SIMULATION INTEGRATION PLATFORMS
FOR
TRANSACTIVE ENERGY STUDIES

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Presentation Outline:

1. Transactive Energy Concerns & Evaluation Needs
2. Introduction to Cyber-Physical Systems Wind Tunnel (CPSWT) – A General-Purpose, Highly Reconfigurable Heterogeneous Simulation Integration Platform
3. Introduction to Mosaik – A Flexible Smart-Grid Co-Simulation Framework
4. Use-Cases for Coupled Evaluations Using both CPSWT and Mosaik

TRANSACTIVE ENERGY CONCERNS & EVALUATION NEEDS

POWER GRID MODELING CONCERNS:

Generation, Transmission, & Distribution	Distributed Energy Resources (DERs)	Distributed Sensors and Controllers	Multi-Physical Domains & Multi-Rate Dynamics

ENVIRONMENTAL AFFECTS MODELING CONCERNS:

Seasons and Weather	Recovery & Management for Natural Disasters	Env. Hazards and Safety	Special Events w/ Demand Surges

CYBER COMM. NETWORK MODELING CONCERNS:

Cyber Network b/n sensors & controllers	Cybersecurity	Large-scale Data Flows & Real-Time Data Delivery	Distributed Data Processing

OPERATIONAL MODELING CONCERNS:

Power markets and pricing	Regulations and Policies (Local and Federal)	Consumer and Business Models	Short-Term to Long-Term Planning

GRID OPERATIONAL ANALYSIS OBJECTIVES:

❖ **Power flow analysis**	• *Generator-consumer matching* • *Grid stability*
❖ **Integration of automated controllers & market factors**	• *Optimize utility services* • *Reliable & secure operations*
❖ **Dynamic effects: Demand-Response**	• *Accurate modeling of DERs – solar/bio/fuel-cell local generation & storage, demand & generation variations*
❖ **System-level impact analysis**	• *Cyber-attacks & Resilient defenses* • *Analyzing diff. market approaches*

HUGE SOCIETAL IMPLICATIONS:

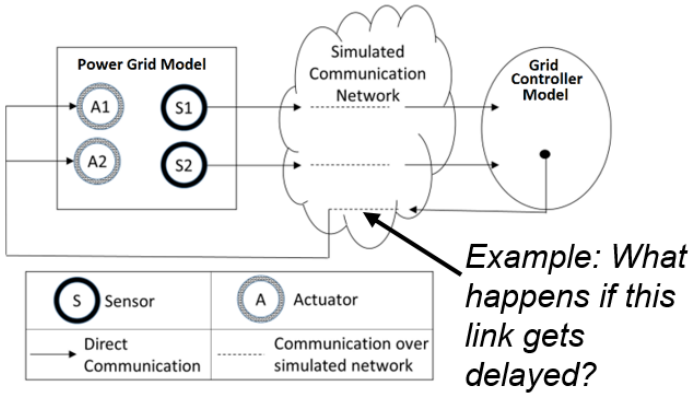
❖ **Privacy**	• *Location & Consumption Patterns*
❖ **Security**	• *Remote Hacking, Disruptions*
❖ **Reliability**	• *Grid Failures, [Un]-Planned Blackouts*
❖ **Equity & Fairness**	• *Access to TE: controllers, storage, etc.*

SYSTEM-OF-SYSTEMS MODELING W/ SPECIAL-PURPOSE SIMULATORS

System-of-Systems (SOSs):

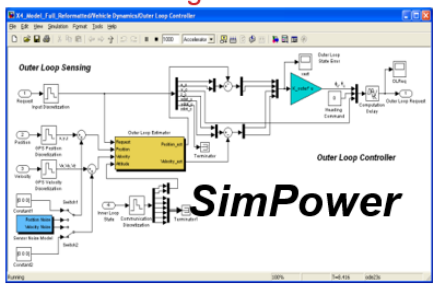
- Has interdependent systems that require many special-purpose simulators.
- Failure in one system can lead to problems in other interconnected systems.
- Comprehensive evaluation of system-of-systems as a whole is needed.

Example: Grid-control via simulated communication network

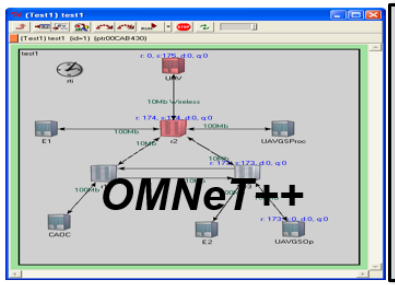


Example: What happens if this link gets delayed?

Grid Modeling: T&D



Communication Network



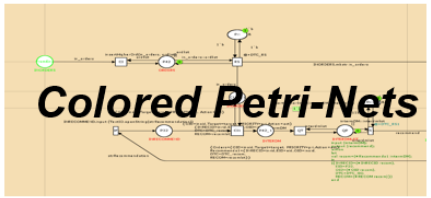
Real-time Components

Hardware devices

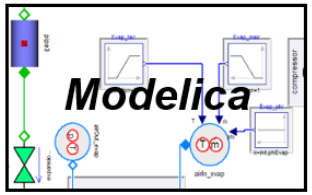
Systems built w/ many h/w and s/w

Humans

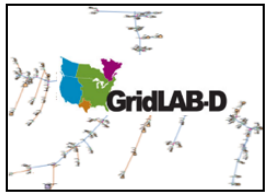
Regulation/Policies/Business



Smart Buildings



Distribution/Market



EVs/Charging Stations

Fundamental composition questions:

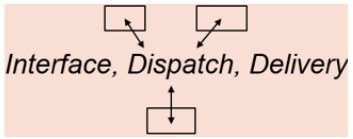
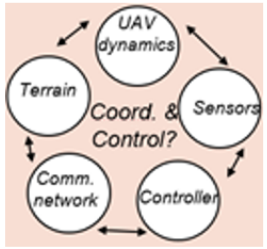
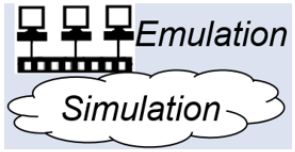
- ***How to compose simulated heterogeneous system models?***
- ***How to compose the different simulation engines?***
- ***How to integrate real-time hardware-, system-, and humans?***
- ***How to rapidly synthesize and deploy integrated simulations?***

Integration Challenges: Heterogeneity, Semantics, Timing

- Simulators have different timing models
- Execution needs to be coordinated
- Data needs to be shared
- Different time-scale and resolution
- Logical time vs. real time
- Different simulation engines

