INTO-CPS: An well-founded integrated tool chain for comprehensive Model-Based Design of Cyber-Physical Systems

Professor **Peter Gorm Larsen**
Department of Engineering, Aarhus University
Head of Software Engineering

INTO-CPS

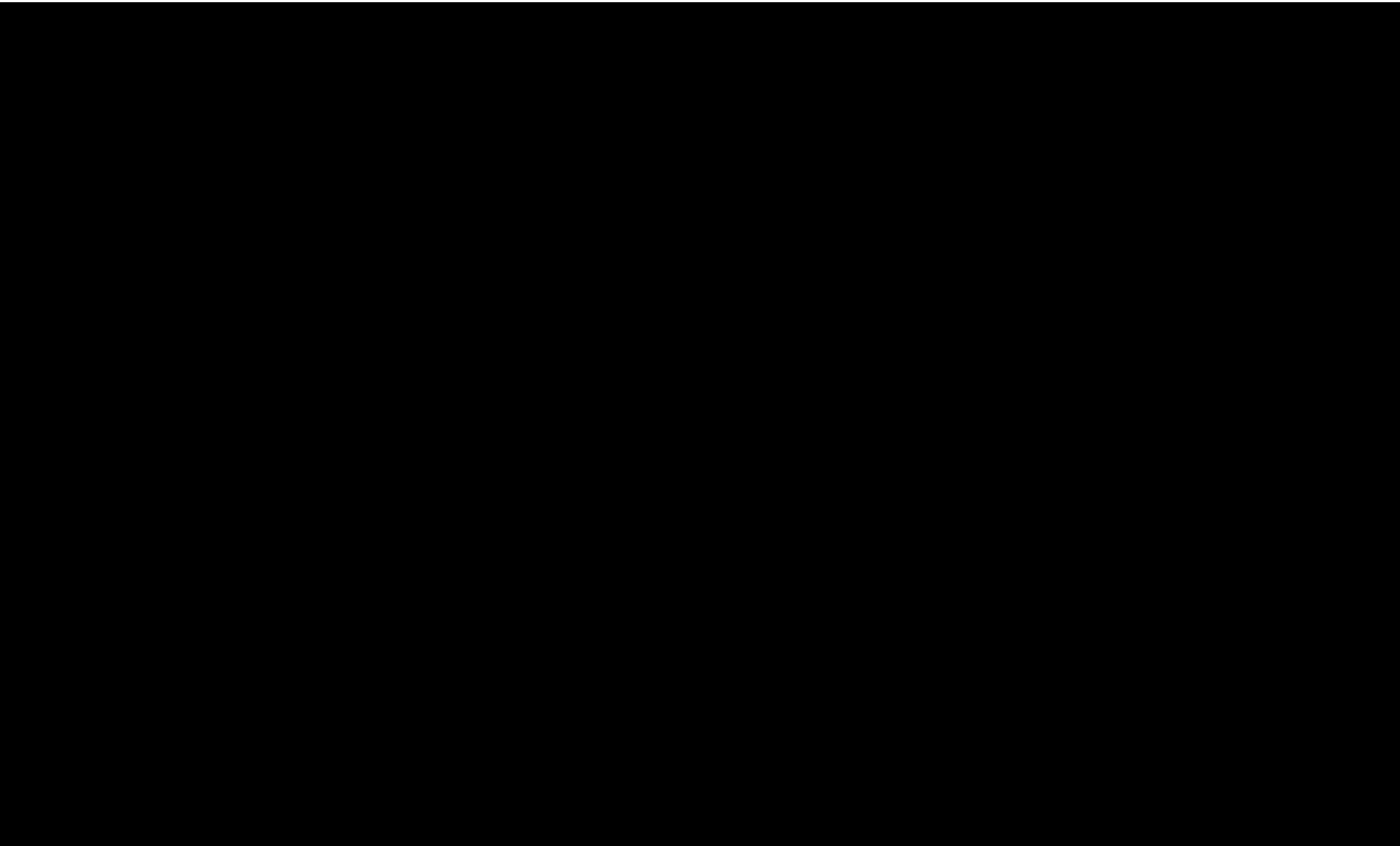
www.into-cps.au.dk

HORIZON 2020

Who am I?

- **Professor Peter Gorm Larsen**; MSc, PhD
- 25+ years of professional experience
    - ½ year with Technical University of Denmark
    - 13 years with IFAD
    - 3,5 years with Systematic
    - 10 years with IHA/Aarhus University
- Reviewer for EU on Research projects and applications
- Consultant for most large defence contractors on large complex projects (e.g. Joint Strike Fighter)
- Mostly proud of the firmware of a NFC chip in 250+ million phones
- Relations to industry and academia all over the world
- Has written books and 100+ articles (in particular about VDM)
- See http://pure.au.dk/portal/da/pgl@eng.au.dk for details

Short video overview of my own research



Outline

Background

- Embedded Systems
- Co-Modelling, Co-Simulation

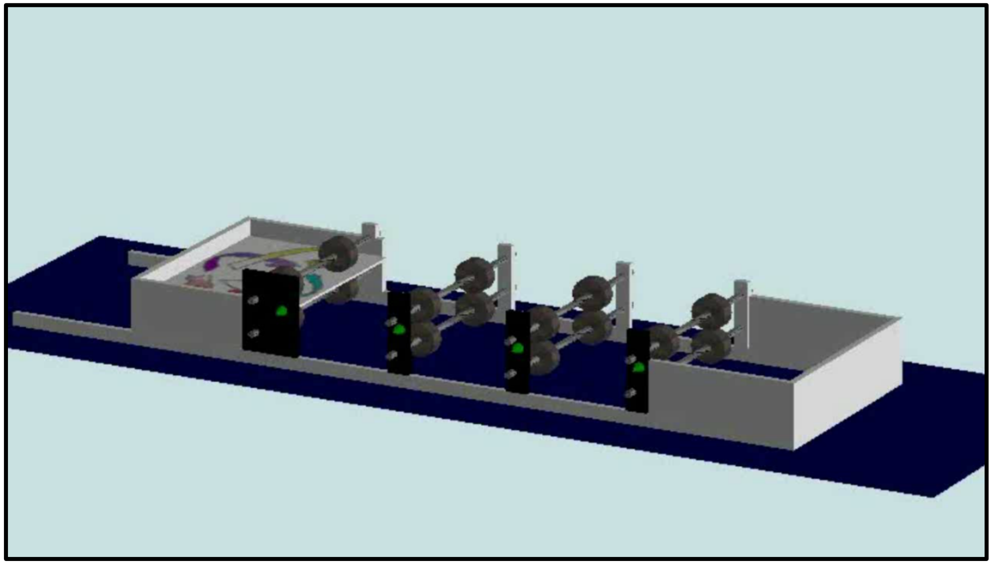
INTO-CPS project

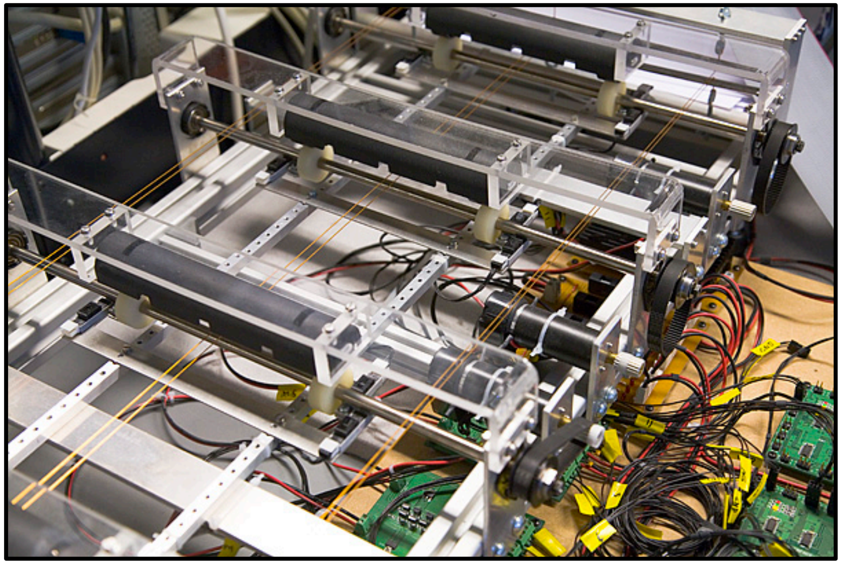
- Cyber Physical Systems (CPSs)
- System Vision

Embedded Systems

- Interacting computing, physical, human elements
- Increasingly complex logic (e.g. moding) ~80% of control software
- Error detection and recovery

- Collaborative development
- Diverse disciplines cultures, abstractions, formalisms
- Typically tackled separately
- Need for **design space exploration**





Model-driven Design

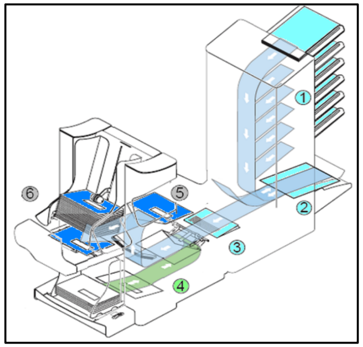
- Modern systems are complex
- To cope with this, we can build models beforehand
  - To perform analysis (e.g. static analysis, proof, model checking, **simulation**)
  - Clarify our assumptions
  - Evaluate potential designs
  - Avoid expensive prototypes
- Different modelling paradigms for different aspects

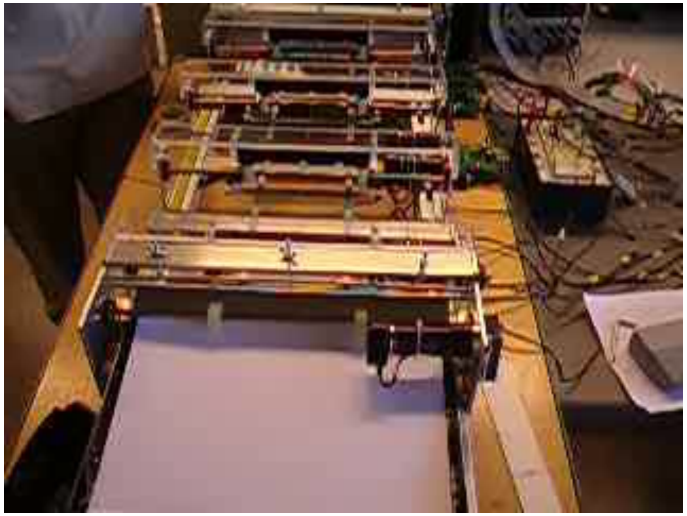
Modelling of Software and Physics

- Typically **discrete-event (DE),** e.g. VDM-RT based on discrete mathematics
- In simulation, only the points in time at which the state changes are represented
- Good abstractions for software,
  - e.g. data types, object-orientation, threading
- Less suited for physical system modelling

- Typically **continuous-time (CT),** e.g. differential equations
- In simulation, the state changes continuously through time
- Abstractions for disciplines,
  - e.g. mechanical, electrical, hydraulic
- Poor software modelling support
  - only basic programming support; no functions or objects

Background: Co-modelling





Software:
- Discrete
- Complex logic

Mind the Gap!

