Model-based Design of Distributed Automotive Systems

TiMoBD - Time Analysis and Model-Based Design, from Functional Models to Distributed Deployments

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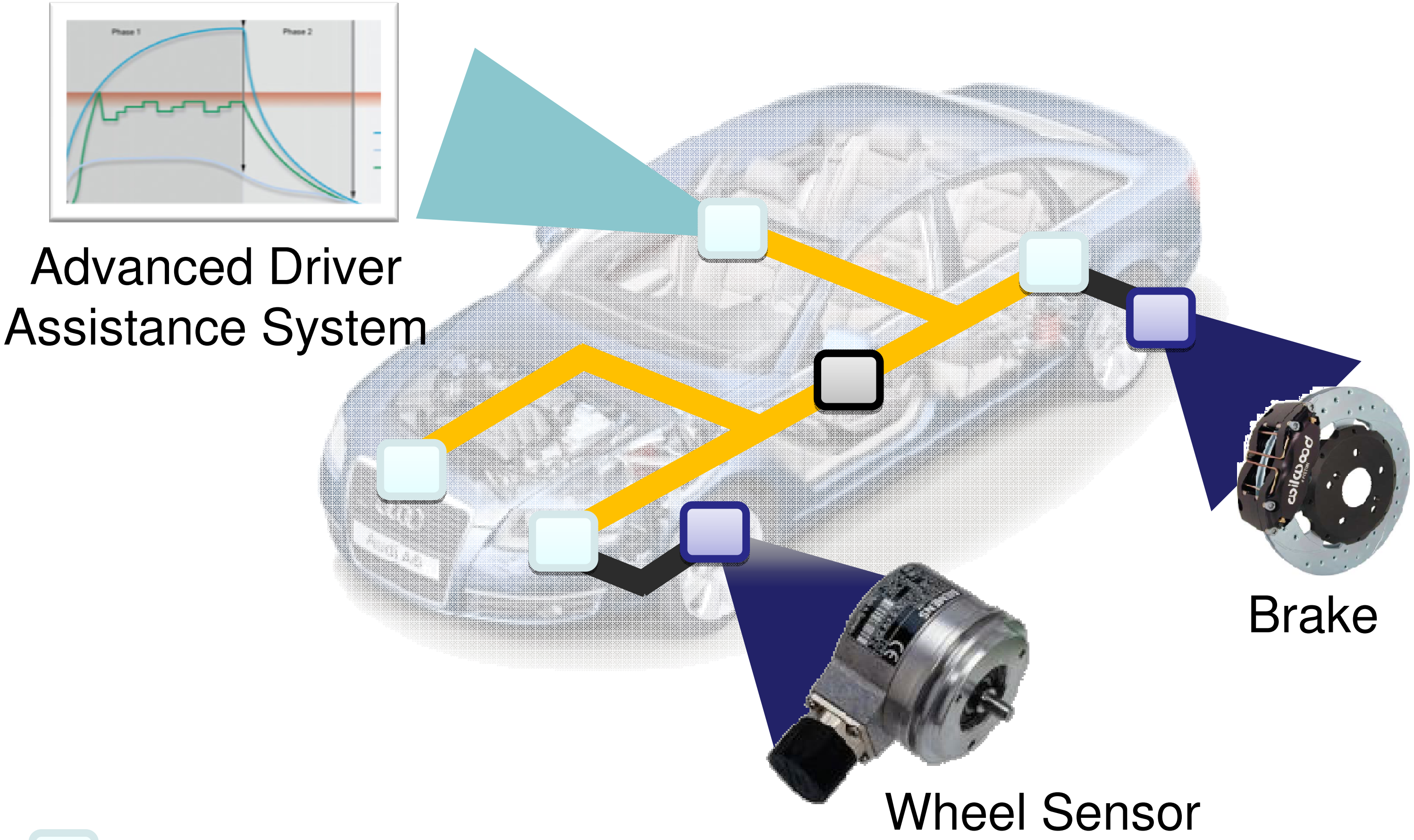
Heterogeneous Network – Motivation

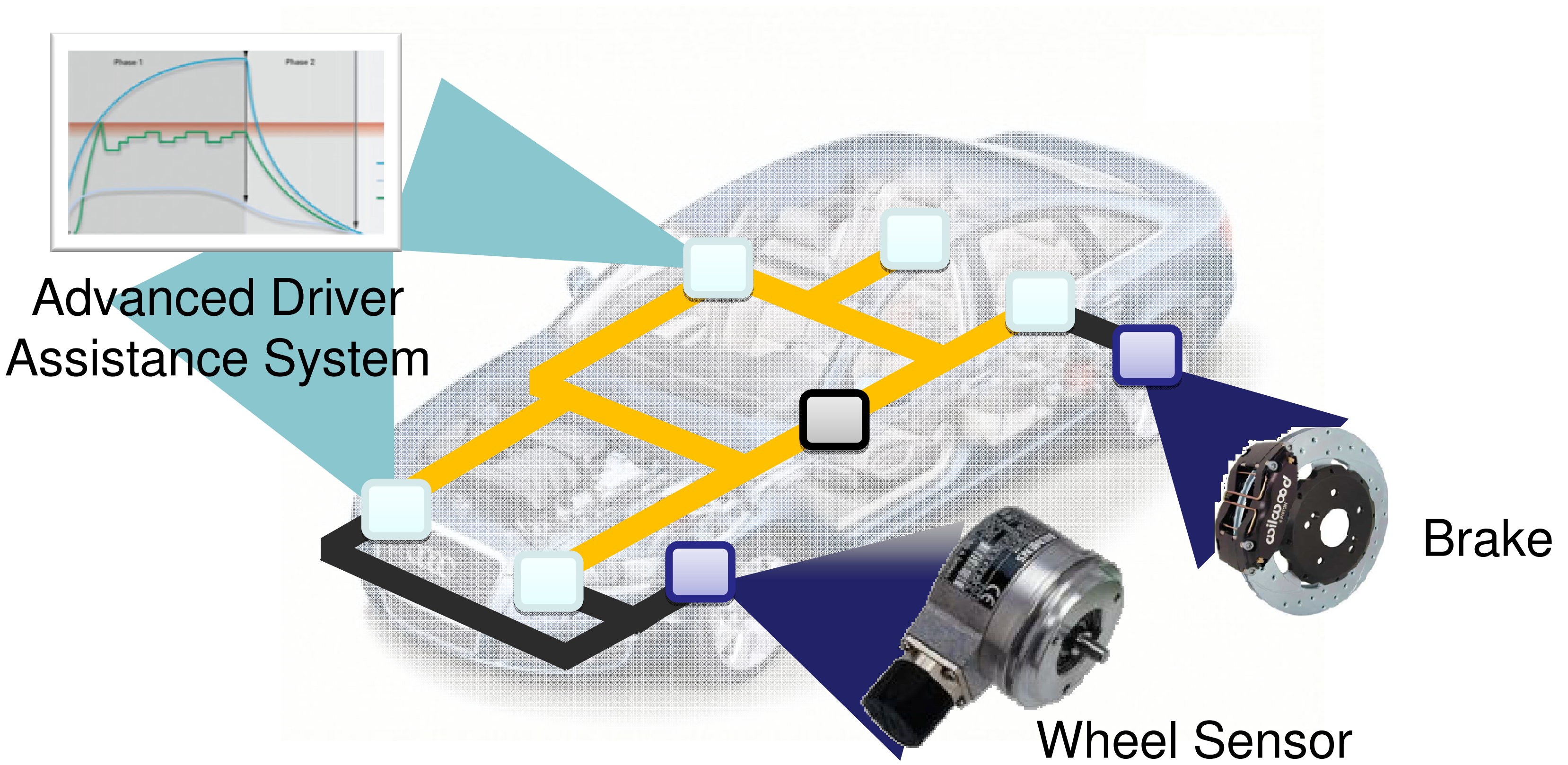


- ECUs (Electronic Control Unit)
- Sensors / Actuators
- Gateways
- Shared bus systems (CAN, FlexRay)
- Point-to-point (LIN)