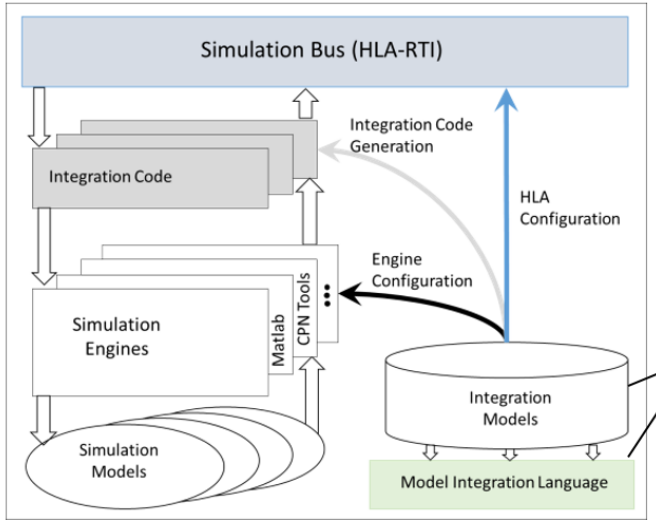
- Modeling languages are different
- Semantics is different – continuous time, discrete time, or discrete event
- Simulated systems are interacting but modeling languages do not have construct to express them
- No support for specifying experiments

ESSENTIAL BUILDING BLOCKS FOR CREATING SOS CO-SIMULATIONS

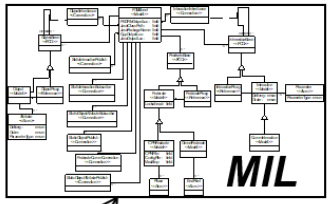
TIME MANAGEMENT		❖ Coordinated time advancing among 'dynamic' simulators • *Time synchronization; execution modes (As Fast As Possible Vs Real-Time); time-resolutions; time-scales; time-regulation*
DISTRIBUTED OBJECT MANAGEMENT		❖ Data types for data exchange + Sharing methods • *Data queuing; dispatch & delivery; stateful/one-off data/messages; delivery mechanisms; delivery order; security, reliability & timeliness*
DISTRIBUTED SIMULATION MANAGEMENT		❖ Coordination and control of distributed simulation (systematic orchestration) • *Coord. & control; sync. points; dynamic ownerships of data and/or distributed simulation*
COMMUNICATION NETWORK SIMULATION & EMULATION		❖ Comm. network simulation cuts across many simulations for data exchanges and info. flows • *Real-world exchange via physical network issues such as delays, drop-outs, corruptions, cyber-attacks*
REAL-TIME COMPONENTS INTEGRATION		❖ Real-world entities plugged into SoS simulation • *Examples: Simulated flight training; Remote laboratories; Test hardware*

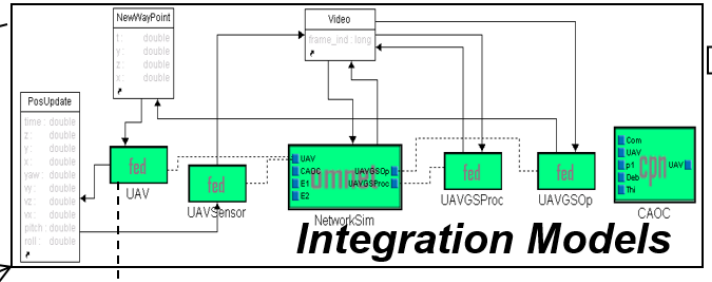
CYBER-PHYSICAL SYSTEMS WIND-TUNNEL (CPSWT) PLATFORM FOR MODEL-BASED HETEROGENEOUS SIMULATION INTEGRATION & EXPTS.

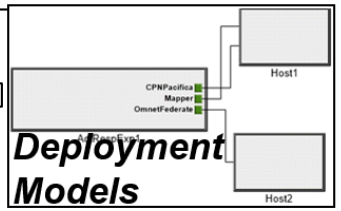
Model-based Integration Approach



built using



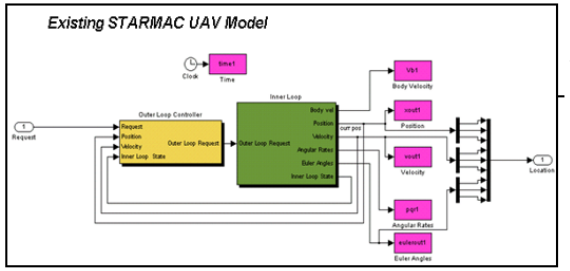




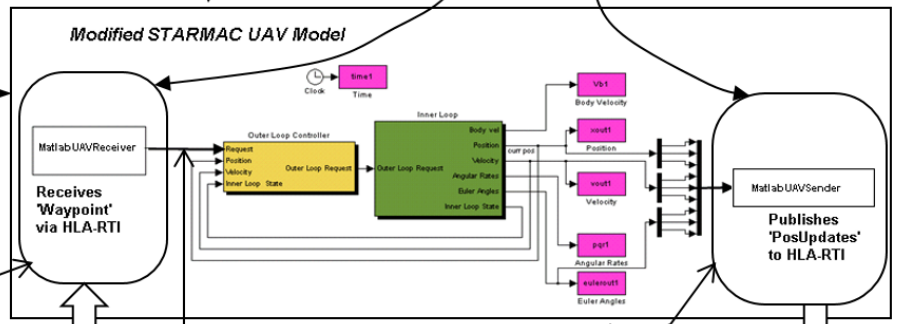
abstracts

Deployment configuration

Generated .m Receiver & Sender S-functions
+
Generic Java code for Simulink federates



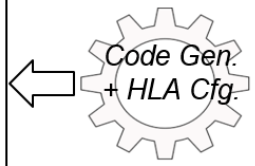
w/ added input/ output bindings



input bindings

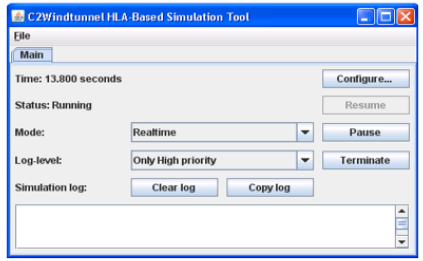
signal flow

output bindings



Simulation Bus (HLA-RTI)

Simulation Manager



- Time-regulating and
- time-constrained
- Real time OR as fast as possible modes
- Pause/Resume/ Terminate Simulation
- Data Logging Tools
- Inject debugging/control interactions
- Inject pauses at pre-determined times
- Simulation monitors by monitored interactions

Library of simulation tools integrated (ready to use in any SoS scenarios):
OMNeT++, CPN Tools, Devsjava, SUMO, TrainDirector, etc.
+ Generic Java and C++ federate APIs for custom sim. wrappers

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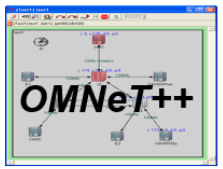
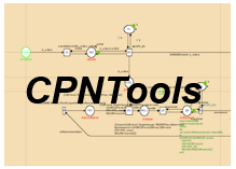
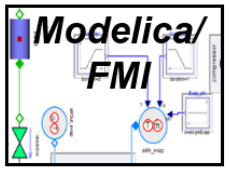
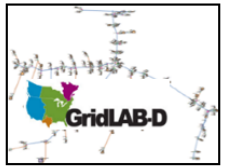
CPSWT CAPABILITIES

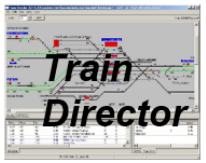
Evolving Library of Supported Simulators



