<CHAPTER XX

Multi-Modeling and Socio-cultural complexity: Reuse and Validation

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ABSTRACT

Socio-cultural complexity is often best approached through the use of hybrid models that blend the effects of atomic models built from different social and mathematical theoretical bases. Such approaches are often referred to as multi-modeling. This paper discusses the types of multi-modeling, with attention to the factors that support reuse and validation. Illustrations of multi-modeling are shown using examples from multiple multi-modeling exercises. Multi-modeling supports in-depth analysis by enabling cross-validation of results through triangulation, insight into implications at multiple levels of granularity through cross-model consistency, and model advancement through re-use across multiple domains.

Keywords: multi-modeling, agent-based modeling, network analysis

1 INTRODUCTION

Multi-modeling is predicated on the use of and inter-relation of multiple models. This inter-relation can take many forms including docking, collaboration, interoperability, and integration. The strength and utility of the multi-modeling approach depends on the geo-temporal-group signature of the models, whether the usage is focused on physical system demonstrations or planning and analysis, and on the type of inter-relationship being used. Finer-grained signatures, physical system demonstrations, and integration all decrease reuse and increase the difficulty of validation. In contrast, coarser grained signatures, analysis, and docking-lite increase reuse and decrease the difficulty of validation. These points are illustrated showing how the level of re-use and the demands on validation were different in the nuclear deterrence and Arab Spring examples.

2 TYPES OF MULTI-MODELING

Multi-modeling requires the use of multiple models. These can be from any modeling tradition, e.g., in the deterrence project the team used social-network, agent-based and timed influence-net models; whereas, in the Arab-Spring project text-mining/machine learning, network and agent-based models were used. Multi-modeling, within the same project can take on one or more forms – see Figure 1. The critical issue in multi-modeling is ensuring that the scale and boundary conditions for those models that are locked are consistent. Three aspects of scale are important to consider temporal, actor, and geo-temporal; i.e.: Are the models operating in the same time window? Are the models taking into account the same actors? Are the models considering the same spatial region in the same time frame?

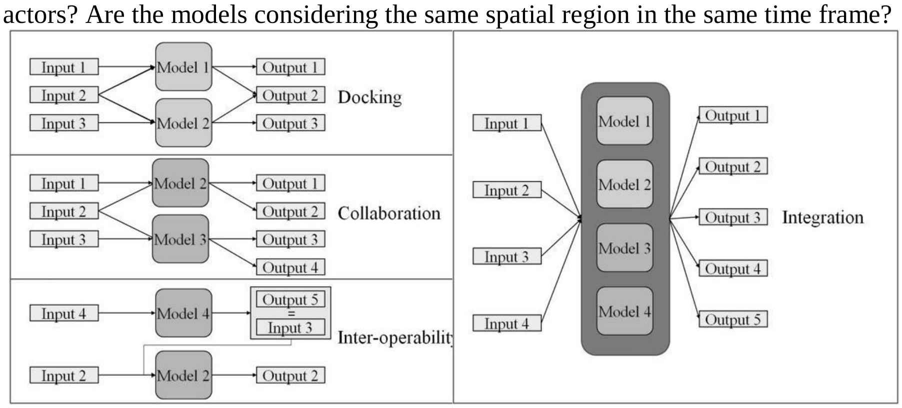


Figure 1 Types of multi-modeling

Integration requires refactoring all models into a single model. This often requires new code, and great care must be taken not to violate the theoretical assumptions of the original models or their boundary conditions when they are integrated. Such models are difficult to validate as they require that all inputs be fused to the same time span, set of actors, and geo-spatial region. Integration is the most costly both in person-years and overall computational costs to develop, the most costly to validate, and the most costly to extend and reuse. In contrast, other forms of multi-modeling present a more feasible approach with greater benefits in terms of extensibility, flexibility, and feasibility. The key to multi-modeling is comparability and consistency for inputs and focus. Multi-modeling supports validation and understanding through triangulation and extensions.

Docking requires that two or more models use at least one identical or comparable input and produce one identical or comparable output; while the other inputs and outputs can be distinct. For docking, both models operate at the same level of granularity on all three dimensions – time, actors, and geo-temporal. Docking enables validation on the identical output (output 2) for both models through triangulation. Collaboration is a variant in which multiple models operate on a set of input such that at least one part is identical or comparable. In this case all outputs from both models can, as in the case of docking, be used collectively to provide greater insight into the phenomena of interest. The collaborative models need not operate at the same level of granularity; which means, that while one model may use the raw data the second model may use an aggregated version of that data. Interoperability is the classic form of multi-modeling where one model's outputs become another models inputs. In integration, sometimes some of the models are linked together into an interoperable system. Interoperation is a key approach used for moving up or down the scale of time periods, actors, and geo-temporal conditions as the outputs from one model can be "averaged" or "unioned" to create the inputs for the next model that is less granular.

