Modeling and Simulation for Testbeds: Semantics and Languages

Building a Model-Based Simulation Integration Platform for Rapid Synthesis of Distributed Heterogeneous Simulations

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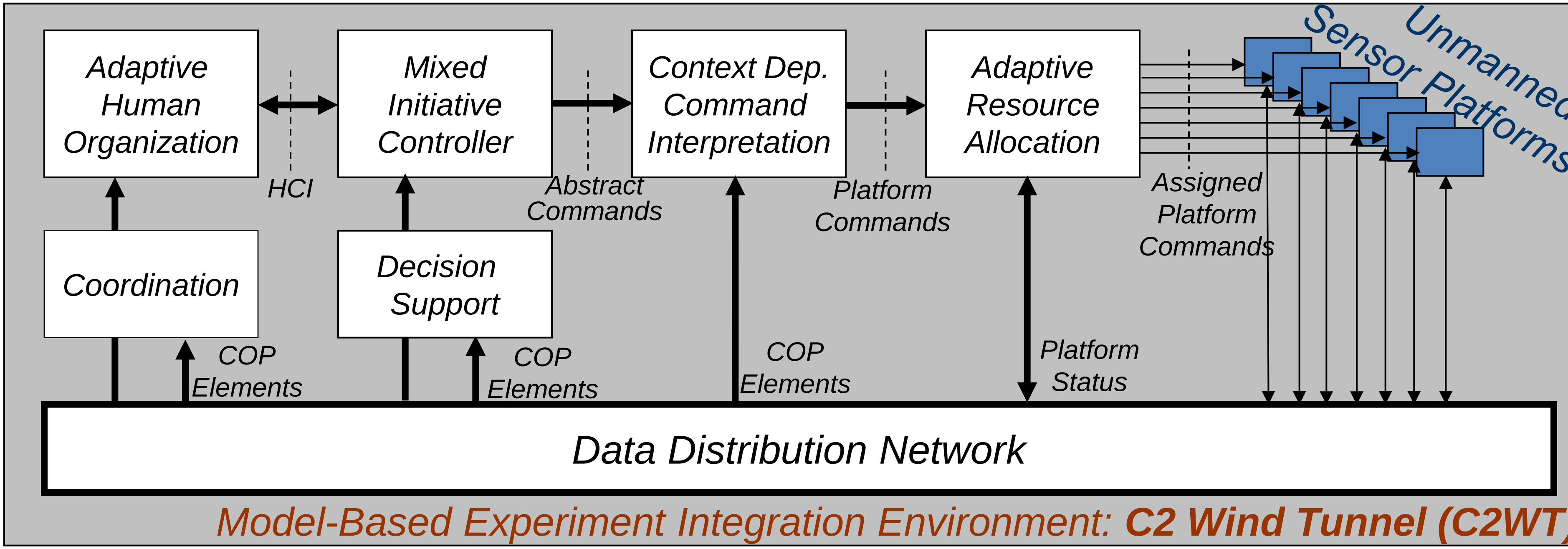
Command and Control (C2) Architecture Analysis

(AFOSR/PRET project with UC Berkeley and George Mason, 2006-2009)

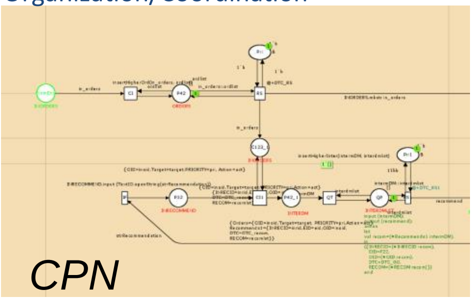


C2 issues to be studied experimentally:

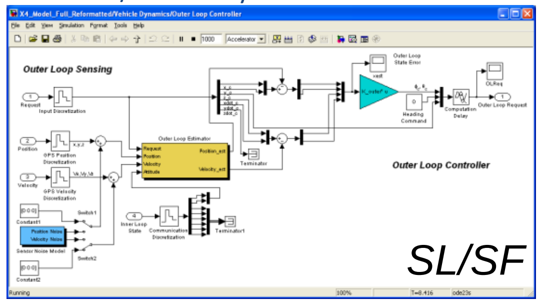
- **Distributed Mission Operation**
  - Synchronization and coordination
  - Distributed dynamic decision making
  - Network effects
- **Seamless Integration of Manned/Unmanned Assets**
  - Mixed-Initiative Teams
- **Increased Information Sharing**
  - Shared situation awareness
  - Common Operation Picture (COP)
  - Network effects
- **System Level Impact Analysis**
  - Cyber attacks and Resilient solutions
  - Strategy/gaming

Result: C2 Wind Tunnel

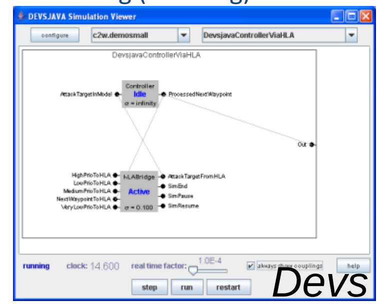
Organization/Coordination



Controller/Vehicle Dynamics

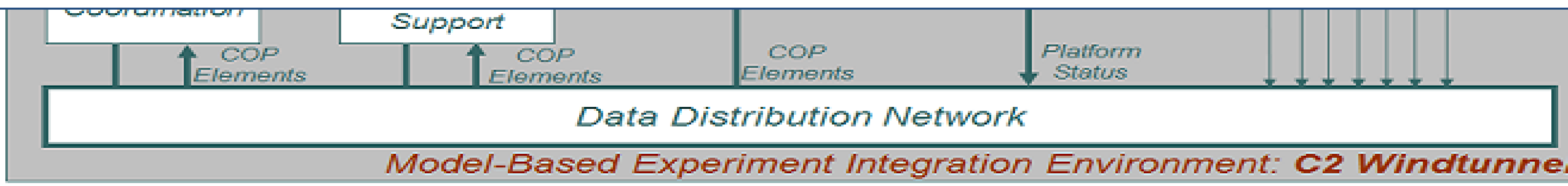


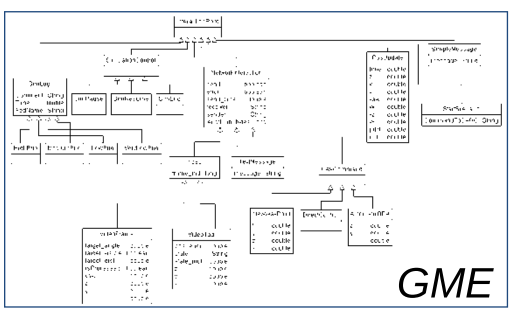
Processing (Tracking)



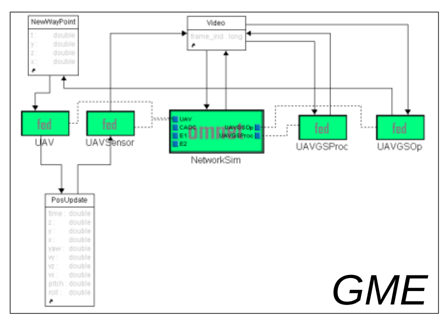
3-D Environment (Sensors)

How can we integrate the simulated heterogeneous system components?
How can we integrate the simulation engines?
How can we rapidly synthesize and deploy integrated simulations?

