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Reasoning with Complex Models Using Compound Computational Experiments and Derived Experimental Contexts

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Abstract

Models of complex social systems offer the promise of providing a wealth of new knowledge. They also present many challenges, both methodological and technological, which must be overcome if this promise is to be realized. Among these challenges, the problem of credible inference is of particular importance. Only in rare circumstances can models be demonstrated (validated) to credibly predict future behavior of social systems in the style of engineering models. The promise of computational social science lies primarily in using models as platforms for computational experiments that are then used in arguments that do not depend on the predictive accuracy of the models. The framework known as "Exploratory Modeling" [Bankes, 1993; Bankes, 1996] provides a rigorous foundation for describing credible uses of computer models to understand phenomena where accurate prediction is not an option. Technology to facilitate reasoning with computer models is being developed that can make this approach much more routine. Two central concepts of this technology, derived experimental contexts and derived contexts supporting compound computational experiments, are described here.

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Reasoning From Complex Models Using Compound Computational Experiments and Derived Experimental Contexts

Steven Bankes

The uses of computer models can be roughly placed in two categories, the use of models to predict system behavior, or the use of models to perform computational experiments. While a predictive model can be a very powerful tool, many of the most interesting and important systems and problems defy rigorous prediction because of open boundaries, inadequately understood component mechanisms, or extreme non-linearity amplifying measurement uncertainty. All of these barriers to prediction can be generally described as "deep uncertainty" [Arrow, personal communication], sometimes known as "Knightian uncertainty. When credible prediction is not an option, models containing relevant knowledge and data can be used for computational experiments. The results of such computational experiments can be used as part of non-deductive credible arguments. This approach is increasingly important for both social science theory and policy analysis.

Current practice in the use of computational experiments is characterized by ad hoc exploration across alternative model structures and cases, and by the display of single examples as hypotheses or existence proofs. Only very limited scientific goals can be accomplished by such means. More aggressive exploitation of the promise of computational social science can be made possible by explicitly defining large ensembles of possible computational experiments and by calibrating search or sampling strategies from these ensembles to reasoning strategies for discovering properties of the entire ensemble. By such means it is possible to reason about the properties of social systems or argue for particular decisions or policies even though no model tested precisely duplicates the details of the system of interest.

The central idea behind Exploratory Modeling [Bankes, 1993; Bankes, 1996] is to use simulations, statistical models of data, or other computer models to create a large ensembles of plausible images of the system of interest. Search and visualization techniques can then be used to perform experiments drawn from this ensemble and to use the results of these experiments to provide information that is useful in distinguishing among alternative theories or strategies. Once it is realized that rigorous **experimental** science makes wide use of non-deductive arguments [Radnitzky & Bartley, 1987 ; Popper, 1972], researchers are free to innovate a wide range of credible research strategies using computational experiments. Of particular significance is the ability, given a sufficiently powerful software environment, for users to interactively specify and observe the results of experiments, and to progressively define ever more general and abstract frameworks in which to describe such experiments. A software environment, the Computer Assisted Reasoning system (CARs) that demonstrates these possibilities is now being developed. This paper will not attempt a complete description of CARs, but will instead describe a crucial feature of this system and the ways it can be used to support computational social science.

Exploring Across Alternative Ensembles

Exploration over computational experiments at an atomic level involves one at a time "what-if"-ing by varying the inputs to the model being used as a platform for computational experimentation. In picking particular values for these various inputs, the researcher is making assumptions or posits about factors not known with certainty. This collection of assumptions, together with any assumptions made in the construction of the model itself, constitutes a specification for a single computational experiment. Performing this experiment will reveal how the system being modeled would behave if all these assumptions were correct. By varying assumptions, the user can conduct a series of computational experiments. This series can be understood as an exploration through the ensemble of experiments that is defined by the set of all possible combinations of inputs.

One at a time exploration can at times succeed in discovering cases that satisfy the researcher's goals, but many of the potential contributions of computational science cannot be achieved in this way. Some goals can only be achieved by discovering patterns of outcome across the entire ensemble of possible experiments, and such patterns cannot be seen in the results of any single experiment. And, as the researcher gains insight from the process of exploration, this insight will change the nature of the search process itself. The goals of the exploration may be changed, or the strategy for seeking this goal may change.

In order to achieve goals beyond those that can be accomplished through single computational experiments with atomic models, other computations will be needed. This can be done by modifying model code, adding software mechanisms that do not represent any phenomena, but rather which perform services of interest to the researcher. This has often been done, and the resulting code still called "a model". But this combining of representational software and analytic software has numerous disadvantages. It clouds and confuses the distinction between those software structures that represent things that are known about the system, those that are being assumed, and those structures that are introduced as analytic device. This lack of modularity increases the likelihood of error, confuses questions of model verification and validation, and increases the costs of model maintenance and construction. And if revising software is the only means available for conducting explorations that leave the ensemble of models as originally defined, such revisions will be accomplished much less readily, greatly impeding computational research.

Typical ad hoc approaches to research based on computational experimentation (exploratory modeling) confuses alterations which can be understood as exploring across the ensemble of models as originally defined and those which are best understood as revising the definition of the ensemble to be explored. Clearly distinguishing between these can provide improved clarity in describing insights gained from exploration. And in order to design software tools to facilitate exploratory modeling, these two types of exploration must not only be distinguished, their properties must be clearly understood.

Experimental Contexts

The fundamental concept of the CARs environment is that of computational experimental contexts. An experimental context is a software mechanism that encapsulates a platform for performing computational experiments, and provides a variety of services relevant to conducting a series of those experiments. In particular, it implements the syntax for a data structure, instances of which serve as specifications for individual experiments, and the syntax for the data structure that contains the results from experiments. The context's platform for performing experiments can be viewed as providing a service that maps input data structures to result data structures. The experimental context can be thought of as representing the ensemble of possible computational experiments. This representation is generative in nature. An infinite ensemble can be represented by an experimental context in the sense that any particular instance of the ensemble can be generated on demand by submitting the data structure to the computational experiment platform. To understand the properties of the ensemble, a method for sampling from the ensemble must be selected, this method used to generate a series of computational experiments, and the pattern of outcomes thus revealed used to infer the properties of ensemble generally. This inference is not deductive, and therefore could be falsified by additional computational experiments. But credible inference is none the less possible.

By encapsulating a computer model and using it as a platform for computational experiments, one can create an **atomic experimental context**, and use this context as a basis for exploring the properties of the ensemble of possible experiments the context represents. CARs provides various services to facilitate this restricted variety of exploratory modeling, which some authors have referred to as **exploratory analysis** [Davis & Carrillo, 1997; Brooks, et.al., 1999].

As described above, the process of exploratory modeling frequently leads researchers to vary not only specifications within a given context (that is, instances within a fixed ensemble of possible experiments), but also to explore across alternative definitions of ensembles of interest. In CARs this could be accomplished as it is in most computational science, by revising the code for the "model", which is often better thought of as the platform for performing experiments. But CARs also provides significant support for exploring across alternative experimental contexts through a mechanism known as derivation operators.

Derived Contexts

CARs supports two variants of experimental contexts, atomic and derived. A derived experimental context is indistinguishable from an atomic context except in the implementation of the platform for performing computational experiments. (In CARs technical jargon, such platforms are known as computational experiment virtual machines, or CEVMs, or "machines" for short.) In an atomic context, computational experiments are performed by using the specification for the experiment to create a case to be run on a model being used as a CEVM. In a derived context, the specification for an experiment is translated to create specifications in one or more **foundation contexts**, which are different than the original derived context. The results from these foundation experiments are then also translated back into the syntax and semantics of the derived context.

CARs supports a library of **derivation methods,** which can be used to create new derived contexts from one or more foundation contexts. Derivation methods can be recursively applied to arbitrary depth. Ultimately, specifications in derived domains must be translated, possibly through a complex series of derivation steps, to create one or more cases to be run in atomic contexts. The derivation mechanism allows users to explore across alternative reframings of the "language" for describing computational experiments, without making changes to the code. Because derivation may be recursively applied, this allows us to provide automated tools for assisting in explorations across alternative contexts, and researchers can over time move to progressively higher level of abstraction in the search for frameworks that provide insights into candidate theories or policies, all without touching the code. Ideally, the code for a model should include only the known "physics" of the system, that is the aspects of phenomenology that are well understood and universally agreed upon. All analytical devices should be applied inside of the reasoning tool, allowing the option of computerized checking of analytic results and tentative conclusions.

CARs supports a wide variety of derivation methods, not all of which are described here. In order to better understand how derivation methods are used, it is useful to first consider a restricted subclass, known as **simple derivations.** Simple derivations create a derived context from a single foundation by applying translation operators that map single specifications in the derived context to single specifications in the foundation context, and translate single result objects in the foundation context back to become single result objects in the derived context. An extremely useful example of a simple derivation method is the **freeze** derivation, which is used in CARs to restrict exploration to a subspace of the foundation contexts ensemble of experiments. A freeze derivation eliminates some number of inputs from the foundation contexts input space by giving them fixed values. These values are specified at derivation time. When a case in requested of the CEVM in the derived context, the derived context specification is translated into a specification for the foundation context by "filling in" the missing inputs using the fixed values given them at specification time.

The freeze derivation allows us to create models with huge numbers of inputs, but to focus on a smaller subset of inputs when manually exploring the model. Frequently, assumptions get made in model writing that cannot really be justified by the facts. Such assumptions seldom get revisited, as doing so would require modifying the code. And frequently, these assumptions are poorly documented, and the "faceplate" of the model provides no hint that they have a role in the model's "wiring". The availability of the freeze derivation encourages and allows model writers to represent the full range of uncertainty as models inputs, without paying a huge price in dimensionality of the input space at analysis time. The decision to simplify the analysis by making some number of assumptions can then be delayed until after preliminary exercise of the model. So, for example, an analysis of variance can reveal those inputs that have the greatest impact on the issue at hand, allowing the researcher to focus attention on inputs most likely to be relevant and to make assumptions primarily on issues that are less likely to be important. Similarly, once tentative conclusions have been reached by an analysis conducted in the limited subspace, these conclusions can be checked using automated methods, without significant researcher labor, or recoding. So, for example, one can launch a "weak method" search, such as an evolutionary method, across the entire ensemble of the foundation context, searching for counter examples to the tentative conclusions. (To see an example of such a research methodology applied to a real problem, see [Robalino & Lempert, xxxx].)

Many other simple derivation methods exist in CARs. New inputs or outputs can be created from mathematical combinations of inputs and outputs in the foundation context. Inputs and outputs can be eliminated through additional simplification mechanisms such as deriving multiple inputs in the foundation context from simple inputs in the derived context. In this paper I will provide one slightly more complex example, that of derivations where a single specification in the derived context will result in multiple experiments in a single foundation context.

Compound Computational Experiments

CARs supports a number of derivation methods where a single experiment in a derived context causes a large number of experiments to be conducted in its foundation context. Thus, it is possible to create compound computational experiments, where single acts by the user of the software environment causes large numbers of atomic experiments to be conducted in one or more atomic contexts, and their results summarized for maximal insight generation. This capability allows researchers to move to create new frameworks for thinking about their scientific or policy problem without needing to iteratively revise model code. This capability can, as a consequence, enormously empower computational science. There is, of course, an impact on performance, where single compound experiments can consume much more processor time than single atomic experiments. However, this can be mitigated by using large numbers of processors to run cases in parallel in the foundation context. As the degree of compounding increases, compound computational experiments can be seen to have infinite parallelism. The capability in CARs to distribute experiments over networks of machines, either across a local network, or over the internet, thus can provide researchers with a substantial "surge" capability in meeting their computational needs.

An example of a compound computational experiment is a Monte Carlo averaging of various outcome measures over probability distributions on various inputs in a foundation context. Consider a foundation context where choices for input values deterministically produce outcome values. In the derived context, a single experiment that specifies the subset of inputs that are not being viewed probabilistically will result in a Monte Carlo averaging over the ones that are to produce averages and variances as results. Among other advantages, this keeps the modeling of the "physics" separate from the Monte Carlo generation and assumptions about probability distributions. As a consequence, robustness testing where one searches for the assumptions on priors that would be required to falsify conclusions reached using nominal probability distributions can be conducted without modifying any code.

A type of compound experiment that is particularly powerful, is the use of search to invert the map that is computed in the foundation context. In CARs there are derivation methods that allow such inverse mappings to be computed for any model, without the modeler needing to get involved in the implementation of search methods employed. One possibility is to search for the maximum or minimum of one of the outputs of the foundation. In a typical derivation, a subset of inputs of the foundation context would be **bound.** The derived context would only have unbound inputs, and for each single experiment in the derived context, a compound experiment would be conducted in the foundation context, searching for the appropriate extremal point. The derived context would map from specifications for each of the unbound variables to a result that includes the values of all results in the foundation context at the discovered "best point", plus the value of all bound variables required to achieve that maximum or minimum.

The semantics of the derived context varies depending on the nature of the map in the foundation (whether it is one-to-one, in particular). Syntactically, it has the interesting property of allowing us to move entries from the input to the output side of the mapping relationship. A somewhat different derivation takes as input a target value for an output in the foundation context's results, and searches for values of bound inputs that achieve that target in the foundation. This has the effect of moving entries from the output side to the input side of the map. Together with a sufficiently rich set of simple derivations, these derivation methods form a "spanning set", any syntactic variation on the input/output map of an atomic context can be achieved by the appropriate series of derivations. In this property, we can see the promise of developing a tool that does allow a strict separation of representation. In the ideal situation, only phenomenology should be represented in model code, with all analytic manipulation being provided by the software environment in which computational experiments are conducted. Although CARs is still undergoing development, in capabilities that are already available, the promise of more powerful tools for computation science can already be discerned.

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Simmelian Hypergraphs in Organizations

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Abstract: Hypergraphs connect actors to various subsets of actors in a network. This simple idea has many applications within the world of network analysis and has provided fertile ground for mathematicians for decades (Berge, 1989). Yet, social network analysts only rarely use hypergraph representations of networks. I argue here that this reticence comes from two factors: 1) There has been little social theory to guide the use of hypergraphs; and 2) Hypergraphs, unconstrained, create intractably large sets of subsets and relations. These two factors are related, in that a good theory would help to select proper subsets of actors to focus on, which would in turn make the size of the hypergraph more manageable. Simmelian tie theory provides such a focus and rationale for selecting appropriate subsets and at the same time allowing the hypergraph to be used to capture important structural features of the network. A hypergraph that restricts the subsets of actors to those identified in Simmelian tie analysis is called a Simmelian hypergraph. This paper demonstrates how Simmelian hypergraphs and their dual can be used in organizational analysis to uncover cultural strongholds, to identify particularly critical bridges, and to generally reveal the bedrock of underlying structure within a mass of noisy relations.

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Simmelian Hypergraphs in Organizations

David Krackhardt

Extended Abstract:

Graphs are defined as a set of nodes {N} and edges {E}, where the edges are composed of a set of unordered pairs of these same nodes in {N}. These unordered pairs map the nodes onto each other. At most, there can be only N^2 of these edges. Hypergraphs are an extension of this concept of graphs. A hypergraph is a set of nodes {N} and edges {E}, where the edges are composed of a set of unordered proper subsets of these same nodes, not just pairs of these nodes. Thus, the edge set in a hypergraph with N nodes can contain all subsets of N with cardinality 1 plus all subsets with cardinality 2, plus all subsets with cardinality 3, etc., all the way up to all subsets of size N-1. Graphs are a special subset of hypergraphs; and, indeed, the size of an edge set of a hypergraph has the potential to be a very large number, far beyond N^2.

Consequently, hypergraphs have not been applied frequently to the study of social phenomena (as opposed to graphs, which are ubiquitous in social science). When they are utilized, the edge set is restricted by some arbitrary exogenous factor, such as observed gatherings of groups of actors (nodes), where each "gathering" is considered a unique edge set. Indeed, hypergraphs are often recommended to represent affiliation structures or person-by-event matrices (Wasserman and Faust, 1994), although this matching is not perfect (for example, one could have several parties at which all the same actors attended, but only one edge set with that full set of actors).

In contrast to this mechanical, exogenous determination of hypergraph edge sets, one could build an edge set based on intrinsic structural features of the relations among a set of actors. Simmel provides us with a theoretical foundation for doing exactly this. In his classic work on dyads and triads, Simmel (1950) argued that groupings of actors were more important structural features than simple dyadic relationships. In particular, he suggested that a relationship that was embedded within a strong group of at least three people took on a different character, a different quality than a dyadic tie that was not embedded in such a group. While he did not define what he meant by group, what was critical is that the individuals recognize each other as being strongly tied to each other.

Thus, we can infer these critical groupings by determining all sets of triples in which all three actors are mutually tied to each other. These strongly tied triplets become the foundation of a Simmelian hypergraph. Through simple aggregations and constructions, we can identify from this hypergraph a set of Luce-Perry cliques. If we take the matrix representation of this Simmelian hypergraph, post-multiply it by its transpose, take the Boolean of the result, we have a matrix representation of Simmelian ties (Krackhardt, 1999).

Simmelian hypergraphs can be used for many different purposes (Krackhardt, 1996; 1999). For this paper, I will focus on Simmelian hypergraphs of individual cognitions of the network and its relationship to organizational culture (Krackhardt, 1988; Krackhardt and Kilduff, 1990).

Research from the tradition of cognitive anthropology treats culture as a cognitive system transmitted through social interactions. Each culture develops its own system of knowledge (Romney and D'Andrade 1964) and this knowledge is dispersed among both experts and novices (Romney, Weller and Batchelder 1986). Interaction between group members results in knowledge diffusion (Carley 1991) concerning important aspects of the culture such as the distribution of roles and relations (D'Andrade 1984: 110). Effective action within a specific culture requires an understanding of how that particular world is organized (D'Andrade 1995: 182). That is, an important part of cultural knowledge is the knowledge of how to operate in this complex web of relations and dependencies. This knowledge in turn depends in part on knowing who is related to whom in important ways (Krackhardt, 1990).

An important question that any approach to culture must address is the relationship between culture and social structure (see the discussion in D'Andrade 1984). In bringing together Simmel's emphasis on triadic relationships with cognitive anthropology's emphasis on culture as a system of knowledge, we bring a fragmentation perspective to this question (cf. Martin 1992: 130-167). Respondents "may give strikingly different descriptions" of the network relations within a particular group (Geertz and Geertz 1975: 1). To understand culture is to understand how the network ties between individuals shape their perceptions of the social world.

Individuals who interact with each other are likely to have higher agreement concerning the culture than non-interacting individuals (Krackhardt and Kilduff 1990). Further, some relations (strong ties, for example) are likely to produce more cultural agreement than others. In particular, I argue that more agreement will result from ties embedded in a Simmelian hypergraph than common dyadic ties.

Agreements among these actors about these critical structural features can come in two forms: They may agree about the actual ties that exist between actors, and they may agree about the groupings (in the Simmelian sense) that exist. Both are critical cultural features in any organization, and the knowledge of these two structural features will enhance an individual's ability to act appropriately within the cultural context.

In general, there was support for the hypothesis that those who were Simmelian tied agreed with each other more on these cultural dimensions than those who were not Simmelian tied to each other. Those who were tied to each other on the advice relation showed an agreement score of only .05 on the average across the three organizations (score based on Goodman and Kruskall's gamma). On the other hand, those who were Simmelian tied on the advice relation on the average agreed with each other at .20 on whether others were tied on the advice relation. Identifying people in Simmelian groups (having a Simmelian tie) was apparently easier. Those were tied together tended to agree with each other at .16 about whether others were Simmelian tied together. On the other hand, those who were Simmelian tied to each other had a much higher agreement level on who else was Simmelian tied: .48.

Friendship exhibited a similar pattern in some ways, but distinct in others. First, apparently people seem to agree more on who is a friend of whom in the organization than on who goes to whom for advice. Those who are friends with each other tended to agree about who else was a friend at .47. Those who were Simmelian tied to each other agreed even more: .65. However, it appeared to be more difficult to agree on Simmelian groups. Those who were friends tended to agree at a .40 level about whether others were Simmelian tied to each other. Again, being Simmelian tied helped in this agreement, with a resulting score of .51. But, what is interesting here is that, while being Simmelian tied to another did induce higher agreement, the agreement was highest about dyadic ties and not Simmelian ties in the friendship network. Thus, while friendships may be obvious to cultural participants, the actual groupings of these friends seem more difficult to get a consensus on between people.

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NETEST: Estimating a Terrorist Network's Structure

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Abstract

Since the events of September 11, 2001, the United States has found itself engaged in an unconventional and asymmetric form of warfare against elusive terrorist organizations. Defense and investigative organizations require innovative solutions that will assist them in determining the membership and structure of these organizations. Data on covert organizations are often in the form of disparate and incomplete inferences of memberships and connections between members. NETEST is a tool that combines multi-agent technology with hierarchical Bayesian inference models and biased net models to produce accurate posterior representations of a network. Bayesian inference models produce representations of a network's structure and informant accuracy by combining prior network and accuracy data with informant perceptions of a network. Biased net theory examines and captures the biases that may exist in a specific network or set of networks. Using NETEST, an investigator has the power to estimate a network's size, determine its membership and structure, determine areas of the network where data is missing, perform cost/benefit analysis of additional information, assess group level capabilities embedded in the network, and pose "what if" scenarios to destabilize a network and predict its evolution over time.

Key Words: Covert Networks, Terrorist Organizations, Bayesian Inference Models, Biased Net Theory, Biased Networks, Multi-agent Systems, Network Estimation, Social Network Analysis

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NETEST: Estimating a Terrorist Network's Structure

Matthew J. Dombroski

The events of September 11, 2001 have illustrated the need for defense and investigative organizations to prepare and innovate for asymmetric and unconventional warfare in the 21st century. Our military and intelligence communities are unprepared to counter the elusive and deadly threat posed by terrorist and other covert organizations in this new century [PAM 525-5, 1994]. The inter-state model of warfare has been replaced by intra-state warfare, which largely consists of guerilla and terrorist forms of warfare [Smith, Corbin, and Hellman, 2001]. Military and intelligence organizations in the United States are adept at utilizing training, tools, and weapons designed to counter conventional threats to national security. However, the enemies of the United States have evolved into network forms of organization that do not obey traditional borders between states and employ unconventional techniques. The networked form of organization promotes the terrorists' covert nature and decentralizes the terrorist network, allowing parts of the organization to effectively operate almost autonomously from the rest of the organization. These deadly forms of organization employ swarming techniques that empower individuals and groups of individuals to remain "sleeping" until the time is right for a well-coordinated and powerful attack [Ronfeldt and Arquilla, 2001].

Terrorist Organizations and the Ability to Track Them

Modern terrorist organizations have learned that they can effectively counter much larger and conventional enemies using dispersed and networked forms of warfare, striking when their target is least likely to expect it. Large terrorist organizations, such as Osama bin Laden's al Qaeda and Hamas, operate in small, dispersed cells that can deploy anytime and anywhere [Ronfeldt and Arquilla, 2001]. Dispersed forms of organization allow these terrorist networks to operate elusively and secretly. There are several factors that allow a terrorist organization to remain covert. Two important factors are:

- Members sharing extremely strong religious views and ideologies that allow them to form extremely strong bonds between one another
- Members are hidden from the rest of the organization, and likely do not know much about the organization's structure, except for the cell to which the members belong.

Even if a member of the organization is detained, these factors hamper investigators' attempts to break the organization down. Investigators are finding that the tools that they have available are not adequate for the task at hand, which is to break down these organizations and permanently remove their capabilities to spread fear, crime, and terror.

Often the only data that is available on terrorist networks is generated from investigations from isolated events. Investigations provide a partial picture of the network, relating the individuals involved with higher levels in the organization through a money trail, resource trail, or communication ties. Investigators would benefit greatly from tools and techniques that combine these partial and disparate data sources into a larger picture providing valuable insight on the size, membership, structure, and collective capabilities of the network and its cellular components. Such tools will provide powerful insight to investigators, displaying explicitly where data is known, and where it is not known. Such tools and techniques will allow investigators to determine where investigations should proceed and it will allow investigators and the military to systematically attack dangerous terrorist organizations, thereby effectively disrupting their activities and breaking the network apart.

Network Estimation Using a Bayesian Approach

Hierarchical Bayesian models provide simultaneous inference of informant accuracy and social structure [Butts, 2000]. Research indicates that informant data has error in it and, taken alone, are not accurate representations of social interaction. However, Bayesian inference models effectively aggregate informant data into an accurate big picture of the social network, thereby providing valuable insight on social structure and network size. There is a great deal of uncertainty that must be dealt with when building an accurate network of social interaction. Because social interaction is often subjective and difficult to accurately measure, inferences will always be vulnerable to error and uncertainty. However, the goal of hierarchical Bayesian models is to minimize and account for all uncertainty associated with drawing inferences regarding social interaction [Butts, 2000].

To effectively describe the approach, a basic assumption is that a Bernoulli graph exists of actual interactions represented as A, where A_{ij} is either 1 or 0, representing a link or no link between nodes i and j respectively. Each observation of A from each informant is a data matrix Y. The distribution of A is represented by the Bernoulli parameter matrix Θ. Θ is updated using a Bayesian updating procedure that aggregates each observation Y with the network prior Θ.

Another basic assumption of the model is that informants make two types of errors; reporting a tie where a tie does not exist (false positive) or reporting no tie where a tie does exist (false negative). The data generation process can be represented using the Bernoulli mixture [Butts, 2000]:

$$p(Y_{ij} \mid A_{ij}, e^+, e^-) = \begin{cases} Y_{ij}e^+ + (1-Y_{ij})(1-e^+) & \text{if } A_{ij} = 0 \quad \text{(p0)} \\ Y_{ij}(1-e^-) + (1-Y_{ij})e^- & \text{if } A_{ij} = 1 \quad \text{(p1)} \end{cases}$$

A network prior is given to Θ representing all prior information on what the larger network looks like.

The simplest Bayesian model is one where error parameters are fixed and known. In such a model the base likelihood for an observed arc is:

$$p(Y_{ij} \mid \Theta_{ij}, e^+, e^-) = (1-\Theta_{ij})(p0) + \Theta_{ij}(p1)$$
$$= (1-\Theta_{ij})(Y_{ij}e^+ + (1-Y_{ij})(1-e^+)) + \Theta_{ij}(Y_{ij}(1-e^-) + (1-Y_{ij})e^-)$$

Applying Bayes Rule, to each arc, the posterior probability for the existence of an arc is:

$$p(\Theta_{ij} \mid Y_{ij}, e^+, e^-) = Y_{ij}\frac{\Theta_{ij}(1-e^-)}{\Theta_{ij}(1-e^-) + (1-\Theta_{ij})e^+} + (1-Y_{ij})\frac{\Theta_{ij}e^-}{\Theta_{ij}e^- + (1-\Theta_{ij})(1-e^+)}$$

Posteriors are updated by simply factoring in each observation of the network, and calculating the posterior using the initial posterior as the network prior for each update.

If each error parameter is fixed and known for each observation, then the network posterior can be calculated using the following procedure:

$$p(\theta_{ij} \mid Y_{ijk}, e_k^+, e_k^-) \sim \frac{\theta_{ij}\prod_{k=1}^{N}(Y_{ijk}(1-e_k^-) + (1-Y_{ijk})e_k^-)}{\theta_{ij}\prod_{k=1}^{N}(Y_{ijk}(1-e_k^-) + (1-Y_{ijk})e_k^-) + (1-\theta_{ij})\prod_{k=1}^{N}(Y_{ijk}e_k^+ + (1-Y_{ijk})(1-e_k^+))}$$

More complex models are developed when error rates are unknown and different for each observation. Priors must be assigned for the parameters of the distributions of the error probabilities. Using the proportionality form of Bayes Rule, the posterior is solved using the following equation:

$$p(\Theta, e^+, e^- \mid Y) \propto p(\Theta)p(e^+)p(e^-)p(Y \mid \Theta, e^+, e^-)$$
$$= \left(\prod_{i=1}^{N}\prod_{j=1}^{N} B(\Theta_{ij})\right)(Beta(e^+ \mid \alpha^+, \beta^+))(Beta(Beta(e^- \mid \alpha^-, \beta^-))\left(\prod_{i=1}^{N}\prod_{j=1}^{N} p(Y \mid \Theta, e^+, e^-)\right)$$

This equation shows that the uncertainty in the error parameters prevents solving for the social structure. The error parameters are needed to solve for the social structure and the social structure is needed to solve for the error parameters. To counter this problem, posterior draws are simulated using a Gibbs sampler. Samples are taken from the full conditionals of the parameters in the model, constructing a Markov chain, which eventually converges to the joint posterior distribution. The full conditional of the social structure is given by the equation above. The full conditional for false positives, assuming the error rates are represented by Beta distributions, is given by:

$$p(e^+ \mid \Theta, e^-, Y) \sim \prod_{k=1}^{N} Beta\left(\alpha_k^+ + \sum_{i=1}^{N}\sum_{j=1}^{N}(1-\Theta_{ij})Y_{ijk}, \beta_k^+ + \sum_{i=1}^{N}\sum_{j=1}^{N}(1-\Theta_{ij})(1-Y_{ijk})\right)$$

The full conditional for false negatives, assuming the error rates are represented by Beta distributions is given by:

$$p(e^- \mid \Theta, e^+, Y) \sim \prod_{k=1}^{N} Beta\left(\alpha_k^- + \sum_{i=1}^{N}\sum_{j=1}^{N} \Theta_{ij}(1 - Y_{ijk}), \beta_k^- + \sum_{i=1}^{N}\sum_{j=1}^{N} \Theta_{ij} Y_{ijk} \right)$$

Draws are taken from each of these conditional distributions to implement the Gibbs sampler. The posterior distributions of the social structure and the error parameters are then constructed, building a big picture of the network and accounting for all uncertainty in estimating the network [Butts, 2000]..

Virtual Experiment Using the Bayesian Model

Now that the model has been introduced, the accuracy of the model and its usefulness must be determined. Two experiments were conducted to understand the interaction of informants and their accuracy in the generation of the posterior.

The first experiment examines the interaction between number of informants and their accuracy in generating an accurate posterior. For this experiment randomly generated informant observations were developed for the Roethlisberger & Dickson Bank Wiring Room friendship data. The observations were then aggregated using the Bayesian model and Hamming distances and absolute errors were calculated from the actual network. In the experiment, the number of informants was varied from 5 to 10 to 15 and their prior error distributions were varied from Beta (2,20) to Beta (2, 10) to Beta (2,5). Results of this experiment indicate that the number of informants plays a very significant role in reducing the error in the posterior. The posteriors were highly accurate for 15 informants regardless of what the prior error probabilities were.

A second virtual experiment was conducted to test whether increased samples given to informants produce more accurate posteriors. In this experiment, 10 informants were simulated. The actual network was the central graph of Krackhardt's Cognitive Social Structure data (1987). In each experiment informants were given a sample of the actual network and the observations were aggregated into the posterior. Samples of the actual network given to the simulated informants included 0, 20, 90, and 210 nondiagonal dyads of the network. All other dyads in the observations were generated using a prior error distribution of Beta (2,10). Although Krackhardt's CSS data provides informant reports, these were only used to generate the actual network, not for the informants. Results indicated that the posteriors only improved significantly for large samples (210 nondiagonal nodes). Absolute errors improved, even slightly, for increasingly large samples, but Hamming distances did not always decrease with larger samples. The reason for this phenomenon is that the Bayesian model assumes that errors are uniformly distributed across the observations. The experiment puts this assumption to the test since in real data, errors are not uniformly distributed across observations. Informants report most accurately on the portions of the network that they are most familiar with and the informants will also provide data on other portions of the network that they do not have extensive knowledge on.

Incorporating Biased Net Theory

According to biased net theory, both chance and bais create ties between population elements. Structural bias ties result from the pattern of links between nodes and not on the properties of the nodes themselves. The Bayesian models may be made more accurate if terrorist biases can be identified and incorporated into the models. Several levels of abstraction exist where biases may be identified at the cellular level, the organizational level, or the overall terrorist level. For example, Hamas may contain several structural biases that are distinct from Al Qaeda. This is an example of structural biases at the organizational level. If data analysis can identify and verify that these biases exist, then powerful inferences can be made about the structure of terrorist organizations and once these biases are incorporated into the Bayesian model, priors can be updated using biased random networks or the network priors can incorporate these biases, thereby building a more accurate posterior.

Three types of structural biases are examined. The reciprocity bias, π, refers to the state where an A to B link is more likely if node B is connected to node A. The triad closure bias, σ, refers to the state where an A to B link is more likely if both A and B have a common parent node, C, where C is connected to both A and B. The triad reciprocity bias, ρ, refers to the state where an A to B link is more likely if both A and B have a common parent node, C, and there is a link from B to A [Skvoretz, 1990].

In order to quantify the likelihoods of these different biases, we have to assess the probabilities that ties are mutual, asymmetric, or null between all nodes in the network. For dyads with no parents:

$$P(M) = d^2 + d(1-d)\pi$$

$$P(A) = 2d(1-d)(1-\pi)$$

$$P(N) = (1-d)^2 + d(1-d)\pi$$

where d is the probability that a dyad occurs by chance alone. The equations become more complicated when parents are incorporated. For dyads with one parent, the equations are:

$$P(M) = \sigma^2 + \sigma\rho(1-\sigma) + d(1-\sigma)(2\sigma(1-\rho)+\rho) + d^2(1-\sigma)^2(1-\rho)$$

$$P(A) = 2\sigma(1-\sigma)(1-\rho) + 2d(1-\sigma)(1-\rho)[(1-\sigma)(1-d)-\sigma]$$

$$P(N) = (1-\sigma)^2 + \sigma\rho(1-\sigma) - d(1-\sigma)[(1-\sigma)(2-\rho)+\sigma\rho] + d^2(1-\sigma)^2(1-\rho)$$

For dyads with k parents, $\sigma' = 1-(1-\sigma)^k$ and $\rho' = 1-(1-\rho)^k$ and σ' and ρ' would substitute in for σ and ρ in the above equations. By analyzing existing and verifiable network data and using the above equations, the three biases and the probability of a dyad by chance can be evaluated for certain types of networks [Skvoretz, 1990].

Virtual Experiment Using Biased Net Theory

Two sets of terrorist network data were analyzed to determine if biases were consistent in the al Qaeda terrorist network. The goal of the experiment was to determine if the probabilities for the different bias types were significantly different from one another, and if not, then we could conclude that al Qaeda exhibits certain predictable and identifiable biases in its structure, based on these two data sets. One data set consisted of 74 nodes generated by Valdis Krebs (2001). The other data set consisted of 121 nodes in a Road to Kabul data set showing the higher levels of the al Qaeda terror network.

The nodes in each set of data were analyzed using the biased net theory equations shown above, and fitted using the Pearson Chi Square approach. The results for the data sets were:

Parameter	Result Krebs	Result Kabul	Description
d	0.006	0.007	Probability that link occurs by chance alone
π	1	1	Probability that a reciprocity bias exists
σ	0.229	0.181	Probability that a triad closure bias exists
ρ	0.995	0.956	Probability that a triad reciprocity bias exists

The Krebs data set had a chi square value of 0.76 with 6 degrees of freedom. The Road to Kabul data set had a chi square value of 2.92 with 6 degrees of freedom. Both these results indicate that ties are reciprocated in both networks. There is between an 18% and a 23% chance that dyads are a result of a triad closure bias. The triad reciprocity bias is not very important in these data sets since there is a 100% chance that dyads are reciprocated. With a high likelihood of significance, dyads are a result of chance less than 1% of the time.

These preliminary results indicate that structural biases do exist and are predictable. The results are only preliminary and they continued analysis will link these structural results with compositional biases, which result from properties of the nodes, to improve the Bayesian models and their accuracy.

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Link Analysis of Social Meta-Networks*

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1 Network Analysis of Knowledge Systems

There has been a great deal of recent work within the knowledge systems community concerning the role that graph and network theory can play in the organization and retrieval of information. The basic idea is that knowledge systems, including document corpora, but most especially the World Wide Web, can be amply represented as a network or graph-theoretical structure. Then, mathematical and statistical properties of these graphs can aid in locating information. While these developments stem from random graph theory [3], they try to identify non-random structures in naturally occuring network structures.