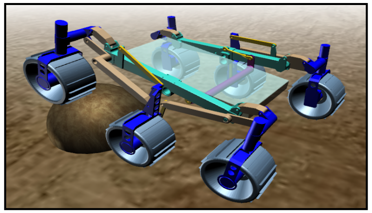
Physics:
- Continuous
- Numerical

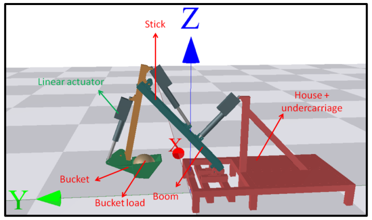
Co-model

DE Model

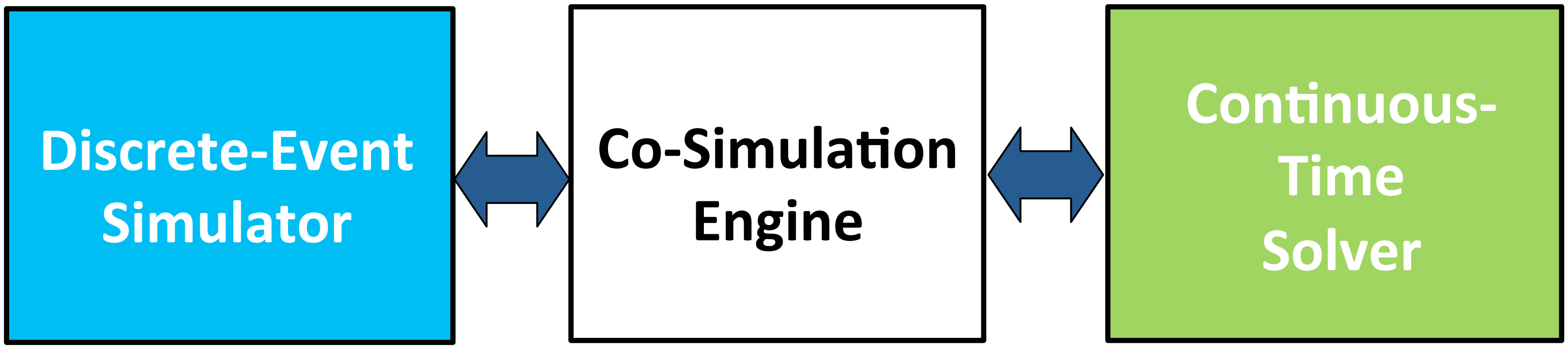
CT Model

Co-model Interface

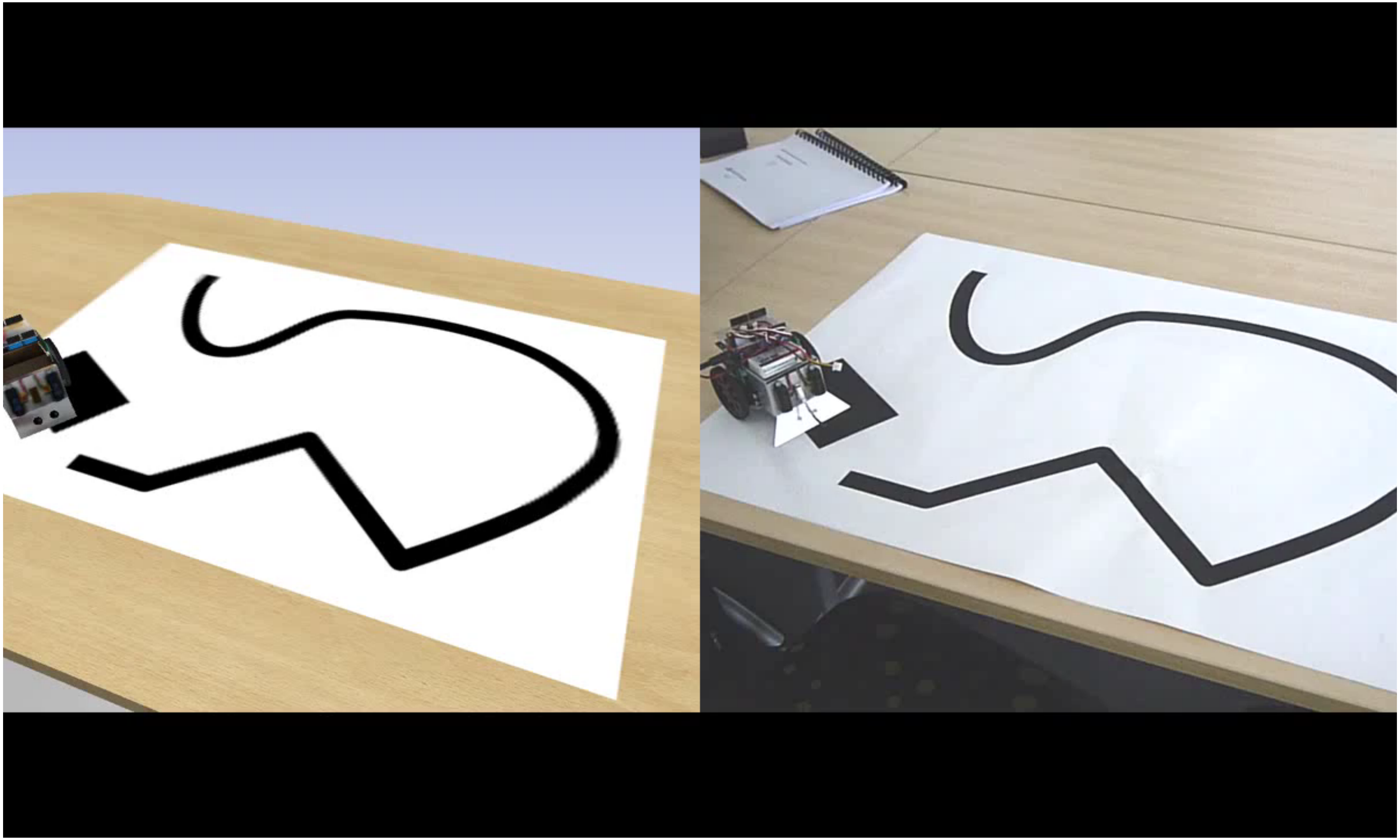




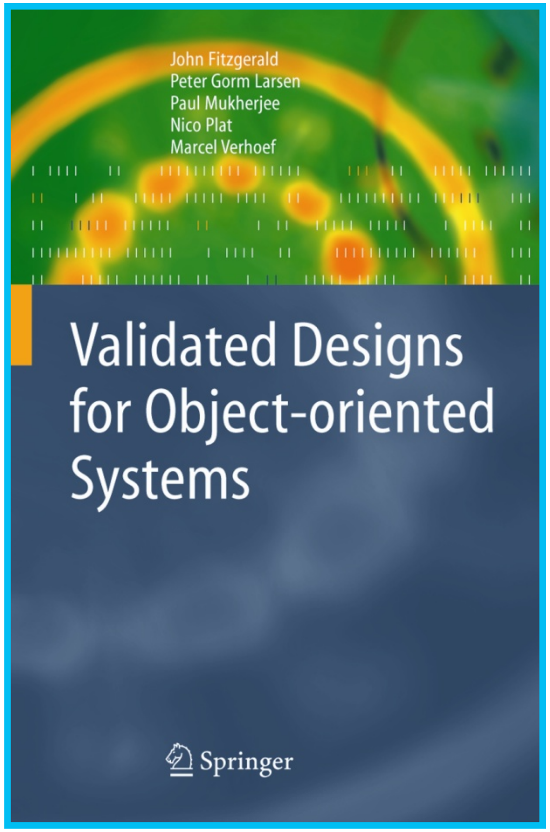
Background: Co-simulation



Co-simulation and real world

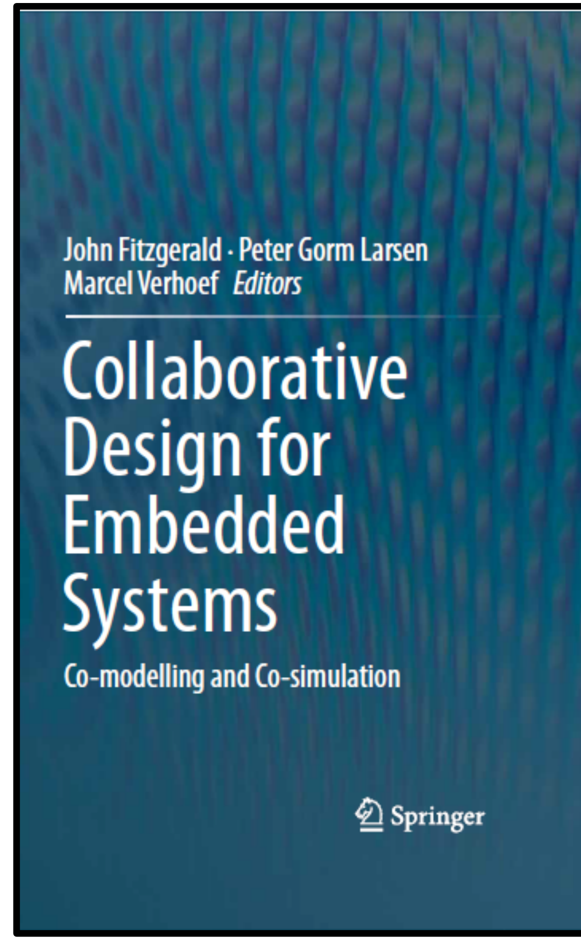


Reference Books



Baseline Discrete Event Modelling

Baseline Continuous Time Modelling



Co-Modelling

INTO-CPS: A new 8 M€ H2020 Project

