Modeling Intelligent Energy Systems

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Smart Nord 10.2.2015

Peter Palensky

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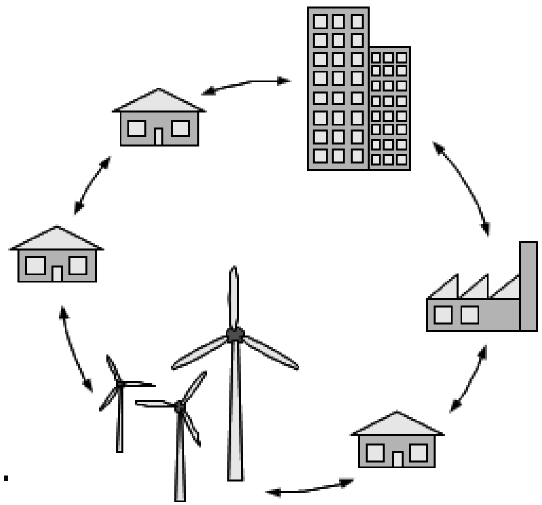
  - Faculty for Electrical Engineering, Computer Science and Mathematics
  - Department for Electrical Sustainable Energy
  - Prof ¨Intelligent electric power grids¨
- Worked in Russia, Germany, Korea, South Africa, California, Austria
- Methods/Theory for hybrid energy systems
  - Modeling, Simulation
  - Optimization
- Applications for hybrid energy systems
  - Controls, Stability
  - Integration

The future power system



- Expectations
  - Increased share of renewable energy sources
  - Host new applications like electric vehicles or cooperative loads
  - Optimized, resilient, flexible, robust, globalized, etc.
- That leads to an increment in:
  - Distributed structure
  - Control and management
  - New energy technologies & markets
  - Links to other “systems”

- **Complex (hybrid / cyber-physical) power systems**

Example Project / Motivation

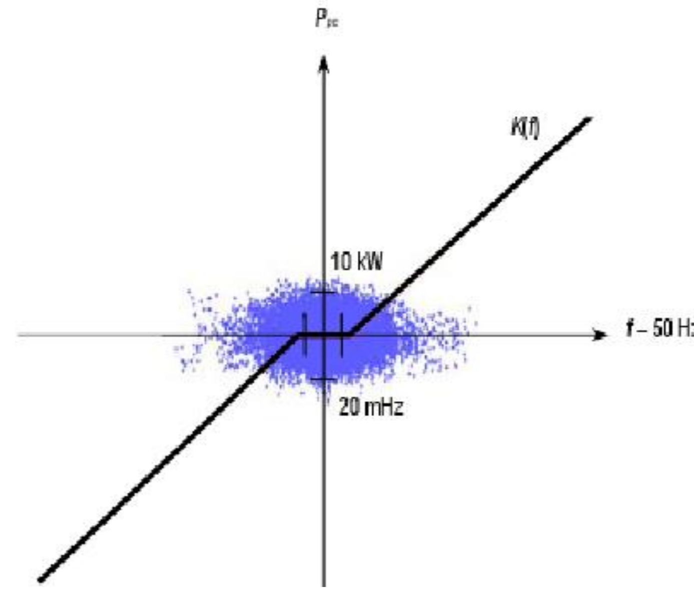
EcoGrid eu
www.eu-ecogrid.net

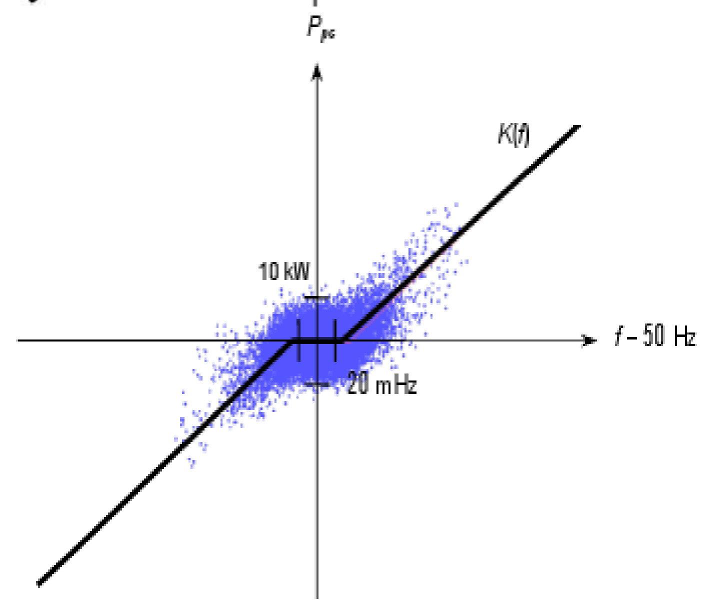
- New energy market design and implementation
- Model-predictive load shed/shift
- Interoperability of equipment
- Information security
- System integration
  - PowerMatcher, DEMS, grid plausibility, market platform, CellControler, etc.
  - OpenADR
- Fine grained distribution grid model parameters
- Intelligent demand side

DEMS: Decentralized Energy Management System (Siemens)
OpenADR: Open Automated Demand Response

Intelligent Loads

- Refrigerators as regulation power providers
- Frequency-dependent setpoint adjustment
- Distributed droop control

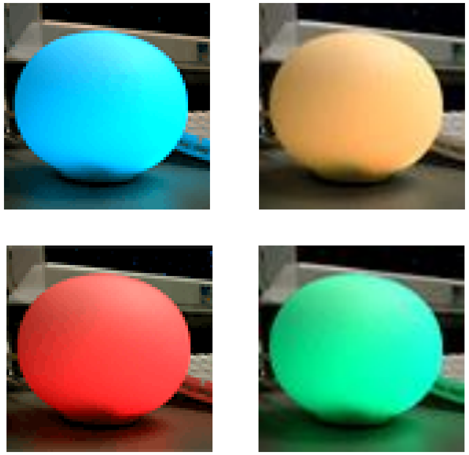




Intelligent Loads

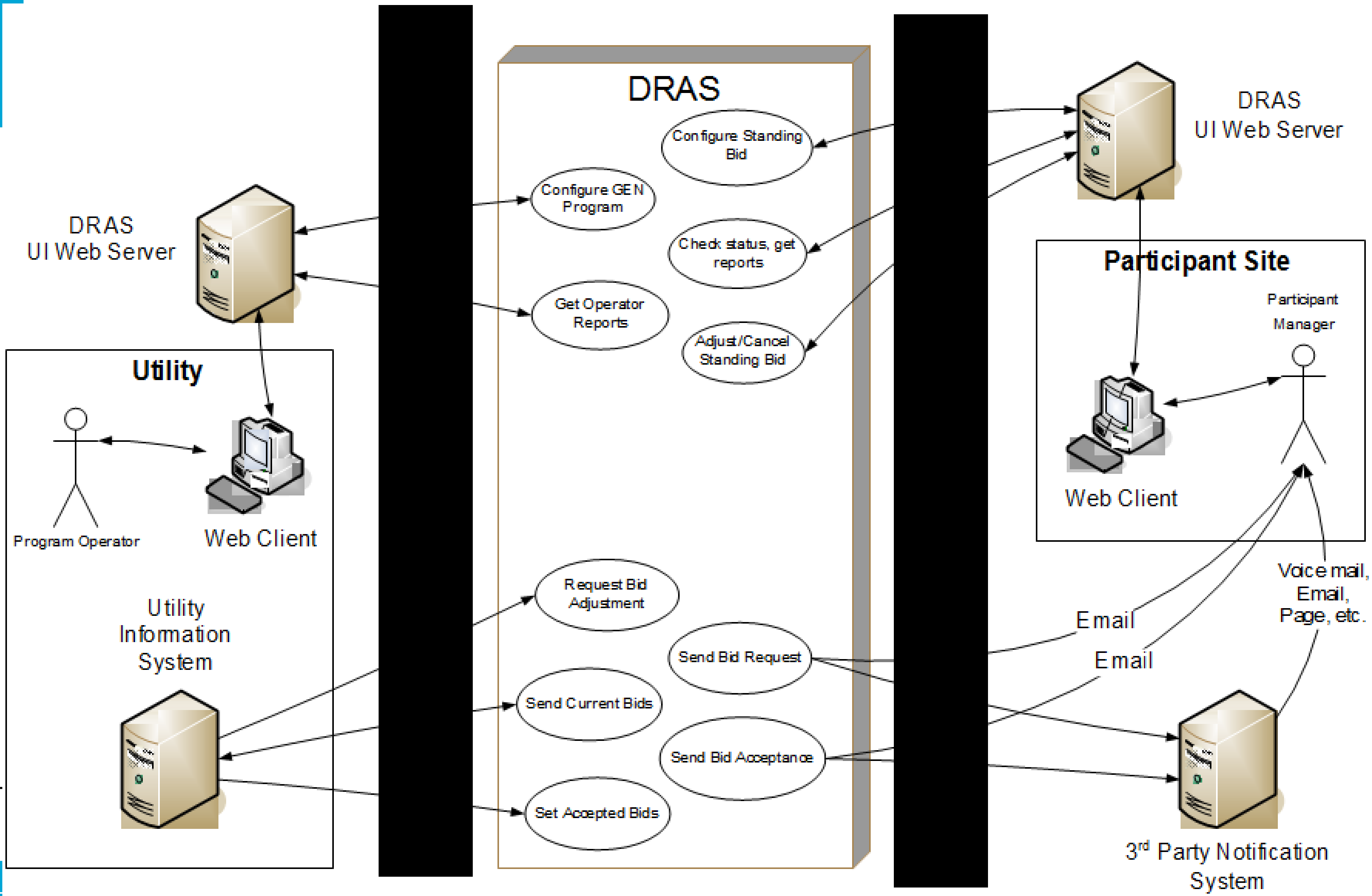
- “GridFriendly” (PNNL)
- KNIVES (Japan)
- California
  - ORB
  - Smart AC
  - PCT
- “50.2 Hz problem” with 10 GW PV inverters in Germany 2011?