Perhaps the most famous of these recent mathematical discoveries are so-called "small world" properties [13, 17]. Derived from the famous "six degrees of separation" phenomena from social network theory, they hold when a locally clustered structure is complemented by "short cuts" which produce surprisingly short average path lengths through the graph. Small world properties have been observed in many networks, including biological, socio-technical, document corpora, and the Web [18].

Other statistical properties of large graphs are also invoked, including power law distributions [1] and Kleinberg's "authoratative sources" method [7]. In turn, there has been research on how to exploit these properties for retrieval and navigation [12] and other applications.

Together we will call such approaches "network analytical". There's currently much excitement over them, to the point where it's fair to say there's a bit of a "bandwagon" effect. We almost want to ask what's not a graph? What doesn't follow a power law?

For example, there is interest in bringing these ideas to bear on counter-terrorism applications. Shortly after the September 11 terrorist attackes, Stewart compiled a network analytical representation of the terrorist cells [16]. The left side of Fig. 1 shows the results, with the strength of connection indicated by the thickness of the link.

What characterizes these network analysis methods is:

- A single directed or undirected graph.
- The possible use of weightings to indicate the strength of connection.
- Methods applicable to very large graphs, on the order of 10^6 to 10^9 nodes.

Data sources for such structures include large single relations or tables, typically represented as matrices. Such structures are also closely isomorphic to standard modern Web hypertext protocols such as HTTP. The right side of Fig. 1 shows a possible representative small case.

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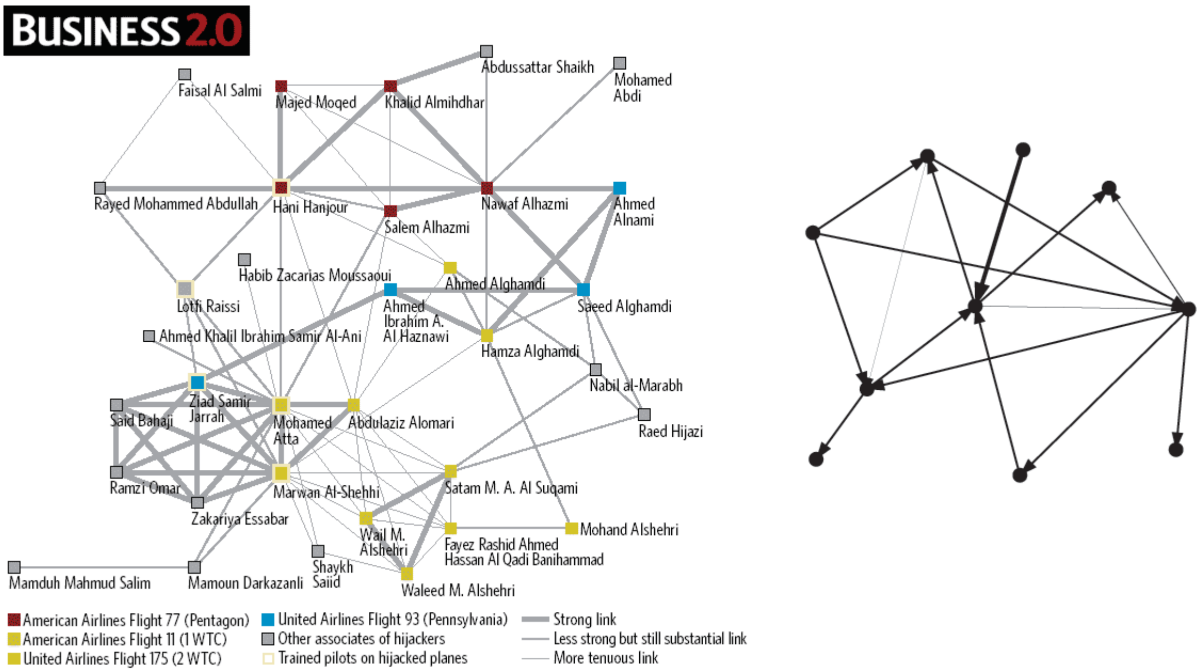

Figure 1: (Left) "The Small World of Mohamad Atta" [16]. (Right) Typical network analysis data structure.

2 Canonical Representations and Typed Link Networks

In prior work [9], we have sought to identify canonical, mathematically sound data structures which are minimally sufficiently complex to serve multiple purposes in knowledge systems, including representation of knowledge networks, dcoument and hypertext corpora, ontologies and other semantic structures, user communities, and virtual world architectures. We have proposed **semantic hyperwebs** as hierarchical lattices of **weighted, directed, labeled, hypergraphs** as being such structures [9], and asserted that they are quite similar to Sowa's conceptual graphs [15].

While semantic hyperwebs are hyper-graphical structures, here we wish to discuss their nature as *labeled* graph structures. Mathematically, we are invoking the structures alternately called multi-graphs, labeled graphs, or graphs with typed or colored links. Where mathematically networks map to a simple binary relations, labeled networks map to a union of such relations.

As shown in Fig. 2, such structures have **heterogeneous link types:** items can be connected in more than one way, and any two items can be connected by more than one link. So unlike simple networks, such labeled systems can represent structures which Carley [4] identifies as **meta-networks**, or networks of networks. These are useful in representing socio-technical networks in particular, as shown by Barret *et al.* [2], who use link types to indicate transportation modalities.

Consider a typical database of interest in counter-terrorism, for example listing known individuals and some of their characteristics, perhaps including name, address, aliases, age, birthplace, nationality, etc. In untyped network approaches, these distinct fields are aggregated together in some manner to give an overall weight on a link of a single type. Thus two people with the same name have a high link, but so do people born in the same place. This is the approach of Stewart, for example [16], where multiple such kinds of information are merged to yield his single link type.

But in typed networks the source fields can be respected, with each data field represented by a distinct link type. Thus typed link networks can be derived from mutiple relations or tables existing in complex schema.

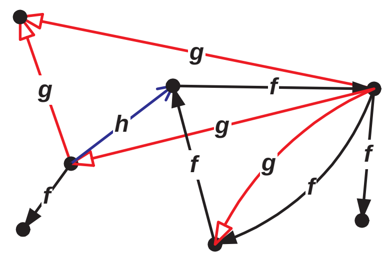

Figure 2: An example of a typed-link network.

Moreover, they are thus more natural representations for the modern knowledge markup and exchange environments such as XML, RDF(S), and OIL. Since link types also map to predicate types (binary or n-ary if hypergraphs are used), such structures also support inference systems such as used in ontologically-based description logic formalisms (see Fensel *et al.* [6] for a brief discussion of all of this).

3 Typed Link Knowledge Discovery

So assume a large, heterogeneously typed social meta-network structure involving multiple data fields (name, aliases, citizenship, address, age, travel dates, education, etc.) Our goal is then to understand how to generate significant hypotheses concerning such questions as:

1. Which fields are important?
2. For which subsets of the data?
3. Where are the "interesting" areas of structure or activity?

Such questions are obviously closely related to now-classical statistical pattern recognition ("data mining") methods in large multi-dimensional databases, including clustering, feature extraction, classification, etc. [5]. Where our approach differs is its emphasis both on a graph- and network-theoretical representation and a desire to respect the original dimensionalities of the database.

The most serious problem in moving from untyped to typed structures is complexity increase. A network with M nodes is hard enough, with $M(M-1)$ possible binary links. But given in addition N link types, one needs to consider not just all $NM(M-1)$ possible binary links of a *single* type, but moreover, to answer in particular question 1 above, potentially all *combinations* of link types. This number grows *very* large in N:

$$\sum_{n=1}^{N} \binom{N}{n} M(M-1)$$

Thus our approach is predicated on the idea that fully automatic knowledge discovery methods addressing such questions will *not* be feasible. Instead, we aim at methods which are:

- Appropriate for *moderately* sized multi-graphs (10^2 - 10^5 nodes).
- *Semi-automatic*, and
- *User expert guided.*

The basic idea is to provide an intelligent analyst, a domain expert with background and training in these kinds of mathematical and computer scientific tecniques, with a suite of tools which will support him or her to iteratively guide search for areas of local structure.

4 Link Analysis

In the full paper we will provide a complete and rigorous definition of the term "link analysis" in this context as one such broad methodology. This term has a definite, but small, presence in the literature [8]. To our knowledge the concept was developed in the mid 1990's within the law enforcement and anti-money laundering communities (see [14], for example), within which it has considerably more recognition.

It is significant to note that link analysis in our sense of discovery specifically in typed-link networks is usually *not* clearly distinguished from "network analysis" in the sense of single-link networks. An example, again, is Kleinberg [11], whose approach is decidedly network-theoretical in our sense, despite being called link analytical. Thus establishing this term in a proper way may be difficult, but we believe proper to attempt at this time.

The kinds of questions which link analysis is intended to address concern *collections* of records distributed over *collections* of link types. So, for example, given such a collection of records, how do they implicate one collection of link types or another? Similarly, how do they implicate other connnected collections of records, perhaps being more, fewer, or somehow overlapping?

A central concept to our sense of link analysis is known as **chaining**. It works like this:

- Assume a database $\mathcal{D}$ with N dimensions and M data points.
- Define a "view" on $\mathcal{D}$ as its projection to a particular subset of dimensions $n \subseteq \{1, 2, \ldots, N\}$ and restriction to a particular subset of records $m \subseteq \{1, 2, \ldots, M\}$, denoted $\mathcal{D}_{n,m}$.
- Chaining then consists of moving from one particular view $\mathcal{D}_{n,m}$ to another $\mathcal{D}'_{n',m'}$, where $n \cap n' \neq \emptyset, m \cap m' \neq \emptyset$, or both.

Conceptually, first an intelligent analyst considers certain aspects (n) of a certain group of records (m), for example the place of birth (n) of a group of people who all went to the same school (m). She then chains to consider another aspect, say the addresses ($n' \cap n = \emptyset$) of those of that group who went to Harvard ($m' \subseteq m$).

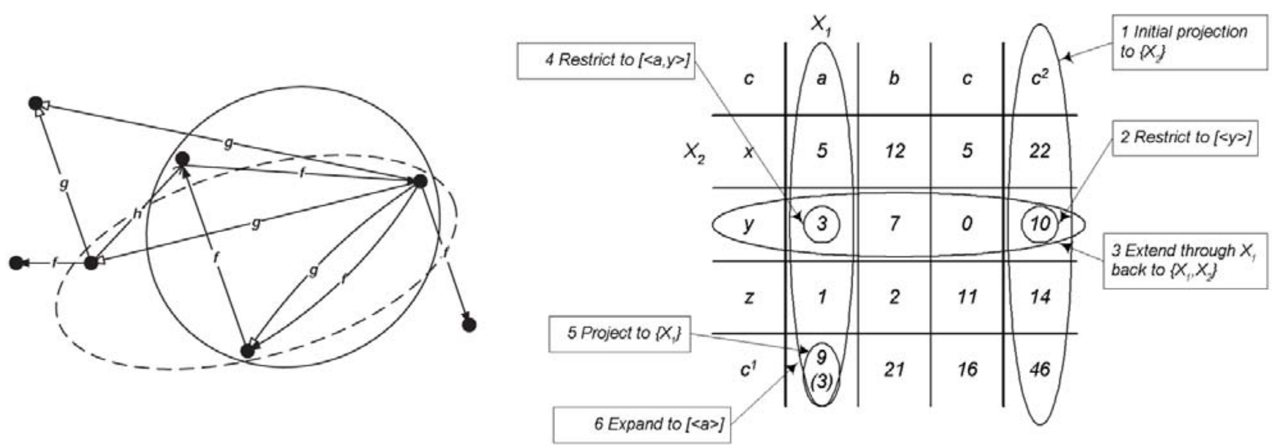

Figure 3: (Left) Chaining in a typed-link network. (Right) In a two-dimensional contingency table [10].

Fig. 3 illustrates this process in two different contexts. On the left, we have a typed-link meta-network. The solid boundary indicates $\mathcal{D}_{\{f\},\{w,y,z\}}$, the dashed boundary the transition to $\mathcal{D}'_{\{g\},\{x,w,z\}}$, so that $n \cap n' = \emptyset$, but $m \cap m' \neq \emptyset$.

On the right is a somewhat more complex example derived from VizTool, an information theoretical data discovery tool developed at the Los Alamos National Laboratory for fraud detection in IRS tax databases.

VizTool implements our methodology Data Exploration through Extension and Projection (DEEP) [10]. Here the representation is not in terms of labeled graphs, but rather of contingency tables, where the dimensions X_1 and X_2 represent different link types. The cells indicate the number of records with a certain vector value, and the marginal counts are included on the edges of the matrix.

While the complete formal relations between the labeled graph and contingency table representations remain to be detailed in the full paper, the concept of chaining in both is quite similar. Step 1 indicates an initial view $\mathcal{D}_{\{2\},M}$, all records projected onto the second dimension. The second step restricts this to $\mathcal{D}'_{\{2\},m}$, where $m \subseteq M$ now indicates those ten records $\{\vec{x}\} = \{\langle x_1, x_2 \rangle\}$ such that $x_2 = y$. In the third step, $\mathcal{D}''_{N,m}$ indicates the same set of records, but now extended back both dimensions $N = \{1, 2\} \supseteq \{2\}$. Similar other steps are indicated.

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Information Channel Effect in Consumer Behavior: an Agent Based Model

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Abstract

Does increasing the number of information channels in the information network society diversify or concentrate consumption variety? To answer this question, we studied how increasing the number of information channels affects consumption behavior in our society. An information channel is defined as an information communication medium, and channel quantity is defined as the amount of information it can exchange between individuals. We attempted to structure a model of winner-take-all phenomena that emerge with increases in information channel number, and analyzed the model through computer simulation.

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Key Words: Winner-Take-All, Information Channel Effect, Consumer Behavior, Agent Based Approach, Internet Society,

Information Channel Effect in Consumer Behavior: an Agent Based Model

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The current development of information networks is increasing the number of interactive information channels and also the quantity and variety of information individuals can access and acquire. This enables customers to now select from a much greater number of alternatives than had been previously possible. Under these circumstances, however, phenomena known as winner-take-all phenomena can now be observed everywhere (Frank and Cook, 1995). Here, we define these phenomena as processes in which consumers' selectiveness is concentrated gradually on particular goods in certain markets. Examples of winner-take-all markets include telephone services and operating systems. One trait these markets share in common is the action of network externality. However, we observed winner-take-all phenomena in our research even in markets such as music or movie software, and action of network externality is not possible in these markets. To analyze the mechanisms of these markets, we focus on information channel characteristics and network structure and simulate a multi-agent model on consumer behavior in response to information acquired.

From the simulation results we obtained, we conclude that the ongoing development of information channels, i.e., the development of interactive information networks, tends to strengthen winner-take-all phenomena. We propose a scenario under which the society branches off from a diverse consumption or a concentrated consumption by interactive effects between the number of information channels and the ratio of consumers.

Diversification of information and concentration of consumption

Is the ongoing development of information networks bringing about a diversification of consumer selectiveness or a concentration of it? Intuitively, it can be said that development on the economic level should give rise to a wide variety of goods which consumers need. In turn, a wide variety of needs gives rise to production on a limited scale of a wide variety of goods and thus forms a basis for a one-to-one marketing.

Development of the Internet has increased and is increasing the quantity and variety of information that individuals are able to gain access to. This is changing society from one in which the mass media distributes information in a mono-directional manner to one in which individuals distribute it in a bi-directional information manner. As a consequence, even the needs of consumers in very small markets give rise to markets in and of themselves, enabling today's consumers to select from a wide variety of goods and information. Examples of such small-size markets are auction markets between consumers such as the eBay and Internet shopping malls such as the Rakuten in Japan. In short, it appears to us that the development of bi-directional (interactive) information networks is generating a society in which the scale of consumption is becoming ever-more widespread and varying.

On the other hand, a new economy known as the "digital economy" has emerged at the same time, through the development of information technology and information networks. According to Arthur(1996), the digital economy has its own set of unique economic laws. A winner-take all society has emerged as a byproduct of the digital economy, and this is a society in which particular winners monopolize almost all goods in a market. For example, NTT DoCoMo monopolizes the mobile phone market in Japan, and Microsoft with its Windows monopolizes the operating system market all over the world. These examples can be explained if one bears in mind that network externality is a prime factor in the digital economy. In addition, there is another winner-take-all phenomenon that occurs due to long-established physical economic laws. A well-known phenomenon in the full-scale economy is that the higher quantity of goods a firm can produce, the lower in price they are, and consequently the firm becomes a winner in the market it operates in. For example, McDonald's became a winner in the fast-food market through mass production and cost management.

From our point of view, some winner-take-all phenomena that affect neither network externality nor the scale of the economy can be observed in markets. For example, in the music and movie software markets, concentration of consumption is observed nowadays. To understand what behavior patterns consumers will follow in the future, we must analyze the development of Internet mechanisms that influence diversification or concentration of consumption, especially the role of information channels between individuals. Thus, we focus our attention on information channels between individuals in information networks. These channels provide communication links such as face-to-face communication, e-mail, and communication over the Web. We hypothesize that increasing the number of information channels will significantly influence winner-take-all phenomena in the music and movie software markets.

Against this background, we constructed a model of consumer purchasing and communication behavior to understand the manner in which an increase in the number of information channels influences consumer behavior.

Development of Consumer Behavior Model

We used knowledge of consumer behavior theory to develop the model (Rogers,1983)(Usshikubo and Ohtaguro, 1984). We classified consumers into four types: "Early Adaptor", "Trend Carrier", "Niche Leader", and "Follower". We modeled consumer behavior with "information retrieval" and "communication" axes. An "Early Adoptor" is one who actively undertakes information retrieval and communication. A "Trend Carrier" is one who actively undertakes communication but is passive in the area of information retrieval. A "Niche Leader" is one who actively undertakes information retrieval but is passive in the area of communication. A "Follower" is one who is passive in the areas of both information retrieval and communication. These consumer behavior patterns are compiled in Table 1.

Table 1: Principles of Agent Behavior

		Information retrieval	
		Active	Passive
Information dispatch	Active	Early Adoptor	Trend Carrier
	Passive	Niche Leader	Follower

We developed a multi-agent simulation model according to these principles. An "Early Adoptor" agent searches and purchases goods that match his own preferences, and sends information about the goods. A "Trend Carrier" agent purchases goods that nearly match his own preferences according to the information he received, and sends information about the goods. A "Niche Leader" agent searches and purchases goods that match his own preferences, but does not send information about the goods. A "Follower" agent purchases goods which are most fashionable at the time, and does not send information about the goods.

Computer simulation

In this section, we describe how we simulated consumer behavior by changing the composition of consumer agents and information channels in order to determine the relationship between an increase in the number of information channels and the winner-take-all phenomenon. We used a Gini coefficient to observe the latter. Figure 1 shows the relationship between an increase in the number of information channels and the winner-take-all phenomenon.. Case 1 is a society with many trend carrier consumers. Case 2 is a society with many follower consumers. Case 3 is actual consumer composition.

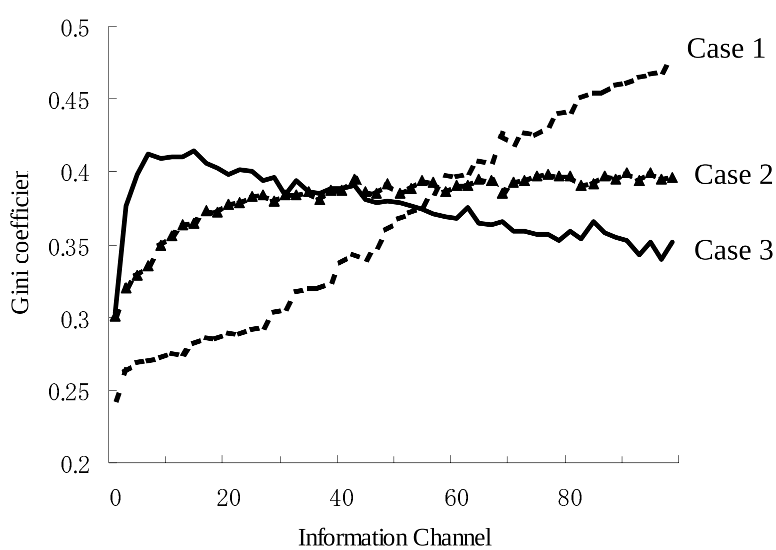

Figure 1: Information channel number vs. winner-take-all

In Case 1, when the number of information channels is small, the occurrence of winner-take-all rapidly rises as the number of information channels increases. As the number of channels increases further, consumer behavior becomes diverse. In Case 2, when the number of information channels is small, there are few consumers who circulate information into society, and agents purchase goods based on local information. Therefore, the overall consumption tendency varies and the Gini coefficient is low. As the number of information channels increases, everybody comes to purchase the same thing since fashion information circulates quickly throughout the whole society. The Gini coefficient becomes high in this case; this is winner-take-all society. In Case 3, the winner-take-all phenomenon becomes more pronounced as the number of information channels increases.

Conclusion

To answer the question of whether increasing the number of information channels in the information network society diversifies or concentrates consumption variety, we constructed a consumer behavior model which takes communication behavior into account. With the model we showed that the winner-take-all phenomenon occurs according to the relationship between consumer composition patterns and the number of available information channels, as follows.

1. In a market with many follower consumers, an increase in the number of information channels induces winner-take-all.
2. In a market with many trend carrier consumers, winner-take-all occurs when there are few information channels. However, diversification of consumption is induced as the number of information channels increases.

These results are summarized in Table 2.

Table 2: Diversification and centralization of consumption induced by the information channel

		Trend carriers	
		Few	Many
Information Channels	Few	diversification	centralization
	Many	centralization	diversification

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Multi-Agent Modeling of Electricity Markets

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Abstract

Electricity systems are a central component of modern economies. Many electricity markets are transitioning from centrally regulated systems to decentralized markets. Furthermore, several electricity markets that have recently undergone this transition have exhibited extremely unsatisfactory results, most notably in California. These high stakes transformations require the introduction of largely untested regulatory structures. Suitable tools that can be used to test these regulatory structures before they are applied to real systems are required. Multi-agent models can provide such tools. To better understand the requirements such as tool, a live electricity market simulation was created. This experience helped to shape the development of the multi-agent Electricity Market Complex Adaptive Systems (EMCAS) model. To explore EMCAS' potential, several variations of the live simulation were created. These variations probed the possible effects of changing power plant outages and price setting rules on electricity market prices.

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Multi-agent Modeling of Electricity Markets

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INTRODUCTION

Electric utility systems around the world continue to evolve from regulated, vertically integrated monopoly structures to open markets that promote competition among suppliers and provide consumers with a choice of services. The unbundling of the generation, transmission, and distribution functions that is part of this evolution creates opportunities for many new players or agents to enter the market. It even creates new types of industries, including power brokers, marketers, and load aggregators or consolidators. As a result, fully functioning markets are distinguished by the presence of a large number of companies and players that are in direct competition. Economic theory holds that this will lead to increased economic efficiency expressed in higher quality services and products at lower retail prices. Each market participant has its own, unique business strategy, risk preference, and decision model. Decentralized decision-making is one of the key features of the new deregulated markets.

Many of the modeling tools for power systems analysis that were developed over the last two decades are based on the implicit assumption of a centralized decision-making process. Although these tools are very detailed and complex and will continue to provide many useful insights into power systems operation [Conzelmann et al., 1999; Koritarov et al., 1999, Harza, 2001], they are limited in their ability to adequately analyze the intricate web of interactions among all the market forces prevalent in the new markets. Driven by these observations, Argonne National Laboratory's Center for Energy, Environmental, and Economic Systems Analysis (CEEESA) has started to develop a new deregulated market analysis tool, the Electricity Market Complex Adaptive Systems (EMCAS) model. Unlike those of conventional electric system models, the EMCAS agent-based modeling (ABM) techniques do not postulate a single decision maker with a single objective for the entire system. Rather, agents are allowed to establish their own objectives and apply their own decision rules. Genetic algorithms are used to provide a learning capability for certain agents. With its agent-based approach, EMCAS is specifically designed to analyze multi-agent markets and allow testing of regulatory structures before they are applied to real systems.

OVERVIEW OF THE AGENT-BASED MODELING CONCEPT

The complex interactions and interdependencies between electricity market participants are much like those studied in Game Theory [Picker, 1997]. Unfortunately, the strategies used by many electricity participants are often too complex to be conveniently modeled using standard Game Theoretic techniques. In particular, the ability of market participants to repeatedly probe markets and rapidly adapt their strategies adds additional complexity. Computational social science offers appealing extensions to traditional Game Theory.

Computational social science involves the use of ABMs to study complex social systems [Carley et. al., 1998][Epstein & Axtell, 1996]. An ABM consists of a set of agents and a framework for simulating their decisions and interactions. ABM is related to a variety of other simulation techniques, including discrete event simulation and distributed artificial intelligence or multi-agent systems [Law & Kelton, 2000; Pritsker, 1986]. Although many traits are shared, ABM is differentiated from these approaches by its focus on achieving "clarity through simplicity" as opposed to deprecating "simplicity in favor of inferential and communicative depth and verisimilitude" [Sallach & Macal, 2001].

An agent is a software representation of a decision-making unit. Agents are self-directed objects with specific traits. Agents typically exhibit bounded rationality, meaning that they make decisions using limited internal decision rules that depend only on imperfect local information.

A wide variety of ABM implementation approaches exist. Live simulation where people play the role of individual agents is an approach that has been used successfully by economists studying complex market behavior. General-purpose tools such as spreadsheets, mathematics packages, or traditional programming languages can also be used. However, special-purpose tools such as Swarm, and the Recursive Agent Simulation Toolkit are among the most widely used options [Burkhart et al., 2000; Collier & Sallach, 2001].

Several electricity market ABMs have been constructed, including those created by Bower and Bunn [2000], Petrov and Sheblé [2000], as well as North [2000a, 2000b, 2001]. These models have hinted at the potential of ABMs to test electricity market structures under controlled conditions.

THE EMCAS CONCEPT

EMCAS is an electricity market model related to several earlier models [VanKuiken, et al., 1994; Veselka, et al., 1994]. The underlying structure of EMCAS is that of a time continuum ranging from hours to decades. Modeling over this range of time scales is necessary to understand the complex operation of electricity marketplaces.

On the scale of decades, the focus is long-term human decisions constrained by economics. On the scale of years, the focus is short-term human economic decisions constrained by economics. On the scale of months, days, and hours, the focus is short-term human economic decisions constrained by economics and physical laws. On the scale of minutes or less, the focus is on physical laws that govern energy distribution systems. In EMCAS, time scales equate to decision levels. There are six decision levels implemented in the model, with decision level 1 representing the smallest time resolution, that is, the hourly or real-time dispatch. Decision level 6 on the other side is where agents perform their long-term, multi-year planning.

EMCAS includes a large number of different agents to model the full range of time scales (see Figure 1). The focus of agent rules in EMCAS varies to match the time continuum. Over longer time scales, human economic decisions dominate. Over shorter time scales, physical laws dominate. Many EMCAS agents are relatively complex or "thick" compared to typical agents. EMCAS agents are highly specialized to perform diverse tasks ranging from acting as generation companies to modeling transmission lines. To support specialization, EMCAS agents include large numbers of highly specific rules. EMCAS agent strategies are highly programmable. Users can easily define new strategies to be used for EMCAS agents and then examine the marketplace consequences of these strategies. EMCAS and its component agents are currently being subjected to rigorous quantitative validation and calibration.

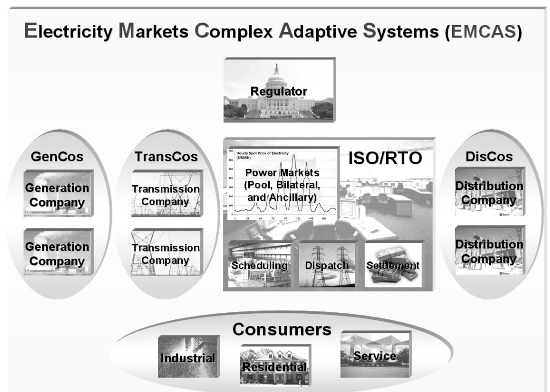

Figure 1: EMCAS Structure and Agents

EMCAS PROTOTYPING: A POWER MARKET SIMULATION GAME

To better understand the requirements of an electricity market structure testing tool, a live electricity market simulation was created. The market game that was developed used individuals to play the role of generation companies. One additional person played the role of the ISO/RTO.

Each generation company in the market simulation game had three identical generators. The generators included a small natural-gas-fired turbine generator, a medium-sized natural-gas-fired combined cycle unit, and a large coal-fired power plant. Players were allowed up to five bid blocks for each unit. Players submitted bids electronically. The bids were collected and used by the system operator. Players based their bids on public information electronically posted by the system operator. This information included historical and projected prices, demands, supply, and weather.

The system operator collected the players' bids on a periodic basis and used to them to simulate the operation of an electricity spot market. The simulation calculated MCPs and player profits based on internally derived demands, supplies, and weather. The actual simulation demands, supply, and weather differed from the publicly posted projections by small random amounts. Generating units also suffered from unannounced random outages.

An initial market simulation game was run with six players. The price results from this run are shown in Figure 2. Subsequently, a second market game with 10 players was run. Experience from these market simulation games suggested that the development of an electricity market ABM might be extremely beneficial. This experience helped to shape the development of EMCAS.

EMCAS AND THE GAME

An EMCAS case has been created based on the previously described market game. Specific agents representing individual market game players were implemented by using EMCAS' agent architecture. The strategies of the individual players were determined by asking them to write short descriptions of their approaches after the completion of the game and then following up the writing with a series of focused interviews. Once the strategies were determined, agents implementing each of the strategies were programmed.

The individual agents developed to emulate the market game players were run using the same data originally used for the game. The resulting prices are similar to those found in the individual market game as shown in Figure 2. The main difference is that the prices near hour 40 are higher in the EMCAS case because the EMCAS agents were programmed to use the evolved final strategies of the players. Many of the market game players had begun the game using a relatively cautious approach to bidding. As the game progressed, they learned to become much more aggressive. For example, several players developed "hockey stick" strategies that have low prices for the majority of each generator's capacity followed by extremely high prices for the last few megawatts. This approach can be effective because players have little to risk and much to gain. The risk is minimal because the vast majority of their generation bids are likely to be accepted. The gain is potentially high because MCP pricing will assign the last few megawatts high prices to all generation during times of shortage. The result lends new meaning to the hockey term "high sticking."

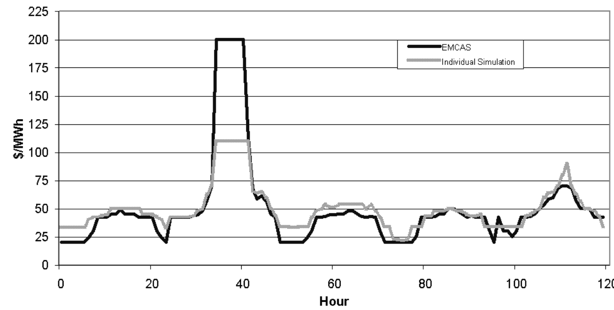

Figure 2: Market Clearing Prices - EMCAS versus Market Game

The EMCAS agents were programmed with the final, more aggressive strategies of the human players. Thus, EMCAS tended to have higher prices throughout the simulation. Once EMCAS was able to replicate the original market game, it was used to explore its suitability as an electricity market structure testing tool.

CHANGING THE RULES

To explore EMCAS' potential, several variations of the original market game case were created and simulated. These variations probed the effects of changing power plant outages and price setting rules on electricity market prices. As previously mentioned, EMCAS and its component agents are currently being subjected to rigorous quantitative validation and calibration. All of the EMCAS results presented here are intended to explore EMCAS' potential to be used as an electricity market structure testing tool. As such, they are not intended to represent complete analyses of the issues described.

Figure 3 shows the results for the baseline case. This EMCAS run assumes a Pay-MCP market without power plant outages with prices closely following the assumed daily load pattern. The first variation to the base case that was tested was the effect of power plant outages in a Pay-MCP market. The hourly prices are shown in Figure 4. In this example, the overall effect of power plant outages is to greatly increase market prices during periods of peak demand. This suggests that an important concern for regulators setting pricing rules is the relative balance between system supply and demand. In particular, systems that have demands that approach the maximum generation supply may experience significant price spikes under Pay-MCP. Such systems might fare better under Pay-as-Bid because they could potentially be victimized by strategies such as high sticking.

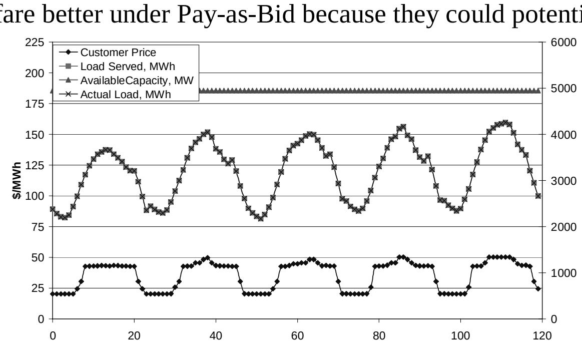

Figure 3: Pay-MCP without Outages

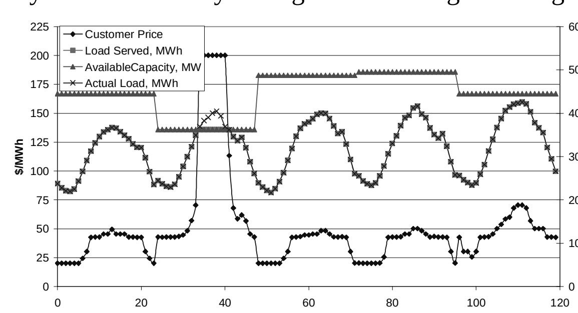

Figure 4: Pay MCP with Outages

In the second variation, the market was set up as Pay-as-Bid. Agent pricing strategies were suitably modified to reflect the new price setting rule. The actual hourly loads, the hourly loads served, the available generation capacity, and the resulting hourly prices are shown in Figure 5. In this case, all of the loads were served, so the actual hourly loads and the hourly loads served are the same. In this example, the overall effect of Pay-as-Bid is to noticeably reduce price fluctuations. This observation suggested a third experiment.

The third variation looked at the effect of Pay-as-Bid price setting with power plant outages. As before, agent pricing strategies were suitably modified to reflect the price setting rule. The hourly prices are shown in Figure 6. As with the previous Pay-as-Bid example, in this run, the overall effect is to substantially reduce price volatility compared to Pay-MCP, particularly during times when high demands intersect with reduced supplies.

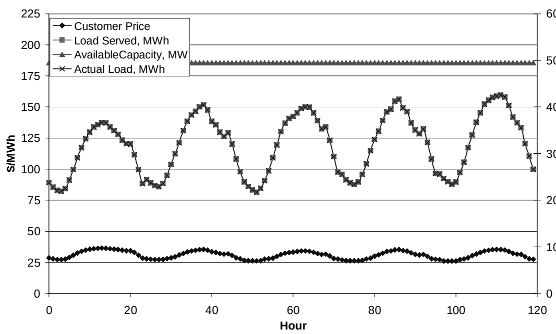

Figure 5: Pay-as-Bid without Outages

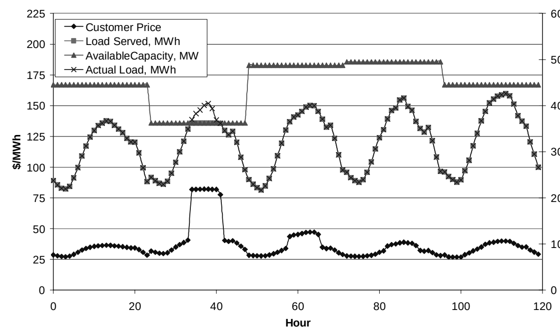

Figure 6: Pay-as-Bid with Outages

THE PROFIT MOTIVE

Considering the lower and more stable prices found under Pay-as-Bid, it appears that this form of pricing is better for consumers under this simplified model run. Producers, however, may have a different view. While prices are lower and more stable under Pay-as-Bid, producers lose money under this approach, as shown in Figure 7. Naturally, unprofitable markets tend to drive producers out. This can greatly reduce long-term competition and result in cyclical price trends with long periods. Clearly, market rules must balance the interests of producers and consumers in order to preserve long-term market stability.