Outline

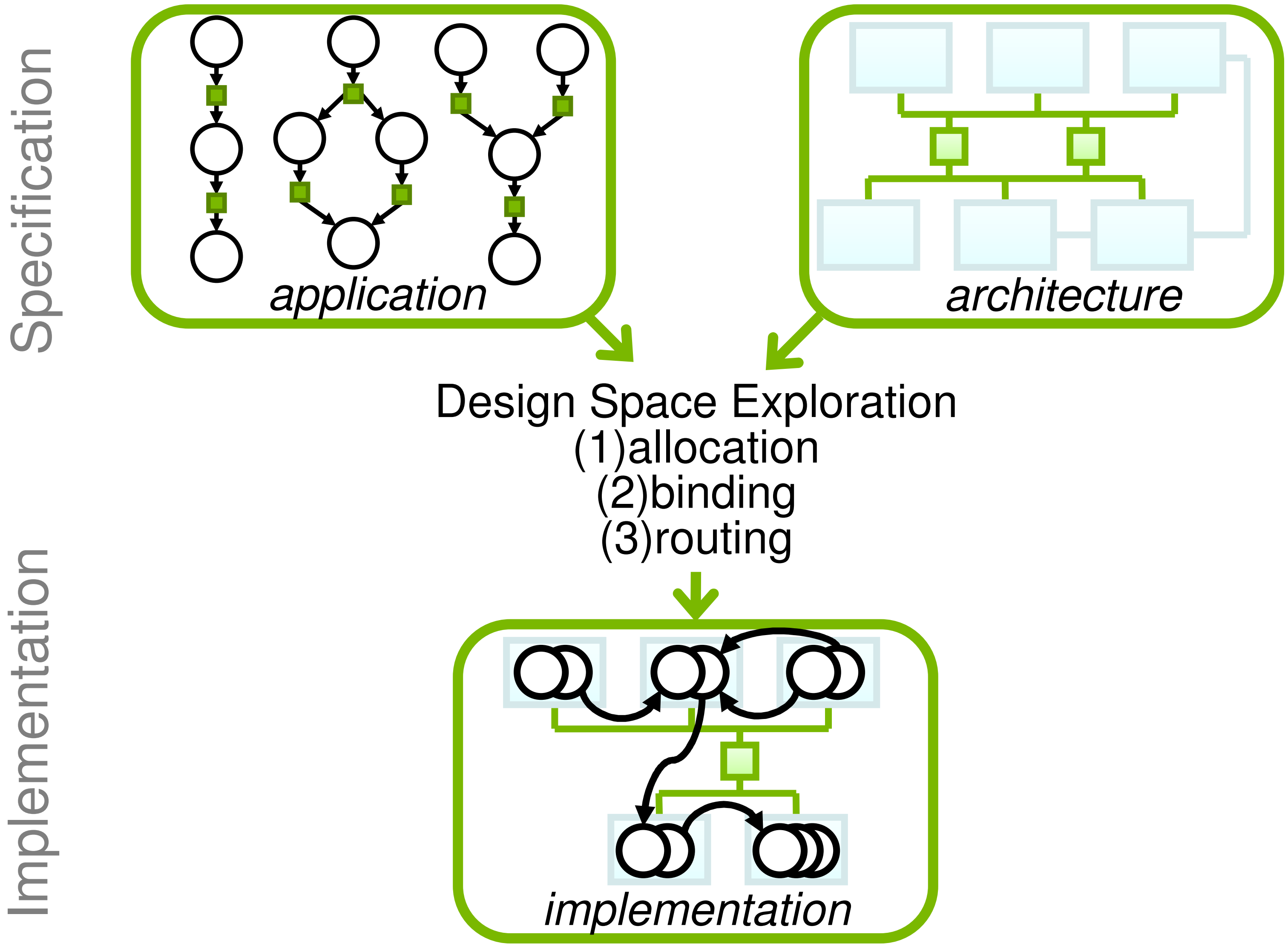
- Exploration Model
- Optimization of Constrained Combinatorial Problems
- Model Encoding
- Timing Aspects
- Case Studies

Motivation – Design Space Exploration

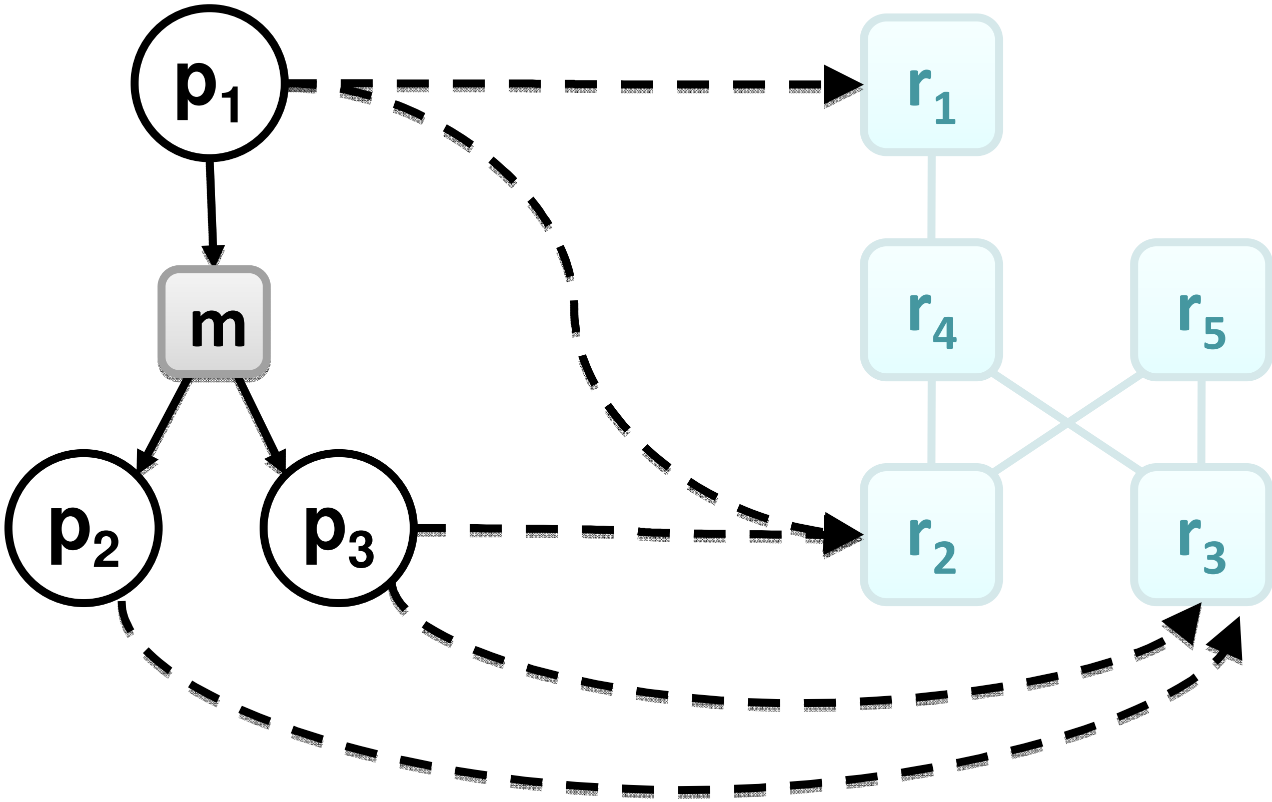


- Allocation of resources (interconnection to buses)
- Distribution of tasks
- Routing of messages
- Parameters (priorities, scheduling policies)

Model (Y-Chart Approach)

