



# Design Space Exploration for Distributed Cyber-Physical Systems

State-of-the-art, Challenges, and Directions

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**ESI ASML**

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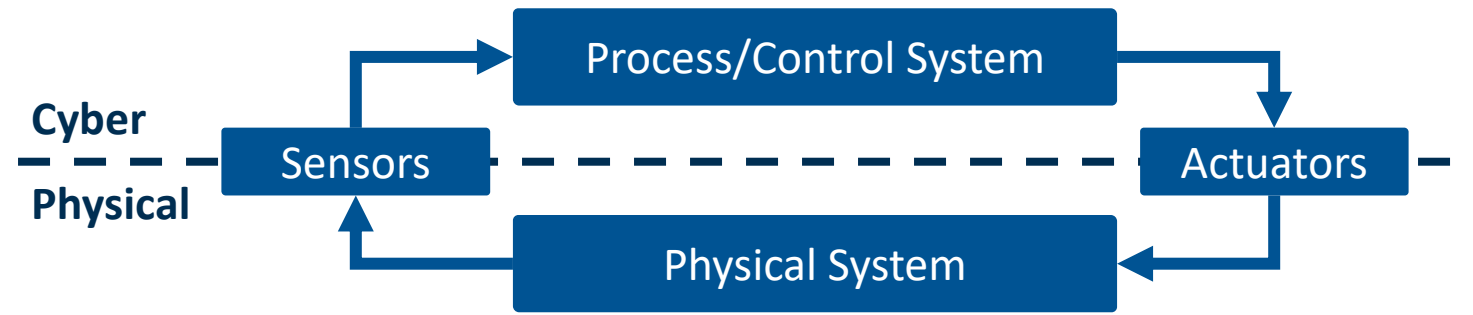
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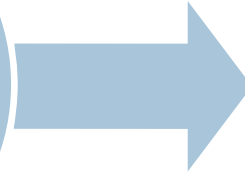
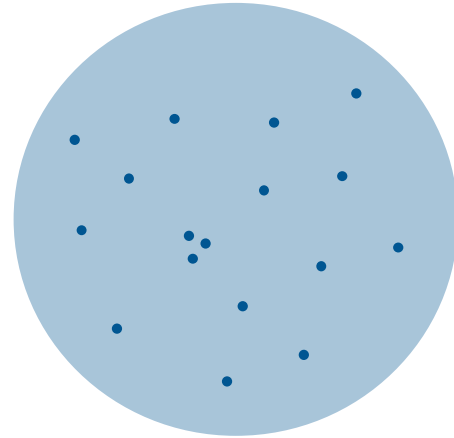
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# Cyber-Physical Systems

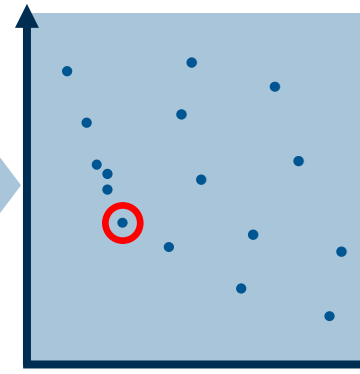


# Design Space Exploration

Design Space with design points and design objectives

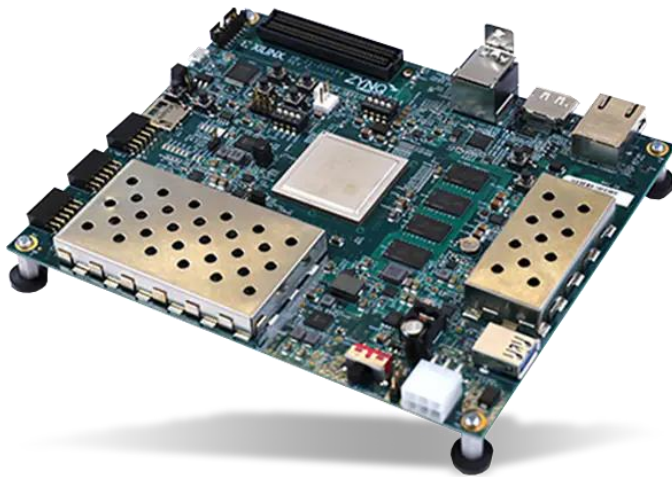


Execution time



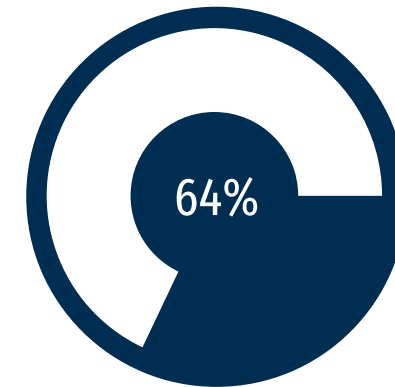
Cost

Systematic analysis and pruning of design points to find desired solution(s)



SoC / MPSoC

SESAME  
Daedalus  
DISPATCH  
...