INTO-CPS

AARHUS UNIVERSITET

UNITED TECHNOLOGIES

TWT GmbH
Science & Innovation

Linköping University

Newcastle University

SOFTEAM
Think Object

controllab

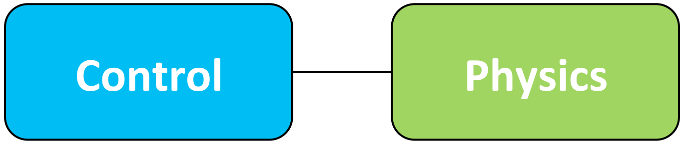
THE UNIVERSITY of York

Verified

AGRO INTELLIGENCE

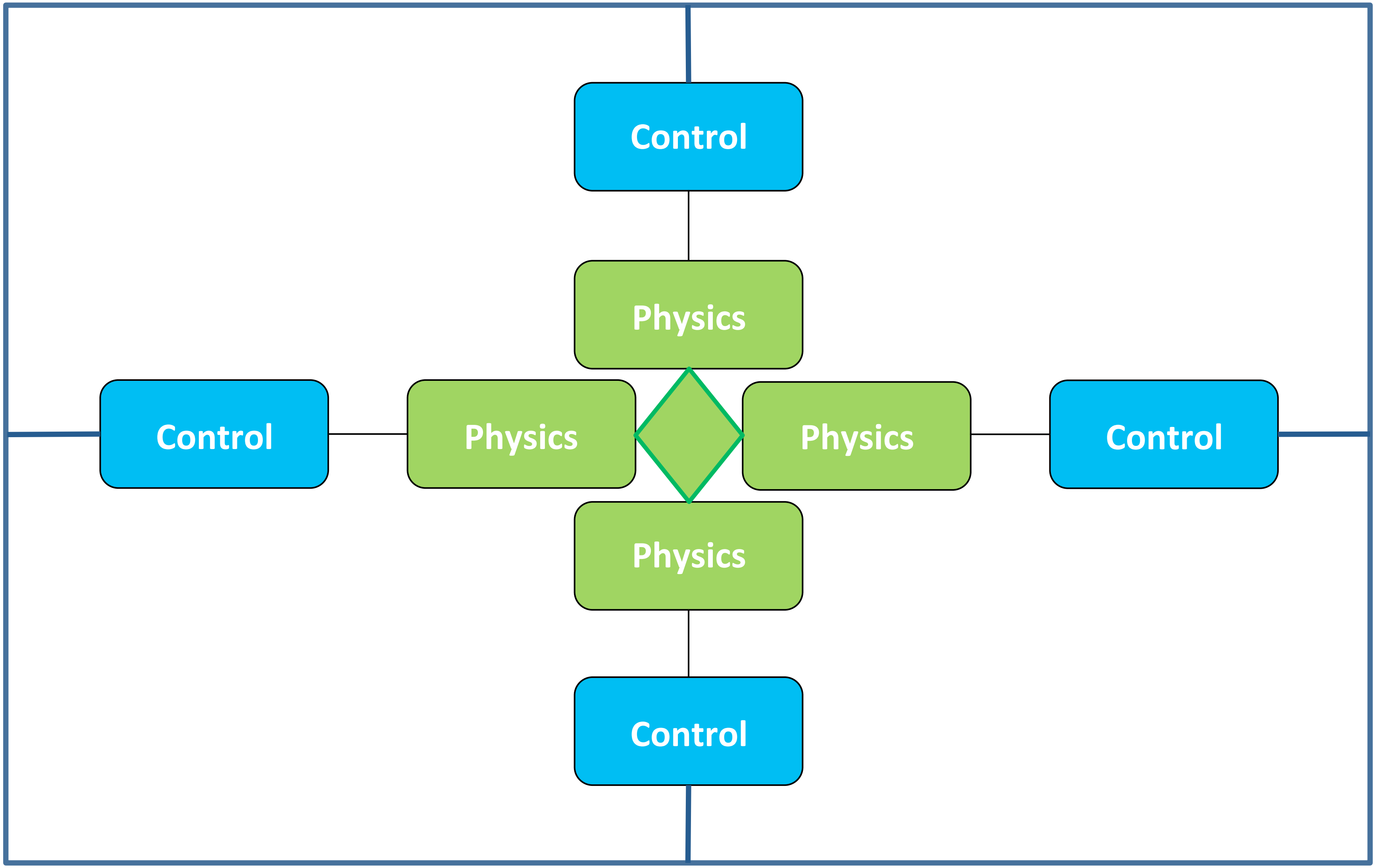
CLEARSY
SYSTEM ENGINEERING

Cyber-Physical Systems

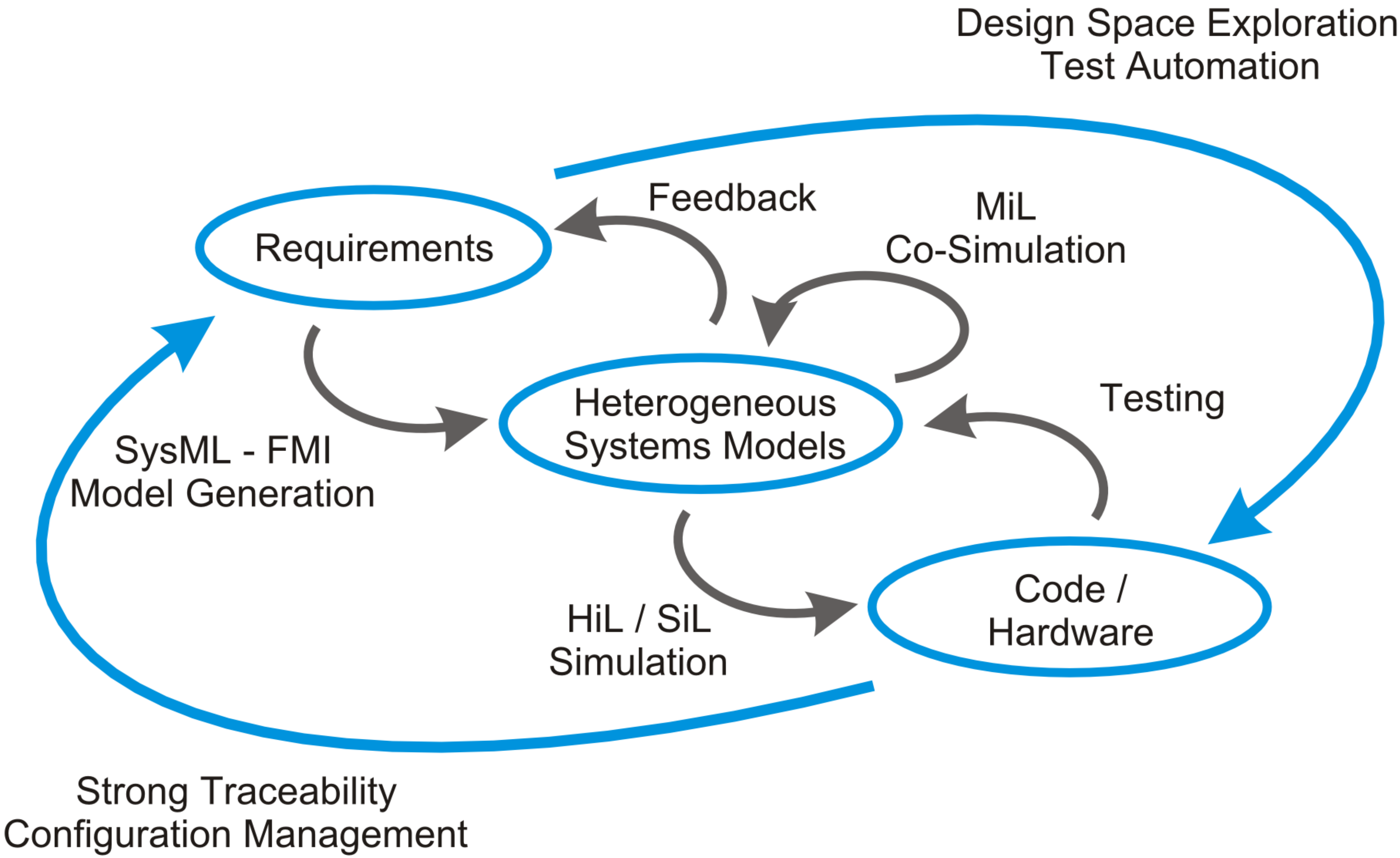


- We have looked at individual embedded systems
- CPSs are networked groupings of digital devices
- … which may require more elaborate co-models!