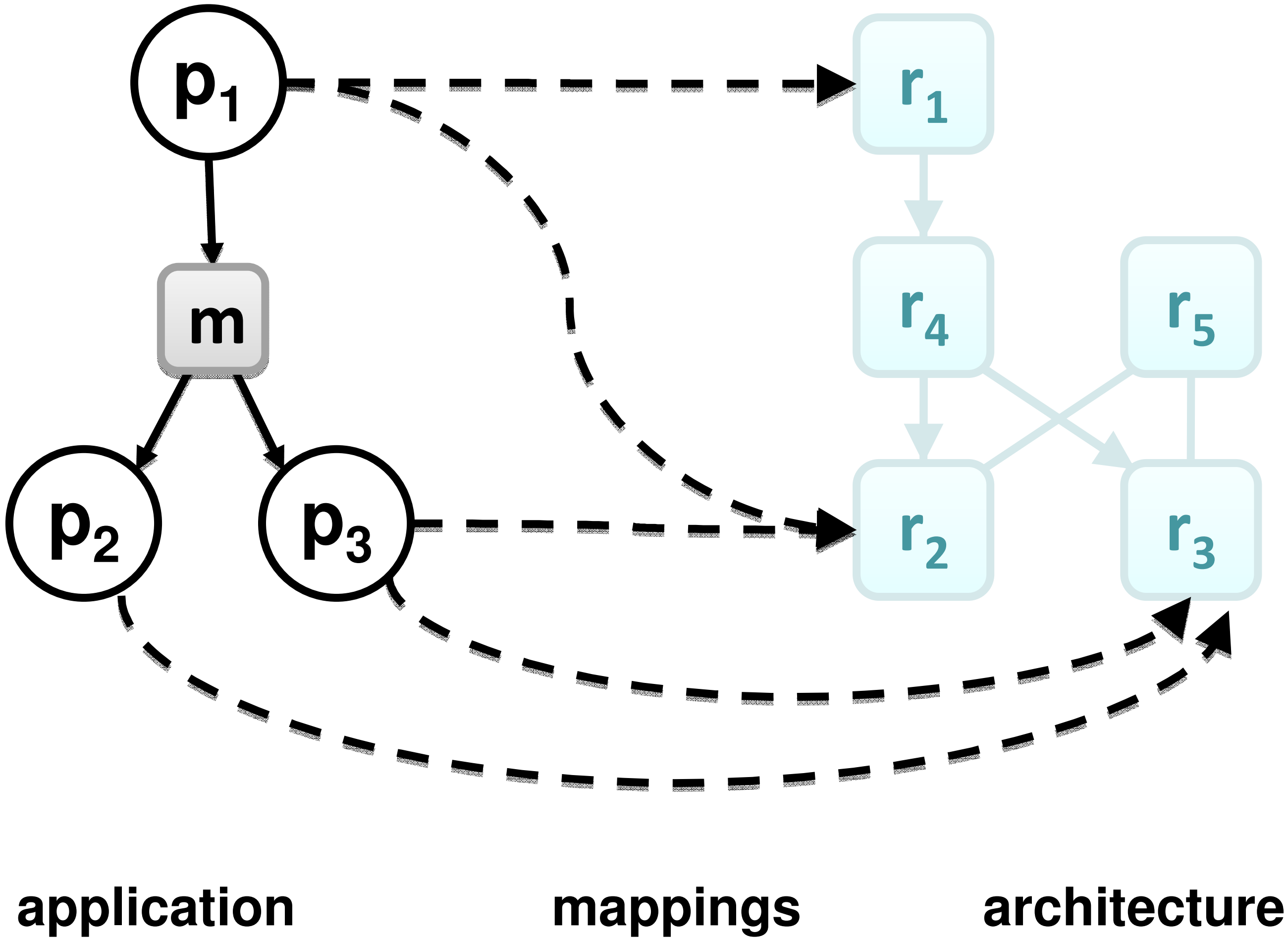


Specification



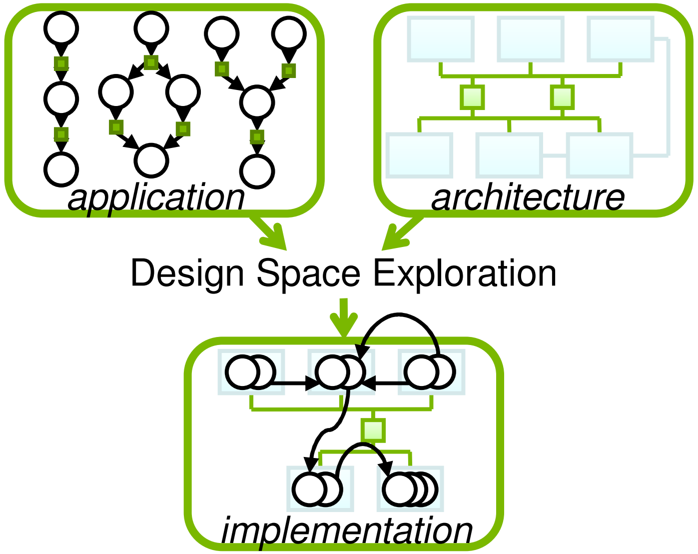
application **<u>mappings</u>** **architecture**

Implementation: Allocation, Binding, Routing



Problem Transformation

Design Space Exploration

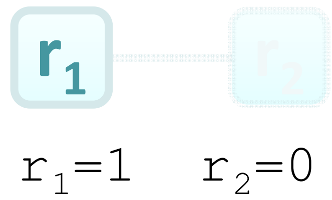


Constrained Combinatorial Problem

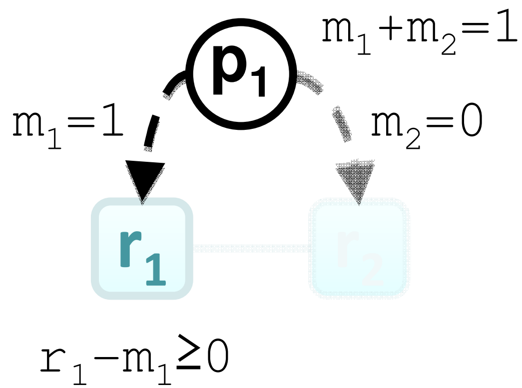
```
Optimize: f(x)
      s.t.   Ax≤b
        and  x∈{0,1}^n
```

Model Encoding

- Allocation encoding
  - Binary variable for each resource



- Binding encoding
  - Binary variable for each mapping
  - Linear constraints for unique binding and binding to an allocated resource



- Routing encoding
  - Binary variables for each pair of resource and time step
  - Linear constraints fulfill dependencies

$$
\begin{array}{c} \\ r_1 \\ r_2 \\ r_3 \\ r_4 \end{array}
\begin{array}{c} \begin{array}{ccc} t_0 & t_1 & t_2 \end{array} \\ \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} \end{array}
$$

Constrained Combinatorial Problem

- Definition:

  Optimize: $f(\mathbf{x})$

  s.t. $A\mathbf{x} \leq b$ and $\mathbf{x} \in \{0,1\}^n$

- Objective function f is non-linear and multi-objective
- Linear constraints define the feasible solution space $X_f \subseteq \{0,1\}^n$