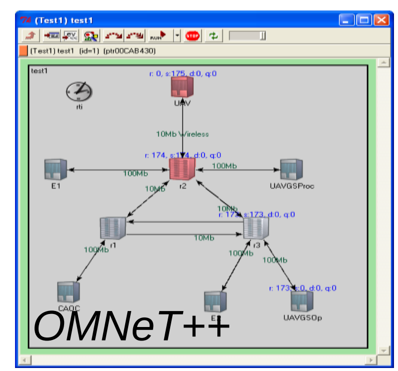




Simulation Interaction

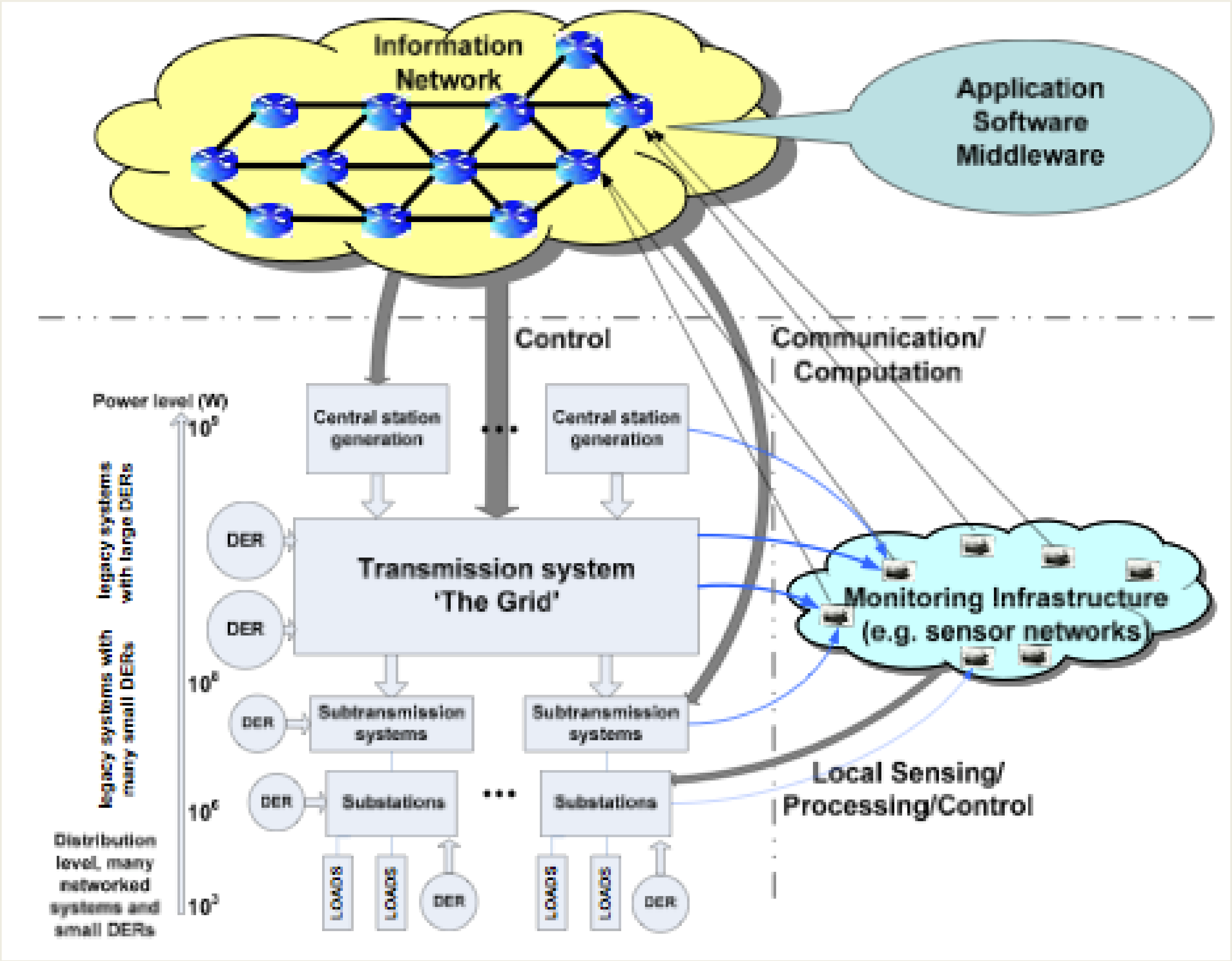


Simulation Architecture

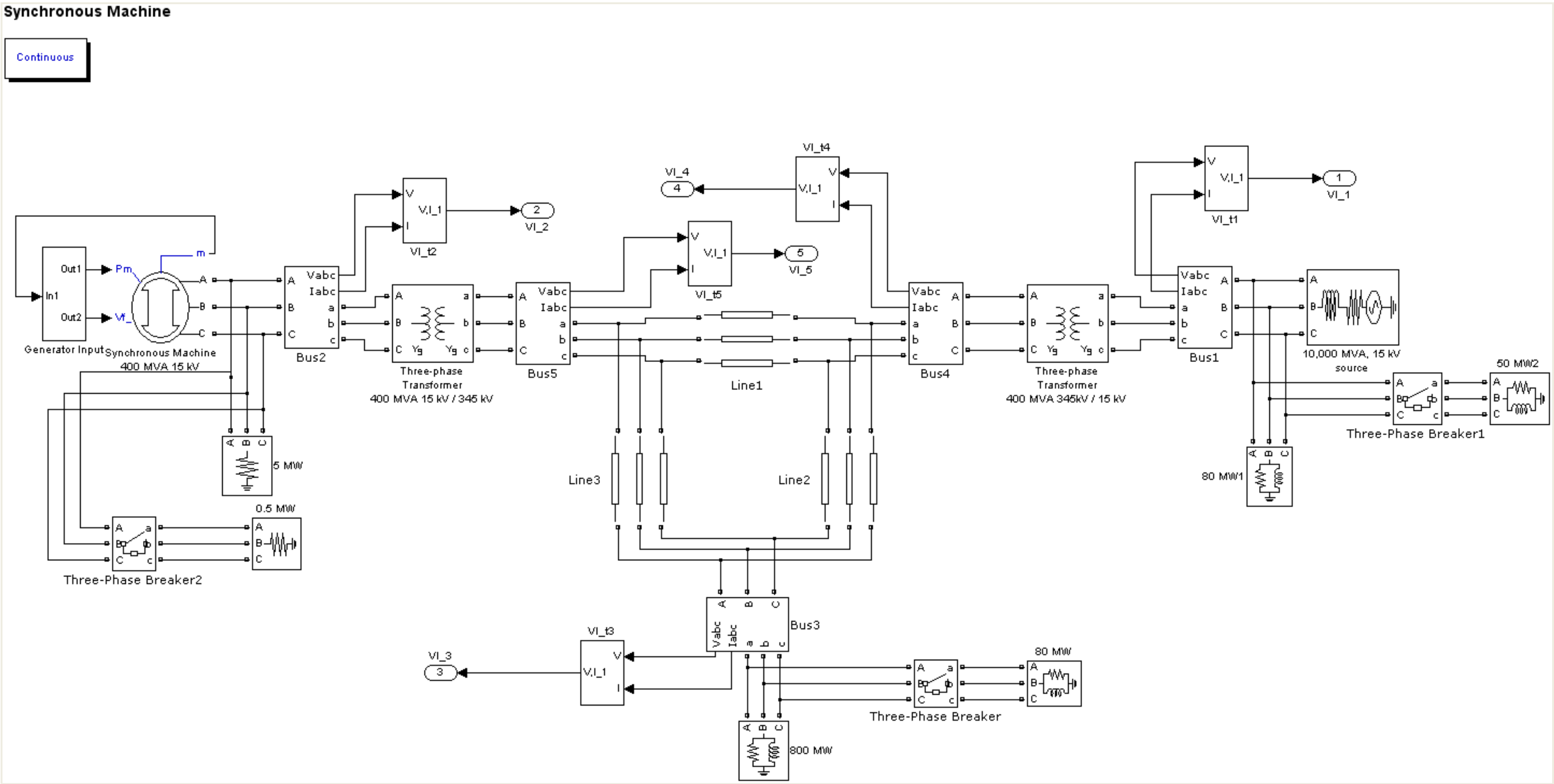


Network Architecture

Integrated control, communication, and power system
(Pilot and joint experiment with WSU, 2011)