Cyber-Physical Systems



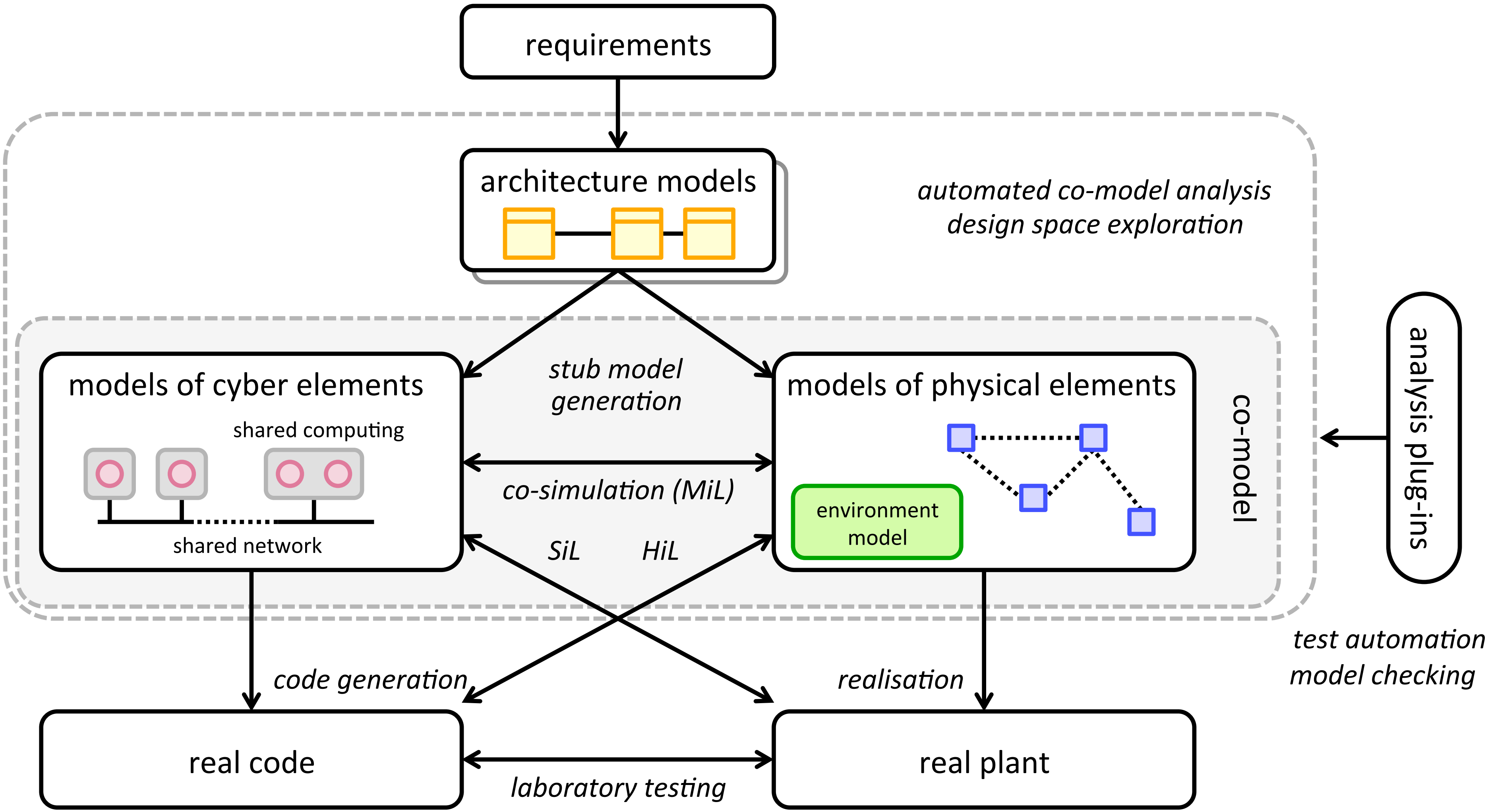
INTO-CPS


Design Space Exploration
Test Automation
Feedback
MiL
Co-Simulation
Requirements
Heterogeneous
Systems Models
Testing
SysML - FMI
Model Generation
Code /
Hardware
HiL / SiL
Simulation
Strong Traceability
Configuration Management

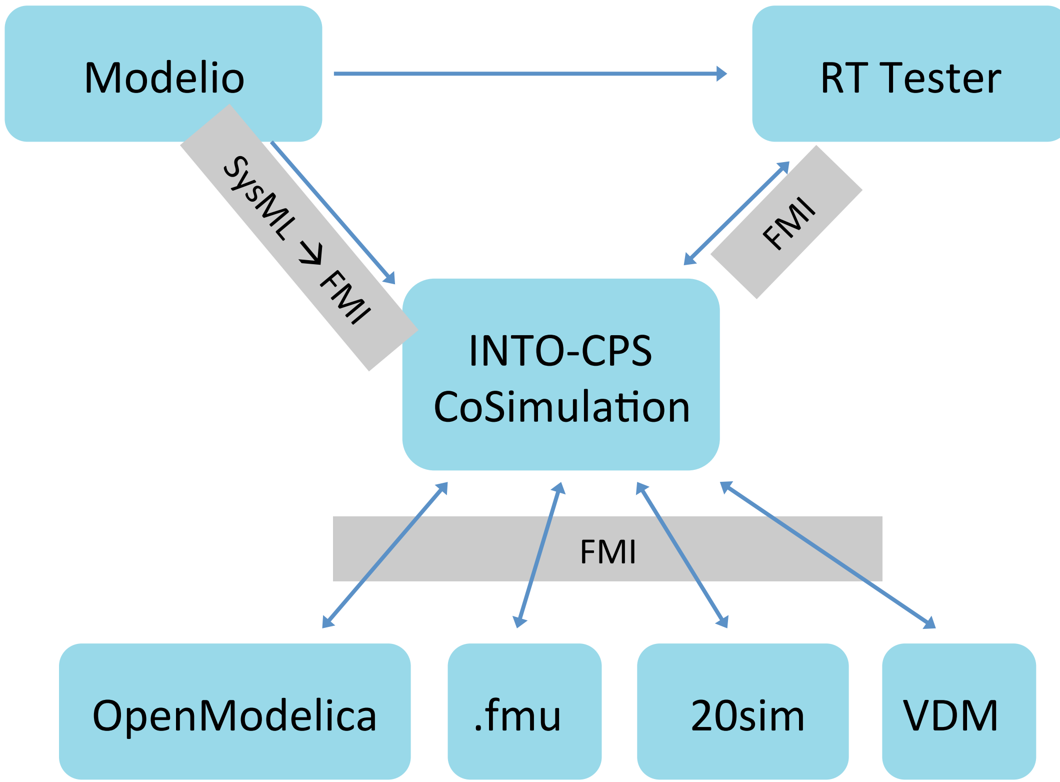
INTO CPS Objectives

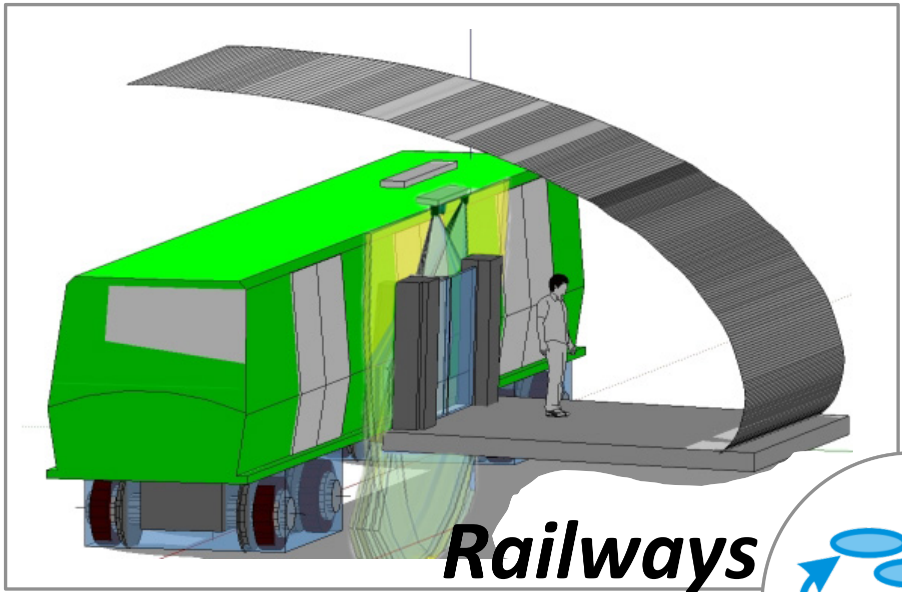
1. Build an open, well-founded tool chain for multidisciplinary model-based design of CPS that covers the full development life cycle of CPS
2. Provide a sound semantic basis for the tool chain
3. Provide practical methods in the form of guidelines and patterns that support the tool chain
4. Demonstrate in an industrial setting the effectiveness of the methods and tools in a variety of application domains.
5. Form an INTO-CPS Association to ensure that project results extend beyond the life of the project

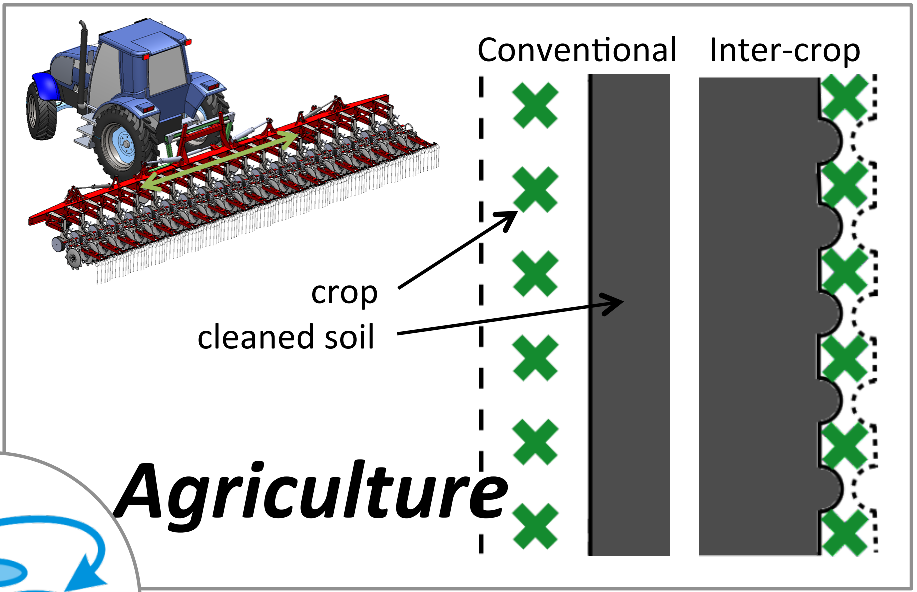
CPS co-modelling



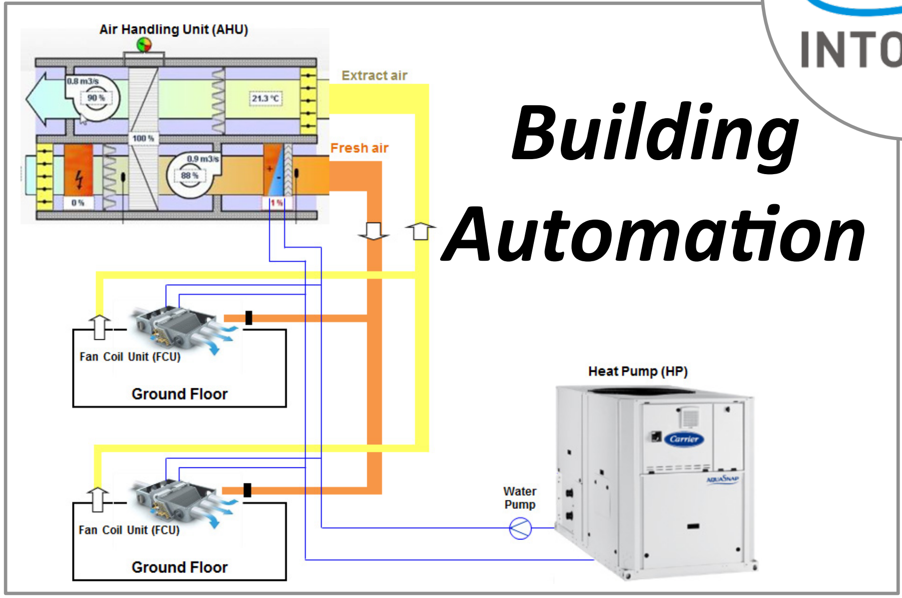
Combining Baseline Tools




Railways


Conventional
Inter-crop
crop
cleaned soil
Agriculture

INTO-CPS


Air Handling Unit (AHU)
Extract air
Fresh air
Building Automation
Fan Coil Unit (FCU)
Ground Floor
Heat Pump (HP)
Water Pump
Fan Coil Unit (FCU)
Ground Floor