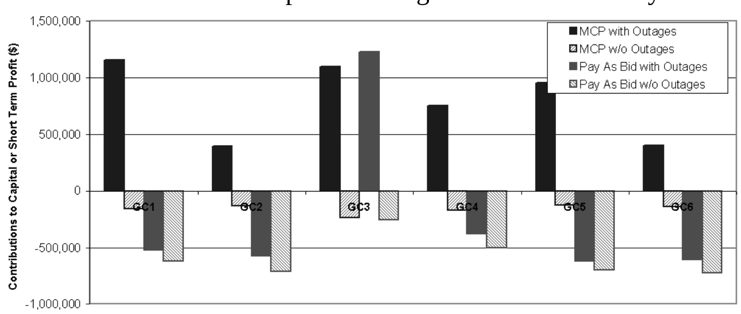

Figure 7: Generation Company Profits under Various Market Rules and Outages Regimes

CONCLUSIONS

As electric utility systems around the world continue to move toward open, competitive markets, the need for new modeling techniques will become more obvious. Although traditional optimization and simulation tools will continue to provide many useful insights into market operations, they are typically limited in their ability to adequately reflect the diversity of agents participating in the new markets, each with unique business strategies, risk preferences, and decision processes. Rather than relying on an implicit single decision maker, ABM techniques, such as EMCAS, make it possible to represent power markets with multiple agents, each with their own objectives and decision rules. The CAS approach allows analysis of the effects of agent learning and adaptation. The simple test runs presented in this paper clearly demonstrate the value of using EMCAS as an electricity market structure testing tool, where regulatory structures can be tested before they are applied to real systems.

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USING CULTURAL ALGORITHMS TO EVOLVE NEAR OPTIMAL OEM PRICING STRATEGIES IN A COMPLEX MULTI-AGENT MARKET MODEL

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Abstract

Software Engineering methodologies have demonstrated their importance in the efficient solution of complex real-world problems. The process of designing and testing programs is related to the heuristic search through the space of possible programs. [Simon 1986] Heuristic search is often performed using evolutionary computation methods in situations of high dimensionality. [Koza 1990] Software design methods when directly applied to evolutionary computation practices can reveal detailed information with regards to program constraints. In this paper we examine knowledge generated by traditional software testing methods. Here, we will examine the complementary white and black box approaches as currently applied to software testing. We then discuss how to utilize the knowledge obtained from both approaches using a Cultural Algorithm framework. These approaches chained together assist in the genetic programming development are described as Dual Cultural Algorithms with Genetic Programming (DCAGP). We then describe Cultural Algorithms as a framework in which to automate the design of complex programs in more detail. Finally we present an implementation of, and give an example application to the generation of a program that computes the quadratic equation.

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USING CULTURAL ALGORITHMS TO EVOLVE NEAR OPTIMAL OEM PRICING STRATEGIES IN A COMPLEX MULTI-AGENT MARKET MODEL

David Ostrowski & Robert Reynolds

1.1 Software Engineering

Software Engineering methodologies have demonstrated their importance in the efficient solution of complex real-world problems. The process of designing and testing programs is related to the heuristic search through the space of possible programs. [Simon 1986] Heuristic search is often performed using evolutionary computation methods in situations of high dimensionality. [Koza 1990] Software design methods when directly applied to evolutionary computation practices can reveal detailed information with regards to program constraints. The identification of program constraints serves as an effective practice of program design and implementation.

1.2 Genetic Programming

Software development can be viewed as the searching through all possible programs. Genetic Programming (GP) applies evolutionary methods to the development of programs by assisting in this search process. GP systems perform this simulating evolutionary concepts in order to derive programs from an infinite amount of possible programs. This process provides assistance to the user in acquiring knowledge with regards to the software development process. With the application of Software Engineering techniques, the search can become a more focused effort.

1.3 Software Testing and Design

A strong relationship exists between software design and testing. Software testing practices reinforce and verifiy the design by the practice of determining program faults by providing knowledge that can allow the programmer to pin-point its causes and relate them back to a specification. Testing allows the programmer to update the software specification and refine it. Two complementary approaches in software testing are white and black box testing [Pressman 1987] White box testing is used to examine a programs structure which includes examination of program logic and control flow. Black box testing allows one to examine a program as one would view a mathematical function: containing a set of inputs corresponding to a set of outputs with no consideration as how they were specifically generated. In the context of program testing, the black box test is applied first with the goal of determining whether the programs performance matches the requirement. When a lack of fit is identified, a white box approach is used to directly relate the behavior back to the specification in the program.

These techniques can be applied in the context of software design in order to provide design knowledge. In design, the white box testing approach is applied first, to support the construction of a prototype. Here, we are examining a program structure, or effectively modifying the structure in response to its performance. Once a program's structure has been developed to a suitable level of performance, then it is given over to the black box testing process. The goal of the black box testing is to identify any faults within the existing program representation. Once faults have been identified, they can in turn be applied in the context of a second phase of white box testing. This alternating sequence of white and black box testing parallels what human programmers do as part of the programming development process. This paper will apply this approach to the automated design of genetic programs where the genetic programs are applied to automated design of agent-base market strategies.

1.4 Cultural Algorithms

Cultural Algorithms enhance the evolutionary process by the application of a belief structure to the traditional evolutionary population. [Reynolds 1994] This second structure emulates symbolic cultural evolution as opposed to biological evolution. This knowledge maintains beliefs about programs performance which is influenced by and in turn influences future populations in a manner similar to the preservation of culture among human populations. This enhanced version of evolutionary computation is suitable for application to program design since the knowledge maintained can complement our approach of the integration of two software development methodologies where both techniques can assist in the overall software design process. Zannoni and Reynolds [Zannoni and Reynolds 1995] demonstrated the use of Cultural Algorithms to speedup the genetic programming development process. We will build upon their approach to further enhance this technique by adding the to the belief space knowledge produced by the application of Software Engineering concepts. The Cultural Algorithm approach that we are going to employ uses two Cultural Algorithms chained together, one for white box testing and the second for black box strategy. They will each utilize a belief space representing implicit and explicit constraints on the developing program. (figure 1.0) It is hypothesized here that this knowledge is necessary to guide the design of solutions to complex multidimensional engineering problems. In order to test this hypothesis our system (DCAGP) will be applied to the design of agents in a complex multi-agent economic system model.

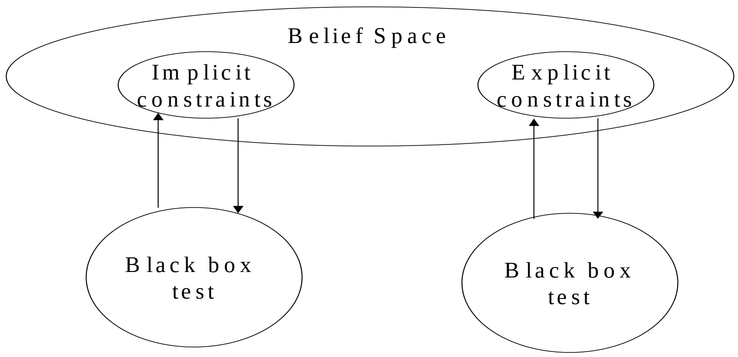

Figure 1.0 Dual –Cultural Algorithms with Genetic Programming

1.5 Agent –Based Systems Configurations

Agent-based environments are created in order that we might be able to represent real-world scenarios. Agent-based systems affords the agents the capability of acting on knowledge as opposed to only reasoning about it as in the classical Artificial Intelligence modeling [Feber 1995] The concept of action is predicated on the fact that agents maintain the ability to carry out actions which are going to modify the agents environment and future decision making. Due to this capability, agent-based environments are viewed frequently as being mathematically intractable. This type of approach necessitates the application of an evolutionary computation approach. In this paper, the calibration of a multi-agent system is used to illustrate the power of combining both white and black box knowledge. Our goal is to a demonstrate an approach to automated software development. By applying a dual approach of white and black box test through the use of Cultural Algorithms we hope to design an agent-based system in the most effective manner.

1.6 Outline of paper

This paper is structured in the following manner: in section two, we examine knowledge generated by traditional software testing methods. Here, we will examine the complementary white and black box approaches as currently applied to software testing. We then discuss how to utilize the knowledge obtained from both approaches using a Cultural Algorithm framework. These approaches chained together to assist in the genetic programming development are describe as Dual Cultural Algorithms with Genetic Programming (DCAGP). Section three describes Cultural Algorithms as a framework in which to automate the design of complex programs in more detail. Section four presents an implementation of, and gives an example application to the generation of a program that computes the quadratic equation. The DCAGP approach demonstrates that the added knowledge produces a speedup in the design process for their program in comparison to the standalone GP. While successful in the design of this program, we wish to test whether the joint knowledge generated by black and white testing allows the system to generate a more complex software object, the design of an intelligent agent in a complex multi-agent system. In section five, we describe the basic concepts involved in multi-agent design and the rationale behind using a Cultural Algorithm in such a framework. We also identify the characteristics of the multi-agent system which we will use in our approach. In section six we describe a customized multi-agent system, marketScape to simulate a durable goods market which will be our target application. This system will be used to compute the solution for a near-optimal pricing model for a given configuration of consumers and an OEM (Original Equipment Manufacturer) based on theories presented by Porter and Sattler. [Porter and Sattler 1999] Porter and Sattler's approach, which has been demonstrated to obtain maximal profits for a single OEM agent while providing a market equilibrium is used as an initial configuration of the marketScape environment . In section seven, we present the results of marketScape when presented with a complex set of consumer buying scenarios that reflect real-world situations in which some of the assumptions of the Porter-Sattler based model are violated. In particular, Porter-Sattler assumes that agents have no memory of price history so their purchasing scenarios are very simple. If we allow agents to have access to the pricing history of the OEM various purchasing strategies such as postpone etc are possible. Thus, the Porter-Sattler based model may not necessarily produce the optimal solution for the . It is shown that that the near-optimal pricing model does not perform as well in terms of profitability. So in section eight, we apply the DCAGP to our marketScape environment in order to design an improved pricing strategy for our agent-based model in these situations. We demonstrate that the DCAGP approach produces OEM strategies that improve profitability by over a million dollars compared to that of the near-optimal model in these scenarios. In section nine, we conclude by suggesting that the knowledge generated by the use of both black and white box testing process together is sufficient to produce designs that improve upon traditional model performance in complex real-world situations. We feel that the key to the development of automated programming systems for complex real-world applications will need the integration of this type of knowledge into the system.

The Utilization of WorkLenz in System Development & Test

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Abstract

The management, measurement, and analysis of organizational performance have evolved significantly with the mainstream adoption of personal computers and, more recently, the Internet. To more fully address the correspondingly changing market demands, and to provide analytical and forecasting capabilities, Métier, Ltd. has developed WorkLenz, its proprietary software for predictive portfolio management. Because of its iterative nature and clearly defined workflow structure, WorkLenz-based analysis of the system development and test project conducted by a global systems integrator in support of the Global Positioning System program provides an excellent illustration of the power and potential of the application. This paper examines the detailed analytical approach applied to the system integrator's work as well as the unmatched accuracy of the resultant forecasts.

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Key Words: project and portfolio management, Internet, forecast, work

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The management, measurement, and analysis of organizational performance have evolved significantly in response to the mainstream adoption of personal computers and, more recently, the Internet. To more fully address the correspondingly changing market demands, and to provide analytical and forecasting capabilities, Métier, Ltd. has developed WorkLenz, its proprietary software for predictive portfolio management. Because of its iterative nature and clearly defined workflow structure, WorkLenz-based analysis of the system development and test project conducted by a global systems integrator in support of the Global Positioning System program provides an excellent illustration of the power and potential of the application. This paper examines the detailed analytical approach applied to the system integrator's work as well as the unmatched accuracy of the resultant forecasts.

Synopsis of Analysis

Following a rigorous data gathering process, the resources, plans, and status updates for the client's first test cycle were entered into WorkLenz. Analytical techniques unique to WorkLenz (and described in detail below) were applied to the data in an effort to forecast the client's performance in a second, similar test cycle. The WorkLenz-based forecast proved to be significantly more accurate than initial management plans, leading the client to request the use of WorkLenz for the validation of the proposed revamping of a third project schedule. WorkLenz analysis suggested that management instincts were correct; the need for a schedule re-plan was significant, and the project's eventual health depended on that re-plan.

WorkLenz Overview

WorkLenz, Métier's predictive portfolio management application, stands at the forefront of distinct technological and strategic advancements in the realm of work ontology. In addition to capitalizing on the flexibility and timeliness afforded by the Internet and the Application Service Provider (ASP) model, WorkLenz also offers a new approach to the way we think about analyzing work and improving processes. When employed in the management of an organization's projects, WorkLenz captures task-based information and aggregates it into extremely accurate predictions about costs, schedule impacts, resource allocation and other metrics for future work. The software's predictive capability allows managers to identify inefficiencies in their business, retool processes to avert similar impediments in the future, and improve the accuracy of long-term planning.

The WorkLenz structure is simple and intuitive. The majority of data is collected at the Task level; Tasks compose Phases, which compose Projects, which compose Programs, which compose the entire Corporation (see Figure A). Tasks can be updated on an individual basis or from the Time Sheet. Projects can be built using existing projects, stored templates, Microsoft™ Project files or other file types. The types and categories used to describe each level of WorkLenz are completely customizable; during the implementation process, each client's individual site is tailored to meet specific structural preferences while ensuring the ability to analyze across all desired divisions and parameters. The result is a familiar, easy-to-use taxonomy that allows for unique analysis and forecasting based upon that analysis (see Figure B).

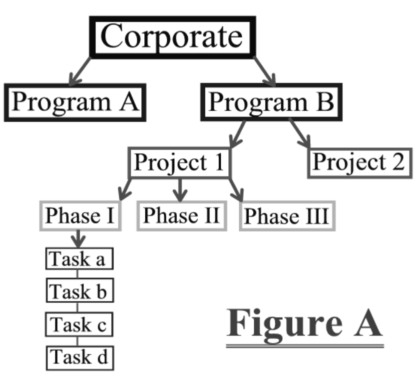

Figure A

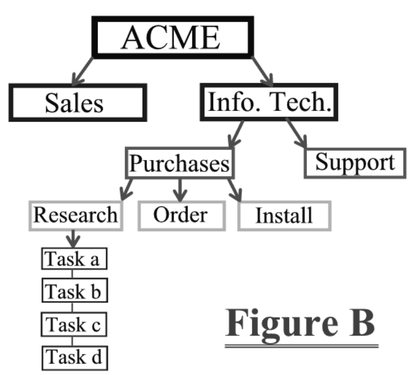

Figure B

Two key concepts distinguish WorkLenz from other web-based and client-side project management applications. The first concept, ***Churn*** – defined as deviation from plan - is divided into three types and involves the movement of tasks into and out of the period in which they were planned to start or finish. **Right Churn** is tallied when a task's estimated start or complete date moves to a *subsequent* period, or when a task's actual start or complete date occurs in a period *subsequent* to the estimated periods. **Left Churn** results when a task's estimate start or complete date shifts to a *prior* period, or when the task's actual start or complete date occurs in a period *prior* to the estimated period. Lastly, **Down Churn** is created when an unplanned task falls into the current period.

The second distinctive WorkLenz concept provides a unique approach to describing the nature of the work performed by an organization. For each WorkLenz task, a **Verb** and an **Object** is selected from a dictionary customized for each Project. Project lists are subsets of a customizable organization-wide list. Verbs & Objects can then be utilized to perform detailed analysis on the nature of the fundamental actions and objects that constitute work for an organization, both independently and in relation to each other. Additionally, the customizability of the Verb & Object dictionaries makes it possible for users to employ their own "language of work" as they manage projects in WorkLenz.

Combining the unique concepts of Churn with Verbs & Objects or other traceable variables allows for the statistics-based predictive analysis known as ***Slipperiness.*** Slipperiness analysis examines the relative likelihood that a task will deviate from plan as compared to a defined norm. For example, WorkLenz can calculate the slipperiness of a specific Verb-Object combination, revealing the probability that a task with that combination will churn relative to the average task. Armed with this knowledge for a wide variety of variables, organizations can more effectively anticipate schedule dynamics and then respond with targeted management focus. Additionally, this information can be incorporated into future plans, thus boosting the accuracy with each iteration of similar projects.

Finally, WorkLenz measures an organization's ability to plan task durations by calculating a ***Performance Ratio***. The Performance Ratio is found by dividing the hours actually spent working on a task by the hours it was estimated would be needed to complete the task. Thus, if an organization's performance ratio (or PR) is equal to 1.2, then, on average, 1.2 hours are spent completing a task for every hour estimated. Available at every level of the application, the PR offers quick insight into the effort an organization is expending relative to plan.

GPS Case Study

The GPS program was developed and is managed by the Department of Defense, which has constructed a worldwide, satellite-based, radio-navigation system. The U.S. Air Force Space Command oversees the operations of a constellation of twenty-four satellites and their corresponding controlling ground stations. The ground stations are responsible for testing the satellites for operational military functions as well as continually monitoring their health and location while in orbit. The reach of GPS technology already transcends its military capabilities through its many real-world applications, which enable thousands of civilians to benefit from its precise location, navigation, tracking, mapping and timing calculations. These commercial GPS receivers are capable of processing coded satellite signals that enable them to compute position, velocity and time all over the globe. The GPS satellites provide accuracy and precision never seen before from navigation systems, military or otherwise.

The focus of this case study is a global systems integrator who reported its work to both the prime contractor for the program and the Air Force. Our client is responsible for developing the software used to control the orbiting satellites from workstations on the ground. In addition to the design and development of the software, our client is also required to test all of the software installed on the satellites and to fix any flaws that may exist in the software. The analysis consisted of a two-part process that focused on different testing cycles and was conducted from April to December of 2001. Following the application of Métier's concepts and methodologies in the initial phase of testing, our final analysis was used to validate a major overhaul of the client's project schedule.

Part 1: Our first step in engaging the client involved the collection of all relevant schedule information used to track the progress of their work. To assist with the predictive process, certain information needs to be collected and entered into WorkLenz; that information includes the details of the executable activities of the projects. Under ideal circumstances, Métier collects real-time data as the activities occur; however, this portion of the analysis was performed as a lessons learned exercise. Because WorkLenz was not utilized from the project's inception, the necessary information for our analysis was scattered amongst a variety of sources instead of residing in one tool. The estimated dates and estimated durations were derived from two different Microsoft™ Project files used to construct the project plans. The actual dates and actual durations were extracted from sixteen binders and three boxes full of test logs. Finally, the resources performing the work were gleaned from two Microsoft™ Excel files that were used by the project manager to track the status of the ongoing work. In this case, three different sources were used to manage the projects; consequently, the effort required to finish pieces of the work was not completely understood, as the effort was not directly linked to the schedule in any of these sources.

In order to provide our client with insight into their work performance, all data was imported into WorkLenz for analysis. The testing at the time consisted of two cycles with identical tasks and identical resource availability. The sample size of the first round of testing was made up of 83 planned activities. In addition, we were able to identify 16 unplanned activities based upon baselined plans and the test logs. The unplanned activities consisted entirely of re-runs, which were iterations of previous tests that either failed the first time or needed to be re-tested for verification purposes. The second round of testing included 67 planned activities while only 7 unplanned activities were needed to complete this test cycle. The breakdown of the estimated and actual hours for the 2 testing cycles follows:

Activity Type	1st Cycle Est. Hrs	1st Cycle Act. Hrs	2nd Cycle Est. Hrs	2nd Cycle Act. Hrs
Planned Activities	790.00	569.50	698.50	525.20
Unplanned Activities	- - - - -	114.66	- - - - -	7.08
Totals:	**790.00***	**684.16***	**698.50**	**532.28**

* The planned re-runs were omitted from these figures because of a discrepancy in the nature of the projects.

Upon first glance at the figures above, one can infer that the project manager padded the estimates when planning the testing cycles. Because the client's system consisted only of storing hard copies of the test logs and project plans, with no searchable electronic repository, its historical data was rendered largely useless. While the manager had excellent first-hand knowledge concerning the nature of the testing - to the extent that she accounted for efficiency gains and fewer expected problem areas in the estimates for the second testing cycle - the estimates still did not comprehensively represent the work that would be done. The manager's estimates still varied by 166.22 hours from the actual work performed in the completion of the second cycle of testing. Often included in plans by experienced managers but rarely supported by quantified underlying factors, human intuition is fundamentally limited in its ability to predict reality on a consistent basis.

WorkLenz helps rectify such management issues by utilizing past data to predict the outcome of future projects of a similar type. WorkLenz accomplishes this by evaluating past performance and predicting the amount of unplanned work expected in the new project. For this example, WorkLenz used the first testing cycle to predict a project plan for the second testing cycle since the planned activities of the two cycles were nearly identical. While this practice opposes conventional statistical approaches, we were justified in doing so based upon the available resources and striking similarities between the two cycles. The foundation for the second cycle's plan is drawn directly from the total actual duration of the first testing cycle - 569.50 hours. In addition, the work performance for the shared activities of the first and second testing cycles can be applied towards the construction of the second cycle's predicted plan, as well as the anticipation of unplanned events. The following calculations for performance ratio and percent of down churn (unplanned work) were vital to constructing the WorkLenz-predicted plan for the second cycle:

Performance Ratio – Planned Activities (all figures for 1st Cycle)
569.5 act. hrs. / 790.00 est. hrs. = 0.72 performance ratio
Down Churn (all figures for 1st Cycle)
16 unplanned tasks / 99 total tasks = 16.16%

The second testing cycle was known to have sixty-seven activities of a similar nature to those in the first cycle. Therefore, the number of unplanned activities was projected to be 10.83 events, and the average duration for a re-run in the first testing cycle was 7.26 hours.

Total Hours of Unplanned Activities
(16.16% predicted Down Churn) x (67 planned 2nd cycle activities) = 10.83 unplanned activities
(10.83 predicted re-runs) x (7.26 hrs per re-run in 1st cycle) = 76.81 Total Unplanned Hrs for Re-Runs in 2nd cycle

A = Client Estimate for 2nd Cycle	B = Performance Ratio of 1st Cycle for Planned Activities	C = Total predicted Down Churn Hrs	Predicted Total Hrs for 2nd Cycle (A*B) + C
698.5	0.72	76.81	**= 579.73**

Attribute	Total Act. Hrs For 2nd Cycle	Client Est. Hrs For 2nd Cycle	WorkLenz Predicted Est. Hrs For 2nd Cycle
Hours	532.28	698.50	**579.73**
Variance	- - - - -	31.2%	**8.9%**

Clearly, the manager's estimates for the 2nd testing cycle were not closely based upon actual performance from the previous cycle. In this case, the client overestimated the time needed to complete the project by more than 166 hours. WorkLenz could have increased the accuracy of the estimates for the 2nd cycle by more than 20%, which would have allowed the client to reallocate 135 work hours to other projects. Additionally, such a dramatic improvement in labor estimation allows for more accurate and advantageous budgeting during the proposal phase. The optimized planning enabled by WorkLenz opens the door to lower-cost, higher-margin proposals.

On the strength of its ability to forecast the client's performance during the 2nd Cycle, Métier was asked to employ WorkLenz to validate a revamped schedule that had been proposed for another area of the project.

Part Two: Before starting the development of a new version of software for the satellites, our client first needed to install other complementary software that had been purchased from vendors. Once these software programs were installed, a team of twenty members was responsible for testing the effects of the new software additions on the satellites' technical environment. The testing was performed in a lab in a remote ground station on the client's site. Our analysis of the testing cycle began at the mid-point of the project and focused on the impending schedule overhaul and budget overrun.

As was the case with the earlier work we had performed for our client, the first necessary steps consisted of identifying the data sources. Again, our client is not in the practice of harboring effort, schedule and cost metrics together while managing its projects, so we needed to assemble this data from a Microsoft Project file, two Microsoft Excel files, and direct input from the project manager. The Microsoft Project file contained the schedule information that provided the basis for extracting valuable churn metrics. One of the Excel files was used to monitor the status of ongoing activities and was updated on a weekly basis by the manager. From iterations of this document, WorkLenz was able to identify problem areas and types of activities that were most likely to deviate from the schedule. The second Excel file provided cost information for the employees performing specific tasks within the testing cycle. In addition to the use of these resources, the project manager also offered significant input regarding client strategy and other factors related to our validation of the planned schedule overhaul.

Of the two different software packages in need of testing, the first (Software A) was only tested in a non-classified lab, while the other software (Software B) was tested in both the non-classified lab and in a classified lab. The testing process for these software installations was very similar to the previous test cycles (see Part 1). Because the effort and scope of these test cycles were much larger than the prior pair, we derived the estimated durations for the testing of Software A and Software B (the estimated durations were not available from the resources) based on the previous cycles. Additionally, the data provided indicated that 5,615 labor hours were budgeted for this project, with 20% of the labor hours allotted to the testing of Software A and 80% of the labor hours for Software B.

As previously discussed, the client did not directly relate hours worked to the tasks at hand for a given week. However, our client did track the total charge hours for each employee on a weekly basis. These weekly charge hours were used in conjunction with the assumed actual hours we assigned each task based upon its status from one scheduling update to the next. Together, the weekly charge hours and the assumed hours comprised an individual performance ratio for each employee, which was multiplied by the assumed actual hours to derive the actual hours entered into WorkLenz.

Example Employee: 85 charge hours for the week

Tasks	Est. Hrs	% Complete	Assumed Act. Hrs
1	50 hrs	100%	**50 hrs**
2	40 hrs	50%	**20 hrs**
3	60 hrs	10%	**6 hrs**

Personal Performance Ratio:
85 charge hours / 76 total assumed act. Hrs = 1.12

Tasks	Assumed Act. Hrs	Personal Performance Ratio	Act. Hrs in WorkLenz
1	50 hrs	1.12	**56.0**
2	20 hrs	1.12	**22.4**
3	6 hrs	1.12	**6.7**

Utilizing the above methodology, WorkLenz calculated that the project was 28.4% complete while our client's Excel spreadsheet suggested that they were 31.8% complete.

Software	Client Excel Spreadsheet	WorkLenz
A	78.8%	81.9%
B	20.0%	15.0%
Overall % Complete	*31.8%*	*28.4%*

Our client's percent complete calculation failed to account for the fact that different tasks possess different estimated and actual durations; the WorkLenz calculation incorporates those characteristics of individual tasks when measuring overall project status. Further supporting the WorkLenz calculation, our client claimed an Earned Value of 28.9% in their Cost System. Using WorkLenz, we predicted that our client would have to work an additional 220 hours to achieve its current claimed status on the Excel spreadsheet.

Our client then asked us to use WorkLenz to validate the fact that they were on pace to exceed the budget, and to verify the imminent re-planning of the schedule needed to help rectify this problem. In order to accomplish this, we identified the Budgeted Hours of Work Remaining for both software installations. Then, using a performance ratio for only Software A and a worst-case performance ratio from the previous test cycles (in Part 1 of our work), we were able to predict the labor hours remaining for Software A, as well as a best case and worst case labor hours remaining for Software B. The average labor week for the testers was determined to be 274 hours from its Earned Value reports of the Cost System.

Testing Cycle	BHWR	PR	Est. Hrs Remaining	Ave. Labor Hrs Per Week	Weeks Remaining
Software A	254 hrs	1.72	**437 hrs**	274 hrs	**2 weeks**
Software B- Best Case	1,850 hrs	1.72	**3,182 hrs**	274 hrs	**12 weeks**
Software B- Worst Case	1,850 hrs	2.70	**4,995 hrs**	274 hrs	**19 weeks**

Since the client informed us that they would be focusing all of their attention on finishing the testing of Software A before continuing with the testing of Software B, we were able to derive the completion dates in a straightforward fashion. Our analysis was conducted during the first week December 2001; therefore, we estimated that the completion of Software A would take place on December 20, 2001, which was two weeks away. Our client was planning on completing that testing cycle by December 28, 2001, at the latest. Considering the holiday season at this time of year, our estimate of December 20th was not as far off as it may appear to be at first glance. Operations for the project were expected to cease on December 21st due to the unavailability of resources for the following week. Hence, our prediction validated the project manager's plan for the remaining work for Software A testing.

Our client also informed us that the testing of Software B would not resume until the second week of January 2002. Armed with this knowledge, we determined that the best-case scenario for our client finishing Software B would be on April 5, 2002, which is twelve weeks from the middle of January. The worst-case scenario for the completion of this testing cycle was determined to be May 17, 2002, or nineteen weeks from the middle of January. Subsequent to the explanation of our estimated completion dates, the client revealed to us that the resultant completion date suggested by the re-planning was May 5, 2002- well within our date range.

Based on the quantifiable support provided by WorkLenz, the systems integrator proceeded with the re-plan.

Additional Analysis - Slipperiness

The ability to identify problem areas before they become problematic frequently sets top managers apart. Unique to WorkLenz, slipperiness analysis spotlights activities that have historically strayed from the original plan and hence often created problems. Slipperiness baselines all activities within the project by assigning a value of 1.00 to the average churn rate for a verb-object pair. In the two cycles for these software packages, the average churn rate was 37.5%, which means that those verb-object pairs (activities) with a slipperiness of 2.00 would have a churn rate of 75.0%. Of all of the activities, 15.7% of them had a slipperiness greater than 2.00. Because those activities were more than twice as likely to churn as the program norm, they demand management attention throughout their execution. Our client was able to proceed with this advance knowledge, and therefore was more prepared to prevent problems that had previously occurred within these functional areas.

Simulation Medical Work: An Organizational Information-processing Approach

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Abstract

Modern medical care is a collaborative activity among health care providers who work in complex, interconnected organizations. To design effective and efficient work processes and organizations, health-care administrators must understand and analyze the complex relationships between work processes, organizational structure, and organizational members. Unfortunately, applying project management simulation tools to medical care has been difficult because of the dynamic organizational structures and non-routine work processes found in medical organizations.

In this paper, I describe the organizational information-processing theory basis for OCCAM, an organizational simulation tool built to model medical care processes, and illustrate the theory with a root-cause analysis of an organizational error. I then describe extensions to the information-processing theory of organizations so that it can be applied to the non-routine "diagnose and repair" work processes and the flexible organizational assignments that are required for delivering medical care. My research develops a theoretical framework and simulation system in which organizational questions about these more flexible organizations can be queried, tested in a simulation environment, and used to guide medical administrators charged with designing new organizations and protocols.

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Keywords: medical organizations, medical errors, information-processing

Simulation Medical Work: An Organizational Information-processing Approach

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Introduction

In engineering management, simulations based on organization theory have been used to ask organizational questions (Carley and Svoboda 1996; Thomsen and Kwon 1996; Christensen, Christiansen et al. 1997). Because these simulations are based on established organizational theories, the results of a simulation can be related back to the organization and systematically used to improve both the work process and the organization structure. In medical organizations however, few comparable simulation tools exist. If similar simulation techniques based in organizational theory could be applied to medical organizations, the results could be used to inform organization and medical protocol designers of design problems before implementation. In this paper, I describe organizational information-processing theory, illustrate the application of information-processing simulation techniques to the problem of medical errors, and describe extensions to information-processing simulation necessary to model and simulation additional kinds of medical processes.

Information-Processing Theory

The information-processing theory of organizations also relates the amount of information available to task uncertainty. In organizations with unlimited processing capacity, additional information reduces the chance of errors, and improves the quality of the organizational produce. Conversely, if necessary information is missing, quality suffers.

A second important organizational concept is the notion of bounded rationality, first described in Herbert Simons book, The Administrative Man. Organizations are composed of individuals who are boundedly rational – although they desire to make optimal decisions based on all the information available, they have limited information processing capacity. Simon suggests that with too much information, organizational members are unable to keep up with the demand, and may miss important pieces of information. In contrast to information-processing theory, bounded rationality suggests that more information may not always lead to better decisions or higher quality processes. If organizational members become overloaded with work, they may miss important communications, and make errors.

Thus in examining organizations using this framework, there is a tension between the capacity of an organization to manage information, and the amount of information necessary to reduce task uncertainty. Too little information, and the organization will make poor decisions. Too much information, and organizational members become overloaded and miss important pieces of information. Information technology, organizational structure, the composition and capabilities of organizational members, and the work process that the organization is trying to accomplish contribute to the balance between information demand and capacity. Within this framework, when a mismatch occurs between organizational information-processing capacity and information-processing demand, organizations are prone to making mistakes.

The principle goal of this research is to develop a tools and techniques to examine the flow of critical information within clinical environments, and to anticipate and correct error-prone processes before harm can occur to patients. In other industries in which the costs of errors can be high, researchers have used organizational simulations to evaluate how well a particular organization responds to the information-processing burden work processes present. For example, organizational simulations in the aerospace industry have successfully identified error-prone processes prior to the development and manufacture of satellite launch vehicles. Previous work in medical organizational simulation suggests that simulation techniques can be used to analyze medication errors and identify the parts of an organization that are susceptible to failure under stress.

OCCAM :A Simulation tool to Examine Medical Organizations

In our simulation work, we have linked information-processing theory to Simon's notion of bounded rationality (Simon 1976). Using these two theories in a simulation environment, we can use an information-processing simulation to explore how different organizational structures, actor skills, and work processes interact to enhance or impede the ability of organizational members to process this information. Not all ways of structuring an organization or work process are equal, and using simulation, we can explore alternative ways of structuring organizations and the work organizations do.

Modeling Framework

To create an information-processing framework, we abstract all activities to a volume of work for which an organizational participant is responsible. Activity or organizational errors are modeled as exceptions—unexpected events that occur stochastically, based on characteristics of an activity. In addition to errors, exceptions also represent requests for information, or notification events that are not part of the usual work process. Exceptions require time to be evaluated by an actor and are time-limited—exceptions will expire if not attended to promptly by an actor. When ignored or not attended to, the actor requesting the information will make a decision by default. Decisions made by default are considered to be of lower quality that decisions in which the exception has been attended to. Thus decisions-by-default raise the probability of future exceptions. Our simulation model consists of a model of the organization (actors, skills, and supervisory relationships), a model of the clinical work process (activities, exceptions, and successor/predecessor relationships), and responsible-for links that connect the organization and work process.

When the organizational model is executed, the simulation breaks each task down into subtasks, and places these subtasks into the responsible actor's inbox for processing. Actors with more skill or expertise in a given task will be faster at completing their assigned subtasks. When a subtask is completed, the simulation stochastically determines if an exception or communication must be generated and calculates the time until the communication or exception expires. For example, a communication sent via phone will have a short expiration time; one that uses the medical record to communicate will last longer. All communications and exceptions are placed in the actor's inbox with the other tasks for processing. If tasks are being added faster than the actor can process them, the actor backlog will increase, and the chance that tasks or communications will expire before it is attended to increases. In this way, an actor's backlog is representative of the cognitive load on an individual. When the work process is examined, those actors with higher backlogs in their inbox will be more likely to miss important communications, and may be more likely to make errors.

An Example: Medication Errors

To illustrate this approach, we analyzed the organizational and work processes involved in writing, ordering, and administrating chemotherapy for a clinical trial protocol and developed a simulation model that reflected the way in which chemotherapy was planned and delivered in a specific medical organization (Fridsma 2000). The model, shown in Figure 1, describes the organizational participants, the activities for which they were responsible, and the interdependencies between activities. To test different organizational structures and start conditions, we varied the organizational reporting structures, the exception rate, and the actor skills for each of the members of the outpatient team.

