AGENDA

9:30 – 10:30	Session 1: Fundamental Issues with Concurrency in Embedded Software Systems from Architectural Point of View
10:45 – 11:45	Session 2: Modelling and DSE Methods for Mixed-Critical Software Systems using Multicore Architectures
12:00 – 13:00	Session 3: Synchronization in Concurrent Software is an Architectural Decision

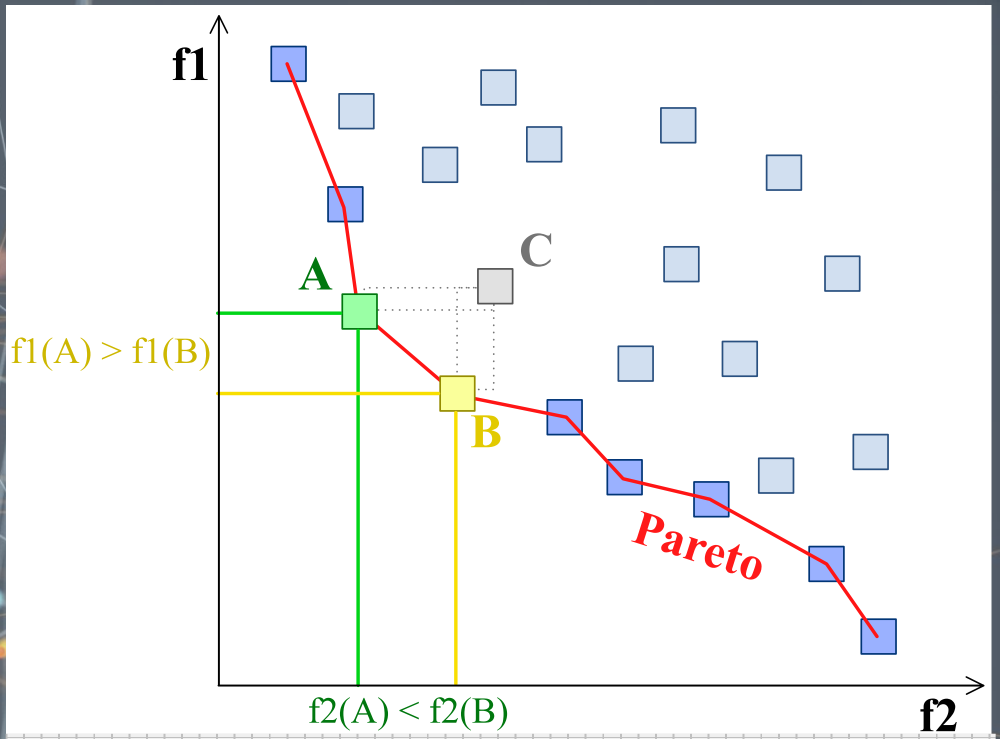
fortiss

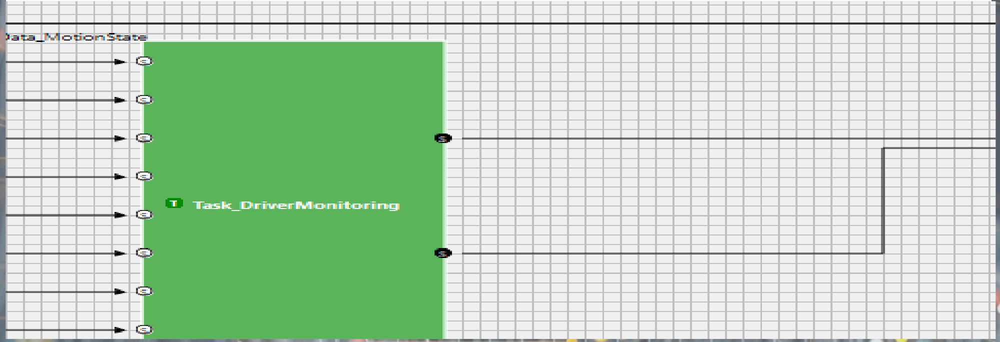
D³SE – Dependency-Driven Design Space Exploration

Activity and Artefact-based Optimization of Distributed Embedded Systems

Alexander Diewald

presented by
Simon Barner

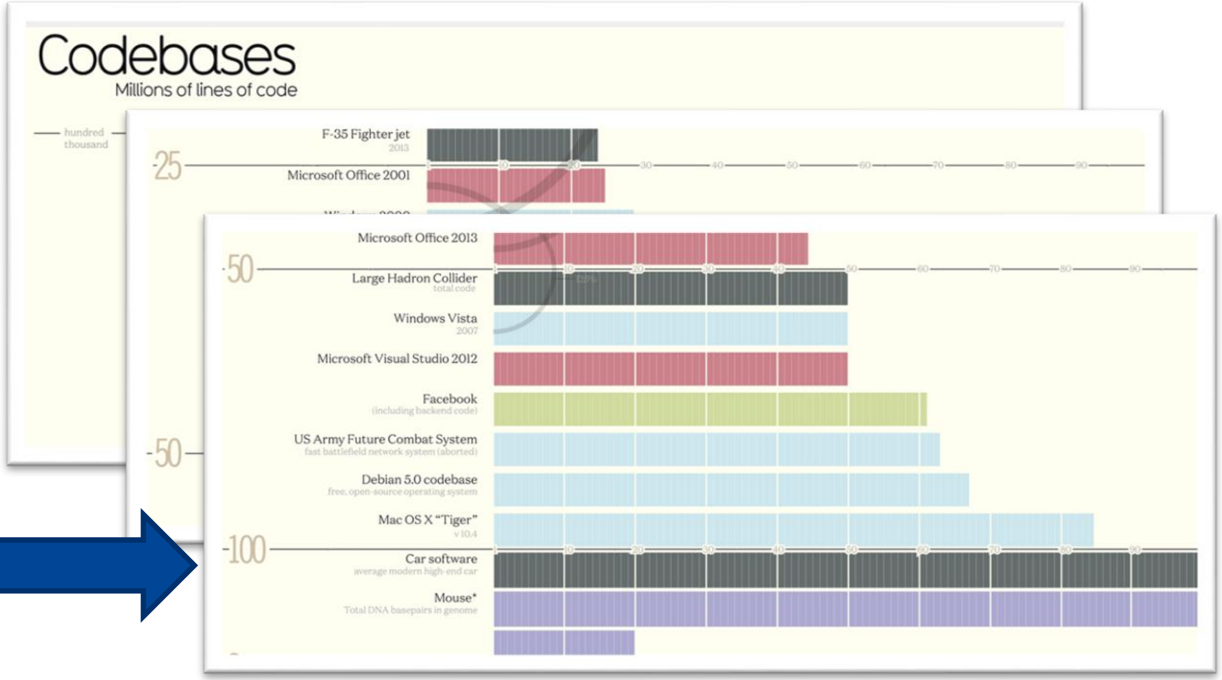




The Systems Engineering Challenge

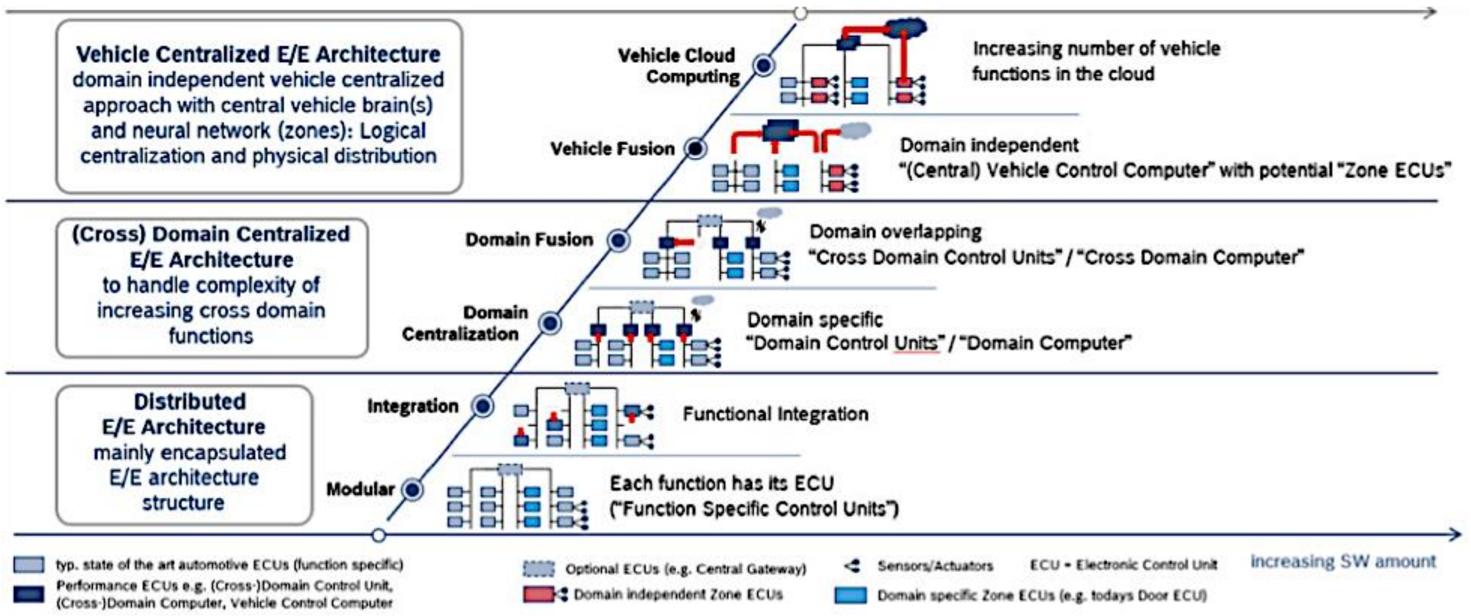
Ever-increasing complexity of software-defined CPS

- Evolving set of **functionalities**
- Multitude of **contradicting requirements**
- Increase in **system variability**
- **Product-line engineering** and **reuse**

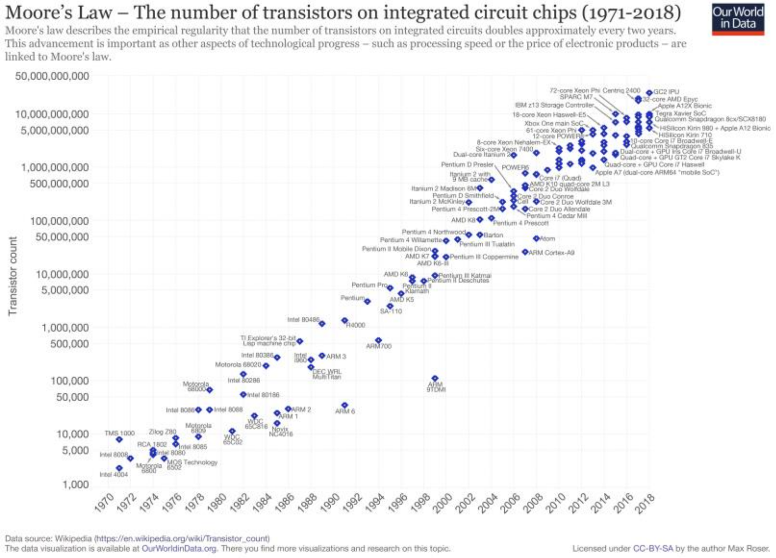


The Systems Engineering Challenge

Complexity of HW/SW platforms



Source: Benckendorff, Tenny, et al. "Comparing current and future E/E Architecture trends of commercial vehicles and passenger cars." 19. Internationales Stuttgarter Symposium. Springer Vieweg, Wiesbaden, 2019.

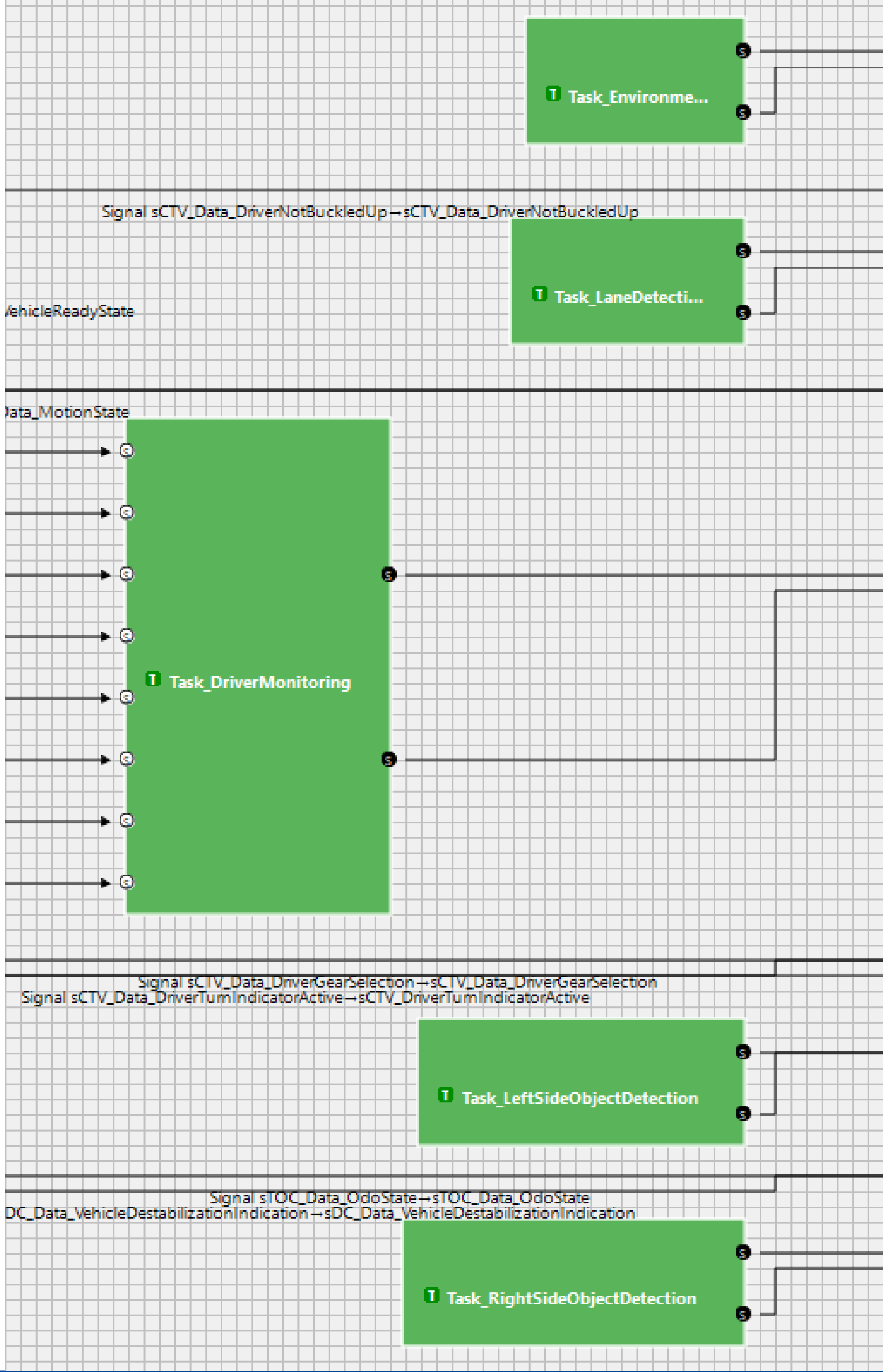


- Increase of software-defined (critical) functions results into massive performance requirements
- Mixed-criticality integration platforms are only a part of the solution & add additional complexity
- **Problem: Now system engineers have to cope with both complexity drivers!**

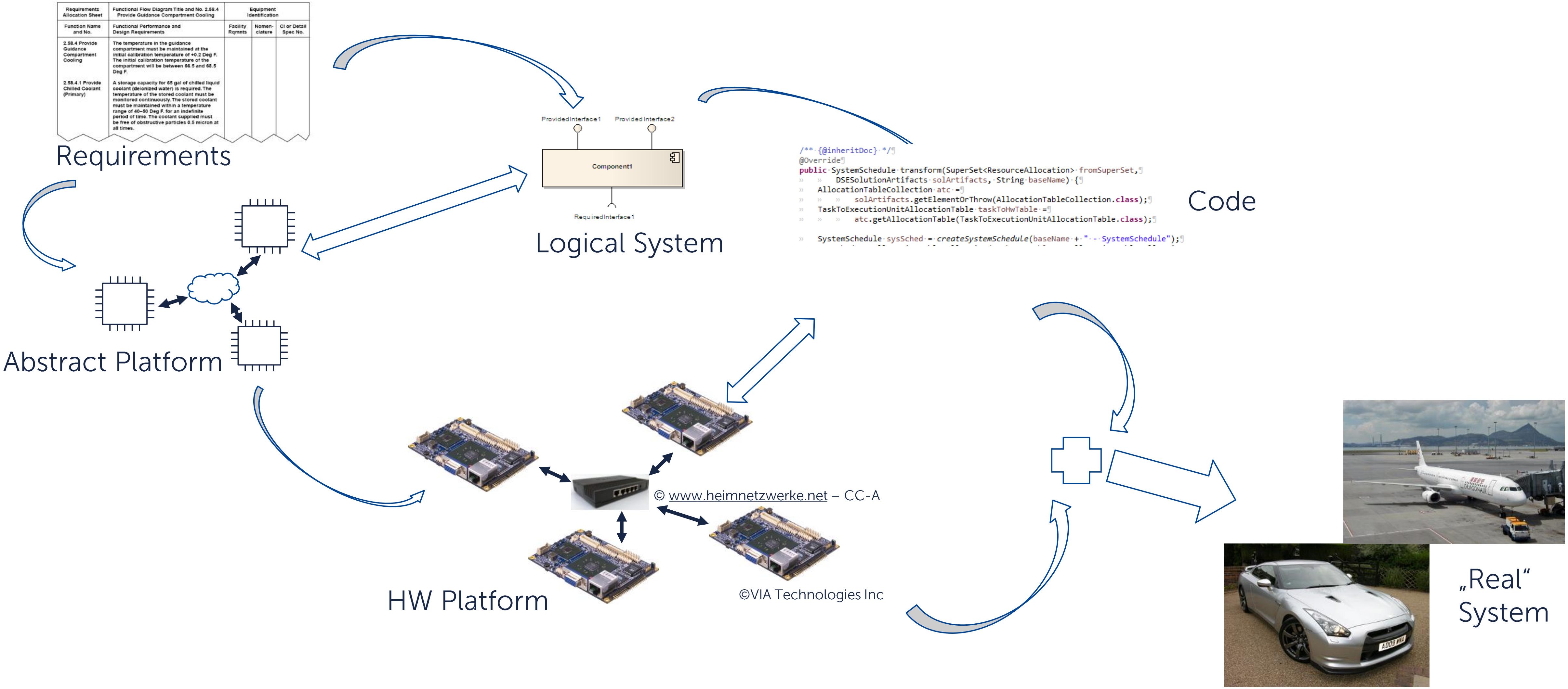
Example: Real world Traffic Jam Assistant

System level engineering

- # of elements imposes complexity
  - ~30 Tasks
  - ~200 Signals
  - ~10 ECUs
  - ~5 networks
- Large number of (non-)functional requirements:
  - Separation constraints
  - Temporal constraints (deadlines)
  - …
- Source: Waters 2019 Industrial Challenge
  (https://www.ecrts.org/archives/fileadmin/WebsitesArchiv/ecrts2019/waters/waters-industrial-challenge/index.html)



Can Development Processes beat Complexity?