Automotive

Industrial Follower Group

- AGCO, Denmark
- Alcatel-Lucent, Ireland
- Almende, Netherlands
- Altran, UK
- Bachmann electronic, Netherlands
- Bakker Sliedrecht Electro Industrie, Netherlands
- Bombardier, Germany
- Carrier, France
- CeTIM, Netherlands
- Chemring TS, UK
- Conpleks Innovation, Denmark
- Danish Aviation Systems ApS, Denmark
- DEME Group, Netherlands
- Denso Corporation, Japan
- Dredging International, Belgium
- DSTL, UK
- ESA, European Space Agency, Netherlands
- EDF, France
- Farmertronics BV, Netherlands
- Goodrich, UK
- Grundfos, Denmark
- GN Resound, Denmark
- HMF, Denmark
- Huisman Equipment, Netherlands
- Irmato Industrial Solutions, Netherlands
- Jaguar Land Rover, UK
- MAN Diesel & Turbo, Denmark
- Mfatech Limited, UK
- National Institute of Informatics, Japan
- ONERA, France
- Polar Electro, Switzerland
- Rockwell-Collins, France
- Rolls-Royce, UK
- Seluxit, Denmark
- Siemens, Sweden
- Terma, Denmark:
- Thales, France
- TTTech Computertechnik, Austria
- UTC Aerospace Systems, UK
- West Consulting, Netherlands