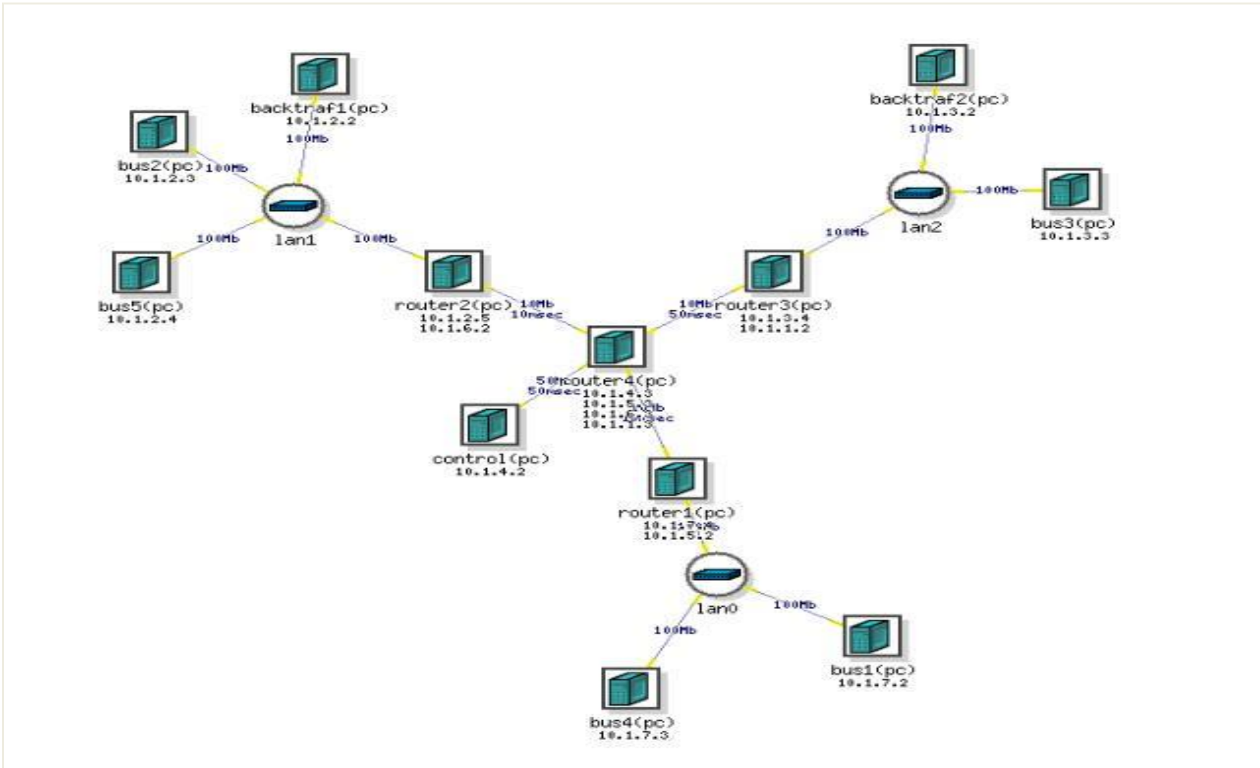
5-Bus Example: Power Grid Model



Tool: SimPower/MATLAB

Semantics: Continuous Time

5-Bus Example: Communication Model

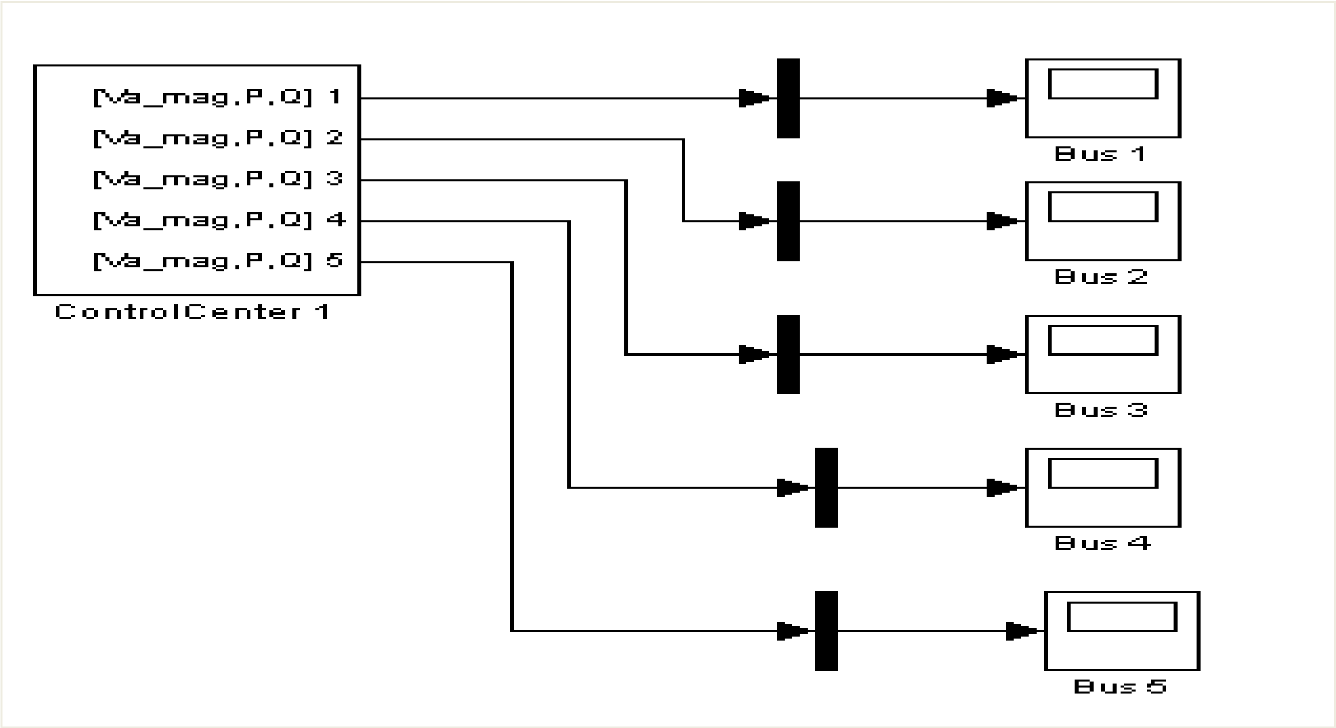


Tool: NS-2

Semantics: Discrete Event

Other Tools: OMNeT++ OPNET, TrueTime,..

