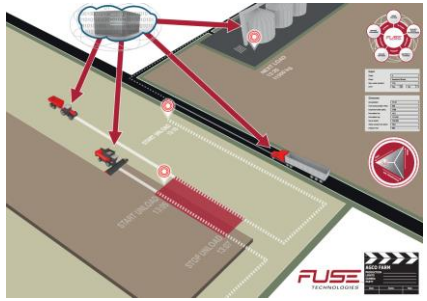
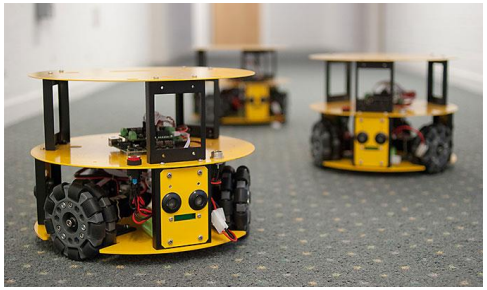
Introduction to Modelling of Cyber-Physical Systems (CPSs)

Slides partially taken from the INTO-CPS Association: https://into-cps.org/

What is a Cyber-Physical System?

- Systems of interacting systems
  - Computing elements
  - Physical elements
  - Human interactions
- Complex, networked character
- Distributed control
- Error detection and recovery



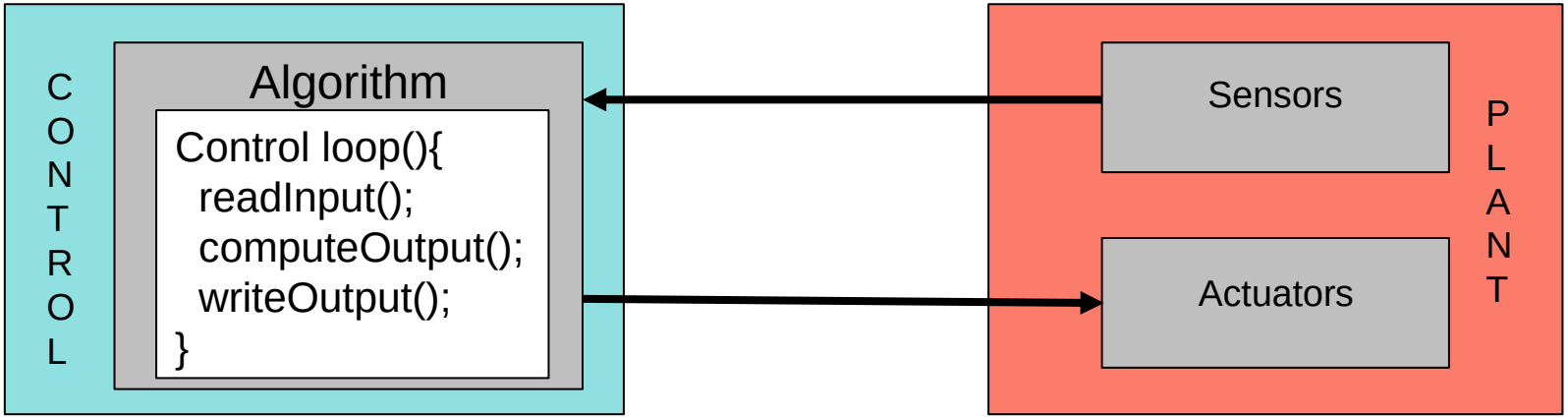


High level representation: Control + Plant

Cyber Physical Systems: discrete control component with continuous-time plant.

Distinct model formalisms

- discrete systems: discrete math
- continuous systems: differential equations



What is a CPS composed of

CPS consist of a discrete-time component embedded in a continuous-time plant, and in most cases have safety requirements.