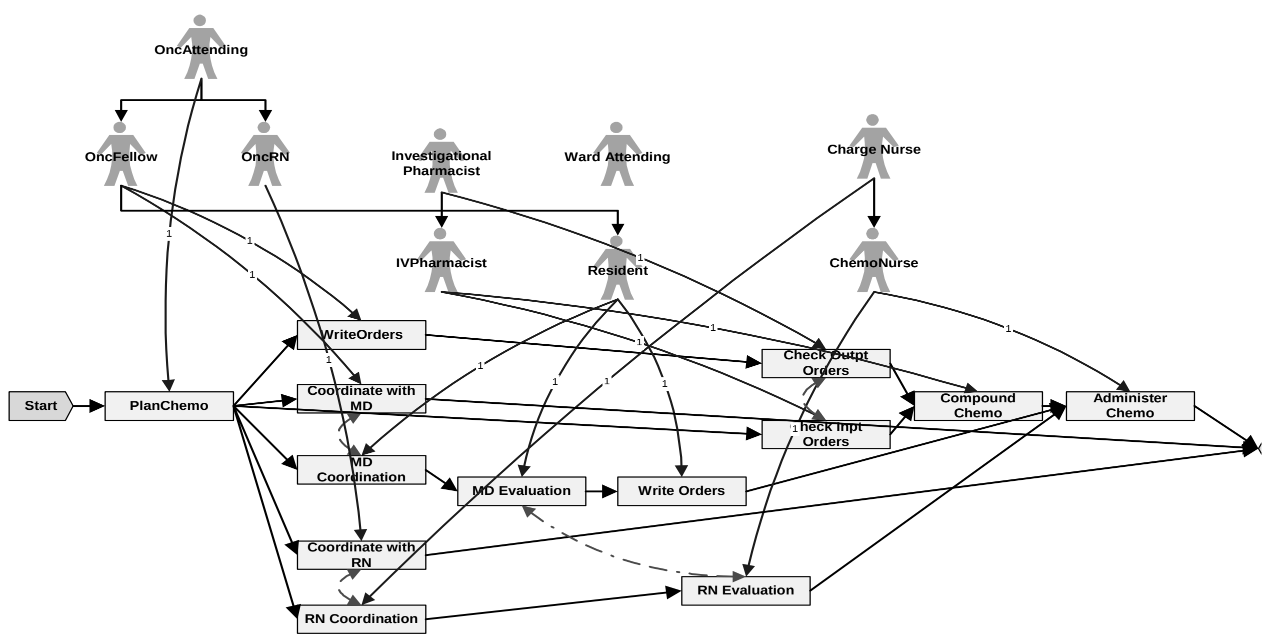

Figure 1. A model of chemotherapy administration. This work process model describes the administration of chemotherapy in an inpatient service. The oncology service is responsible for writing the orders and explicitly coordinating the inpatient care. Arrows between actors and activities define responsible-for relationships.

Each scenario was stochastically simulated 100 times, and the results of each scenario aggregated prior to analysis.

Figure 2 shows the actor backlog when low rates of exceptions—the base case that we used for comparison. With low exception rates, we found that the work tasks were relatively well distributed among the organizational participants—no single individual appeared to be differentially overloaded with work tasks when compared to other organizational participants.

High rates of exceptions, correspond to a situations in which there are many questions or problems encountered while caring for a patient. Not all of these exceptions represent errors—some may be missing information, unexpected events, and problems that require clarification. When we simulated high rates of exceptions, all members of the organization had more work to do, but the oncology fellow was affected more than other organizational members were affected. This is shown in Figure 3. The higher backlog for the oncology fellow suggests that the oncology fellow is more likely to miss important communications than others are, and may be unable to effectively manage or detect potential errors.

We then examined alternative organizational strategies to reduce the differential burden on the oncology fellow. Adding a clinical nurse specialist, or changing the reporting relationships of the oncology fellow had little effect on oncology fellow's backlog. However, increasing the oncology fellow's knowledge about the protocol (and thus his speed and accuracy in the task), normalized the distribution of work within the organization, and suggests the oncology fellow would be more effective in managing and detecting errors.

In this example, we modeled a work process that resulted in a medication error, simulated it at low and high exception rates, and analyzed which elements of the model were most likely to be overloaded and error-prone. The base case simulation reproduced the actual experience of the organization, and identified the oncology fellow as the person who, in the face of high levels of exceptions, was overworked more than other members of the team. The largest improvement in the oncology fellow's performance came with increasing her protocol knowledge, rather than adding the clinical nurse specialist into the work process.

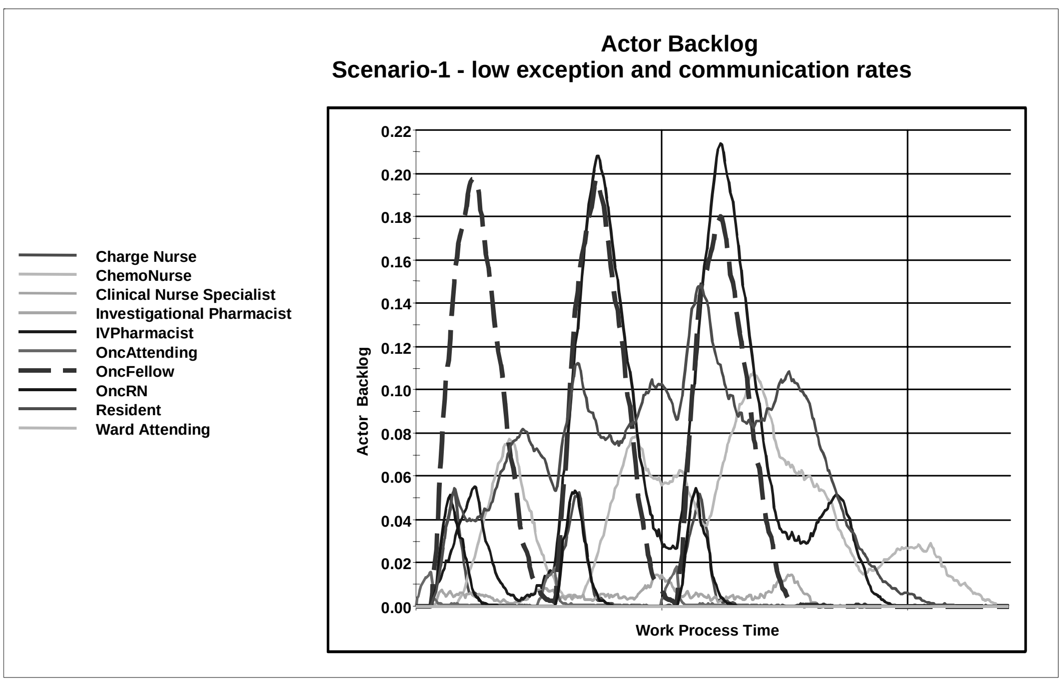

Figure 2. Actor backlog with low exception and communication rate. This figure shows the backlog for each actor in the model for three patients admitted to the hospital. The three peaks shown for the oncology fellow correspond to the time of admission for each of the three patients. No single actor is significantly backlogged.

Evaluating and Predicting Organizational Performance

Medical organizations use a variety of means to identify errors and improve patient care. The Joint Commission on Accreditation of Healthcare Organizations for example, is a mechanism to evaluate organizational performance. Unfortunately, the Joint Commission uses a retrospective evaluation of an organizational performance, and it is likely that poor outcomes have already occurred by the time that the problems are identified.

Organizational simulation however, allows managers to evaluate the "weak links" in their organization before problems occur, and identify potential solutions. In the example above, we identified that improving the knowledge of the oncology fellow was more effective in reducing the oncology fellow's actor backlog than adding additional staff. This suggests that adding knowledge sources for the oncology fellow would improve her ability to resolve questions regarding patient care more efficiently and effectively than other interventions.

It is important to note that using these simulation techniques we cannot predict all the ways in which a process might fail. Perrow and other organization theorists would suggest that it is impossible to predict "normal failures" within an organization(Perrow 1984). However, simulation can be used to prospectively test the parts of the organization or work processes that are most prone to failure, and a way to explore alternatives to solve those problems. As an organizational "stress test", simulations that are based in organizational theory hold the promise to improve organization performance before catastrophic failures occur. Additional work is needed to test each of the input parameters and link them to real organizations. Further experience with simulations—both prospective and retrospective—will improve the usefulness of simulation tools, and provide another means of evaluation and testing of work processes within health care organizations.

Discussion

We have used OCCAM to successfully modeled diagnostic work processes, and currently are testing additional contingent extensions with diagnosis and treatment protocols. Our initial simulation with traditional information-processing simulations suggest that these techniques are applicable in the medical domain, and should allow a wider range of medical protocols to be simulated.

The challenge will be to continue to refine and validate the modeling methodology. Similar tools in engineering have had over a decade of experience in modeling and simulating engineering organizations before being widely used and validated, and the validation of OCCAM is an ongoing process, both within medical organizations and within other service and maintenance organizations.

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Overview of Collaboration Patterns in Microarray-based Cancer Research

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Abstract

Over the past two decades, universities have become increasingly involved in the development and patenting of biomedical treatments and technologies. This is one indication of the changing role of academic institutions in the system of biomedical innovation. Although this change has attracted attention from the scientific, government, and industrial communities, a great deal remains unknown about many aspects of the new roles of academic institutions in the research system. One such aspect is the nature of university participation in inter-organizational and inter-sectoral relationships. This presentation is an overview of university participation in collaborative collaborative cancer research between 1998 and 2001, using coauthored publications as a source of data.

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Overview of Collaboration Patterns in Microarray-based Cancer Research[1]

Tiffany Tummino
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Over the past two decades, universities have become increasingly involved in the development and patenting of biomedical treatments and technologies. This change has attracted attention from the scientific, government, and industrial communities, but a great deal remains unknown about many aspects of the emerging role of academic institutions with respect to commercial activity. One such aspect is the nature of university participation in inter-organizational relationships. A description of the inter-organizational ties held by academic institutions will contribute to our understanding of how they currently function in scientific and technological development. It will also enable a systematic comparison of their participation in several types of research, including work oriented to treatment development, work oriented to diagnostic development, and work oriented primarily to extension of knowledge about cancer biology. To the extent that universities participate differently in more and less commercially oriented areas of R&D, federal policy on research support and intellectual property may impact these areas in distinct ways. Further, while universities have always held multiple roles within the system of biomedical research and development, the emergence of new functions opens the possibility of new conflicts and complementarities between roles.

Coauthorship in Microarray-based Cancer Research, 1998-2001

This presentation is an overview of university participation in collaborative cancer research between 1998 and 2001, using coauthored publications as a source of data. Partly because of the size of the cancer research system, the dataset is restricted for the time being to studies that utilize cDNA microarrays, a recent genomic technology. Microarrays were developed in the mid-1990s to analyze gene expression in cell lines and tissue samples for large numbers of genes in parallel. By observing differences in gene expression patterns across sample types, researchers investigate the functions of specific genes in a variety of biological processes. Microarrays are not yet ubiquitous in biomedical research, but they are frequently used in studies of cancer biology, and a growing body of research attempts to construct new diagnostic criteria and to speed the drug development and screening process using array techniques. The choice of array-based research restricts the size of my analysis while including a cross-section of several types of research. Moreover, array-based research is in a stage where the interaction of academic researchers with researchers in other organizations is particularly important to scientific and commercial progress in the area. Because microarrays are a recent technology, approaches to many aspects of experimental design and data analysis are not standardized. The potential value of arrays in R&D is widely recognized in the public and private sectors, but the technology and techniques of array-based research are developing primarily in universities.

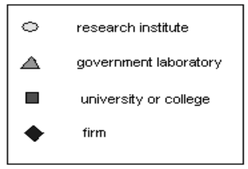
The coauthorship data presented here are drawn from publications in the Pubmed and ISI Web of Science databases in which cDNA microarrays are used to conduct original cancer-related research. The data is presented as a network, where vertices represent organizations and an edge between two vertices indicates that researchers in the two organizations have coauthored a paper together. The types of organizations in the network are research institutes, government laboratories, universities and colleges, and firms. In cases where a single organization has geographically separated components, such as a university with several campuses in different cities, the components were treated as different organizations. Hospitals were not included in the network analysis because, in many cases, affiliated hospitals and universities are not distinct organizations. Hospitals in the dataset that are not affiliated with universities typically have a strong dual focus on research and patient care; these are included in the network as research institutes. Two networks are constructed, one for 1998-1999 and one for 2000-2001, to illustrate changes over time in the network structure. General measures that do not depend on the network structure are taken for each year separately, and in some cases for 2000-2001.

Several general trends emerge over 1998-2001. These include increasing numbers of participating organizations (72 in 2000 : 156 in 2001), published papers (60 in 2000 : 129 in 2001), and average number of collaborating organizations per paper (2.5 in 2000 : 2.89 in 2001). Universities are by far the most common organization type, representing 61.8% of all participants in the period 2000-2001. The absolute numbers of all organization types have increased from year to year, with the largest percent gains in universities (44 in 2000

1

:102 in 2001). However, it should be remembered that researchers in universities may be more likely to publish than researchers in other organization types, especially firms. Other sources of information on collaborative research, such as patent records, will eventually be combined with coauthorship data for a more complete picture.

Figures 1 and 2 below show the networks for 1998-1999 and 2000-2001.



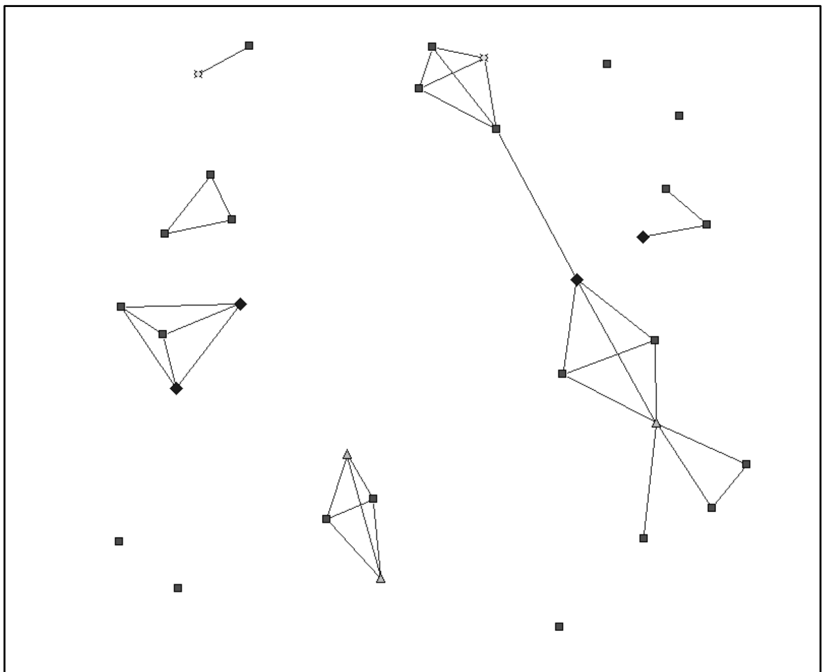
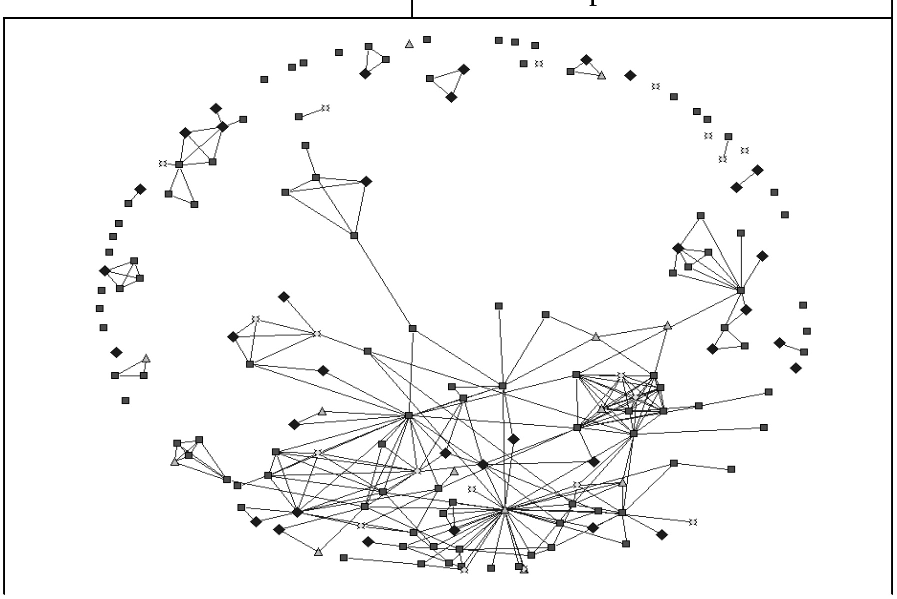


Figure 1
Collaboration network 1998-1999

Figure 2
Coauthorship Network 2000-2001



The network shows that research institutes, government organizations, and firms all collaborate disproportionately with universities, in the sense that the proportion of each type's collaboration partners that are universities tends to exceed the proportion of universities in the organizational population. Figure 3 below illustrates this.

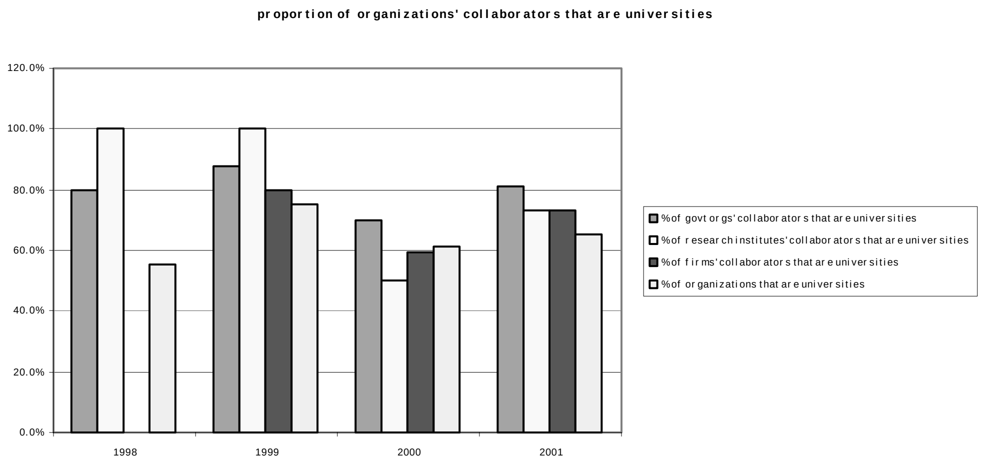


Figure 3

In contrast, universities tend to collaborate more with research institutes, government organizations, and firms, and less with other universities, than might be expected given the proportion of each in the population. See Figure 4 below for comparison of university representation as other universities' collaborators and in the overall population.

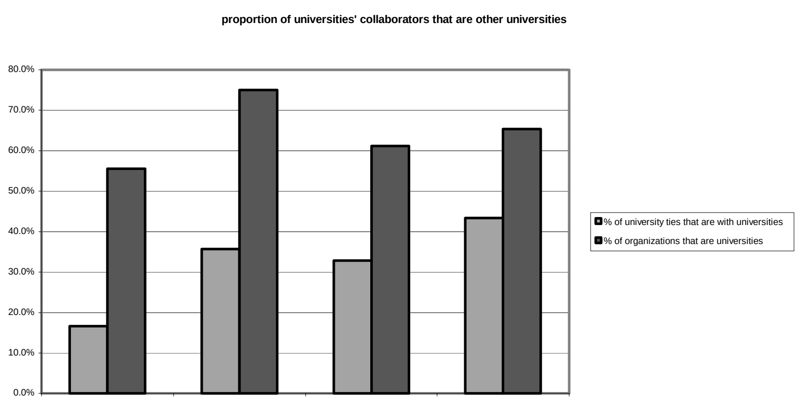


Figure 4

Every organization type, including universities, tends to have many more universities than other organization types as collaboration partners. However, the collaboration partners of universities then to be more diversified than those of other organizations, which collaborate primarily with universities.

While universities as a group collaborate with diverse partners, this does not necessarily mean that individual universities do. That is, universities may each individually work with several types of organization, or different univerisities may 'specialize' in different partner types. Figure 5 below shows the average number of organization types with which the average research institute, government lab, university, and firm collaborates. (Note that this 'average' is calculated only for organizations that have at least one collaboration partner; so, the minimum possible average is 1, the maximum is 4. Many universities publish independently, so when non-collaborators are included, universities have a much lower average.) On average, individual research institutes, government labs, and universities each collaborate with 2 kinds of organization. Looking at the network, we see that the average (collaborating) university tends to work with other universities and with one other organization type, which may be a research institute, government lab, or firm. Apart from working with one another, universities seem to specialize in one partner type. However, this result may just be an effect of the short time period examined, and will need to be confirmed with longer-term data that includes multiple publications for more universities than the current dataset has. Even then, if the result still holds, it may be because of repeat collaborations involving the same group of scientists than because of organizational 'specialization' per se.

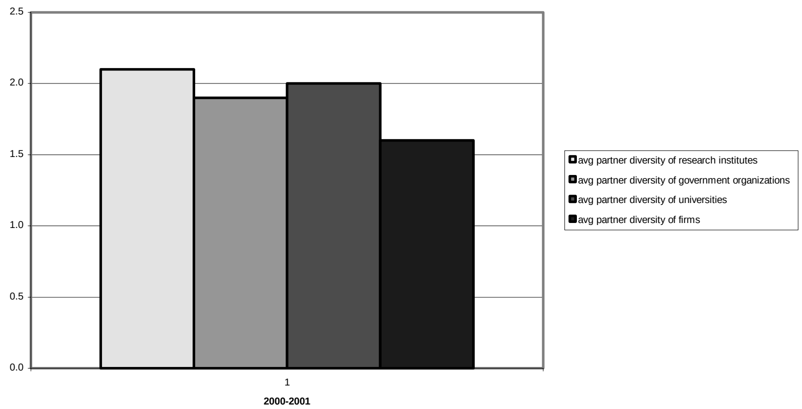


Figure 5

The most relevant network properties for the purposes of this discussion involve the bicomponents and the geodesics matrix of the graph. Figure 6 below shows the articulation points of the 2000-2001 network. White nodes (University of Tokyo and U.S. National Institutes of Health) connect 5 bicomponents of the graph; that is, removing a white node would cause its component to split into 5 new components. The blue node (Corixa Corporation) connects 4 bicomponents; red nodes (University of Washington and Baylor College of Medicine) connect 3; and green nodes connect two. The green nodes are primarily universities: University of Wisconsin, University of Iowa, University of Texas (Houston), Georgetown University, University of Glasgow, University of Basel, University of Helsinki, Osaka University, Jikei University, University of California (San Diego), University of Pennsylvania, Harvard, Stanford, Washington University, University of South Florida, the Weizmann Institute of Science, Jefferson Medical College, and Chung Shan Medical and Dental College. The non-academic 'greens' are Affymetrix, a firm, and the Memorial Sloan-Kettering Cancer Center, categorized here as a research institute. In sum, academic institutions and the NIH are nearly the only organizations that publish collaborative research with two or more distinct sets of coauthors. While the NIH links several otherwise unconnected organizations, many universities support the overall cohesion of the network through collaborations with two or more distinct groups of partners. In addition, it is interesting to note that the University of Tokyo seems to play an integrating role for the Japanese organizations in the network, similar to the role of the NIH for the U.S. and European organizations. (A graph with all the labels is necessary to see this.)

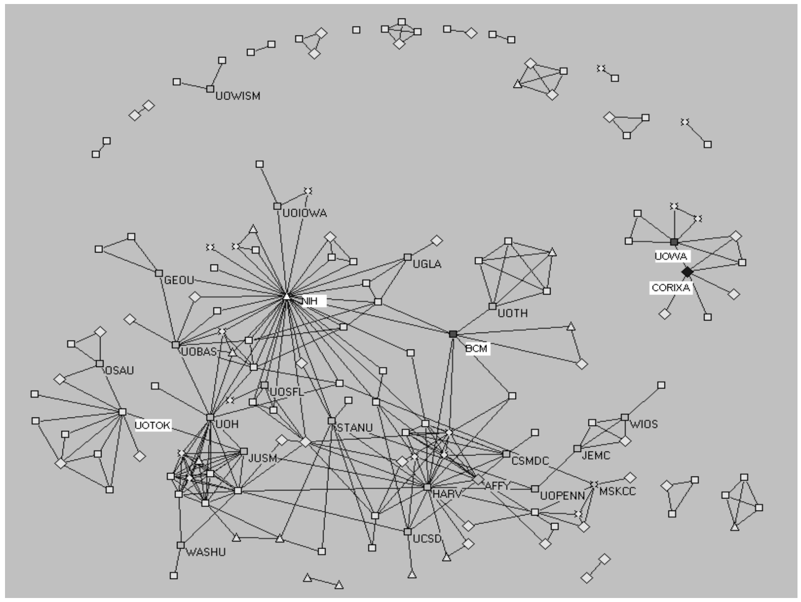


Figure 6

The bicomponents graph is a helpful, but not ideal, tool to analyze the role played by universities in overall network cohesion. A method that is somewhat similar to identifying articulation points, but less strict, is calculation of betweenness centrality. Like an articulation point, a vertex with high betweenness centrality links areas of the network that are otherwise less closely connected. A vertex with high betweenness, however, does not necessarily connect bicomponents of the network. Freeman betweenness centrality is mathematically defined as follows: “Let bjk be the proportion of all geodesics linking vertex j and vertex k which pass through vertex i. The betweenness of vertix i is the sum of all bjk where i, j, and k are distinct and j < k” (Freeman 1979). To estimate the betweenness of universities as a group, we could average the betweenness scores of all the universities in the network. However, it may be more useful to estimate the betweenness of universities with respect to other organizational types; for example, we may wish to measure the extent to which universities function as 'gatekeepers' between government laboratories and firms, which rarely collaborate with one another. To this end, it may be helpful to look at a variant of Freeman betweenness centrality which deals with groups of organizations, such as the following: let I, J, and K be nonoverlapping groups of vertices within a network. Let bJK be the proportion of all geodesics linking vertices in J with vertices in K which pass through a node in I. bJK may be thought of as the ‘betweenness’ of group I with respect to groups J and K. Measured this way, universities as a group have a betweenness of approximately .9 with respect to government organizations and firms. I cannot attribute meaning to this number without looking more closely at the calculation, but at first blush it seems high; universities seem to play a gatekeeper role between government and the private sector.

The purpose of this presentation was to give an overview of the role of universities in the coauthorship network of array-based cancer research papers. Future work will include other types of organizational interaction, use citation analysis to follow the contribution of array-based research to treatment and diagnostic innovations, break down the network by research area and degree of commercial orientation, and incorporate content analysis of the publications used in the network.

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BioWar Simulation and Causality

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Abstract

While the current state of BioWar simulation and results is promising, better methodology is needed for BioWar to be scientifically sound and more useful to users. Current BioWar simulation is based on the assumption that the causal relations (what causes what and who causes what) between events are already known. However, these causal relations are often what human designers think they would be, which do not necessarily correspond to the reality (in case they do, a formal method to verify this is still needed). Statistical correlations could not elucidate what/who causes what; this is why causal calculus is needed. In this paper, I would describe ways that BioWar simulation could benefit from (1) acquiring causal relations from data, (2) processing causal relations to produce an explanation of events. Elucidating causal relations would enable BioWar simulation to perform "what-if" scenario analysis more efficiently as noncontributing factors are elucidated. Causal relations also constrain the search over scenario and/or policy space so that the search can be conducted efficiently. Multi-agent network model modifies and contributes to causal relations. This work adds a new layer of "what causes what" and "who causes what" relations to the PCANSS formalism [Carley & Krackhardt, 1999]. This automated elucidation of causal relations, along with the PCANSS formalism, would facilitate the birth of an inference engine capable of automatically creating and testing new organizational theories. This paper consists of two parts: first, the description of the current state of BioWar; second, the description of how causal relation elucidation could enhance BioWar.

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Key Words: biowar, simulation, causal relation, multi-agent, network, meta-matrix

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PART I: BioWar Simulation

BioWar simulation is capable of generating the patterns of disease manisfestations for a heterogeneous population over space and time. It can simulate theoretically unlimited number of agents and diseases with user-defined time step. On a PC with 256 Mbytes memory, it is capable of simulating 160,000 agents.

BioWar is based on a diverse set of data as inputs:

1. General Social Survey (GSS): this data set describes the general and comprehensive social characteristics such as work status (working full time, working part time, unemployed, in school), occupation (transportation worker, farmers, military people), work hours, medication taking habits, who to talk to in time of need, family networks (sibling, brothers/sisters, single mothers), working in a small or big firm, Internet use, commuting time, etc. GSS is used to parameterize agents in biowar simulations to reflect the people in the real world. For example, the working time in the simulation is modeled after the real world data from GSS, resulting in a much fewer people work at weekends and during the night. If a bioattack occurs at night, it has a different effect than if it occurs during the working hours of most people. Other GSS data, such as the Internet use, provides estimates to what people would be able to effectively use during/after a bioattack.
2. Census 2000: this data set describes the demographic characteristics of a population, income level, area profiles, birth & death rates, migration rate, estimate of population growth, among others. This census data set is used to parameterize agents with appropriate demographics for a certain area as agents have the spatial dimension. It will also be used to provide the natural birth, death, and migration rates of agents.
3. Quick Medical Reference (QMR) data: this data describes the interrelationship between diseases, symptoms, diagnosis, and treatments, among others. QMR itself is diagnostic decision-support system with a knowledge base of diseases, diagnoses, findings, disease associations and lab information. The data set is used to parameterize the disease models on the relationship between diseases and symptoms.
4. Hospital data: describes the capacity of a hospital, the patient admission rate, and the number of nurses and physicians. This hospital data is used to parameterize hospital abstract agents in biowar simulations. The hospital data is useful for determining the capacity of care in case of a bioattack.
5. Emergency Room Statistic (ERS): describes emergency room visits based on demographics. This data set is used to parameterize how demographics affect agent’s decisions to go to Emergency Room.
6. Doctor Visits (DV): describes doctor visits based on demographics. This data set is used to parameterize how demographics affect agent’s decisions to go to a doctor.
7. Purchase of Over-the-Counter drugs: describes the over the counter drug purchasing rate based on demographics. This data set is used to parameterize how demographics affect agent’s decisions to purchase over the counter medicine.

Simulation Architecture

Figure 1 below shows the Biowar's multi-agent simulation architeture.

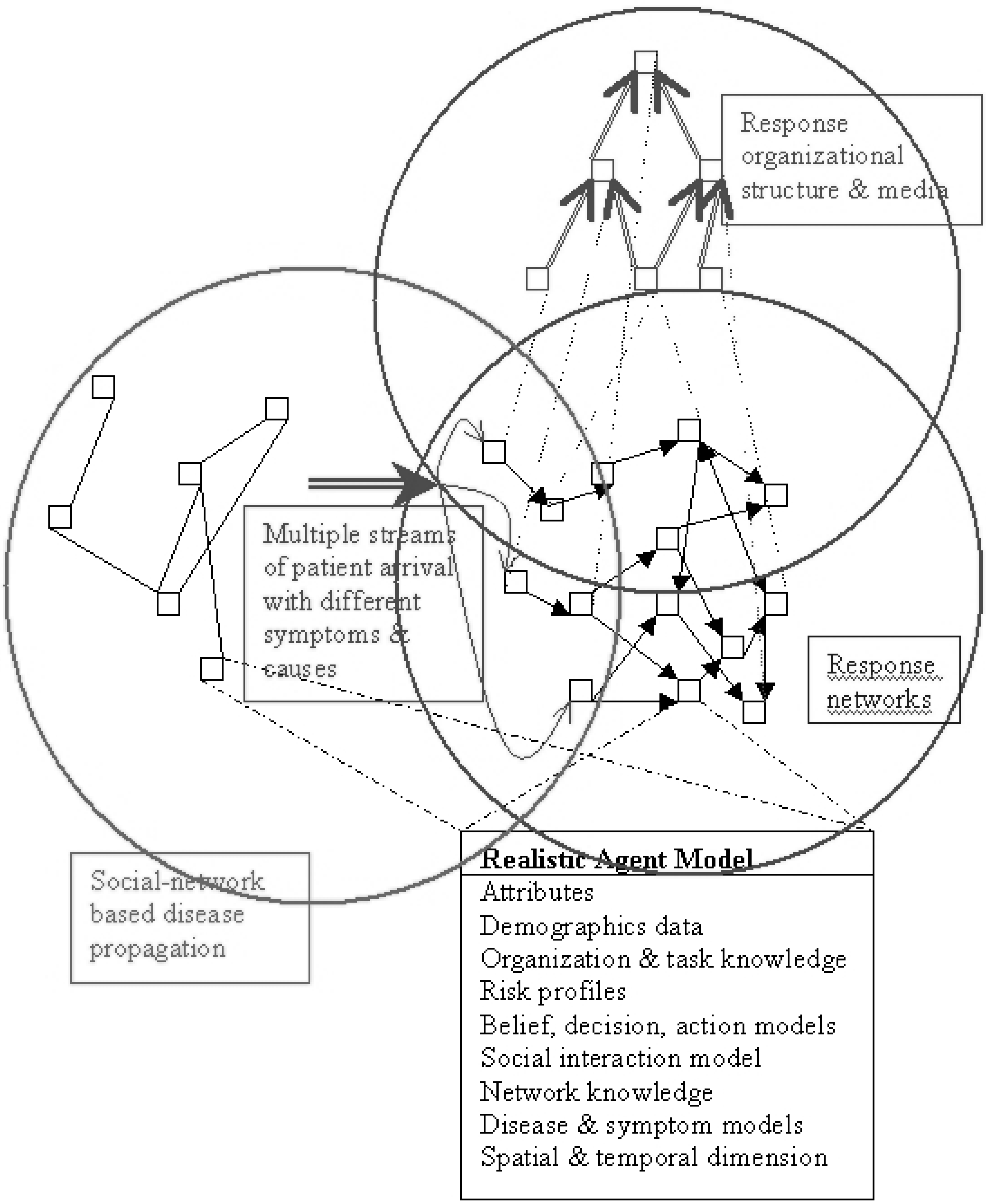

Figure 1: Biowar Architecture

The agents in the simulation are initialized with demographics data (age, gender, race, occupation, location, etc.), knowledge in the form of bit-string, risk profile, initial social network, disease model, symptom model, and belief & action models. The simulation clock then starts. When a certain disease outbreak occurs, it affects certain segment of the population depending on the location, agent's risk profile, and whether or not the disease is contagious. In case of anthrax, the wind direction plays a role in the direction of disease propagation. Agents are infected with normal diseases like influenza over time. Each disease may have more than one strain. Having a disease, an agent will enter infectious phase, during which this agent is infected but does not infect others. After a passage of certain time depending of the disease strain, an agent will enter the communicable phase, during which this agent could infect others. An agent will also enter the symptomatic phase, during which this agent acquires symptoms. Based on the severity of the symptoms, the agent will change its beliefs. This change in beliefs would result in change in actions. For example, if the agent experiences a severe symptom, it would go to ER, while less severe symptoms would prompt the agent to go home, talking a day off to rest. Going to pharmacy, doctor office, and ER would have its associated treatment option and effectiveness. While an agent is sick, it is absent from work and/or school (depending on the age of the agent).

Disease and Symptom Models

Disease is modeled individually for each agent. This differs from the conventional epidemiological and spatio-epidemiological approaches. The disease model consists of the infectious phase, communicable phase, symptomatic phase, and treatment phase. Each disease could have several strains. Each strains have the time and place of outbreak, the susceptibility rate among the population, and the transmissivity rate. These rates are influenced by demographics, the time of the year, and location. Furthermore, actions of the agents and media influence affect both the realized susceptibility rate and transmissivity rate. For example, if network news inform the population about the outbreak of a bioattack in a certain area, people would cancel their travel to/across the area, resulting in a lower realized transmissivity rate.