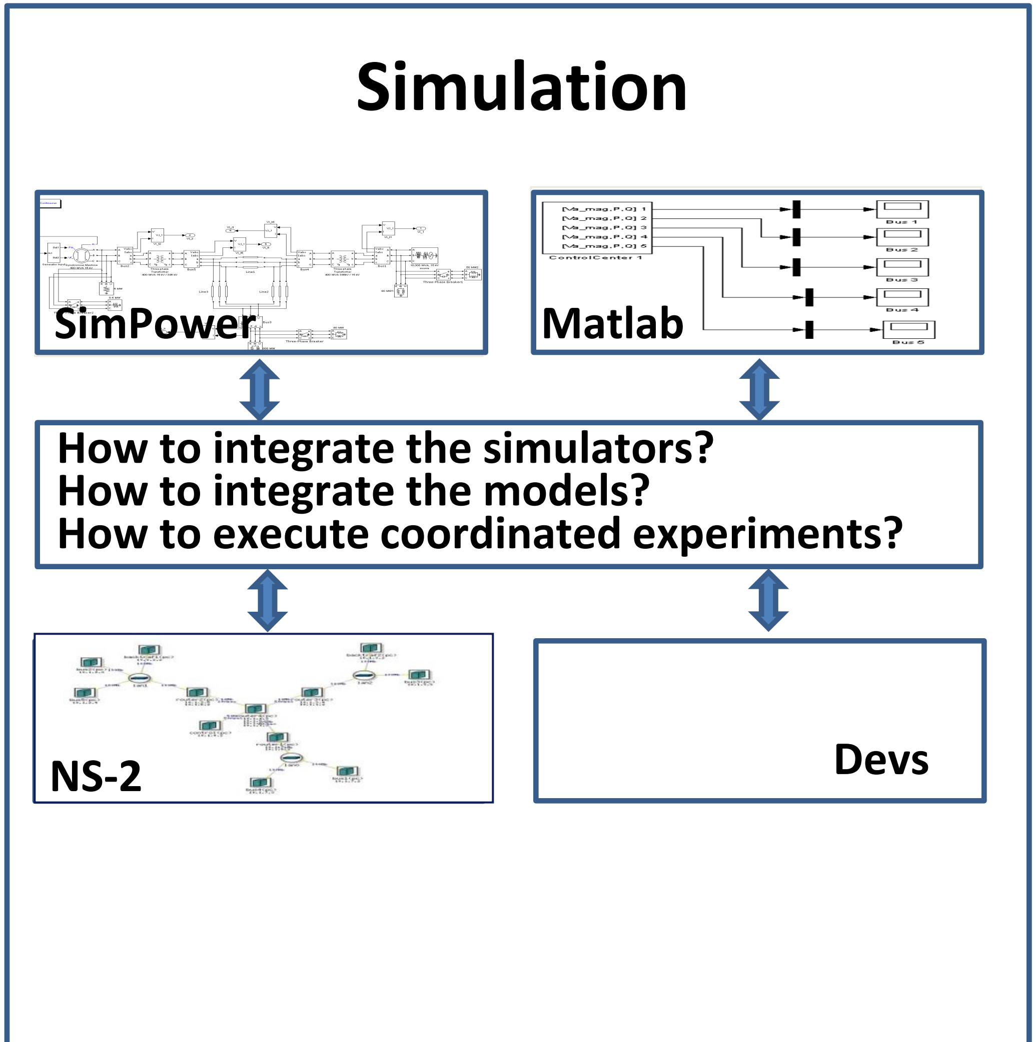
5-Bus Example: Control Center Model



Tool: MATLAB
Semantics: Discrete time

Other Tools: DEVS, LabView,
Semantics: Discrete Event

Integration Challenges



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

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

Multi-Model Integration Challenges

Integrating *models*

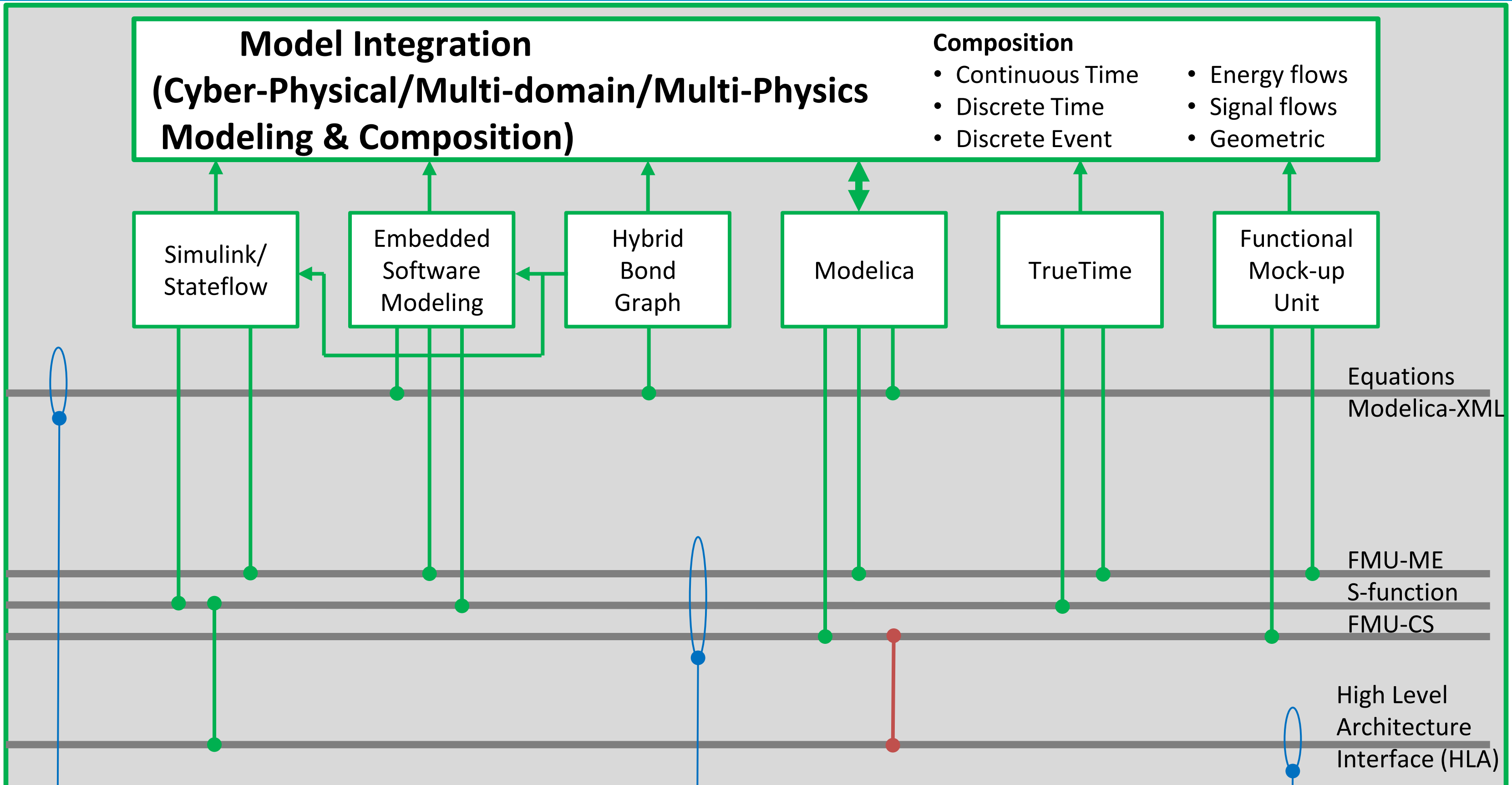
- Heterogeneous models for different domains: human organizations, communication networks, C2 software systems, vehicle simulations, etc. These models need to talk to each-other somehow.
- Needed: an overarching *integration model* that **connects** and **relates** these heterogeneous domain models in a logically coherent framework.

Integrating *simulations*

- Heterogeneous simulators and emulators for different domains: Colored Petri Nets, OMNET++, DEVS, Simulink/Stateflow, Delta3D, etc.
- Needed: an underlying *software infrastructure* that **connects** and **relates** the heterogeneous simulators in a logically and temporally coherent framework.

Key idea: Integration is about messages and shared data across system components. Why don't we model these messages and shared data elements and use these models to facilitate model and system integration?

