Multi-Modeling and Meta-Modeling of Adversaries and Coalition Partners

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ABSTRACT

Models developed using different modeling languages but the same data provide different insights of the human terrain. Interoperation of such models, i.e., multi-modeling, can produce a more robust modeling and simulation capability to support operational commanders or intelligence analysts. The C2 Wind Tunnel is a platform that enables multi-modeling and the conduct of simulations and computational experiments. However, to establish that the interoperation of the models is valid, meta-modeling analysis is required. An approach using concept maps is described and then is illustrated through application to a human terrain example.

1.0 INTRODUCTION

No single model can capture the complexities of human behavior especially when interactions among groups with diverse social and cultural attributes are concerned. Each modeling language offers unique insights and makes specific assumptions about the domain being modeled. For example, social networks [1] describe the interactions (and linkages) among group members but say little about the underlying organization and/or command structure. Similarly, organization models [2] focus on the structure of the organization and the prescribed interactions but say little on the social/behavioral aspects of the members of the organization. Timed Influence net models, [3], [4] a variant of Bayesian models, describe cause-and-effect relationships among groups at a high level.

In order to address the modeling and simulation issues that arise when multiple models are to interoperate, four layers need to be addressed (Fig. 1). The first layer, Physical, i.e., Hardware and Software, is a platform that enables the concurrent execution of multiple models expressed in different modeling languages and provides the ability to exchange data and also to schedule the events across the different models. The second layer is the syntactic layer which ascertains that the right data are exchanged among the models. Once this is achieved, a third problem needs to be addressed at the Semantic layer, where the interoperation of different models is examined to ensure that conflicting assumption in different modeling languages are recognized and form constraints to the exchange of data. In the Workflow layer valid combinations of interoperating models are considered to address specific issues. Different issues require different workflows. The use of multiple interoperating models is referred to as multi-modeling while the analysis of the validity of model interoperation is referred to as meta-modeling. Such an approach has been used in simulation mode or to explore the possible outcomes of proposed courses of action; it has not been used to predict outcomes.

In this paper, we focus on issues relating to the syntactic and semantic layers. The Physical and Syntactic layers have been addressed through the development of the C2 Wind Tunnel (C2WT) [5], [6] by Vanderbilt

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14. ABSTRACT
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University in collaboration with UC-Berkeley and George Mason University. This is described in Section 2. The modeling languages currently implemented in the C2WT are described briefly in Section 3. In Section 4, the approach taken for the meta-modeling analysis is presented. Finally, in Section 5, the approach is illustrated through a complex scenario that involves Intelligence and Surveillance in order to defeat adversaries from using IEDs and developing weapons of mass destruction (WMD).

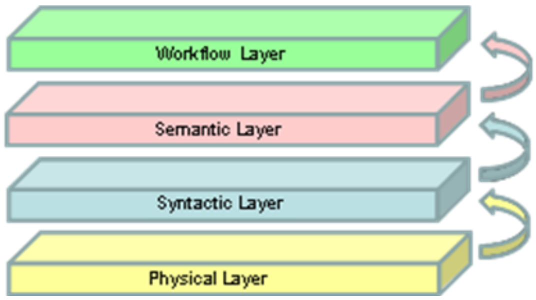

Figure 1: The four layers of Multi-modeling.

2.0 THE C2 WIND TUNNEL

The C2WT is an integrated, multi-modeling simulation environment. Its framework uses a discrete event model of computation as the common semantic framework for the precise integration of an extensible range of simulation engines, using the Run-Time Infrastructure (RTI) of the High Level Architecture (HLA) platform. The C2WT offers a solution for multi-model simulation by decomposing the problem into model integration and experiment or simulation integration tasks.