Modelling and simulation formalisms for discrete systems and those for continuous systems are distinct

- discrete systems: evolve through a set of states (e.g.,Statecharts, Timed Automata)
- continuous systems: described by a set of variables whose value changes continuously according to a set of laws, usually defined by differential equations (e.g., Matlab, OpenModelica)

The two subsystems should be modeled in the appropriate formalism, also because digital control experts may not be familiar with plant modelling, and conversely

Besides being validated by simulation and testing, they should be formally verified too

CPS Engineering Needs

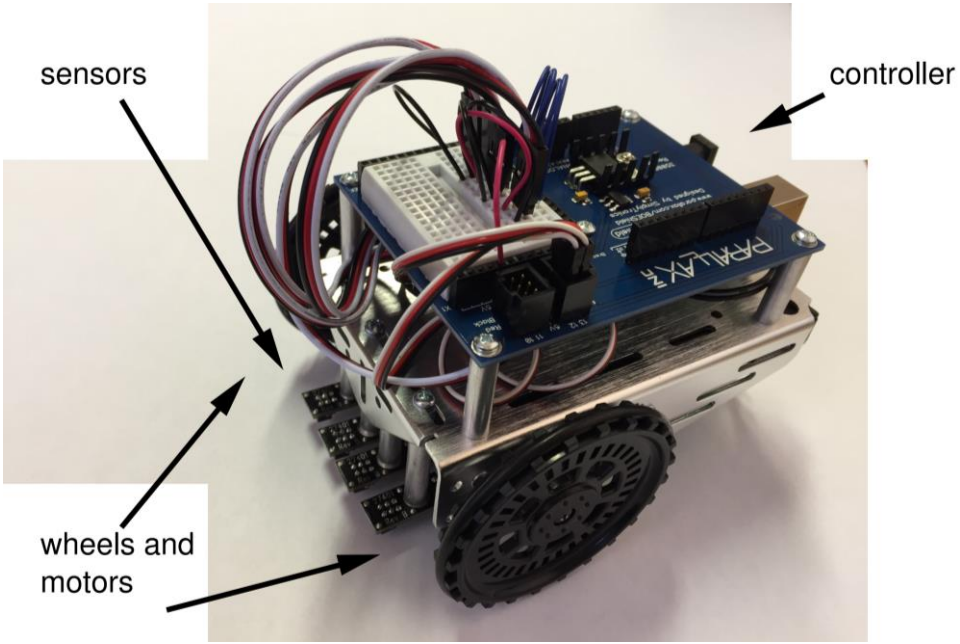
- Enable collaboration across disciplines
- Keep development costs low
- Keep time-to-market short
- Explore the complex design space efficiently
- Ensure tolerance against “nasty” faults
- Build up documentation for the working solution
- Provide confidence to external stakeholders

Example of CPS

The line contrasts from the background and the robot uses a number of sensors to detect light and dark areas on the ground

Equipment:

- 4 light sensors
- 2 wheels (with motors)
- 1 Arduino board
- 6 Batteries



INTO-CPS Association in a nutshell

Advocates:

- Cyber-Physical Systems Engineering
  - The product is a system: software is not the end!
- Multidisciplinary collaborative modelling
- (Co-) simulation as well as verification
  - Promotes Design Space Exploration
  - Entails well-founded co-simulation orchestration

Proposed approach:

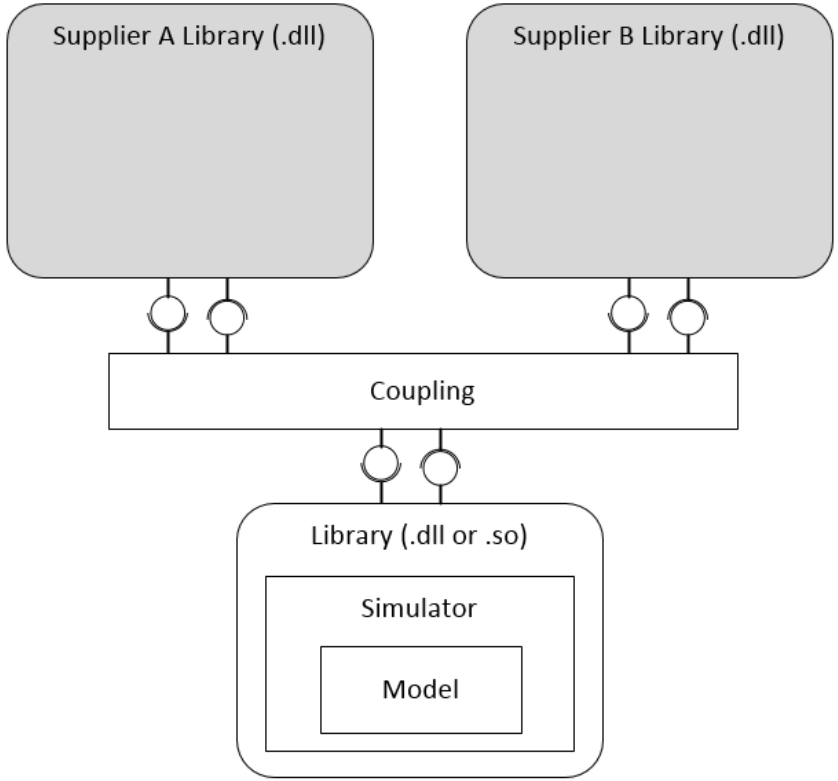
- Co-simulation of multiple Discrete Event and Continuous Time models
- A tool chain – not single tools
  - Requirements and Architectural models (in SysML)
  - Traceability support through development
- FMI interfaces constituent models
- Semantic foundations in Unifying Theories of Programming

What is Co-simulation?

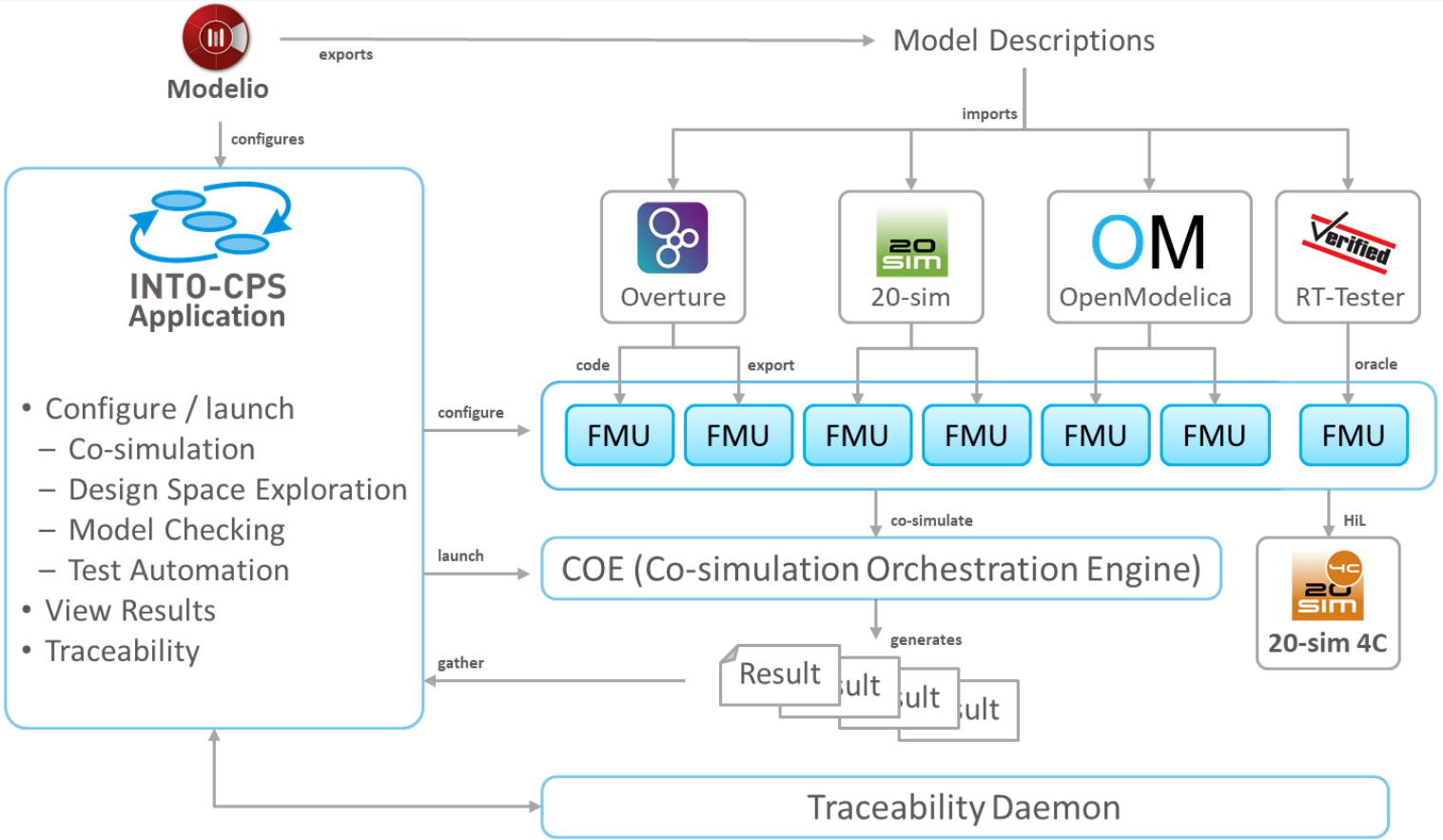
- Coupling of multiple simulators
  - Optionally as black-boxes
  - Each simulating one or more models
  - Built with different formalisms/tools.
- Co-simulation scenario
  - Description of the system
  - The simulators and their dependencies
  - Data about the capabilities of each simulator.