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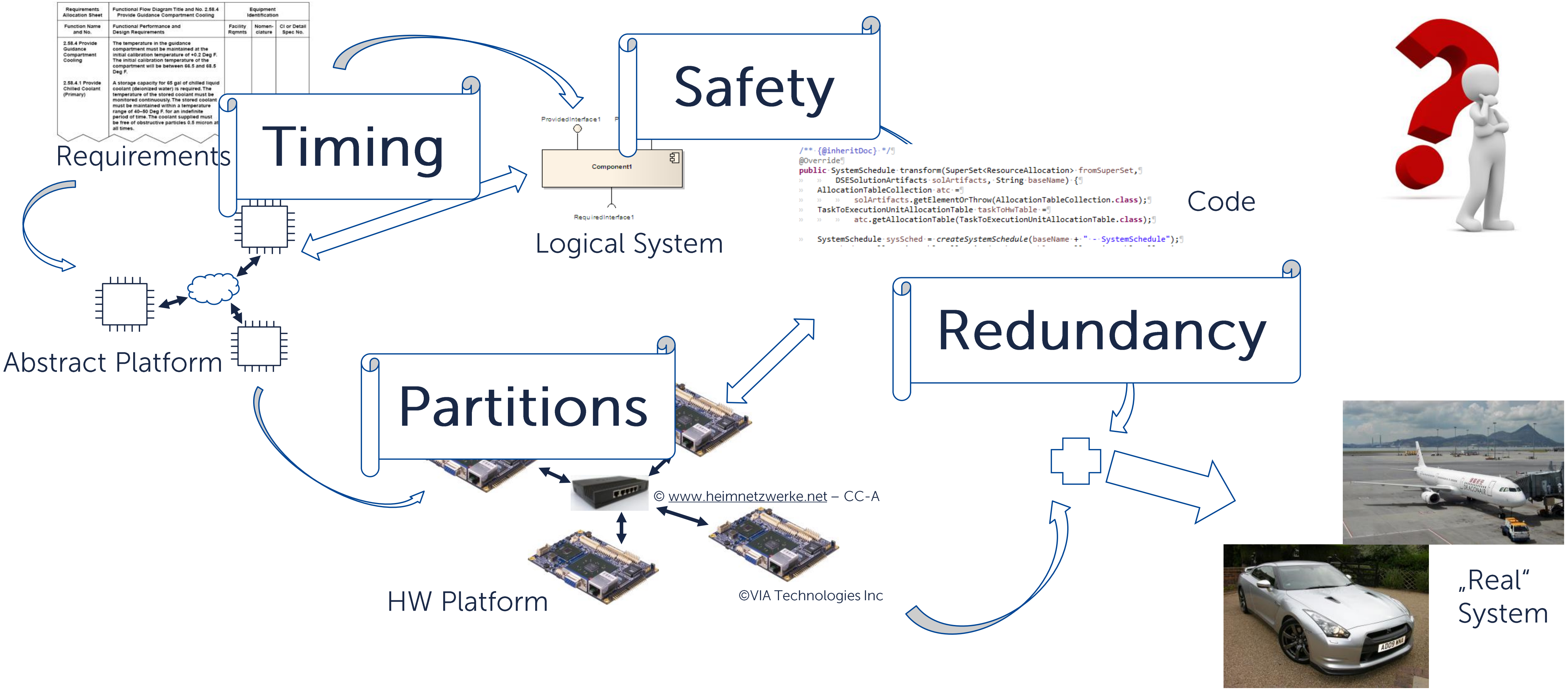

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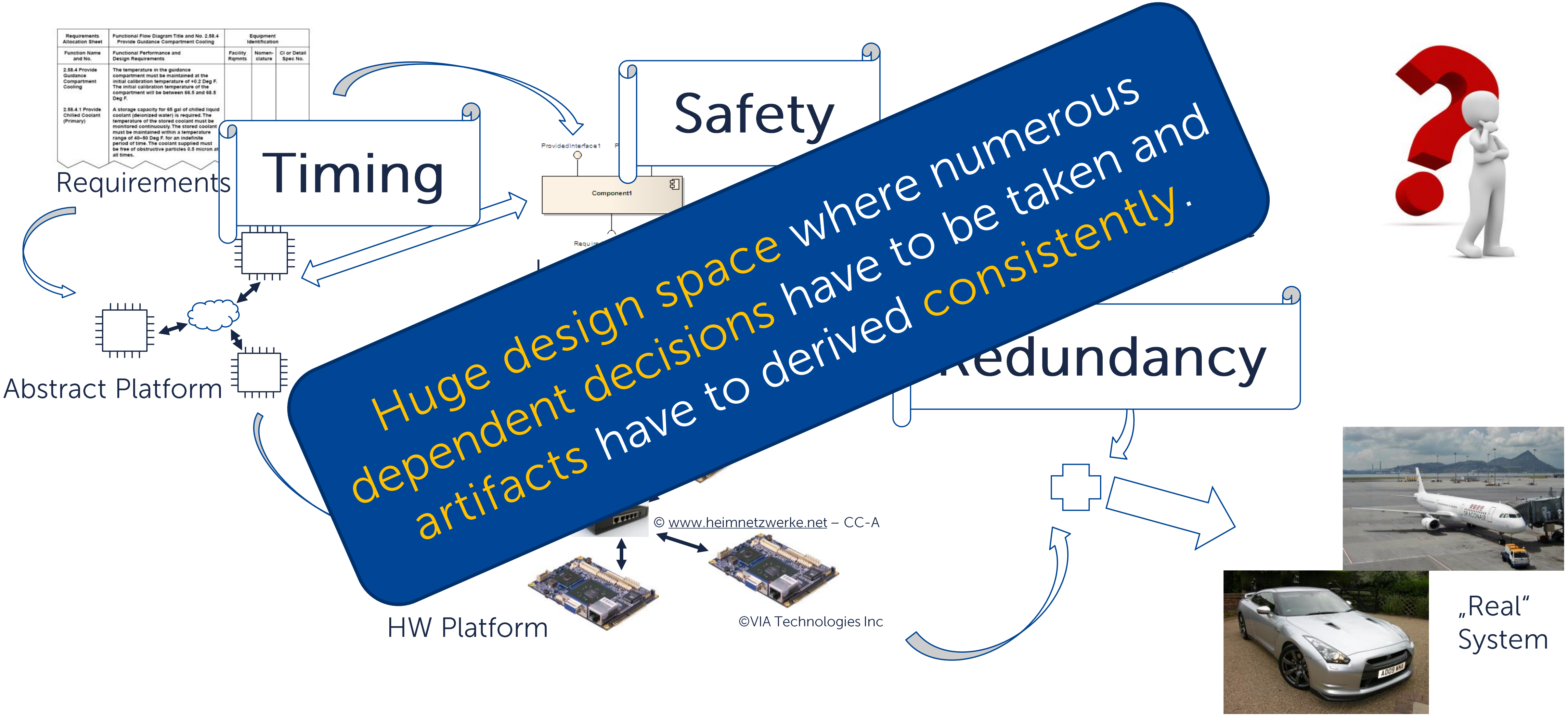


Huge design space where numerous dependent decisions have to be taken and artifacts have to derived consistently.

Can Design-Space Exploration relieve System Engineers?

Needs and suggested approach

- Compensate complexity of system functionality and platforms
  - Speed-up by means of **design automation**
  - **Frontloading of architectural and design decisions**
  - **What-if analyses**
  - **Decompose decisions** in different layers of the system (SW, HW)

- **User guidance**
  - Handle dependencies in development processes
  - Meaningful presentation of design-alternatives
  - Take the user into the exploration loop

- Suggested approach
  - Combination of DSE and Model-based Systems Engineering (MbSE)
  - **Model-based Design-Space-Exploration (MB-DSE)**

Model-based Design-Space-Exploration

Overview

Why are integrated models needed ?

Code-centric vs. Model-Based Development

Textual Requirements (.docx, .xlsx, …)

Traceability-matrix

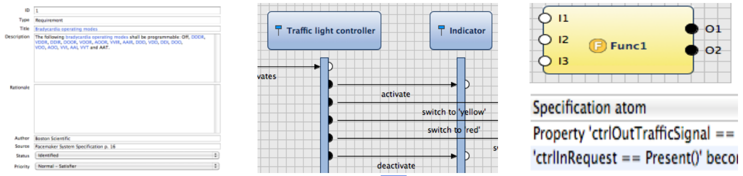
			X
	X		

Code (e.g., C, C++)

Config.

Platform

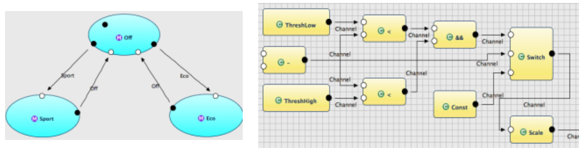
Requirement Models



Glossary,
Use-Cases,
MSCs,
Interfaces
Data-Types
Contracts, …

Consistency Checks

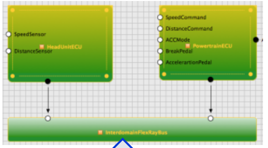
Application Models



Components,
State-machine,
Code,
Tables, …

Deployment

Platform Models



ECUs,
BUS,
I/O,
Cores,
Memory

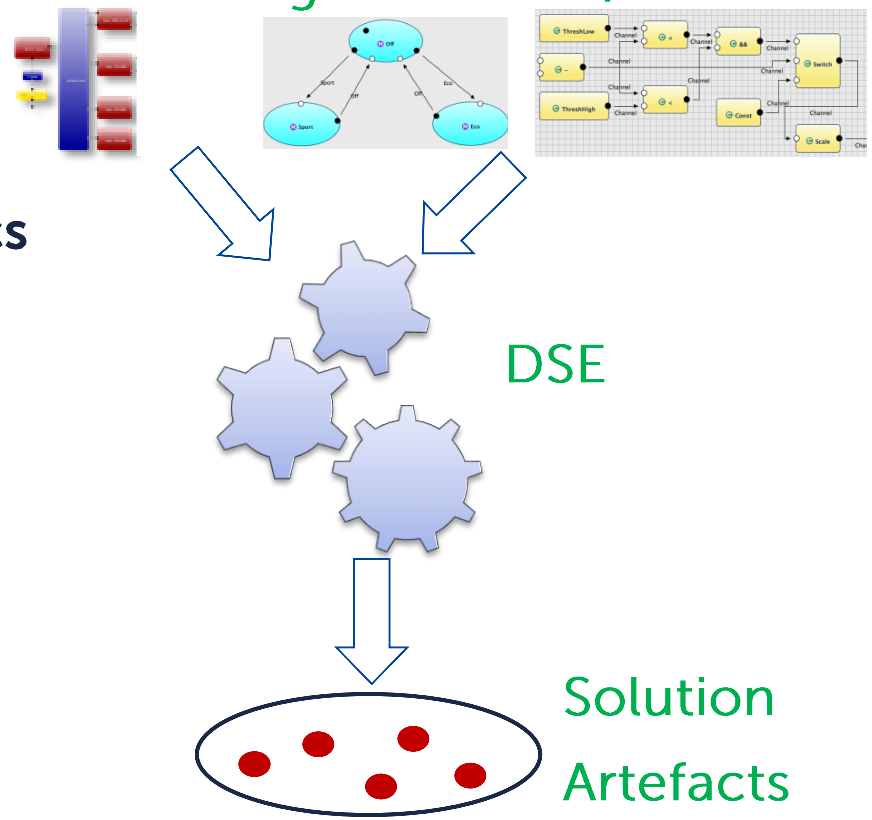
Platform

Model-based Design Space Exploration

- DSE aims at compensating design complexity
  - Automated **exploration of alternatives**
  - Use of **optimization and/or formal methods**

- **MbSE boosts DSE with models that have a strong semantics**
  - **Validation of user input**
  - Evaluation of design alternatives / solution candidates
    - Verification of **constraints**
    - Optimization of **design goals**
  - **Tracking of dependencies** between artefacts
  - **Automatic synthesis** of implementation artifacts for selected alternative(s)

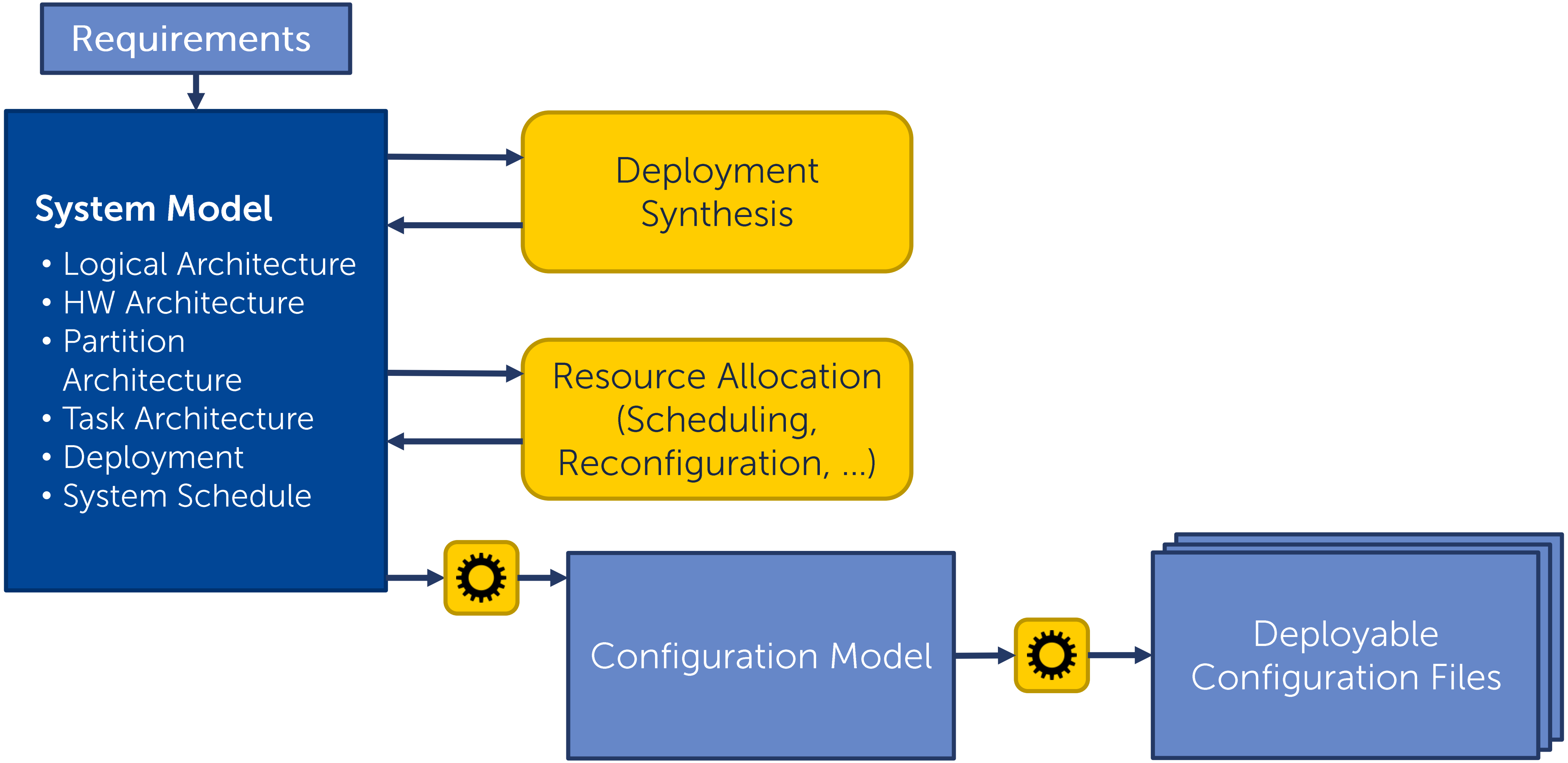
Platform & logical model / artefacts



DSE

Solution Artefacts

MB-DSE Engineering Process

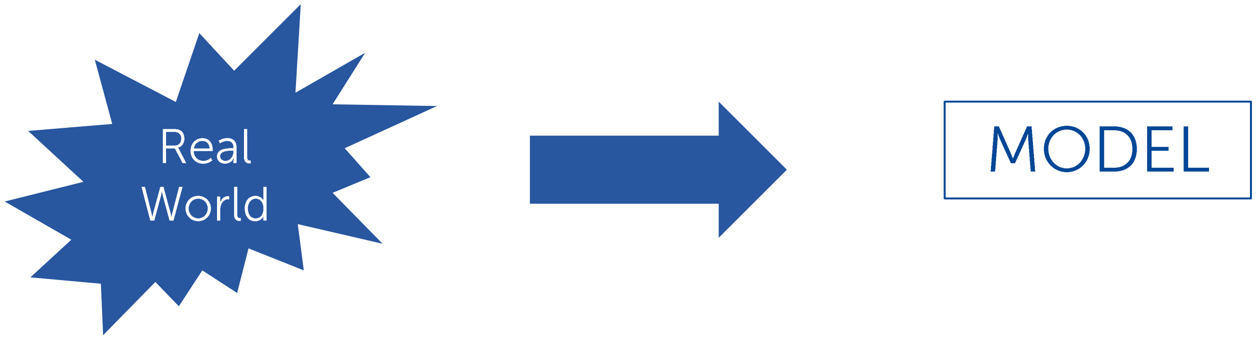


System Model

Modeling Viewpoints and Assumptions

Models and Artifacts

Terminology



„A model is an ***appropriate abstraction*** *for a* ***particular purpose***“

[Broy 2011]

An **artifact** is one of many kinds of tangible (by-)products produced during the development of software.

e.g., use cases, class diagrams, models, requirements and design documents or artifacts concerned with the process of development itself—such as project plans, business cases, and risk assessments.