In summary, each disease has

- A set of symptoms
  - Evoking strength, P(D|S), where D=disease, S=symptom
  - Frequency, P(S|D)
  - Cost of diagnosis and treatment
- Progression of disease for each agent
  - Infectious phase
  - Communicable phase
  - Symptomatic phase
  - Variations in onset and length of each phase

During the symptomatic phase, each agent accumulates the severity of the symptoms, measured by a weighted value of evoking strength. If this sum of severity exceeds certain values, agents modify their beliefs about whether or not it has a disease, a life-threatening disease, and whether it should go to a health care provider. When agents are treated and recovered, they cease to have the treated symptoms, but may contract a new disease and its associated symptoms. Depending on the disease and demographics, agents may become immune to certain diseases.

The diseases include respiratory diseases (influenza, influenza pneumonia, staph pneumonia, pneumococcal pneumonia, col/rhino/adno-virus), gastrointestinal (viral gastroenteritis, food poisoning), and skin disease (cellulites). The bioattacks include cutaneous anthrax, respiratory anthrax, bubonic plague, and smallpox.

Realistic Agents

For a simulation to be useful, it needs to have both high and appropriate degrees of fidelity. We have taken an approach of multi-agent network model to Biowar. Our agents are cognitively realistic, socially realistic, spatio-temporally realistic, and can use communication technologies. Our approach is an intelligent hybrid of disease, spatial, network, cost, agent, social, geographical, and media models.

Our agents are divided into general and specialized agents, with the goal of having all agents have both general and specialized aspects. The general agents are the parent class of all agents, while the specialized ones are the inherited class of agents.

The general agents have:

- Race, gender, age, education, other demographics data from census and GSS data
- Social interaction model CONSTRUCT (Carley, 1990).
- Spatial and temporal dimension, including type of locations and geography from GIS data
- Variation in risk profile by race, gender, age, location, and history of illness
- Disease and symptom progression
- Beliefs, decision, actions, and consequences (that is, agents could die of diseases)
- Some agents are in sentinel populations
- Some agents are part of response organizations, for example: doctors and nurses.

Doctor agents are an example of the specialized agents. They:

- Have diagnostic model, based on combined evoking strength and alert status
- Diagnosis affects further testing
- Alert status is based on media and prior cases

Virtual Experiment

Biowar program is capable of simulating 160,000 agents in memory on a PC with 256 Mbytes of memory. Biowar is also capable of theoretically simulating unlimited types of locations (homes, workplace, schools, pharmacy, doctor offices, Ers, etc.). In a virtual experiment described here, however, we simulate 20,000 agents having 10 workplaces, 10 schools, 10 pharmacies, 10 doctor offices, and 10 emergency rooms. The length of simulation is 365 days. The background disease is 36 strains of influenza, while the bioattacks are 2 bubonic plague attacks at day 75 and day 175, and 1 anthrax attack at day 225.

Figure 2 below shows agent activity during the simulation period. An agent could choose to go to work, go to school, stay at home, go to pharmacy, go to doctor office, or go to ER Moreover, an agent could die and cease its activity as a result of unrecovered disease it suffers. The three peaks in “pharmacy” (go t pharmacy) lines show the (delayed) onsets of the three bioattacks.

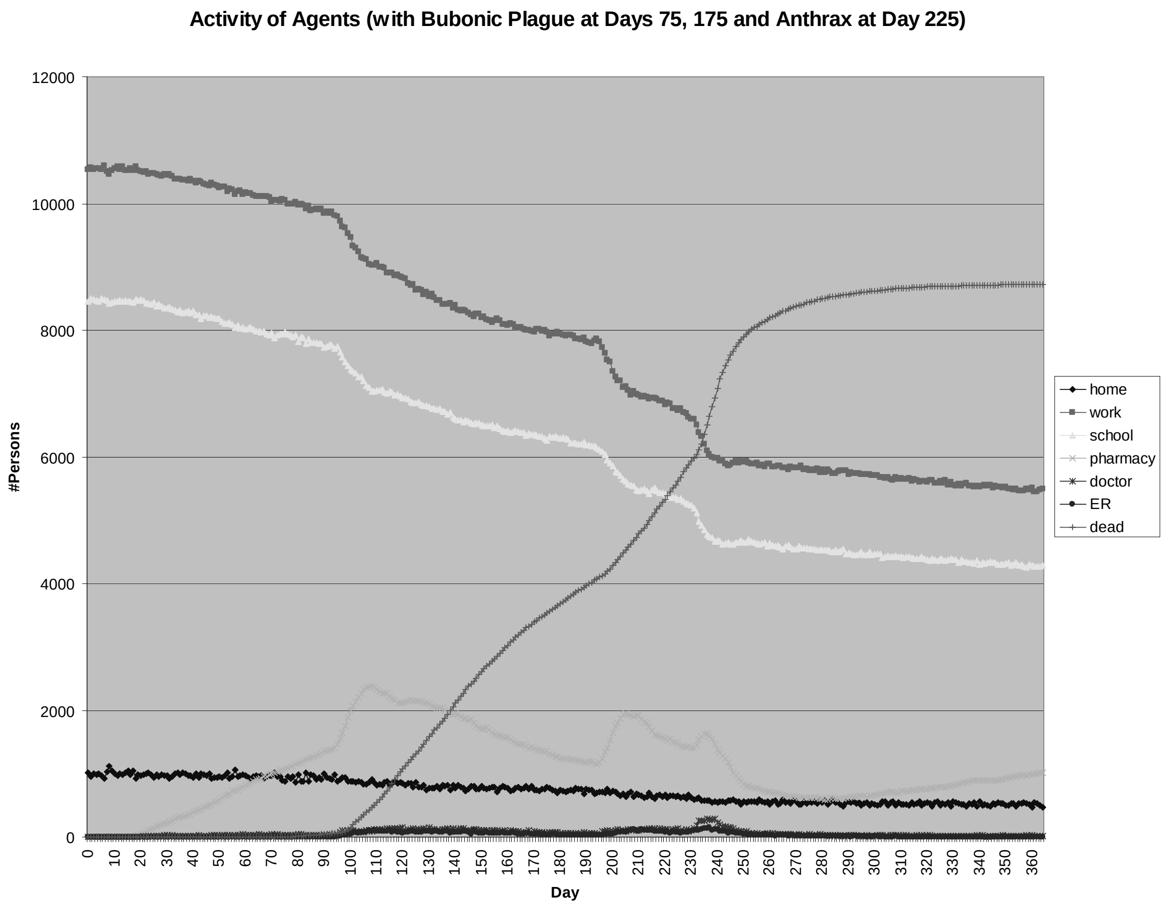

Figure 2: Agent Activity

Figure 3 below shows the state of disease in agents and the number of agents who died as the result of uncured disease.

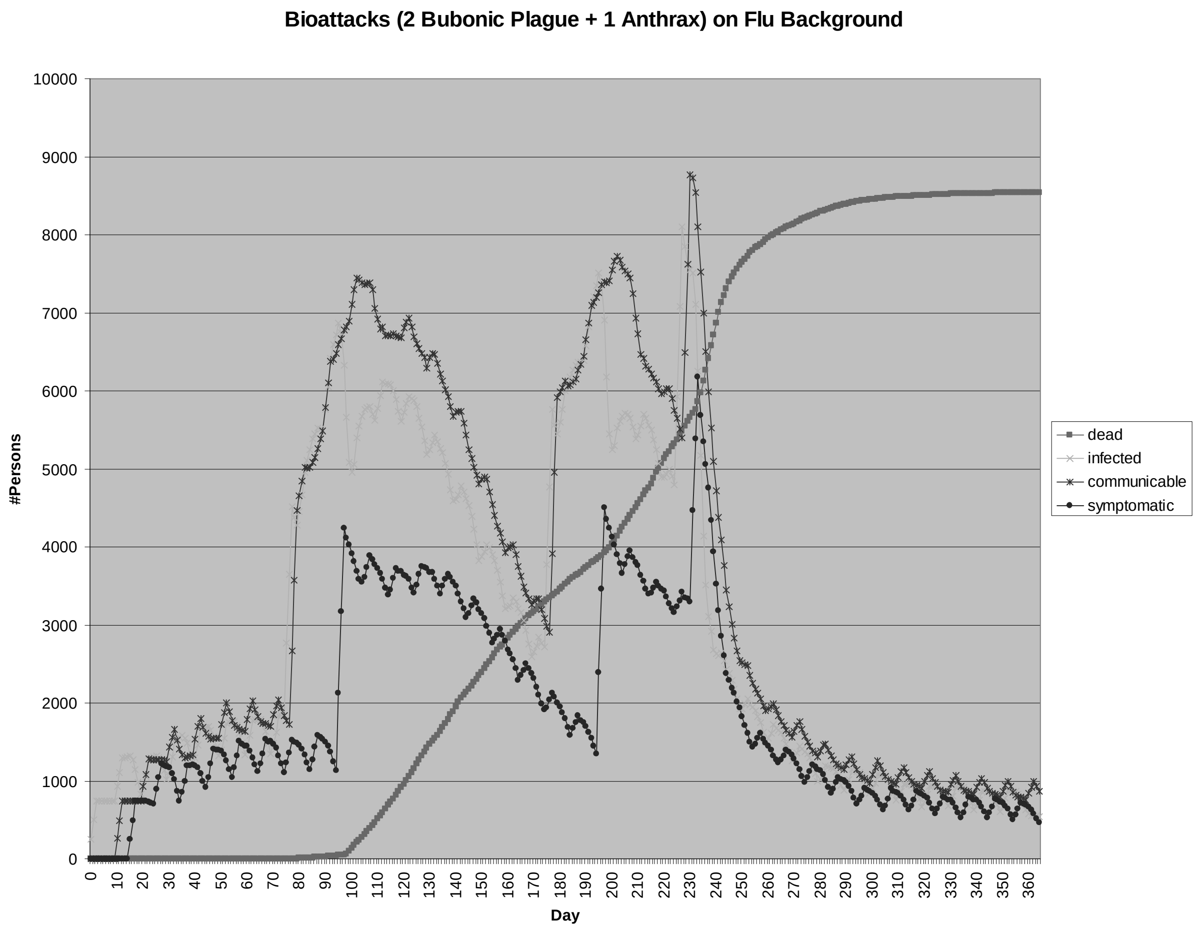

Figure 3: State of Disease in Agents

Figure 4 below shows the school absenteeism of one of the 10 schools during this period.

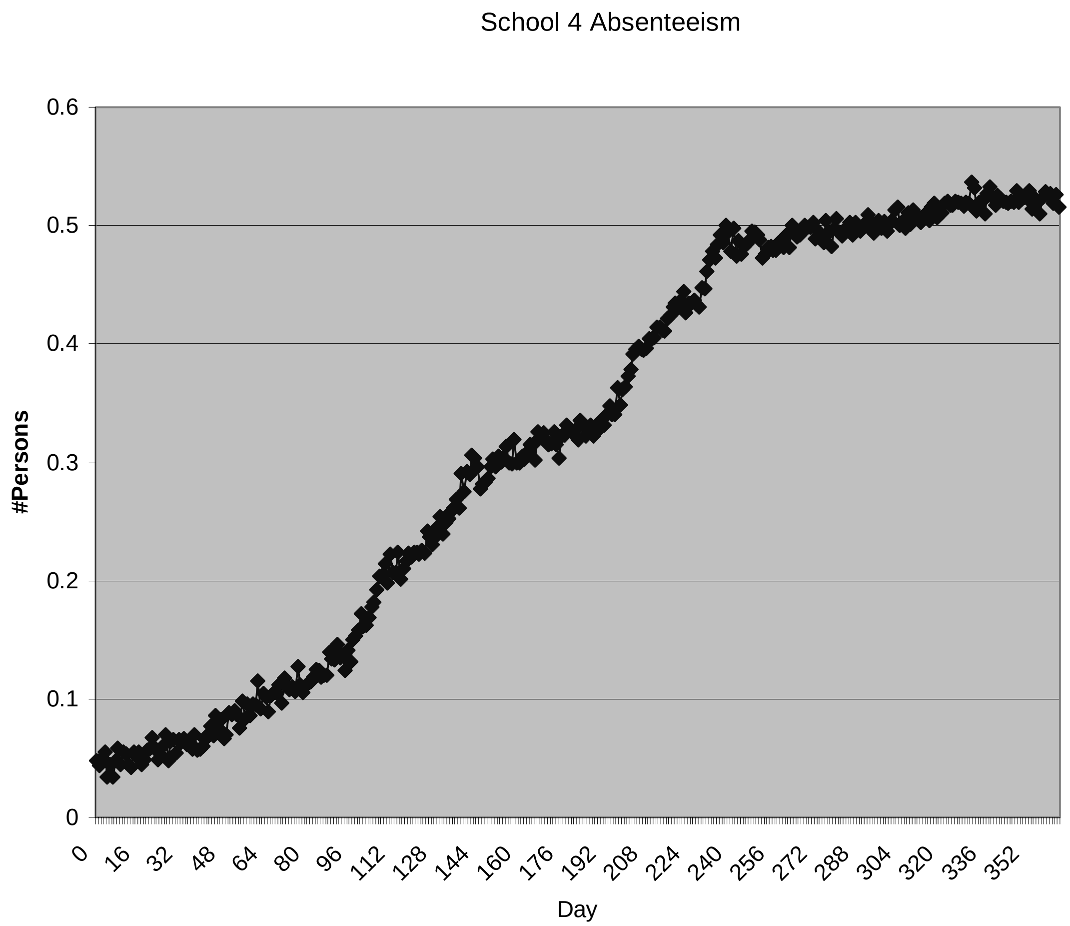

Figure 4: Absenteeism in One School

Figure 5 below depicts the drug purchases at one of the 10 pharmacies. It shows that the drug purchases peack sometime after bioattacks occurred.

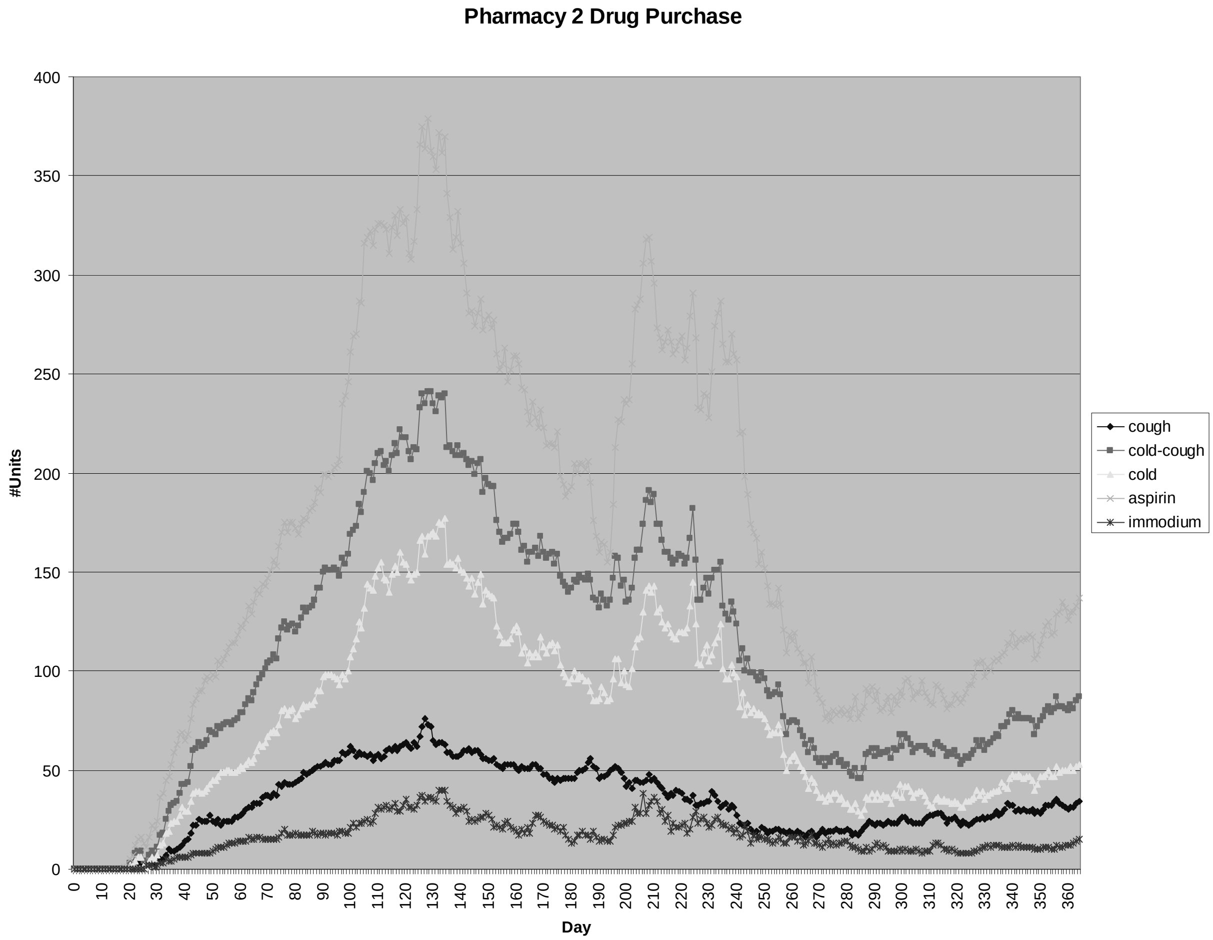

Figure 5: Drug Purchases at One Pharmacy

Figure 6 below depicts the doctor office and ER visits in greater detail.

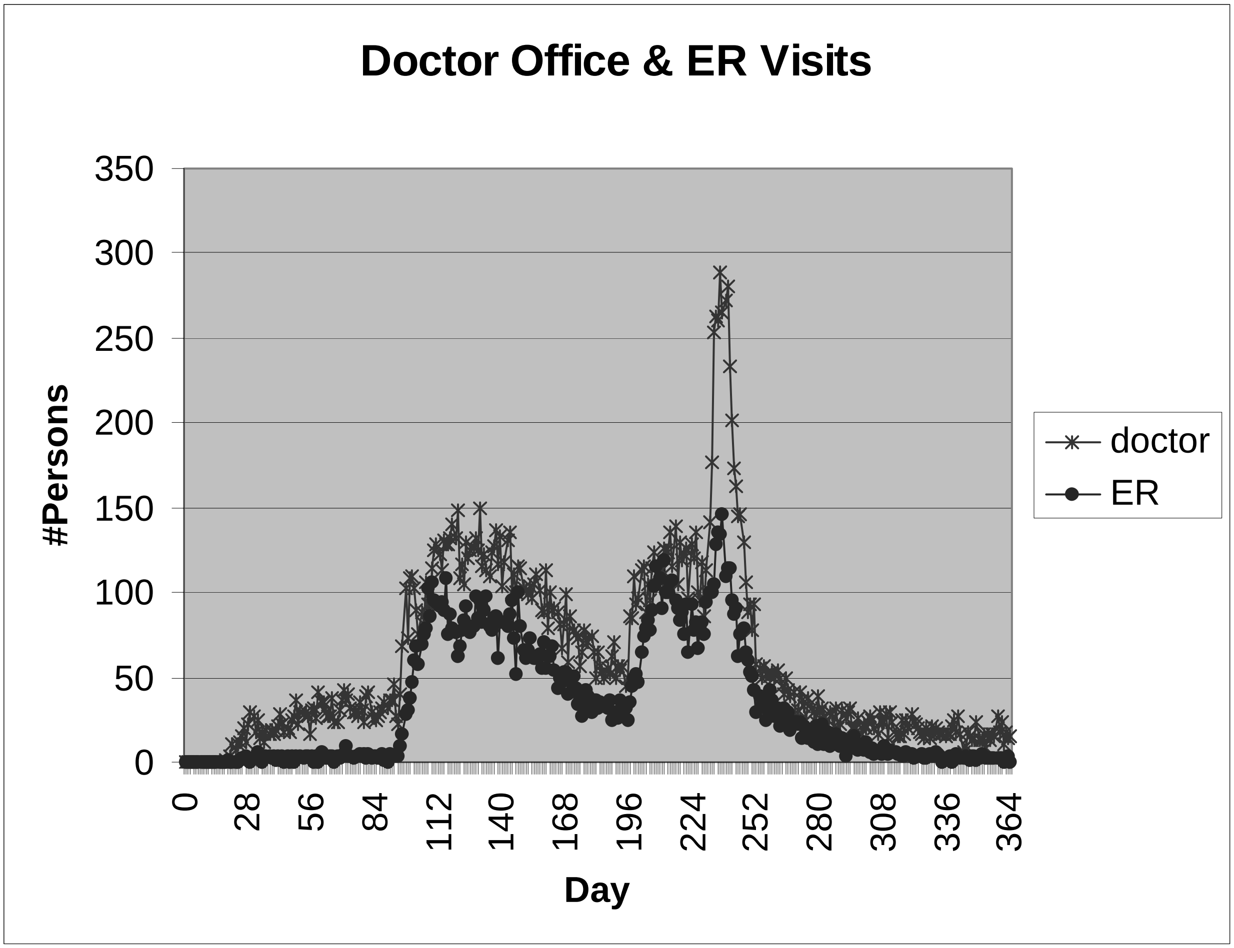

Figure 6: Doctor & ER Visits

Figure 7 below shows pharmacy, doctor, and ER visits in greater detail.

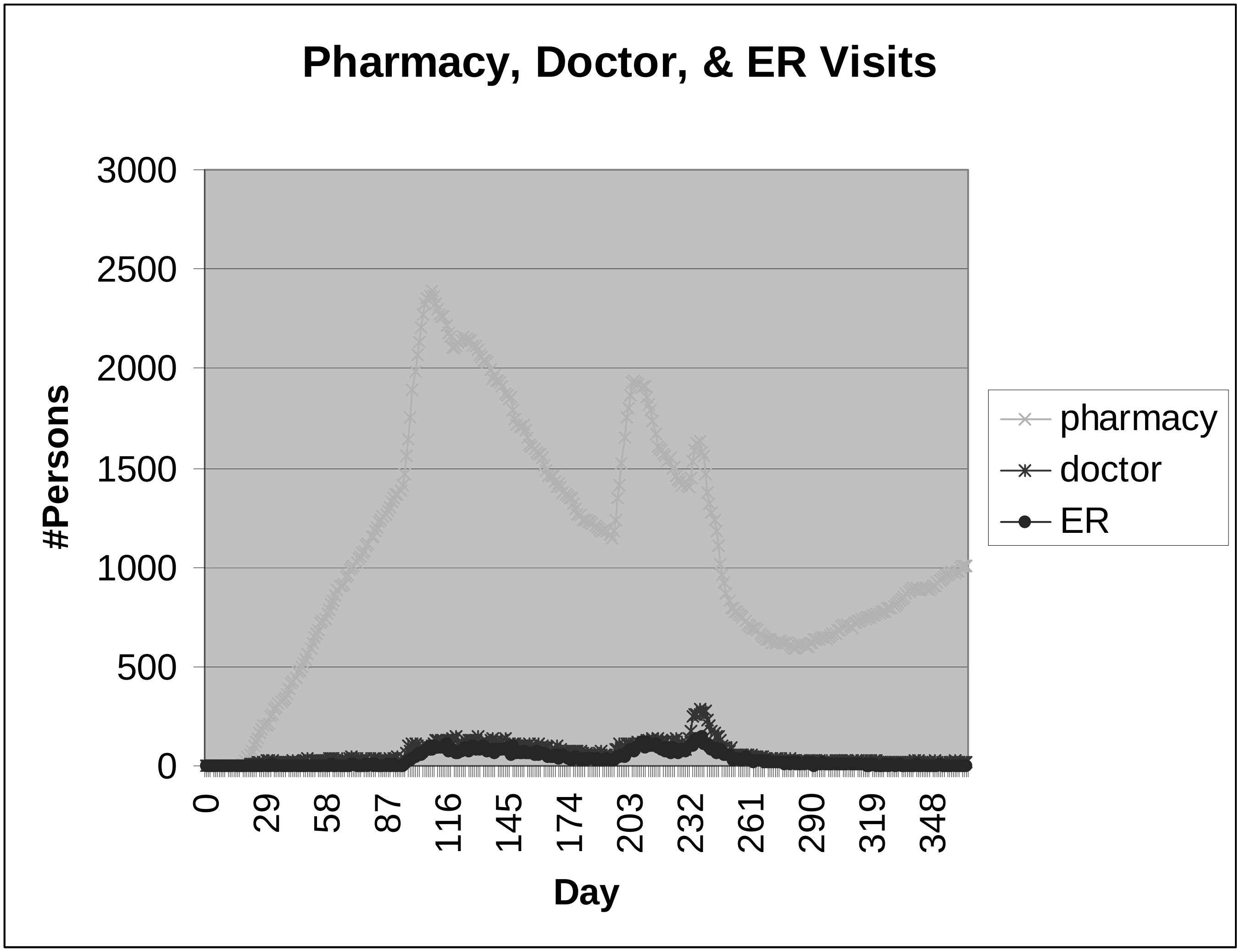

Figure 7: Drug Purchases at One Pharmacy

Part II: Causality Elucidation for BioWar

Biowar simulation currently rests on the following assumptions:

1. The order and the cause-effect of events as given by human designers completely match the reality.
2. To do “what-if” scenario analysis, human users could simply change the input variables and see what happen to the output.

In reality, the above assumptions are not correct, because:

1. Human designer judgments are often erroneous, resulting in an incorrect simulation model.
2. Causal relations of events are not simply a correlation or an order of events.
3. While human users could change several input variables and observe what happen to the output, the human cognitive ability limits the number of variables humans could correctly change and observe. For BioWar, the number of input variables and parameters is very large, thus necessitating a better approach to handling ”what-if” scenario analysis.
4. Because of the complex scenarios we need to consider, chaining of “what-if” equations does not work, as it does not preserve causal relations.
5. The passive observation of BioWar simulation is different than an active intervention of BioWar simulation in order to see how different scenarios play out. Conventional statistics is sufficient to describe passive observations, but causal calculus is needed to formally describe active interventions.

Thus it is necessary to have:

1. An automatic analysis of scenarios by searching through the space of all possible scenarios, guided by causal relations.
2. A causal relation inference from data.
3. Biowar to have PCANSS formalism with augmented causal relations (“what causes what” and “who causes what”).
4. A causal calculus based on multi-agent networks. This forms a foundation for an automated organization theory inference engine.

Causal Calculus: The Basics

Science rests on two components: one consisting of passive observations (the science of seeing), and the other consisting of voluntary intervention (the art of doing). However, until recently, mathematical techniques were developed exclusively to support the former (seeing) not the latter (doing). The modern causation begins with the philosopher David Hume. Hume stated that:

1. A sharp distinction exists between analytical and empirical claims. The former are product of thoughts, the latter matter of fact.
2. Causal claims are empirical.
3. All empirical claims originate from experience.

The above brings two questions:

1. What empirical evidence legitimizes a cause-effect connection?
2. What inferences can be drawn from causal information? And how?

Recent work [Pearl, 2000][Spirtes, et. al., 2000][Heckerman, 1995] has elucidated how we address the above two questions. We can do causal discovery from observational data via constraint-based and Bayesian approaches.

To illustrate the danger of doing simple “what-if” analysis without paying attention to causality, let us have the following logical sentence:

INPUT:

1. If the grass is wet, then it rained.
2. If we break this bottle, the grass will get wet.

OUTPUT:

If we break this bottle, then it rained.

Thus simple “what-if” chaining would produce an erroneous conclusion. While humans are unlikely to make a mistake given the above two logical sentences, for more complex situations, humans are not infallible. BioWar simulation is one of these complex situations in which humans alone are ill equipped to draw sound conclusions. Judea Pearl proposed three basic principles for the encoding and inference of causation [Pearl, 2000]:

1. Causation: the encoding of behavior under interventions
2. Interventions: surgeries on mechanisms
3. Mechanisms: stable functional relationships, encoded as equations and graphs

The world is organized in the form of stable mechanisms, or physical/chemical/biological laws, which are sufficient for determining all event that are of interest. The mechanisms are autonomous: we can change one without changing the others. Interventions always involve the breakdown of mechanism, or “surgery”. Causality tells us which mechanism is to be surgically modified by any given action. Based on the above three principles, a causal model is constructed. A causal model consists of action sentences, counterfactuals, and explanation.

The applications of causal model include:

1. Predicting effects of actions and policies, which is what BioWar simulation is designed to assist elucidating.
2. Learning causal relationships from assumptions and data. BioWar simulation is required to have sound cause-and-effect relationships and a way to generate and/or validate these relationships is to learn them from data.
3. Troubleshooting physical systems and plans. During the lifespan of its use, BioWar simulation architecture “system” needs to allow constant improvement. If problems occur, BioWar needs a troubleshooting tool.
4. Finding explanations for reported events. The usefulness of BioWar is determined by the value it provides to the policymaker in elucidating the effects and the explanations for various scenarios. Causal relation elucidation would greatly enhance this value.
5. Generating verbal explanations. Using causal relation inference engine, BioWar would be able to generate verbal explanations understandable by human users. This would allow BioWar and human experts to actively interact during BioWar simulations.
6. Understanding causal talk. Using causality inference engine, BioWar would be able to understand what human experts express in the form of causal talk. BioWar would then verify and check the truthfulness of the expression and act upon it.
7. Formulating theories of causal thinking. Multi-agent network system of BioWar simulation is a new factor in the causal thinking. The current state-of-the-art of causal thinking abstracts away agents by variables. It would be interesting to see how agents and networks affect causal thinking.

Based on the above description, the nature and the purpose of BioWar simulation necessitate the careful consideration of causality.

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Identifying Sets of Structurally Key Players

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Abstract

This paper discusses how to identify sets of structurally key players, particularly in the context of attacking terrorist networks. Three specific goals are discussed: (a) identifying nodes whose deletion would maximally fragment the network, (b) identifying nodes that, based on structural position alone, are potentially "in the know", and (c) identifying nodes that are in a position to influence others. Measures of success, in the form of fragmentation and reach indices, are developed and used as cost functions in a combinatorial optimization algorithm. The algorithm is compared against naïve approaches based on choosing the *k* most central players, as well as against approaches based on group centrality.

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Identifying Sets of Structurally Key Players

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Introduction

The motivating context for this paper is the problem of defending against terrorist networks. There are three basic reasons why we would want to identify sets of structurally key players in this context. One reason is based on the assumption that forcibly removing nodes from the network will disrupt the functioning of the network and that, for practical reasons, we cannot eliminate more than a small handful of nodes. The problem then becomes which nodes to remove, so as to achieve the greatest disruption.

The second reason is based on the idea that there are certain nodes that, because of their structural position, are likely to know more of what flows through the network than others. These are people we would like to debrief (ideally on an ongoing basis) or simply place under surveillance.

A third reason, perhaps more farfetched than the others, is based on the idea of planting conceptual seeds that we would like to diffuse through the network. Presumably, these ideas would appear innocuous but would in fact disrupt the network through lowering morale, creating dissensus, etc. Of course, in non-terrorist contexts, such as the fight against AIDS, the notion of using key players to diffuse healthful practices is not at all far-fetched.

In all cases, we assume that the data available are accurate and limited to the network structure itself. Clearly, if we knew that certain individuals possessed key skills, such as bomb-making or plane-flying, or special responsibilities, such as being in charge of operations, we would want to target them regardless of network position. We also do not consider the issue of what network ties represent. We take as given that a certain relation (communication, trust, etc.) has been identified as important and the data collected.

Criteria for Selection

Let us begin with the goal of removing individuals to disrupt the network. Exactly how to disrupt a network is unclear, particularly in the absence of a general theory of how networks function. However, a common sense assumption is that a disconnected network is not a well-functioning network. That is, if the network is broken into many components (whose elements cannot reach any elements of other components), it cannot function. Therefore, one obvious criterion for success is the number of components in the graph.

However, this criterion does not work well in practice. In most networks, there are a few nodes that are not well connected, such as nodes with degree 1 (known as pendants). Thus, we can easily increase the number of components in the graph by deleting the intermediaries that link pendants to the rest of the network. The result is a pruned graph which is even better connected than before, except for a set of isolates (components of size 1). The number of components in the graph has gone up, yet most nodes remain connected. In other words, the distribution of sizes of components makes a difference. A network of 10 nodes that is fragmented into two components of size 5 is more fragmented than a network that is fragmented into components of size 9 and 1.

A better measure of graph fragmentation is the number of pairs of nodes that are disconnected (i.e., are in separate components). To calculate this efficiently, we can identify all components in the graph (an $O(n^2)$ operation), and then compute

$$Fr = n(n-1) - \sum_k s_k(s_k - 1)$$

Equation 1.

where s_k gives the number of nodes in the *k*th component, and *n* is the number of nodes in the graph. Note that in this paper we assume undirected graphs. For convenience, we can express the graph fragmentation measure in terms of proportions instead of frequencies:

$$F = 1 - \frac{\sum_k s_k(s_k - 1)}{n(n-1)}$$

Equation 2.

A closely related measure is the heterogeneity coefficient recommended by Blau (1977) and Uzzi (1996), among many others. In this context, heterogeneity is defined as

$$H = 1 - \sum_k \left(\frac{s_k}{n}\right)^2$$

Equation 3.

Obviously, *H* approaches *F* as *n* gets large. For small *n*, *F* is perhaps preferable to *H* because it achieves its upper bound of 1 when all nodes are isolates, whereas *H* can only reach $1 - 1/n$. On the other hand, from an absolute point of view, *H* gives a higher fragmentation score to 100 than to 10 isolates, which makes some intuitive sense when comparing networks of different sizes.

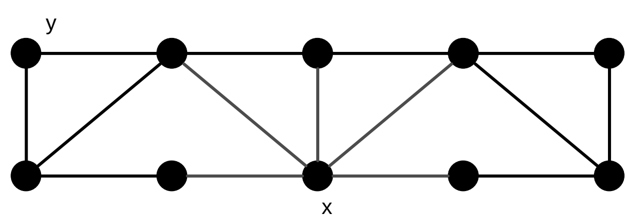

Figure 1

The difficulty with the fragmentation criterion is that some graphs are so well connected that they cannot be fragmented by removing a small set of nodes. Even so, it is clear that some nodes will be more disruptive if removed than others. For example, in Figure 1, removing node *x* does not disconnect the graph, but greatly increases the graph-theoretic distances between many pairs of nodes. Removing other nodes, such as *y*, has no effect. Hence, we should consider a second criterion, which is the extent to which distances are long between all pairs of nodes. When the graph is connected, we can simply use:

$$T = \sum_{i,j} d_{ij}$$

Equation 4.

Ideally, however, we would like a criterion that can be used with disconnected graphs as well. One possibility is to use something based on the reciprocal of distance, $1/d_{ij}$, with the convention that if *i* and *j* are disconnected, the reciprocal of their distance is 0. Hence we could use

$$C = 1 - \frac{2\sum_{i>j} \frac{1}{d_{ij}}}{n(n-1)}$$

Equation 5.

The function achieves its minimum value when the graph is fully disconnected (contains only isolates) and achieves its maximum when the graph is a clique – all nodes adjacent to all others. The *C* measure agrees with *F* whenever components are complete (i.e., are each cliques), and "factors down" the F index to the extent that distances within components are large.

We now turn to the goals of identifying sets of nodes with potentially (a) more knowledge due to being well-connected, or (b) more ability to influence others. These are essentially two sides of the same coin – the former focuses on inflow, while the second focuses on outflow. In the present context, and assuming undirected graphs (symmetric social relations), these are the same, and we shall treat them together.

The connectedness of a set of nodes is precisely the group centrality problem identified by Everett and Borgatti (1999). They note that each individual measure of centrality described in the literature can be converted into a group measure. For the two goals we are concerned with here, we are probably most interested in group degree centrality – the number of distinct nodes that a member of the chosen set has a direct tie with. Particularly in the case of choosing individuals to influence others, intuition suggests that direct ties are considerably more valuable than indirect ties. However, we can then relax this notion to incorporate notions of distance by counting instead the number of nodes that can be reached in k links or less, where $k = 1$ is the case of simple degree. Note that the distance of a node to a set of nodes can be approached in a number of different ways. Since we are generalizing the basic degree measure, however, the appropriate definition of distance here is the minimum distance from any member of the set to the node in question. To see this, consider the case of degree, where $k = 1$. The idea is to count nodes that are adjacent to some member of set *K*, not every member.