Model Integration: Integrated experiments or simulations are specified by a suite of domain specific models, including for instance: human organizations (expressed using the Colored Petri Net modeling language and social networks), networks (OMNET++ network simulation language), physical platforms (Matlab/Simulink based models), and the physical environment (e.g., Google Earth). While the individual behaviors simulated by the different simulation models are essential they must interact as specified by the workflow for the particular simulation or experiment. Their interactions need to be formally captured and the simulation of the components needs to be coordinated. This is a significant challenge, since the component models are defined using dramatically different domain specific modeling languages. The C2WT, therefore, uses the meta-modeling technology and the Vanderbilt MIC tool suite[1]. The key new component is the Model Integration Layer (Fig. 2), where a dedicated Model Integration Language (MIL) is used for model integration. The MIL consists of a carefully selected collection of modeling concepts that represent the domain-specific simulation tools.

Model-Based Experiment Integration: C2WT uses the MIC model interpretation infrastructure for the generators that automatically integrate heterogeneous experiments on the HLA platform deployed on a distributed computing environment. After finalizing the component models, the integration models, and setting the parameters, the MIL model interpreters generate all the necessary configuration information and

[1] MIC is a meta-programmable Model-Integrated Computing (MIC) tool suite for integrating models, to manage the configuration and deployment of scenarios in the simulation environment, and to generate the necessary interface code for each integrated simulation platform. It has evolved over two decades of research at the Institute for Software Integrated Systems at Vanderbilt University and is now used in a wide range of government and industry applications.

run-time code. The architecture of the C2WT is shown in Fig. 2. Each modeling language is depicted as a federate on which models built using that language run.

Time Management in C2WT: Time Management is critical to preserve causality with simulations operating at different timescales. The C2WT builds upon the time management features of the underlying HLA standard, which has provision for both discrete time and discrete event models.

The main elements of time management in HLA are: a) a Logical Timeline, b) Time ordered delivery of interactions between simulations, and c) a protocol for advance of Logical Time. In a causality preserving execution (note that HLA supports untimed executions as well), the underlying RTI maintains a logical time, and interaction messages generated by simulations are time stamped with the logical time and delivered to their destinations in a timed order. The logical time is advanced by a cooperative Time Advance Request and Grant protocol. A similar protocol is supported for event driven simulation in which the event driven simulation requests the Next Event to the RTI. The simulation logical time is advanced either to the earliest available interaction or to the time stamp of the next event local to the requesting simulation

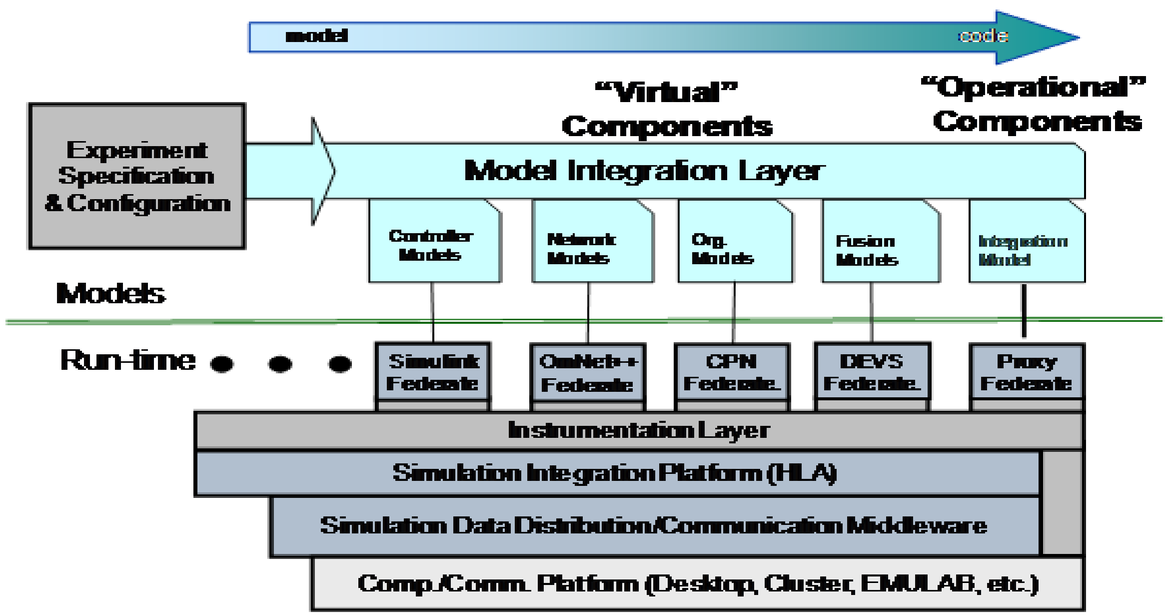

Figure 2: The C2WT architecture.