Use Case for Model- and Tool Integration: Lumped Parameter Dynamics



Formal Verification

- Qualitative reasoning
- Relational abstraction
- Model checking

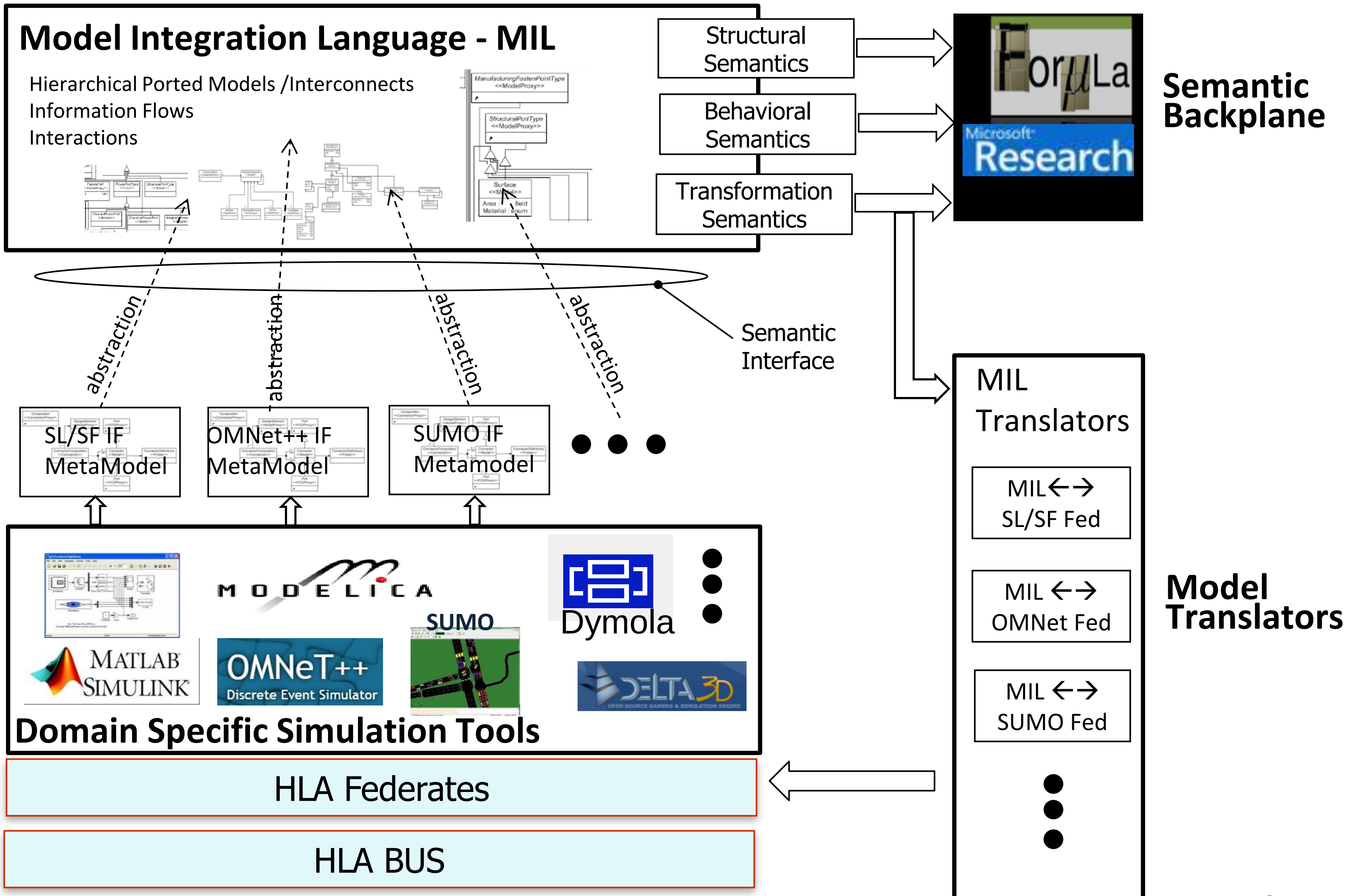
Simulation

- Open Modelica
- Delta Theta
- Dymola

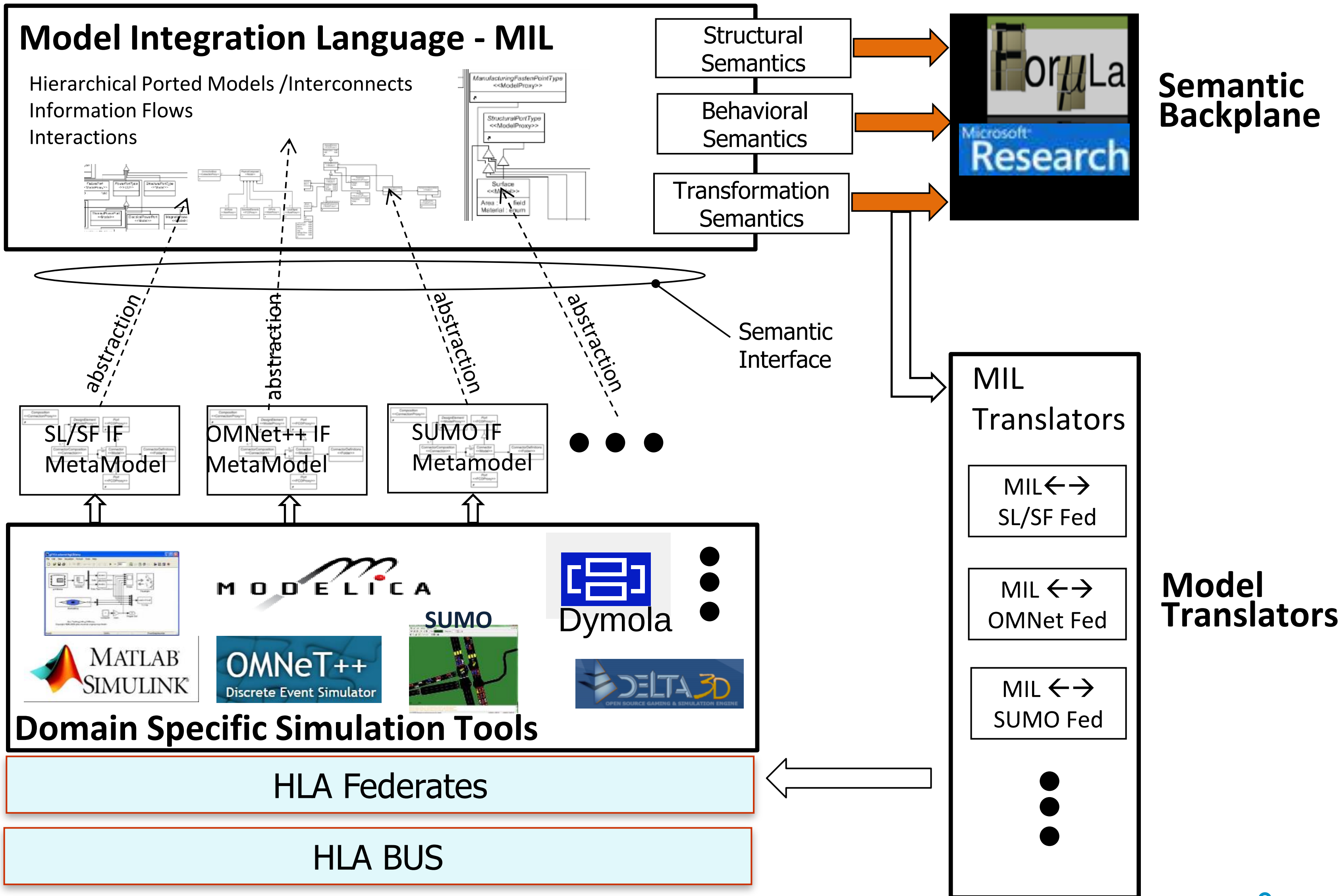
Distributed Co-Simulation

- NS3
- OMNET
- Delta-3D
- CPN

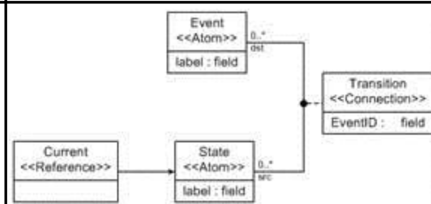
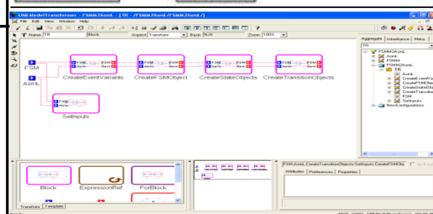
Model and Simulation Integration Approach in C2WT