The first stage of multi-modeling is to tune the representations so that the models are focused similarly (Levis, Carley and Karsai, 2011). Three processes support creating the basic representation used by the models; concatenation, amplification and model construction. Concatenation: Two models share a representation and so can get instances from each other. Concatenation can occur at the input level and may only use some of the inputs. Note concatenation underlies all of docking, collaboration and interoperability. Amplification: One model adds or augments one or more class representations provided by the other model. This typically occurs for collaborative or interoperable models. Model construction: One model is used to create another as when a machine learning model for extracting data is used to create a network model for assessing changes in leadership.

Once the basic model representations are set, the analyst moves to the next stage of multi-modeling, running the unified model collection. The workflows may not be linear. For example, the output of one model may be used to set the parameters on another, to set the input for another, or to constrain the region wherein another operates. These are all sub-processes within interoperability. For two models, the first may be used to set parameters of the second and the second used to constrain the time frame of the first. Hence, the interoperability process may require multiple iterations as the models are calibrated to each other prior to the run that produces results.

3 APPLICATIONS OF MULTI-MODELING

3.1 Nuclear Deterrence

The nuclear deterrence project sought to demonstrate the value of interoperation at the combatant command level in model construction, using a multi-modeling approach for a specific scenario (Levis, Carley and Karsai, 2011). The specific scenario was a historic India-Pakistan confrontation overlaid with a hypothetical movement toward potential nuclear activity. The underlying models were then extended to look at nuclear deterrence more broadly and to demonstrate what could be learned about the relative effectiveness of different courses of action using a multi-modeling approach (Carley, 2011). In this latter case, the scenario was current and involved the Pacific Rim. In both cases the work was carried out jointly with George Mason University and their various tools were involved.

The basic multi-modeling approach taken for the India-Pakistan confrontation is shown in Figure 2. Pythia and CaesarIII are the GMU tools, the output shows how a particular action over time alter behavior. The GMU tools focus on the organizational structure and the influences among actions. They handle time more precisely than do the CMU models. In contrast, CMU tools create and generate networks and focus on change in activity and beliefs, with time merely expressed as an ordering. Using AutoMap in the D2M process a basic model was constructed and expressed in ORA. This informed the Caesar III and Construct agent-based model (ABM) (Carley, Martin and Hirshman, 2009). These three model were then concatenated into a collaborative system. AutoMap-ORA-Construct interoperate as do CaesarIII and Pythia. The collaborative system was run and the results passed through interoperation. The results were then used to set parameters for other models and the overall system rerun to generate results. Essentially the same approach was used in the Pacific Rim case; with the change that subject matter expertise was used to build the ORA model rather than text-mining. From a multi-modeling perspective, the key is that the calibration used was a non-linear process with Pythia being used to set parameters in Construct, and the joint results from a calibrated run of Pythia and Construct used to triangulate in on the result that most interventions would not prevent a nuclear war in this scenario.

