Short Overview

**openCPS**

COLLABORATIVE R&D ON METHODS, STANDARDS & OPEN SOURCE TOOLS FOR **EFFICIENT DEVELOPMENT OF CYBER-PHYSICAL SYSTEMS**

- Duration: December 2015 to December 2018
- 4 countries: Sweden, France, Finland, Hungary
- Current status: 46 Person Years, 6.3 M€, 18 partners
Top 3 Key Innovation Areas

Overall aim: Increase **front loading** capability in development of cyber-physical systems by enabling **large-scale simulation**

1. FMI Master Simulation Tool including UML/Modelica Interoperability
2. State Machine and Real-Time Debugging & Validation
3. Efficient Multi-Core Simulation
Top 3 Key Innovation Areas

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Validation of project results in **advanced industrial demonstrators**!
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Current SotA in M&S of Aircraft Vehicle Systems
- Simulation of individual physical subsystems using detailed equation-based models
- Simulation of complete aircraft using simplified models of physical systems
- **Need**: Simulation of several connected subsystems using detailed models
**Work Packages**

- **WP1**: Management
- **WP2**: Base Runtime System
- **WP3**: Translation and Validation
- **WP4**: Debugging and Testing
- **WP5**: Efficient Multi-Core Simulation
- **WP6**: Industrial Demonstrators

- **FMI Master Simulation Tool including UML/Modelica Interoperability**
- **Efficient Multi-Core Simulation Optimization**

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**Industrial Requirements & Results Validation**
Enabling focus on key innovations

- **Strong focus on the core collaborative development effort:**
  - OpenCPS FMI Master Simulation Tool *OMSimulator*
    - Integrated Project Team including key developers and end-users
    - Prioritized backlog linked to end-user requirements, enabling iterative development and continuous monitoring
    - Github and automated testing

- **Successful delivery of tool supporting industrial demonstrators**
Open Source & Dissemination Strategy

- Well established open source consortiums including several project partners, further developing & disseminating project results
  - Open Source Modelica Consortium (OSMC)
  - Papyrus Industrial Consortium & Eclipse foundation
  - Project results publicly available in latest versions of OpenModelica & Papyrus

- Standardization activities
  - OMG: Proposal on UML state-machine execution semantics accepted
  - FMI & SSP: Ongoing coordination on improved support for discrete-time systems & Transmission Line Method (TLM) co-simulation, FMI Change Proposal submitted
  - Modelica Association: Promote and standardize results related to Modelica language, e.g. code generation and V&V of Modelica models

- Partners engaged in dissemination of project results, >70 documented papers and presentations
  - In-house at industry partners
  - Workshops & conferences: Both in M&S communities and industrial application domains
  - Public project website
Energy Demonstrators - Business case

**Challenges**
Frequency quality of Nordic Grid is deteriorating
Grid frequency variations are increasing

**KPI Targets**
Methods & tools ready for exploitation in subsystem closed-loop environment & energy system simulators
Detailed knowledge required for industrial use and further development of OMSimulator
Power energy demonstrator - OMSimulator enable promising results for efficient distributed co-simulation of several connected detailed subsystem models incl. human factors
Heat Recovery Steam Generator in the Joint Energy Demonstrator

Compressor
Combustion chamber
Turbine
Steam generator (boiler)

Gas turbine
TAC(GT)

Generator
Connected to KTH grid model
Replaced with Siemens GT model
Heat provided to EQUA district heating network model

Heat exchangers

Steam turbine
ST

Connected to KTH grid model
Replaced with Siemens GT model
Heat provided to EQUA district heating network model
Simulation of Complex Systems
Energy Co-simulation

Goal
Simulate a combined cycle power station with huge detailed accurate models from different suppliers, provided as FMUs
To have an accurate result requires very long execution times due to:
- a need to set low error tolerance and use a short communication interval
- Inaccurate: 24 minutes
- Accurate: 500 h (estimated from present results)
The result depends upon application

The result improves by:
- Shortening communication interval
- Reducing the error tolerance

The HRSG connected to GT reveals good accuracy, deviations seen are caused by the deviation in GT power shown above
Improvements to the state-of-the-art

- Ability to use open source Modelica tool for the modelling and simulation of power plants (and energy systems at large).

- Ability to reuse verified Modelica models for data reconciliation (ability to identify faulty sensors and improve the quality of measurements by reducing uncertainties).
Cyber-Physical Simulation Application Model interact with physical instances

Examples of business use cases:
• Early warning & increased availability
• Fault detection & diagnostic
• Predictive maintenance
• Increased customer value
• ...
Cyber-Physical Simulation Application Model interact with physical instances

1. Problem:
   Continuous load variation at site tears out guide vane

2. Detection:
   Complains from customer
   Mimic the behavior with model

3. Solution:
   New control feature to be implemented
   New control tested and adjusted before implementation

4. Result:
   Positive response from customer
   Guide vane operation more smooth preventing tear out

5. Closing the Loop:
   Agent implemented in supervision system
   Supervision system detects and warns at similar operation
The Demonstrators is an example of good collaboration between Universities and Industry.

It's the first large scale multi-FMU test of complex energy systems.

The FMU technology enable wide spread use of advanced simulation at low cost.

Good behavior models based on algorithms is fundamental for e.g. Machine Learning and AI technology.