Exploring the Implications of Time in Discrete Event Social Simulations

Jonathan K. Alt, Stephen Lieberman, and Ahmed Al Rowaei

Modeling of Virtual Environments and Simulations Institute
Naval Postgraduate School
Monterey, California 93943

Abstract

Representing human behavior and cognition, from individuals to societies, presents a range of challenges to the modeling and simulation community. A common thread through many of these challenges is formulating an authentic representation of time. Many of the issues related to time representation, from the sequencing of cognitive decision processes and information processing, to communication and interaction between agents, to the longer term time scales associated with ideas such as belief revision, remain open research areas throughout the community. The inherent variability between human subjects makes generalization difficult even with data from designed experiments. Discrete event simulation (DES) provides a well-documented alternative to time-step simulation and shows potential for applications across the domain of human behavior representation. This paper provides an overview of a modular discrete event framework for social simulation, along with the social and behavioral theories underlying the currently implemented modules. We discuss the practical challenges presented by time in the representation of human cognition, and provide a case study analysis of the output of the discrete event social simulation.

Introduction

The time domain presents multiple challenges to authentically representing human behavior. The idea behind a Discrete Event Social Simulation (DESS) relies on a centralized notion of time that tracks population-wide changes via a central event list, leaving the individual states of agents tracked and managed internally. We use the example of our implementation of a DESS, the Cultural Geography (CG) model, to explore the implications of time in understanding and forecasting changes in the beliefs, values and interests (BVI) of individuals in a population.

The problem of human behavior representation scales from individual entities through representations of societal behavior. Regardless of the scale, whether it be the representation of a single decision maker or a full simulation of society, the processes can largely be categorized as internal entity cognitive processes or external interactions with the environment or other entities within a given simulation. Time and sequencing play a critical role in developing a realistic and traceable representation of human cognition and the resulting observable behavior.

Time and sequencing decisions in the representation of human behavior must necessarily be made, ironically, by human decision makers with incomplete information as to their own internal processes. This process must be informed by interdisciplinary work develop representations based on research from the fields of cognitive psychology at the individual level and social science at the society level of representation. Time stepped and discrete event methods of implementing simulation each possess strengths and weaknesses in regards to the representation of cognition.

The need for social simulations and greater fidelity in the representation of human decision makers within modeling and simulation is clear. Well constructed social simulations possess the potential to provide great insight to public policy decision makers seeking to allocate scarce resources in order to maximize the benefit to a given population. Social simulations provide the ability to examine multiple potential futures when used in conjunction with designed experiments.

This paper will examine the implications of time and sequencing through an overview of a discrete event framework for a modular social simulation, a review of the social theory underpinning the modules used in the current implementation of this simulation, compare and contrast discrete event and time stepped applications in this domain, and provide a case study analysis of the output of the implemented discrete event social simulation.

The CG model is a java-based DESS framework that works on the basis of implementing and integrating social science "modules" based on social and behavioral theories. Identities of agents are populated using real survey data about beliefs, values and interests. Each agent is ensouled with social factors, i.e., those attributes that contribute to an individual's BVI, and a social network for the population is generated such increasing similarity among social factors increases the frequency or opportunity for a pair of agents to interact. Individual agents report changes in their internal states, while population-

wide events, including communication events across the social network, are managed and reported by the centralized event manager. We posit that this DES approach to managing events in a multi-agent system (MAS) [1] allows researchers and users to authentically represent both individual and social behaviors, and yields several noteworthy additional benefits. As described in detail below, benefits of a DESS approach include:

- Information preservation,
- Traceability,
- Event-Causal Mapping,
- Control for Different Timescales,
- Validation of Simulation Results.

