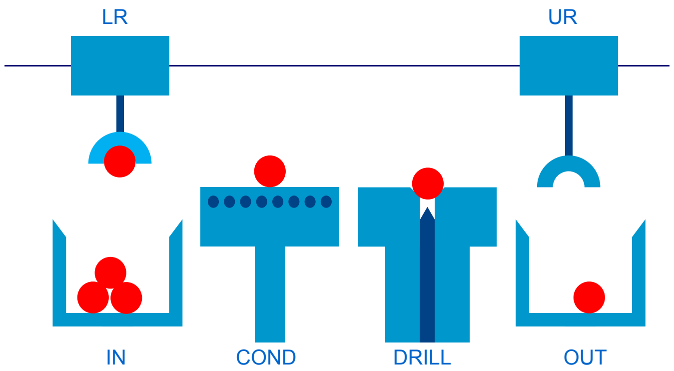
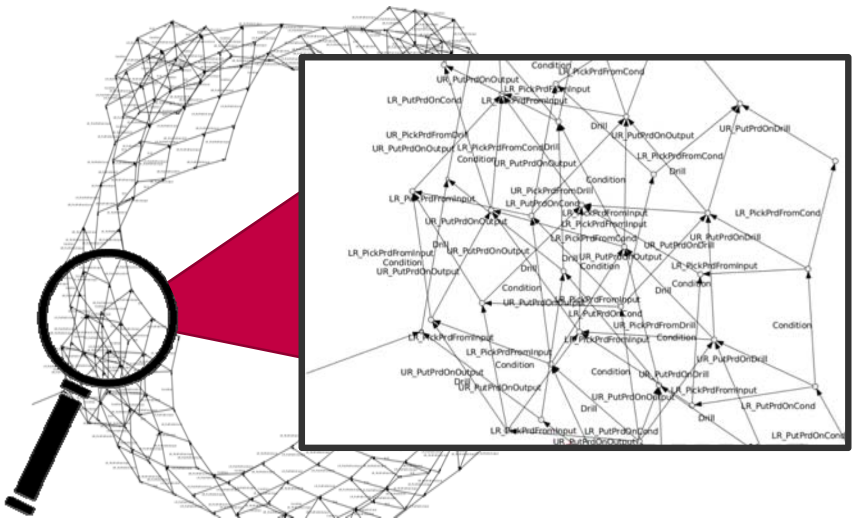
- Supervisory control
- Embedded computing

30 Supervisory control: ensuring safe behavior

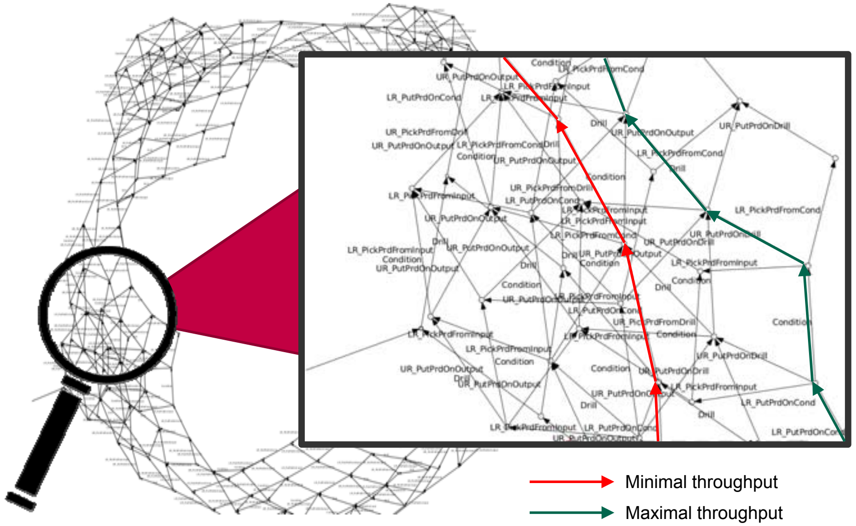


- Avoid collissions
- Drill only when material present
- …

31 Supervisory control: state-space explosion



32 Supervisory control: timing analysis



Win-win: avoid low throughput paths during controller synthesis

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Best practices

34 System scenarios and rigorous foundations

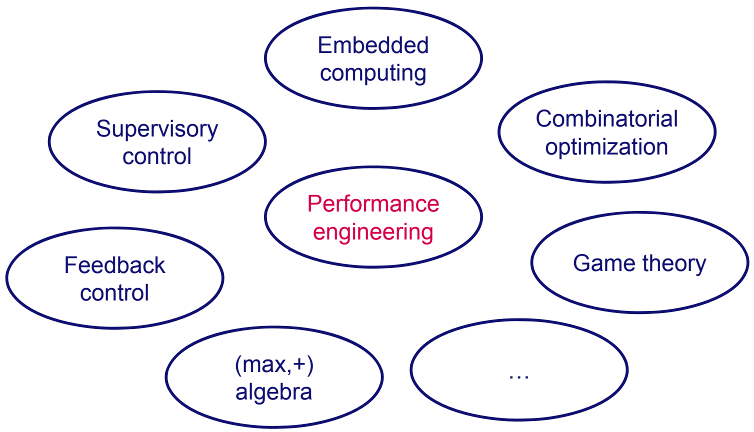
- Scenario-based design – modes, configurations
  - Design-time optimization per scenario
  - Run-time reconfiguration between scenarios
- Timing analysis for communicating processes: (max, +)-algebra

$$t_3 = t_4 = \max(t_1, t_2) + E$$

- Run-time optimization – game theory, Pareto algebra

35 Conclusions

- Crossing boundaries



- Strategic collaborations between academia and industry pay off