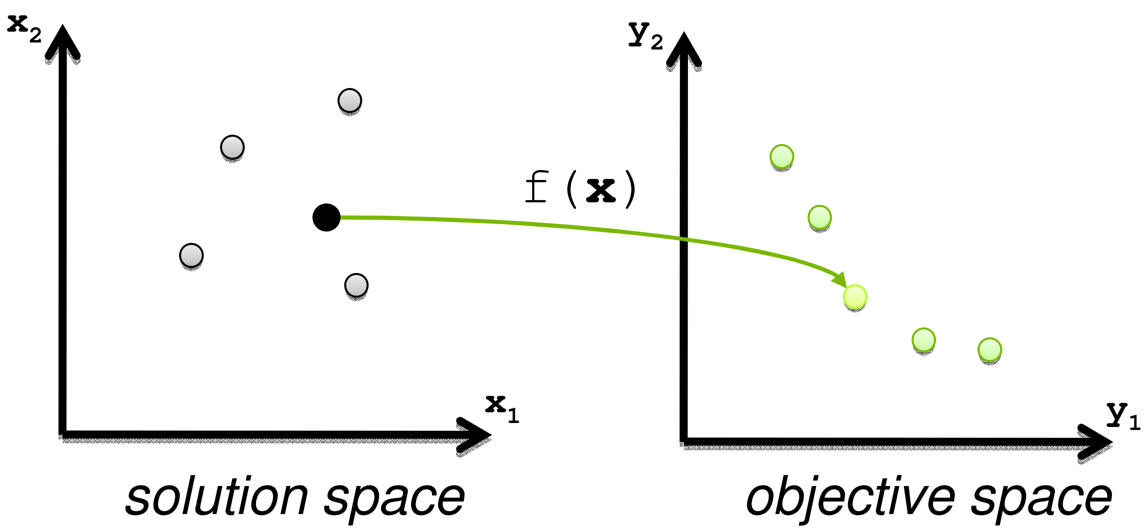
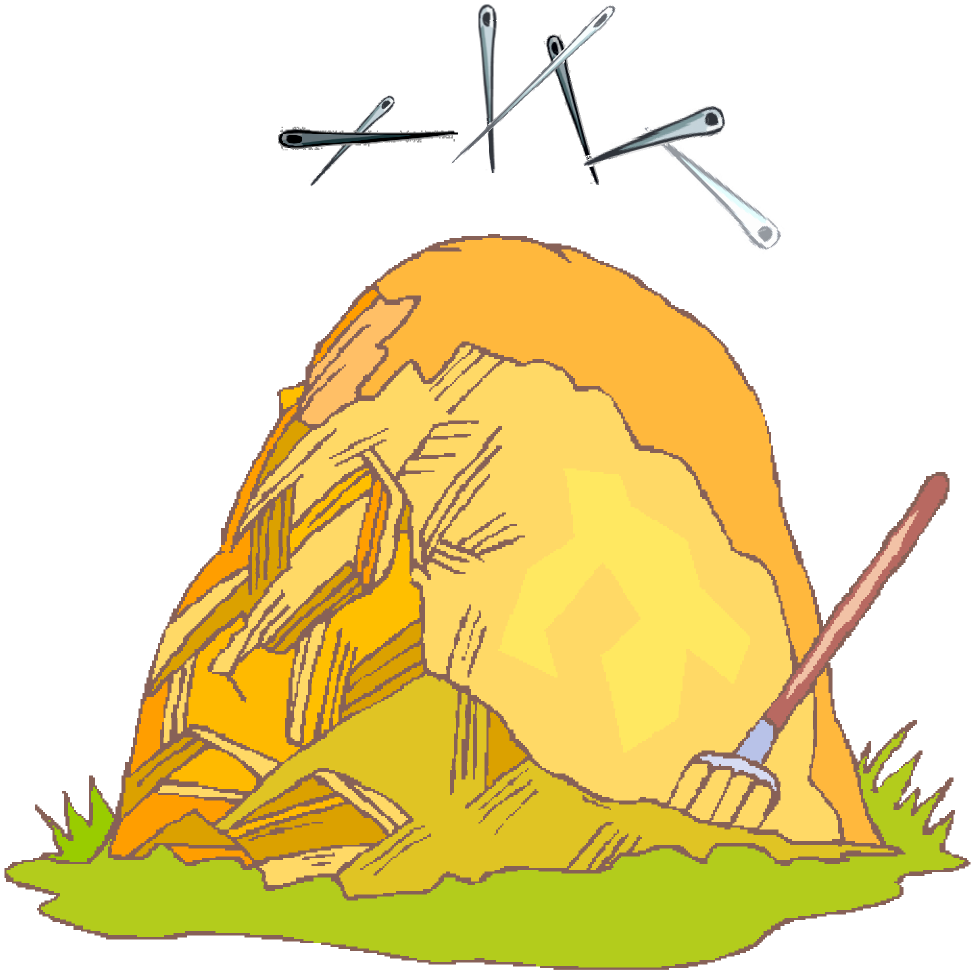
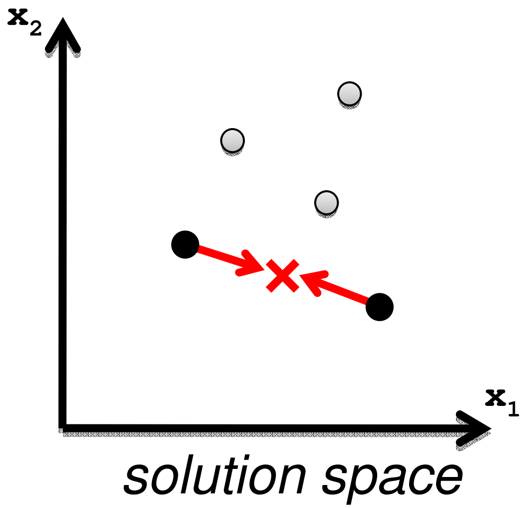


Illustration of Problem Complexity

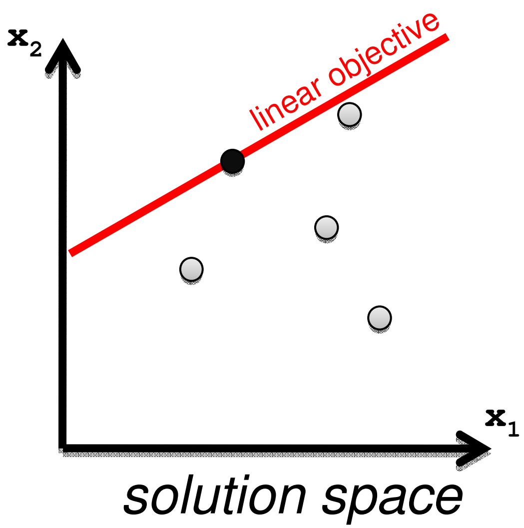


Common Approaches

- Evolutionary Algorithms (EA)
  - Suitable for multi-objective optimization problems
  - Restricted-use for constrained optimization problems

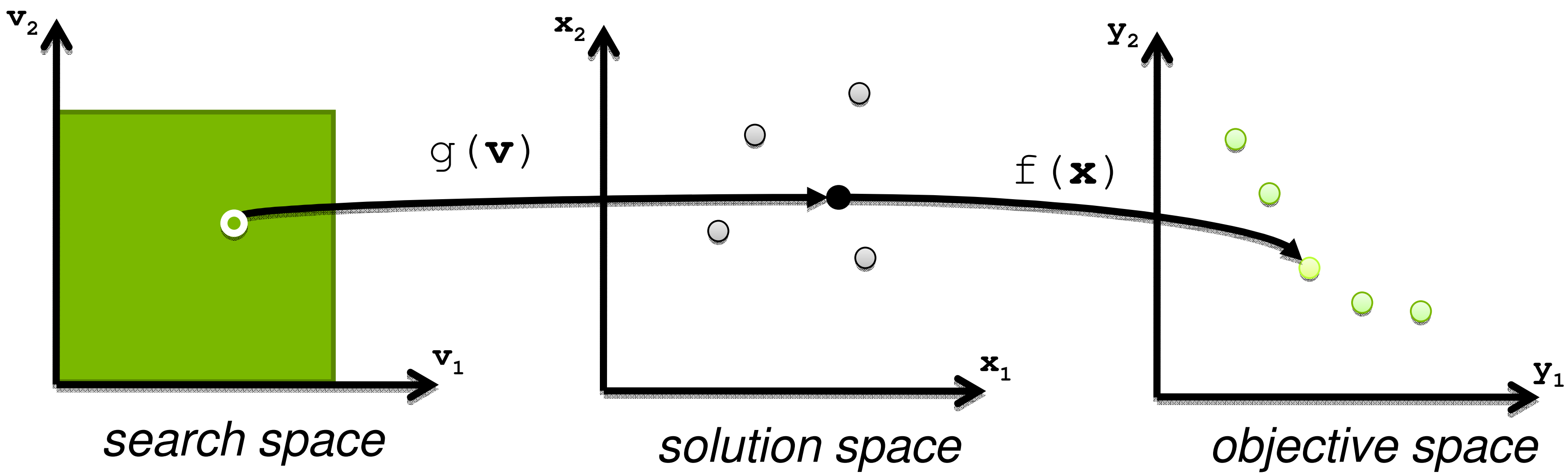


- Integer Linear Programming (ILP)
  - Suitable for linearly constrained optimization problems
  - Restricted to single linear objective function