Information Preservation

Agents keep track of their own internal state and can report/output state changes individually, without central oversight. Likewise, agents communicate through a social network representation of the population, and communications across the networks can be reported for analysis without regard to the internal states of agents. This lets researchers segment the population in any way they see fit, focusing the analytic effort to address specific questions based on, for instance, specific times, specific events, or specific groups of (heterogeneous) agents. Analysis can range from top-level population measures all the way to tight granular analysis of one specific agent across a short period of time. Agents, or groups of agents, can be compared with one another, either at the same point in time, or different points in time for simulation-length longitudinal analysis. In the same way, different parts of the social network can be examined concurrently or longitudinally. Information preservation means that deeper analysis is available by using the dichotomy of a centralized event list in concordance with endogenously managed agent states.

Tracebility

Information preservation lets us look specifically at the effects of actions through time. We can track and analyze the series of events, actions, and network communications that lead to a single agent's change of belief, or changes in the topology of a specific part of the agent's social network. We can also trace the events that lead to population-level measures by examining, for instance, averages or distribution in the population's belief structure over time. Traceability of single or group quantities permits a host of useful time series analytic techniques to, in our case, gain insight in to how the beliefs, values, and interests of individuals change over time.

Event-Causal Mapping

The corollary benefit to individual traceability is the capability to examine, specifically, what events in the simulation lead to given outcomes. We can investigate, for instance, what range of impact an event has on the population. Do single events, observed by the agents, have a variety of effects on agent internal states? What is the likelihood of a heterogeneous group of agents reacting homogenously (however defined) to a series of events? The real power of event-causal mapping rests in the ability to view data as both emergent (e.g., changes at the population level), and deterministic (e.g., at the individual agent level), and this benefit is derived through information preservation and data output tactics.

Control for Different Timescales

Multiple timescales are in effect when representing human behavior. Stimuli from the environment in the form of preceptors generate both immediate responses and responses might not generate observable behavior until some future point in time. DES preserves the authenticity of both cases through the scheduling of events on the event list.

Validation of Simulation Results

The CGM uses real social survey data to populate the internal state of each agent before the simulation run. Given that many of the social surveys use the same questions on the same population year after year, we have developed methods of validating simulation results by comparing model output with longitudinal survey data about the same population. For instance, the model can be populated using U.S. General Social Survey data from 1994 [2], and the simulation output compared with GSS data from 1996 through 2004. This allows us to not only validate simulation results, but characterize the ratio of simulation time to real time. In the future, we hope to use longitudinal survey results to automatically parameterize models of different populations.

Framework for Discrete Event Social Simulation

The representation of human behavior, from individuals to societies, requires a multi-disciplinary approach. The variable nature of humans and populations motivates the development of a reusable modular framework for experimentation and the integration of social theory into a coherent conceptual model describing the phenomena that occur in societies. After exploring the use of time-step driven simulation platforms for use in this setting, work began on a Java implemented discrete event simulation, the Cultural Geography (CG) model [3].

The CG model frames the complex adaptive system that makes up the civilian populace as a "conflict ecosystem", implying that once one enters the system they inherently become intertwined in the interactions that occur within the confines of the ecosystem. The model uses Ferber's multi-agent system (MAS) approach, consisting of actors, objects, and laws [1]. Actors are those entities capable of executing actions within the model. Actors interact with objects. Laws govern the interactions within

the model. The model encapsulates implementations of fundamental social and behavioral science theories that govern the behavior of entities (actors and objects) within the simulation as laws or internal actor rule sets.

The CGM framework is composed of "plug and play" modules that allow researchers and users to implement and integrate different social theories in order to address precise and novel research questions. We posit that the minimum set of modules necessary to authentically represent human behavior includes an entity cognition module that manages the internal attributes of each agent, and a social structure module that manages agent interaction. These are described briefly above. In the paragraphs that follow, we discuss the representation of time in these modules, and how these representations relate to the overall structure of the DESS.