The Grid Friendly™ controller uses data from the power grid to balance energy supply and demand.



PNNL: Pacific Northwest National Laboratory
AC: Air Conditioning
PCT: Programmable Communicating Thermostat
PV: Photovoltaics

Intelligent Loads (OpenADR, bidding)



Research on future power systems

- Usually: Experimental
- Wanted: Model-based

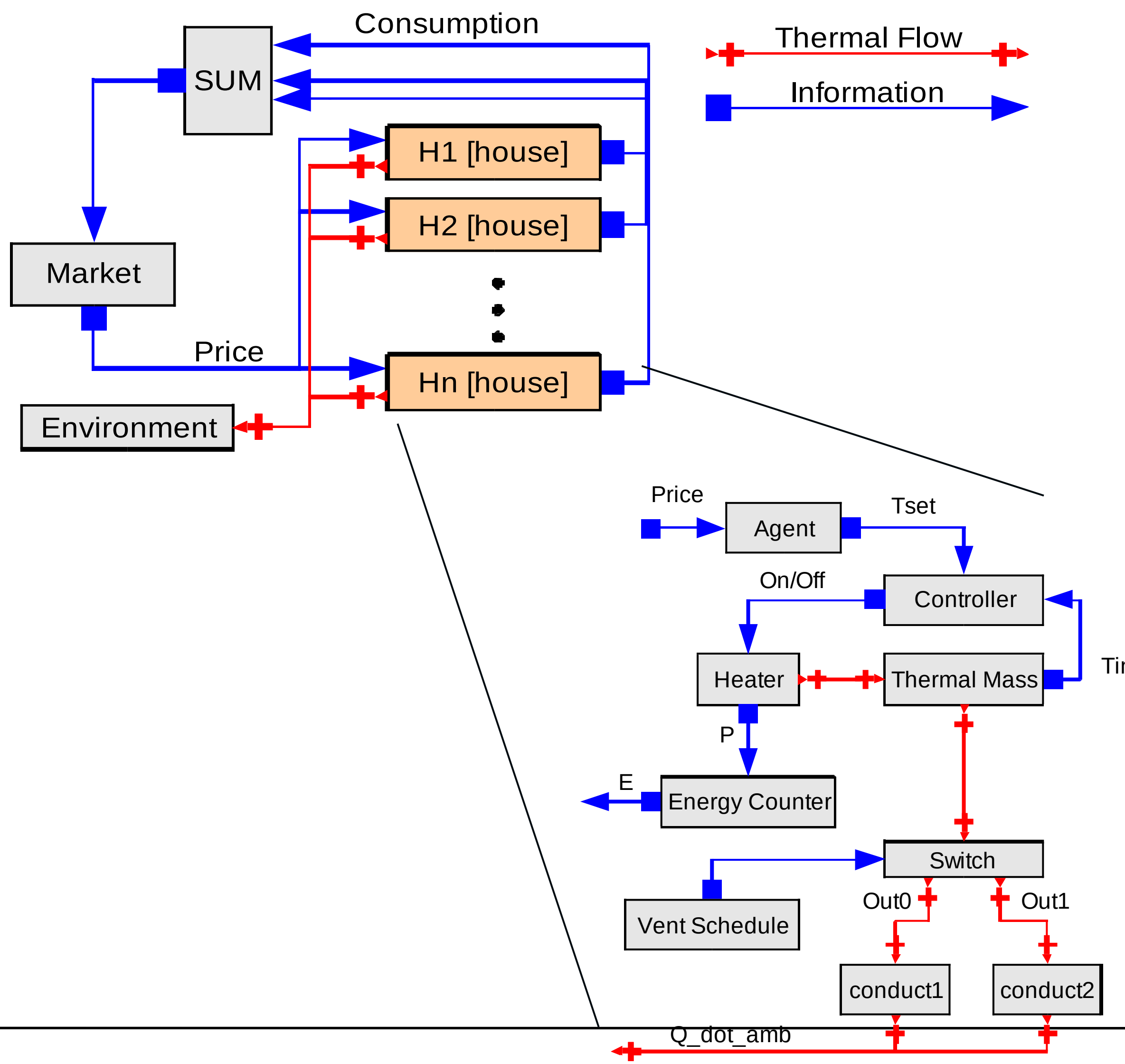
- Four fundamental types of hybrid system elements
  - **Continuous**: energy technology, infrastructure, physics
  - **Discrete**: ICT, software, controls, communication
  - **Game Theory**: markets, market players, roles, agents
  - **Stochastic**: weather, people, aggregated/not-modeled behavior, statistics

- Scalability
  - Large (interconnected grids) <-> Small (microgrids)
    Quick (frequency balance, harmonics) <-> Slow (weather, fuel price, demographics)

Use Case 1: Simple Hybrid System

- Thermal domain
- Discrete controller
- Agents/Market
- Stochastic events

- Describe via bond graph
- Analyze interplay of continuous domain and asynchronous events
- Scalability of platforms

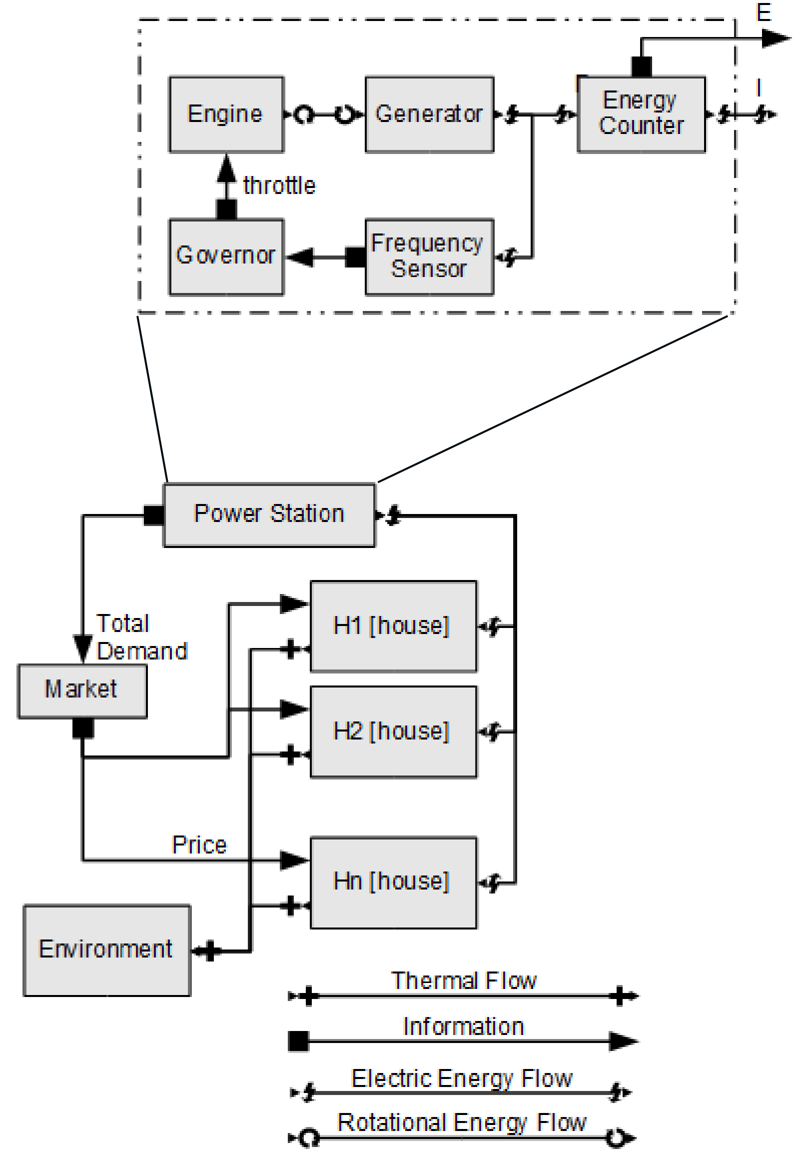


Use Case 2: el. power station

- Physical parts not isolated
- Plus: Electrical domain
  - Ideal grid
  - Non-ideal power station
- Plus: Mechanical domain