A different way to incorporate distance is to count all nodes reached by members of the set, but weight them inversely by the minimum distance to the node. Hence, a set that reaches many others at short distances is better than one which fewer nodes at longer distances. If we again use the convention that the reciprocal of an infinite distance is zero, we can define the weighted reach measure even in disconnected graphs as

$$R = \sum_j \frac{1}{d_{Kj}}$$

Equation 6.

where d_{Kj} is the minimum distance from any member of the set *K* to node *j*. Note that when the distance to a node is one, the node is given full weight. When the distance is two, it is counted only half as much, and so on. Also, the nodes in *K* are counted as well, always receiving full weight.

It is worth pointing out that the fragmentation and reach criteria are fundamentally different. When we use a fragmentation criterion, we seek nodes whose removal reduces communication possibilities in the network. We therefore seek nodes that are along short paths between others. We might call this property betweenness, or, to be more general, *mediality*. In contrast, when we use a reach criterion, we seek nodes that are well connected in the sense of being the origins or endpoints of many short paths to others. In the fragmentation case, we are interested in the quantity and lengths of paths among the nodes outside the key set, whereas in the other reach case we are interested in the quantity and lengths of paths from the key set to the outsiders. This is a property we might call *radiality*. The suggestion is that measures of centrality, whether individual or group level, can be divided into medial and radial camps, and that this represents a fundamental distinction.

Method

The criteria given above can be used to evaluate a given set *K* of candidate key players. However, we still need a method to populate the set in the first place. The naïve approach would be to compute standard centrality measures for each node, and then pick the top k nodes on a given measure. For example, for the goal of disrupting the network by fragmentation, it would make sense to pick the k individuals with the highest betweenness centrality, as defined by Freeman (1979). Similarly, for the reach goal, one could pick the k individuals with the highest degree or closeness centrality.

There are two problems with this strategy. First, the published centrality measures are not intended to maximize the quantities described in Equations 1 to 6. For example, removing the node with highest betweenness is not guaranteed to maximize Equation 2, simply because betweenness centrality was not designed specifically for that purpose.

Second, choosing a set of individuals that together maximize the set's medial or radial centrality is a very different task from choosing one individual. Consider the reach situation in which we seek the set of three individuals who reach (in one step) the most remaining nodes. Suppose we choose the top three nodes in terms of degree centrality, but it happens that these three are structurally equivalent – that is, they are adjacent to the same third parties. Then whether chooses just one or all three makes no difference: the number of third parties reached is the same. Hence, a better strategy would be to pick complementary nodes that have non-redundant sets of contacts, even if some of these nodes are not highest in centrality.

An computationally convenient alternative to such heuristic strategies is to employ a combinatorial optimization algorithm to directly maximize Equations 1 to 6. The program I have written (KeyPlayer, available for downloads at www.analytictech.com) uses a simple greedy algorithm which begins by assigning nodes randomly to the key player set and then systematically swaps every member for every non-member. This process continues until no more swaps are possible that lead to an improvement in the fitness function. For fragmentation, the program implements – at the user's option – both Equation 3 (chosen over Equation 2 because of a slight speed advantage) and Equation 5. For reach, it implements Equation 6 as well as simple counts.

Conclusion

Although the motivation for this work was the problem of defending against terrorist networks, the techniques presented here have much wider applicability. For example, the reach criteria were developed in order to identify nodes to surveil or to use as a vehicle for dissemination. The turning scenario in particular is a subset of a general class of situations in which one wants to implement a change or interventions. These occur in public health settings where the objective is to introduce healthful concepts and behaviors in a population, such as practicing safe sex or cleaning needles with bleach. They also occur in organizations where the objective is to introduce a new way of doing things, such as self-managed teams or quality circles.

The fragmentation methods can also be used in situations other than attempting to delete nodes in a network. For instance, the technique can be used in a defensive way to determine how vulnerable a system is to attack, and which elements need to be protected. Of course, the systems need not be human networks. For example, given data on the interdependencies of elements in a complex system such as an airplane, the key player technique can be used to identify which combination of element failures would cause the most damage.

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Stopping Adaptation

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Abstract

One of the key features of multi-agent systems is that the are adaptive. Behavior emerges. We ask here, how to use this technology to stop adaptation, to inhibit or at least direct change. Over the past decade, progress has been made in understanding the set of factors that enable adaptation. This paper reviews the findings on what makes organization's adaptive and provides suggestions for how to inhibit adaptation. A number of lessons learned about how to inhibit adaptiveness are presented particularly as they apply to covert networks.

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Stopping Adaptation

Kathleen M. Carley

Over the past decade, progress has been made in understanding the set of factors that enable adaptation in groups and organizations. It was previously discovered that it might not always be possible, particularly in the short run, to be both adaptive and extremely high in performance [Carley & Ren, 2001]. Organizations, particularly covert organizations, may give up some performance to achieve a more adaptive flexible organization. Here we ask, what has been learned about adaptation? And, if we turn these findings around, what do they tell us about inhibiting adaptation? Moreover, in terms of covert networks in particular, are their particular strategies that inhibit their ability to adapt?

In this paper, to increase generality, the term "organization" will be used to refer to the group – whether it is an organization, a team a covert network, a governmental or non-governmental unit. Not all findings will be applicable to all organizations; but, in general, most will be applicable to the organization of interest to the reader. A key feature of organizations is that their architecture can be represented as set of interlinked networks composed of people, resources, knowledge, tasks and the relations among them [Carley & Krackhardt, 1999; Carley, Ren & Krackhardt, 2000]. Another key feature is that organizations adapt by altering the set of people, resources, knowledge or tasks, or the relations among these entities.

Multi-Agent Network Models

It is widely recognized that organizations are complex adaptive systems. As such, they are frequently and appropriately studied using computational models; particularly, multi-agent models. Using such models it is possible to examine the root causes of adaptability and its linkage to individual learning. In multi-agent models social behavior grows out of the ongoing interactions among and activities of the intelligent adaptive agents within and outside of the organization. For the work in organizations, researchers use not only multi-agent models but connect these agents through the multi-network. The resultant multi-agent network models are particularly suited for examining the factors making these organizations adaptive or maladaptive.

Most computational organizational models represent the organization's architecture as a meta-network linking two or more of the following entities — agents (personnel and information technology), resources, knowledge and tasks. Thus, the actions of each agent are constrained and enabled not just by the activities of other agents but by what resources or knowledge they have, what tasks they are doing, the order in which tasks need to be done, the structure of communication and authority, and so on. Within these models, the agents are intelligent, adaptive and computational information processing systems. As noted by Carley (1999) "[a]ny entity composed of intelligent, adaptive, and computational agents is also an intelligent, adaptive, and computational agent." Thus organizations, like humans, are intelligent adaptive agents whose behavior emerges out of the actions of the member agents and the complex interactions in the meta-network [Carley, forthcoming]. A change in any one of the underlying networks can potentially result in a cascade of changes in the others. For example, an individual's discovery results in change in the knowledge network and in turn leads to change in the interaction network [Carley, 1991]. Understanding this meta-network and the way it evolves and can be altered is key to effectively enabling and inhibiting adaptation.

What Facilitates Adaptation

Learning is ubiquitous and a fundamental feature of humans. Since adaptation results in part from learning it is impossible to totally prevent adaptation. The best that can be achieved is to limit the adaptability of the organization or to control the direction of adaptation. The potential for adaptation is dependent on the structure of the organization. Moreover, there are different types of adaptation. One type of adaptation is re-active - rapid change to a rapidly changing environment. A type of re-active adaptation is social shakeout that occurs when a group moves from interactions based on shared visible demographic features to relative similarity at a deeper knowledge level. Another type is pro-active – establishing the structure of the organization to minimize the chance of error cascades. Organizations structured as a team are often adaptive in the short run due to a re-active strategy. Organizations structured as a hierarchy can exhibit long-term adaptivity if they employ a pro-active strategy.

Previous work showed that organizations were more adaptive when there was a greater need for individuals to negotiate with each other to get tasks done, individuals had higher cognitive load (more to do), and there was redundancy in access to resources and assignment to tasks. Moreover, organizations where there was a common operational picture were more adaptive. Common operational picture was specified as occurring when individuals knew who was doing what and who knew what; i.e., when individuals had an accurate transactive memory.

In terms of inhibiting adaptation these results suggest that to mitigate adaptation excess capacity (money, resources, personnel) should be eliminated, redundancy reduced (e.g., by increasing the number of tasks, the number of types of resources, and increasing the cost of redundancy), additional tasks should be taken on. Additionally, placing legal and economic barriers on changing the organizations architecture can inhibit adaptivity. If organizational shaking is encouraged – large scale turnover or change in high level personnel or goals, this will in effect, at least in the short run, reduce redundancy or at least make the existing redundancy ineffective. From a knowledge perspective, a decrease in redundancy can be achieved by, e.g., creating lots of simple tasks, discouraging job swapping, limiting training, and providing information on a need to know basis.

Reducing cognitive load can also mitigate adaptivity. Cognitive load includes takes in to account all the cognitive activity that an individual needs to do. Hence it is a function of the number of others that the individual talks to, depends on, is depended on by, negotiates to get or give resources, works with, the number of tasks that the individual does the complexity of those tasks, the amount of resources that the individual accesses and so on. A reduction in cognitive load can be achieved in a number of ways, e.g., by giving personnel less to do, giving them simpler tasks, ordering the tasks such that there are fewer dependencies among task so that the individual relies on fewer other and is less relied on, discouraging interaction so that individuals talk to fewer others, and so on. Adaptivity can be reduced by inhibiting the development of a common operational picture or by making the current picture rapidly move out of date. This can be done by taking steps to prevent individuals from building a transactive memory or destroying the accuracy of that memory. Ways of limiting transactive memory include altering phone books and web pages, move personnel without providing forwarding information, make tasks simpler and requiring less information so that there is less need for negotiation, destroying referential databases (databases that provide information on who knows what and is doing what, lower and inhibit joint training. Since adaptive organizations tune, i.e., change who is reporting to whom and who is doing what, things that inhibit tuning should make the organization less adaptive as they destroy transactive memory. Similarly maladaptive organizations tend to spend excessive time bringing on and letting personnel go. This too destroys transactive memory as it makes personnel have to spend excessive time learning who is still in the organization or learning what personnel know. Thus factors encouraging such personnel changes will also inhibit adaptivity.

The case of personnel change and adaptivity is quite complicated. The removal of individuals from an organization can lead to improved, degraded or no impact on performance. Size alone does not impact adaptability. On the one hand, reducing the number of personnel reduces redundancy and so can lower adaptability. On the other hand, as personnel change it impacts cognitive load. When personnel leave, this can decrease cognitive load by reducing the number of others interacted with; or, it can increase cognitive load by resulting in the individual having to do more tasks and use more resources. This is essentially a complex non-linear process such that simple predictions about the impact of personnel change are difficult.

A Network Reformulation

To try and make better sense of these changes, it is useful to have an overarching framework. It was previously noted that organizations can be usefully represented in terms of the meta-network – the set of personnel, resources, knowledge, tasks and the relations among those entities. This meta-network is comprised of a variety of sub-networks including, but not limited to, the social network (interactions among personnel), the knowledge network (who knows what), and the precedence network (what tasks come before what).

At the most basic level, adding and dropping nodes or adding and dropping relations can change the behavior of networks. One way of reframing the adaptivity question is: “What is the relative impact of adding or dropping personnel, knowledge, resources, tasks or the relations among these entities?” When any node or relation is removed or added to a network it can lead to an avalanche of changes – a cascade. Clearly, on average, the addition or deletion of nodes – whether they are personnel, knowledge, resources or tasks, should lead to more of a cascade than the addition or deletion of relations. The reason is simple, the addition or deletion of a node necessitates many relation changes. Whereas, the addition or deletion of a relation need not alter what nodes are present. Thus, from a relative impact perspective, changing nodes should have a greater impact than changing relations.

The question remains, across the types of nodes, will the addition or deletion of personnel, knowledge, resources, tasks lead to greater error cascades. For specific organizations, the answer depends on the specific architecture – the exact network. However, on average, some guidelines can be constructed. Note, previous work has demonstrated that maladaptive organizations change personnel and adaptive organizations tune – alter who is doing what, knows what, has what resources. In general, since removing it takes a long time to train personnel an since resources accrue status changes in knowledge or resources are more difficult than changes in tasks. These two arguments taken together suggest that there will be a ranking such that as we move from personnel to knowledge to resources to tasks the potential size of cascades decrease. Future research should examine the relative impact of adding and dropping the types of nodes. Since change in nodes, and personnel in particular, is likely to have the biggest impact on the adaptivity of the organization the rest of this paper focuses on changes in nodes.

Both adding and dropping personnel can affect the adaptivity of organizational structures. When personnel are added the number of ties or relations can increase; whereas, when personnel are isolated or leave the number of ties can decrease. Conceptually, there is a curvilinear relationship between the number of ties in the organization’s structure and performance. With too many or too few ties performance can degrade. Exactly where the peak is depends on a variety of factors including the task, the information technology, and the cognitive limitations of the personnel. Without knowing where this peak is for the organization in question, it is difficult to know whether adding or dropping personnel will necessarily degrade performance and make the organization less adaptive. There are also secondary factors. That is, as personnel are added or dropped, the impact of such changes on altering the adaptivity of the organization may also be a function of the number of changes made at once, the characteristics of the personnel being added or dropped, and so on. It is critical to define the difference between organizational adaptation and learning. Learning occurs when the individual or group gains new knowledge. This can be the creation of knowledge nodes or the addition of agent to knowledge links in the meta-network. Adaptation occurs when the performance of the organization is maintained or improved in the face of change.

To address this problem of adaptivity in a more systematic fashion, simulation is used. In particular, the model CONSTRUCT-O [Carley, 2001; Carley, 1999] is used to examine how changes in personnel affect the performance and rate of information in the organization. Several features of CONSTUCT-O are salient to the ensuing discussion. First, a variety of organizational architectures can be studied in this computational framework. Second, the networks are inherently dynamic. That is, even if personnel were not added or isolated the underlying networks would change as personnel learned thus changing the knowledge network and in turn the social network. Third, this model has been used to successfully predict change in interaction in organizations and change in beliefs. Using this model, a number of virtual experiments are run to see the impact of personnel change on different types of organizations. In this model, the basic adaptation cycles centers on learning. Individuals are engaged in a cycle of interacting, communicating, learning, and changing whom they interact with which is intermittently interrupted when the need to make a decision arises. The result is a set of co-evolving dynamic networks in both the social and knowledge dimensions.

Destabilizing Structures

In general, adding personnel can inhibit adaptivity as it diverts training resources, enables you to gain intelligence on the opponent, and can lead to erroneous decisions. From a practical standpoint, adding personnel, particular to an opponent, in the hopes of destabilizing it, is a perilous and slow strategy. Basically, it takes time to build ties and so infiltrating is slow. Secondly, there is no guarantee apriori that you can get the right person in to the right location. A huge amount of data is needed on the opponent to determine what the right location is, and the right spot changes over time. Moreover, since individual's beliefs are a function of the beliefs of those they interact with, putting someone in to the opponent organization runs the risk that the plant will change his or her beliefs to match those with whom they are interacting.

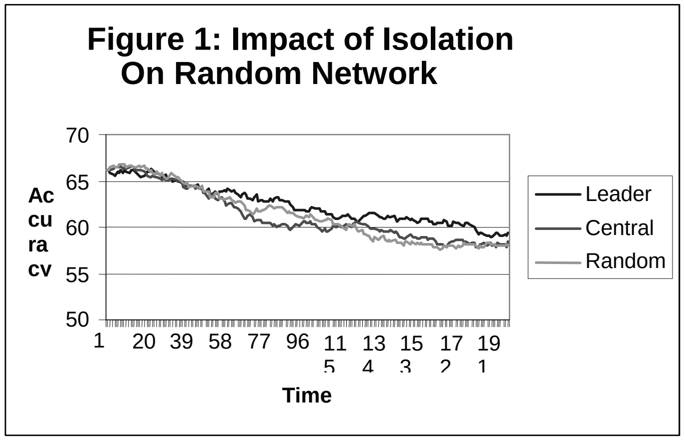
Two points are key. First, these arguments are consistent with the way in which CONSTRUCT-O works and/or results from that model. Second, due to the impracticality of adding personnel, the ensuing analysis, and the associated virtual experiment, focus on the removal or isolation of personnel. The central question thus becomes "Who should be isolated?". A related question is, "How does the structure of the organization influence whether or not a destabilization strategy works?".

Most of the work in the field of social network analysis has focused on the removal of individuals who are highly central. One measure of centrality is degree centrality – the number of others that the individual in question interacts with. Such individuals are seen as having greater power in the organization to affect the flow of information and decisions as they are more connected. From the meta-network perspective, another candidate for isolation is the individual with high cognitive load. Previous work suggests that such individuals are emergent leaders and critical to the way in which things get done by the organization [Carley & Ren, 2001].

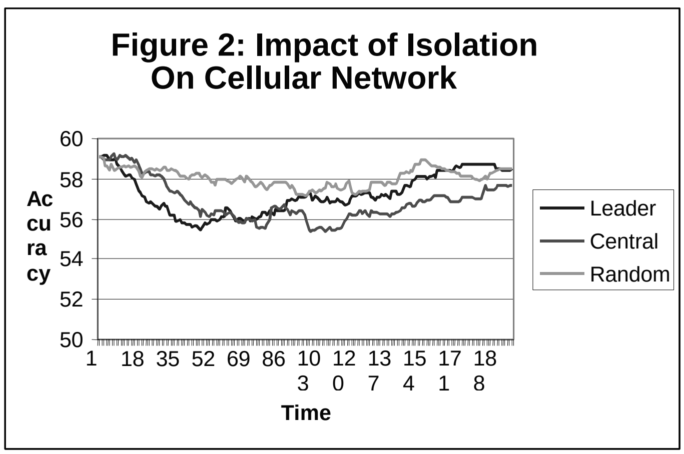
Using this model, previous work demonstrated that hierarchies can be temporarily destabilized by isolating the leader [Carley, Lee and Krackhardt, 2001]. However, hierarchies rapidly reform in to a new hierarchy. This is true whether the person isolated is the leader or the most central individual. In contrast, networked organizations are harder to destabilize. Moreover, the removal of the leader typically leads to many other leaders emerging. Removing the most central person may or may not lead to the emergence of multiple leaders.

To move beyond this analysis it is critical to look at alternative networked organizations. That is, while all hierarchies behave more or less the same, the behavior of networked organizations is much more dependent on the structure. Now the relative impact of different kinds of networks are examined. There are two key ways in which networked organizations differ. First, they may vary in the extent to which they are divided in to cells. That is, on one extreme, the set of ties may be distributed evenly across the personnel. On the other hand, the personnel may be organized in to cells such that the propensity of the individuals to interact is higher within cells than between cells. Within these organizations personnel may vary in whether they are encouraged to seek information from the "expert," from those who are "similar" to themselves, or some combination. These organizations also vary, in terms of the available technology, for example, they may or may not have databases established to retain expertise and that can be used to facilitate training. These choices suggest a number of virtual experiments.

The results indicate that, in general, when personnel are being continuously isolated, it will be easier to disrupt the performance of cellular organizations than random networks or hierarchies. While both structures can achieve high performance in the presence of attrition, the cellular's drops further. Second, we find that there is a main effect due to attrition strategy; but it is not robust. On average, random attrition may have a slight advantage is destabilizing the underlying organization. However, this effect can be reversed depending on the exact structure of the network, the information search strategy, the presence of databases, the style of communication, and so on. This suggests, however, that if intelligence is not available on these details, a random isolation strategy is likely to be effective; not the best, but satisfactory. The impact of search strategy is varied and small.



A key difference between standard network and cellular network structures is that a sustained attrition strategy manages to destabilize the standard network in such a way that performance is continuously compromised (see Figure 1). In contrast, within a cellular network, efforts to destabilize it meet with mixed success. In fact, such strategies can actually lead to improvement in the cellular networked organization's performance depending on the nature of the task being done (see Figure 2). Cellular networks are in this sense extremely adaptive. One reason for this is that the cellularization encourages rapid information flow. In figures 1 and 2 the information search strategy employed by the personnel within the networks is that of preferring to interact only when there is expertise they need. Under this condition, the adaptiveness of cellular networks can be better inhibited by using a more "socially intelligent" isolation strategy. That is, the isolation of individuals with special positions in the underlying meta-network is more effective than random isolation on a cellular network where an information search strategy based on expertise is used. Were the personnel within the network most likely to only communicate with each other if they had a lot in common then, although the cellular network would be the most adaptive, the most effective way to inhibit adaptation would be to use a random isolation strategy. In general humans use a mixed information search strategy. In that case, once again, a socially intelligent isolation strategy is best for inhibiting adaptation.



As the world becomes more unformatted it is expected that technology will of enable greater adaptivity. In general, the idea is that information technology, such as databases, can prevent information loss and facilitate the rapid training of recruits. Preliminary results suggest that this may not be the case. For example, we see that the value of databases for standard networks will be strongest in the long run when after there has been sufficient attrition; whereas, in cellular networks, in the long run databases may actually serve to exacerbate the destabilization caused by attrition. One reason for this is that in the cellular network the strong divisionalization that enabled adaptivity is broken by the database. Clearly much additional work needs to be done here, however, the results demonstrate that there may be unanticipated effects in terms of adaptivity as information technology comes on line.

Conclusion

This work provides guidance for how to inhibit or enhance the adaptability of an organization. It is critical to note that although the term organization is used for simplicity of exposition, the actual structures studied can be equally thought of governmental and non-governmental units, task forces, corporations, or covert networks. In general, this research provides a set of specific guidelines for how to make organizations more or less adaptive, a rank ordering across types of high –level strategies, and a detailed analysis or several personnel isolation strategies.

There are two key themes underlying these results. First, it is easier to determine how to impact the performance or the flow of information through an organization that it is to determine exactly how it will adapt. It is easier to destabilize a network than to determine what new goals it will form or new tasks it will take on. This is a function of our lack of knowledge about the processes of adaptation other than learning. Second, the relative impact of destabilization strategies strongly depends on the underlying organizational architecture; i.e., on the meta-network itself. As such, a key interpretation of these results is in terms of destabilizing different classes of networks.

Another factor to consider is the relatively "culture free" nature of this approach. The ability of individuals to learn and respond is a function of their cognitive capabilities and social position. Cultural differences enter in by affecting: a) the structure of the networks, b) the type of directives sent through the network (simple or detailed), and the preference for choosing interaction partners based on similarity or expertise. This makes culture a set of measurable parameters such that cross-cultural differences can be seen by setting differences in these parameters.

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Intrusiveness, Trust and Argumentation: Using Automated Negotiation to Inhibit the Transmission of Disruptive Information

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Abstract

The question of how to promote the growth and diffusion of information has been extensively addressed by a wide research community. A common assumption underpinning most studies is that the information to be transmitted is useful and of high quality. In this paper, we endorse a complementary perspective. We investigate how the growth and diffusion of high quality information can be managed and maximized by preventing, dampening and minimizing the diffusion of low quality, unwanted information. To this end, we focus on the conflict between pervasive computing environments and the joint activities undertaken in parallel local social contexts. When technologies for distributed activities (e.g. mobile technology) develop, both artifacts and services that enable people to participate in non-local contexts are likely to intrude on local situations. As a mechanism for minimizing the intrusion of the technology, we develop a computational model of argumentation-based negotiation among autonomous agents. A key component in the model is played by trust: what arguments are used and how they are evaluated depend on how trustworthy the agents judge one another. To gain an insight into the implications of the model, we conduct a number of virtual experiments. Results enable us to explore how intrusiveness is affected by trust, the negotiation network and the agents' abilities of conducting argumentation.

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Intrusiveness, Trust and Argumentation: Using Automated Negotiation to Inhibit the Transmission of Disruptive Information

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This paper is concerned with the problem of inhibiting the diffusion of low quality, disruptive information within a social context. How can the performance of a joint activity be enhanced by controlling the amount and quality of the information that the participants receive? How should interruptions be managed without losing any potentially important and high quality information? How should a message be evaluated in terms of its potential intrusive impact upon the execution of a joint activity? As a possible mechanism for addressing these problems, we propose a model of argumentation-based negotiation among autonomous agents [Sierra *et al*., 1998]. Messages are received and evaluated by agents on behalf of their users who, in turn, are involved in a parallel joint activity. Upon receiving a message, the agents negotiate with one another in order to reach an agreement as to whether or not their users' joint activity should be interrupted by the transmission of the message. During negotiation, the agents use arguments and counter-arguments in an attempt to impact upon each other's mental states [Panzarasa *et al.*, 2001]. In our model of argumentation-based negotiation, a fundamental role is played by the concept of trust. In fact, the extent to which argumentation is a successful mechanism for managing intrusiveness depends on what type of arguments are used and on how they are evaluated by the agents. In turn, both the choice of arguments and how the agents react to them depend on how trustworthy the agents judge one another. To explore the implications of the model, we conduct a series of virtual experiments. Results show the individual and combined effects of argumentation and trust upon the generation of a final agreement and, ultimately, on how effectively intrusiveness is dealt with.

Intrusiveness and the Diffusion of Information

The question of how to promote the growth and diffusion of information has been extensively addressed by a wide research community. Early work on the diffusion of innovations has typically emphasized the role of the network structure in the promotion and spread of new information [Valente, 1996]. Similarly, recent work on the internet, social networks and the power grid has addressed the resilience of these systems to perturbations of the pattern of interaction between their components [Albert *et al.*, 2000]. A common assumption underpinning all these studies is that the information to be created and propagated is useful and of high quality. However, relatively little research has focussed on the equally pressing question of how to prevent the diffusion of unwanted information. In fact, one of the ways to promote the growth and diffusion of high quality information is to ensure that low quality information can be identified and eradicated. Along these lines, in this paper we address the problem of how to manage and maximize the growth and diffusion of high quality information by focussing upon the complementary issue of how to prevent, dampen and minimize the diffusion of low quality, unwanted information.

Clearly, whether or not a piece of information is of high quality and is, therefore, to be transmitted, depends not only on how the information was generated and by whom, but also on the target of the transmission. This involves the recipient's mental state (including goals, beliefs, preferences, etc.), what task is being carried out and the environment in which the recipient is located. Typically, low quality information includes unverified, inaccurate, erroneous messages. However, there are cases in which even severely flawed messages might convey high quality meta-information. This might happen if, for example, the main task of the recipient is precisely to evaluate the trustworthiness of the sender. This suggests that an appropriate criterion for determining whether a piece of information is of high or low quality is to evaluate whether or not that information helps the recipient to sustain or improve the performance of its task. The diffusion of low quality information typically brings about interference with the realization of the main task. Here, we use the notion of intrusiveness to refer to such interference caused by the spread of useless, disruptive and damaging information.

Recent work in human-computer interaction has suggested a number of ways for dealing with intrusiveness [McFarlane, 1999]. The idea is to promote the diffusion of constructive task-related information by efficiently handling the interruptions caused by incoming messages. On the one hand, any interruption should be considered in order to ensure that any important incoming information will be received. On the other, however, being constantly interrupted by any incoming message might jeopardize the efficient performance of the main task should the received message convey unimportant, disruptive information. Thus, the recipient of a message of unknown informational value is confronted with a trade-off. Being interrupted by any incoming message ensures that no potentially important information is lost, but this brings about the risk of being interrupted by intrusions detrimental to the performance of the recipient's main task. Overcoming this trade-off requires mechanisms for dealing with incoming messages that, while maximizing the access to interruptions of informational value, at the same time minimize the effects that possible intrusions might have upon the recipient's task. For example, repeatedly checking an interface can provide information updates, while at the same time allowing the recipient to choose when to deal with the interruptions and possible intrusions. Similarly, interruptions can be managed through an alerting interface or through peripheral broadcast of the messages.

All these mechanisms are concerned with the problem of how to manage interactions by determining how and when to have access to them. However, the core problem of elucidating efficient mechanisms for filtering out intrusiveness remains relatively unexplored. Furthermore, most research has concentrated on the effects of interruptions on isolated recipients. Conversely, little work has focussed on the problem of how to manage the potentially disruptive effects caused by unexpected interruptions upon the execution of a joint task (e.g. within a group, an organization). This paper presents one possible approach to these problems by proposing argumentation-based negotiation among software agents as a mechanism for dealing with intrusiveness within a social context. Agents receive messages on behalf of their users who, in turn, are engaged in the execution of a joint task. Upon receiving a message, the agents assess the value of the information conveyed. They then negotiate with one another in order to get to a joint decision as to whether or not the execution of the users' joint task should be interrupted by the transmission of the message. This joint decision will depend on the value that each agent assigns to the message received, on the arguments used during negotiation and on how trustworthy the agents judge one another during their interactions.

Persuasive Negotiation among Autonomous Agents

A fundamental component of our model of negotiation is the agents' abilities to persuade each other by using arguments. Argumentation-based negotiation represents one of the ways in which autonomous interacting agents manage their interdependencies and coordinate their activities [Sierra *et al.*, 1998]. In this form of negotiation, agents generate and exchange arguments that indicate the reasons why their proposals should be accepted. In this sense, argumentation-based negotiation is persuasive because the arguments exchanged are aimed at impacting upon, and thereby altering, the mental states (e.g. preferences, acceptability thresholds, goals) of the agents involved [Panzarasa *et al.*, 2001]. Arguments may take the form of threats, rewards, appeals or they may merely convey information reflecting the agents' beliefs. Their key function is to speed up the generation of a final agreement by making the agents' proposals more attractive to the counterparts. However, how effective and appropriate an argument is depends on the agents involved in negotiation and on the social structure in which argumentation takes place. In our model, agents are endowed with a reasoning mechanism through which they can autonomously choose what argument to use for justifying or supporting their proposals. The value that a proponent assigns to an argument is here formalized as a function of a number of attributes including the number of times the argument turned out to be successful in a set of previous negotiations. In addition, once an argument has been received, it needs to be evaluated. Evaluation occurs by checking the validity of the argument against the recipient's mental state. An argument is rejected when, once evaluated against the recipient's goals and beliefs, it does not provide sufficient support to a proposal. In this case, the argument fails to impact on the recipient's mental state. Conversely, the acceptance of an argument alters the recipient's mental state by modifying its range of acceptability and/or its rating function over this range.

Reputation and the Social Structure of Trust

Another basic component of our model is trust. It is often argued that trust is a fundamental prerequisite for good organizational performance [Nicholas, 1993]. Without trust, information needs to be rechecked, decisions need to be reevaluated, agreements take longer to be reached and collaboration diminishes. Recent work on communication in a simulated organizational task suggests that the extent to which truth telling affects organizational performance depends on the environmental conditions and the size of the organization [Prietula and Carley, 1999]. Trust is typically facilitated by face-to-face interaction and affects people's judgements by triggering emotional and cognitive responses. Thus, as we move to distributed groups, virtual organizations and web-based teams, the sources of trust and its effects on the agents' behavior are likely to become more critical and controversial. In such distributed environments, is trust always necessary for good performance? To what extent does trust impact on the choice and evaluation of the arguments that agents exchange among one another to come to an agreement? Under what conditions is trust likely to emerge within a network of negotiating agents?

We address these questions by modeling trust as a cognitive and structural construct. In our model, a critical component of trust is reputation. An agent's reputation is a characteristic or attribute ascribed to it by its partners [Raub and Weesie, 1990]. An important source of an agent's reputation is its observed behavior. Information about an agent's interaction with a current partner can be used in subsequent interactions by this partner or by other partners when contemplating their own interactions with that agent. Thus, a fundamental empirical basis of an agent's reputation is the direct observation of its current and past social behavior. However, another important source of an agent's reputation is the information about its social behavior that can be obtained by communicating with other agents. In turn, the extent to which this information is judged accurate and trustworthy depends upon the established reputation of the agents from whom the information is obtained. Therefore, cognition and social structure work together to produce a combined effect upon the generation of trust. How trustworthy an agent is judged by another agent depends on what the latter knows about the former. And this knowledge results from the agents' positions in a network of social relations [Carley, 2001]. "Who interacts with whom" affects "who knows what", and "who knows what" represents the cognitive source of reputation. Thus, trust can be regarded as dependent upon the "embeddedness" of the agents' interactions in structures of social relations [Buskens, 1998]. In turn, since "who knows what" impacts upon "who interacts with whom", trust motivates the agents' social behavior and, ultimately, drives the establishment and evolution of social relations.

Trust and Arguments

Trust and argumentation are inherently intertwined and dynamically affect each other during the course of negotiation. Since an agent's reputation depends on its observed behavior, it is affected by information about the type of arguments used by the agent in its past negotiations. To capture how the cognitive and structural components of trust are shaped by a process of persuasive negotiation, we formalize trust as a function of: (i) the structural properties of the negotiation network; (ii) the frequency of negotiation over time; (iii) the outcomes of past negotiations; and (iv) the arguments used to impact on the partners' mental states. Clearly, how an agent is structurally connected to a potential partner determines how accurate the information it has about the partner's past behavior is. This, in turn, will determine the extent to which that information will affect the agent's assessment of its partner's reputation. Furthermore, trust is affected by the frequency of negotiation: interacting repeatedly with the same agent over a long period of time is likely to generate stronger effects on that agent's reputation than only one single interaction in the past. How trustworthy an agent is regarded also depends on the success or failure of previous negotiations with that agent. A broken commitment, for example, is likely to be detrimental to an agent's reputation, thus making future negotiation with that agent less attractive. Finally, trust is affected by how an agreement is reached, namely by the type of arguments that the agents use to persuade one another. For example, an agent's decision to speed up negotiation by threatening its partners will make these and other potential partners less inclined to interact with the same agent in future negotiations. Or, if an agent does not fulfil the promises made to persuade its previous partners, then making promises will become a less effective strategy for impacting upon future partners' mental states.

Even though trust is affected by negotiation, nonetheless it affects negotiation in a two-fold way. Firstly, judgments about an agent's trustworthiness impact upon the type of arguments used by the agent's partners in their attempts to support their proposals. For example, using a threat during negotiation with an agent of low reputation is more likely than simply providing meta-level information in the form of logical statements. Secondly, an agent's reputation determines how its partners evaluate and react to the arguments they receive from that agent. An agent's high reputation is likely to emphasize the effects that its arguments have on its partners' mental states. Conversely, low reputation mitigates the strength of arguments in terms of their potential for making proposals more attractive and acceptable. For example, the extent to which a statement indicating the reasons why a proposal should be accepted is convincing, depends on how trustworthy the sender is. Similarly, the effectiveness of a promise depends on the reputation of the agent who made it, and particularly on whether or not its past promises were honored. Thus, trust impacts on the recipient's reaction to the received proposal, and in particular on whether the proposal will be rejected, accepted or modified. Finally, trust will affect the generation of further arguments for supporting counterproposals.

Virtual Experiments

Using our model of argumentation-based negotiation, a series of experiments are conducted. The domain under consideration is a meeting room scenario in which each participant has a number of personal devices (e.g. cellular phones, laptops, PDAs). Each message received through these devices might have different informational value. For example, it might be important for both the recipient and the other individuals attending the meeting. In this case, the meeting should be interrupted and the message displayed within the meeting room. However, messages can also have low informational value for both the recipient and the meeting, or they can be important to the recipient, but intrude on the joint task undertaken within the meeting. Thus, whenever a message is received by any of the participants' devices, a decision is to be made as to whether or not the meeting should be interrupted and the message displayed within the meeting room. The idea is to explore the potential conflict between activities in a local physical and social context (the meeting room) and parallel activities in distributed contexts (the software environment). When technologies for distributed activities (e.g. mobile technology) develop, both artifacts and services that enable people to participate in non-local contexts are likely to intrude more and more on local situations. Potentially this phenomenon is a threat to the effectiveness and efficiency of the activities undertaken in such local situations. Thus, to minimize the intrusion of the technology, pervasive computing environments necessitate intelligent management.