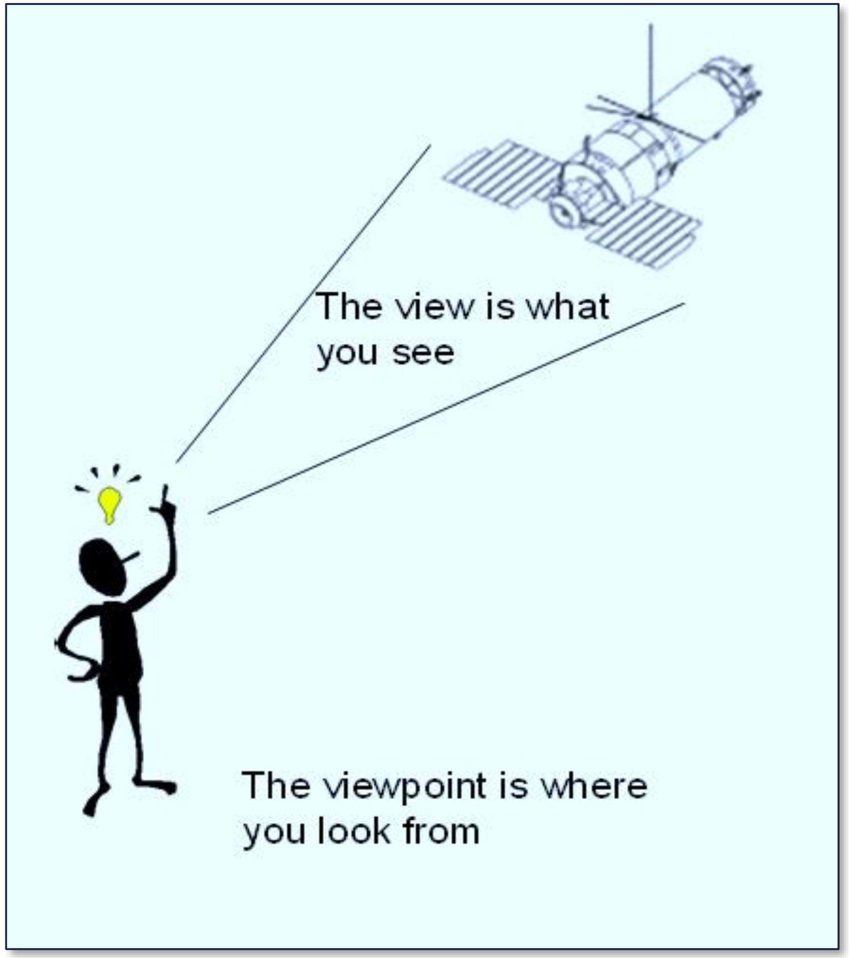
System Viewpoints and Views

- A viewpoint reflect the **specific interests of dedicated stakeholders** and **conventions,** that enable the **generation** and **analysis** of a view

- These conventions could be languages, notations, model-types, design restrictions or modelling methods, analysis techniques as well as further operations, that can be applied to that view

- A view is an instance of a certain viewpoint in context to a **specific system**. A view is generated by a set of models that are representing the relevant characteristics.

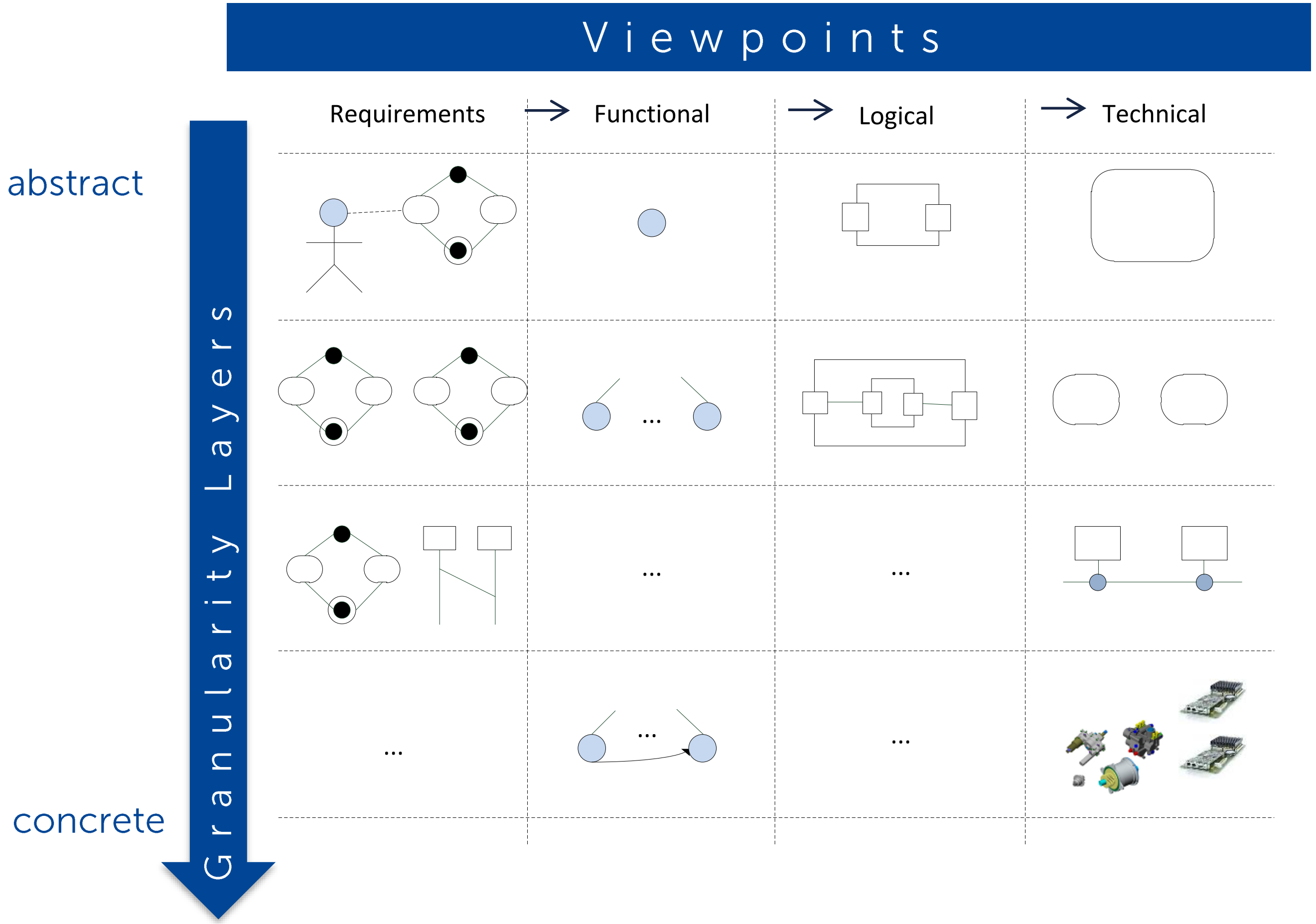
In relation to: IEEE 42010



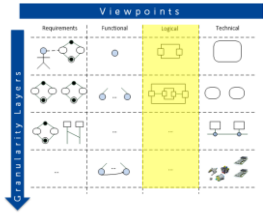
Systems Engineering Viewpoints

SPES Matrix

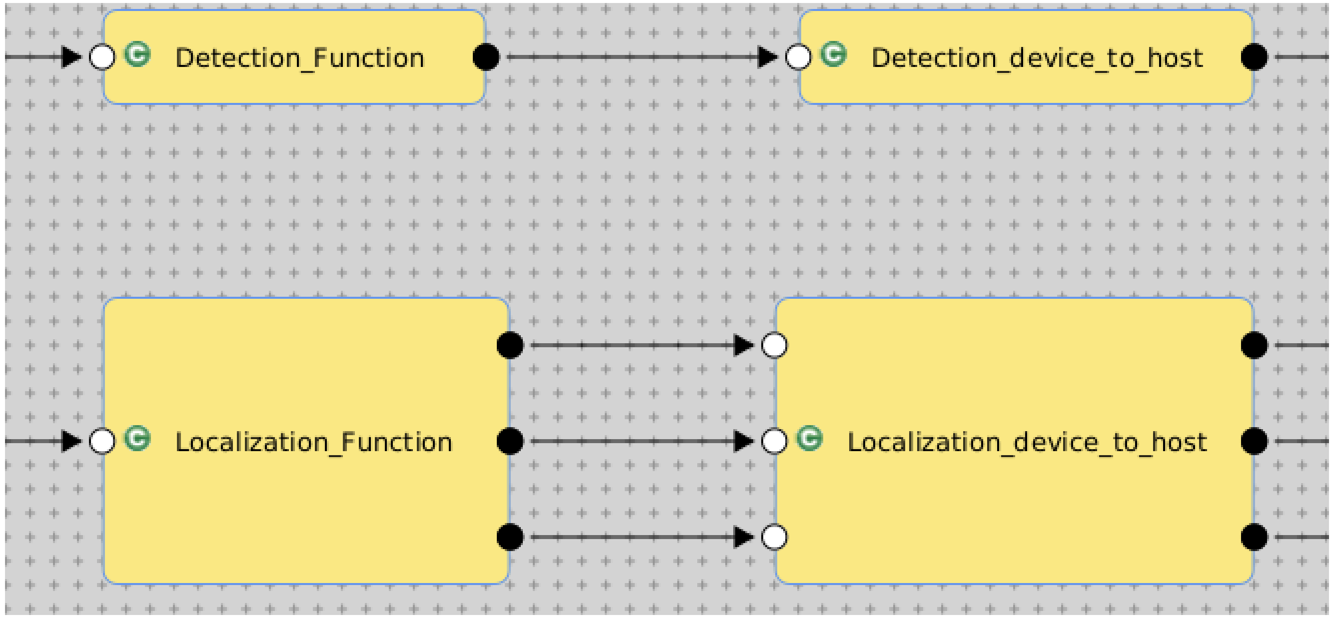
- Differentiation between **viewpoints** (according to ISO/IEC 42010)
- Differentiation by **granularity levels** of a system and its decomposition
- **Artefact model** with a well-defined semantic of artifact types and their relation to other artifacts
- Overall system properties



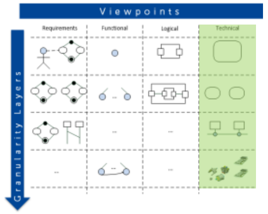
Component Architecture



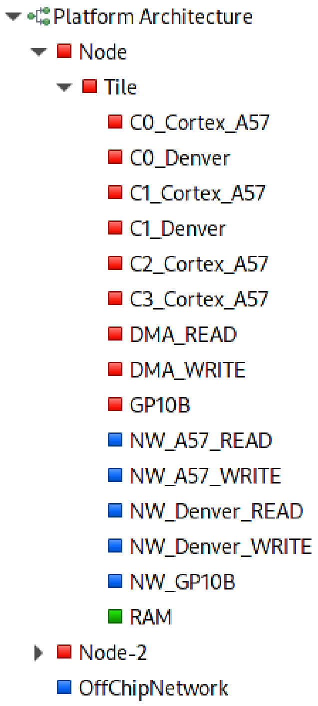
- Hierarchical component network
- Components model behavior (e.g. states)
- Data transfer by typed ports via channels
- Components can be distributed on the target platform
- Agnostic of memory model
  - Shared memory
  - Message passing

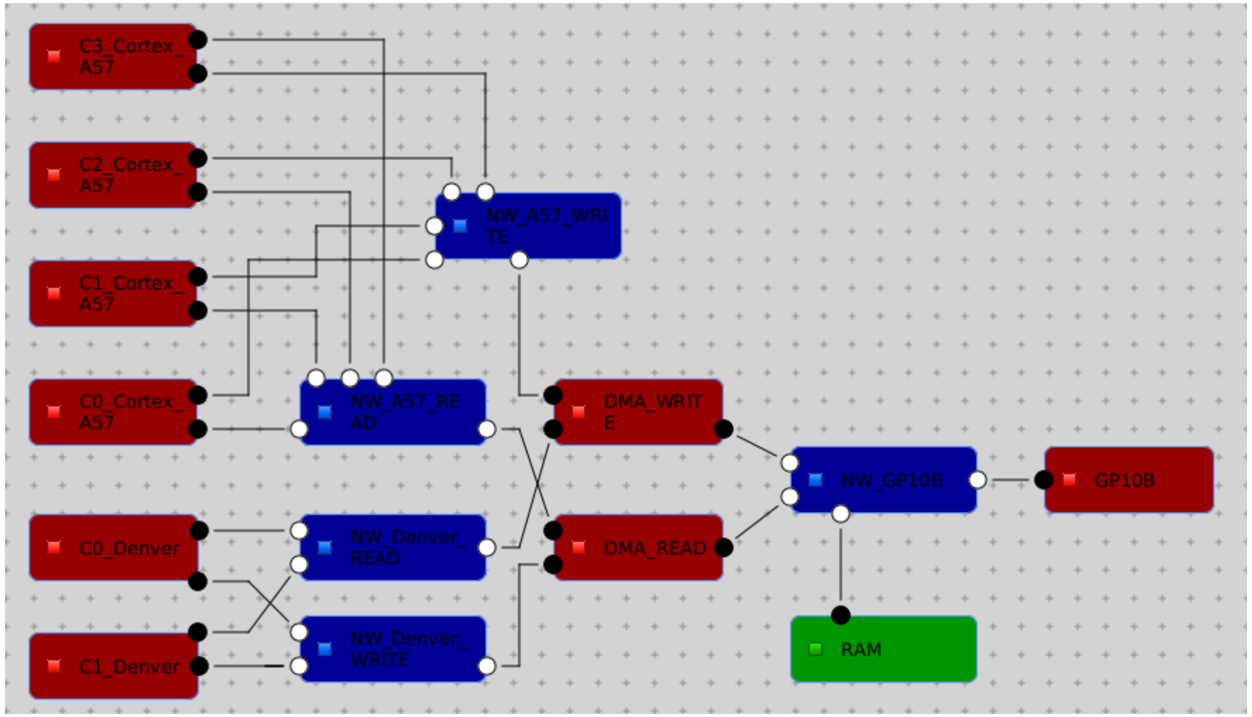


Platform Architecture

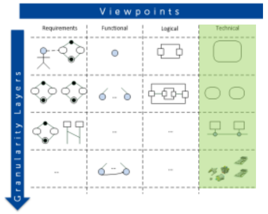


- Hierarchical Platform
- Technical architecture for HW
  - Distributed systems
  - MPSoCs
- Prerequisite to consider non-functional properties
  - Safety
  - Performance