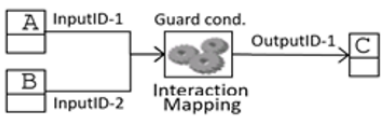






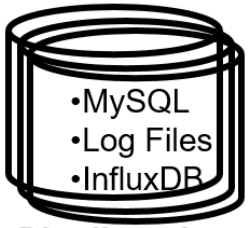


Auto-Mappings for Legacy Sims. w/ Fixed Data Models



Automation Tools for Experiment Deployment, Logging, Collaboration, and Analysis

- Experiment Modeling
- Deployment Modeling
- Hardware-in-the-loop (HIL) Config
- Loggers, Monitors, & Analysis Config
- What-if Scenarios



Distributed Deployment: VM(s), Local cluster, Cloud

Analysis Tools

Experimentation and Analysis

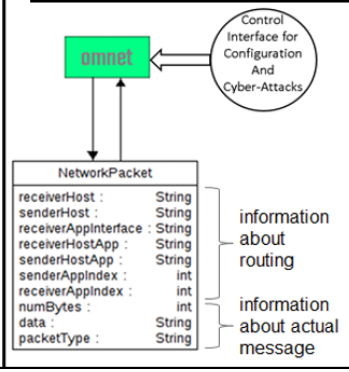
CPS-VO Design Studios

Cloud Backends for Expts.

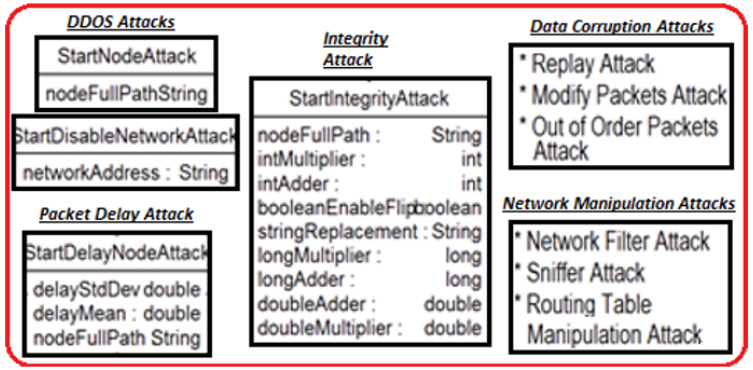
- Collaborative Modeling
- Model Libraries
- HLA Federate Libraries
- CPS-VO Expt. Platform
- Reusable & Reconfigurable Expts.

CPS Cyber-Resilience Evaluation Tools
1.Network Sim.
2.Cyber-Attack Lib.
3.What-if Scenarios (COAs)

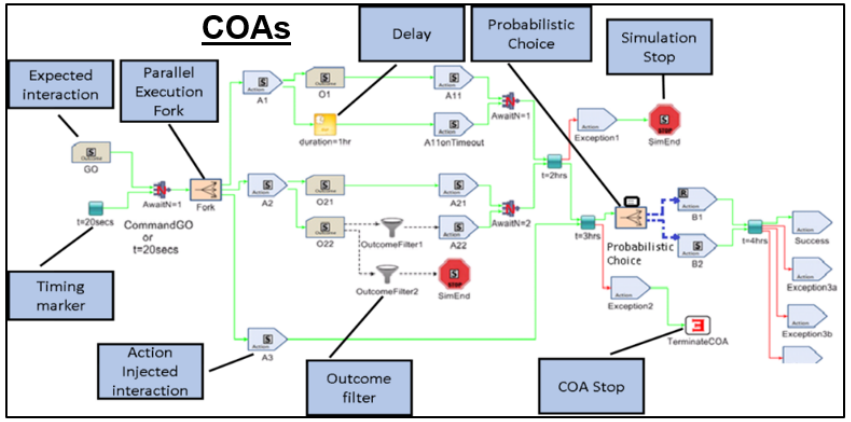
Reusable Comm. Network Simulation Component



Reusable Cyber-Attack Library



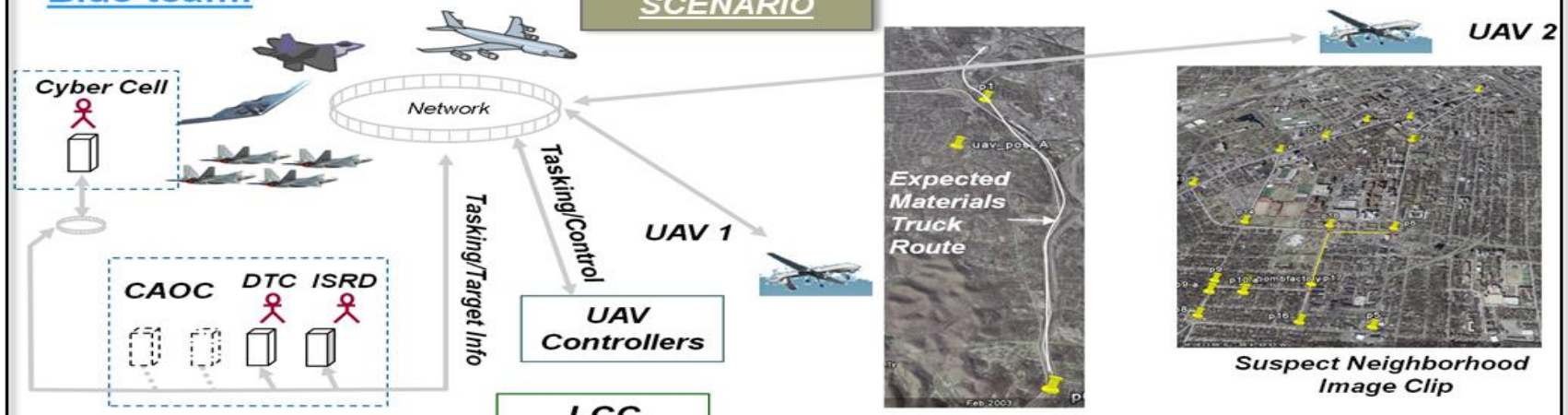
COAs



EXAMPLE 1: C2 MISSIONS

Blue team:

SCENARIO



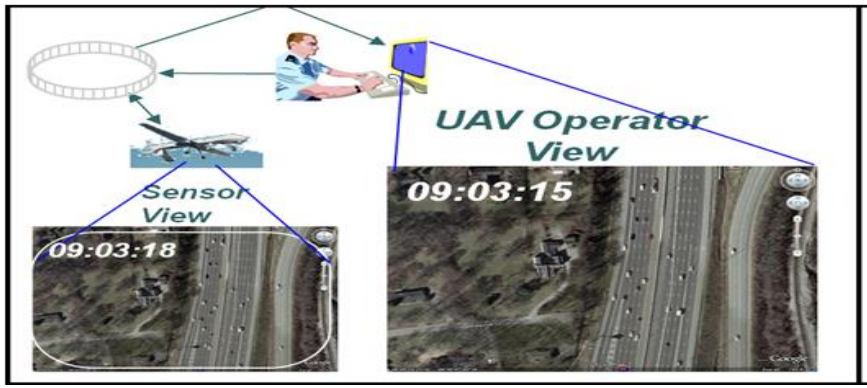
- CAOC
  - Commander
  - Dynamic Targeting Cell (DTC)
  - ISR Division (ISRD)
- Cyber Cell