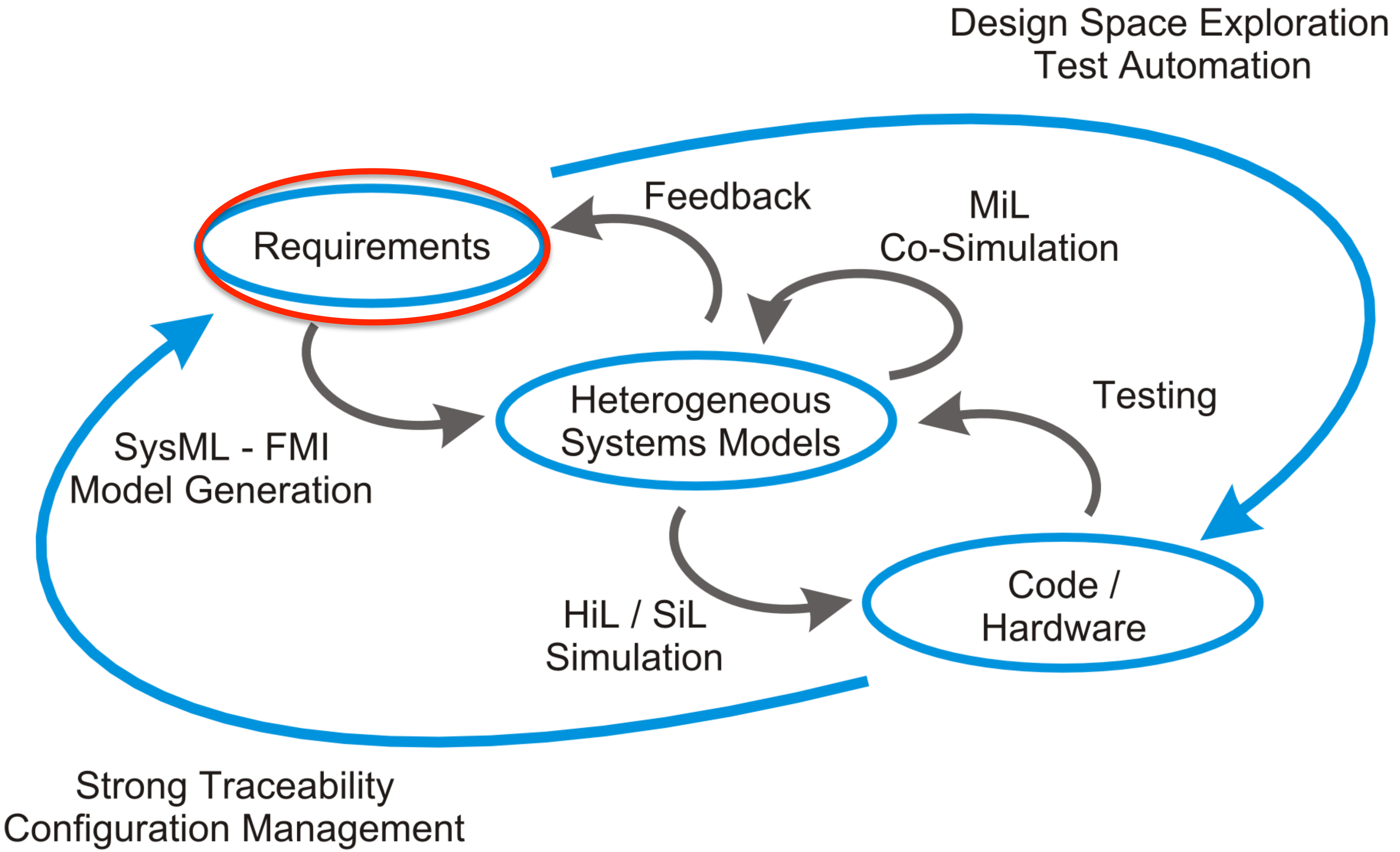
Initial Vision

INTO-CPS

www.into-cps.au.dk

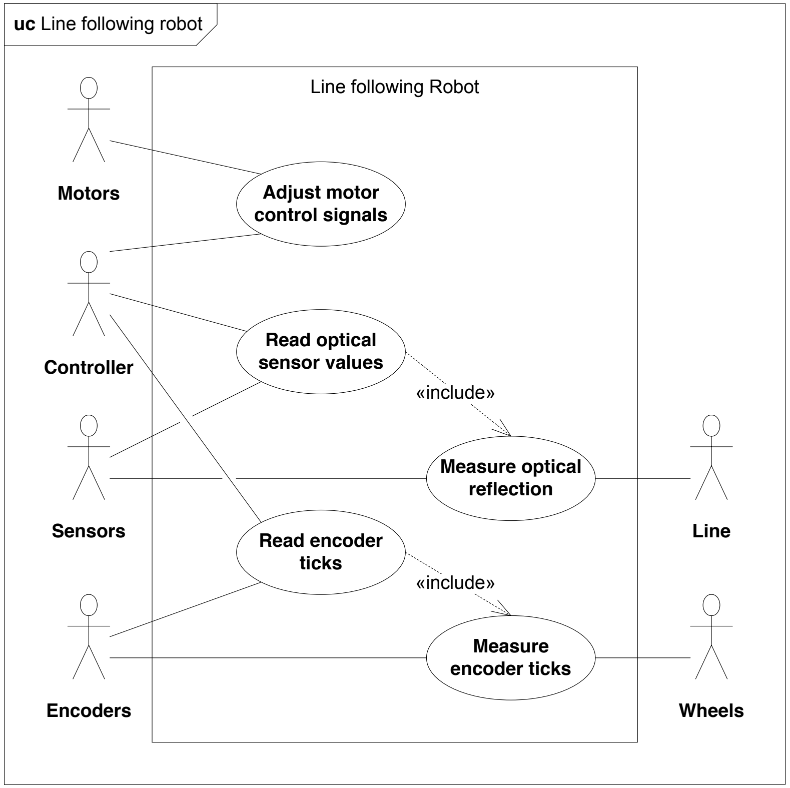
HORIZON 2020

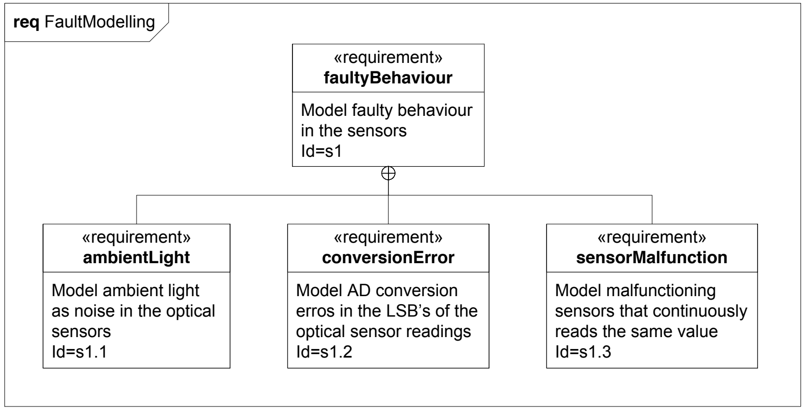
The Initial INTO-CPS Vision

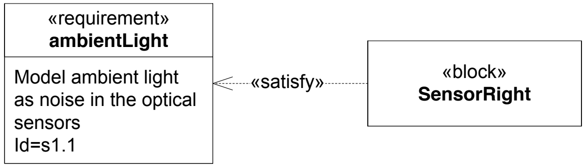


Requirements Modelling

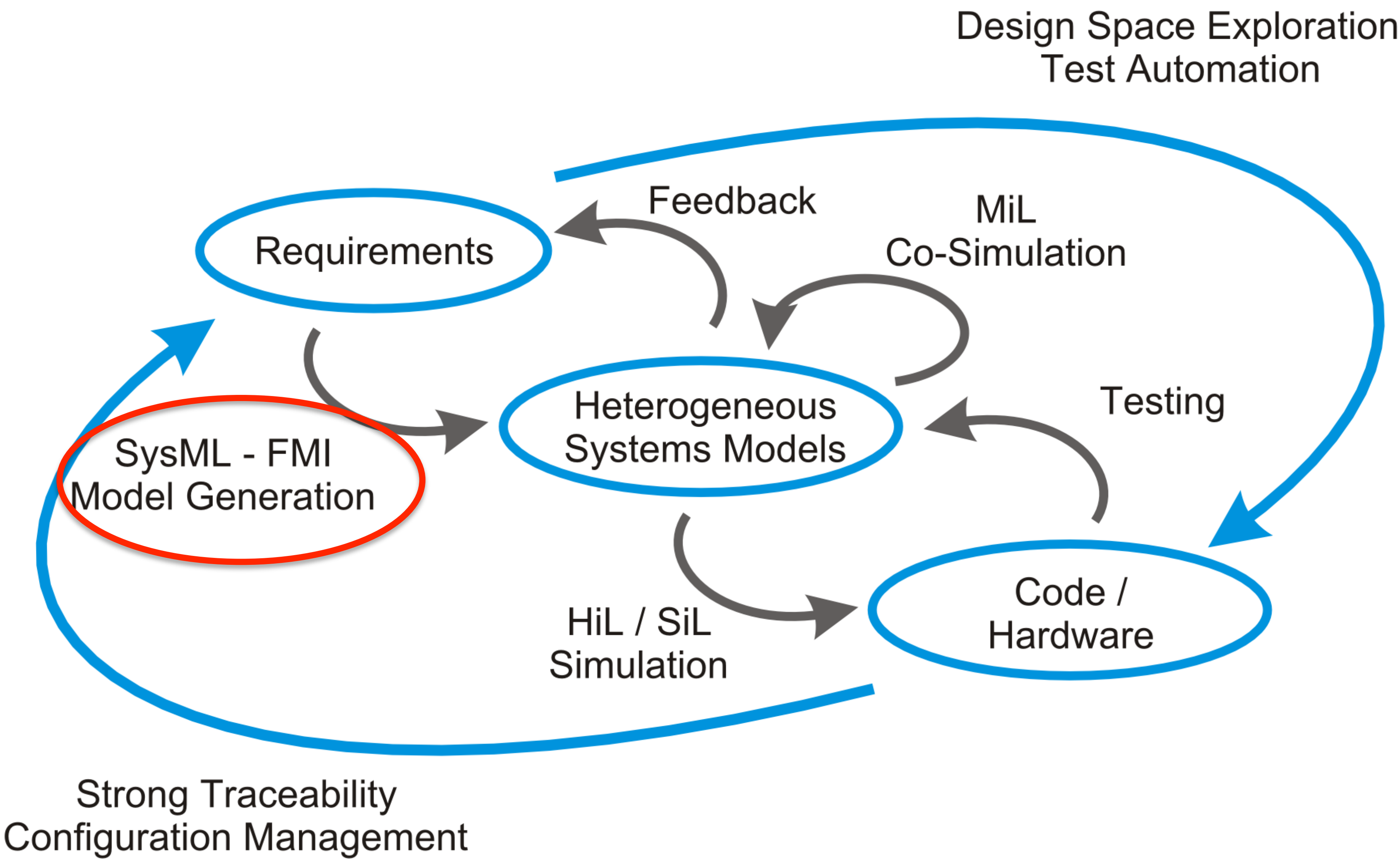
- SysML
  - Use Case diagrams
  - Requirements diagrams
    - Informal (link and traceable)
    - Formal (LTL, Test automation)





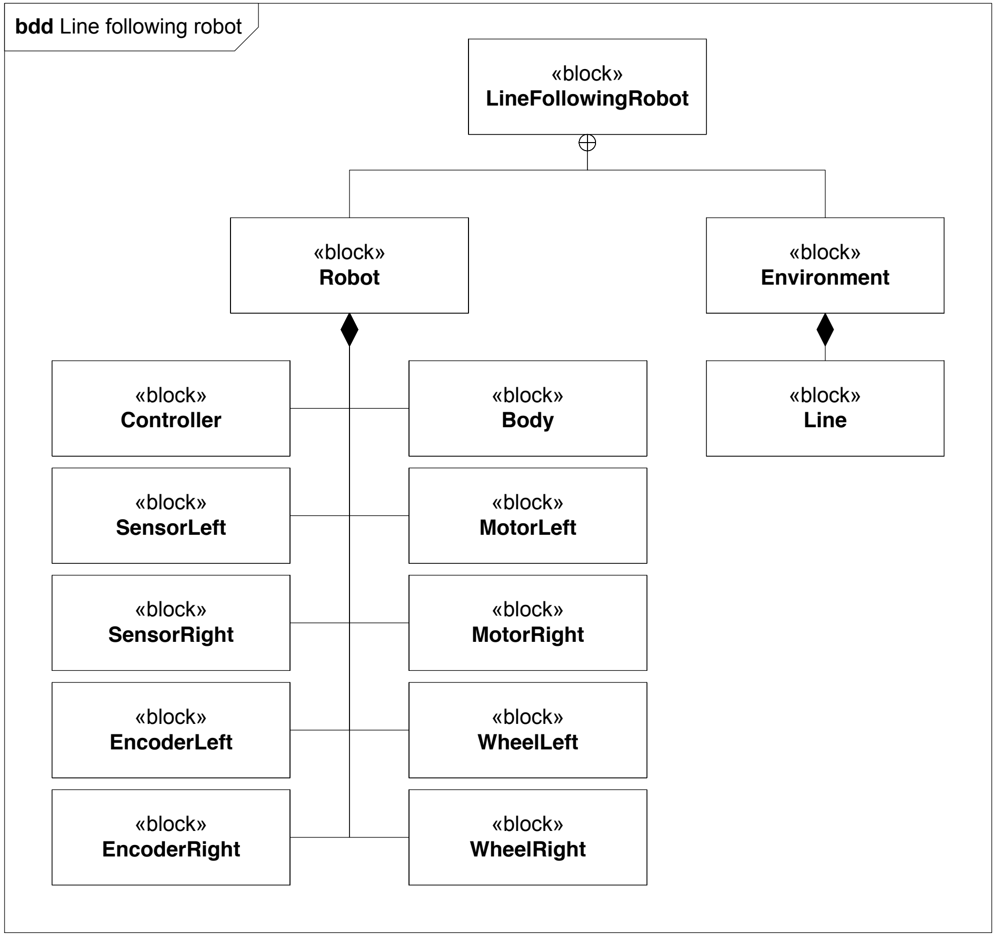


The Initial INTO-CPS Vision



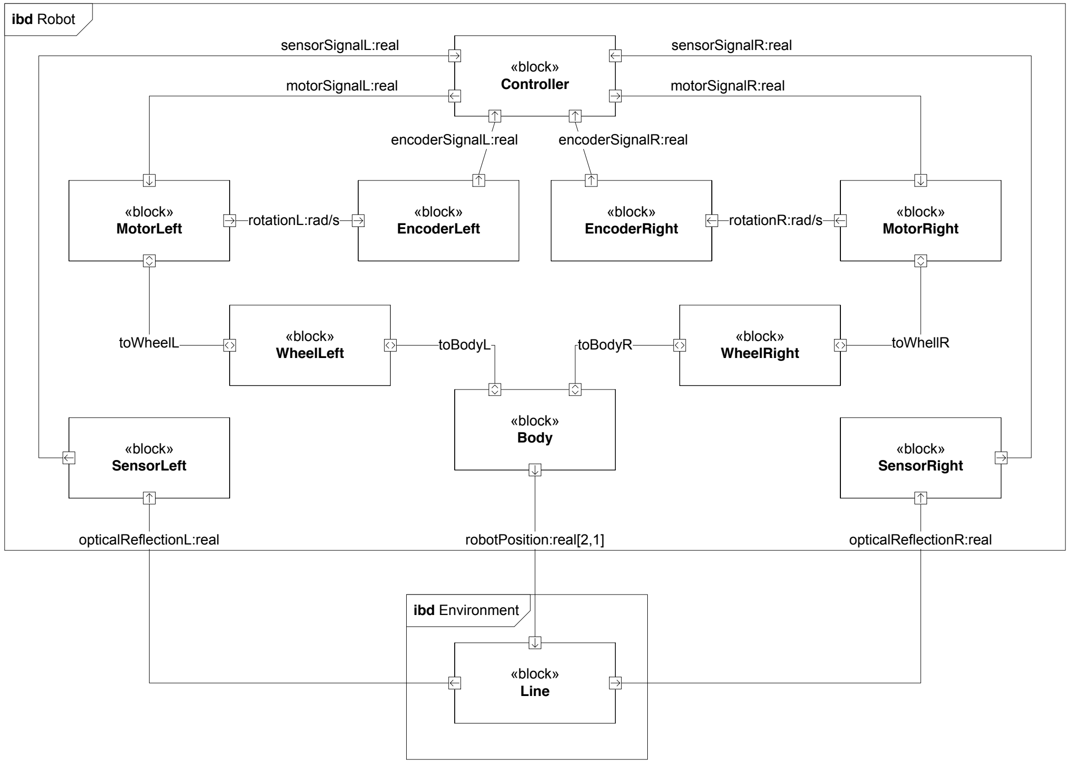
System Decomposition

- Block Definition Diagram (top level)