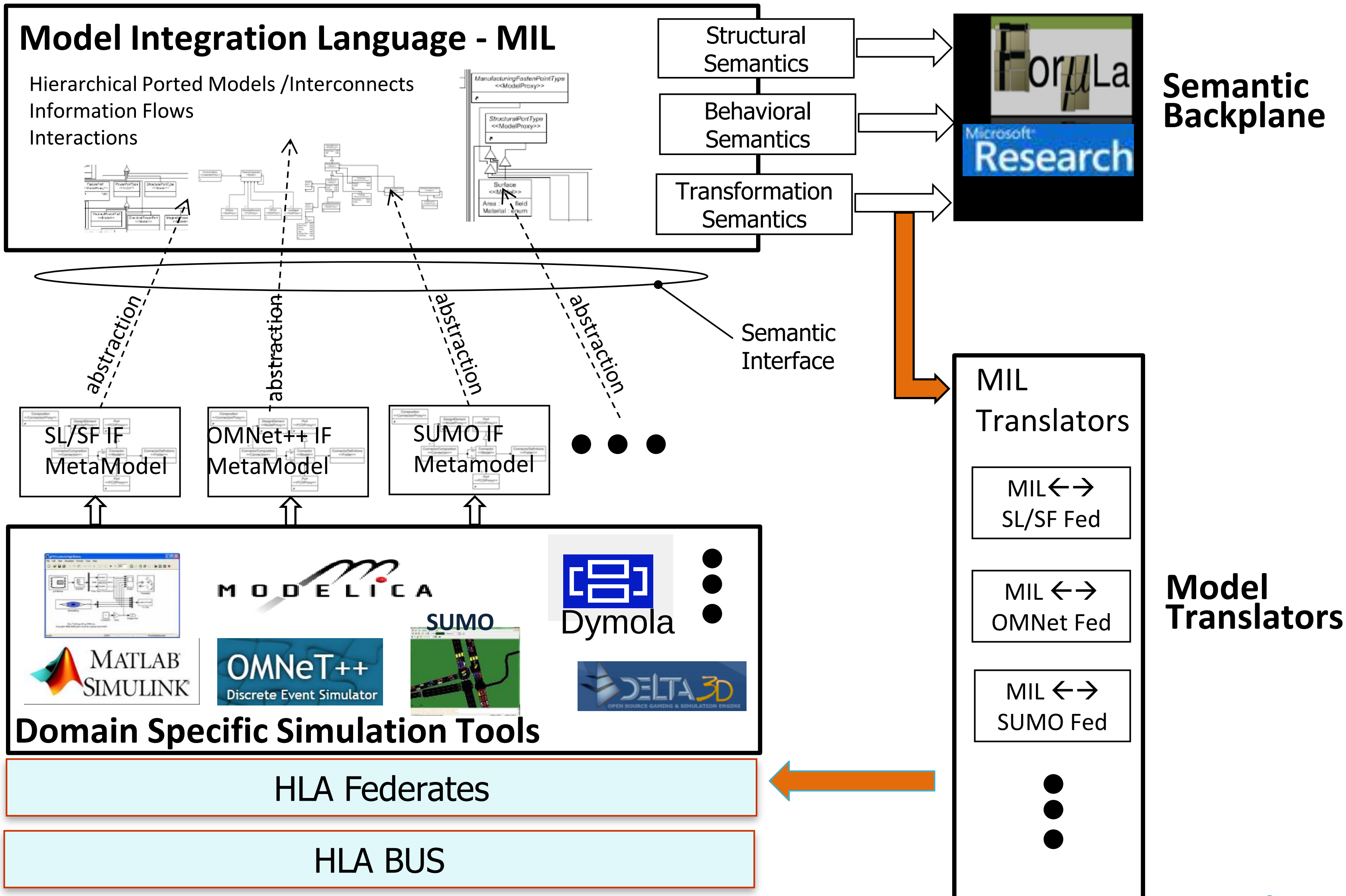
Model and Simulation Integration Approach in C2WT



Semantic Backplane

Functions	(Meta)Models	Languages	Tools	Role
Metamodeling		MetaGME	• GME (WebGME) • WebGME-2-Formula	• DSML spec. • Constraint Checking • Metaprog.
Transformation Modeling		UMTL	• GReAT • UDM	• Transf. spec. • Compiling spec to transformer
Formal Metamodeling	domain DFA { primitive Event ::= (lbl: Integer). primitive State ::= (lbl: Integer). [Closed(src, trg, dst)] primitive Transition ::= (src: State, [Closed(st)] primitive Current ::= (st: State).	