Multi-Model Simulation: The C2 Wind Tunnel (C2WT)

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AFOSR PRET Project Team

- Vanderbilt University: Institute for Software Integrated Systems (ISIS)
- George Mason University: System Architectures Laboratory (SAL)
- UC Berkeley

in collaboration with

- GMU – led MURI including SAL and the CMU Center for Computational Analysis of Social and Organizational Systems (CASOS)
- AFIOC
- AFRL/RI
Outline

- Principles
- Architecture
- Project Status
Project Objectives

Theoretical and experimental foundation for integrated C2 architectures for manned and unmanned assets operating in urban environments.

- Develop rapid system integration technology for empirical studies in human system interaction paradigms in dynamic C2 architectures: C2 Wind Tunnel (ISIS-Vanderbilt)

- Develop adaptive models and algorithms for groups and organizations. (GMU)

- Develop adaptive modeling, model validation, and design techniques for mixed initiative teams of distributed decision makers. (UC Berkeley, University of Arizona)
Notional C2 Architecture

Model-Based Experiment Integration Environment: C2 Windtunnel

Issues to be studied experimentally:

• Distributed Mission Operation
  – Synchronization and coordination
  – Distributed dynamic decision making
  – Network effects

• Increased Information Sharing
  – Shared situation awareness
  – Common Operation Picture (COP)
  – Network effects

• Seamless Integration of Manned/Unmanned Assets
  – Mixed-Initiative Teams

• System Level Impact Analysis
  – Cyber attacks
  – Resilience solution
  – Strategy/gaming
Architectural Questions

- **What is the acceptable QoS in the COP?**
  The maximum acceptable data latency across the networks and C2 nodes has major implications on the required network bandwidth and architectural complexity.

- **What are the mission performance and cost tradeoffs between pursuing architectural solutions (better QoS control, networking, adaptive information management) versus augmenting human capabilities with improved training, better HCI design?**

- **What is the impact of increased automation on C2 organization architecture?**

- **What are the impacts of cyber attacks on mission and how to increase resilience against attacks?**
Project Evolves Along a Series of Vignettes (GMU)

Year 1 Vignette:
- UAV sensor platform deployed to search for target
- Ground control station
- Network link to CAOC

Goal: Prove feasibility of end-to-end simulation of heterogeneous C2 architectures

Year 2 Vignette:
- Time critical target search in urban terrain
- Multiple small UAV and a large UAV platform
- Complex tactical scenario

Goal: Conduct experimental studies of impact of level of UAV autonomy on mission performance
Organizations and coordinated activities are modeled in Colored Petri Nets using CPN tools and CEASAR III of GMU

- Colored Petri Net language
- Time automata semantics
Mobile Sensor Platform Control (UC Berkeley)

Control Objectives:
- Automatic information gathering
- Safe interaction

Constraints:
- Power budget
- Communication bandwidth
- Computational resources

- Simulink/Stateflow modeling language
- Hybrid automata semantics
Model and Simulation Integration: C2 Wind Tunnel (VU-ISIS)

How can we integrate the models?
How can we integrate the simulated heterogeneous system components?
How can we integrate the simulation engines?

Data Distribution Network
Model-Integrated System and Software Laboratory Environment: C2 Wind tunnel

Simulation Interaction
Simulation Architecture
Network Architecture
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C2WT Integration Challenges

Integrating *models*
- Heterogeneous modeling for different domains: human organizations, communication networks, C2 software systems, vehicle simulations, etc.
- Needed: an overarching *integration model* that connects and relates the heterogeneous domain models in a logically coherent framework.

Integrating the system
- Heterogeneous simulators and emulators for different domains: Colored Petri Nets, OMNET++, DEVS, Simulink/Stateflow, EMULAB, 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 interactions across system components. Why don’t we model the interactions and use these models to facilitate model and system integration?
C2W Integration Solution / Platform

 Goals

- provide an environment to integrate and execute heterogeneous domain specific simulation models or ‘real’ system components
- support easy configuration and evaluation of scenarios

 DoD/HLA was chosen as the base run-time integration platform. Rationale: HLA was designed as a simulation integration platform and it provides services for run-time integration of large simulators. Has sophisticated support for coordination among simulation engines.