- Further use cases
  - 3: Thermal grid
  - 4: Non-trivial market
  - 5: Communication network
  - 6: non-ideal grid
  - 7: EV-charging

EV: electric vehicle



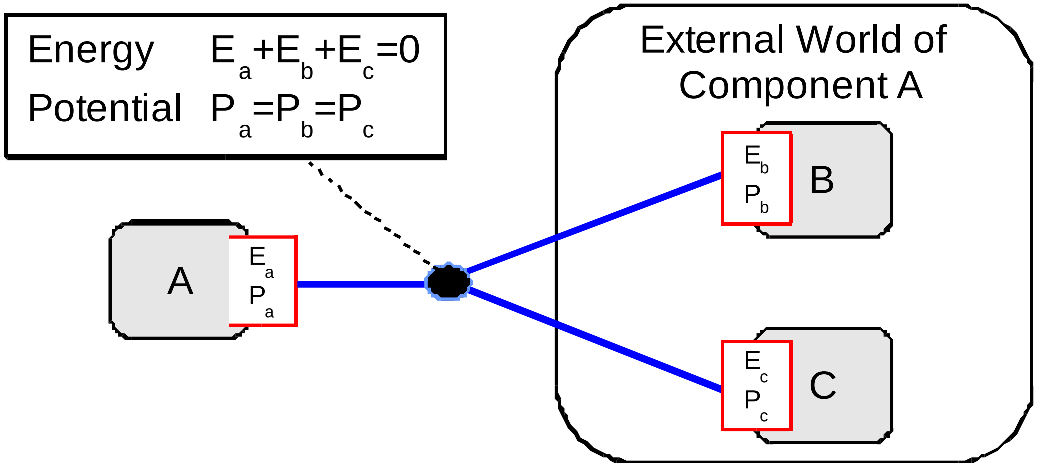
Two types of Modeling Paradigms

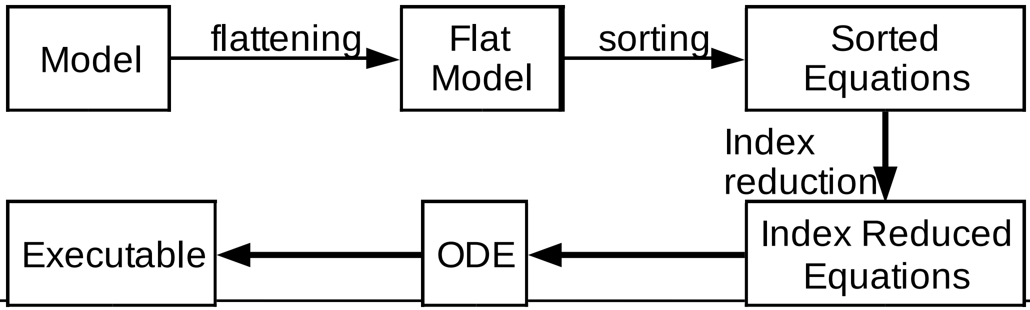
- Agent-oriented
  - Autonomous modules
  - Components determine synchronization points
  - Examples: GridLAB-D, Omnet++
- Monolithic
  - Equation-based model of physics -> ODE-> code
  - Solver integrates and tries to find zero crossings
  - Examples: Modelica, Simscape

ODE: Ordinary Differential Equations

Monolithic Modeling

- E.g.: Simscape, Modelica
- PRO
  - Convenient
  - Multi-domain physics
  - Strong syntax
  - Good docu
- CON
  - Low Performance
  - Closed platforms?





Modelica / Simscape code example

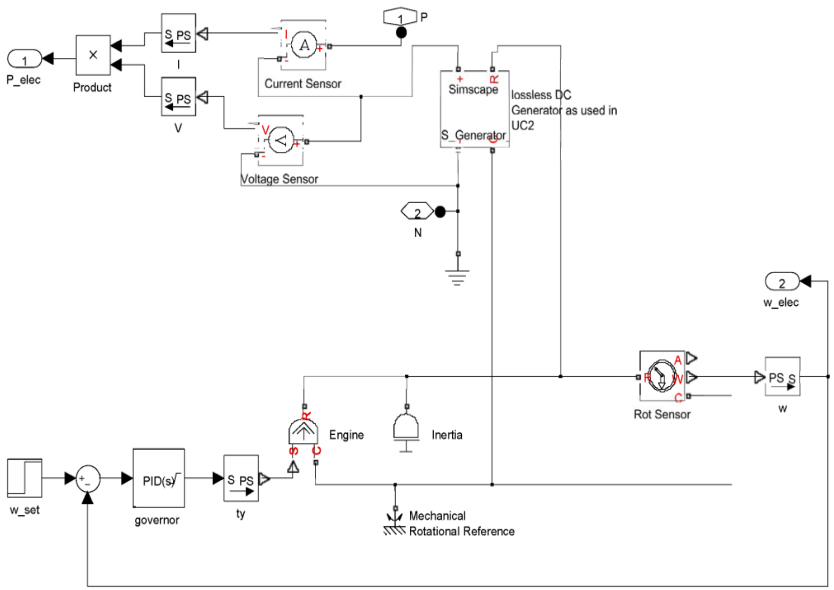
.

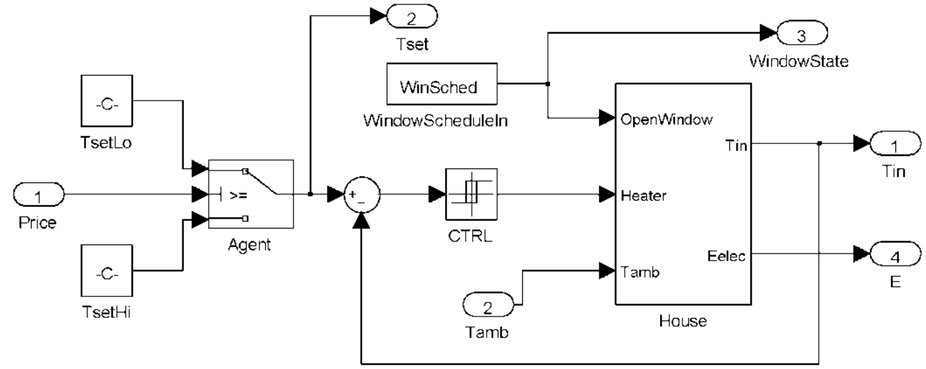
```
package Energy
  package Interfaces
    partial connector
HeatPort
         "Thermal port for 1-
dim. Heat transfer"
      Types.Temperature T;
      flow Types.HeatFlowRate
Q_flow;
    end HeatPort;
    ...
  end Interfaces;
  package Components
    model House4
"House lumped thermal heat"
       Types.Temperature T(st
art=20 + 273.15,

displayUnit="degC") "Temperat
ure of element";
       parameter Energy.Types
.ThermalCapacity

Cth = 430.578  "Heat capacity
 of element";
       parameter Types.Densit
y ro = 1.2041;
       parameter Types.Volume
 volume = 200;
       Interfaces.HeatPort_a
port_a;
    equation
       T = port_a.T;
```