Functional Mock-up Interface Standard

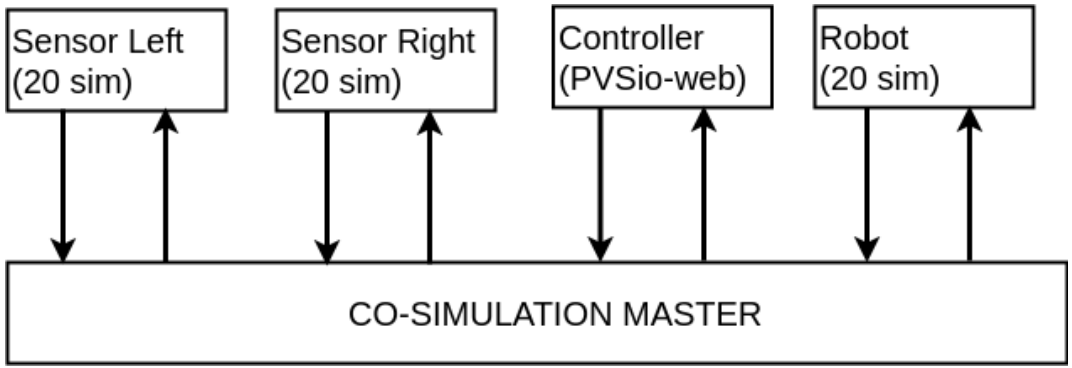
- Simulator and model exported as a standardized C library
- Standard interaction with any simulator
- Every simulator is a black box.
- Executed locally but can communicate with a remote server