Proposed Approach

- Decoding Approach
  - Search in the simply constrained *search space* V
  - Decoding to a feasible solution in the *solution space* X_f
  - Combination of EA und *PB (Pseudo-Boolean) solver*

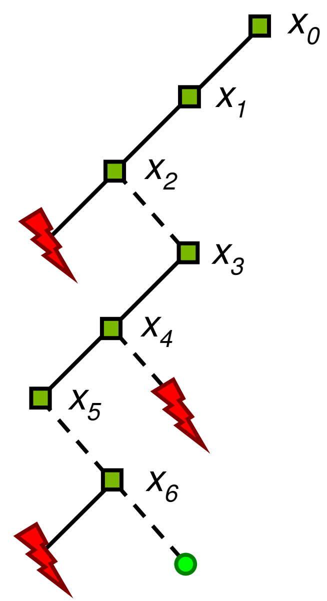


PB Solver

- Backtracking algorithm for ILPs with binary variables
- Branching determined by
  - ρ - priority for each variable
  - σ - decision phase for each variable

```
while true do
    branch()
    if CONFLICT( ) then
        backtrack()
    else if SATISFIED( ) then
        return x
    end if
end while
```

backtracking algorithm

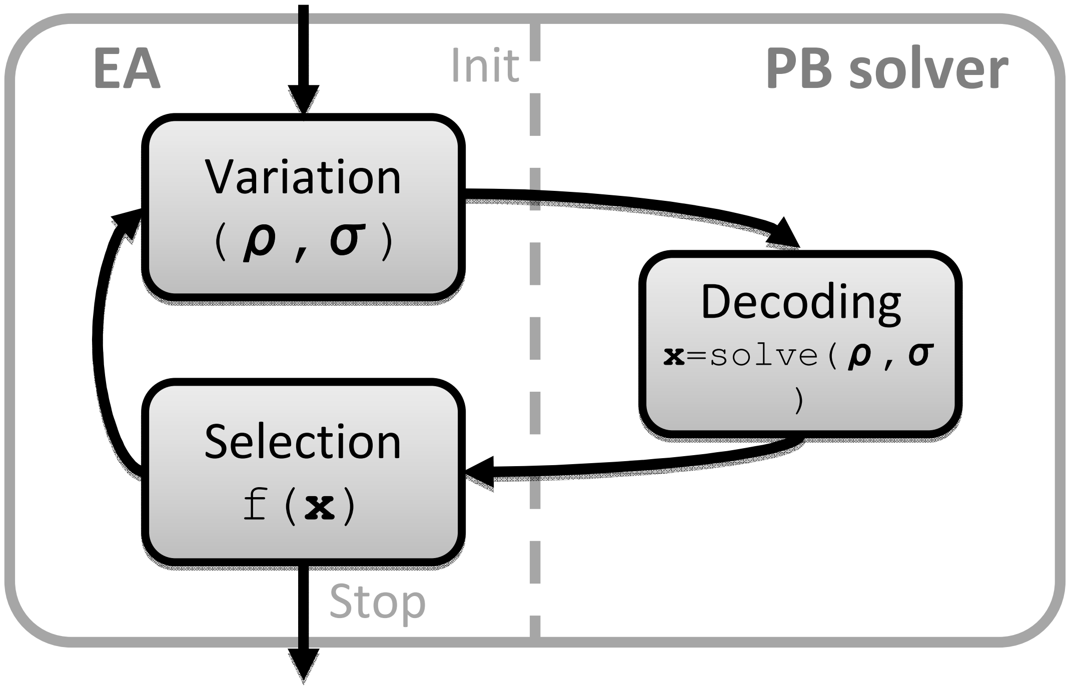


$\mathbf{x} = (1, 1, 0, 1, 1, 0, 0)$

branching example

Proposed Approach – Flow

- The search space $V=R^n \times \{0,1\}^n$ is defined as the set of all branching strategies for the PB solver