- **SIGINT**
- **UAV Operators/Controllers**
- **Land Component (LCC)**

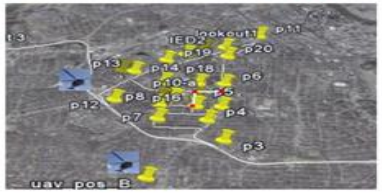
Red Team: Red Leader, WMD and VBIED trucks, truck drivers, Bomb factory

- Demonstrates integration of loosely coupled models in support of operations of Central Command and Control (Blue team)
- Focusses on finding, tracking, and acting on time-critical adversary targets (Red team)
- Includes human organization models involving tactical and operational decision making
- Exemplifies Command and Control resilience in the presence of cyber attacks
- Demonstrates time-sensitive and reactive (adaptive) modeling of Red and Blue actions.
- Demonstrates two-sided action in an urban environment

EXPERIMENTATION



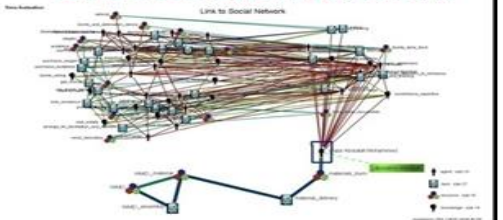
Ground Truth



Key Events/Messages Blue's View

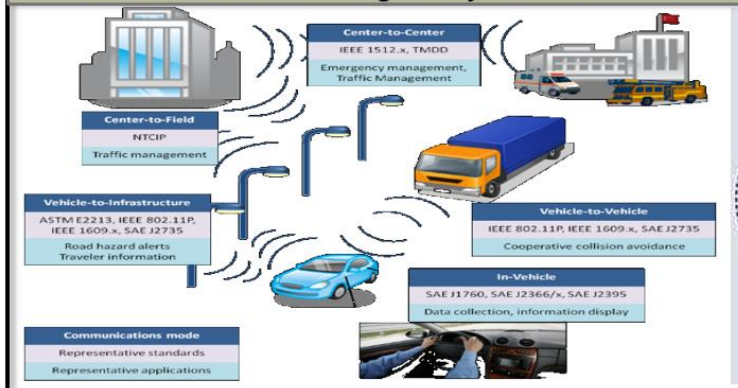
Cell Phone Intercept
UAV 1 Tracking Vehicle
UAV 1 locates building
....

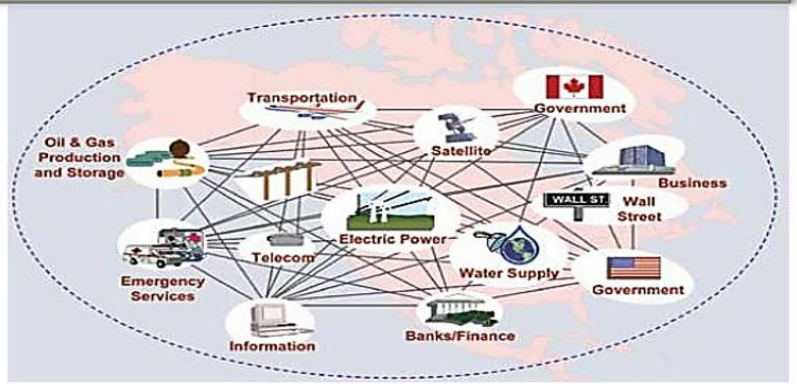
ORA Social Network



EXAMPLE 2: SMART TRANSPORTATION SYSTEMS (STS) AT NIST'S SMART-AMERICA CHALLENGE IN 2014

Problem: Smart Transportation Systems require a global web of connected IT infrastructure
→ Creates vulnerabilities against cyber attacks

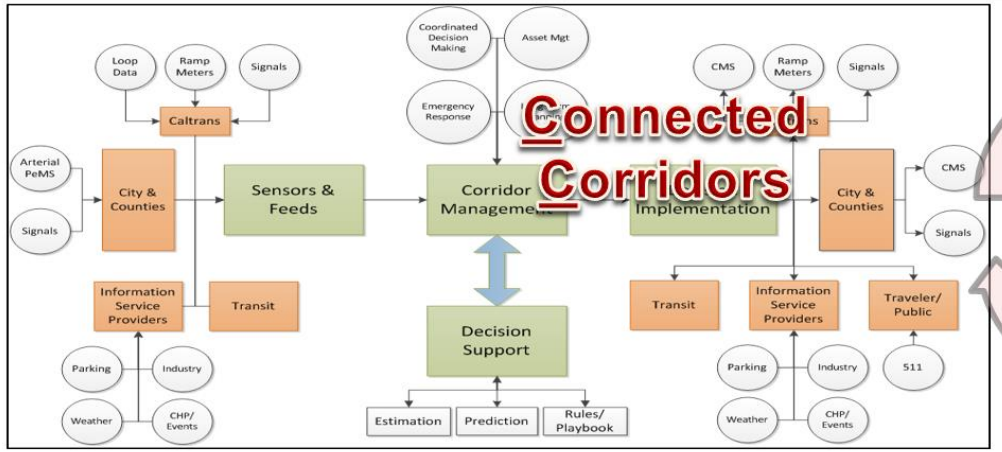


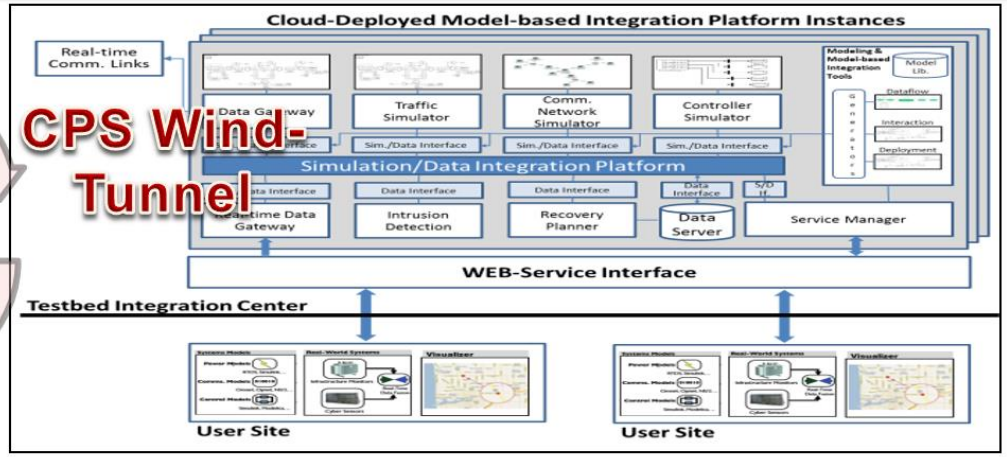


Complex and interconnected road networks

Emergency vehicles delayed due to traffic

Solution: Smart Roads Platform* integrates advanced control algorithms and high-fidelity simulation software with real-time data to *predict* and *manage* traffic flows, to support resilience to cyber attacks.