Insufficient level  
of attention for  
model-driven  
DSE [1]

[1] Bram Van der Sanden et al. "Model-Driven System-Performance Engineering for Cyber-Physical Systems : Industry Session Paper", Oct. 2021.



# Outline

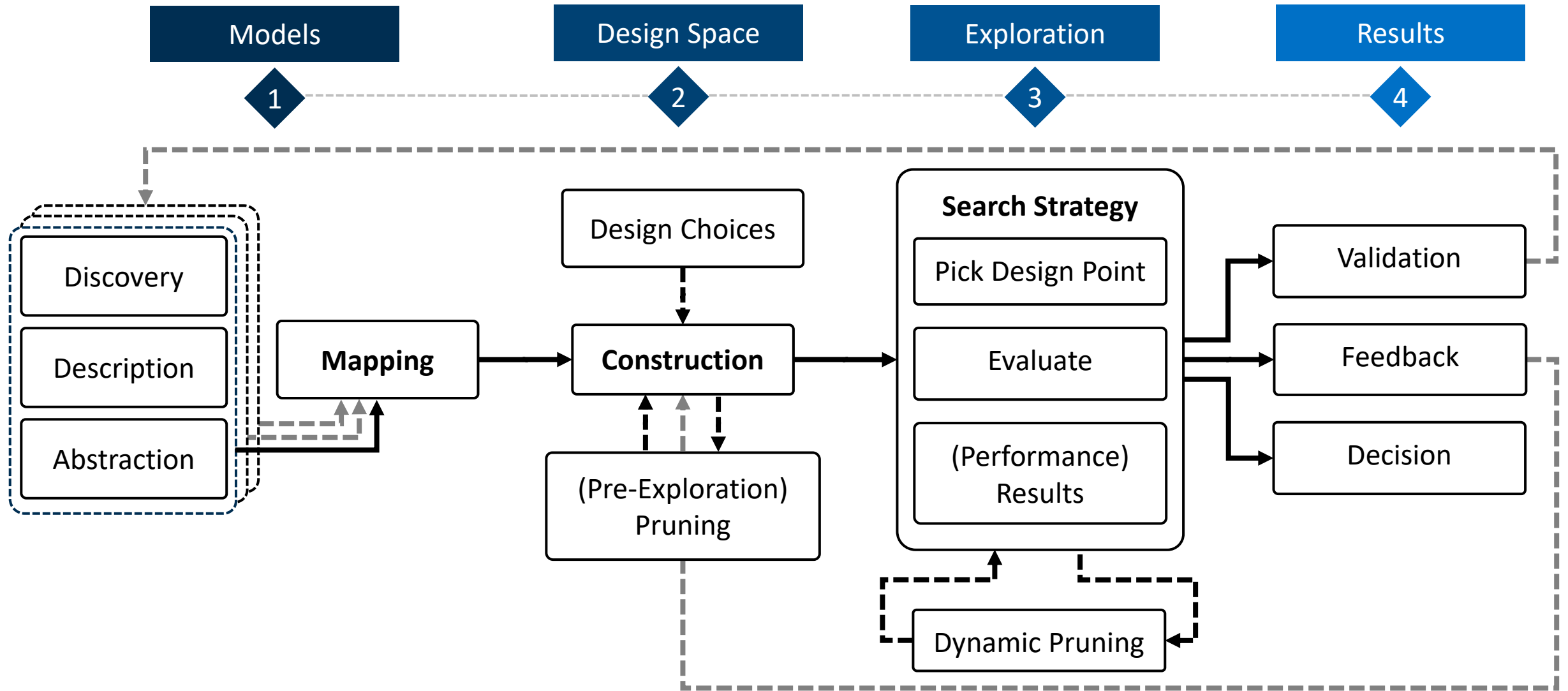


## Position paper

with the goal of **surveying** and **structuring the state of the art**, identifying **challenges**, and propose **directions**.