Formula (MSR)	• Domain Comp. • Trace Gen.	• Metamod. checking • Example gen. • Semantic units
Formal Transformation Modeling	transform Step<fire: in1.Event> from DFA out1.State(x) :- in1.State(x). out1.Event(x) :- in1.Event(x). out1.Transition(s, e, sp) :- in1.Trans out1.Current(sp) :- in1.Current(s), ir out1.Current(s) :- in1.Current(s), fai }		• Semantic Anchoring	• Semantics for complex DSMLs • Composiiton

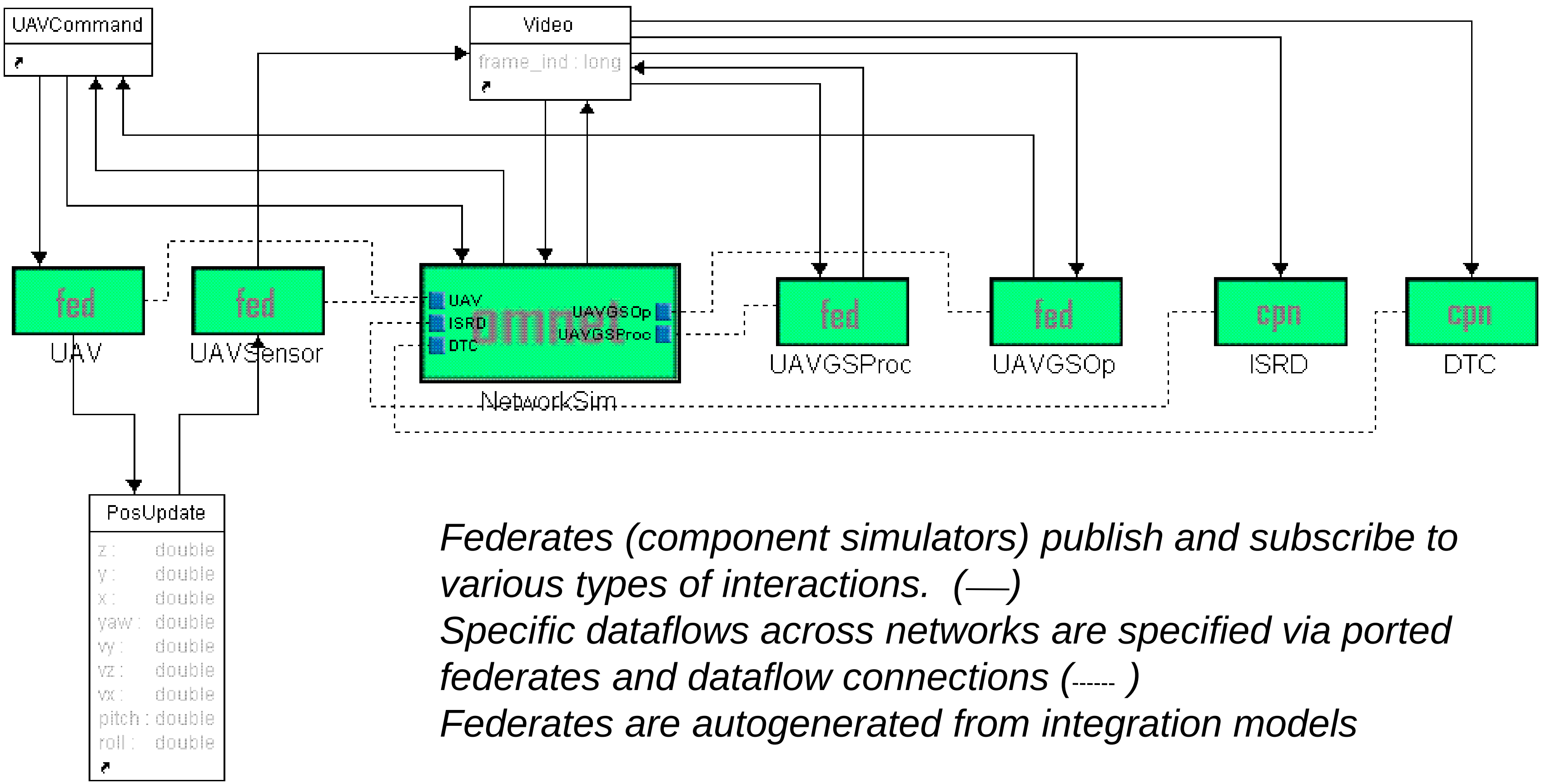
Model and Simulation Integration Approach in C2WT