 C2WT additions:

- Model based integration of domain specific simulation models (CPN, Simulink, Omnet++, DEVS, etc)
  - Data models
  - Integration models
  - Transformation (import, export, code generation)
- Support for execution of domain specific models
  - Runtime execution engines

Key idea: Integration is about interactions across system components. We model the interactions and use these models to facilitate model and system integration.
C2WT Metamodel
Defines language for integrating models in scenarios

Note: Only a part of the metamodel is shown here.
Example: Interaction Hierarchy Model

Segment of an Interaction Hierarchy Model:

```
InteractionRect

SimulationEnd

NetworkInteraction
  error: boolean
  send_time: double
  receiver: String
  sender: String
  length_in_bytes: int

Video
  frame_ind: long

VideoFrame

VideoTag
  x: double
  y: double
  z: double
  object_type: String
  damage_level: double
  from_ind: long

UAVCommand

DirectControl
  TODO: String

NewWaypoint
  t: double
  y: double
  z: double
  x: double

AutomaticEDA
  z: double
  y: double
  x: double

PosUpdate
  z: double
  y: double
  x: double
  yaw: double
  roll: double
  pitch: double
```

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Example: Model for simulation architecture for a specific scenario

Federates (component simulators) publish and subscribe to various types of interactions. (—)
Specific dataflows across networks are specified via ported federates and dataflow connections (----)
C2WT Integration Platform Modeling

C2WT integration models
(design flow, timing, parameters)

Domain specific simulation models
configuration

Based on C2W simulation model configuration files are generated for the various simulation components.
- configure how the component is connected to the simulation (input-output binding)

C2WT Data models
(interaction and object models)

Federates have to have a common data model to be able to share data.
- data model can be imported from domain specific models
- domain specific models can be generated from data models

Domain specific simulation models
transformation

- OMNET component
- CPN component
- Simulink component
- Delta3D...

- Omnet models
- CPN models
- Simulink models
- Delta3D...
C2WT Integration Platform

Domain specific models

- Simulink Models
  - Vehicle simulator

- CPN models

- Network models

- Terrain models, 3D object models

Reusable C2W integration simulators

- Simulink Integration Federate
- Colored Petri Net Integration Federate
- Omnet++ Network Simulation Integration Federate
- 3D Visual Sensor Simulator Federate (Delta3D, GoogleEarth)

HLA Run-Time Infrastructure (RTI)
Example: Simulink Model Integration (Vehicle dynamics)

Original Simulink model (X4 simulator)

Modified model

Input binding

Add input-output bindings

Output binding

Signal flow

Signal flow

HLA Run-Time Infrastructure (RTI)

GME integration model

Code generation

Generated .m Receiver and Sender S-function code

.java code for representing Simulink federate

RTI runtime communication
Data Collection Support

- C2 Wind Tunnel support on federation level
  - Fixed vector file format (.vec) for numeric data. Simple, easy to export to other tools (Excel, Matlab)
  - Visualization tool for numeric data (Plove, part of the Omnet package)
  - Built in interactions to support centralized logging
  - Federation Manager GUI shows and logs built in log interactions
  - Monitor specific interactions and convert them to vector files

- Federate level
  - Each domain specific simulation environment has its own data collection support
  - Federates can generate log interactions
  - Federates can generate vector files
Experiment Configuration and Execution

- Configure domain specific simulators
  - Each domain specific simulator has its own configuration files
  - Configuration files are collected to an experiment folder
- C2W support
  - Main configuration file
    - Control the scenario by scheduling interactions
    - Registering monitors
    - Registering pause points
  - Execution script
    - Remote execution of federates
    - Control from one machine through the Federation Manager (pause/resume simulation)
- Future work
  - Scripting language support (python)
  - Experiment modeling language
Three levels of modeling in C2WT

- **Modeling the modeling tools - Infrastructure**
  - Technique: Metamodels
    - Describe the modeling tools
    - Also used to define all modeling languages

- **Modeling the integration of the models – Scenarios**
  - Modeling and models tools used (‘federates’)
  - Interactions among the models

- **Modeling the situations – Experiments**
  - Execution platform, experiment setup, deployment
C2WT Capabilities

- **Scenario driven experimentation**
  Extensible infrastructure supported by metamodeling. Rich suite of modeling languages already covering C2 team/organizational modeling aspects. Model-based simulation integration exploring metamodeling and model transformation.