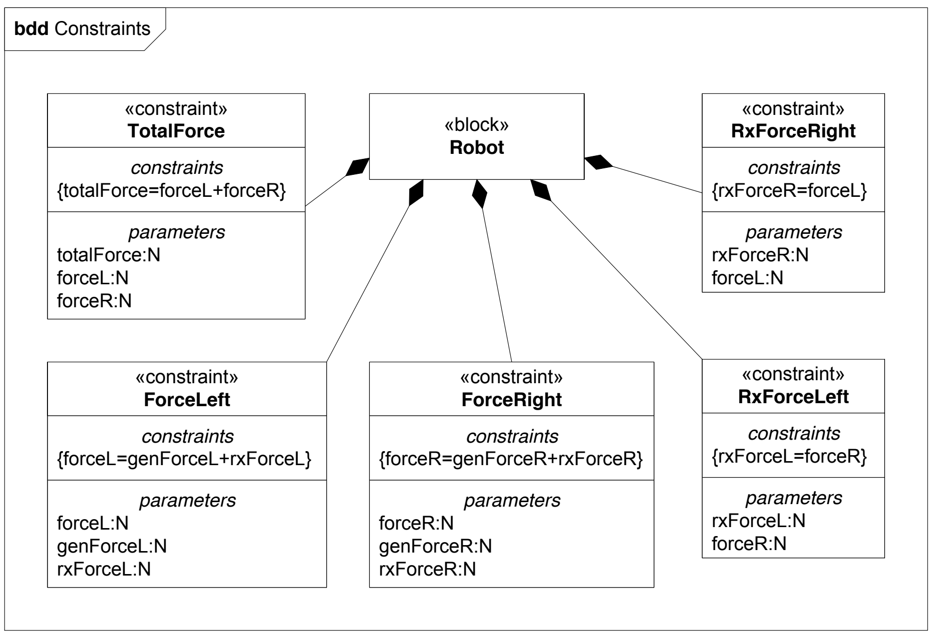
System Interface Modelling

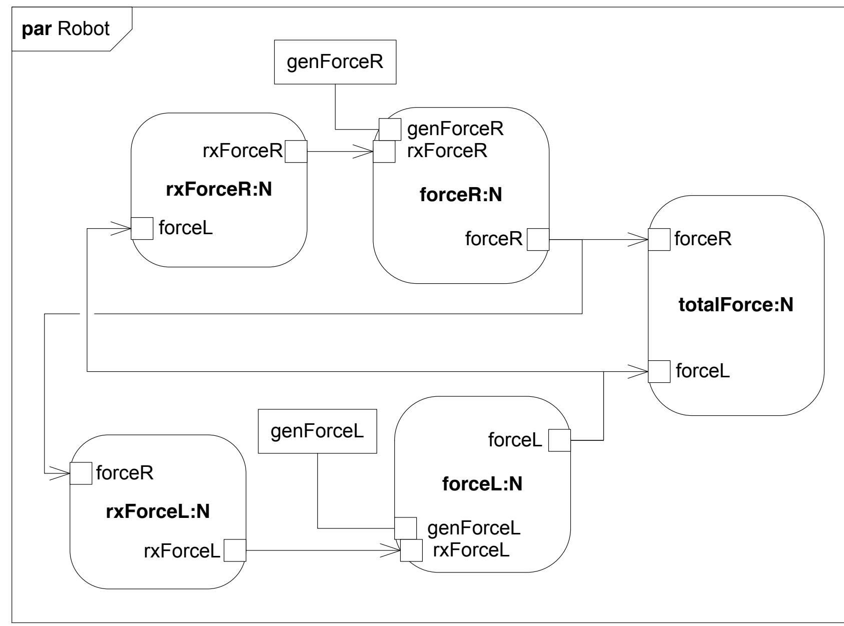
- Internal Block Diagram
  - Divide into CT/DE constituent models/systems/components
  - Define interfaces between different components



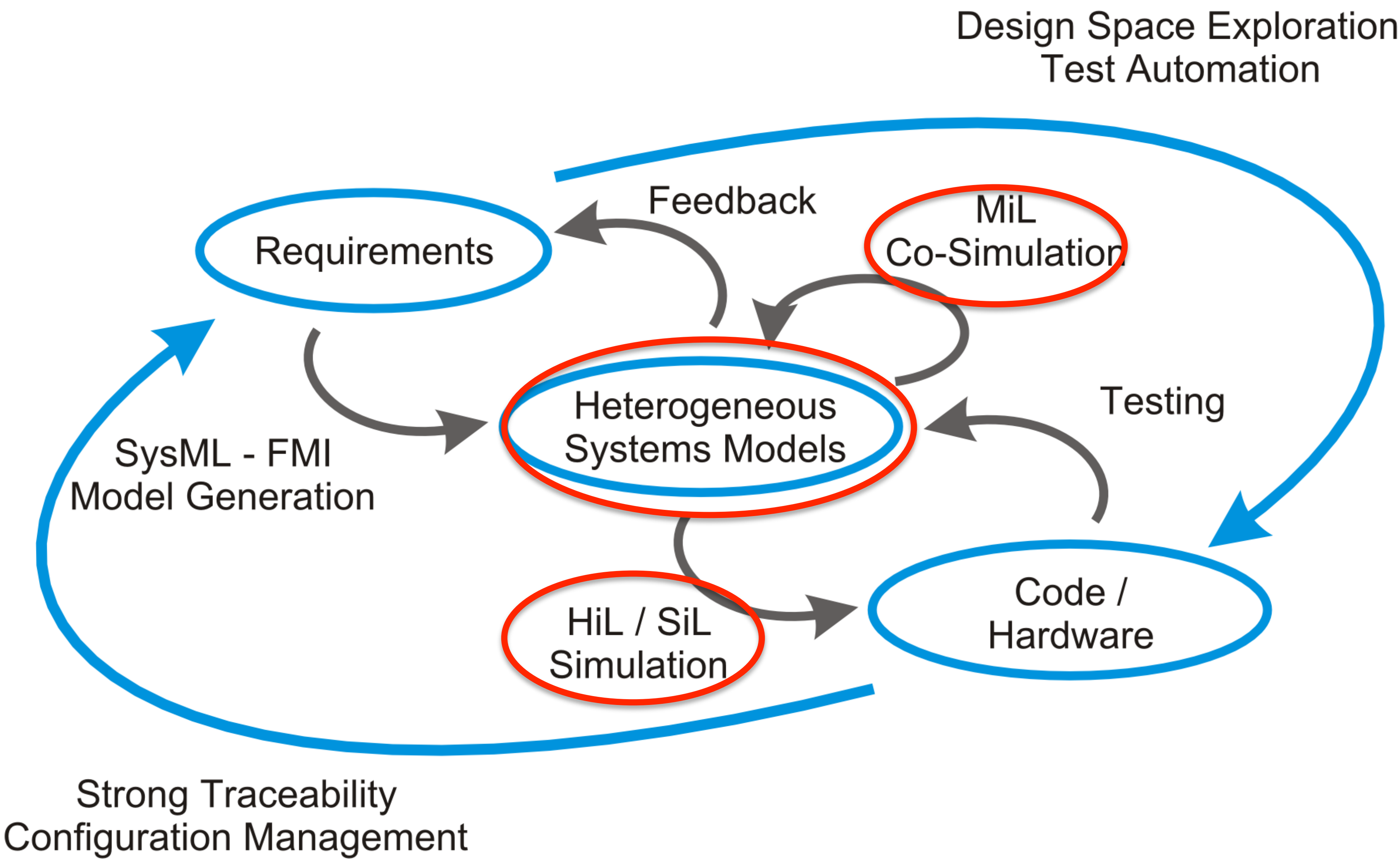
System Behaviour

- Parametric Diagram
  - Define continuous behaviour of CT components
- State Machines (DE models generated for tests)
  - Define discrete behaviour of DE components