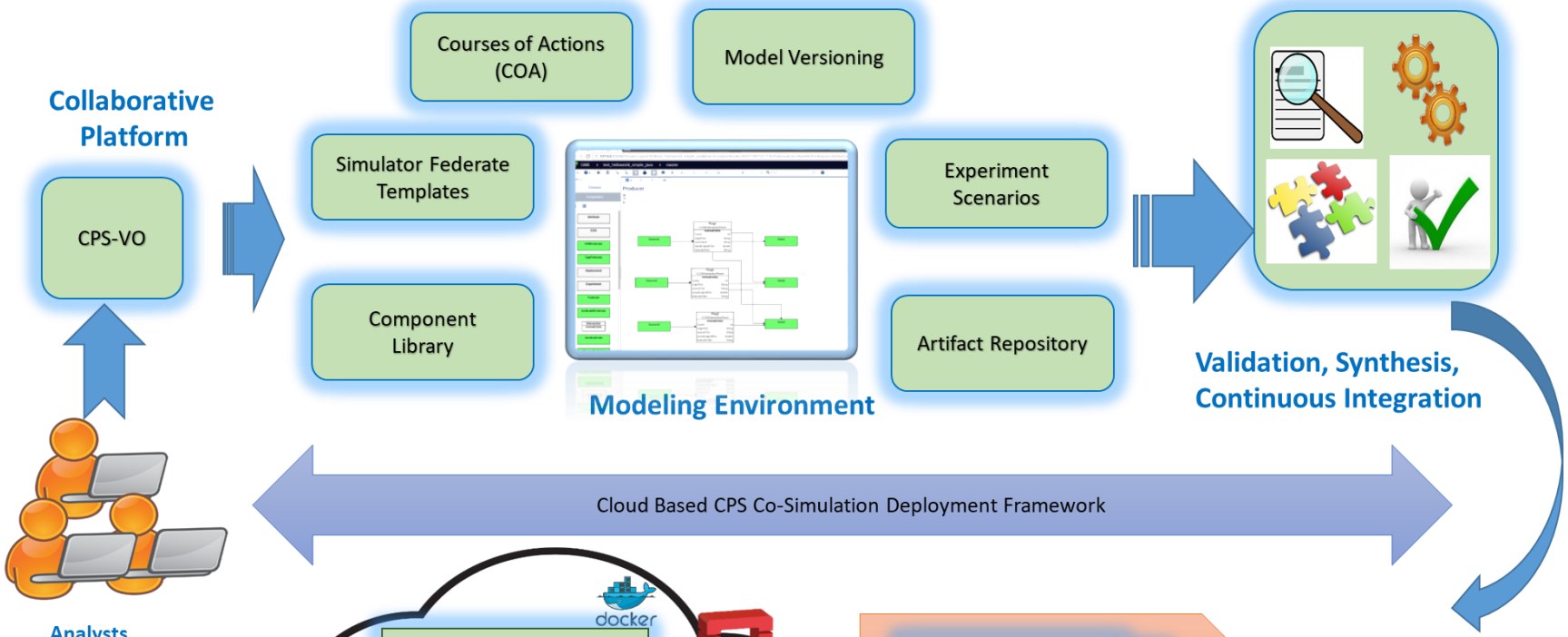




* *Demonstration Video: http://youtu.be/aWI3WK2STJc*

CUSTOMIZATION OF CPSWT FOR TRANSACTIVE ENERGY EVALUATIONS

EXAMPLE 1: CPSWT-TE CPS-VO DESIGN STUDIO



CPSWT-TE Platform Tools & Methods:

- Build system
- Repositories
- Change tracking
- Authentication
- Analysis tools
- Error handling
- Experiment tools
- Monitoring & control
- Cloud deployment

URL: https://cps-vo.org/group/CPSWTTE

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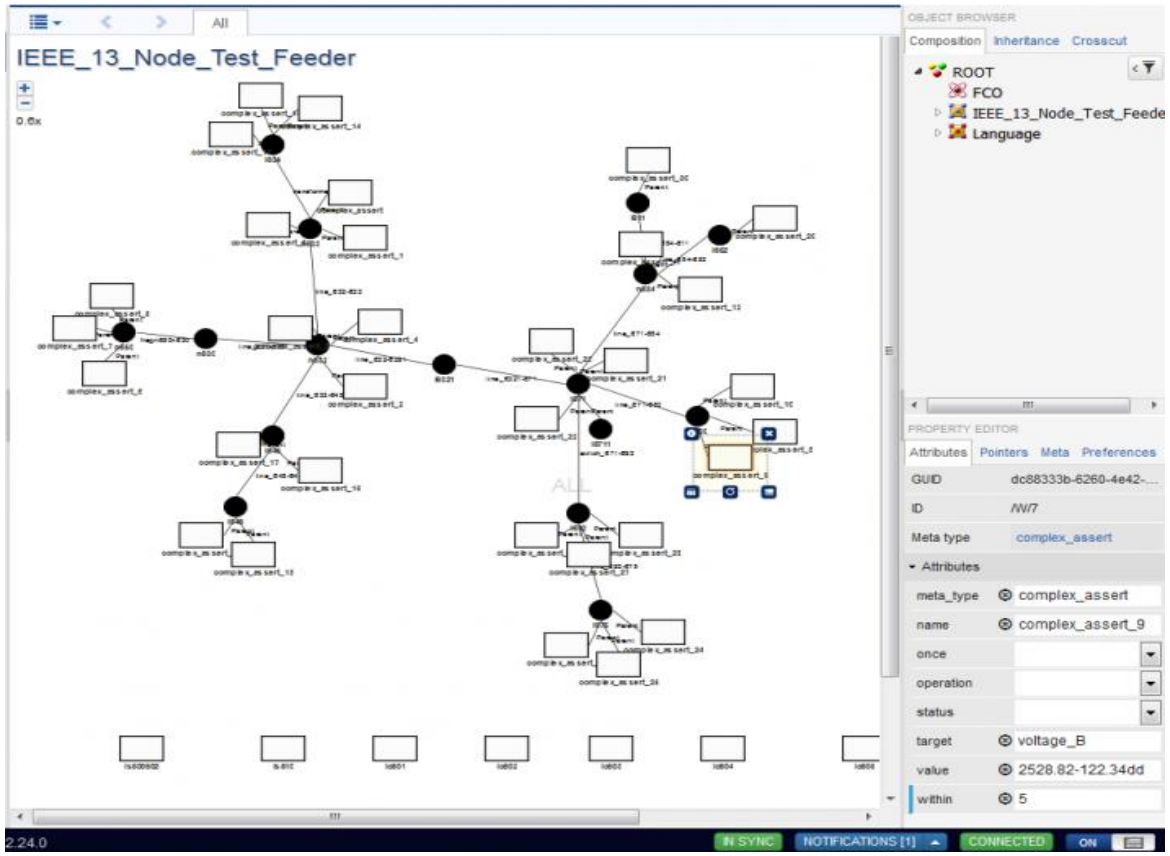
CUSTOMIZATION OF CPSWT FOR TRANSACTIVE ENERGY EVALUATIONS