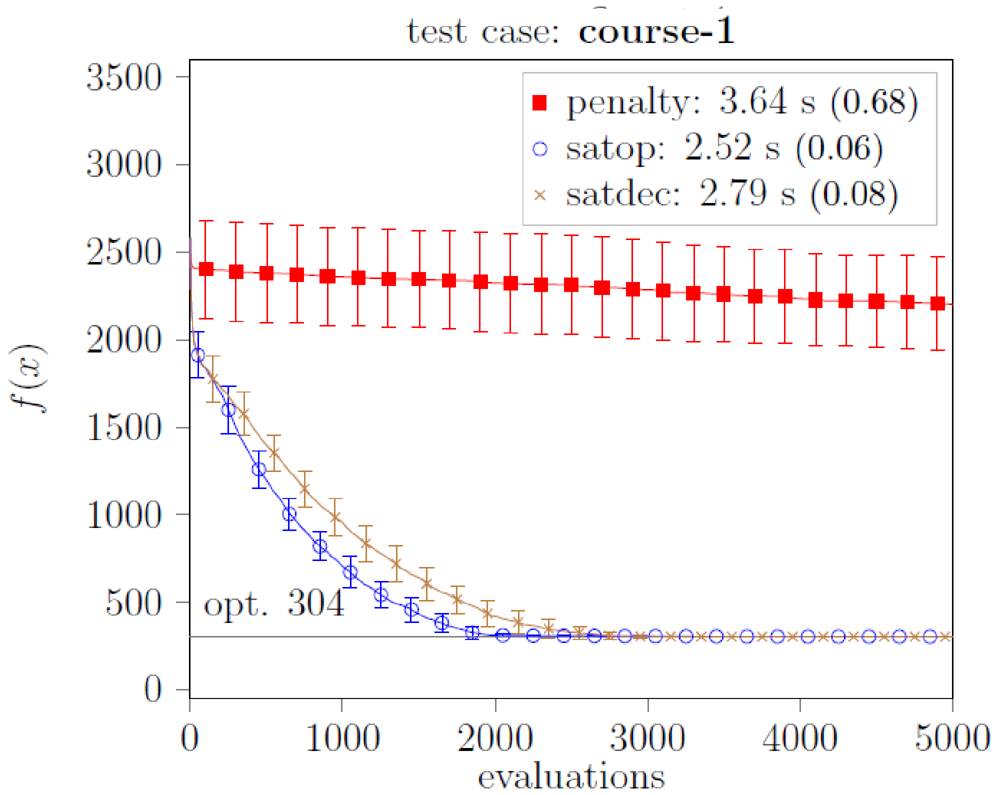


(**ρ**, **σ**) – branching strategy for the PB solver

x – feasible solution

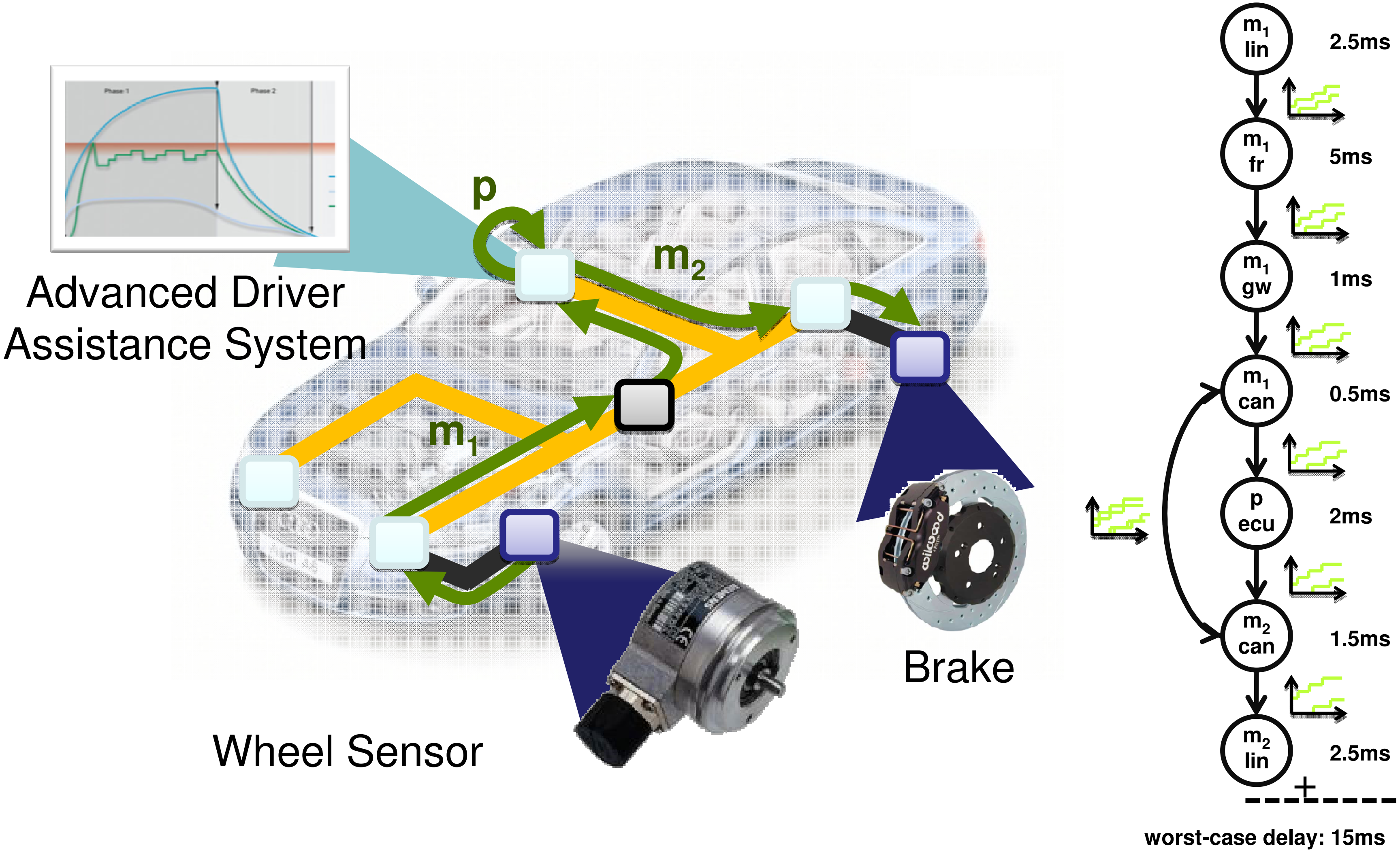
Results

- Comparison using test cases from „*PB Evaluation 2009*“
  - ILPs with a single objective function and binary variables

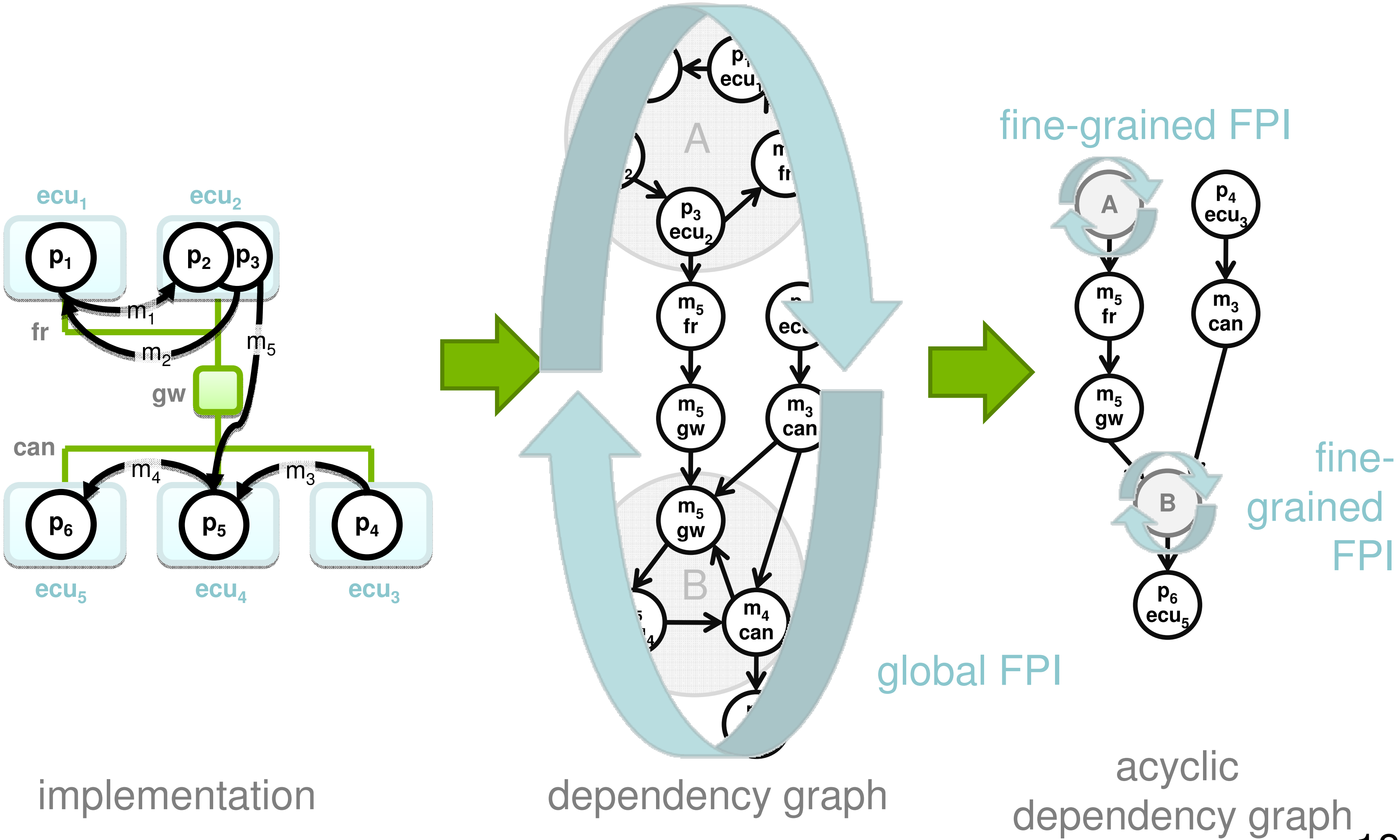


Course Assignment Problem (257 var., 37 con.)