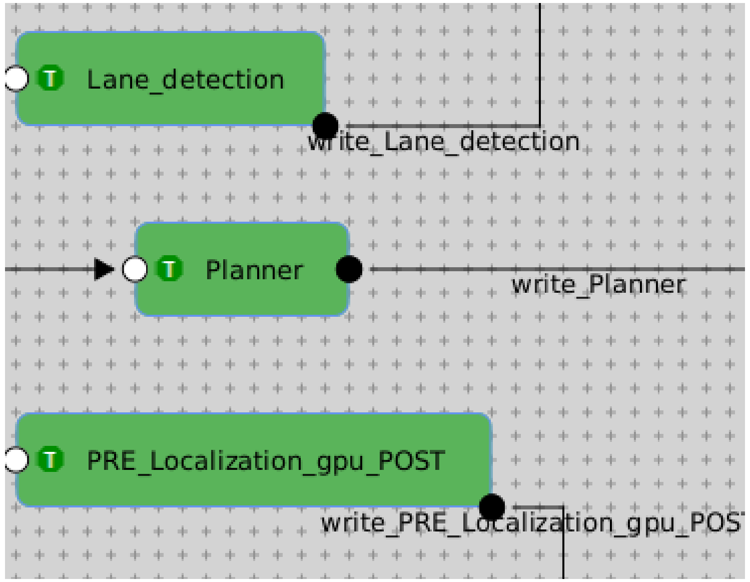


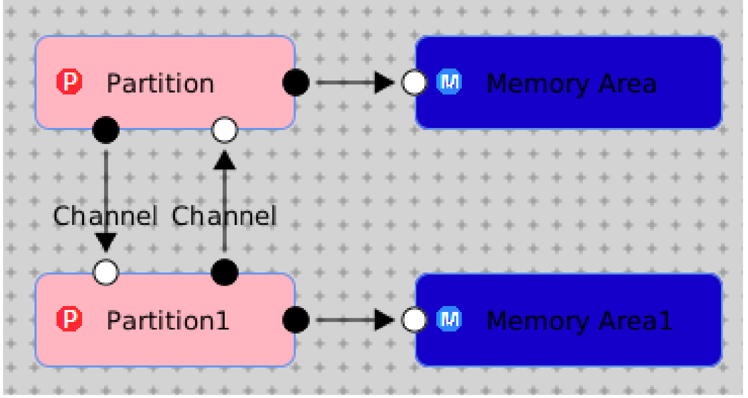


Task & Partition Architectures



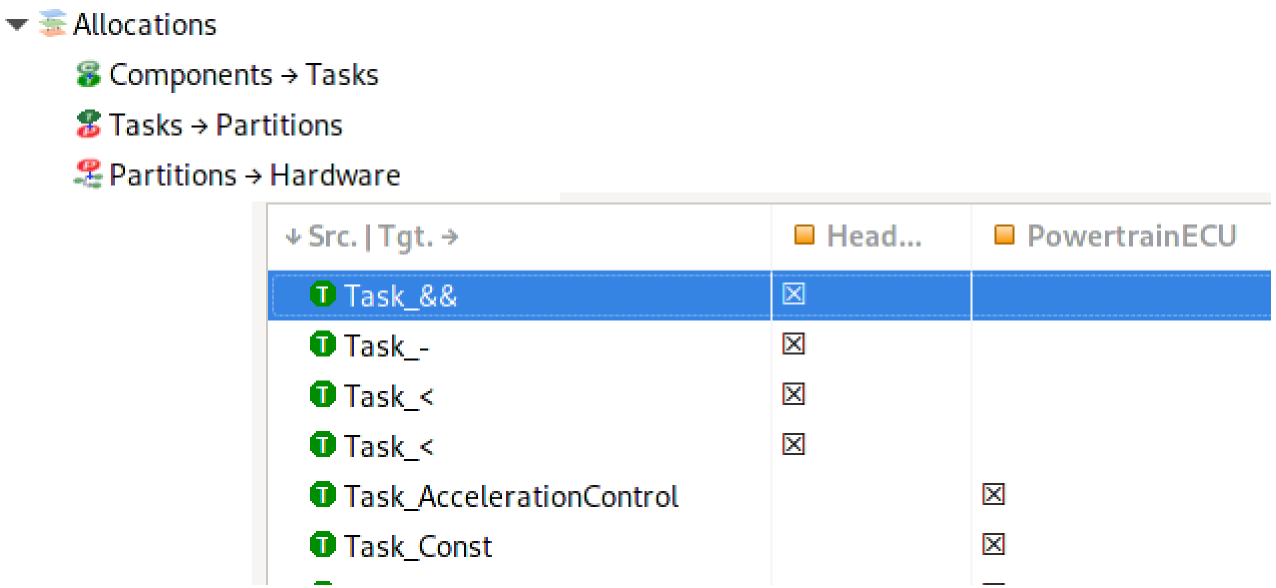
- Flat technical architecture models for system SW
- Task architecture
  - Runtime “containers“ for (groups of) components
  - Defines port semantics (sampling, buffering)
- Partition architecture
  - Execution containers for tasks
  - Isolation by safety levels





Allocations & Model Element Annotations

- Allocation Tables model element to element mappings, such as
  - component → task
  - task → execution unit
  - task → memory
  - task → partition → phys. execution unit. (while multi-layer mapping)



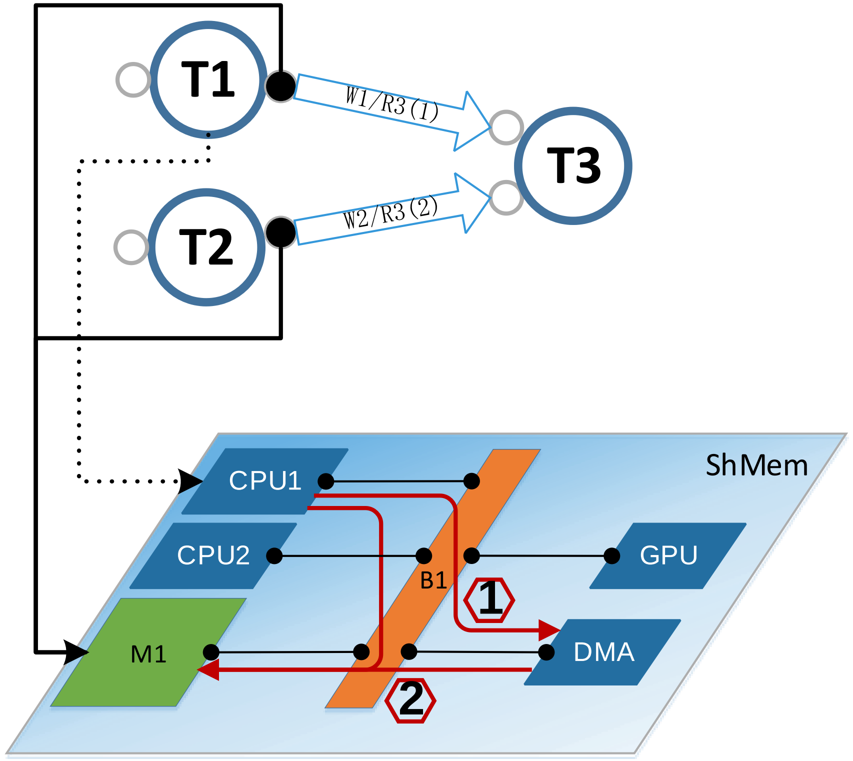
- Annotations
  - properties attached to model elements,
  - orthogonal and extensible.

Model Element	Architecture Domain	Bandwidth [Mbit/s]	Failure rate [λ]	Flash	Hardware Cost
GP10B	Processor		0.0	300	30
BusMasterPort	Processor		0.0		
NW_A57_READ	Processor	25600.0	0.0		

AER Execution Model

- Abstraction that enables accurate prediction of temporal behaviour of tasks
  - at design time
  - for shared memory-based systems

- Separates tasks into *acquire, execute,* and *restitution* phases
  - Worst-Case Execution Times (WCETs) of tasks show reduced variance
  - Large variance is caused by interferences at data fetching phases *
  - Enables orchestration of data fetching to avoid interferences at design time



* C. Maia, L. Nogueira, L. M. Pinho and D. G. Pérez, "A closer look into the AER Model," 2016 IEEE 21st International Conference on Emerging Technologies and Factory Automation (ETFA), Berlin, 2016, pp. 1-8, doi: 10.1109/ETFA.2016.7733567.

D^{3}SE – Dependency-Driven Design Space Exploration

Framework for Activity and Artefact-based Optimization of Distributed Embedded Systems

Reminder: Model-based Design Space Exploration

- DSE aims at compensating design complexity
  - Automated **exploration of alternatives**
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- **MbSE boosts DSE with models that have a strong semantics**
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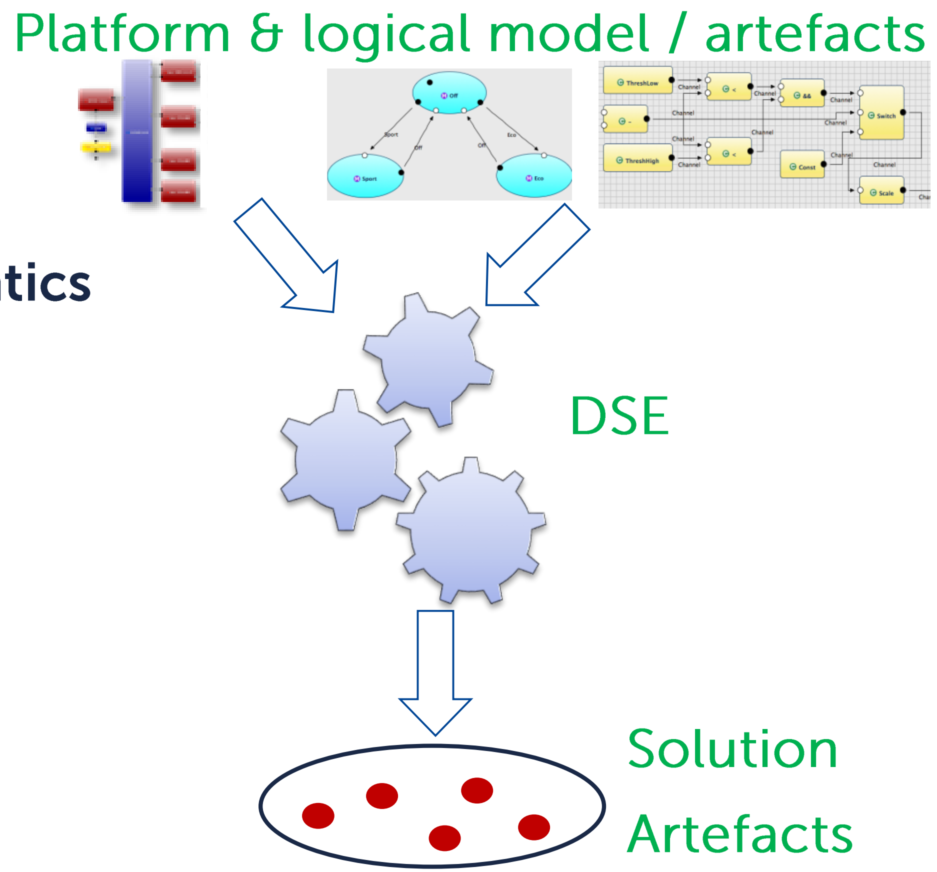
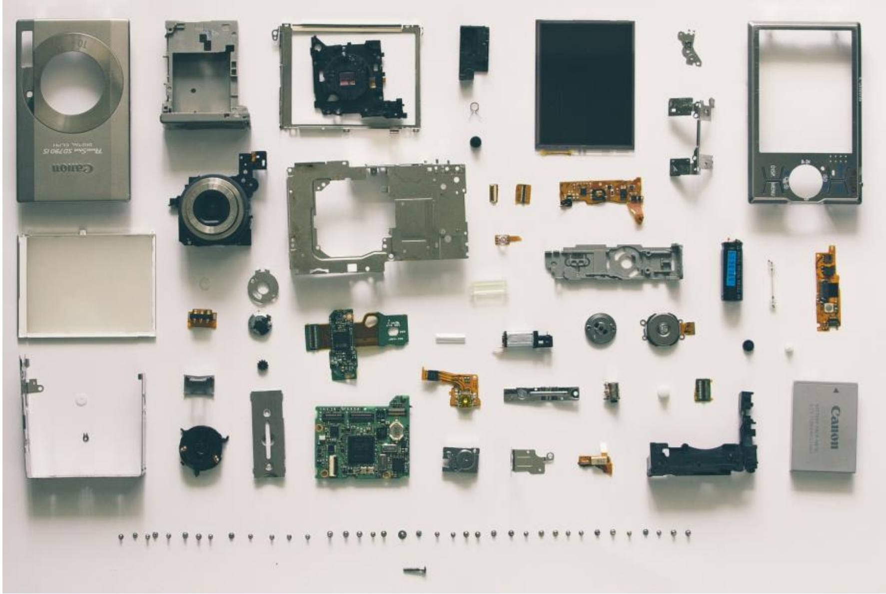


Decomposition: DSE and Development Processes

1. **Approach**: Decompose development of embedded system into (a set of) **activities and artefacts**
2. **Artefacts/activities structure the development process**:
   - **Horizontally**, by adding (or synthesizing) additional artefacts from existing ones
   - **Vertically**, by adding details to artefacts
3. An **exploration feature** represents a **development activity**
4. An exploration feature consists of **exploration modules** that **operate on artefacts**



Design Goals for the D^{3}SE Framework

Goals: DSE Expert Productivity, Ease-of-Use, and Performance

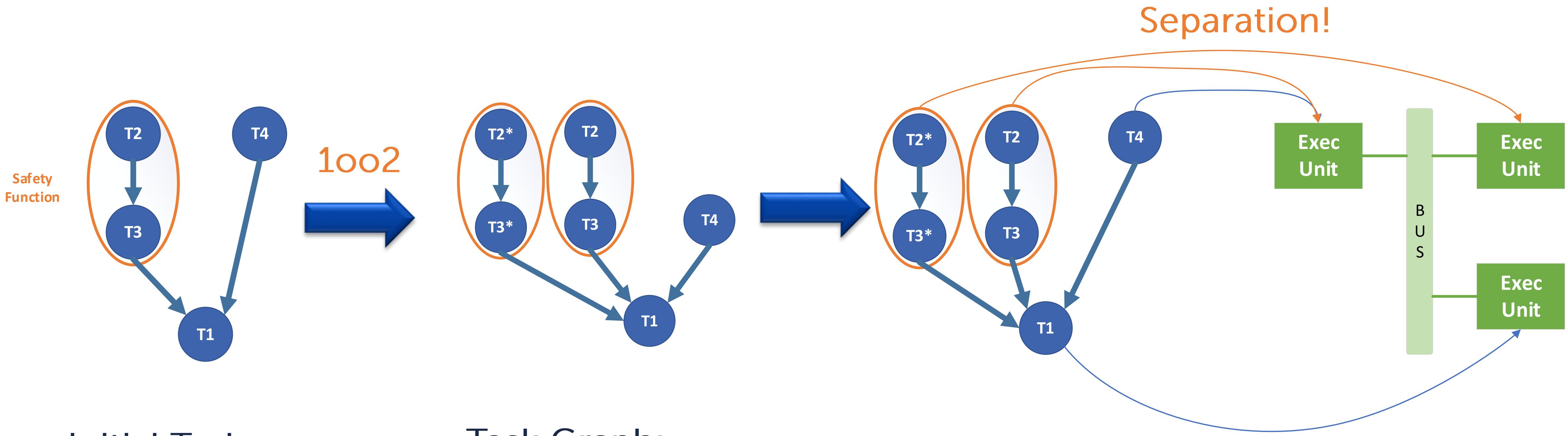
- **Supporting system engineers by ease-of-use:**
  - Users can tailor DSE executions to their system by enabling/disabling features
  - Artefact-based approach allows a deep integration in tools

- **Increasing productivity of DSE experts:**
  - Interface-driven „orthogonality“ of features eases problem thinking
  - **White box** approach simplifies debugging

- **Performance of iterative approach:**
  - Optimizing the elements of a loop pays off
  - Avoid infeasible candidates

Dependencies Dominate the DSE

Example: 1oo2 Safety Function → Task Graph → Task Allocation



Initial Task Graph

Task Graph: Unrolled Safety Function

Mapping the *final* Task Graph

Dependency-Driven Optimization Decomposition

- State of the art methods require compositionality:
  - Convex solution space
  - No couplings of subproblems

t_x: Timestep x

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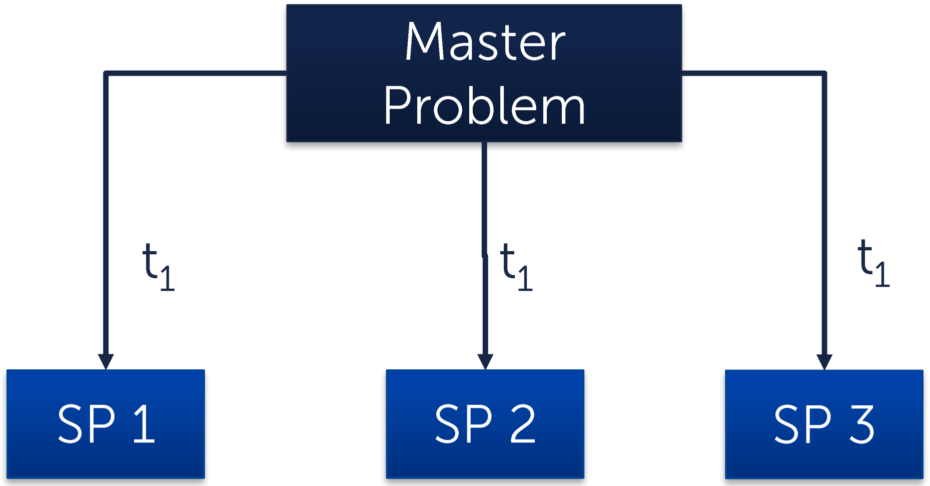

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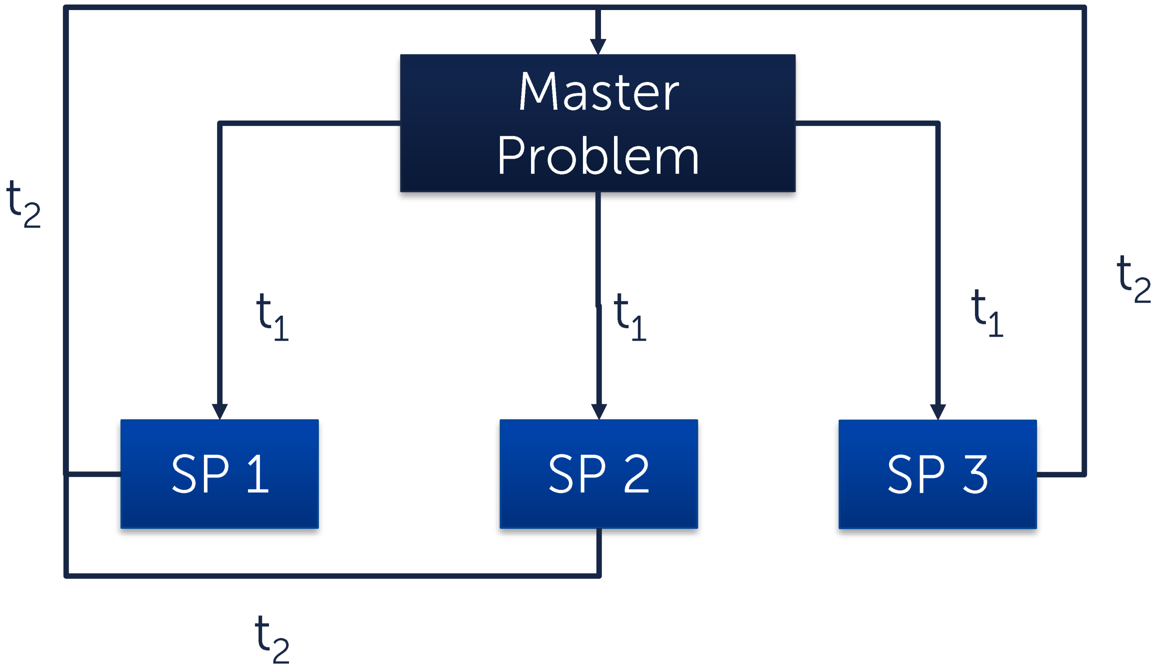