What is High-Level Architecture (HLA)?

- An IEEE standard for "interoperable" and "reusable" models and simulations.
  - Most used specification (also used in the demo) is IEEE HLA 1.3 (1998)
  - Most recent specification is IEEE HLA 1516 (2000+)
- DoD-wide policy requires ALL defense models and simulations to comply with the standard.
- Primary goal is to provide a general purpose infrastructure for "distributed" simulation and analysis.
- Software implementing the HLA specification is called Run-Time Infrastructure (RTI).
  - Several commercial and open-source RTIs are available.
  - In the demo we used an open-source RTI PORTICO v2.0.1 implemented in Java language (http://porticoproject.org/).
- *Semantics of the Model Integration Language for C2WT is defined by HLA's service models* (federation mgmt., declaration mgmt., object mgmt.time mgmt., data distribution mgmt., ownership mgmt.)

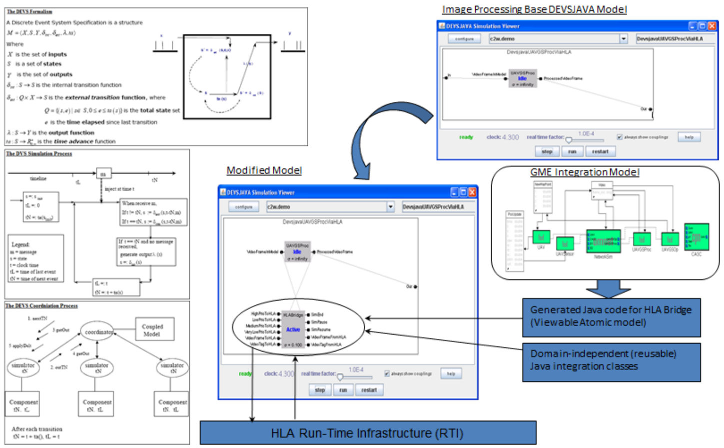
Example: Integration model of a specific C2 scenario



Federates (component simulators) publish and subscribe to various types of interactions. (—)
Specific dataflows across networks are specified via ported federates and dataflow connections (------)
Federates are autogenerated from integration models

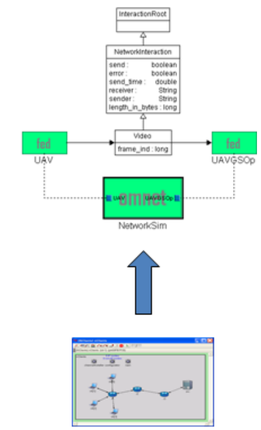
Other tool integration examples and capabilities

DEVSJAVA Discrete Event Simulation (DEVS)



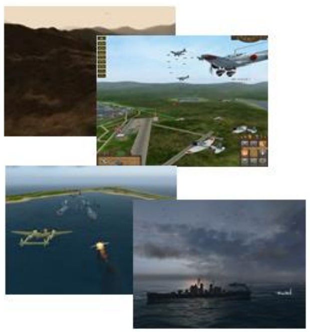
OMNeT++ Network Simulation integration

- Omnet, Inet packeges
  - Omnet is a generic discrete event simulation package (module specification with .ned files, implementation in c++, modular, customizable plugin architecture)
  - Inet: network protocols for omnet (ip, wiresless, ad hoc, etc)
- Omnet integration
  - Challenges
    - Scheduler integration
    - Data type mapping
  - C2 Wind Tunnel network support
    - Build in NetworkSim federate, takes care of omnet scheduler synchronization and data conversion
    - Built in network interaction (NetworkInteractions)
    - Derive interactions from the NetworkInteraction to specify custom data types
    - Derived interactions will be sent through the network simulator
    - Federates can be connected to network endpoints, addressing is based endpoint names



3D Visualization model integration

- OGRE 3D (open source graphics engine)
  - Widely used 3D engine in games
  - C++ implementation
- C2 Wind Tunnel integration
  - Simple java interface for OGRE (most of our federates are java based)
  - The UAVSensorFed federate: An example visualization federate
    - Interpolation for smooth animation
      - Time interpolation
      - Object position estimation (dead reckoning)



Library of supported tools and mechanisms:

- ***Other simulation tools*** (NS-2, Delta3D, Google Earth, Java/C/C++, FMU-CS, etc.)
- ***Passive federates*** (e.g. Loggers, monitors, etc.)
- ***Live components*** (e.g. Emergency response, Traffic conditions, Human-in-the-loop, etc.)
- ***Advanced support*** (e.g. Legacy FOMs, COAs, Expt. Config., Remote deployment, Gaming, etc.)

Ongoing efforts

- With NIST:
  - Building automation with Cyber & Network Effects Analysis
  - Performance Impact of Securing Security Industrial Control Systems (uses Railroad Infrastructure and Network Simulations)
- With AFRL:
  - System Science of SecUrity and REsilience (SURE): Threat modeling, Cyber effects analysis, Resilient Architectures, Decentralized security
- Global Cities Challenge (sequel to Smart America)
  - Real-time Optimized Metro Routes (from an App) based on real-time traffic input and look-ahead of traffic demands based on historical information. Also, support for analytics to improve metro efficiency in a number of ways.

Key URLs and Contact

- Cyber-Physical Systems – Virtual Organization – http://cps-vo.org
- C2WT community wiki – https://wiki.isis.vanderbilt.edu/OpenC2WT
- Functional Mock-up Interface – www.fmi-standard.org
- HLA standard – IEEE standard for modeling and simulation (M&S) high-level architecture (HLA) – framework and rules http://ieeex-plore.ieee.org/servlet/opac?punumber=7179
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