Entity Cognition Time

DES relies on a description of the process to be modeled along with accompanying data to populate parameters describing functions within the process. Parameters are static through a single run, state variables change in piecewise constant state trajectories [4], events cause state transitions, and interactions between events are handled through scheduling processes. This implies that the process to be modeled is well understood and that observable data is on-hand to populate the model in order to appropriately replicate the system under study. In the case of human behavior modeling task network implementations have been used effectively to replicate human task performance [5]. Task decomposition is well known and process times and probabilities for decision nodes can be determined for observable actions. These types of processes lend themselves to be well represented within DES.

Human cognition and the steps taken in the cognitive process can be similarly decomposed [6, 7]. Process times for cognitive actions do not lend themselves to ease of observation, but in these cases the processes that are not differentiable can be scheduled near simultaneously or developed as a single process. Reaction time data is observable for action oriented responses and data on decision making can be collected from a variety of context dependent situations [8].

The processes that lead impact stances on issues, as represented within the CG model, lend themselves to a Bayesian representation. In this context, when an observation occurs, an update to the entities Bayesian network is scheduled with an appropriate update to the state variable, issue stance, resulting from the interaction. Single events over a magnitude threshold or the accumulation of events might then cause the scheduling of belief revision, involving the entity's relearning of the conditional probabilities in their belief network relating to the particular issue stance.

Social Structure Time

We follow Blau, *et al.*, McPherson, *et al.* and others [9][10][11][12][13] by using internal attributes of individual agents to represent the overall social structure of the population. We use the social network metaphor to link agents and track the communication, and opportunities for contact, between every pair of agents. The overall social structure is generated using the idea that the opportunity for contact between agents increases as the similarity of their social factors (BVI) increases. This tendency is often called *homophily*, and we call this implementation of social structure a *homophily network*.

The BVI of agents changes in response to events both exogenous and endogenous to the homophily network. Social structure is dynamic, and by definition, changes to an agent's BVI will change the social structure of the population based on BVI similarity. A significant change to an agent's BVI may alter the agent's communication and interaction patterns. Likewise, significant events that affect many agents in the population may alter the overall topological properties of the homophily network.

Agents communicate with each other about events they experience in person (firsthand knowledge), and events that they know about through previous communications with other agents (secondhand knowledge). Both firsthand and secondhand knowledge change an agent's BVI, and hence the homophily network. The only difference between the two is that secondhand knowledge is gained through communications across the network. While the homophily network represents opportunities for contact, the actual communications that take place between agents generate the *communication networks* in the simulation. Communication networks are simulation output that can represent the actual set of communication instances between agents that occurs 1) leading up to an event, 2) following an event, or 3) over a user-defined period of time.

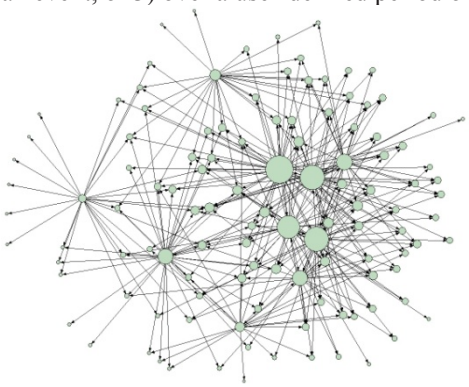

Figure 1. Inter-Agent network of communications following an event. Node size represents relative importance (eigenvector centrality) of each actor to the communication of information about the event.

Given that it takes time for knowledge about events to pass through the social network, this presents another in-

teresting challenge and opportunity to explore the implications of time in social simulations. A large body of literature on social networks is devoted to characterizing the "diffusion of ideas" [14][15] including the characterization of timescales for this diffusion. In the CGM, we can analyze BVI output from individual agents, or groups of agents, together with the communication network representation of their interactions. For instance, investigating percentage change in a certain belief throughout the agent population over time gives us a direct look at the latency of social information. Linking this back to the validity testing using longitudinal data, we can generate characteristic timescales for the latency of social information, or the diffusion of ideas, in the real world.