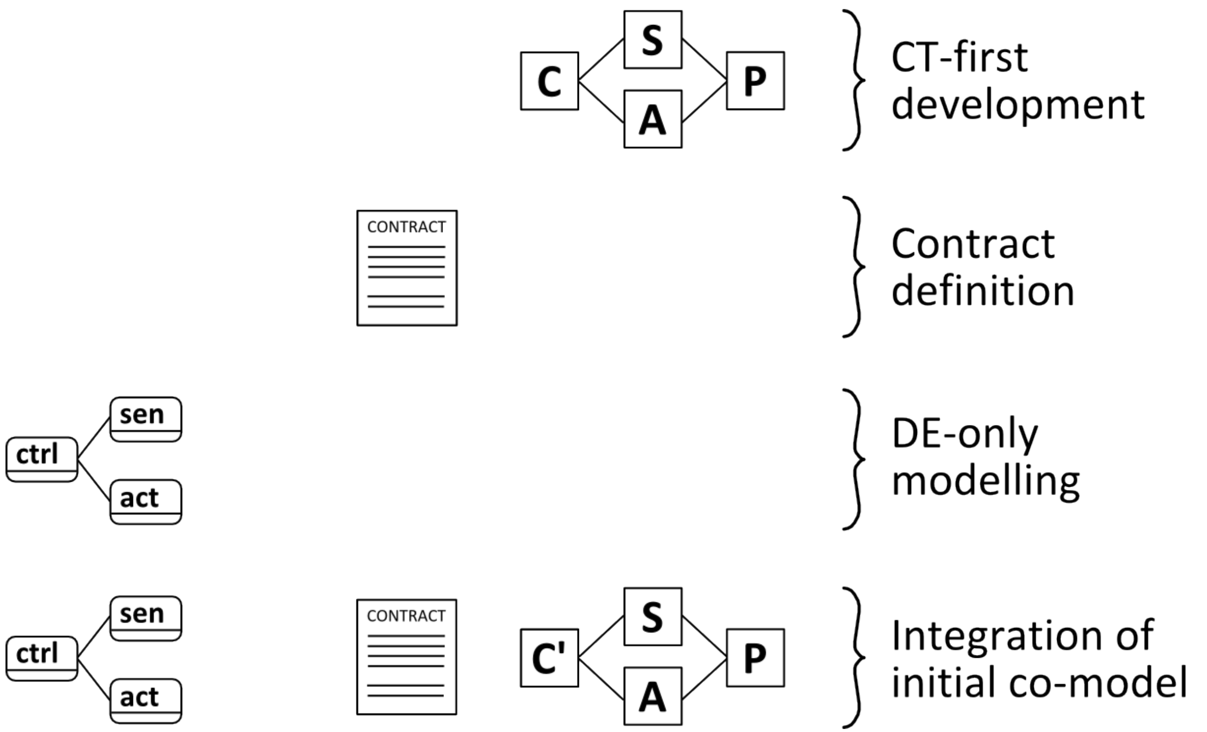


The Initial INTO-CPS Vision

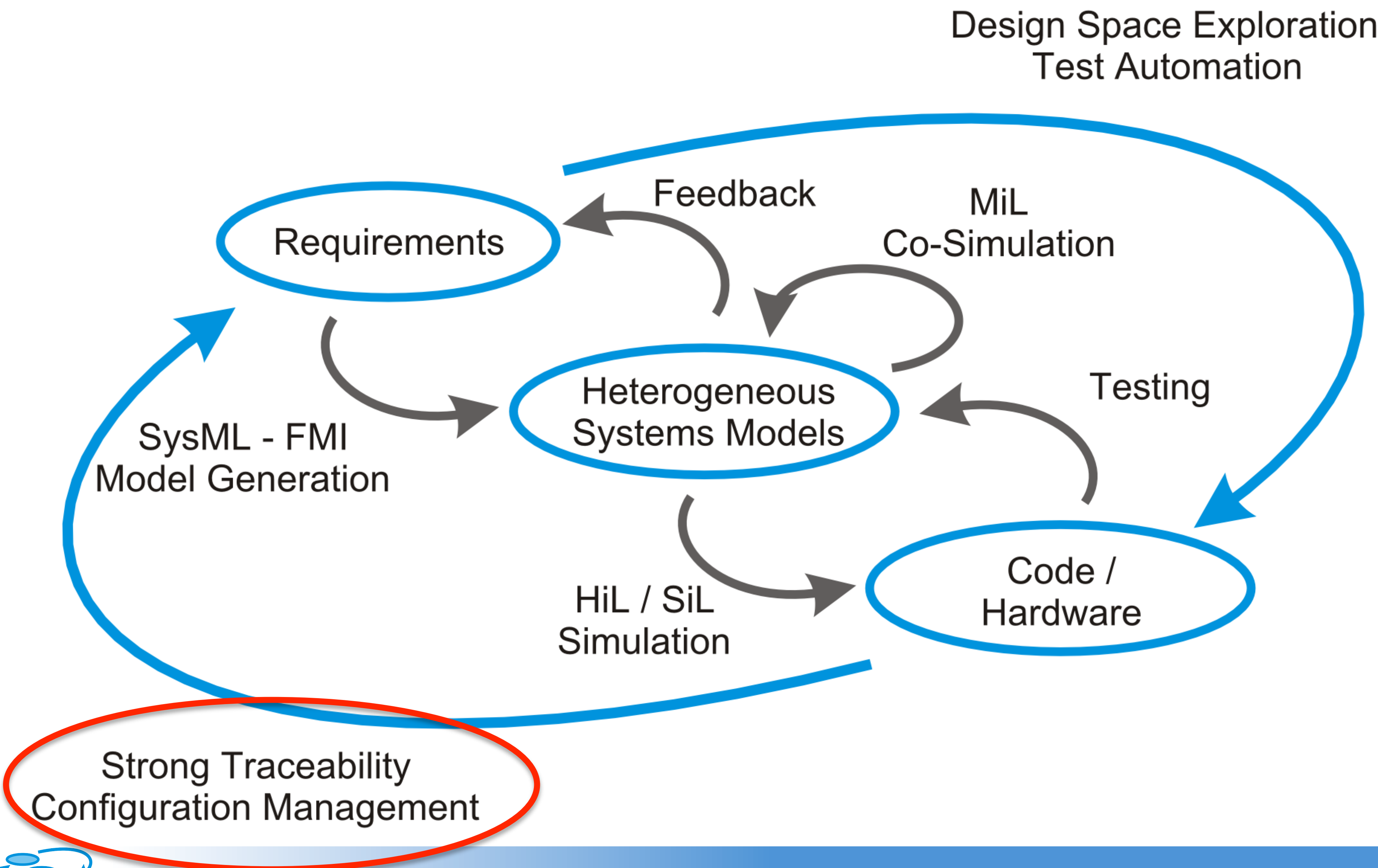


Co-model Development

- Model fidelity influence simulation speed
  Methodology: Ideal -> Reality -> Faulty
- DE/CT/Contract(interface)-first



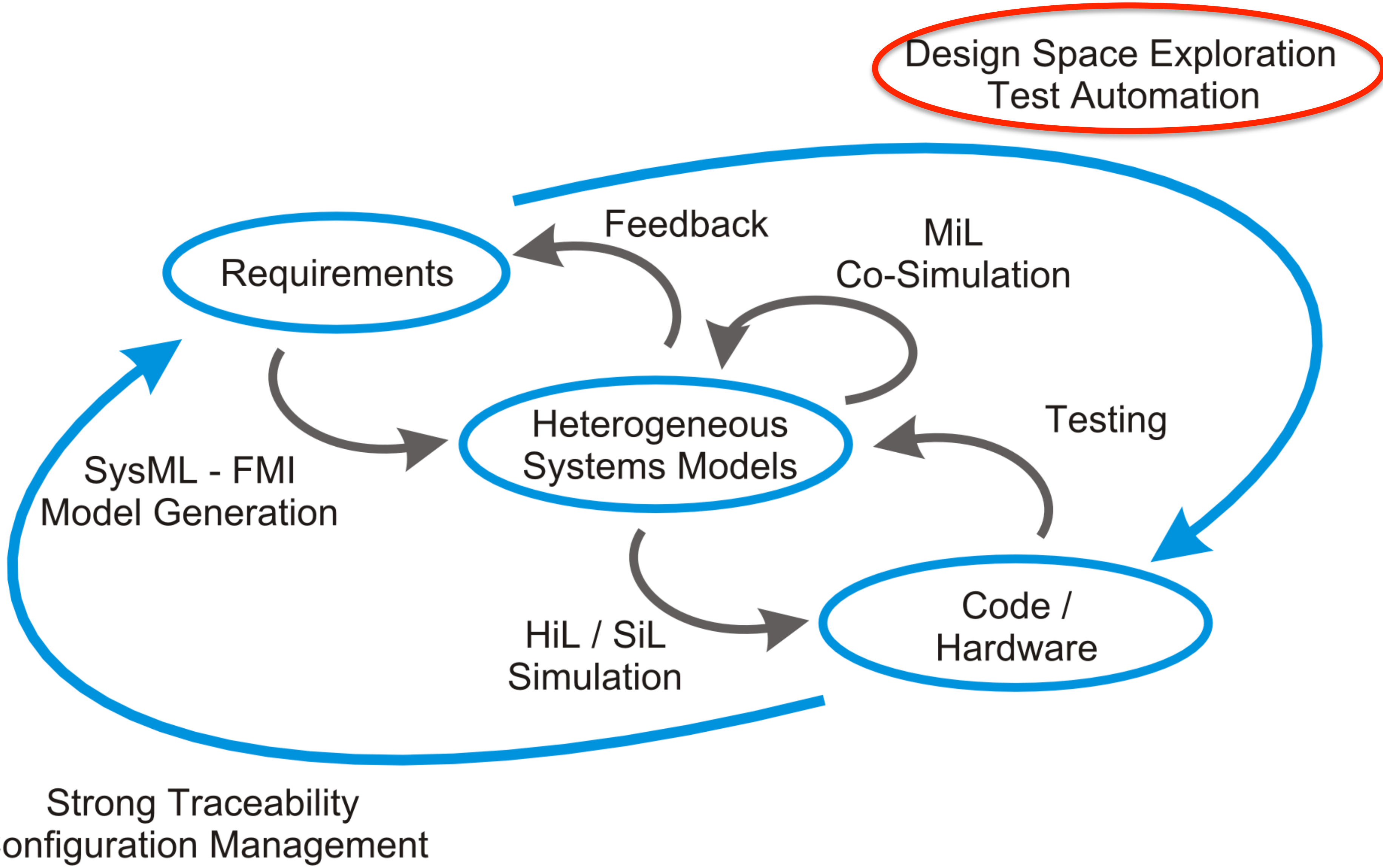
The Initial INTO-CPS Vision



Co-model Traceability

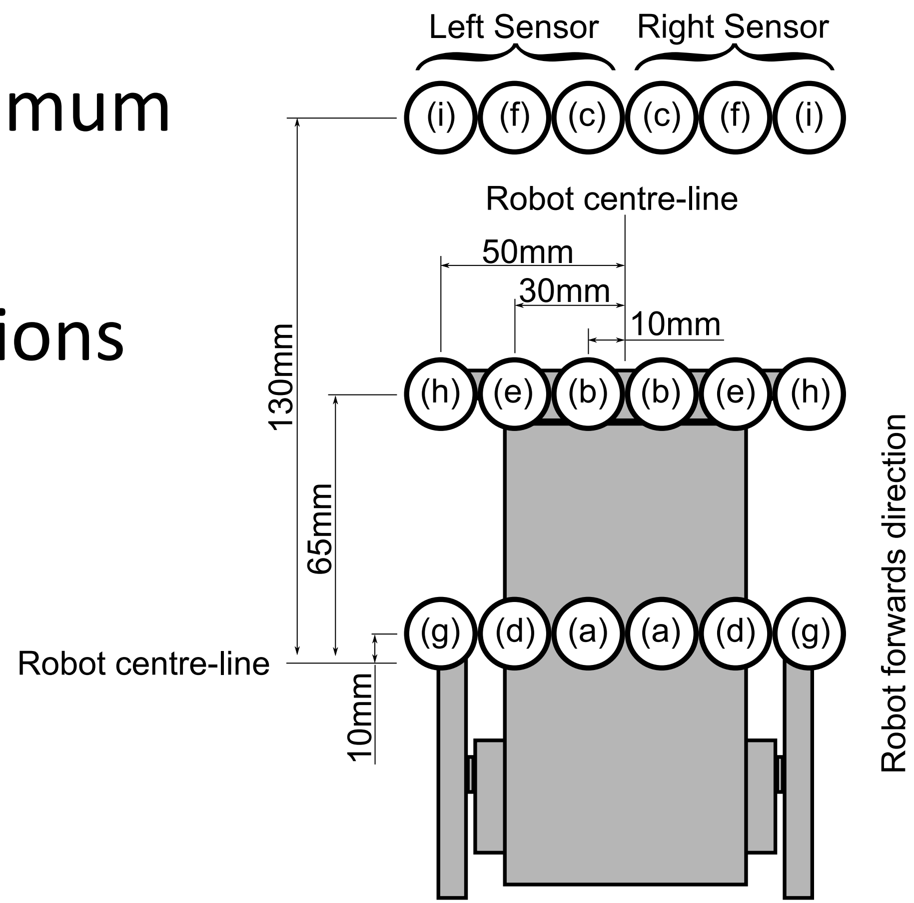
- Trace of model artifacts
  - Can be accessed both from VCS and graphically
  - Show multiple models and their properties
  - When multiple possibilities exist, use Design Space Exploration experiment design
  - If component can be finite, use model checking partially automated from semantics of model
  - Trace of model results/evidence

The Initial INTO-CPS Vision



Design Space Exploration

- Determine significant dimensions
- Design experiments
- Start sweeping to find optimum
- Determine fault tolerance
- Choose desired configurations



Co-model Development

- When experiments show the model is fit for purpose, create co-model for Design Space Exploration
- When experiments show the model is fit for purpose, start test automation
- When experiments show the model is ready, gradually incorporate SiL + HiL in simulator
- User able to get an overview of development and evidence produced (access from different tools)

Any questions?