- **Instrumentation and event I/O**
  Foundation for driving operational tools (e.g. ORA) and cognitive performance monitoring tools

- **Parameterizable models and scalable distributed infrastructure**
  Human in the loop simulation.

- **High quality, open source tools and components.**
  Many elements are used worldwide by the research community and industry (MIC Tools, Omnet++, Portico, Devs, Delta3D, CPN, OGRE).

- **Very low cost, open-source infrastructure that can be distributed to the research community and government industry users**
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Major C2WT Milestones

1. Feasibility demonstration
   Vanderbilt, 13 September 2007

2. First public release
   December 2007

3. 1st Demonstration for LtGen Robert J. Elder. 8th AF CC & JFCC-GSI
   Barksdale AFB, 1 February 2008

4. AFRL-RI, AFRL-IFS and AFIOC technical coordination meeting
   Vanderbilt, 5-6 May 2008

5. 2nd Demonstration for LtGen Robert J. Elder. 8th AF CC & JFCC-GSI
   Barksdale, 10 October 2008

6. Second public release
   June 2008

7. Third public release
   December 2008
The Oct 2008 Demonstration Scenario

- The scenario was defined by Alex Levis’ team at GMU
- It illustrates the C2 Wind Tunnel (C2WT) capabilities for:
  - Using multiple, loosely-coupled models in support of operations
  - Representing Blue-Red interactions (two-sided)
  - Including Tactical and Operational decision making
- Time-sensitive Operations Scenario provides
  - Red Objectives, Course(s) of Action, and Assets (Red follows a script, but may react to Blue’s actions)
  - Blue Objectives, Course(s) of Action, and Assets in anticipation of Red’s actions
• Two sided action in an urban environment (with non-combatants; non-combatants have not been modeled for this demo)
The Storyline: Two Contemporaneous Tasks

Task 1: WMD
- Blue is trying to determine if the adversary is developing WMD
- HUMINT and SIGINT efforts are under way
- Blue knows certain information about the adversary at the start of the scenario (Initial Situation Awareness)
- Blue assigns assets to track a WMD materials truck in order to locate the WMD Laboratory

Task 2: VBIED
- Red deploys a Vehicle Born IED (VBIED)
- Blue assigns ISR assets to track the VBIED
- Red recognizes Blue’s effort and changes behavior

Tasks 1 & 2: CAOC
- Blue commander needs to make operational level decisions
Blue Organization

- CAOC
  - Commander
  - Dynamic Targeting Cell (DTC)
  - ISR Division (ISRD)
- Cyber Cell
- LCC
- UAV Controllers
- Network
- Tasking/Control
- Suspect Neighborhood Image Clip
- Expected Materials Truck Route
- SIGINT
- UAV Operators/Controllers
- Land Component (LCC)

2/4/2009
What You See

Key Events/Messages
Blue’s View

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

ORA Social Network
Way Ahead

1. Scenario and methodology for using C2WT in TTP development for fighting through cyber attacks.
   - Scenario development for Human Centric C2
   - Methodology for explicit modeling of TTPs
   - Experiment design for TTP evaluation

2. Advanced mixed initiative control techniques for UAV operations
   - Extension of controller model libraries
   - Distributed C2 for decentralized sensing

3. Extension of C2WT capabilities
   - Parameterized scenario and experiment specification
   - Extension of modeling languages via metamodeling: TTP modeling language
   - Fourth public release of the C2WT
   - Final Demo

2/4/2009
Summary: New Opportunities

- **System-level impact analysis of cyber attacks**
  - Coordinated network attacks
  - Component compromise
  - Human intervention

- **Design for resilience**
  - Evaluation of architectures
  - Performance security tradeoffs
  - Performed BEFORE the systems built

- **Development and evaluation of defensive strategies**
  - Modeling adversaries
  - Dynamic architectures and behaviors
  - Gaming