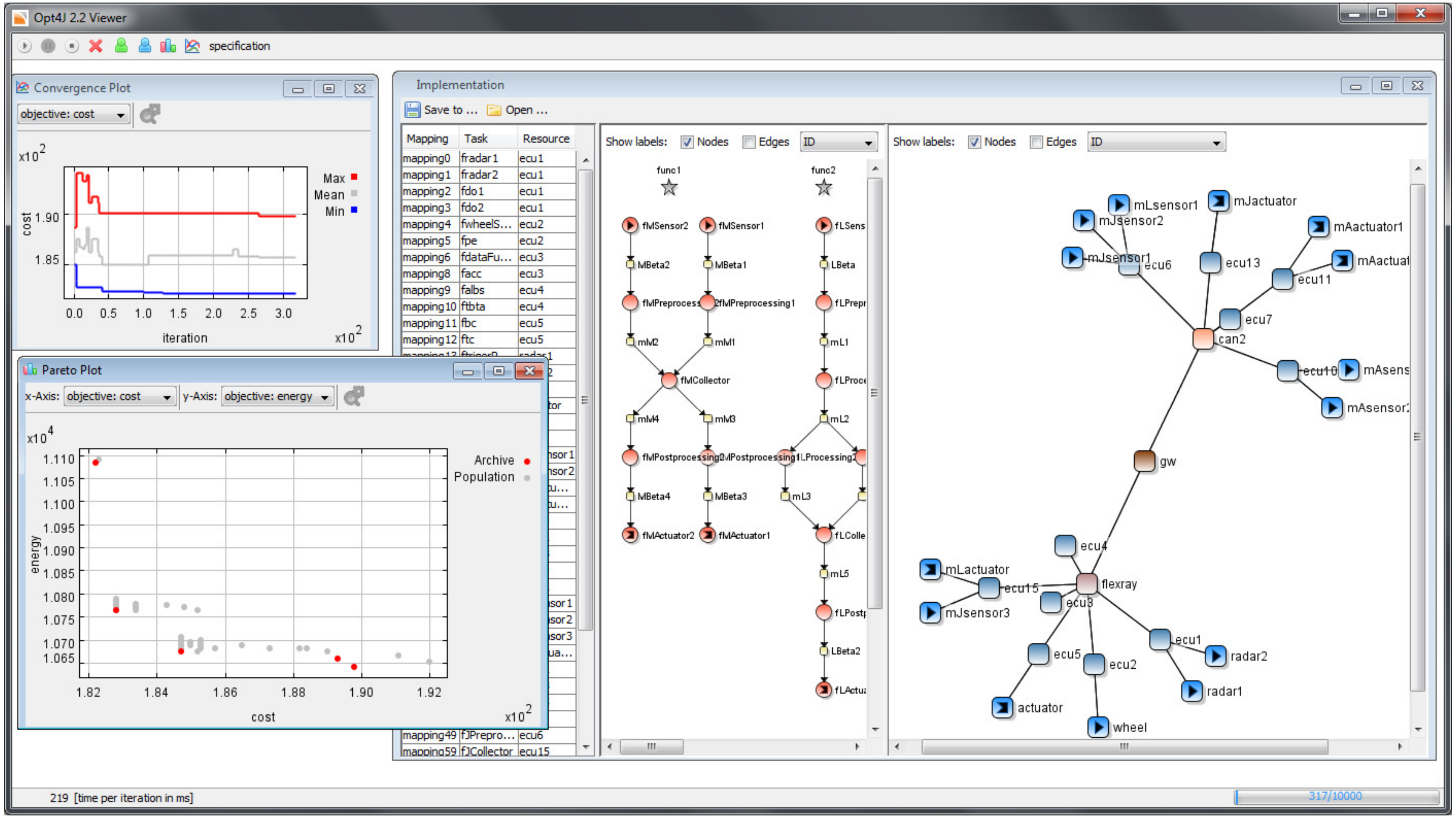
Compositional Timing Analysis – Motivation