Software agents can be used to handle such heterogeneous computing environments. Each individual (user) in the meeting room is represented by a personal agent located in a parallel software environment. Each agent controls the devices possessed by its user and evaluates the messages received by these devices against the user's preferences. To minimize the intrusive impact of the devices they control, agents then negotiate with one another and eventually get to a final joint decision as to whether or not to display the messages received. Agents use argumentation to support negotiation, and argumentation, in turn, affects and is affected by how trustworthy the agents judge one another. We explore the individual and combined effects of argumentation and trust on intrusiveness from a three-fold perspective. Firstly, we look at different degree of sophistication of the agents' cognition, and we examine to what extent different capabilities of conducting argumentation affect the rate of information diffusion and the level of intrusiveness caused by the messages displayed. Secondly, we investigate the impact that the network structure in which negotiation takes place has upon the agents' reputation and, ultimately, upon agreement generation and intrusiveness. Along these lines, we ask whether the transmission of high quality information can be enhanced by destabilizing the negotiation network and by isolating agents according to their structural positions and/or their cognitive skills. Finally, we analyze the combined effects that the network structure and the agents' abilities to negotiate have upon intrusiveness. This will shed light on a number of issues concerned with the relation between network and cognitive complexity.

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Effect of Compositional Demography in Small and Large Work Groups

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Abstract

This study uses simulation experiments to bridge demography (Pfeffer, 1983) and diversity (Schneider, 1987) research studying the effects of differences among members of diverse work groups in the field and in laboratories. This research also seeks to clarify some ambiguities about whether or not there is value in diversity by establishing context for the work groups and measuring simulated performance. Context is created by defining group composition, group size, timing of entry, and connections among members of groups without hierarchy. Attained knowledge—collective and individual—is the key performance measure. We intend to show whether or not simultaneous start times enhance performance in heterogeneous work groups and if new entrants have different impacts on small and large groups.

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Key Words: Demography, diversity, simulation, knowledge, composition, size, entry time, ties

Effect of Compositional Demography in Small and Large Work Groups

This study investigates how demographic differences among members of work groups affect performance outcomes as group composition varies. The model will evaluate knowledge levels attained over time when demographically different members start at the same time as other group members and when they join previously established work groups. These effects will be explored for small (6 members) and large (12 members) groups.

BACKGROUND

Differences among members of work groups have been studied following one of two related, but independent, research traditions—organizational demography or diversity.

Demography. Demography research is grounded in Pfeffer's (1983) sociological model about convergence of attitudes and values among individuals with similar demographic characteristics. Relevant characteristics include: age, tenure, sex, race, socioeconomic background, and religion. Pfeffer (1983) suggests that "distributional properties of organizational demography, not merely single descriptive statistics or proportion of the work force with a given length of service, can be crucial in understanding the effects of demography on organizational processes and outcomes" (p. 307).

Demography research is typically conducted using field studies of organizations. Demography research studies causes and consequences of composition or distribution of specific demographic groups, generally considering the impact of compositional differences on all members, not just minority members of organizations or groups (Tsui, Egan, & Xin, 1995). Pfeffer (1983) describes *compositional demography*, as "… composition in terms of basic attributes such as age, sex, educational level, length of service or residence, race, and so forth of the social entity under study" (p. 303).

Diversity. Diversity research is often grounded in social psychological theories like the similarity attraction paradigm upon which Schneider's (1987) attraction-similarity-attrition (ASA) model is based. This model suggests that people are attracted to similar others and discomfort among dis-similar others leads them to:

- seek membership in groups comprised of others perceived as similar to themselves,
- select people into their groups perceived to be similar to themselves, and
- discontinue membership in groups whose members are uncomfortably dis-similar.

In contrast to demography research, diversity research often uses laboratory studies, which have generated mixed results about the effects of diversity on performance. Diversity research studies effects of heterogeneity in social and cultural attributes on employment experiences, usually emphasizing the impact of differences on minority members of various groups (Tsui, Egan, & Xin, 1995). Students are frequently used in one-time decision making or creativity scenarios for diversity research. Generalizability of findings from this research has been questioned by some researchers, including Jackson and her colleagues (1991), who studied top management teams.

Research Opportunity. While researchers like Jackson and her colleagues (1991) have combined common elements of Pfeffer's (1983) organizational demography and Schneider's (1987) ASA models, or used the two models separately, as the theoretical basis for their work, reviewers have interpreted results from both streams of research as somewhat ambiguous. Williams and O'Reilly (1998) concluded there was more ambiguity in findings from field research, which is frequently associated with demography. At the same time, Levine and Moreland (1998) observed mixed results among laboratory studies of small groups, which are often associated with diversity research.

For example, researchers like Cox, Lobel, and McLeod (1991) have argued there is "value in diversity", meaning diversity can be beneficial for organizations and improve performance. Other researchers have shown strong evidence diversity can actually diminish group performance (e.g. Brewer, 1979; Guzzo & Dickson, 1996; Messick & Massie, 1989; Triandis, Kurowski, & Gefland, 1994).

One explanation for the observed inconsistencies might be that performance effects are measured at different stages in the life cycles of groups studied by demographers. Levine and Moreland (1998) attributed inconsistencies to factors such as contrived settings in laboratory studies, while Williams and O'Reilly (1998) attributed observed differences to this factor plus truncated duration of laboratory experiments. Both sets of reviewers suggest that limited interactions among members of laboratory groups prevent these temporary groups from having equivalent experiences to real-world groups whose outcomes may determine individual members' salaries or other tangible benefits.

Despite lack of consensus about the sources of the ambiguous results from existing demography and diversity research, computer simulation tools like iShare can be used to complement either field or laboratory research. In contrast to field studies, simulation models enable experimenters to control: (1)characteristics of individual group members, (2)similarities or differences among new or existing group members, (3)group size, or (4)timing of members' entry into work groups. By defining group processes, and measuring output at fixed intervals, simulation models also allow outcome evaluation at consistent stages of group development.

While simulation models offer meaningful benefits, they also have some limitations, in that these models can not fully replicate internal or individual factors like stereotyping or other affective processes like attachment or commitment, which have been shown to affect group process and performance by other researchers (Crocker & Major, 1989 Martin & Shanrahan, 1983: Moreland, 1985; Stephan & Stephan, 1985; Triandis, Kurowski, & Gefland, 1994). Thus, simulations studies are not a replacement for field or laboratory experiments using human subjects to study differences.

HYPOTHESES

Allport's (1979) observation that people use available categories of distinction to simplify their existence was the basis for Williams and O'Reilly's (1998) social psychological definition of diversity. They specified diversity as the most salient or visible differences among people in a given situation, acknowledging that some of the most visible, and ascriptive, characteristics are not particularly related to task performance. Since simulation models do not fully represent human interaction processes, one of the available vectors will be designated as a generic ascriptive characteristic. However, race may be a simpler characteristic to represent than gender, because we are not aware of ethnic empirical research, using field data, with conclusions comparable to Ibarra's (1992) findings that women gain instrumental access and expressive support from different network sources, while men develop networks that meet these needs via common sources.

Specifying group process as required to run the simulation models is consistent with McPherson and Smith-Lovin's (1987) induced homophily (like me) concept, which is influenced by availability for contact. Tsui and O'Reilly (1989) assert similar entry times, of members of heterogeneous groups, may be linked to increased homophily because individuals who enter groups at the same time have increased opportunity for interaction and shared experiences. Pfeffer (1983) also argues that similarity of entry time leads to increased communication, which can promote integration and cohesion among group members.

- H1: Heterogeneous groups whose members all start simultaneously will achieve higher performance, knowledge levels, than heterogeneous groups whose members start at different times.
- H2: Simultaneous start times will yield performance benefits relative to staggered start times, independent of group size, large or small.

Field studies often use one of four indicators of diversity: (1) proportion of group members considered different (e.g. Keck & Tushman, 1993; Konrad, Winter & Gutek, 1992); (2) group level coefficient of variation for continuous demographic variables (e.g. Smith et al., 1994); (3) proportion of a given category for categorical demographic variables (e.g. Pfeffer & O'Reilly, 1987), or (4) Euclidean distance measures of isolation from other group members (e.g. Wagner, Pfeffer & O'Reilly, 1984).

Laboratory studies often operationalize diversity in terms of number or proportion of members who are different (e.g. Espinoza & Garza, 1985; Kirchmeyer, 1993). As proportion of individuals with unique characteristics decreases, thes characteristics may become more important in defining a member's social identity (Abrams, Thomas & Hogg, 1990; Ethier & Deaux, 1994; Kanter, 1977). Because new entrants in these simulation models have equivalent education and training to existing members, their status as new entrants becomes salient as a point of distinction. As group size increases, the contribution of each additional member decreases in importance to achieving collective performance goals, allowing larger groups to succeed without effectively integrating new entrants.

- H3: New entrants to large groups will have lower performance, knowledge levels, than new entrants to small groups.
- H4: Large groups will achieve higher performance, over time, than small groups.

EXPERIMENTAL PLAN

<u>Assumptions</u>. All four experiments in this simulation study are based on a number of key assumptions. First, agents are arranged in a ring-like communication network without hierarchy (Carley, 1991). Equality among group members is also consistent with Allport's (1979) premise that equal status contact promotes interaction for pursuit of common objectives. This network allows exchange of knowledge necessary to perform a simple task like

bookkeeping, or any other task with clearly defined education and credential requirements. Further, all agents have identical knowledge levels on one dimension, which represents equivalent education and credentials. Also, the production function used to estimate knowledge levels attained presumes error-free transmission of knowledge between actors in the network. These assumptions preclude testing Williams and O'Reilly's (1998) conclusions that group heterogeneity leads to decreased communication, message distortion, and increased errors (e.g. Barnlund & Harland, 1963; Triandis, 1960). Finally, in large groups, new entrants are located in the networks so that there is no overlap between new group members and their respective partners who were original members of the network.

Characteristics and Similarities. Group members are differentiated on at least one dimension, which might connote race or another ascriptive characteristic. Since having a single dissimilar member makes less of an impact than having two or more dissimilar members (e.g. Espinoza & Garza, 1985; Kirchmeyer, 1993), each experiment includes two members who are demographically different from the remainder of the group. In the conditions where group members do not all start simultaneously, a third member who is similar to the remainder of the group joins the group at the same time as the two new entrants who are different.

Group size. Group size will vary so that there are either six or twelve total members in the small or large groups respectively. Six is the smallest group size that will allow more than one demographically different group member along with another majority member in the new entrant condition. Also, six members is the upper limit for naturally occurring groups, which are usually comprised of two or three people (Desportes & Lemaine, 1988). Twelve was set as the upper limit on large group size because it is twice as large as the small group, plus it is a practical group size to exist without hierarchy, one of the initial assumptions.

Entry Time. To test the premise of similar entry times promoting homophily, there are two formation strategies. Either all group members join simultaneously, or three new members join an established group. The second knowledge dimension is used to connote differences in start times. In the simultaneous condition, all group members are equivalent on this knowledge dimension, indicating that they know have basic knowledge about how to perform the task plus how that particular job is done within the environment in which the group operates. New members have 25% less knowledge on this second dimension than existing members, which connotes that they may know the fundamentals about how to perform the task, but not the context-specific aspects of performing it.

Ties. In the simultaneous start conditions, all group members will be connected to every other member of the group, regardless of similarities or differences. In the new member introduction conditions, new members will be connected to every other new member plus the two agents in immediate proximity to the new agents.

Measures. Total knowledge, determined for each agent, will be the measure of group performance. It will be modeled as a function of time, number of ties, distance between an agent (group members) and its partners, plus interaction between number of ties and distance. The model will be run for the number of cycles or interactions needed to show a distinct pattern for large and small groups with simultaneous and staggered start times.

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The bifurcation of friendship in organizations

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Abstract

A preliminary simulation was run to determine the long term consequences of chain reactions that can occur in a group when the sentimental relations among its members (liking or disliking each other) change to restore equilibrium or *balance* [Heider, 1946]. Contrary to the expectation that fission would predominate, leading to a large number of small cliques, the simulation indicated that groups almost always bifurcate, dividing into two stable subgroups of about equal size. All members of each subgroup like each other and dislike all members of the other subgroup. The results suggest that two, equally-sized and mutually antagonistic factions will eventually emerge in any organization. Eventual dissention within a faction is likely to result in new alliances with members of the other faction, contributing to an organization's metamorphosis.

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Key Words: balance theory, social networks, simulation

The bifurcation of friendship in organizations

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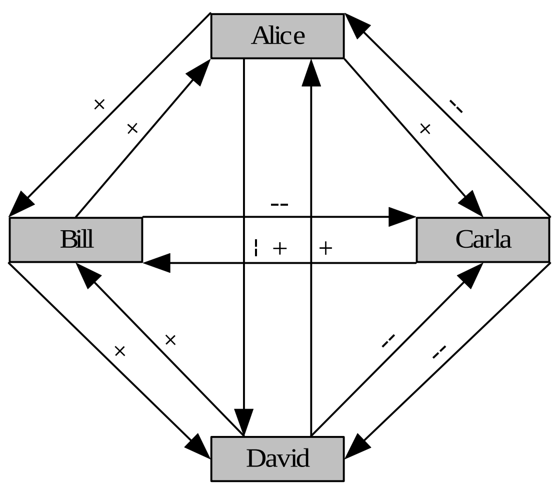
Suppose Alice, Bill, Carla and David form an organization. Soon after formation, friendship and its opposite develop among the four. Alice likes Bill and Carla but dislikes David. Bill likes Alice and David but dislikes Carla. Carla likes Bill but dislikes David and Alice. David likes Bill and Alice but dislikes Carla. As Heider [1946] argues, such complexities of sentimental relations are the stuff of social tension or imbalance, creating a motive to change friendships until tension is reduced, balance restored.

According to one part of Heider's Balance Theory, people have a natural inclination to seek balance in their social relationships. These relationships can be of at least two kinds: *unit* relations (similarity, possession, causality, etc.) and *sentiment* relations (liking-disliking, evaluation). Sentiment relations are the stuff of friendships and the alliances that form around them. A positive sentiment relation (+) exists when one person likes another. A negative relation (-) exists when one person dislikes another. No relation exists when the two do not know each other. The map of relations among Alice, Bill, Carla and David is shown in Figure 1.

Figure 1. Sentiment relations among Alice, Bill, Carla and David



Heider theorized that balance exists among people when the relations among them multiply algebraically to +1. Thus, if Alice likes Bill (+1) and Bill likes Alice (+1), their relation is balanced (+1 x +1 = +1) and presumably stable. So too is the mutual dislike shown between David and Carla, since –1 x –1 = +1. if Alice and Bill and Carla all like each other (+1 x +1 x +1 = +1), or if David and Bill both dislike Carla but like each other (-1 x –1 x +1 = +1), the triadic relation is balanced. They are imbalanced if, for example, Alice likes Carla but Carla dislikes Alice (+1 x –1 = -1) or if Bill likes Alice and Alice likes Carla but Bill dislikes Carla (+1 x +1 x –1 = -1).

Heider restricted most of his discussion to the relations among two or three people. Cartwright and Harary [1956] generalized Hider's ideas to several people in a social network, but overlooked an important issue. Restoring balance by changing a relation in one imbalanced dyad or triad might create imbalance in an adjacent, balanced dyad or triad. Thus, if Bill changes his feelings toward Carla from negative to positive to restore balance with Alice, he will create imbalance with his friend Bill, who dislikes

Carla. Restoring balance to the new imbalanced relation might, in turn, create a third imbalance in a chain reaction. When and where might the chain reaction end? In the end, will everyone like each other? Dislike each other? Will several stable cliques form, or will friendships forever fluctuate in unstable alliances? The present simulation was a preliminary to address these questions.

The Simulation

We wrote a programme in Matlab to exploit its matrix manipulation facilities. Each 1,000-cycle run of the programme, began with a new setting of three variables: (1) the number of people = N in a hypothetical organization (we used 10, 20 and 40), (2) the number of positive sentiment relations = NP among these people, (3) the number of their negative sentiment relations = NN. An NxN friendship matrix was then created, each cell representing the sentiment relationship between the person in row X and the person in column Y. The main diagonal, representing relations of a person with him/her self, was ignored, leaving (NxN)-N cells to fill at random with NP (+1) and NN (–1) sentiments. The remaining (NxN)-N-NP-NN cells were filled with 0, representing "relation not established."

Once the NxN matrix was thus configured, a modified Knight's Tour of the matrix was made in each of the 1,000 cycles of a run. In a Knight's Tour, triads of people (for example, persons A, F & Q, persons B, D & M, persons R, P & C) were selected at random, without replacement until the maximum number of triads was reached. Thus, if one run began with 20 people (N=20), six triads would be randomly formed for the first Knight's Tour, and the remaining 2 people would be ignored; six new triads would be randomly formed for the second Knight's Tour and two other people in the 20 would be ignored. In 1,000 such tours, each person would be represented and ignored about the same number of times.

Once a triad was selected, our simulation looked for imbalance in the relations among its three members. The following transition rules were used in this version of the simulation:

- If there were no imbalance (relations = +++, +--, +-+, or -++), change nothing and go to the next triad;
- If there were imbalance (relations = ++-, +-+, -++ or ---), reverse one of the three relations at random to create balance and go to the next triad;
- If all three relations were 0, change nothing and go to the next triad;
- If two of the three relations were 0, change nothing and go to the next triad;
- If one of the three relations were 0, examine the other two relations, determine which third sentiment (+1 or –1) would make the triad balanced, change the 0 to this sentiment to balance the triad and go to the next triad.

Results

Detailed results of our preliminary simulation are beyond the scope of this abstract, but general results can be reported. As expected, when there were no negative sentiments (NN = 0) and enough positive sentiments to sustain a chain reaction (NP > about 10% of matrix cells), the result was a "love in" – at the end of each run, everyone liked everyone else. However, when negative sentiments linked more than a few people at the beginning of a run, the result was quite different and surprisingly consistent. The original group always tended to divide into two subgroups of approximately equal size. All members of the first subgroup liked each other and disliked every member of the second subgroup. All members of the second subgroup liked each other and disliked every member of the first subgroup. Regardless of the number of people in the group, and across a wide range of negative initial relations (NN), the simulation consistently produced a bifurcation of friendship, a split of the group into two warring camps. This occurred even when all relations in a simulation run were first set to be negative. Increasing the proportion of no-relations (= 0) slowed the bifurcation but did not stop it.

Discussion

Though our results are preliminary, they strongly suggest that even a small salting of negative relations in a group will cause a chain reaction ending in two stable subgroups, members of each liking one other and disliking all members of the other group. Who finishes in which group likely depends on small variations of the initial sentiment bonds; we are now running simulations to explore this sensitivity. We are also exploring other rules of changing sentiment relations, some based on the strength of a relation, others based on the number of people who like or dislike each member of the imbalanced triad, still more based on balance with unit relations.

The bifurcation of one large group into two mutually disliked factions can certainly happen within each faction as well. If a small proportion of one faction began to dislike its own members, a second bifurcation could occur. Subsequent bifurcations are unlikely to produce a regression to hostile individualism, in which everyone dislikes everyone else, simply because it would be imbalanced. Instead, those feeling imbalance in their own subgroup are likely to find balance among those in another subgroup, thus rearranging alliances. It remains to be seen if changes in specific bonds can lead to predictable changes in larger alliances, as it remains to be seen how many sentiment relations must first be known before good predictions can be made about the larger consequences of a few changes. These are topics of future simulations.

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A Structural Approach to the Representation of Life History Data

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Abstract

We propose a structural approach to the representation of life history data, based on an interval graph formalism. Various ``life history graphs" are defined using this approach, and properties of such graphs are related to life course concepts. The analysis of life history graphs using standard network methods is illustrated, and suggestions are made regarding the use of network analysis for life course research. A duality is demonstrated between individual life history graphs and social networks, and connections between life history graph analysis and conventional life course methods are discussed.

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Key Words: life history data, interval graphs, life course, data representation, network analysis

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A Structural Approach to the Representation of Life History Data

Carter T. Butts and Joy E. Pixley

Many questions in modern sociology deal with the properties of individual lives -- the events, transitions, and roles which make up the history of each actor as he or she passes from birth to death. Such questions are particularly central to the life course perspective [Elder, 1992; Moen et al., 1995; Gotlib and Wheaton, 1997; Giele and Elder, 1998], which emphasizes the internal and external factors which shape life histories. One difficulty faced by life course researchers is the apparent complexity of their subject matter: the life course encompasses numerous qualitatively distinct elements, which are related to each other in a nontrivial fashion [Singer et al., 1998].

Here, we take a *structural* approach to the representation of individual life histories. In particular, lives are conceptualized as being composed of a number of theoretically important subintervals (``spells''), and the life history is then represented by these subintervals together with one or more relations among them. As implemented here, the relations under consideration will involve temporal overlaps, leading us naturally to an interval graph formalism for life history data. Given this formalism, we then demonstrate the application of network analytic techniques [Wasserman and Faust, 1994] to questions of life history structure, illustrating the methods on sample life histories taken from the Cornell Community Study [Moen et al., 2001]. Finally, we discuss the relationship between the structural approach to life history analysis and conventional life course methods, connections between individual life history structures and social networks, and the possible application of the methods presented here to organizational life histories.

Network Representation of Life Histories

Let T represent an ordered set, and let $s=(t_1,t_2)$ be an ordered pair such that t_1,t_2 belong to T and $t_2>=t_1$. Then s is said to be a ``spell'' on T. For a pair of spells, $s_1=(t_1,t_2)$, $s_2=(t_3,t_4)$, define the relation $s_1\sim s_2$ to be true iff $(t_3<=t_2)\&(t_4>=t_1)$; where $s_1\sim s_2$, we say that s_1 is (weakly) *coterminous* with s_2. Given a spell set **S**, the relation ~ forms a graph on the elements of **S**. Such a graph is commonly known as an *interval graph*, this stemming from the fact that if each spell is thought of as forming an interval on T, the graph formed by the coterminousness relation can be drawn by connecting all spells which overlap one another.

In the context of life history analysis, T typically represents physical time, while the various spells, in turn, represent periods of time in which a given individual participated in some substantively important activity or relationship. Interval graphs formed from such spells we refer to as *life history graphs.* Examples of typical spell categories for a late 20^{th} century American might include intervals of marriage or cohabitation, full-time or part-time employment, education, co-residence with young children or aged relatives, etc. Depending on the problem of interest, spells may be chosen at varying levels of detail; in general, the interval graph representation is most useful where a large number of life domains are to be considered simultaneously. Figure1, below, provides two examples of life history graphs based on data from the Cornell Community Study [Moen et al., 2001]; the domains of full-time employment(FTW), marriage (MAR), education (EDU), and child co-residence (CHI) have been included. As can be seen, the two subjects' life histories result in quite distinct life history graphs, each of which constitutes a parsimonious encoding of the structure of coterminousness among the subjects' life spells.

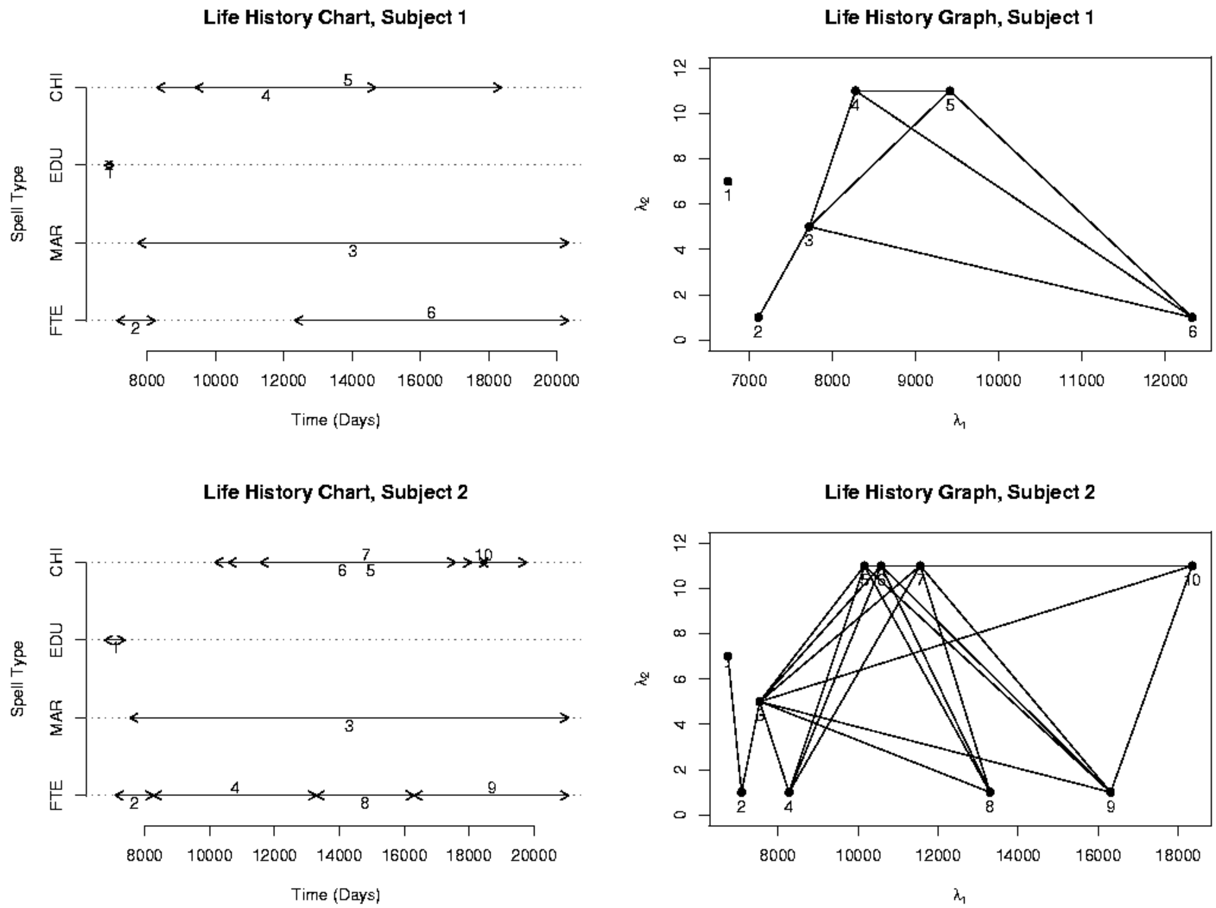

Figure 1: Two Sample Life History Graphs

Life History Graph Analysis

The life history graph, as we have defined it, is an *intra-personal* network: each such graph represents the life history of a single individual, and thus the structural properties of each life history graph provide information regarding features or elements of an individual's life course. Given this, tools developed for the study of single networks should be expected to have utility in studying life events (or structures thereof) in context, much as these tools are often used in social network analysis for understanding the structural contexts in which actors operate. In addition to such intra-personal analyses, life course researchers are often interested in making comparisons across individuals and/or populations. To understand how the life course is shaped by structural and cultural factors, we must compare the life histories of individuals in different cultures, demographic groups, cohorts, etc.; such comparisons can be performed via standard methods for interstructural analysis, i.e., the simultaneous analysis of multiple networks. Thus, by applying the techniques of conventional network analysis to life history graphs, we are able to study both properties of individual life histories and features of the population of life histories within a given social system via a single formalism. We hope that the use of this formalism will facilitate the further development of rigorous methods for the study of life history data at both the individual and population levels.

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Drugmart

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Abstract

Illicit drug epidemics are infamous for their unexpected arrival and their speed of onset. Based on ethnographic work with youthful heroin experimenters in the Baltimore metropolitan area, an explanation was constructed based on circulating stories of drug reputation. An agent-based model was built in SWARM to evaluate the explanation with good and bad stories about the drug passed among agents, which changed their initial attitudes. On repeated runs with different initial attitudes the model shows wide variation in outcomes and a dampening effect of increased social connections, contrary to epidemiologic expectations. The conclusion spells out implications for drug intervention and social research that relies on single case studies.

Keywords:
Multi-agent, drugs, epidemiology

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Drugmart

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No one has yet explained why illicit drugs, like heroin, appear so unexpectedly and generate steeply rising incidence curves. Here is the case study we mean to use to contruct an agent-based model to test an explanation derived from ethnographic research. An upsurge in heroin use among white suburban youth occurred in the late 1990s. The full analysis of this and other cases led to what is called trend theory. We will not go into the details of the theory here. At the moment we just note that the full theory requires an analysis of production and distribution systems and their interactions with a population under certain historical conditions. The work we report here centers on populations who are more or less disposed to try illicit drugs, with no explanation of why those differences in disposition or production accessibility might exist.

Ethnographic research with the 1990s youth revealed a most interesting result. According to the youth, the primary engine that drove the heroin epidemic curve—both its acceleration and its flattening out--was the *local reputation* of the drug. Reputation was conveyed from person to person in the form of stories, advice, observations, etc. The "buzz" around the drug, good and bad, was mostly learned from *experience*, either of the person doing the talking, or of another youth that the person doing the talking knew or had heard about.

The importance of reputation in spread of illicit drug use, based on one's own experience or the experiences of others, is not a novel argument. In fact, it is compatible with other kinds of studies. A model developed by RAND makes the same basic claim, and epidemiological work during the 1960s/70s heroin epidemic showed that first use typically occurred when a peer who had recently experimented initiated another in the same social network . One robust finding of the national U.S. survey of adolescents, called "Monitoring the Future," is that frequency of use of illicit drugs varies monotonically with peer attitudes towards them.

The question is, if we build a world of adaptive agents who circulate good and bad stories about an illicit drug, what sorts of incidence curves will that world produce? Will circulation of good and bad stories produce an emergent incidence curve at the system level? And if so, can the way the model works teach us anything new about how epidemics work? Or what we might do about them?

We want to report on the current state of the model we have built that takes these questions seriously. We call the model Drugmart**.** To foreshadow what is to come, we want to show three results in this presentation.

The first result is obvious—raising or lowering the initial attitude of the agents towards illicit drugs affects the curve in predictable ways. If Drugmart begins with anti-drug agents, then fewer of those agents will use in the end. Less obvious, though, is that the simple circulation of stories is, in fact, *sufficient* to produce curves of the sort we see in real epidemics.

The second result is not so obvious—when we run the program numerous times under the same parameters, with only the random seed varying, it produces a wide variety of incidence curves. Sensitivity to initial conditions is of course to be expected, but given the general image of heroin—once it lands, massive use ensues—the range of outcomes is striking. In other words, the *phase space* of Drugmart epidemics is larger than we imagined.

And the third result is less obvious still—more densely connected social networks result in *less* use, in contrast to the epidemiologic expectation that denser networks would produce more, and more rapid, "infection." The reason, as we will see, lies in the circulation of both positive and negative stories, together with the higher credibility of stories from "friends"—i.e. those with whom an agent has a social connection.

Risk, Attitude and Influence: The Heart of the Agent

Drugmart, implemented in SWARM, creates 500 randomly placed agents in a world defined by an 80 by 80 grid. One cell is randomly selected and heroin is placed there. Each agent is assigned a risk value between 0 and 1, based on a random-normal distribution. The use of this distribution is justified by the many decades of research in “diffusion of innovation” that shows that willingness to try something new is distributed in just that way in numerous populations for numerous kinds of innovations.

An attitude value, also varying between 0 and 1, is set as a parameter. That value is assigned to all 500 agents. This parameter allows us to experiment with different orientations to illicit drug use when heroin first appears. Agent worlds, in other words, can range from strongly anti- to strongly pro-illicit drug use.

The first basic mechanism of the model is this: If an agent lands on the cell where heroin is located, or on a cell where another agent has heroin (more on this in a moment), then the agent checks the current value of its attitude. If its attitude is greater than one minus its risk, it takes heroin. If its attitude is less than one minus its risk, it does not.

But an agent’s attitude changes as the program ticks along. Agents change their attitudes for two reasons. The first reason is, the way attitude changes depends on whether an agent has a good or bad experience with a drug. Agents also change their attitudes depending on the “buzz,” what they hear from other agents as they move through the world.

Those are the basics; now for the longer story. First, what determines whether an agent has a good or bad experience? The answer is simple, on first glance. We define a table of probabilities for good or bad experiences, and an associated amount by which the value of the attitude increases or decreases.

But the answer is more complicated, on second glance: The probability of a good or bad experience depends, in turn, on what kinds of prior history an agent has had with the drug. All agents are “clean” at the beginning of the program, “clean” being the usual informal term for one who does not use illicit drugs. But with time, the experience of different agents will have varied. So we will find users, or non-users, of several different types:

1. A **clean** agent has never tried heroin.

2. An **experimenter** has tried heroin at least once.

3. A **user** uses “regularly.” A random number is generated for each agent, between 0 and its risk value. This is its “user threshold.” If attitude becomes higher than one minus the user threshold, then the agent becomes a user. If the number drops below that value, it stops being a user. A user also carries heroin, and uses at intervals ranging from n1 to n2, those numbers being set as parameters.

4. An **addict** is a user who has used to a certain threshold value, a value also set as a parameter. The threshold value decays by a certain proportion each time heroin is not used, a proportion that is also set as a parameter. An addict, like a user, carries heroin.

5. An **ex-addict** is an addict who has stopped using, though there is a possibility of relapsing into heroin use. This is an aspect of Drugmart we have not worked with yet, so it is neglected here.

So, for example, if a clean agent tries heroin, it has a probability of a good experience, and it has a probability of a bad experience. If the experience is good, attitude will increase by a certain amount. If the experience is bad, attitude will decrease. The same is true for experimenters, users, addicts and ex-addicts, although for those other types of agents, probabilities and amounts of change will be different. But the same mechanism operates--If an agent uses, there are probabilities of good and bad experiences, and depending on whether the experiences are good or bad, the value of their attitudes will change.

The probabilities and amounts we have just discussed, in the example table above, tell us what an agent does when it *itself* uses heroin. The table is a guide for the *direct* experience of the agent. But direct encounters with the drug are not the only way the agent changes its attitude. It also *hears about* the drug—the good, the bad, and the ugly—from other agents it encounters as it wanders around its world.

To model how an agent picks up on "the buzz" around the drug, we have each agent check with all other agents immediately adjacent to it, or other agents that share the cell where it lands, after each tick of the program. Those other agents might or might not influence its attitude. The chance that those other agents will or will not influence it? It depends on two things.

First of all, both agents—the one who is checking for influence and the one who is doing the influencing—are classified as a certain type of user. The categories were described earlier—experimenter (with or without a bad experience), user (with or without a bad experience), and so on. The probability of influence, and the amount of attitude change, will depend on what kind of agent is trying to influence what other kind of agent. For example, two experimenters neither of whom have had a bad experience, will be likely to influence in a positive direction. If the influencing agent has had a bad experience, then there is a strong likelihood that it will influence the other experimenter in a negative direction. On the other hand, there is a strong likelihood that an addict will influence experimenters or users in a negative direction.

So, to guide how the "buzz" influences agents, the model relies on a matrix, with kind of user in the rows influencing kind of user in the columns. And, as noted earlier, going over each individual matrix entry is beyond the scope of this article, so we neglect that exercise here. The general idea remains the same—an agent looks up the probability of good or bad news about the drug, depending on its own category and the category of the agent that is in a position to influence it. If the influence occurs, it looks up the amount of attitude change that corresponds to that user/user pairing.

The second thing that guides how buzz flows through Drugmart—Some agents are connected by a social link, and others are not. We'll call those that are connected "friends" and those that are not "strangers." The number of connections is set as a parameter, and this parameter will be important in the next section when we report results. For this article, we ran Drugmart under three conditions. In the first, there are no connections among agents; Drugmart is a world of strangers. In the second, we specify 200 connections. The program draws two agents at random, checks to see if there is already a connection and, if not, puts one in place. It does this until it has successfully connected 200 agents. In the third condition, the parameter is increased to 400 connections.

If two agents land in a position where influence on attitude is possible, and those two are socially connected, then a different matrix comes into play. If two agents are adjacent, and the two are "friends," then the agent who is looking up the chances of being influenced has to use different matrices. Friends have more influence than strangers in both positive and negative directions.