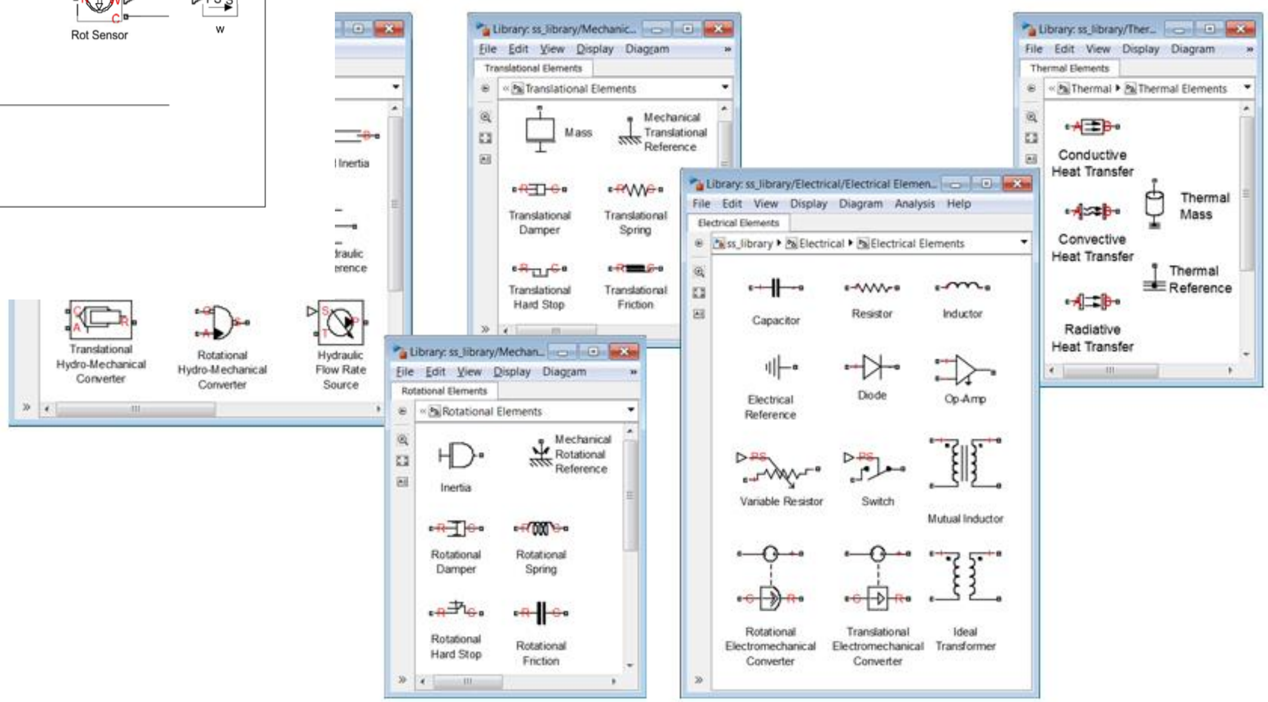
.

```
                    component ElHeater <
             foundation.electrical.branch
                                    nodes
                                      M =
           foundation.thermal.thermal; %
                                  B:right
                                      end

                                   inputs
             Level = { 0.50, '1' }; %
                                    :left
                                      end

                               parameters
                R = { 40, 'Ohm' };    %
                               Resistance
                                      end

                                variables
                       Q = { 0, 'J/s' };
                                      end

                           function setup
                through( Q, [], M.Q );
                                      end

                                equations
                         v == R*i*Level;
                                 Q == v*i;
                                      end
                                      end
```

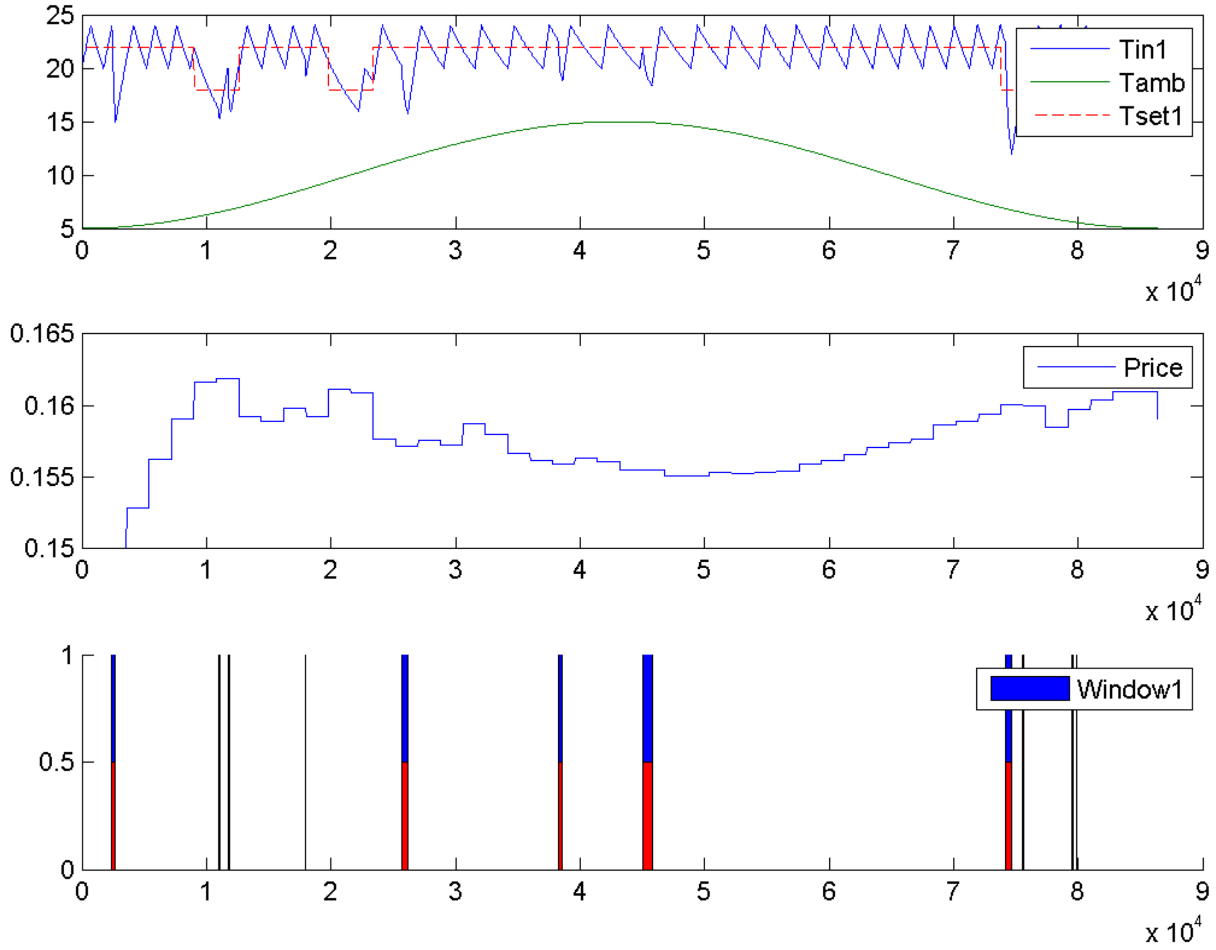
Multi physics, multi-everything...







Use Case 1 monolithic results



Good for components!

Events?

Scalability?

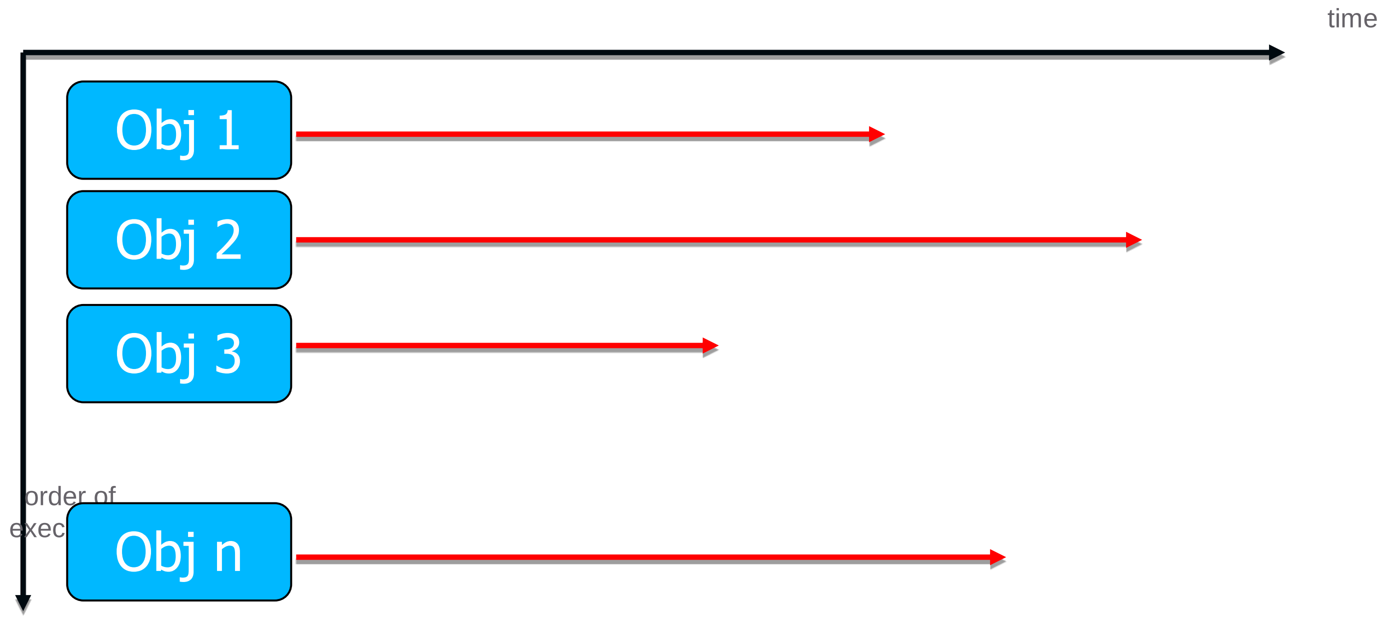
Libraries?