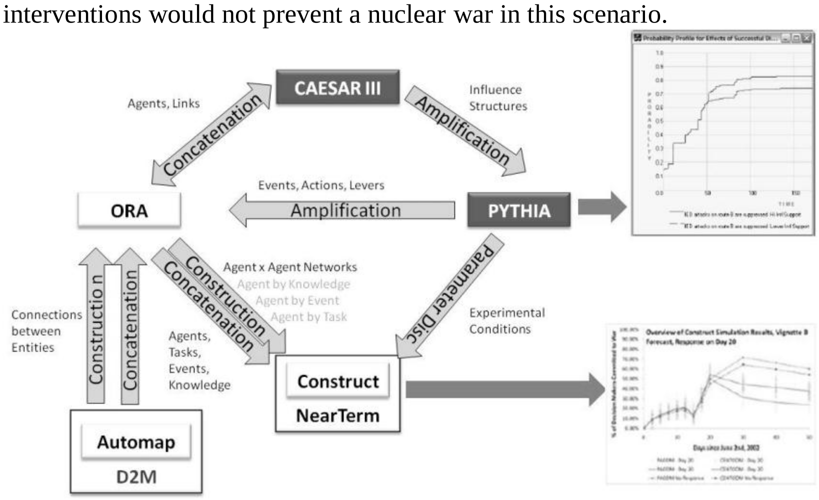
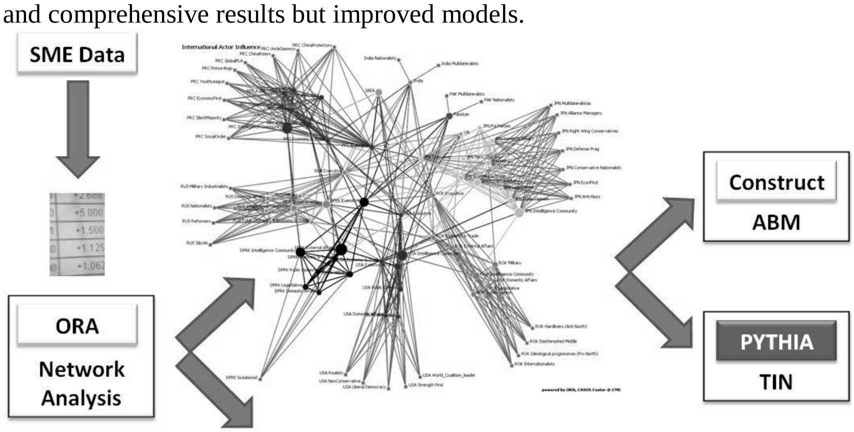


Figure 2. Multi-Modeling for Deterrence

The results, though non-linear and complex, represented accurately the theoretical precepts that informed the model's development and, more interestingly, allowed analysis of secondary and tertiary effects caused by the connections between these nation-states. This was true for both the India-Pakistan and the Pacific-Rim scenarios. For both the scenarios modeling deterrence via multiple distinct modeling methodologies improved the modeling efforts.

In the India-Pakistan scenario, multi-modeling the data-to-model (D2M) analysis, the network analysis, and the Pythia timed-influence network analyses (TIN) were used to create initial and improved reiterations of each model. The D2M products were analyzed as static network models – e.g. see Figure 3. These network models were used to initialize the Construct belief diffusion models. The TIN and Construct models were evaluated using the same scenario texts, and were able to provide interesting validation of each other's results. The models agreed, in broad strokes, on the various scenarios - and the Construct model showed how sensitive and precarious those results were to additional provocation. In the Pacific Rim scenario, the models were created at the general deterrence level and at the more detailed specific regional level. Moving from the general to the regional, the two different theoretical analyses done by the agent-based modelers informed the TIN model by suggesting additional factors to incorporate into the model. Initial versions of the TIN model suggested actions which should be considered within the agent-based Construct models. In this way, multi-modeling led to not only more robust and comprehensive results but improved models.



Actor	Rank	Betweenness Unscaled (Scaled)
DPRK External Affairs	1	724.68 (0.25)
USA Intelligence Community	2	643.37 (0.22)
JPN Intelligence Community	3	525.67 (0.18)
DPRK Executive	4	461.00 (0.16)
DPRK Intelligence Community	5	444.23 (0.16)

Figure 3. Overview of the Role of Networks in the Multi-modeling Process

Multi-modeling enables improved depth of results and supports reuse – with distinct results in distinct scenarios. In the India-Pakistan scenario, the results indicated that fast early and sustained responses could avert crisis. Strong sustained efforts initiated within a week of the first events of the crisis' 90 day timeline would have reduced the majority of decision-makers desire to go to war. Whereas typical diplomatic responses would probably not be sufficient due to the weeks it would take for them to affect a response. In the Pacific Rim scenario, the results suggested that efforts to convince a state that it cannot express itself via conventional means was likely to cause that state to seek nuclear means. Further, the presence of a strong unitary executives resulted in greater resilience in beliefs than was seen in states with more distributive government functions.

3.2 Arab Spring

The Arab-Spring project sought to understand the factors associated with the movement from conflict to revolution to the overthrow of various governments. From a multi-modeling perspective this project was an exercise in interoperability (Pfeffer and Carley, Forthcoming). First hundreds of thousands of documents were downloaded from Lexis-Nexis, meta-networks were constructed from the tags, and data was associated with the country of origin for 18 countries in the Northern Africa and the Middle East. This was done using the world-map approach which can be run directly and is currently being augmented to run using the SORASCS (Schmerl et al., Forthcoming; Carley et al., 2011c) framework. Geo-spatial images, as in Figure 4, were created with GIS tools. A dynamic network model of change in each country was created and assessed using ORA to identify emergent leaders and points of contention. The current step is simulation of each country to forecast the change of the regime-change “belief” that the government should be overthrown. We note that the data as extracted from Lexis-Nexis is already the output of an integrated model which employs language technology models for cross-classification of the articles.