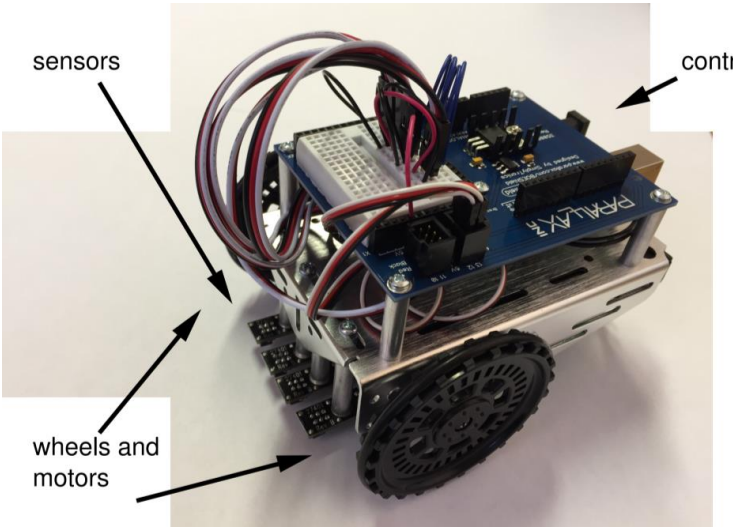


The INTO-CPS tool-chain



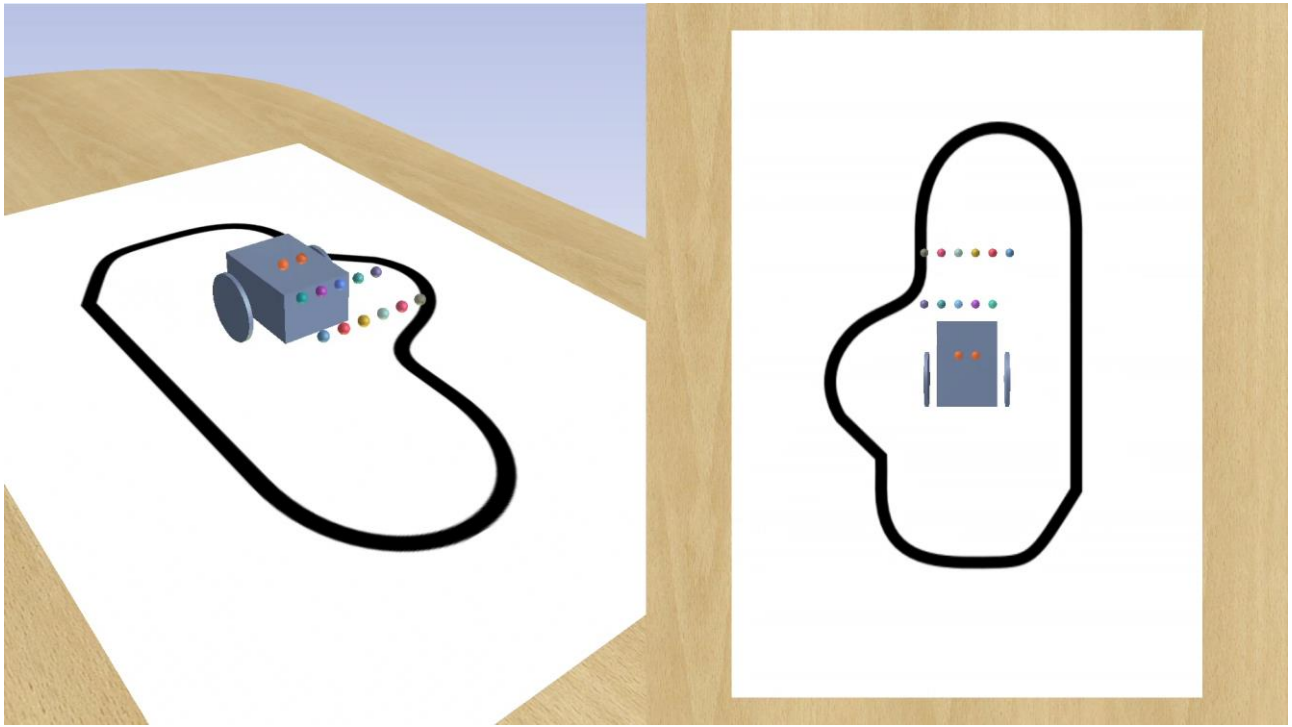
LFR co-simulation





Design Space Exploration

Explore the behavior of the system with different parameters



Let’s see what happens when we change the position of the light sensors of the line following robot

Solutions for CPS Engineering Needs

- Enable collaboration across disciplines
  - Collaborative well-founded tool chain
- Keep development costs low
  - Lower need for physical tests by virtual co-simulation examination
- Keep time-to-market short
  - Enable concurrent engineering and gradual integration
- Explore the complex design space efficiently
  - Using Design Space Exploration
- Ensure tolerance against “nasty” faults
  - Experiment with what-if scenarios in a virtual setting
- Build up documentation for the working solution
  - Using combination of ad-hoc and automated tests
- Provide confidence to external stakeholders
  - Traceability between all project artefacts