Compositional Timing Analysis



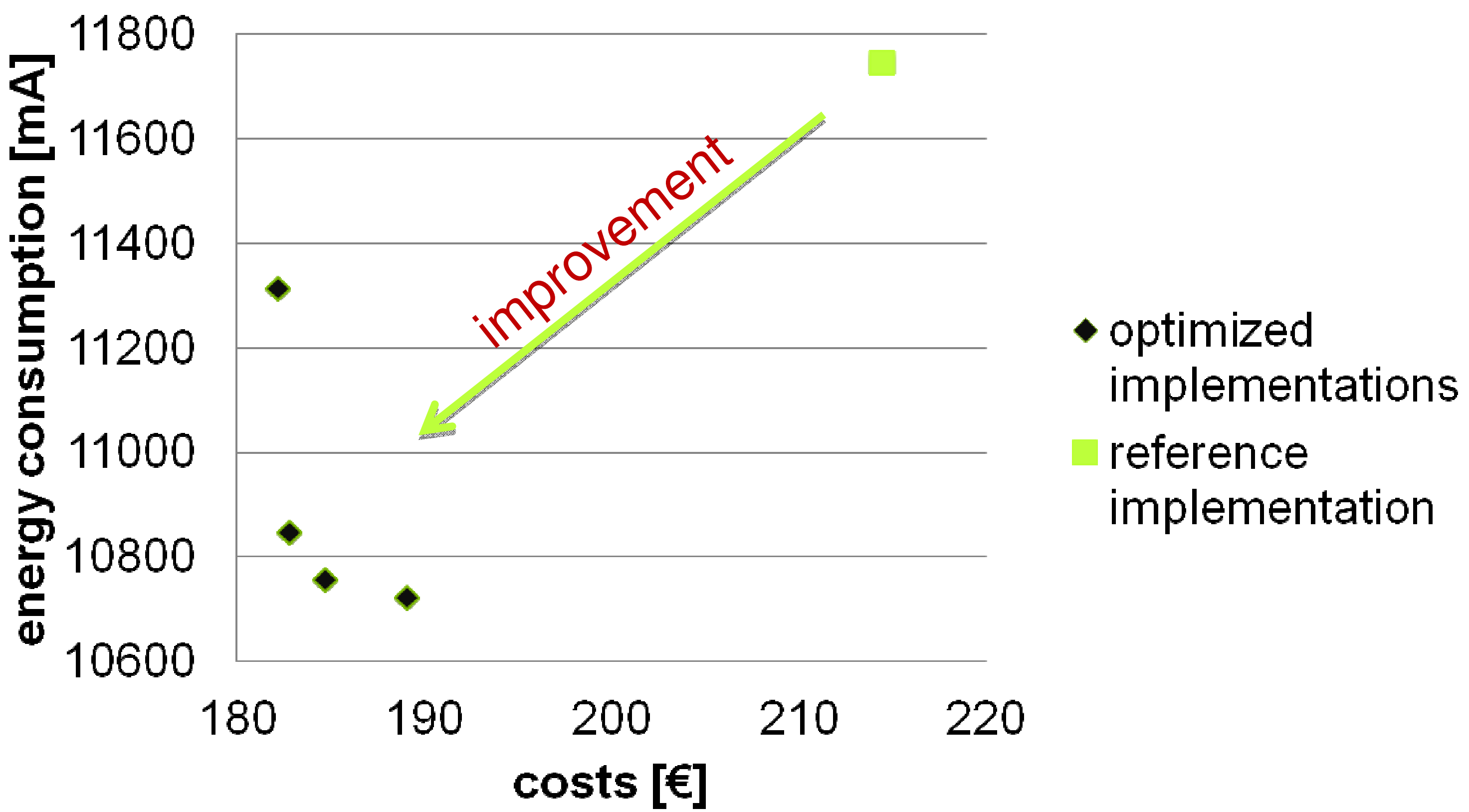
Design Space Exploration Framework



Based on open source optimization framework *www.opt4j.org*

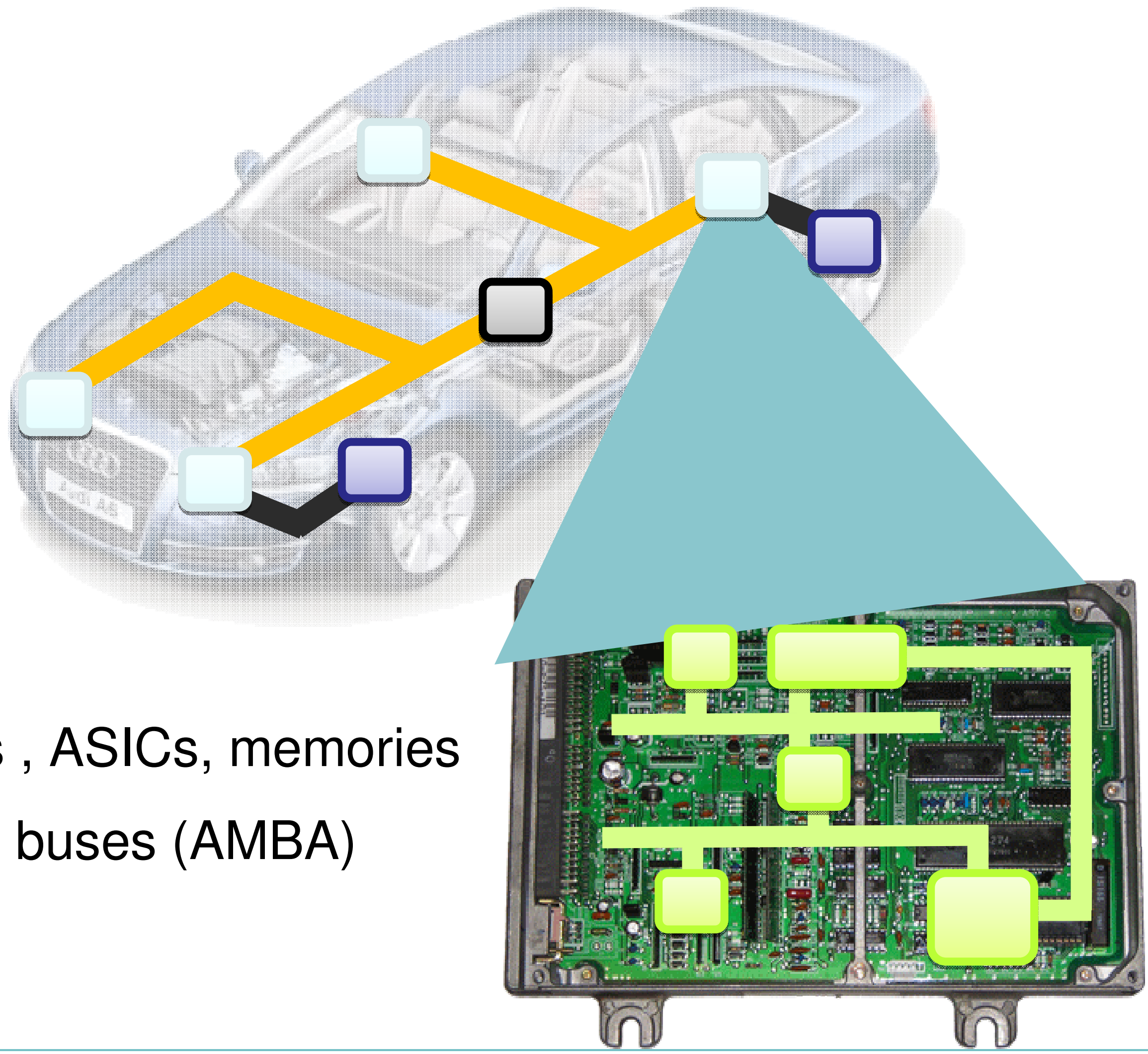
Automotive Network Case Study

- Application: 46 tasks, 42 messages
- Architecture: 15 ECUs, 2 CANs, FlexRay, Gateway
- Optimization runtime: 1h (timing analysis)



Application Domains

Network

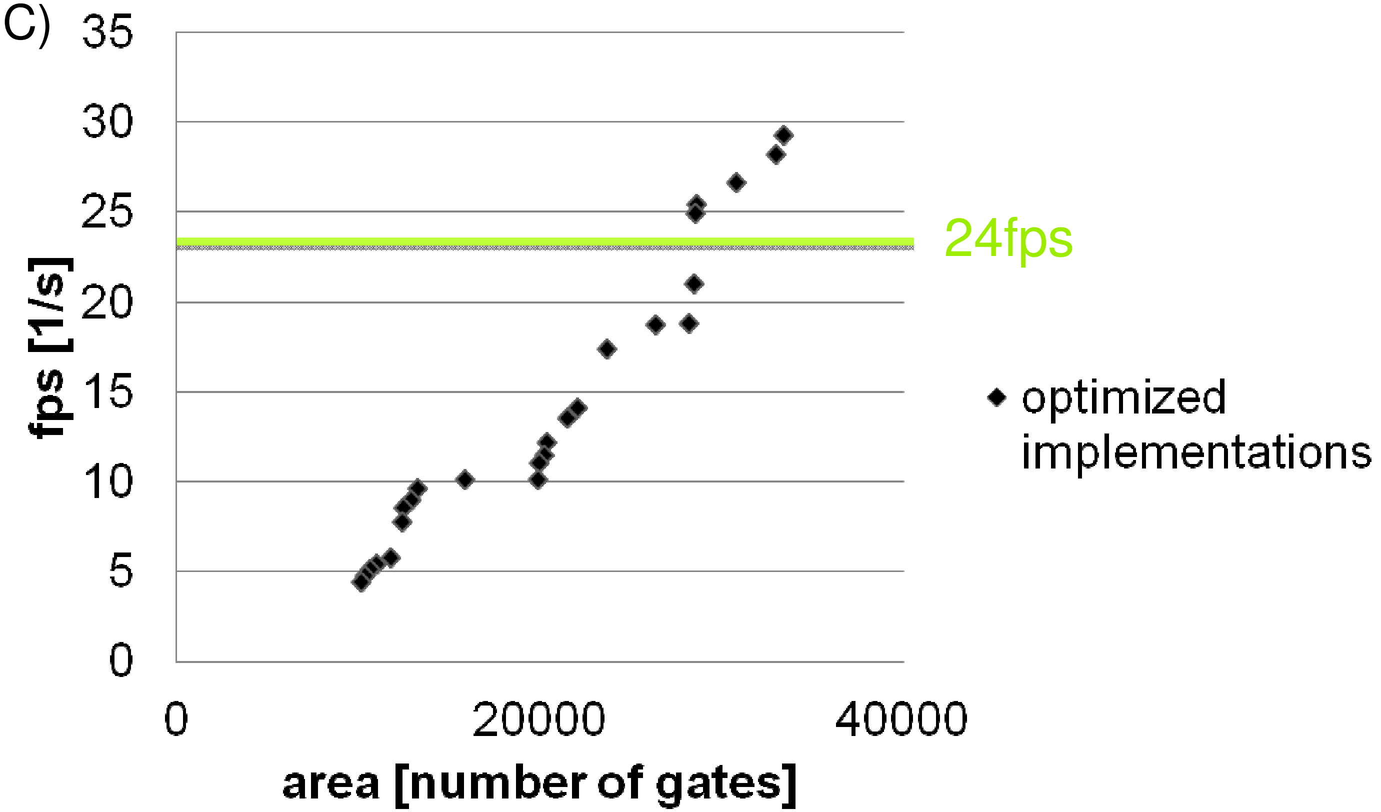


ECU

- CPUs , ASICs, memories
- Links, buses (AMBA)

Motion-JPEG Decoder Case Study

- Application: 21 tasks, 56 communication tasks
- Architecture: ARM processors, DSP, buses, gateway
- Optimization runtime: 17h (performance simulation with SystemC)



Conclusions

- Design Space Exploration
  - Flexible model
  - Flexible multi-objective optimization
  - Applicable to arbitrary domains, e.g., automotive networks, MPSoCs, NoCs
- Timing Analysis
  - Worst-case analysis
  - Simulations