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- State of the art methods require compositionality:
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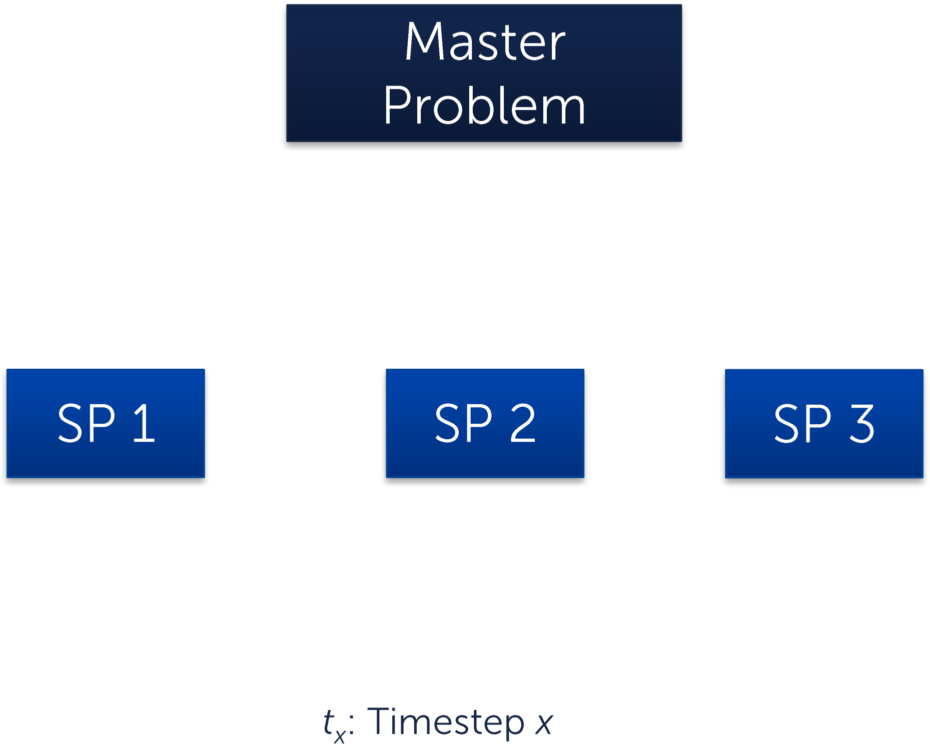
- **Decomposition by dependencies**
  - **Master problem** manages
    - dependencies between subproblems and
    - synchronization between iteration loops.
  - **Subproblems**
    - Are solved in order (in parallel where possible)
    - Includes problem-specifics, e.g.
      - SP1: Allocate partitions → execution units
      - SP2: Allocate tasks → partitions
      - SP3: Schedule tasks s.t. SP2



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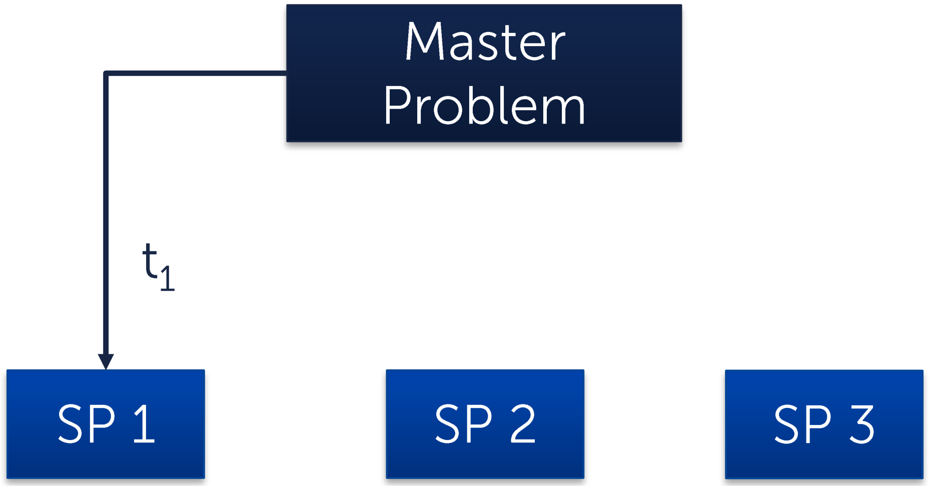

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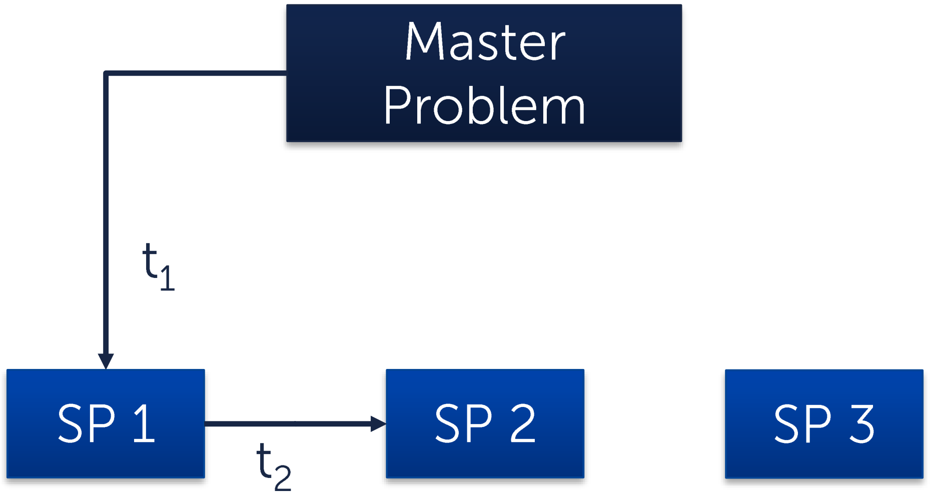

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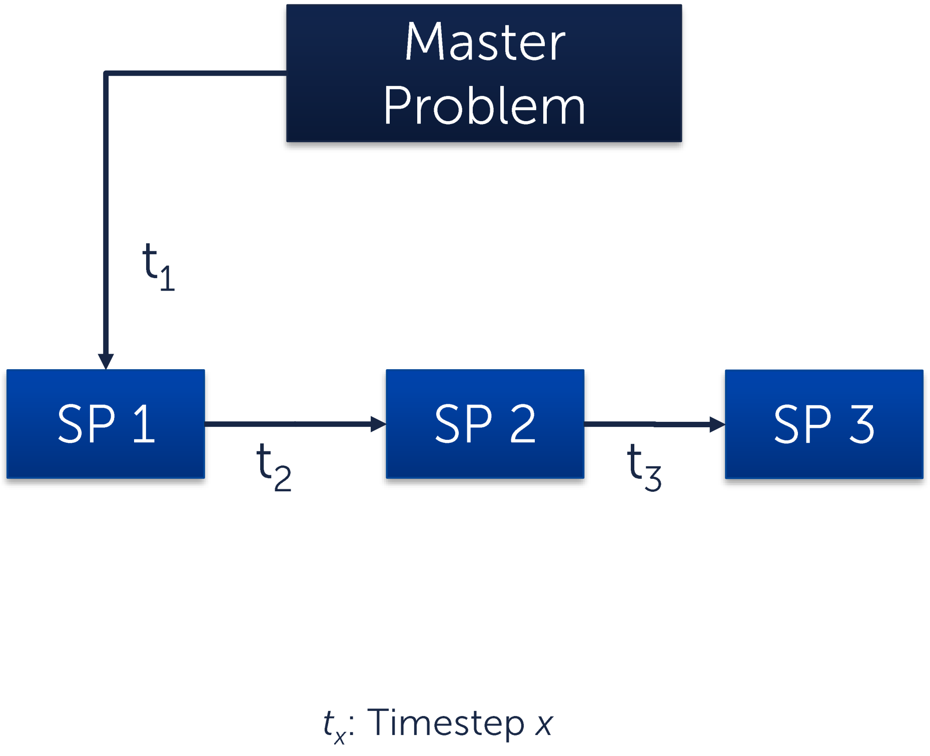

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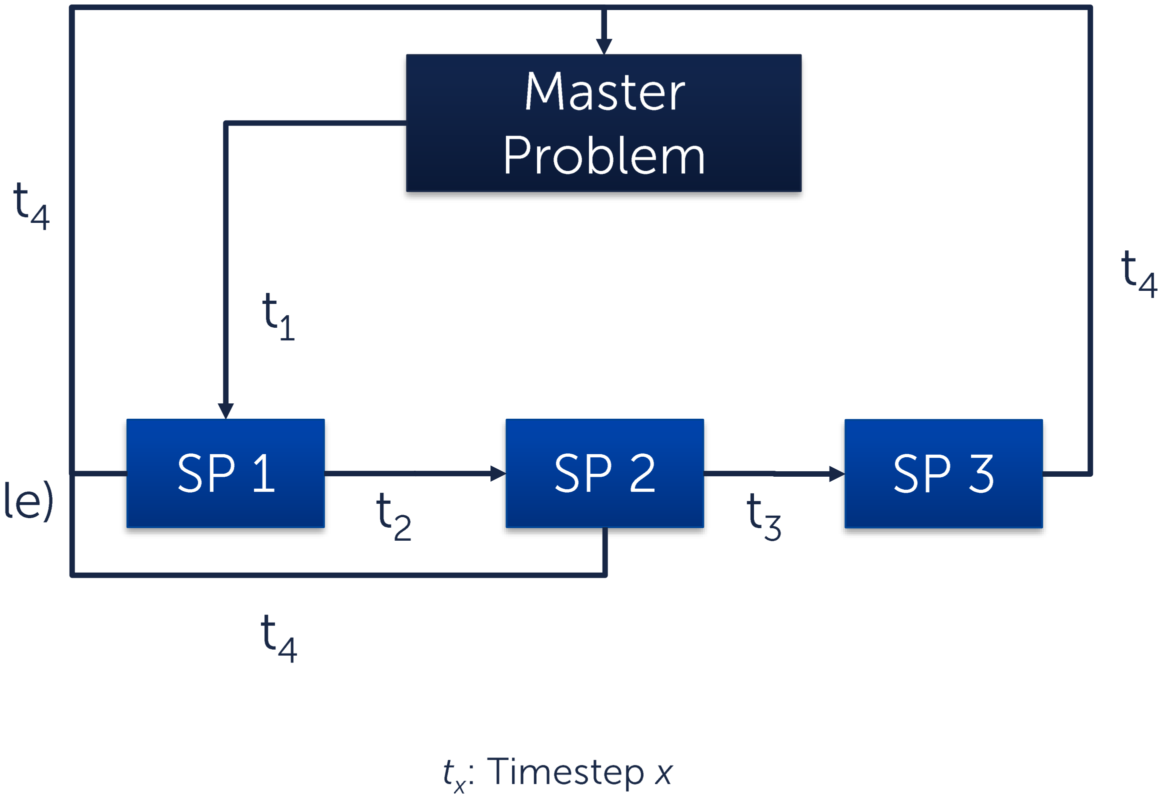
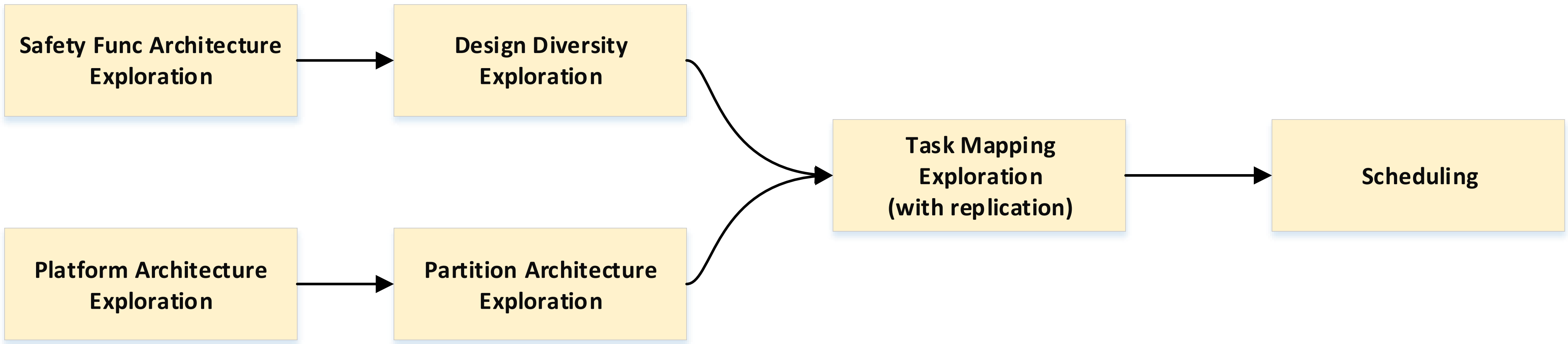


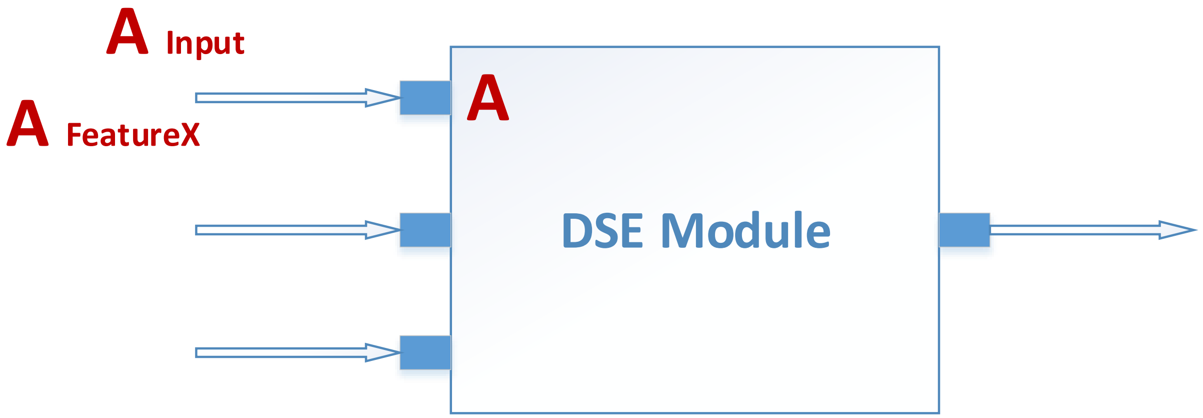
Dependencies - Exploration Feature Graph



- Represents **dependencies between development activities**
- **Allows switching DSE features on or off** according to the system-under-design
- Avoids hard dependencies between artefacts ➔ **Reusability, flexibility**
- High-level dependency considerations, low-level problem thinking

Dependencies - Exploration Modules

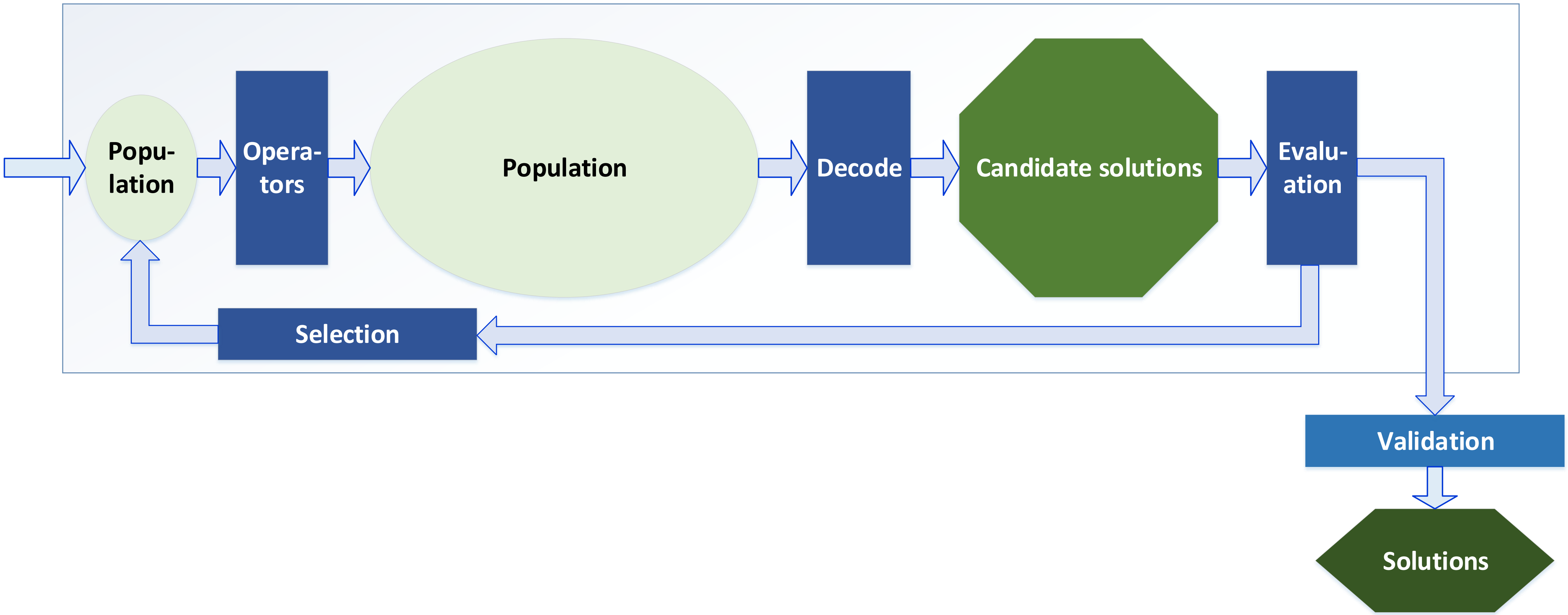
- **Exploration features** consist of **exploration modules**
- **Exploration modules** modify / transform artefacts (N:1), e.g.
  - Task graphs (e.g., include task replica)
  - Platform graphs (Exec. Unit Variance)
  - …
- **DSE Framework implementation**
  - **Dependency Injection** (Guice)
  - I/O artefacts are **annotated** with their corresponding **exploration features**
- **DSE Execution**
  - Execution order determined by artefact dependencies
  - Identical artefact types ordered by *exploration features*