3.0 MULTI-MODELING

Current military operations need, and future operations will demand, the capability to understand the human terrain and the various dimensions of human behavior within it. Behaviors in the human terrain context extend across the spectrum from adversaries to non-combatant populations, to coalition partners, and to government and non-government organizations. As the type of missions that current and future commanders must address has expanded well beyond those of traditional major theater combat operations, the need to broaden the focus of models that support planning and operations has become critical. Actions taken by all agents together with the beliefs, perceptions, intentions, and actions of the people involved in an area of operations, interact to affect the outcome of a conflict or coalition operation, a disaster relief plan, and/or a peacekeeping effort. No single set of models and tools can support the operational commander addressing the challenges of conducting non-conventional warfare missions. For example, while there are many models using diverse data bases, none can address the complexities of coordinating kinetic and Information Operations when the adversary is embedded within a complex non-combatant population.

Figure 3: Modeling applications using different modeling languages.

We and our collaborators at Carnegie Mellon University [7] have developed a suite of models that address different aspects of modeling the attitudes and behaviors of adversaries. While they address man-made threats, they are proof of the concept that model interoperation is feasible. A subset of the currently available suite of tools is shown in Fig. 3.

Caesar III [8] is a Colored Petri Net tool for designing and analyzing organizational structures. The Timed Influence Net application, ***Pythia*** [9], [10] is used to develop Courses of Action and compare their outcomes. ***Temper*** [11] is a temporal logic inference tool that is used to address the temporal aspects of a course of action. ***Ruler*** [12] is a tool for evaluating whether a proposed course of action is in compliance with the prevailing legal and regulatory environment. ***SEAT*** is a tool for visualizing and comparing the results of the simulations with measures of performance and measures of effectiveness.

ORA [13] is an application for the construction and analysis of social networks while ***DyNet*** [14] is a computational model for network destabilization. In addition, **WebTAS** [15], a GFE visualization and timeline analysis tool developed by AFRL/RI that accesses data in data bases and can receive streaming live data form sensors, has been integrated in the C2 Wind Tunnel thus enabling showing data and results on maps. Each of these federates uses a different modeling language and a different simulation engine.

Multi-modeling can serve as a means of reducing data ambiguity and identifying missing data. For example, by comparing two distinct, incomplete models and using inferences from one model to inform the other, a much less ambiguous representation of the system of interest can be obtained. When this approach is coupled with meta-modeling research to determine what inferences from one model can be validly "exported" to another, the opportunity arises for exploring ambiguity, uncertainty, and missing data issues.

Effective multi-modeling requires that the modeling languages used, the models themselves, and the supporting data, do not contain assumptions that invalidate the specific model interoperation. This leads to the need for meta-modeling analysis.

4.0 META-MODELING

With the capability provided by the C2WT infrastructure, different models addressing the same problem can be utilized, all drawing upon the same data set. This provides a means for exploring the suitability of using models of different resolution and exploring their range of applicability through computational analysis and evaluation.

Our approach to understand modeling language semantics so that multiple models can be used together, i.e., can interoperate, has been to use concepts maps [16] to describe the characteristics of the set of modeling languages and data that are available to support analysis. A fragment of the concept map for the Timed Influence Net modeling language is shown in Fig. 4.