EXAMPLE 2: GRIDLAB-D CPS-VO DESIGN STUDIO

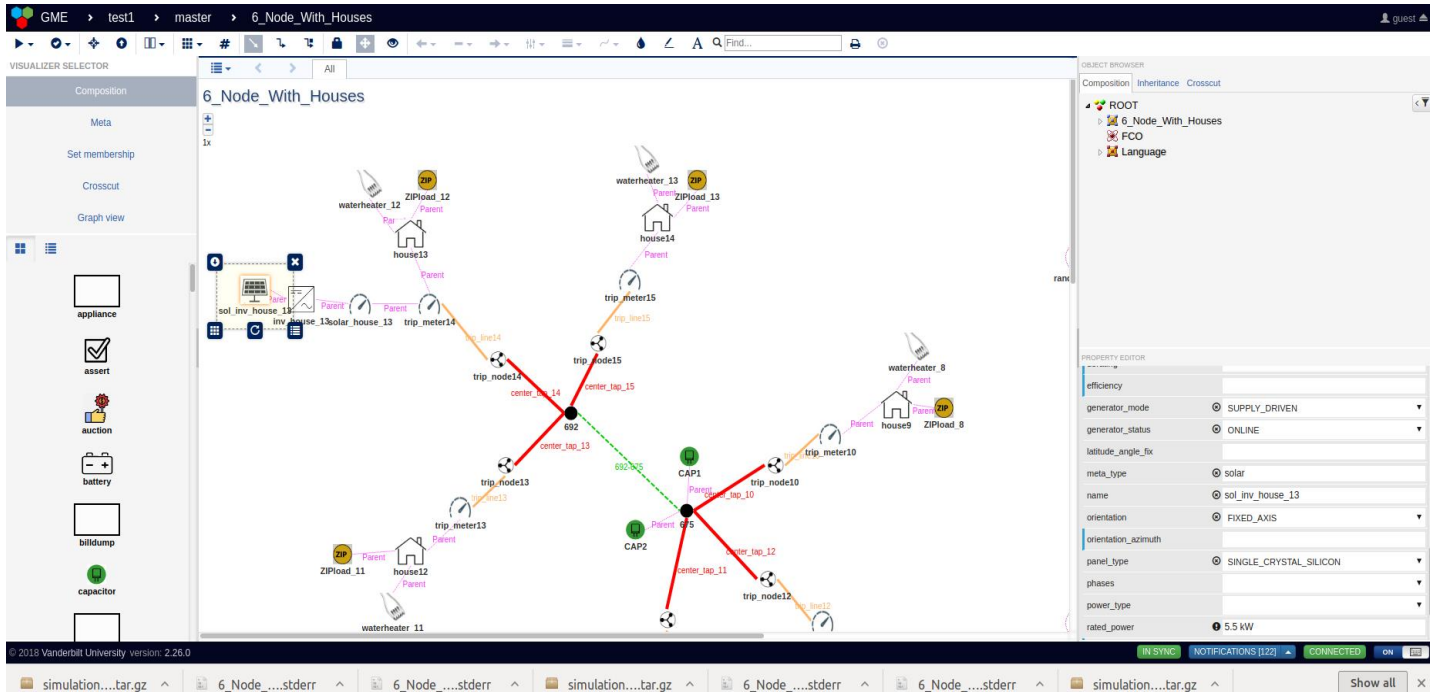


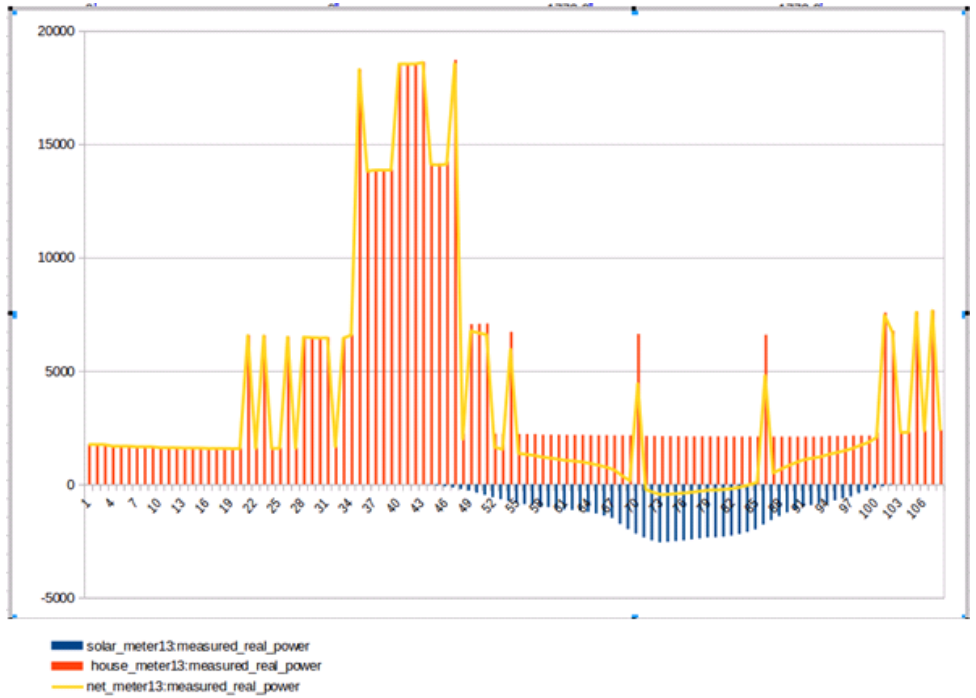
GridLAB-D Design Studio Features:

- Modeling tools to design power distribution systems
- Import existing .GLM files with auto graphical layout
- Generate .GLM GridLAB-D files from models
- Download .GLM files for current models
- Simulate .GLM file on CPS-VO design studio cloud server
- Full editing of GridLAB-D models with all parameters
- Automatic upgrade of modeling language for a newer version of GridLAB-D simulator
- Web-based access for expts., re-runs, storing results in repository
- Current work-in-progress: for evaluating **privacy and security** of the power-grid under a variety of market/ consumer/ regulatory models