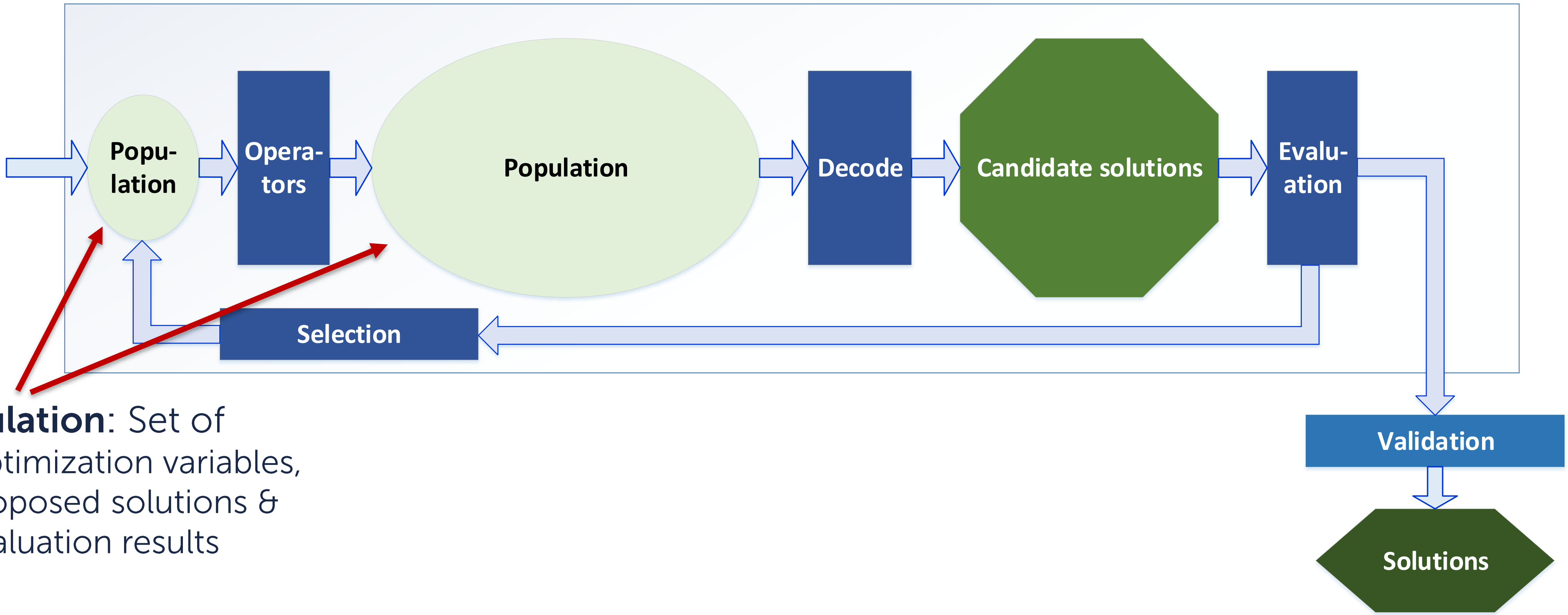

```java
/**
 * Takes a {@link PlatformCommunicationGraphEncoding} genotype and provides it as its
 * {@link Phenotype} representation.
 *
 * @author diewald
 */
public class PlatformCommunicationGraphExecUnitInstanceDecoder
		extends DecoderModule<PlatformCommunicationGraphEncoding> {

	/** See {@link PlatformCommunicationGraphExecUnitInstanceDecoder}. */
	@Decodes
	@Provides
	public PlatformCommunicationGraphEncoding decode(
			@InputArtifact PlatformCommunicationGraphEncoding pcgEnc,
			@Genotyped PlatformExecUnitInstanceEncoding peuiEnc,
			PlatformExecUnitTemplateEncoding execUnitTemplateEnc) {
		PlatformCommunicationGraphEncoding decodedPCGEnc =
				new PlatformCommunicationGraphEncoding(pcgEnc);
		DefaultDirectedGraph<IResourceAdapter<?>, DefaultEdge> pGraph =
				decodedPCGEnc.getActualGraph();

		for(IExecutionUnitAdapter<?> execUnitContainer : peuiEnc.getAbstractContainerExecUnits()) {
```

A method signature is sufficient to declare dependencies

DSE Framework for Architectural Exploration

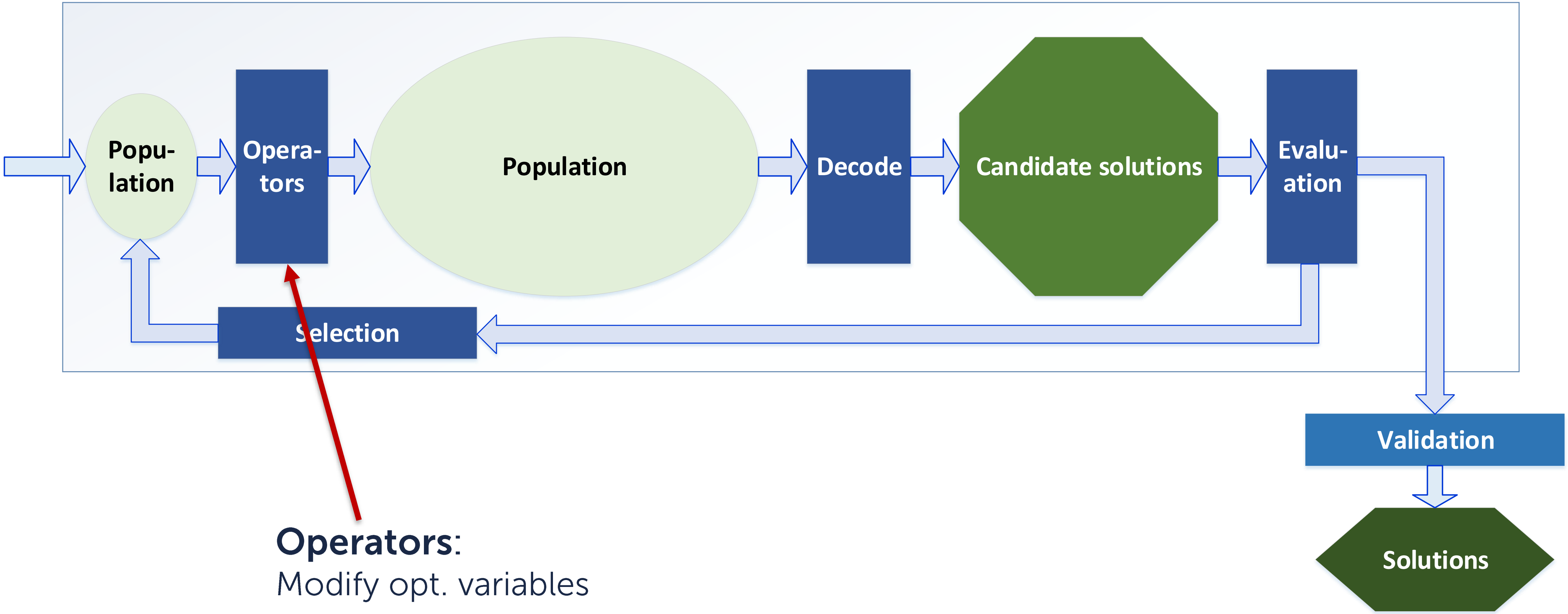


DSE Framework for Architectural Exploration



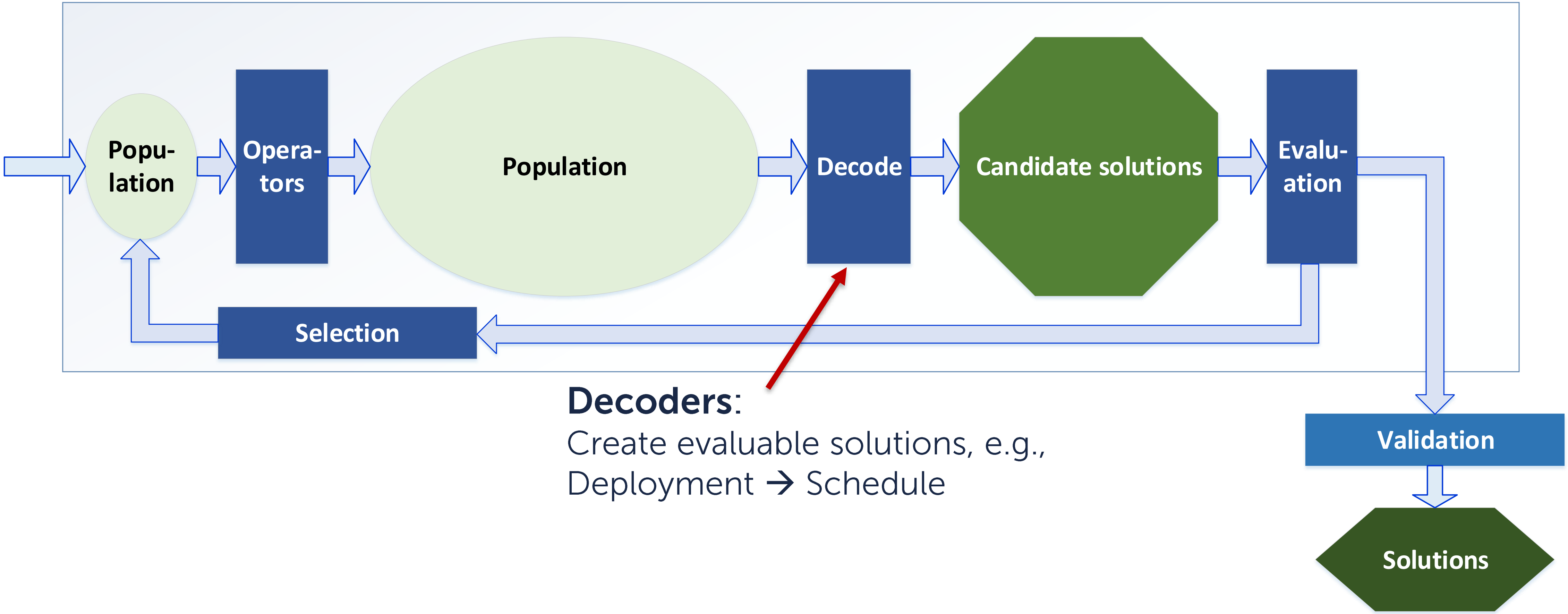
Population: Set of
- Optimization variables,
- Proposed solutions &
- Evaluation results

DSE Framework for Architectural Exploration



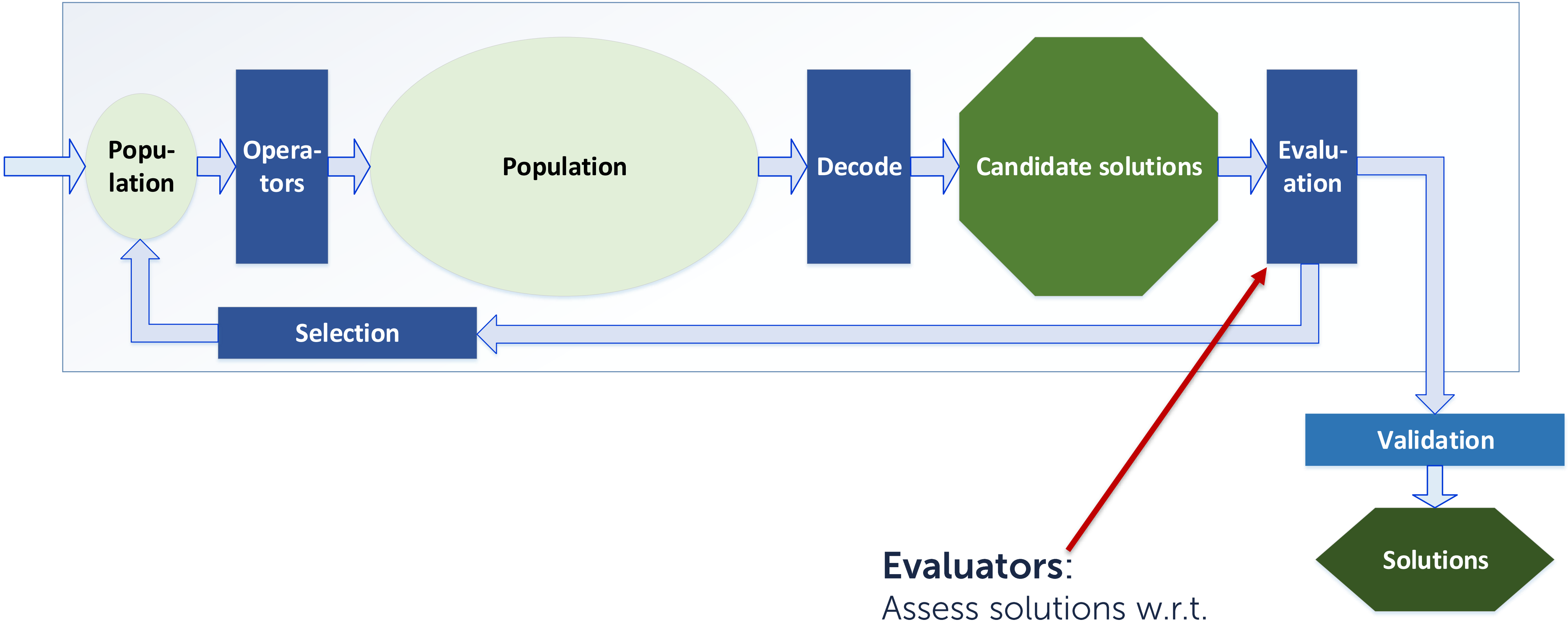
Operators:
Modify opt. variables

DSE Framework for Architectural Exploration



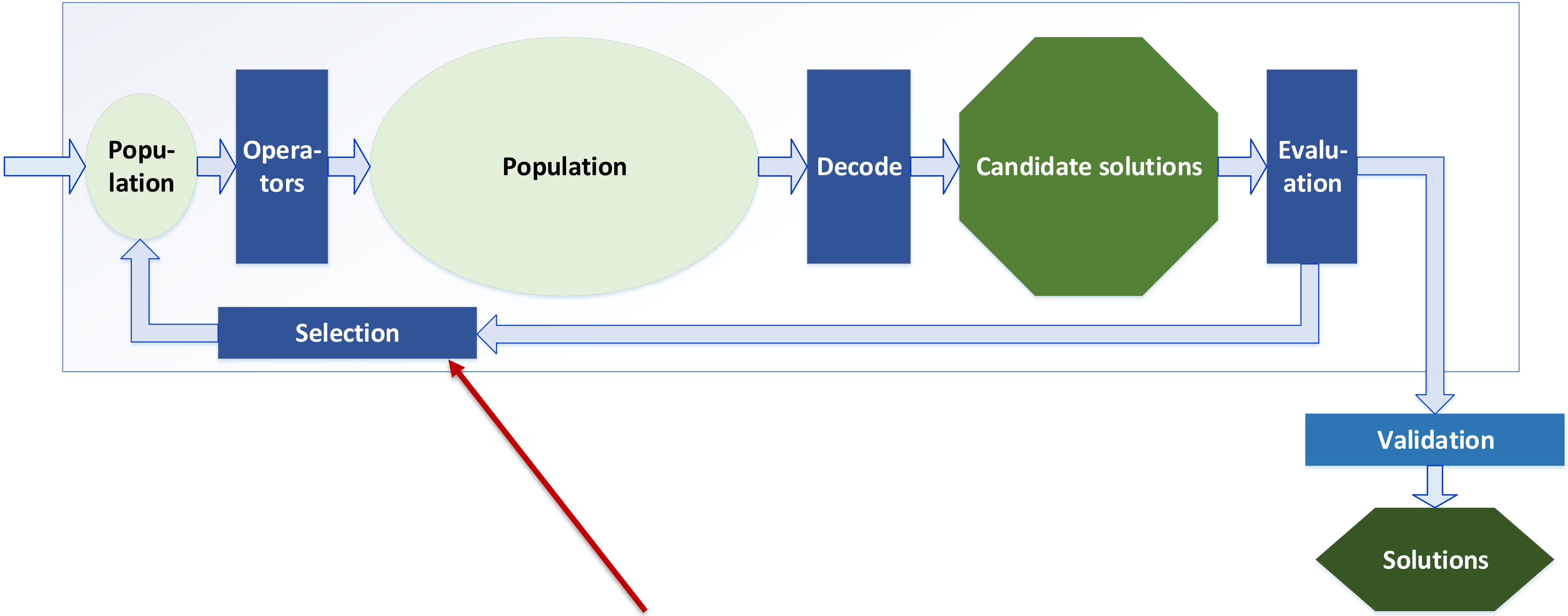
Decoders:
Create evaluable solutions, e.g.,
Deployment → Schedule