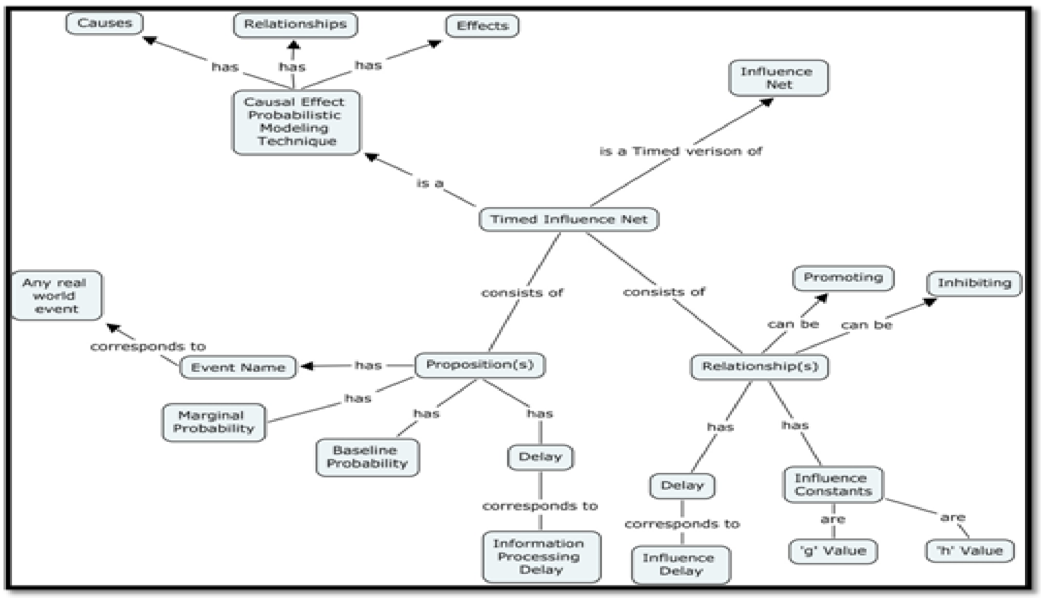

Figure 4: Fragment of the concept map for Timed Influence Nets.

Meta Modeling analysis indicates what types of interoperation are valid between models expressed in different modeling languages. Note that model interactions can take a wide variety of forms: (1) One model runs inside another; (2) Two models run side-by-side and interoperate. The interoperation can be complementary where the two run totally independently of each other supplying parts of the solution required to answer the questions, or supplementary where the two supply (offline and/or online) each other with parameter values and/or functionality not available to either individual model; and (3) One model is run/used to construct another by providing design parameters and constraints or constructs the whole or part of another model (Fig. 5). These are all aspects of the need for *semantic interoperability*.

We assume that two models can interoperate (partially) if some concepts appear in both modeling languages. By refining this approach to partition the concepts into modeling language input and output concepts and also defining the concepts that are relevant to the questions being asked by the analysts and decision makers, it becomes possible to determine which sets of models can interoperate to address some or all of the concepts of interest, and which sets of models use different input and output concepts that are relevant to those questions.

In order to support semantic interoperability we must be able to interchange models across tools. This requires model transformations. The transformations are formally specified in terms of the meta-models of the inputs and the outputs of the transformations. From these meta-models and the specification of the semantic mapping we synthesize (generate) a semantic translator that implements the model transformation. [17]