Discrete Event and Time-Stepped Comparison for Human Behavior Representation

Time stepped models generate multiple simultaneous actions within the simulation environment. In most cases all entities within the environment represent all planned behaviors and the model adjudicates the outcome of those behaviors for each step through time. The ability to trace cause and effect in this type of model is often lost. DES provides an alternative to time stepped models that bears consideration.

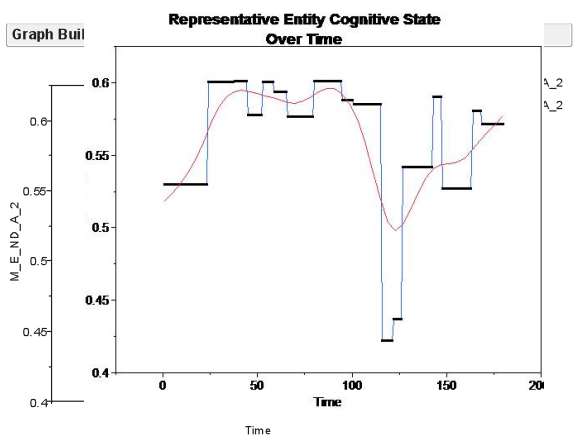

Figure 2. Entity cognitive state over time, discrete state level shown in black with smoothed value in red, note ability to identify time of major state changes.

The use of the event list facilitates a traceable view of cause and effect within the simulated environment. Figure 2 above illustrates this with sample data from a single entity within the CG model over the course of a representative model run. The event list serves as a master schedule of actions within the model for all entities and objects within the model. Given the inherent difficulty in representing human behavior within models and simulation, the ability to explain outcomes in a reasonable manner adds great clarity to any supported analysis and facilitates validation efforts. DES requires that the actions within the model be decomposed and sequenced. This implies that social science theories regarding cognitive processes must be transposed into this format.

Event graphs, commonly used in DES, serve as a ready means to translate domain subject matter expert knowledge into concepts for implementation. The modular architecture facilitates the use of multiple theoretical implementations depending on the particular use case. DES has clear advantages over time-stepped simulation for representing phenomena that occur on differing time scales.

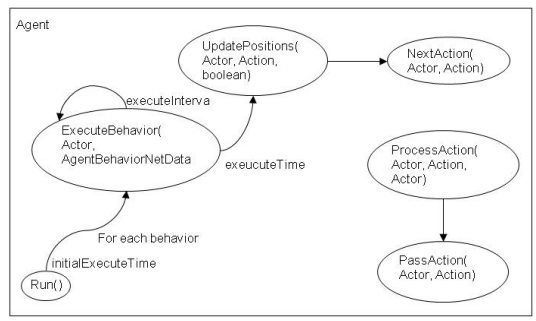

Figure 3. Sample event graph from CG model [16].

Timescale for Action Choice versus Belief Revision

Representing events that occur on competing timescales within models and simulation can be challenging particularly in the domain of human behavior representation. Communications within the CG model are generated in response to the receipt of new information, as opposed to belief revision, which occurs over a longer period of time. When an entity receives information and determines it will communicate that information to other entities within its social network it schedules those events on the event list at some point in the future, usually the next period of time. Belief revision occurs on a much longer time scale. Based on thresholds or rare events impacting entities within the model, belief revision might be scheduled at some distant point in the future. DES accommodates either case. We feel that the literature on time step models does not generally address the representation of these phenomena.

We can also examine characteristic timescales for both belief revision and action choice in another way. Since the homophily network changes as agents change their BVI, we can explore timescales for belief revision and action choice using internal state change, and using collective population dynamics. This allows us to directly ask questions regarding the influence of social structure on belief revision and action choice, as well as questions regarding

their effects on one another. As before, comparing our simulation results with longitudinal data enables the characterization of relative timescales for belief and action.