DSE Framework for Architectural Exploration



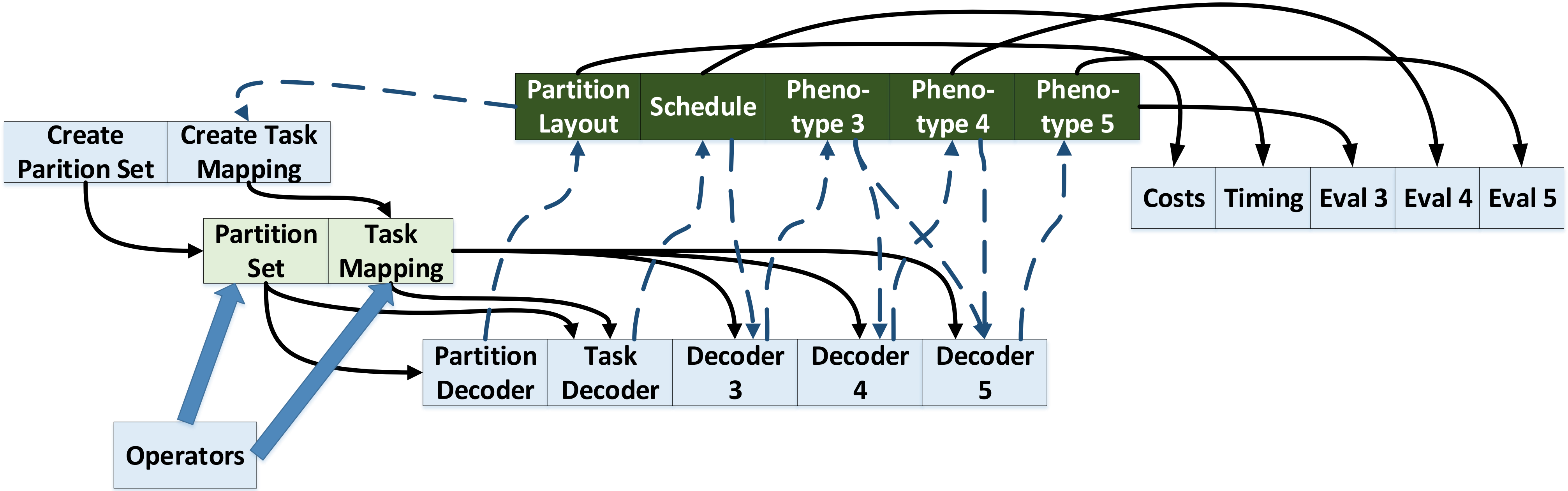
Evaluators:
Assess solutions w.r.t.
objectives & constraints

DSE Framework for Architectural Exploration

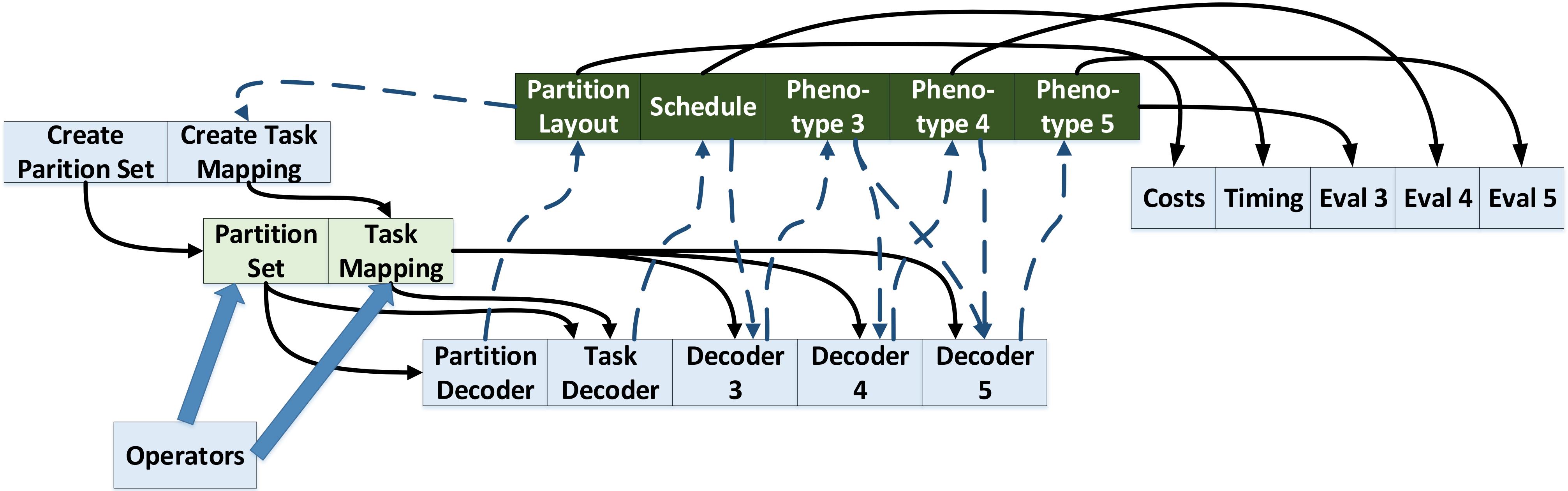


Feedback loop:
Pick promising solutions

DSE Framework for Architectural Exploration



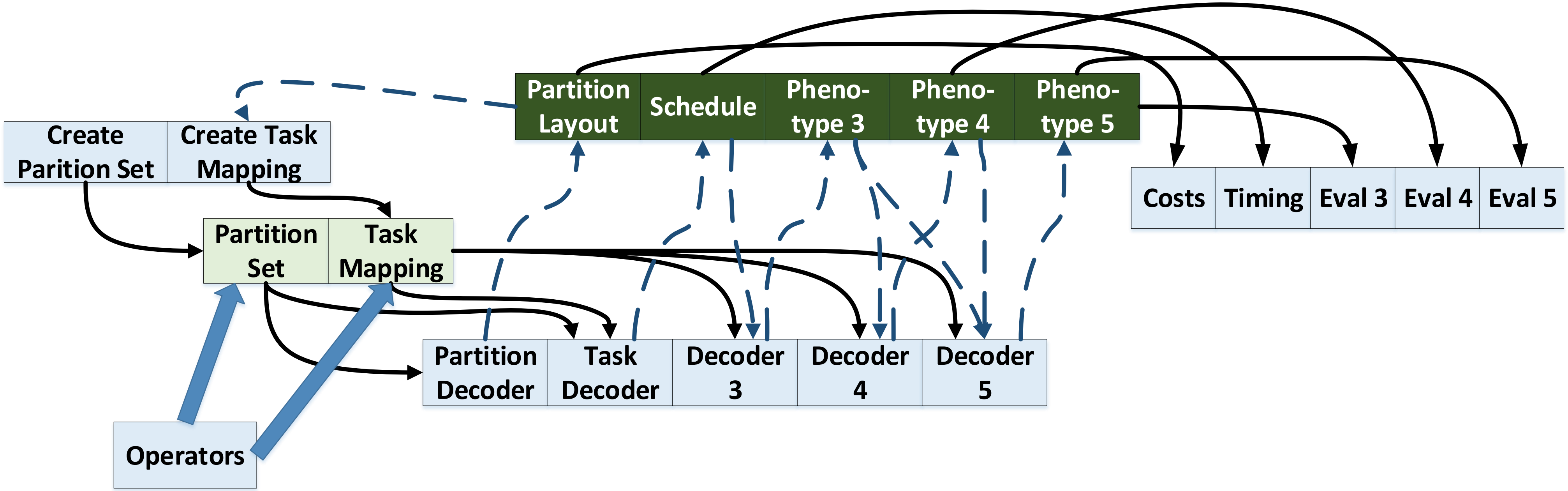
DSE Framework for Architectural Exploration



Exploration Modules

- Combine sub-problems with matching decoders, etc.
- Example:
  Variable: Safety architecture;
  Operators: $\pm$ number of safety function channels

DSE Framework for Architectural Exploration



Exploration Modules

- Combine sub-problems with matching decoders, etc.
- Example:
  Variable: Safety architecture;
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Process-oriented DSE

- Optimize multiple design steps in a loop
- Automatically resolve dependencies, e.g., safety architecture impacts deployment (fault isolation)

Available DSE features (1/2)

- **Safety function architecture exploration**, e.g., 1oo2D
  - Instantiation of isolated safety channels
  - Instantiation of diagnosis units
  - Operates on a task graph
- **Platform exploration**:
  - Explores an optimal number of execution units
  - Adjust the underlying platform graph
- **Partition exploration**:
  - Optimizes the number of partitions
  - Optimizes task-partition & partition-exec. unit allocations
  - Generates communication channels between partitions

Available DSE features (2/2)

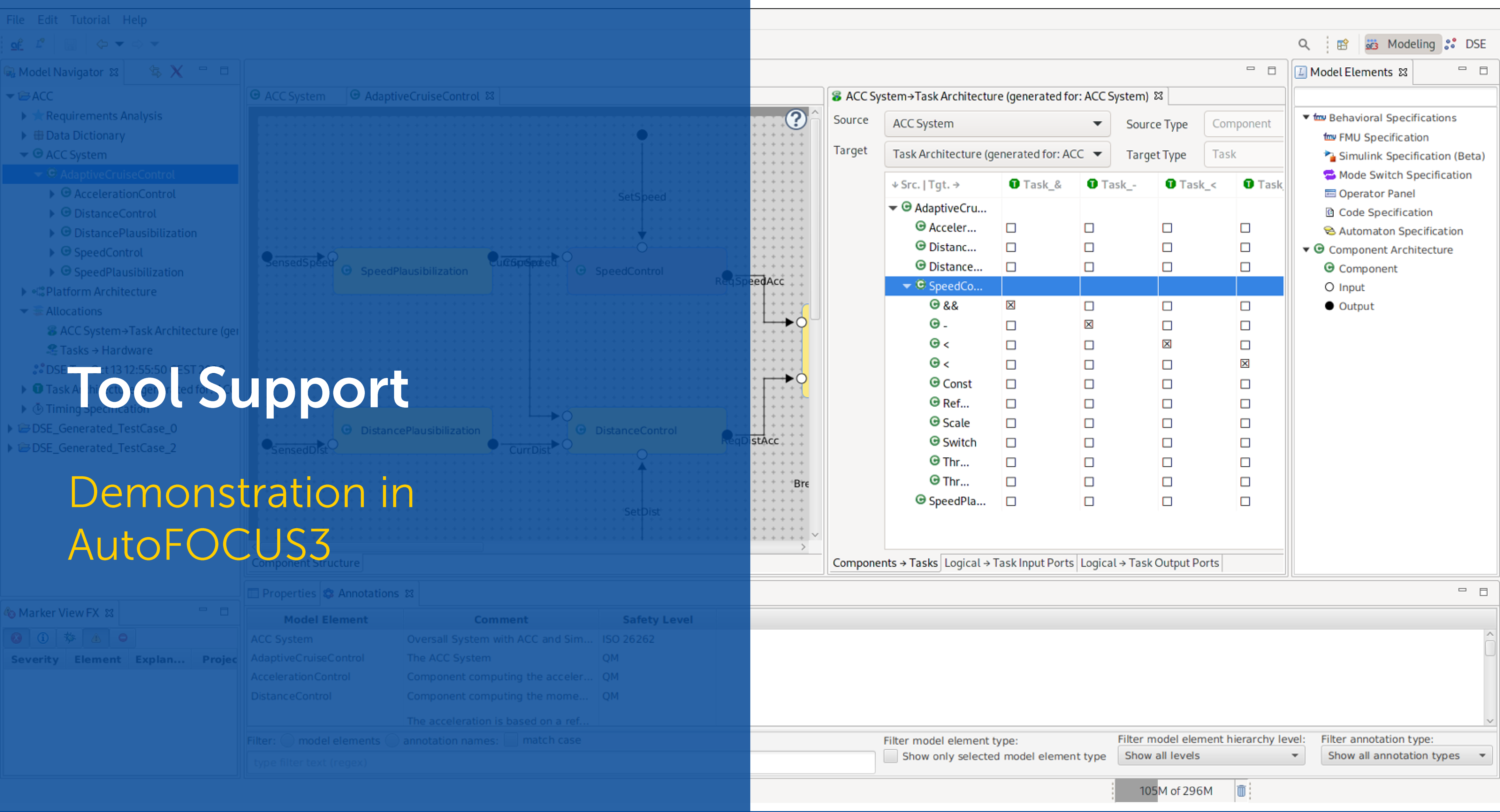
- **Design diversity**:

  Instantiates template tasks (→ task interfaces) with task implementations from a library.

- **Bare-metal task mapping exploration**
  - Optimizes allocations from tasks to execution units
  - Allocation mechanism shared with the partition exploration

- **Heuristic scheduling**

  Generation of simple time-triggered system-wide task and communication schedules



Tool Support

Demonstration in AutoFOCUS3

AutoFOCUS3

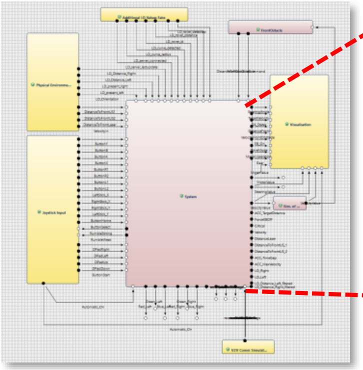
Fully model-based platform to research future CPS engineering principles

FOCUS ON THE SYSTEM

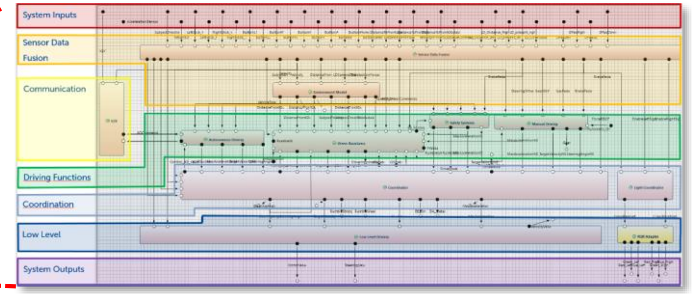
AutoFOCUS 3 Homepage

Open Source Tool and Research Platform based on the Eclipse Platform

- Foundation for **applied research** with automotive and avionics OEMs and suppliers
- High-quality research platform for **efficient prototyping of novel engineering methods** and **collaboration within the team**



Logical architecture w/ simulation context



ADAS/AD system of fortissimo rover

Architecture Analysis & Synthesis

Code Generation

(Co-)Simulation

Safety Cases

Research Areas

- **Architecture Analysis and Synthesis**: “*What are the cheapest and most efficient HW/SW architectures satisfying all constraints?*”
- **Re-Use & Variability**: “*How to incrementally develop product-lines and reusable components in an agile manner?*”
- **(Co-)simulation**: “*Do my components behave as intended? In particular, does my system when I integrate everything?*”
- **Safety cases**: “*How to build structured modular safety argumentation, and how to maintain it on model changes?*”

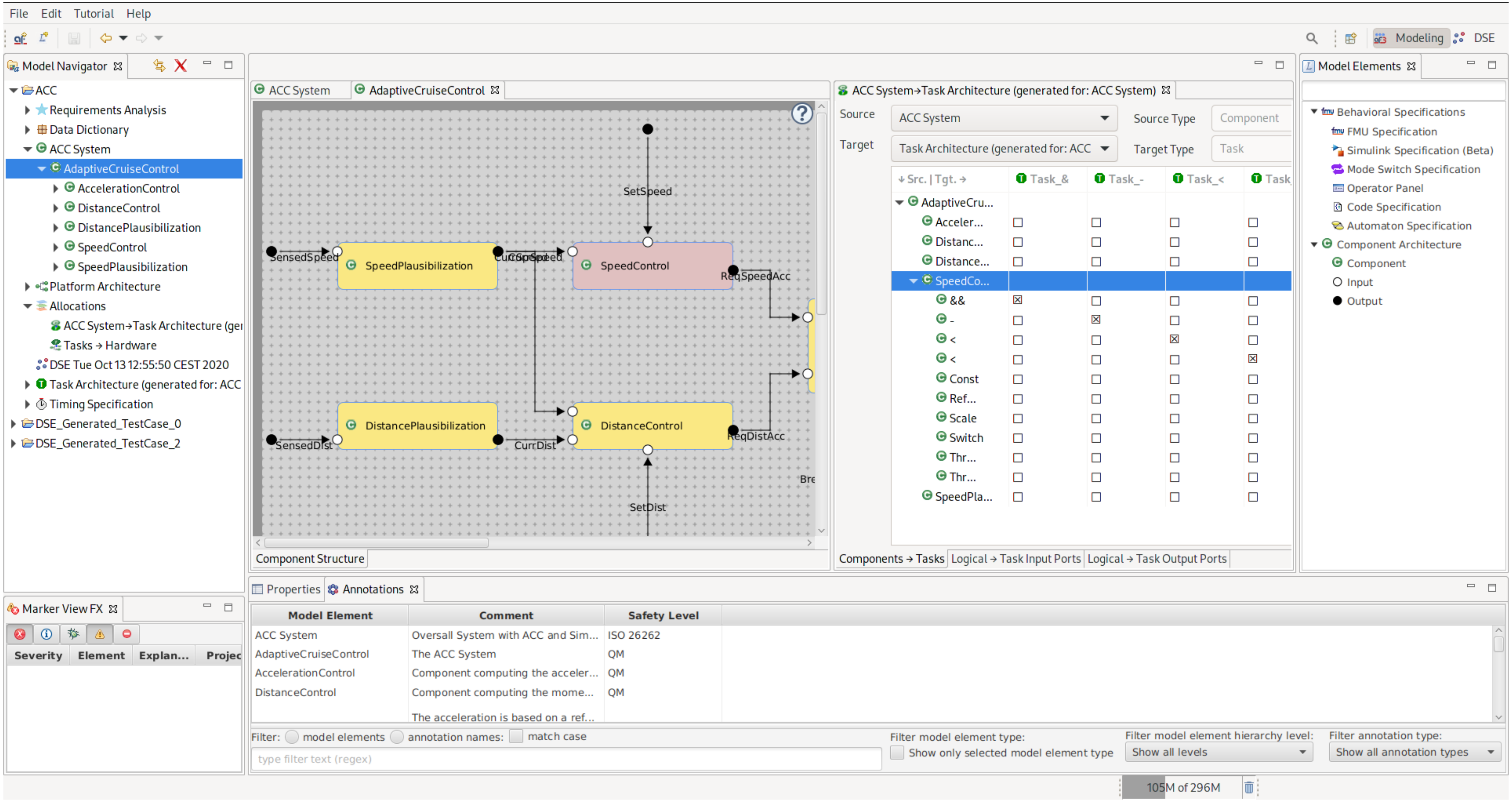
Latest Publications (see here for all 40+)