Agent oriented: GridLAB-D

- Simulation environment **specifically designed** for the analysis of modern power systems
    - open source, developed by PNNL
- Main features:
    - command line tool written in C/C++
        - runs under Windows (MSVC, MinGW, Cygwin) and Unices
    - flexible agent-based simulator
        - can model the behavior of many objects over time
    - comprises a modular design
        - buildings (residential, commercial, industrial)
        - electric network (generation, transmission, distribution, controllers, reliability)
        - markets (retail double auctions, transaction journals)
        - climate
    - implements a modeling language
        - parametric syntax for dynamic model generation
    - provides various simulation utilities
        - debugging, profiling, plotting, histogramming, write to file etc.

GridLAB-D: Results

- **Sophisticated time synchronization** of objects
  - **each** object has to **update** its **current state**
  - **each** object can tell when it wants to **update next**
- **Good for systems...**
- **Physics?, Libraries?**



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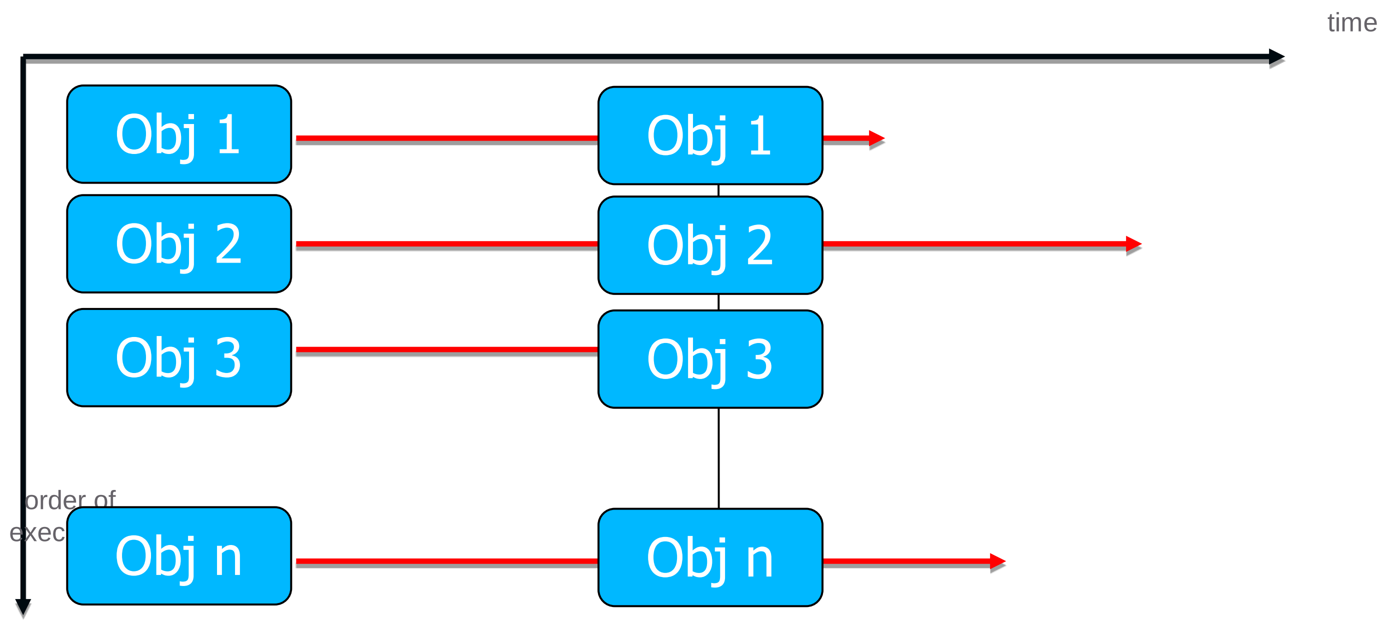

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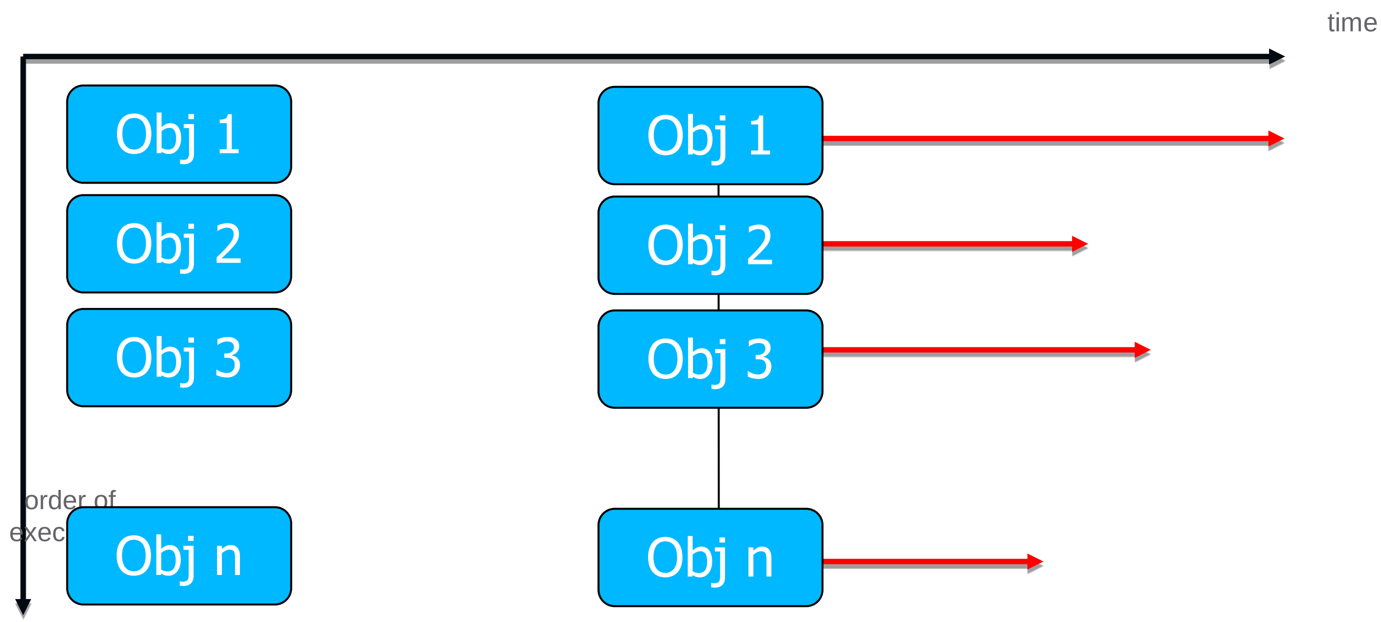
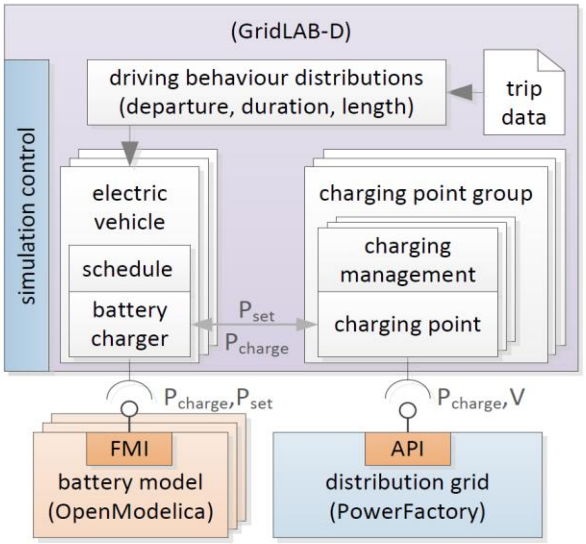


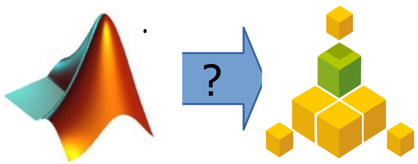
Co-simulation environment

- Many possible ways to couple simulations
- **Direct** coupling of tools
  - small overhead
  - typically not reusable
  - complicated for complex scenarios
- **Generic** coupling of tools
  - introduces overhead
  - reusable
  - more flexible