Verification, Validation and Accreditation Implications of the DESS Framework

The ability to document input into human behavior representations through the use of event graphs and the ability to trace state changes back to events on the event list to determine causality serve as powerful tools for verification, validation and accreditation (VVA). Many issues exist with the VVA of human behavioral and societal models, but transparency of actions and events concerning the inner workings of models and the use of data within them greatly facilitates this effort. The validation of theoretical underpinnings and conceptual models for use in this domain is an open question. DESS, however, provides this transparency and requires clear documentation of the underlying processes and uses of the data. As data on issues regarding the time related aspects of human behavior and cognition are illuminated by further research the DESS framework can serve as a ready platform for integration of this new knowledge.

Conclusions and Future Work

The time domain presents many challenges in the representation of human behavior within models and simulation. The choice of DES or time-stepped implementations depends equally on the use case and available data and challenges exist for either approach. In this regard DES's main advantage over time-stepped model implementations from an analytic point of view is in the ability to understand causal relations as represented in the model through the power of the event list. This traceability facilitates the validation and verification of model results based on the appropriate social or cognitive science theoretical underpinnings. The use of event graphs as a means of facilitating model development also lowers the bar required to gain insight from subject matter experts in the domain on the processes under study. Given the complex nature of societies and the complex adaptive systems they form the need to understand the implementation of processes through event graphs and to be able to trace model results via the event list makes the use of DES attractive.

This paper provided an overview of DES and its implications for the time domain, the challenges presented by time in human behavior representation, and a brief comparison of DES and time-stepped approaches. Future work will explore alternative models of human behavior and the implication s of varying time scales on cognitive process representation.

References

1. Ferber, J. *Multi-Agent System: An Introduction to Distributed Artificial Intelligence*. 1999: Harlow: Addison Wesley Longman.
2. www.norc.org\gss+website.
3. Jackson, L. *Narrative Paradigm in Cultural Geography Modeling.* in *Human, Social-cultural Behavioral Representation Committee Focus 2010.* 2009.
4. Buss, A., *Discrete Event Simulation Modeling*. 2009, MOVES Institute, Naval Postgraduate School.
5. Allender, L. *Modeling human performance: Impacting system design, performance, and cost*. in *Proceedings of the Military, Government and Aerospace Simulation Symposium*. 2000. Washington, D.C. 32(3), 139-144.
6. Endsley, M.R. *Direct measurement of situation awareness: Validity and use of SAGAT*. Situation awareness analysis and measurement, ed. M.R. Endsley and D.G. Garland. 2000: Mahwah.
7. Miller, N.L. and L.G. Shattuck. *A Dynamic Process Model for the Design and Assessment of Network Centric Systems*. in *2006 Command and Control Research and Technology Symposium: The State of the Art and the State of the Practice*. 2006.
8. Alt, J., and C. Darken. *A Reference Model for Soldier Attention and Behavior*. in *Behavioral Representation in Modeling and Simulation Conference*. 2008.
9. Blau, P. M. *Structural Context of Opportunities*, 1994, University of Chicago Press.
10. Blau, P M. and J. E. Schwartz. *Crosscutting Social Circles: Testing A Macrostructural Theory of Intergroup Relations*. 1997: Transaction Publishers.
11. McPherson, M., L. Smith-Lovin, and J.M. Cook, *Birds of a Feather: Homophily in Social Networks.* Annual Review of Sociology, 2001. **27**: p. 415-44.
12. McPherson, J. Miller and James R. Ranger-Moore; *Evolution on a Dancing Landscape: Organizations and Networks in Dynamic Blau Space*. Social Forces, vol. 70(1); 19-42. 1991.
13. McPherson, J. Miller, Pamela A. Popielarz, and Sonia Drobnic; *Social Networks and Organizational Dynamics*. American Sociological Review, vol. 57. 1992
14. Lewis, T.G. *Network Science: Theory and Applications.*2009, John Wiley and Sons.
15. Jackson, M.O. *Social and Economic Networks.* 2008, Princeton University Press.
16. Yamauichi, H. *CG Event Graphs*, cg_events.xls. 2009.