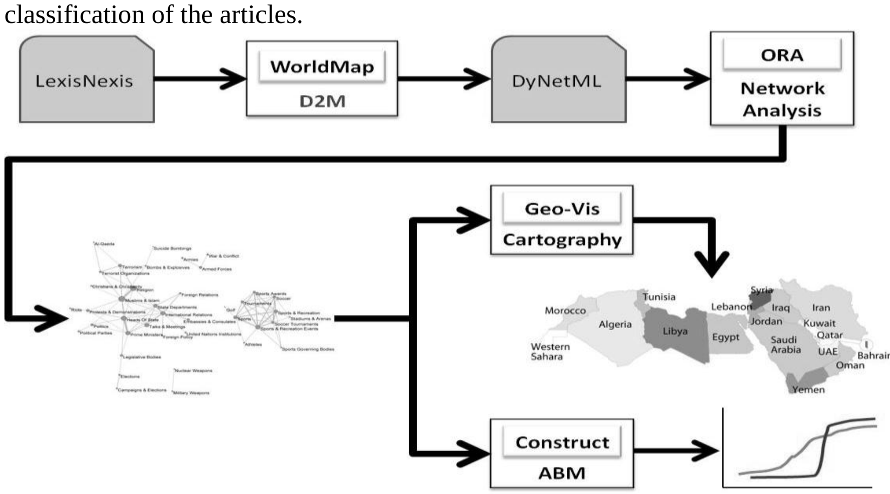


Figure 4. High level view of Arab Spring interoperation

Unlike the deterrence project, the Arab-Spring project is at a high level, a more linear workflow - see Figure 4. Reuse is provided through the use of standard tools and a common workflow which can and is being instantiated in SORASCS. In this case, a key benefit of multi-modeling is rapid data analysis for vast quantities of data with minimal strain on the user by using a set of interoperable tools in a common workflow. To date, this same workflow, and the resulting model interoperation has been reused for all 18 countries, for each of ten months, and has been used in a completely different context – a more historic examination of Afghanistan. A key result of this analysis is that the movement of revolution was not geographically based, nor correlated (as popularly depicted) with an interest in internet/facebook usage; but instead, was presaged by an increase in the complexity with which the issues were discussed and the overall concern with human-rights. Moreover, as revolution came to the fore, terrorism issues moved into the background.

4 VALIDATION

In a multi-modeling environment, as is the case for any simulation system, the type and level of validation should be selected to meet the needs of the system as it will be used. Most models, and so most multi-modeling systems, do not need extensive validation as they are intended to foster conversation and illustrate key points. Socio-cultural models are difficult to validate. In part this is because they typically violate the assumptions of standard validation theory as developed in engineering. And, in part, this is because to garner sufficient data, one must first engage in a data collection, cleaning and fusion exercise. To reduce these problems, an approach referred to as validation in parts is often used in which the model is validated at the input, process and output level separately. Validation in parts is particularly valuable for multi-modeling. The difficulties in validating process increase at least exponentially as models are integrated due to interaction effects. Multi-modeling enables higher levels of validation when the models are inter-related at less stringent levels. Docking is a validation of process as it demonstrates that two models given the same input can produce the same output. All of the models used herein are part of the family of models defined by Carley and Newell (1994) as being the family "model-social agent." As noted by Carley and Newell (1994) the point of a model-social agent is that for the parts of the model not of relevance to the purpose of interest random processing assumptions can be made, and if the results are still comparable and recognizably human socio-cultural behavior, then the models are valid at the process level and the internal processes are functionally equivalent in that context. Finally, the use of multiple models when operating on consistent input and focusing on similar outcomes is in itself a form of validation often referred to as triangulation.

In the two projects described, validation was conducted in multiple ways – see table 1. As the sub-models are often operated separately many have been validated separately. Those models used to extract and codify data were validated using sample empirical data. The network models were validated on prior empirical data sets, the metrics verified, and so on. These specific network models and the predictions made by the simulators were reviewed by subject matter experts (SMEs) to determine whether they passed a face validity, i.e., a giggle, test. Where possible, pattern validation was used to ensure that the models produced results with consistent patterns.