# DSE Workflow



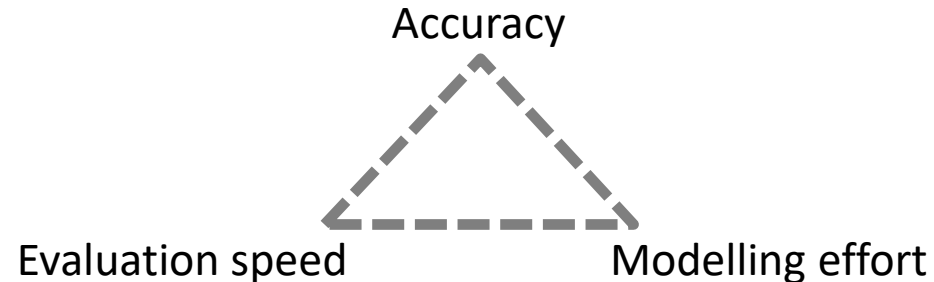
# Scientific Challenges

## Modelling Complex dCPS

### Understanding the system

- Drastically more complex than SoC
- Multiple heterogeneous subsystems
- Complex network
- New and legacy software

### Abstraction level



Concepts and techniques to automatically infer the (initial) models

## Scalable Design Space Exploration

### Vast design space

- Various application workload behaviour scenarios
- Huge amount of possible design points in comparison to SoC/MPSoC

### Evaluation speed

- Complexity and size of models increase the computational effort of evaluations
- Balancing various factors (i.e. accuracy, or cost of implementation)

Novel scalable search and pruning strategies and efficient design point evaluation

# Motivational Experiment

## Setup

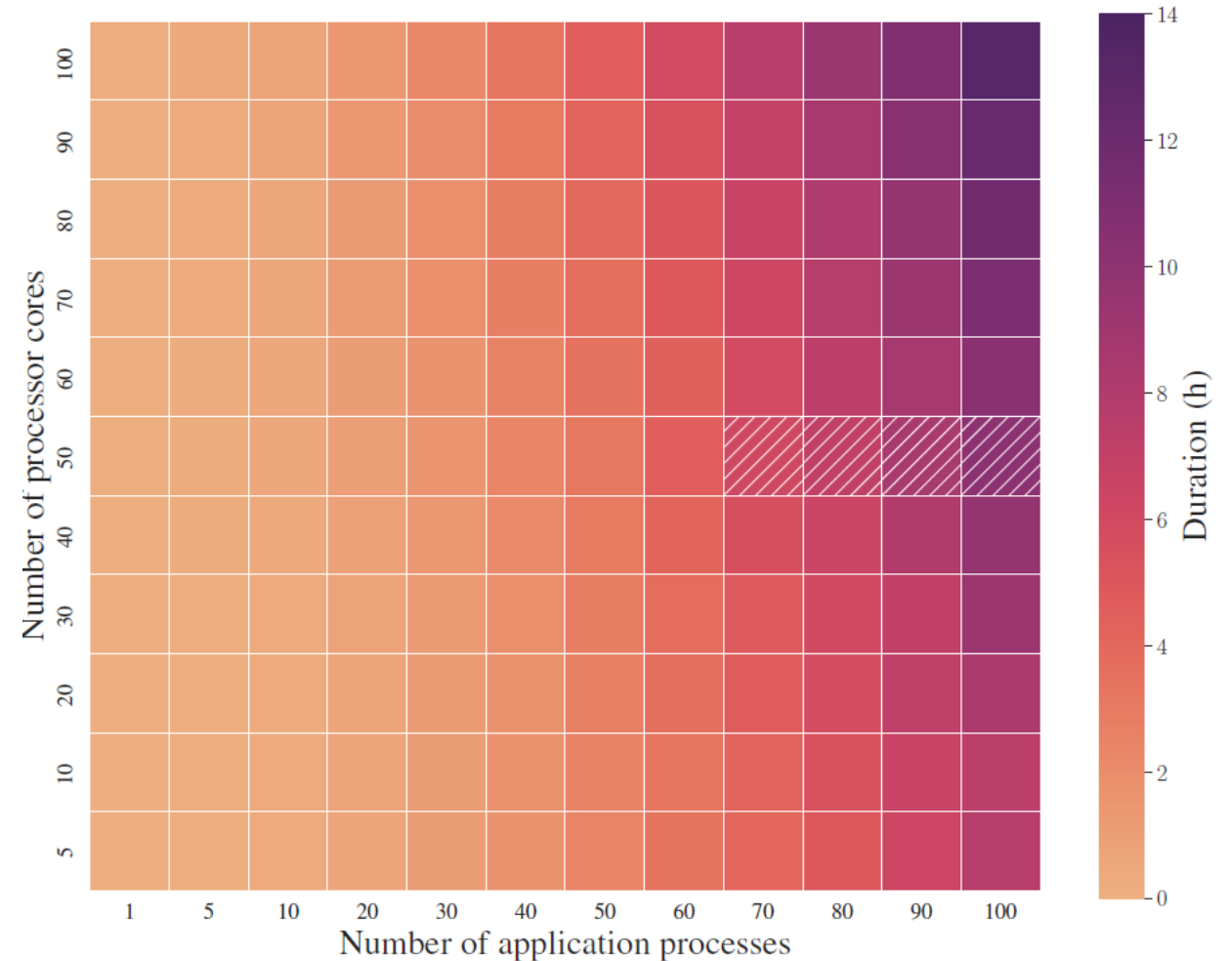
- State-of-the-art DSE framework: SESAME
- Models:
  - Multi-media encoding application
  - MPSoC hardware platform