- J. Eder, S. Voss, A. Bayha, A. Ipatiov, and M. Khalil, “Hardware architecture exploration: automatic exploration of distributed automotive hardware architectures,” *Software and Systems Modeling*, Mar. 2020, doi: 10.1007/s10270-020-00786-6.
- A. Diewald, S. Barner, and S. Saidi, “Combined Data Transfer Response Time and Mapping Exploration in MPSoCs.” in 10th Int. Workshop on Analysis Tools and Methodologies for Embedded and Real-time Systems (WATERS). Jul. 2019.

fortissimo simulator

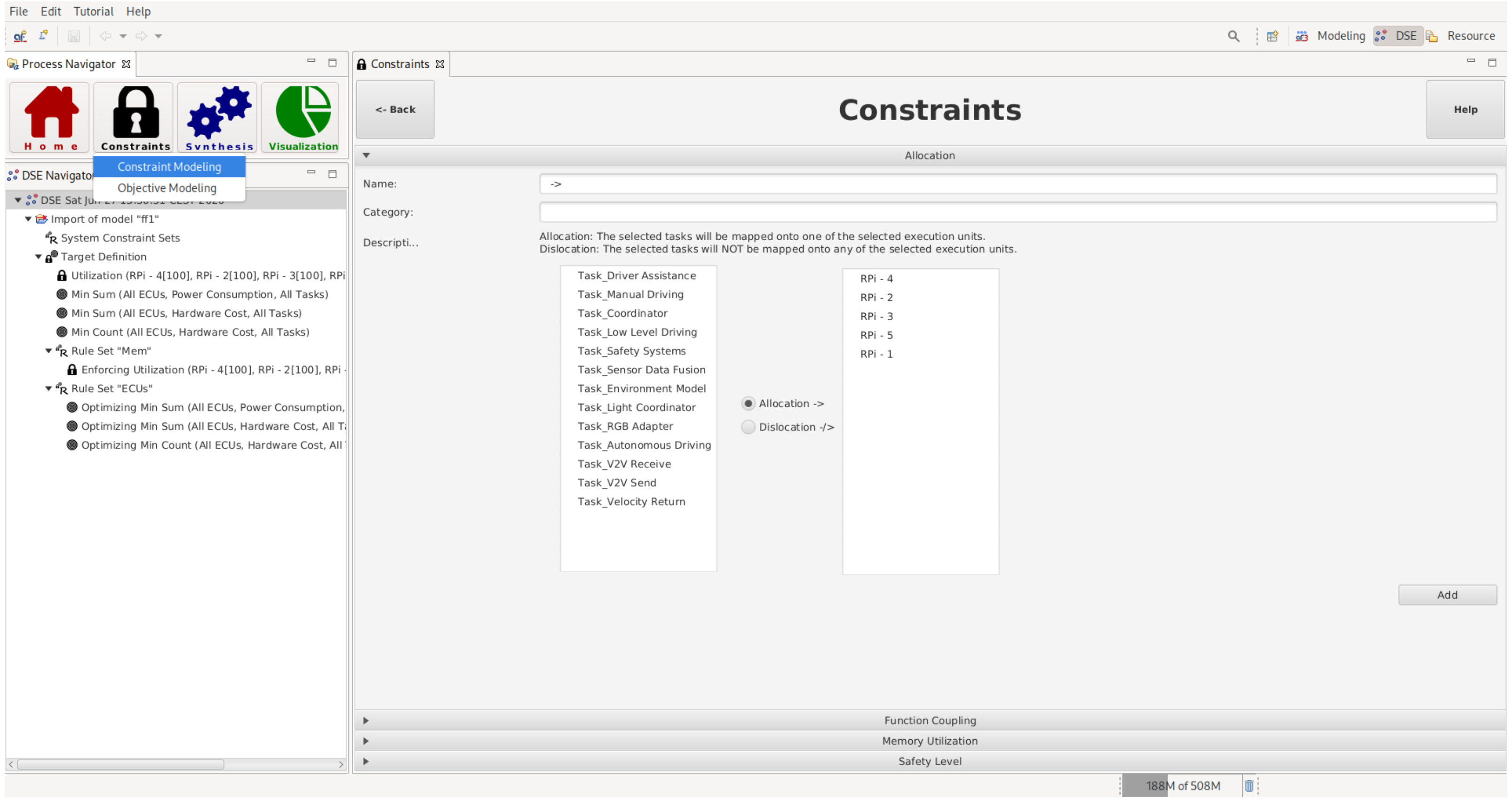
fortissimo rovers

AutoFOCUS 3 - Modelling



AutoFOCUS 3 – DSE Perspective

- Modelling of **Constraints & Objectives**
- **Synthesizing artefacts** by a DSE algorithm
  - Platform
  - Deployments
  - Schedules
- **Result visualization & model export**
  - Spider chart
  - Schedule view



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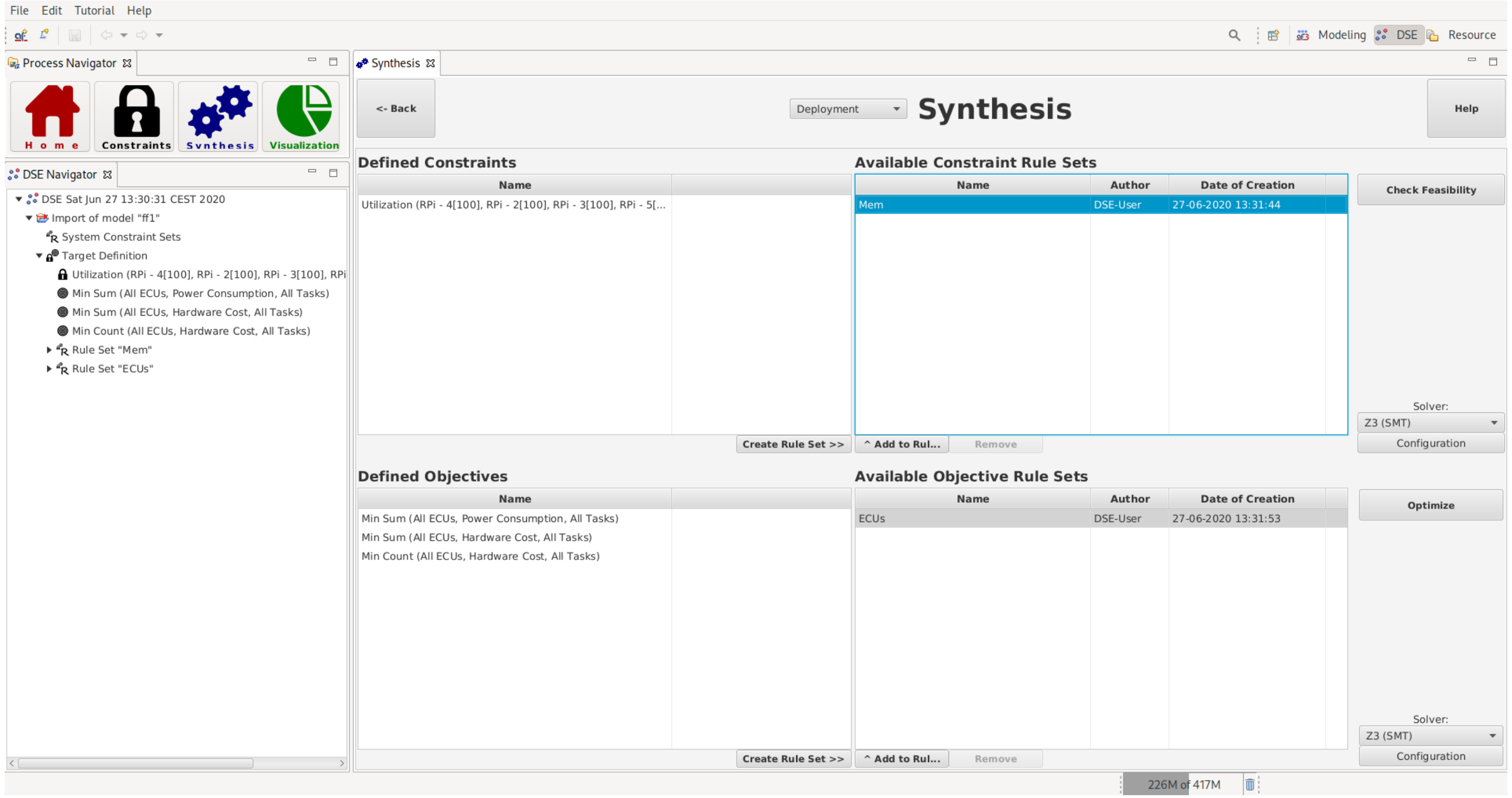

AutoFOCUS 3 – DSE Perspective

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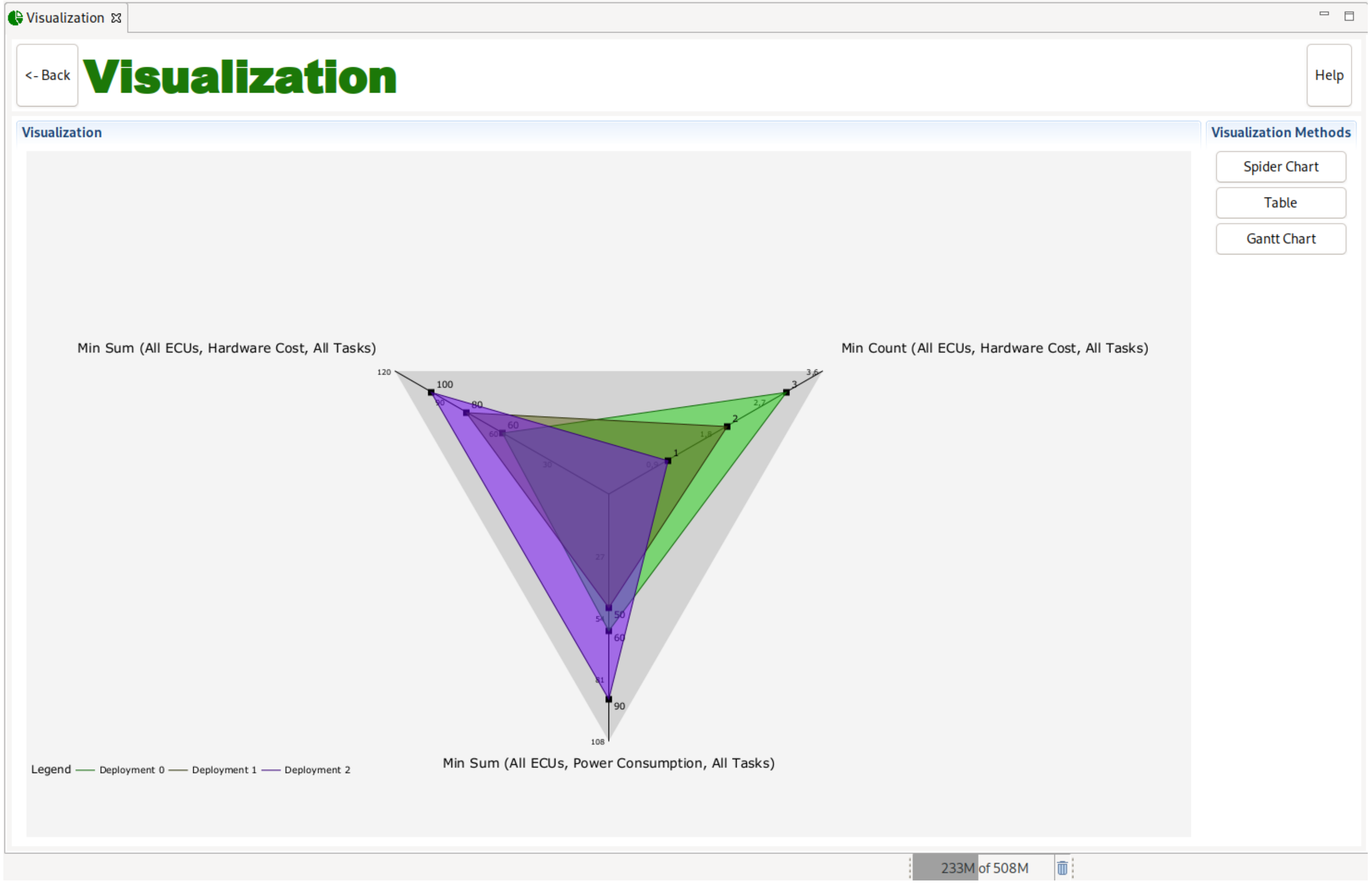

Take Home and Outlook

- **Model-based System Engineering** supports to
  - define and structure the development of complex embedded systems,
  - ease reuse of development artifacts (e.g., to adapt to new platforms), and
  - uncover the underlying design space.

- **A dependency-driven DSE**
  - Enables reuse and extensibility through **modular exploration features**
  - Can be adapted to different systems under design by means of artifact and I/O thinking,
  - Allows to consider design constraints through dependencies, and to offer design alternatives by multi-objective optimization.

- **Implementation in AutoFOCUS3**
  - https://www.fortiss.org/veroeffentlichungen/software/autofocus-3

Thank you for your attention!

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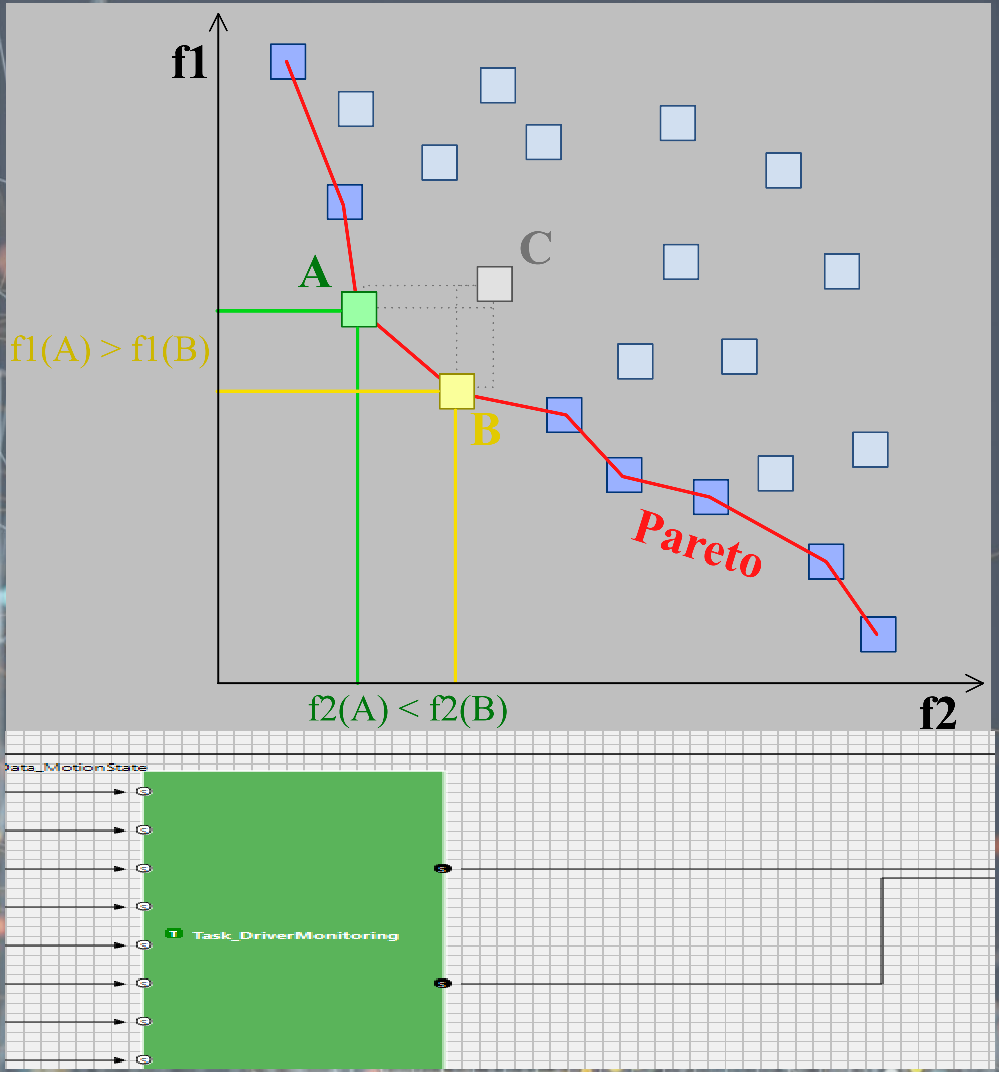

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A. Diewald, S. Barner, and S. Voss, “Architecture Exploration for Safety-Critical Systems,” in *Proceedings of the DATE Workshop on New Platforms for Future Cars: Current and Emerging Trends (NPCAR)*, Mar. 2018.

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A. Diewald, S. Barner, and S. Saidi, “Combined Data Transfer Response Time and Mapping Exploration in MPSoCs.” in 10th Int. Workshop on Analysis Tools and Methodologies for Embedded and Real-time Systems (WATERS). Jul. 2019.

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AGENDA

9:30
Session 1: Fundamental Issues with Concurrency in Embedded Software Systems from Architectural Point of View
10:30

10:45
Session 2: Modelling and DSE Methods for Mixed-Critical Software Systems using Multicore Architectures
11:45

12:00
Session 3: Synchronization in Concurrent Software is an Architectural Decision
13:00