Table 1. Validation Used for Projects

Validation Method	Nuclear Deterrence	Arab-Spring
Validation in parts		
Inputs	Pattern	Distribution
Process	Historical Case Studies	Sample datasets
Outputs	Subject Matter Experts	Subject Matter Experts
Face Validation	By Subject Matter Experts	By Subject Matter Experts
Empirical Validation - Distribution	Network sub-models	Machine learning and network sub-models
Empirical Validation - Pattern	Simulation forecasts	Simulation forecasts

Of possibly greater utility is the validation provided by the multi-modeling approach. In the case of the deterrence work, the models produce by GMU and CMU were docked for the India-Pakistan study and then used interoperably and in a docked fashion in the Pacific Rim study. In both cases, the different models produced results that were comparable for those output streams or variables that were produced by both models, and consistent relative to an over-arching story for those variables that were produced by only one of the models. Thus triangulation suggests a higher level of validity to the collective set of outputs. SMEs reviews of the outputs suggested that the model predictions were plausible.

For the Arab-Spring, multi-level modeling was provided by interoperability. Each model was validated separately. Many of the sub-models had been previously empirically validated using a training/accuracy assessment approach, historical prediction, and calibration with existing models validated in other domains. Overall validity vis- à-vis the finding in the Arab-Spring were found through the process of reuse and comparison. Replication across 18 countries for 10 months provided some validation.

Re-use and validation go hand-in-hand. In general, simulation models that can be designed to operate within or link to the analytic environment are easier to instantiate, re-use, and validate; the results tend to be easier to assess. Multi-modeling that combines analytic and data models with simulation models thus supports re-use. In both projects several factors enabled reuse. First, the sub-models were designed for reuse. Second workflows that ordered the sub-models into patterns of use, which were not necessarily linear were created. These workflows enabled the overall multi-model system to be reused. Third, we used a meta-network data representation to support interoperation. Fourth, network analytics were applied to the meta-network using ORA (Carley et al., 2011b). Fifth, predictions were made; specifically, ORA generated predictions with the immediate impact report and generated the simulation input for Construct which was then used for forecasting the space of possibilities over longer temporal sequences. Sixth, Construct generated output in the same format allowing ORA to be used to compare the empirical data with the simulated data. This multi-step process was repeatable in general and with specific tools. Further, these processes can be done directly or in the SORASCS workflow system thus enabling others to use the same workflow.

One point where divergence is generally needed in the multi-modeling process is in the model representation and construction phase. Many alternative approaches to collecting the data and putting it into the format needed by the analytic and simulation models may produce equivalent results. We employed both model driven and SME driven approaches. Texts were coded as meta-networks (this was done using both a data-to-model approach (Carley et al, Forthcoming; Carley et al., 2011d) which employs AutoMap (Carley et al., 2011a) in the deterrence work for India and Pakistan, SME derived networks for the Pacific Rim, and a rapid ethnographic world mapping approach for the Arab Spring (Pfeffer and Carley, Forthcoming). As noted, in the case of the India-Pakistan deterrence case, we used the diffusion of information across a network of strategic decision makers to inform our results. The network of strategic decision makers was developed using AutoMap and the D2M process. For the Pacific Rim, the scope of the model was enlarged to consider the interactions of multiple (more than two) nations, multiple key beliefs of interest (specifically, six beliefs - three related to the causes for the desire for nuclear deterrence capabilities and three related to outcomes), and multiple 'national narrative' beliefs. For the Pacific Rim the networks of interactions were developed by leveraging the input of SMEs, presenting them with an abstracted model of the influence of key government stakeholders on national posture, and asking how those stakeholders were connected to stakeholders in other nations of interest. The SMEs confirmed that they approved of the abstracted model, and felt that the data gathering process was intuitive and sensible.

5 CONCLUSIONS

Multi-modeling is a valuable approach for understanding human socio-cultural behavior and for forecasting the space of future possibilities. The key is to have compatible inputs when operating across levels of granularity and comparable or identical inputs when operating at the same level of granularity. Three levels of granularity must be considered in identifying relevant inputs: temporal, actor, and geo-spatial. Overall, multi-modeling, in contrast to integration is faster, more flexible as it enables new models to be added in, and places less demands on data fusion for validation. Future research needs to consider how architectures like SORASCS can be provided to support multi-modeling.

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