## Experiment

- Increasing workload  
**by duplicated application model**
- Increase hardware resources  
**by adding processor cores**

## Results

- 458 experiments – total runtime **ca. 64 days**
- DSE runtime increases superlinearly
- Best-case scenario
- Even simple models are too complex to simulate with a state-of-the-art framework

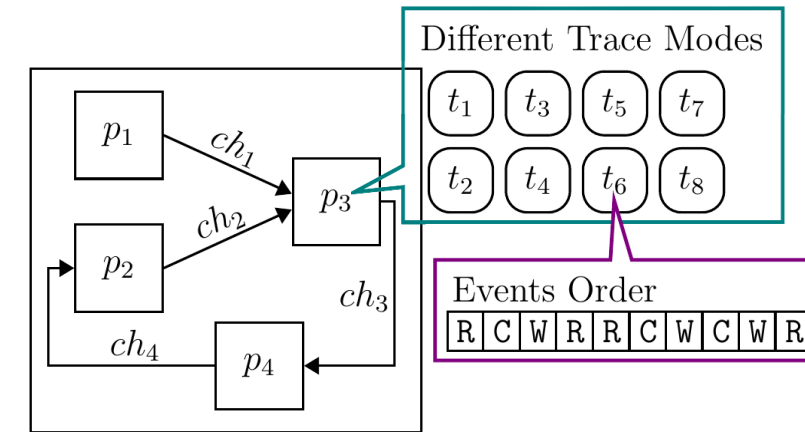


# Proposed Approach

We follow the **separation-of-concerns** approach:

### Application Workload Model

- Software processes triggered by events and exchanging messages
  - Process is triggered and performs some computation and communication
  - Messages trigger other processes
  - Fire-and-exit behaviour in a circle
- Results in a directed graphTraces are collected (not the model) using run-time monitoring and the abstract workload model is inferred from those traces.



### Architecture Platform Model

- Custom pipeline to receive initial platform model:
  1. Discover network topology
  2. Obtain computational information and metadata for each component
  3. Combine to achieve a complete description of the system
  4. Condense into a comprehensive model



### Design Space

- *Structural* design decisions
  - Modifying the network topology
  - Modifying communication channels
  - Exchanges of key characteristics of a components (e.g. GPU to ASIC)
- *Behavioural* design decisions:
  - In-/Decreasing performance characteristics (e.g. CPU frequency)
  - Mapping of processes to different component

### Design Point Evaluation

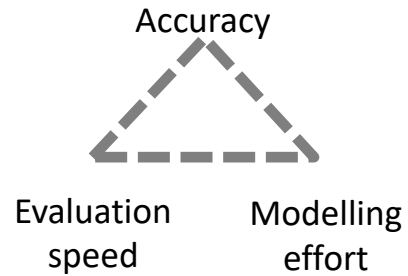
- Discrete event simulator
- Experiments combined in campaigns to parallelize evaluations of independent design points
- Use and extend state-of-the-art techniques
  - Hierarchical DSE methods
  - Design space pruning by adding domain knowledge to the search algorithm