URL: https://cps-vo.org/group/gridlabd

NEW CPS-VO DESIGN STUDIO: SOCIETAL IMPLICATIONS OF TE





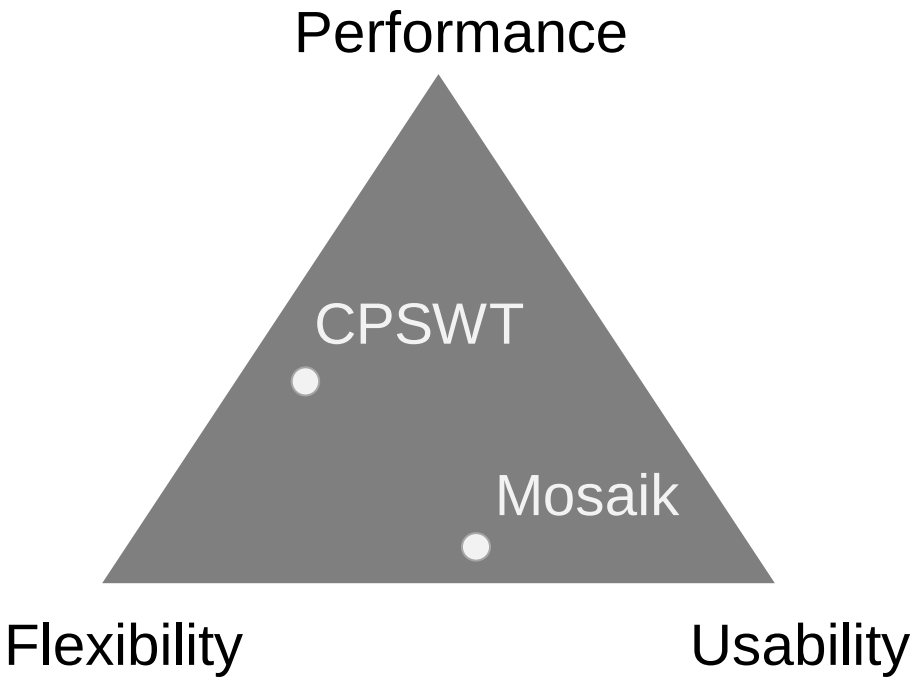
- Focus is on evaluating these societal implications: (1) **Privacy**, (2) **Security**, and (3) **Equity & Fairness**.
- This work is in progress – currently working on making Transactive Controller and Market as configurable for diff. experiments.
- Sample gird experiment: 6 houses distribution system with houses, grid, transformers, triplex lines, and triplex meters.
- Uses weather data from Columbus, Ohio for year 2009.
- The outcome of simulation is recorded in a multi-recorder at discrete time stamp. Outcome recorded are power consumption by each house and power generated by each house and solar panel attached to the grid.

MOSAIK FRAMEWORK

mosaik
Eco-system

- APIs for several languages:
  - Python
  - Java
  - C#
  - …
- Easy scenario description:
  - Single python script
  - Rule-based connections
  - Manageable specification effort

COMBINATION CPSWT - MOSAIK



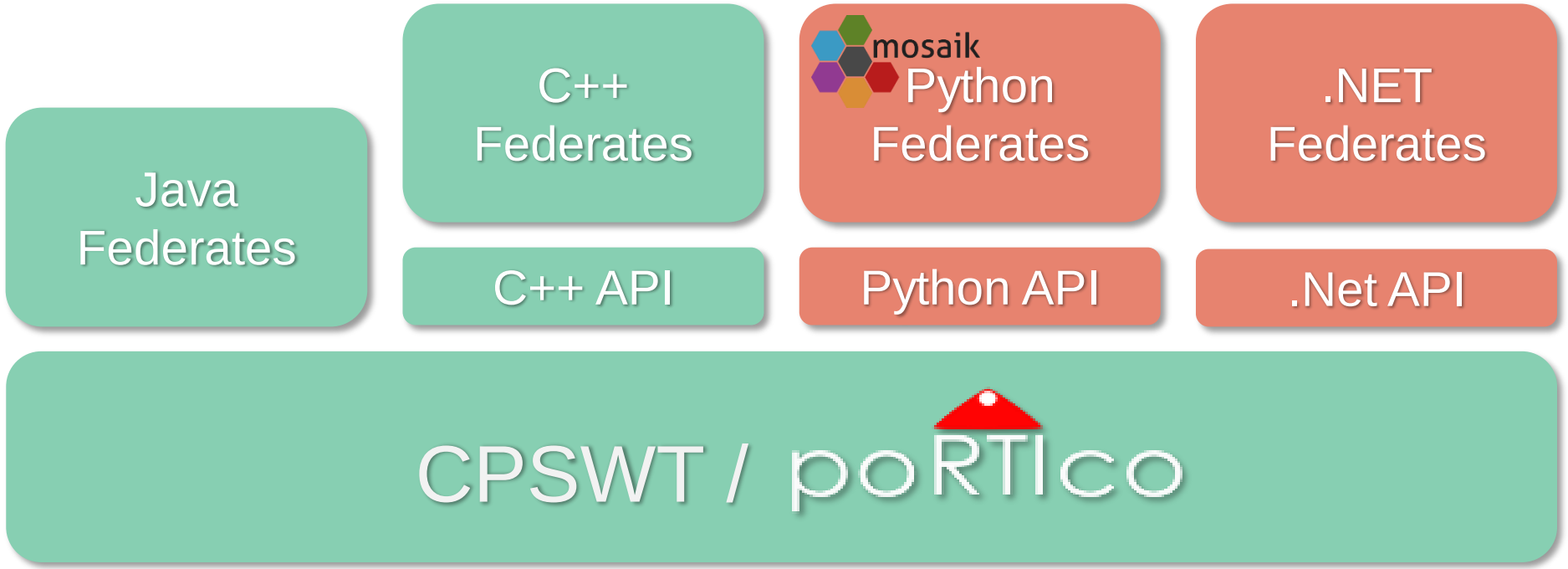
CPSWT:
Freedom in federate design and synchronization

Mosaik:
Comfortable coupling and simulation scenario description

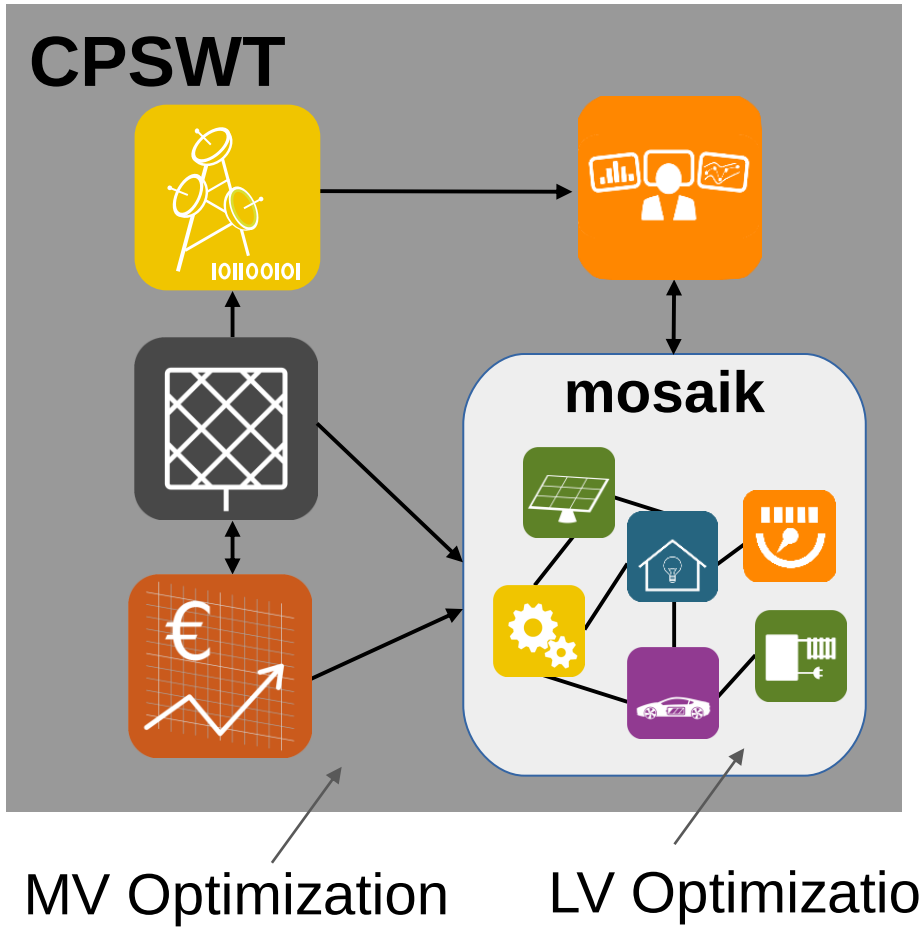
Idea:
Combination to get a highly usable testbed with flexible synchronization possibilities