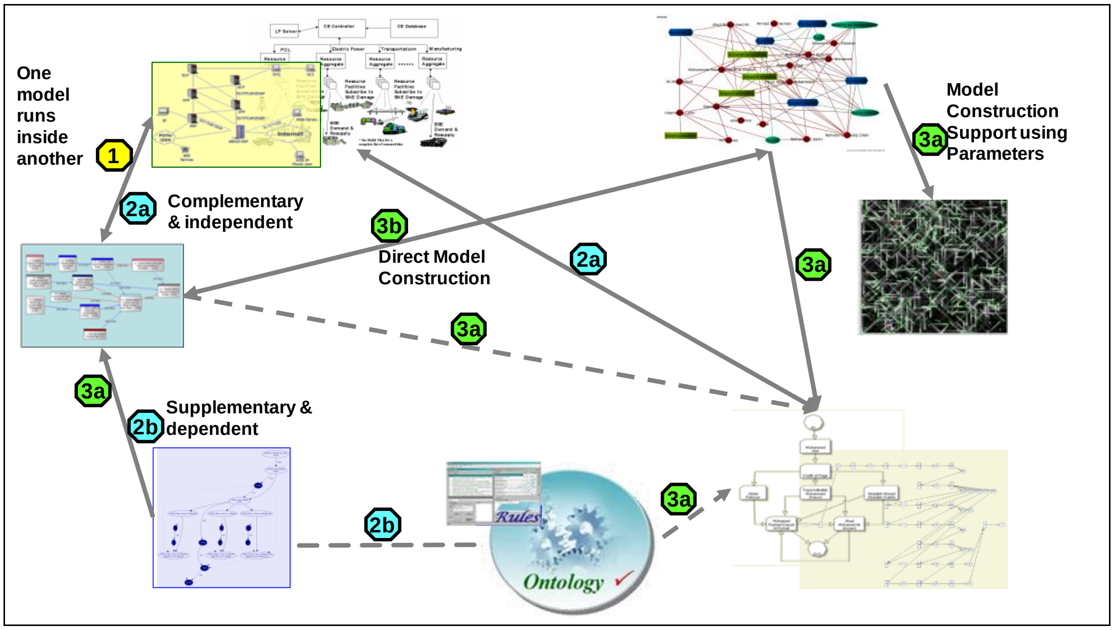

Figure 5: Multiple types of model interoperation.

5.0 HUMAN TERRAIN EXAMPLE

The C2WT technology has been applied to several different defense-related domains. However, to demonstrate the technology and the use of the C2WT as a platform for computational and mixed initiative experiments, a scenario was developed that required the inter-operation of several disparate models. The scenario is summarized below.

Blue suspects that Red is engaging in the development of WMD, but does not know where the development is being done. The key idea of the scenario is that Red has a covert house in which vehicle borne improvised explosive devices (VBIEDs) are manufactured and Red is also using the same house for the WMD development. Blue does not know that they co-located.

Blue has some limited intelligence about both of these activities and would like to locate the facilities. A shipment by truck of WMD materials provides an opportunity for Blue to discover the WMD factory. However, concurrently, Red decides to deploy a VBIED following his usual Tactics, Techniques and Procedures that have proven effective in the past. Blue has to make decisions as to how to allocate scarce ISR assets (two Unmanned Air Systems, UAS) among the two Red activities while at the same time he wants to make the VBIED ineffective and gather additional intelligence about the VBIED making factory. A cyber cell was added to the Blue organization to provide additional ISR capabilities (SIGINT) for Blue.

The scenario was designed to illustrate the benefits of information sharing over networks. If different Blue operators and decision makers share the information that they collect from different resources in a timely manner, then the tactical and operational level commanders will be provided with the maximum information that, in the case of the scenario, results in Blue locating the combined WMD and VBIED factory and identifying and locating the VBIED operation. If some of the information is not shared for any reason, such as operator error by the Blue operator – the UAS pilots - or Red interference, Blue may be unable to identify the location of the covert bomb factory or track the VBIED to its final location.

GoogleEarth was selected as the scene visualization application because it is freely available and very realistic. Human operators may be used to control the two UASs; alternatively, the UASs may fly autonomously. The operators received directives from the Colored Petri Net representation of the CAOC operators and the information from the UASs was sent to those CAOC operators over the simulated network modeled in OMNeT++.

Figure 6 shows some of the screens generated by the execution of this scenario on the C2WT. One screen shows, using GoogleEarth, what the sensors on the UAS sees; the second shows what the human operator of the UAS sees after the sensor data are transmitted through the network. In this way, the effects of network delays or jamming or cyber exploits can be observable directly. Another screen shows the ground truth – the location and tracks of the UASs and of the targets as they drive through an urban environment. Still another screen shows the situation reports and other messages that go through the system. Finally, when the driver of the VBIED is identified, ORA generates the social network to which he belongs and thus helps identify other actors in the exploit.