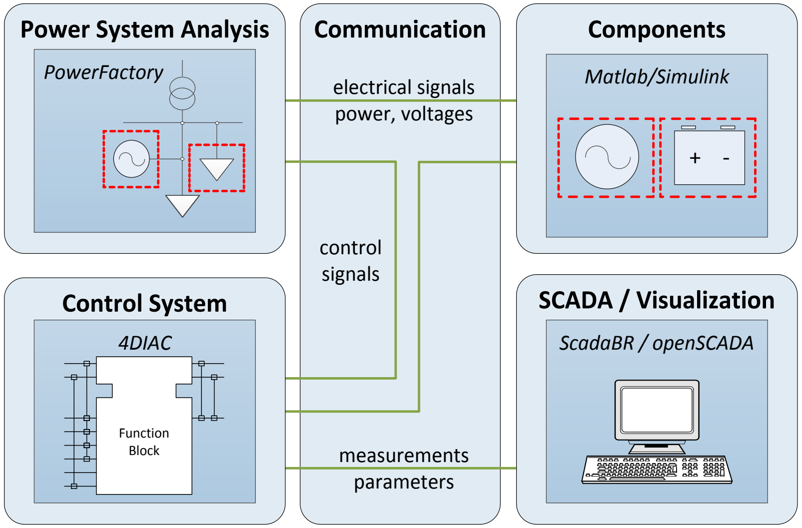
GridLAB-D
OpenModelica
PowerFactory



MATLAB **TRNSYS**



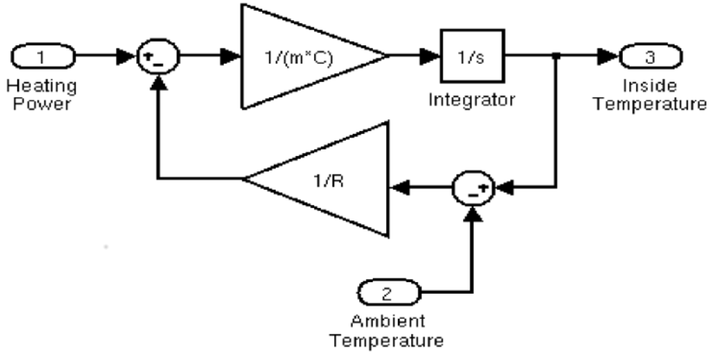
PowerFactory, OMNet++, 4DIAC, SCADA

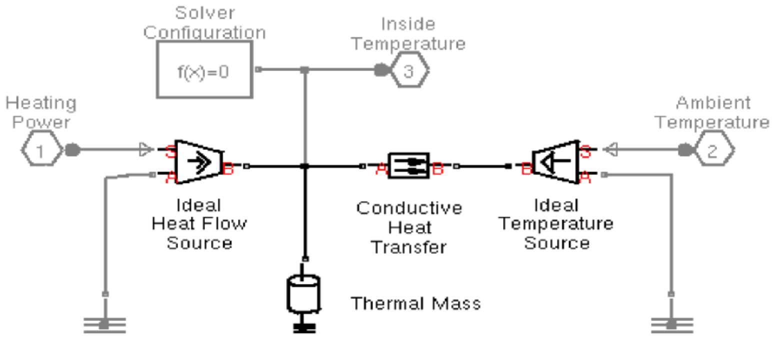


Physics: causal vs. acausal modeling

- Block diagrams are very suitable for modeling of controls/signal processing
  - each block represent a *set of equations*
    - typically ordinary differential equations (ODE)
  - connections define **uni-directional** (causal) relations *between* blocks
    - i.e. between input signals, output signals and state variables
  - use *numerical solver* (ODE integrator) to compute successive states of system

- **Bi-directional** (acausal) connections are more intuitive for physics modeling

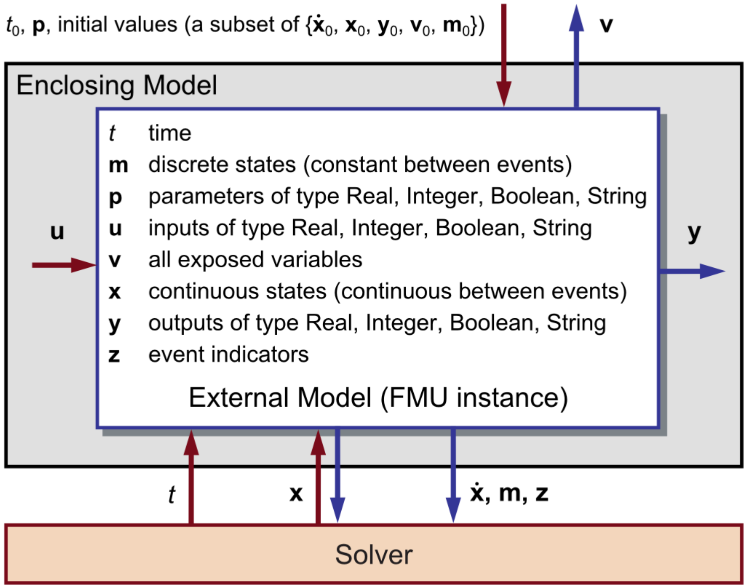




FMI for Model Exchange/Co-Simulation

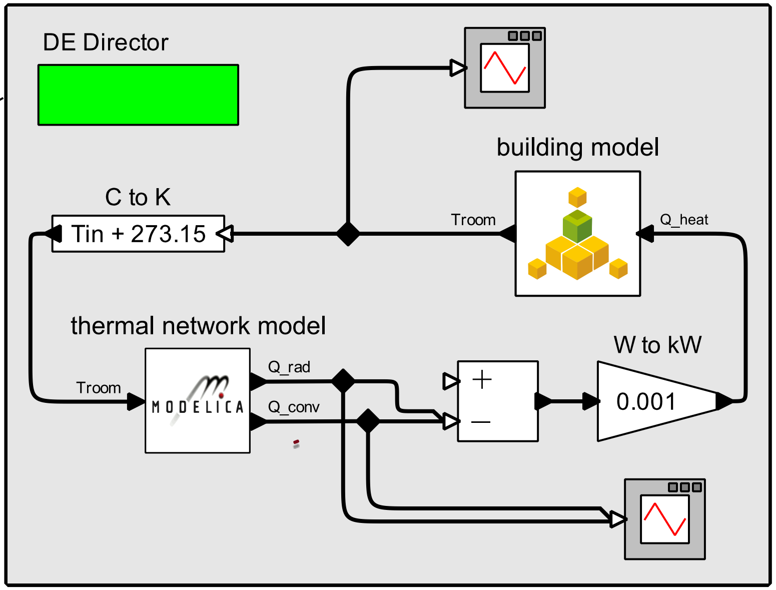
- Functional Mock-Up Unit
  - model *interface* (shared library)
  - model *description* (XML file)

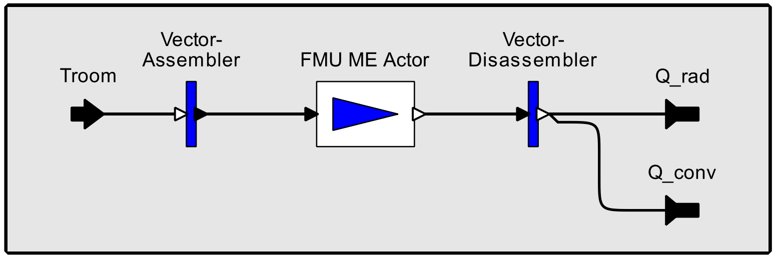
- Executable according to C API
  - *low-level* approach
  - most *fundamental* functionalities only
  - tool/platform *independent*
- FMI provides only well-defined access to the model
  - *master algorithm* definition left out on purpose!