STUDENT EXCHANGE

- Visit of Bastian Cornelsen and Dennis Weller at Vanderbilt University
- Adapters for python and .Net (like C#) federates
- Starting point to integrate mosaik as a HLA federate

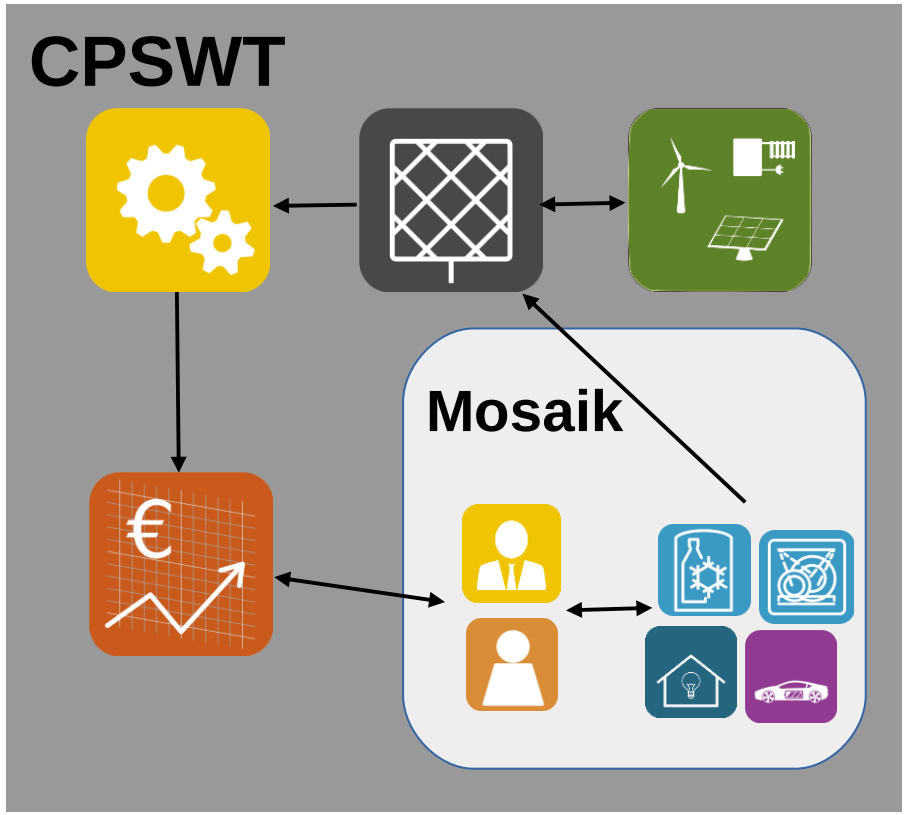


POTENTIAL USE CASE I



- Possible use cases in H-CPS:
  - Mosaik: Smart City / VPP/ E-community
  - CPSWT: Grid + comm. + market
- Goals (possible):
  - Bi-level optimization (e.g. city + region)
  - Effects of different asset mixes
- Advantage:
  - High flexibility in smart city / VPP / community co-modeling
  - High throughput of scenarios

POTENTIAL USE CASE II



- Possible use cases in H-CPS:
  - ➔ Mosaik: Different sets of user groups + appliances
  - ➔ CPSWT: Grid + market + DERs
- Goals:
  - ➔ Bi-level optimization
  - ➔ Effects of different user behavior

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KEY REFERENCES

1. Xenofon Koutsoukos, Gabor Karsai, Aron Laszka, Himanshu Neema, Bradley Potteiger, Peter Volgyesi, Yevgeniy Vorobeychik, Janos Sztipanovits, “SURE: A Modeling and Simulation Integration Platform for Evaluation of SecUre and REsilient Cyber-Physical Systems,” in Proceedings of the IEEE, vaol. PP, no. 99, pp. 1-20. doi: 10.1109/JPROC.2017.2731741. 2017.
2. Neema, H., J. Gohl, Z. Lattmann, J. Sztipanovits, G. Karsai, S. Neema, T. Bapty, J. Batteh, H. Tummescheit, and C. Sureshkumar, "Model-Based Integration Platform for FMI Co-Simulation and Heterogeneous Simulations of Cyber-Physical Systems", 10th International Modelica Conference, vol. Proceedings of the 10th International Modelica Conference, Lund University, Sölvegatan 20A, SE-223 62 LUND, SWEDEN, Modelica Association and Linköping University Electronic Press, pp. 235-245, 03/2014.
3. Neema, H., W. Emfinger, and A. Dubey, "A Reusable and Extensible Web-Based Co-Simulation Platform for Transactive Energy Systems", 3rd International Transactive Energy Systems, Portland, Oregon, GridWise® Architecture Council , 05/2016.
4. Roth, T., E. Song, M. Burns, H. Neema, W. Emfinger, and J. Sztipanovits, "Cyber-Physical System Development Environment for Energy Applications", ASME Power and Energy Conference 2017, Charlotte, USA, 06/2017.
5. Neema, H., B. Potteiger, X. Kousoukos, G. Karsai, P. Volgyesi, and S. Janos, "Integrated Simulation Testbed for Security and Resilience of CPS (accepted)", The 33rd ACM Symposium on Applied Computing - Cyber-Physical Systems Track, Pau, France, ACM, 04/2018.
6. Neema, H., J. Sztipanovits, M. Burns, and E. Griffor, "C2WT-TE: A Model-Based Open Platform for Integrated Simulations of Transactive Smart Grids", 2016 Workshop on Modeling and Simulation of Cyber-Physical Energy Systems, Vienna, Austria, 04/2016.
7. Hemingway, G., H. Neema, H. Nine, J. Sztipanovits, and G. Karsai, "Rapid Synthesis of High-Level Architecture-Based Heterogeneous Simulation: A Model-Based Integration Approach", SIMULATION, vol. March 17, 2011 0037549711401950, no. March 17, 2011, Online, Simulation: Transactions of the Society for Modeling and Simulation International, pp. 16, 03/2011.
8. Chabukswar, R., B. Sinopoli, G. Karsai, A. Giani, H. Neema, and A. Davis, "Simulation of Network Attacks on SCADA Systems", First Workshop on Secure Control Systems, Cyber Physical Systems Week 2010, 04/2010.