The entire scenario with all federates was created and installed on multiple computers with several large screen displays. The execution of this particular scenario was conducted in real time because of the presence of the human operators and lasted about 20 minutes. Furthermore, the C2WT was instrumented for the collection of data so that excursions from the scenario could be evaluated. Two extensions were created to the main scenario involving Red's use of jamming to attempt to reduce the effectiveness of Blue. In the first case, the jamming was effective. In the second case, anti-jamming procedures were employed by Blue and the data links from the UASs to the CAOC were re-established. However, it was determined that the length of the time interval during which the signal was jammed was a critical parameter. If the interval was too long, then the UAS was not able to re-acquire the target in the urban environment. Currently, a series of experiments is being conducted with variants of this scenario exploring the effect of cyber exploits on performance.

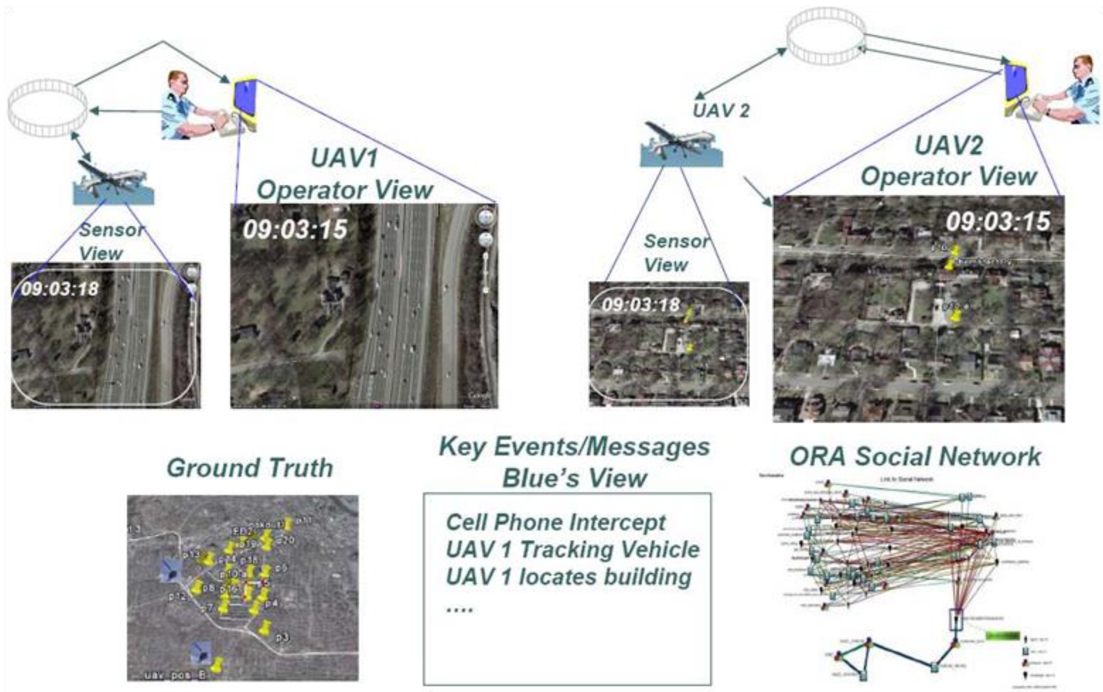

Figure 6: Large Screen Displays for C2WT Demonstration.

6.0 CONCLUSIONS

The C2WT has been installed and is operational at Vanderbilt, GMU, CMU, and AFRL/RI (Rome, NY) and is being applied to a number of research projects and defense industry applications. The concept of multi-modeling has promise for addressing the complexities of modeling adversary behavior especially when only incomplete data are available. This has led to the need for research on meta-modeling to ascertain that the interoperation of multiple models for a particular problem is valid. Such research is continuing while additional federates are being prepared for installation on the C2WT.

7.0 ACKNOWLEDGMENT

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