Co-Simulation: thermal system simulation

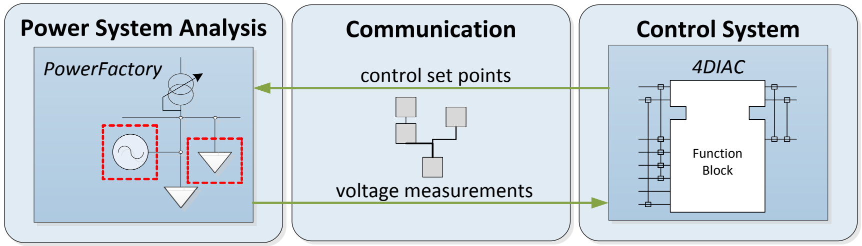
- *domain-specific* co-simulation components
  - developed by domain experts
- *generic coupling* via Ptolemy II & FMI++
- mixed use of FMUs for *Model Exchange* and *Co-Simulation*
  - make use of what is available
- mixed used of *dynamic* and *fixed step* simulation
  - handled automatically by the environment

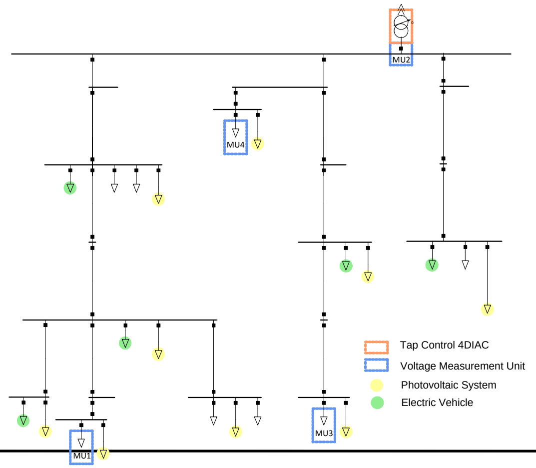


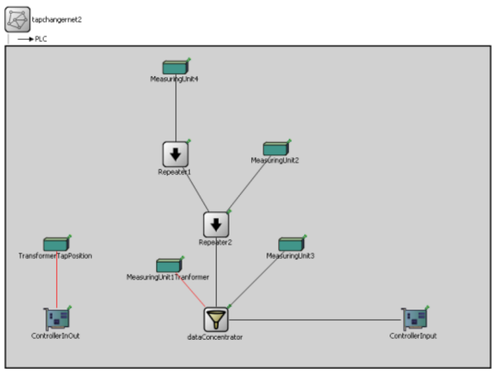


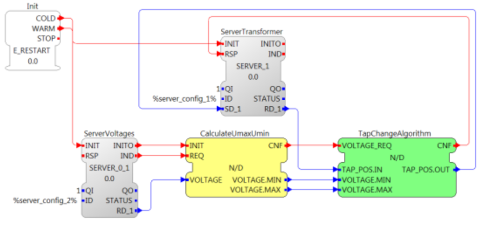
Co-Simulation: Power System, Communication & Controls

- Coupling of *event-based* and *continuous* simulation
- *Real-time* simulation
  - coupling with physical components (C-HIL)



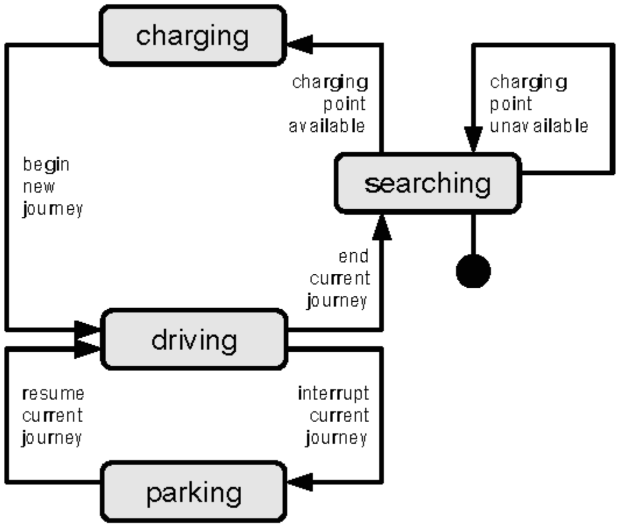


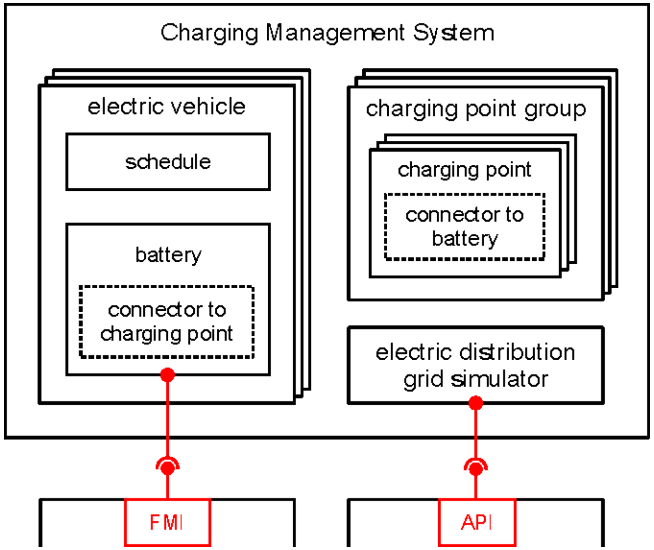




Co-Simulation of hybrid systems

- Usecase 7: Flexible EV Charging as real-time demand response
- Co-Simulation
  - Gridlab-D -> Middleware
  - OpenModelica –> Components (Batteries, etc.)
  - PowerFactory -> el. grid
- Standardized Interface: Functional Mockup Interface (FMI)
- Combination of highly accurate physical models and large-scale system