# Conclusion



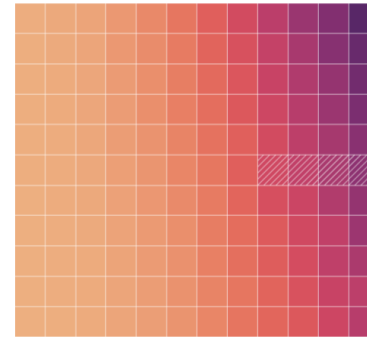
**High demand  
for DSE of (d)CPS**

by industrial  
dCPS companies  
*e.g. ASML, Philips,  
or Canon Printing*



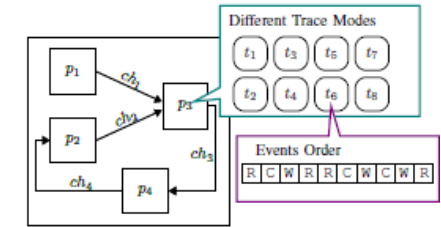
**Scientific  
challenges**

to identify the  
main research  
opportunities



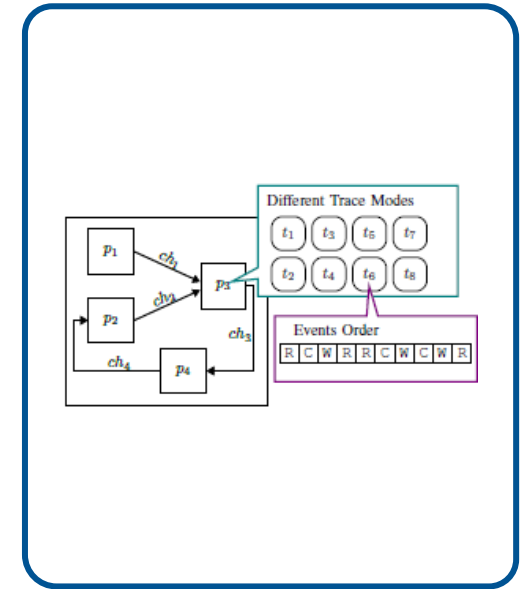
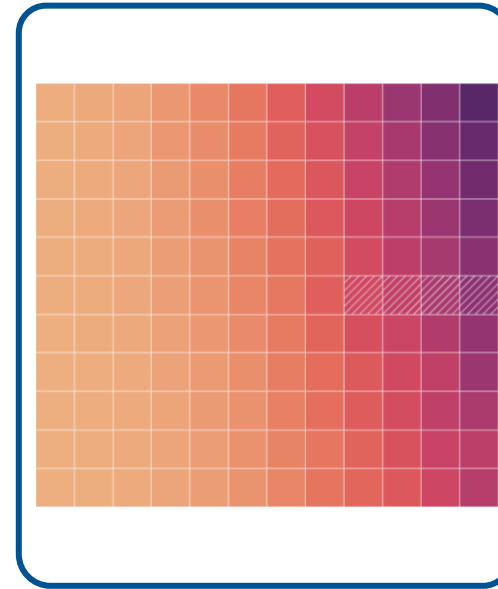
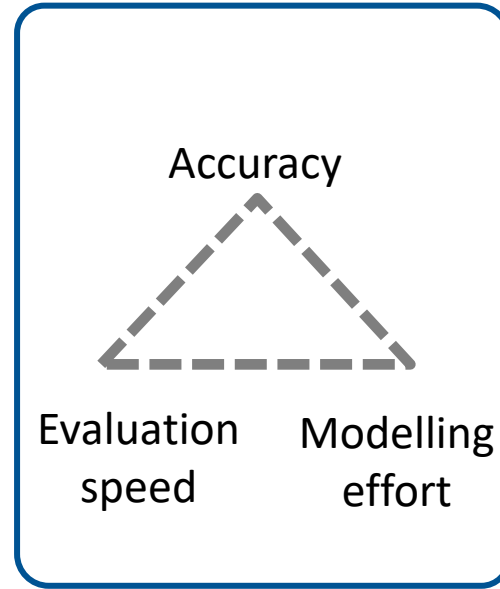
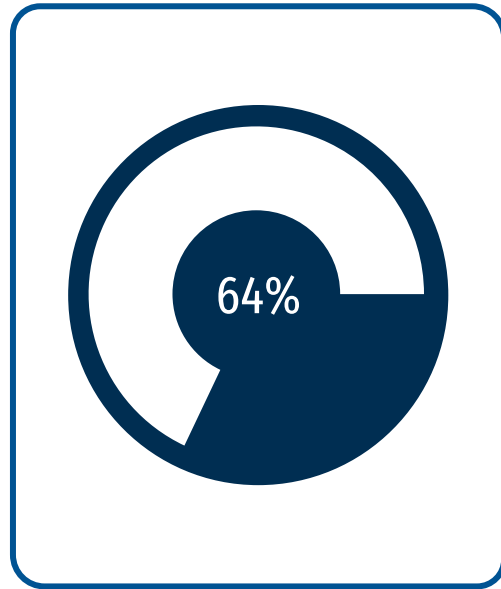
**State-of-the-Art  
is not sufficient**

to cover the needs of  
the dCPS domain  
*as shown by our  
experimental data*



**Directions**

to address  
the challenges  
of DSE for complex  
distributed CPS



**Thanks for your attention!**

Feel free to ask any questions



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