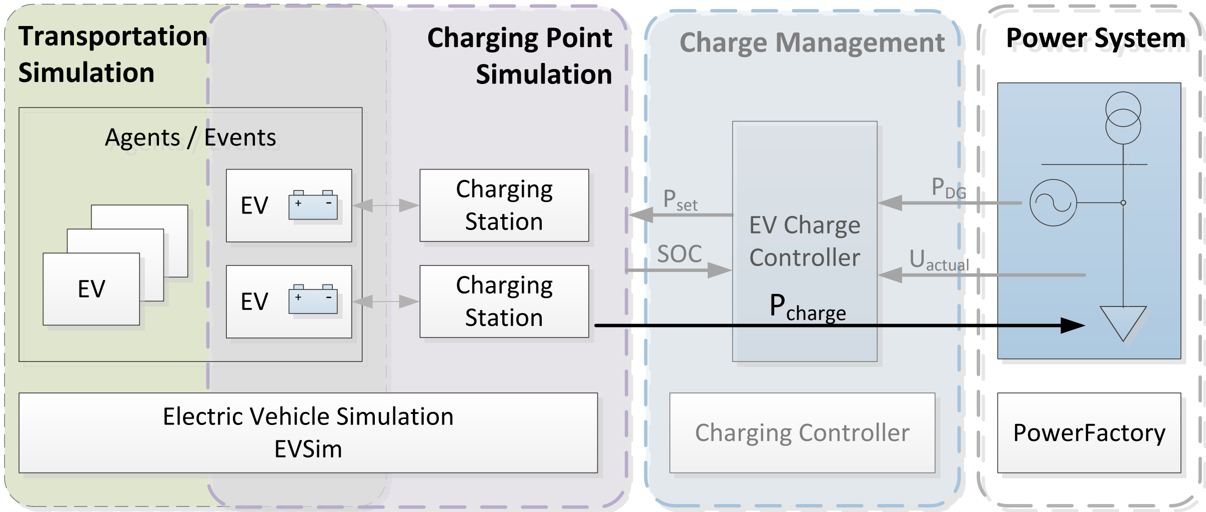


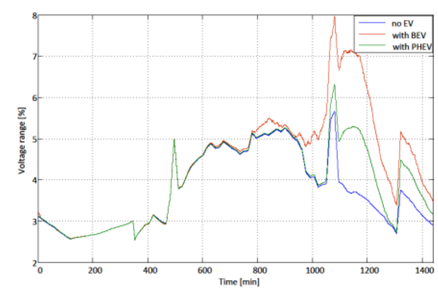


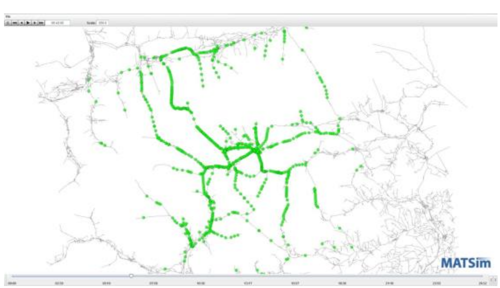
EV: Electric Vehicle

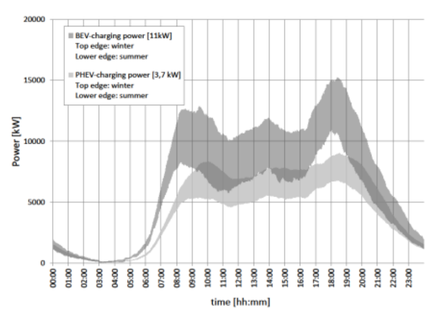
Use Case 7: MATSim, EVSim, PowerFactory

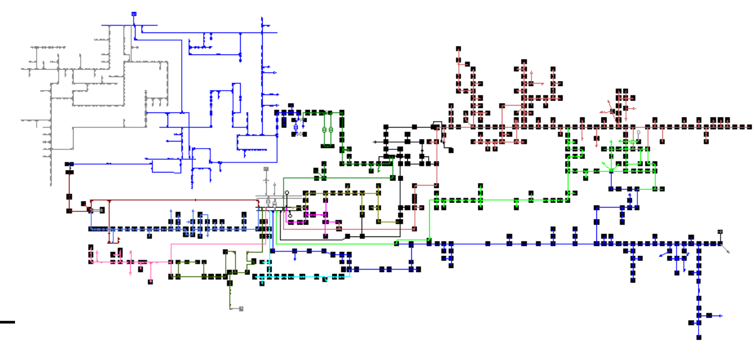
Simulation Environment



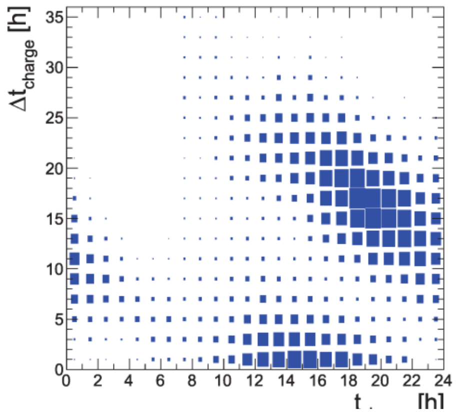


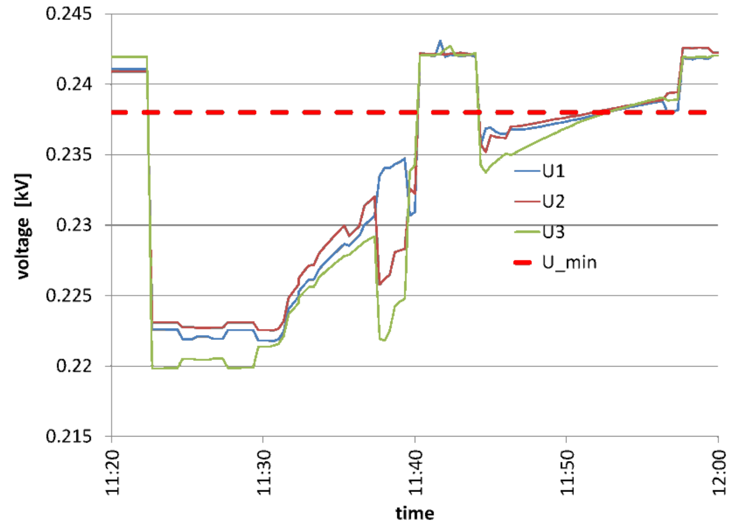


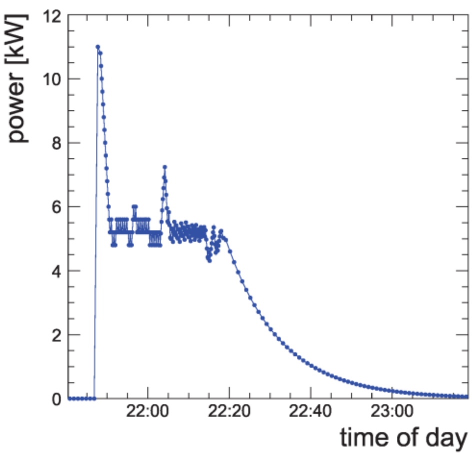


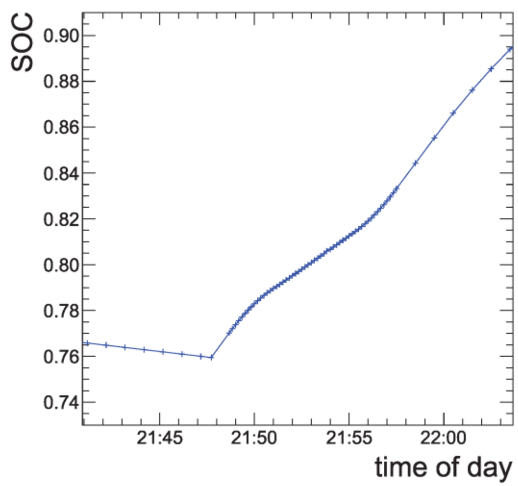


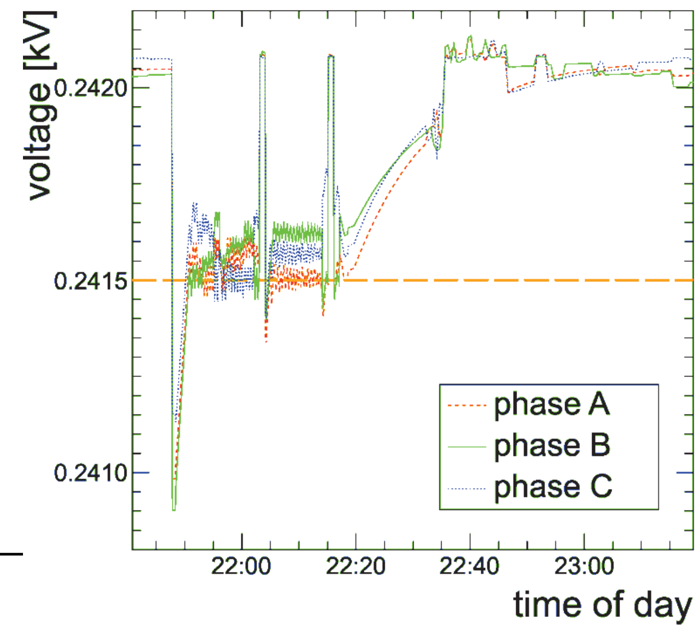
Co-Simulation Results







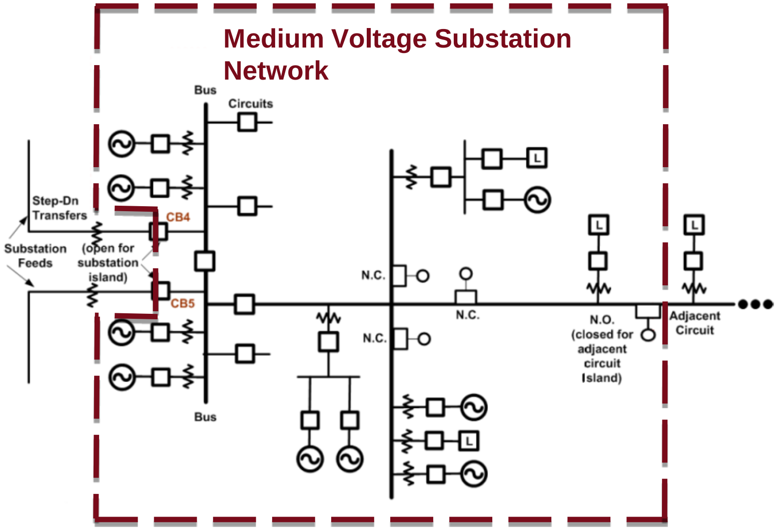


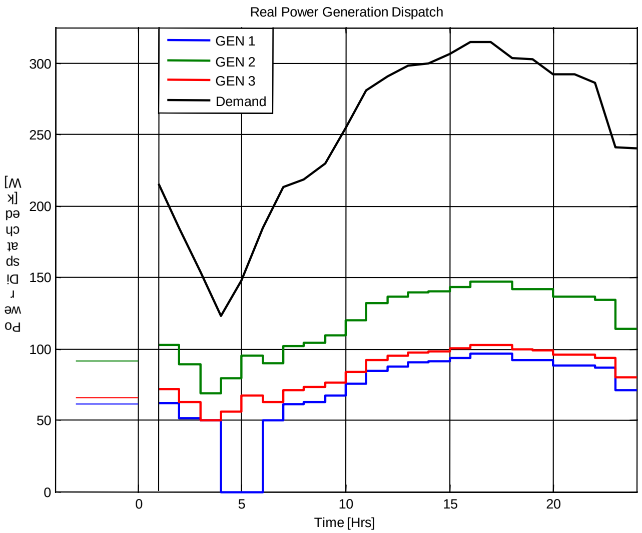


SOC: State of Charge

Optimization of complex systems

- Uncertainties, Constraints, Risk, etc.





Quadratic Optimization problem
Constraints : 1587
Scalar variables : 330
Integer variables : 120
Solver Used: MOSEK
Platform: Windows/64-X86

Objectives: Cost Minimization
Constraints:
Generator specific: Ramp rate, Minimum time for ON/OFF, power limits
Network Specific: Power flow constraints, bus voltage limit

Hot Topics 2015++

- **Fundamentals**: Modeling and Simulation of (complex) power grids
  - Co-simulation, Modelica for power, power and controller HIL, etc.
- **Application**: Distributed, network-based controls of power grids
  - Stability, scalability, structure, resilience, self-organization, etc.
- Interdisciplinary teams
  - Mathematics, Computer Science, Physics, Electrical Engineering
  - Policy making, Markets, Socio-economic phenomena
- International network
  - UC Berkeley/Berkeley National Lab (us), NREL (us)
  - TU Delft (nl), AIT (at), DTU (dk), OFFIS (de)

Thank you!

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