For present purposes, we assume that the numbers we put in the matrices are at the right "order of magnitude," but it bothers us that the production of these numbers raises so many critical questions from both qualitative and quantitative points of view, critical questions that we neglect here. Can we derive any reasonable numerical summary of how a moment of influence, one agent to another, will always go? And if we can do that, can we represent the force of that general influence in a numerically sensible way, in a field where numbers on that same scale represent other kinds of influence that may be qualitatively different? Research aimed at obtaining these numbers, should they turn out to be reasonable snapshots of complex interactions at all, would take a long time to do. We would never get to the model.

This is, and will continue to be, such a recurrent problem in agent-based model building for social research that we should name it something—like the *complexity conundrum*. Any complex model involving human agents will require translations of contingent and socially constructed "qualities" of life into static numerical form. Usually the translation will be problematic, in that neither data nor guidelines will exist for accomplishing it. More problematic still, the translation will be buried in program details, as exemplified by our matrices of likelihood and amount of influence, likely to be passed over as the general operation of the model is viewed and evaluated.

Results: Helpful Friends and Variable Curves

We decided, for this first exploration, to look at the "attractor space" of Drugmart under varying conditions. Such exploration is, of course, a major attraction of complex models for those who begin their research with detail in a single case study. Such researchers can model the explanation of that single case and run it several times to see what kinds of variations on the theme might also occur, thus achieving a kind of "generalization" that otherwise would not be possible. Sampling *in silico* we might call it.

We ran Drugmart under three conditions, corresponding to the way we set the attitude parameter—a strong anti-drug attitude, a strong pro-drug attitude, and an attitude midway between the two. For each of these conditions, we ran the program with no social connections, with 200 social connections, and with 400 social connections. Under each set of conditions, the program was run 100 times. Each run ended when no significant changes were occurring or after 500 ticks, whichever came first.

The first results, with its strong anti-drug attitude, didn't produce many agents who had ever used or who became addicts. Maximum ever used was less than 30 out of 500. The story changes when the attitude parameter increases to .5, midway between the possible values of 0 and 1. Numbers rise dramatically in these second results. Now the maximum number of experimenters is around 150 out of 500 and the maximum number of addicts is just under 100. In fact, looking across all three sets of runs with attitude set at .5, it is worth noting that research usually shows that between 10% and 20% of a population become addicted during a heroin epidemic. But, though the numbers are different, the general pattern seen in the first results holds up here as well—striking variation in ever used and addict numbers, general increase in addiction with ever used but not linear, and dampening effect of increasing social connections.

Now let's turn the attitude up to strongly pro-drug with a value of .8 on a 0 to 1 scale. All hell broke loose, with maximums of ever used above 400 out of 500 agents and addiction upwards of 250, or fully half the agents. Notice at this extreme attitude level that variation is less when compared to the first two results, and that the dampening effect of social connections does not have much influence on ever used numbers. At the same time, even at these high values, social connection still reduces the numbers of addicted.

An agent-based model built on circulation of stories that convey heroin's reputation is *sufficient* to generate epidemiologic curves of the sort we find in actual illicit drug epidemics. The *variation* in outcomes is striking under the same initial conditions, or at least striking given the usual stereotype of heroin epidemics. Although the number of addicts increases with number who have ever used, it is not a simple linear relationship. And finally, an increase in the number of social connections has a dampening effect on both ever used and addiction, contrary to what infectious disease models from epidemiology would lead us to expect.

Results of the model to date already suggest interesting possibilities for policy. For example, the operation of the model suggests that material for drug prevention is already available in the world of the population experimenting with that drug. In fact, Agar tried this application in drug education courses when he simply opened a narrative space for youth to discuss what they'd heard about heroin. The session just focused and amplified the dynamics represented in the model and came out, on balance, negative as to heroin's mid- and long-term effects on a user.

In the near future, we hope to add features to Drugmart that will reflect drug supply variations, effects of media/education, and the importance of activity regions where agents congregate. We also hope to experiment with ways to create more cognitively active agents who learn in more sophisticated ways that go beyond their current evaluations of "good" and "bad" experience.

Linking Ego-Networks Using Cross-Ties

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Abstract

An ego-network, or ego-centric network, is a specific kind of social network which contains a focal individual and his or her direct contacts or alters, whether they are friends or coworkers or fellow drug-users. Additionally, ego-networks may include ties between these direct contacts; these ties are often referred to as "cross-ties". Ego-networks are sampled networks and generally exist within a greater social structure; the alters of the ego are similarly connected with other individuals in the world at large, unless we are dealing with an isolated population. Traditional social networks methods and measures are applied to socio-metric data, containing linkages between all the members in the population of interest. One generally cannot infer valuable aggregate network level measures, such as centralization scores, cliques, and connectivity, from discrete ego-networks without knowing whether and how these ego-networks may connect or overlap. The task of linking ego-networks which contain egos and alters which are all uniquely identified, using full name and address or a unique id in the dataset, is obviously trivial. When either the egos or alters or both sets are not uniquely identified, the task of inferring a global linked structure becomes far more difficult. In this paper, a method is presented for linking these ego networks when both sets are not not uniquely identified.

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Linking Ego-Networks Using Cross-Ties

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Introduction

An ego-network, or ego-centric network, is a specific kind of social network which contains a focal individual and his or her direct contacts or alters, whether they are friends or coworkers or fellow drug-users. Additionally, ego-networks may include ties between these direct contacts; these ties are often referred to as "cross-ties". For instance, a survey respondent lists his parents, brother, and two friends as members of his confidant ego-network (i.e. people with whom he discusses important matters). A more complex ego-network would contain information about how close the parents are to each other as well as to this sibling and whether the friends are acquainted with any of the family.

Ego-networks are sampled networks and generally exist within a greater social structure; the alters of the ego are similarly connected with other individuals in the world at large, unless we are dealing with an isolated population. Traditional social networks methods and measures are applied to socio-metric data, containing linkages between all the members in the population of interest. One generally cannot infer valuable aggregate network level measures, such as centralization scores, cliques, and connectivity, from discrete ego-networks without knowing whether and how these ego-networks may connect or overlap. The task of linking ego-networks which contain egos and alters which are all uniquely identified, using full name and address or a unique id in the dataset, is obviously trivial. When either the egos or alters or both sets are not uniquely identified, the task of inferring a global linked structure becomes far more difficult.

One obvious approach towards linking ego-networks employs attribute data on the egos and alters: the more attributes, the better. For instance, if an unidentified ego who is the only 30-year old sociology grad student in the dataset lists, as an alter, the only 26-year old math student in his friendship network, we can infer that the 26-year old math student, located elsewhere in the dataset, who lists the 30-year old sociology grad student is the same individual. More attribute information leads to greater accuracy in the matching.

However, larger and denser networks make the task more difficult by expanding the choice set, for each alter of each ego-network. Uncertainty in the structure arises when a unique match for a single alter cannot be found, and one of several candidates must be selected; a greater candidates set increases the overall uncertainty that the final structure is correct.

There does exist research, though little, that has employed this procedure of assembling ego-centric data, including a software tool for the end-user. Friedman et al (1997)(1999) constructed socio-metric data from ego-centric data on HIV/drug using networks in order to determine core components of drug injectors. Also, funded by the NIDA, MDLogix, Inc. markets a software product named "Sociometric LinkAlyzer", designed to link ambiguous alter nominations using a host of potential attributes such as gender, age, hangout location, nicknames, physical features, etc. (*Sociometrica LinkAlyzer* abstract, 2002).

However, both the research and the tool employ node attribute data and not the within-ego-network linkages of the alters, whether due to difficulties in incorporating this information or because it was never collected. A prominent ego-network dataset that does contain alter-to-alter cross-ties data is the Social Network module of the 1985 General Social Survey (GSS 1985). While the GSS ego-networks do not necessarily comprise a complete subpopulation, it is nevertheless valuable to estimate a connected structure especially given that there exist regularities in ego-network level measures. For instance, the pervasiveness of homophily leads us to expect friendship ties between individuals of similar demographic traits such as gender, age, and education level. Another example is parental bonds, which generally occur between individuals whose ages differ by at least 20 years and less than 40 or so.

In Friedman et al (1999), matches that were not one-to-one had to be resolved through other data sources, such as ethnographic observation. Such alternative data sources might not be available, as in the GSS, requiring us to "guess" and have an understanding of the certainty, or uncertainty, of that guess.

This paper reports the findings of an algorithm written with the explicit intention of including the alter-to-alter cross-ties, as well as attribute data of the nodes and strengths of the ties between all nodes (i.e. ego-to-alter and alter-to-alter), in the process of ego-network matching. We highlight the conditions under which a significant gain in accuracy is obtained by the inclusion of cross-ties for randomly generated ego-networks, of varying size and density, and empirical ego-networks.

Description of Algorithm

The process of matching an ego-alter pair of one ego-network to the alter-ego pair of a different one basically requires a matching of identifying attributes, both node-based and structural. Examples of node-based attributes in empirical ego-network data include demographic traits such as gender, age, race and situational variables (e.g. physical location like permanent addresses or "hang-out" spots) found in drug injector data. Structural attributes include ties between alters that the respondent ego may have provided, as in the 1985 GSS.

If we considered solely nodal attributes, the following individuals with ego-networks that are demographically similar but structurally different would constitute an ego-network match. However, if we considered their local structures, we may find that these two egos do not constitute a perfect match since the common alters between the ego and candidate alter do not align. The matching procedure using just attributes can be described as follows, explained using pseudo-code:

```
For each ego e1, select an alter a1 {
   Select another ego e2 whose attributes match alter a1 {
       If ego e2 has an alter a2 whose attributes match those of ego e1
       Then it is possible that alter a2 and ego e1 are the same individuals
   }
}
```

The matching procedure which incorporates cross-ties goes as follows:

```
For each ego e1, select an alter a1 {
   Select another ego e2 whose attributes match alter a1 {
      If ego e2 has an alter a2 whose attributes match those of ego e1
      Then do {
           Collect the set of alters who are connected to both e1 and a1
           Collect the set of alters who are connected to both e2 and a2
           If these two sets match attribute-wise, then we have a potential
match {
               alter a1 ?= ego e2
               ego e1 ?= alter e2
           }
      }
   }
}
```

Each possible match is marked and saved until all the alters of every ego are tested with other egos in the dataset. It is possible that an alter may have several candidates; that is, several other egos have properly matched. This can easily occur if the set of identifiers (i.e. the combination of all compared attributes) cannot uniquely identify all the nodes. For instance, if our network consisted of several hundred individuals and the attribute set consisted of only gender and race, each alter of one ego-network is likely to match several egos of other ego0-networks even if we include cross-ties in the matching process.

Measuring Accuracy

We can measure the gains in accuracy resulting from including the cross-tie information via simulation. By generating a random Bernoulli, symmetric network and extracting its ego-networks, we can apply the algorithms and compare the results to the correct answer. Accuracy is measured as the percentage of ego-alter nominations that are matched correctly. For a completely saturated network of size n (i.e. a complete clique), the number of ego-alter nominations equal $n*(n-1)$.

Preliminary Conclusions

Based on results, not included in this abstract, the desired outcome of introducing a method for yielding higher accuracies in ego-network matching has been unequivocally met. Unless there is enough and varied non-structural information, such as attributes, to uniquely identify almost every node, the matching processes which do not include alter-to-alter cross-ties will yield numerous inaccuracies. While the inclusion of cross-ties will not always result in perfect matches, as in extreme circumstances of low information and large size or low densities, cross-ties will provide a potential half-fold to four-fold gain in accuracy. Future direction now includes symmetric selection of ego choices when the choice set for a given ego-alter pair is > 1, assessing the error when holes exist between ego-networks (i.e. incomplete data), and dealing with asymmetric ties. The issues and complications for these are beyond the scope of the current paper and will be discussed in future writings.

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Uncertainty theory and complex systems scenarios analysis

MinhHa-Duong

Abstract

Coupled socio-economic-physical systems are the complex systems. They involve vastly different types of uncertainties, including those related to human behavior and those of a scientific nature, such as Earth system feedbacks. The integrated assessment community, as an evolution of the system analysis community, has been looking for decades to go beyond subjective probabilities to model uncertainty. This fundamental difference between risk (when probabilities are available) and uncertainty (when they may not be) is crucial to understand how, if not why, the IPCC declined to put probability weights on scenarios.

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Uncertainty theory and complex systems scenarios analysis

MinhHa-Duong

1. Introduction

Coupled socio-economic-physical systems are the most complex of all. They involve vastly different types of uncertainties, including those related to human behavior and those of a scientific nature, such as Earth system feedbacks. These uncertainties cannot be dealt with in a uniform manner. The integrated assessment community, as an evolution of the system analysis community, has been looking for decades to go beyond subjective probabilities to model uncertainty.

The recent history of climate change prospective illustrates the point. A critical limitation of the Intergovernmental Panel on Climate Change (IPCC) special report on emissions scenarios (SRES) is that the scenarios are symmetrically presented, and no judgment is offered as to the preference for any of them. Admittedly, the political sensitivity of alternative plausible futures played a significant role in this reluctance to quantify. Yet this lack of specificity was explained by a deeper theoretical issue about uncertainty and probabilities. We need first to remember the difference between two kinds of situations, hereafter named Risk and Uncertainty.

In this text, Risk describes a situation in which all the possible outcomes are known in advance, and each has a probability weight. Uncertainty describes a more general class of situation in which, while all possible outcomes are known, probabilities may or may not available (higher order of ignorance such as incompleteness and surprises will not be considered here).

This fundamental difference between risk (when probabilities are available) and uncertainty (when they may not be) is crucial to understand how, if not why, the IPCC declined to put probability weights on scenarios. This difference has been stressed by social scientists at least since Knight (1921) and Keynes (1921). The dominant paradigm in the second half of the last century to model uncertainty was to use subjective probabilities, yet the IPCC position is only the last of a long history of challenges to this dominant paradigm, exemplified by Allais in 1953.

This conceptual distinction has been common in decision analysis for a long time. But until recently the distinction did not matter in practice for technical reasons: IPCC wrote that there was no widely accepted mathematical methods to deal with Uncertainty that is not Risk in integrated assessment. Realizing at the same time that future emissions are definitely an uncertainty situation, it was a legitimate way out of a political minefield when Grübler and Nakicenovic (2001) stated “the concept of probabilities as used in the natural sciences should not be imposed on the social sciences. Scenarios [...] are radically different.” These leading IPCC authors’ point of view was important in the refusal to assign probabilities to the new scenarios.

A few climate change integrated assessment using alternative uncertainty formalisms appeared in the late nineties. Leimbach (1996, 1998) worked on fuzzy optimization for climate strategies. Welsch (1995) examined greenhouse gas abatement under ambiguity (Ambiguity is used by economists to name uncertainty that is not risk). While fuzzy techniques appear to be used in models of impact and land-use changes, so far they remain absent from energy policy decision analysis. There is no standard alternative to subjective probabilities in integrated assessment.

There are several reasons why. The first is that uncertainty theories are rather new. The theory of evidence using belief functions was published by Shafer in 1976, and possibility theory (based on fuzzy sets) was proposed as a complete alternative to probability theory by Zadeh in 1978. Another problem was that because they are non-linear, these theories are better suited to numerical computations than to algebraic analysis. Third, there may be too many mathematical methods to deal with non-probabilistic uncertainty.

Reactions to this last issue may be dogmatic (only one theory should be used), eclectic (each theory is good in its domain of validity) or unifying (each theory correspond to a projection of a more general notional theory). This paper defends the unifying conception.

2 The simplest theory of uncertainty theory: Belief functions

Beliefs are defined as [0, 1]-valued function on the set of possible futures, hereafter the forty SRES scenarios (*S40*, similarly IPCC sets of six and four scenarios will be denoted *S6* and *S4)*. One way to do so is to consider a probability distribution *m* (called a basic belief assignment) defined on all subsets of *S40*. For any subset of *S40*, for example *S6*, the strength of the belief that the future world is in *S6* is given by the formula $\mathrm{bel}(S6) = \sum m(A)$, for all $A \subseteq S6$.

The crucial point of all theories of uncertainty is that support for *S6* is not equal to the absence of evidence against *S6*, so that bel(S6) is less than 1 - bel(*S40* - *S6*). The latter is called the plausibility of *S6* , it can also be defined as $\mathrm{pl}(S6) = \sum \mathrm{bel}(A)$, for all A such that $A \cap S6 \neq \emptyset$. Beliefs may be low, but plausibility high: this is the key to quantifying uncertainty in scenarios.

In sum, any of three following elements define beliefs:

- A basic belief assignment, that is a probability distribution *m* defined on all subsets of *S40*.
- The belief function, that is $\mathrm{bel}(E) = \sum m(A)$, for all $A \subseteq E$
- The plausibility function; that is $\mathrm{pl}(S6) = \sum \mathrm{m}(A)$, for all A such that $A \cap S6 \neq \emptyset$

For any subset *E*, the basic belief *m*(*E*) represents the amount of non-specific weight of evidence given to *E*. Non-specificity means that the information can not be pointed further to any element in *E*. This allows to make judgments about classes of scenario, such as "high and rich population scenarios are not likely".

bel(*E*) represents the strength of the belief that the real state of the world is described by a scenario in *E* . Beliefs are super-additive: $\mathrm{bel}(A \cup B) \geq \mathrm{bel}(A) + \mathrm{bel}(B)$ even when $A \cap B = \emptyset$. Note that $\mathrm{bel}(\emptyset)$ represents the belief that the real state of the world is not in *S40*. It is normalized to zero if one assumes from the start that *S40* represents the complete list of possible futures.

Even if the belief in *S4* is likely to be very close to zero, its plausibility will not be necessarily small. This is the key characteristic of all uncertainty theories, as we will see now.

3 The unity of uncertainty theories

Evidence theory (beliefs functions) is only one of a large number of superficially different approaches to uncertainty. This section outlines the main links of an unified view of uncertainty theories, referred to as Imprecise Probabilities theory by Walley (1991).

The first link between all uncertainty theories is the difference between "support for an idea *E"* and "absence of evidence against *E"*. Support for *E* , denoted $\underline{P}(E)$, relates to the notion of belief, necessity or lower probability. The absence of evidence against *E*, that is $1 - \underline{P}(S\text{-}E)$, corresponds to the concepts of plausibility, possibility or upper probability. Situations of risk, and only those, are characterized by the identity of the two notions: $P(E) = 1 - P(S\text{-}E)$. In all other uncertainty situations, the two numbers do not add up to unity.

The second link is the correspondence between qualitative (*A* is more believed than *B*) and quantitative (P(A) = 0.2 is greater than P(B) =0.1) approaches. Trivially each quantitative approach represents a comparative ordering of beliefs. The converse is true in many interesting cases: given reasonable axioms on a partial order relation defined on subsets, it is often possible to find a real function representing the relation. This correspondence is useful because elicitation of beliefs is easier using the qualitative approach.

The third link is the canonical Boolean algebra homomorphism between set theory and propositional calculus. The union of two subsets corresponds to the disjunctive operator OR, the intersection corresponds to the conjunction AND, and inclusion corresponds to implication. This correspondence is useful because computer implementations are often easier using formal logic. It uses a small finite set of symbols to build propositions, instead of using a very large finite set of states of the world.

This correspondence also it leads to two important remarks. First, there are many different operators to connect propositions. There are as many different of ways to combine beliefs. Second, the Gödel incompleteness theorem suggests that it is very easy to build axiom systems containing undecidable propositions. On the contrary, representing beliefs using a finite set of all states of the world excludes surprises.

The fourth link is the correspondence between finite, countable and continuous versions of the theories. With respect to these differences, probability was been unified by measure theory a long time ago. Similarly, belief functions are the finite case of Choquet capacities of order infinity, but going beyond the finite case will not be necessary in this research project.

Fifth, there are several equivalent approaches to belief functions: we have already seen basic belief assignment, combination of elementary pieces of unspecific information and Choquet capacities totally monotone set functions. there are more (many-valued mappings for example).

Six, there are inclusion links between uncertainty formalisms. A probability distribution is a belief function where the basic belief assignment *m* is non-zero only on singletons. A possibility distribution is a belief function where *m* is non-zero only on a nested family of subset.
Moreover any belief function canonically defines a family of probability distributions *F* by:
$p \in F$ if and only if for any event *E*, $\text{bel}(E) \le p(E) \le \text{pl}(E)$.
The belief function can be recovered as the lower envelope of the family *F*. Any probability in this family is compatible with beliefs, but no single *p* is enough to represent them completely. Of particular interest in *F* is the so-called pignistic probability distribution, representing rational betting under uncertainty by spreading equally unspecific information across all possible states.
Finally, some families of probability distributions (hence belief functions) can be regarded as special case of coherent lower previsions. Lower previsions represent willingness to pay and availability to accept gambles, they are directly relevant for decision making. In this introduction of imprecise probabilities in integrated assessment, this level of generality is not needed.

All these correspondences explain at the same time a superficial diversity of uncertainty theories and a deeper unity. Most of the residual conflict between theories can be attributed to the differences in the nature of the uncertainty being represented. These lead to different semantics, therefore to different operators to combine the mathematical objects representing uncertainty.

4. Analysing uncertainty in complex systems: Quantifying prospective scenario sets

I propose to use belief functions to quantify uncertainty for long-term prospective scenarios.

Quantifying uncertainty: Uncertainty on *S40* can be quantified by considering evidence from IPCC reports and from the larger database of all scenarios submitted during the SRES open process. Obviously, the belief function on *S40* will not be represented by tabulating $m(A)$ for all $A \subseteq S40$. Following standard practice, beliefs will be defined by and represented as the combination of elementary pieces of unspecific information about scenarios, such as the assumption that high per capita income and high population growth are not likely.

Probabilizing the scenario sets: Beliefs can be transferred from *S40* onto the smaller *S4* and *S6* scenario sets and given explicitly for *S4*. Different ways to parameterize value judgments by norms, distances and other weight factors imply different rational probability distributions for a given belief function. Upper and lower probabilities can be found for *S4* and *S6*, as well as the entropy-maximizing probability distribution on each of these scenario sets.

Reducing the number of scenarios: For each of the 64 scenario sets obtained by deleting various scenarios from S6, the loss of information, the loss of plausibility and of credibility compared to S6 and S40 can be explored. This will make explicit how well S4 and S6 represent the uncertainty on S40. One can quantify (in bits) the information gap between S4 and S6. This task will identify which scenarios to remove from S6 and S4 in a way that minimize the information loss. It defines scenario sets S6-3, S6-1 and S4-1, the first removing 3 scenarios from S6, the second removing 1 scenario from S6, and the last removing one scenario from S4.

Extending the scenario sets: One can quantify which scenario from S40 would be the most interesting to add to S6 or to S4. Interest will be defined as the overall plausibility of the scenario set, the credibility of the range it covers and the information content. The same questions as in the previous tasks will be answered: What are the probabilities of the augmented scenario sets? What is the gain in information, plausibility and credibility? This will lead to augmented scenario sets S6+1 and S4+1.

Comparing SRES with optimal the scenario subsets: There are 91390 ways to pick up four scenarios from S40. Only a few are really interesting: those maximizing plausibility, credibility and information content. The constructive IPCC method to define S4 and S6 in no way guarantees optimal results. I will study the role of rationality in the open process, and then assess its efficiency by comparing S4 with optimal quadruples of scenarios from S40, and also comparing S6 with an augmented S4+2 obtained by optimally adding two scenarios to S4.

5. Conclusion

This conclusion outlines three advanced questions relevant for future research on uncertainty.

The dynamics of uncertainty. The counterpart of stochastic dynamic programming remains to be explored in Uncertainty situations. A central practical question is how to reduce the curse of dimensionality over time by allowing time to flow on a graph (a network) instead of a tree. The fuzzy horizon effect is commonly used in rendering landscape on a computer. An information kinetic counterpart of this could be that probabilistic uncertainty decays into unspecific uncertainty over time. This allows decreasing conflict and effectively reuniting separated threads of time. For example, it may be initially known that a variable can be A with probability p, and B with probability 1-p ; but in the long run it is only known that the variable is either A or B. This replaces a two-cases situation by a single case.

Knowledge-based integrated assessment modeling. This research also paves the way for bridging traditional system analysis with a radically new approach to integrated assessment: defining the model purely as structure on the belief function. Theoretically, this approach encompasses traditional modeling analysis: believe only in the couples (parameters, results) that are given by the model. But this is more general, it allows for uncertain relationships. Early applications of this new approach can be found in robust modeling, fuzzy systems or constraint-based programming. One example of this approach is the NetWeaver method by Parker (2001).

Sampling and experimental design. Sampling is important for integrated assessment, as some coupled models of earth dynamics take months for a single run. Uncertainty theories are promising a fresh approach of these issues addressed at length in the Bayesian framework. Belief functions allow for proper vacuous priors: instead of the uninformative interpretation of equi-probability over *S40* , the belief is defined by $m(S40)=1$, $m(E)=0$ otherwise. They also offer new insights on information measures. Given a model, a scenario set should explore all qualitative regions of the outcome space, but there are two problems with this. First, the number of attractors for the dynamic system may be larger than the number of scenarios. Second, the outcome space is computed by the model, so even assuming a small number of well-defined qualitative results, it is not possible to know how many beforehand. The guideline to define robust scenarios will be to use the model to transfer uncertainty from parameter space s to the outcome space. The principles of maximizing entropy, plausibility and credibility allow to define what is a interesting scenario set, which fairly represent the diversity of results in a maximally informative way.

Decision-making It is un-controversial that each action a in a scenario set should be rational with respect to the decision making problem under uncertainty. The problem is that non-specificity does not necessary allow to single out just one optimal course of action. But the key advantage of scenario-based analysis is that having only a partial ordering of actions is sufficient for the purpose of scenario building. A partial order allows to reject dominated actions, and to find the maximally preferred ones. The specific research objective is to operationalize Willey's (1991, 3.8-3.9) partial order based on avoiding sure loss and coherence.

Overall, recent mathematical developments on uncertainty analysis translate into a general quantitative method for building more plausible and credible scenarios sets. Models are often used in politically charged situation, with the goal of providing a cold analysis. In a scenario building methodology, the informal steps represent a major point where non-scientific, vested interest parties can capture the process. Beliefs functions provide a wider mathematical framework for experts to formalize their knowledge and reach consensus.

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Computational framework for modeling the dynamic evolution of large-scale multi-agent organizations

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ABSTRACT

The process by which complex social entities such as the state emerged from lower level structures and other supporting economies has long been of prime interest to anthropologists and other disciplines as well. This is because the emergence of such a social structure can have a profound impact on the societies' physical and social environment. However, the task of developing realistic computational models that aid in the understanding and explanation of state emergence has been a difficult one. The goal of this project is to produce a large-scale knowledge-based computational model of the origins of the Zapotec State centered at Monte Alban, in the Valley of Oaxaca, Mexico.

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Computational framework for modeling the dynamic evolution of large-scale multi-agent organizations

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The results of the data mining (Weiss 1998) process can be used in many different ways. Therefore, the form of the knowledge collected will have a major impact on the efficiency and effectiveness of its use in a given application. In this paper we examine the problem of extracting knowledge for use by agents in a large-scale multi-agent system (Russell 1995). Here, the knowledge is ontological knowledge that represents constraints that the physical and social environments placed upon the agents and their interactions. The ontological knowledge represents the semantic building blocks around which the world models are formed. For an agent in a particular model, only the things in his ontology can exist and it cannot perceive things that are not represented in the ontology. An *ontology* (Fox et al 1998) is a basic level of knowledge representation scheme, a formal definition of entities and their properties, interactions, behaviors and constraints. Each agents' decisions need to be checked against these constraints prior to their execution. In a complex multi-agent system, hundreds of thousands of agents may need to check these constraints regularly which means that a successful data mining activity will need to produce a relatively small set of syntactically simple rules for the process to be efficient. Fox et al (1998) have used data mining techniques to produce corporate ontogenies.

There are several factors that can influence the nature of the ontological constraints that are produced. First, the nature of the data collection and measurement process and the uncertainty induced into the data set by the presence of noise. Second, the nature of the representation used to express the extracted patterns; e.q. whether it allows for uncertainty or not. Third, the data mining technique employed and the assumptions that it makes about the collected data. Fourth, how these constraints will be stored, accessed, and used by the agents involved.

For a given data set one can compare the different data mining techniques in terms of the syntactic and semantics of the induced constraints. In this application we are interested in simulating the emergence of the archaic state in the Valley of Oaxaca, Mexico. A state is among the most sophisticated and powerful structures that has emerged from the social evolution process. In the modern world these are termed "nation states' with a government composed of a hierarchical decision-making structure where the decision-makers are either elected or appointed. States are supported by various economies and are able to interact with each other via warfare, trade, etc . Most states in the ancient world-often called archaic states-were ruled by hereditary royal families. These archaic states exhibited much internal diversity with populations numbering from tens of thousands to millions. They had a bureaucracy, organized religion, a military presence, large urban centers, public buildings, public works, and services provided by various professional specialists. The state itself could enter into warfare and trade-based relationships with other states and less complex neighbors.

The process by which complex social entities such as the state emerged from lower level structures and other supporting economies has long been of prime interest to anthropologists and other disciplines as well. This is because the emergence of such a social structure can have a profound impact on the societies' physical and social environment. However, the task of developing realistic computational models that aid in the understanding and explanation of state emergence has been a difficult one. This is the result of two basic factors:

1. The process of state formation inherently takes place on a variety of temporal and spatial scales. The emergence of hierarchical decision-making can be viewed as an adaptation that allows decision-makers to specialize their decisions to particular spatial and temporal scales.
2. The formation of the state is a complex process that is fundamentally directed by the social variables but requiring dynamic interaction between the emergent system and its environment. Identifying the nature of these interactions is one of the reasons why the process of state formation is of such interest.

The goal of this project is to produce a large-scale knowledge-based computational model of the origins of the Zapotec State (Flannery 1996), centered at Monte Alban, in the Valley of Oaxaca, Mexico. State formation took place between 1400 B.C. and 300 B.C. While archaic states have emerged in various parts of the world, the relative isolation of the valley allowed the processes of social evolution to be more visible there. Extensive surveys (Blanton 1989, Blanton, Kowalewski 1982, Kowalewski 1989) of the 2100 square kilometer valley, were undertaken by the Oaxaca Settlement Pattern Project in the 1970's and 1980's. The location and features of over 2,700 sites dating from the archaic period (8000 B.C.) to Late Monte Alban V (just prior to the arrival of the Spaniards) were documented.

Several hundred variables were recorded for each site. In addition, they surveyed the 6.5 square kilometer urban center of Monte Alban, a site that contained over 2,000 residential terraces. This site was the focus for early state formation in the valley.

Both surveys provided the knowledge needed to create our multi-agent simulation model. We then produced a spatial temporal database that contained the results of both surveys and used data mining techniques from Artificial Intelligence (Russell 1995) to produce knowledge about site location, warfare, trade, and economic decisions to be used for the construction of the multi-agent model. However, in order to do this we needed to add more data about the spatial and temporal context to both the regional and urban center surveys. Specifically, we had to add variables that allowed us to locate each site spatially and temporally to a level of precision consistent with the scale of our simulation. For example, temporal periods are characterized by the presence of pottery of different styles. That data was available only in text form. All of this pottery data, over 130 variables for each residential terrace, was scanned into the computer, corrected for errors, and added to the Monte Alban data set. This data allowed us to identify the periods that each terrace was occupied. Pottery data was also integrated into the regional data set.

In addition, the survey had produced hundreds of pages of hand drawn maps for both the Monte Alban and regional surveys that contained the spatial context for the location of each site. Since our goal was to ask specific questions about the spatial and temporal context we needed to tie each site into its mapped location. We then proceeded to digitize each of the maps and to associate each site object with its corresponding data record. This allowed us to produce a geographical information system (GIS) that serves as our “virtual valley of Oaxaca”. This acts as a vehicle for our data mining activities and as a knowledge base for the multi-agent simulation and allows the results of the simulation to be displayed and compared with the actual data in a spatial context. It is envisioned that the resultant GIS system will be a useful tool for researchers and students from various fields to study the emergence of complexity in the future.

In order to perform the data mining activities, we extended traditional data mining techniques and developed new ones in order to deal with the complexities inherent in the Oaxaca database. At the regional level we used Utgoff’s incremental decision tree algorithm (IDTI) (Utgoff 1989) to generate the Decision Trees for each region and phase of the valley. The approach was used to generate decision trees that discriminated between sites that were targets for warfare and those that were not for a given period (Reynolds 1999). However, given the many disperate steps under which the data was collected and organized it was felt that perhaps some improvements might be made by using a technique that took into account the presence of uncertainty in the data -especially in regions and periods when the social and settlement patterns were complex and prone to data collection error.

Since the majority of the data was discrete rather than continuous in nature we selected rough sets as a vehicle for representing uncertainty here. We employed an evolutionary technique, Genetic Algorithms, to control the search in this case because Genetic Algorithms had been successfully used with Rough Sets previously. The decision systems or rule sets produced by both approaches were then compared in terms of their ability to decide about the location of sites that are targets for warfare in this period. We then compared the two approaches over all relevant phases of social evolution in the valley in terms of their syntactic structure and complexity..

Next the semantic impact of the two different rule sets on the evolution of complex social structures in the valley was tested with a multi-agent simulation based upon the model of Marcas and Flannery (1997). A multi-agent system model of the origins of an archaic state was developed. In the model agent interaction is mediated by a collection of rules where the rules can pertain to various types of interaction such as trade, warfare, and ritual.

Our goal is to run the simulation with the two different set of warfare rules to determine the semantic differences that each places on the emergence of complexity in the valley. Social networks are produced as the result of each run and the extent to which a valley wide control network emerges, a signature of state formation, is determined. Different levels of warfare can be generated using each set of rules. The results suggest that in terms of the model of Marcus and Flannery, the observed rate of emergence of social complexity in the real world can only be achieved by allowing for a sufficient amount of warfare among agents. Also, the patterns produced by the rough set approach were more likely to exhibit the valley wide networks than the crisp set approach using decision trees.

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Boxed Economy Simulation Platform for Agent-Based Economic and Social Modeling

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1 Introduction

The recent advancement of agent-based modeling and simulation has been revolutionizing the social sciences, and the expectations are rising in social sciences. In the current state in the study of simulating agent- based economic models, however, there are some problems, as follows, that need to be resolved: (1) absence of integrated environment to support a whole research process, (2) difficulty in reusing program components of model, (3) entry barrier of programming, and (4) difficulty in securing the software quality of simulation. These problems did not become serious too much up to now, because the models were small-scale and for experimental use. It becomes, however, indispensable to resolve these existing problems, as the simulations come to be used practically in social science and policy analysis. In this paper, we propose concrete solutions to resolve the problems in the study of simulating agent-based economic models.

2 Background

In the last some years, several languages, frameworks and tools for agent-based simulations have been proposed. For example, "Swarm Simulation System", which seems to be the most famous and to be used, provides the class library (Objective-C language and Java language) for the simulation of complex adaptive systems[1]. "MAML" (Multi-Agent Modelling Language) which is macro language for Swarm makes programming more easily than original Swarm[2]. As well as Swarm, "RePast"(REcursive Porous Agent Simulation Toolkit) provides the class library (Java language) to make the multiagent model[3]. "Ascape" provides the framework (Java language), and it is said that the amount of the code description can be less than that of Swarm and RePast[4].

These support systems try to solve the problem with a necessary support to the model builder who has a little (or, no) experience of the computer programming. As the solution, those systems assist the model builders to write programs by providing a general library and framework, and in fact these systems are useful for the reduction of programming.

These systems, however, support for the model builders to build the agent-based model including the molecular interaction or the ecosystem, but not to build the economic or social model directly. In the social scientific viewpoint, it is necessary to share some basis, for example, the scheme for modeling, terms, and description method.

Moreover, these systems do not support to share the simulation models among two or more researchers, although they support for the model builders to construct the simulation alone. In order to support such a cumulative research process, the design rule for the model by which perpetuity and the reusability of the model are considered

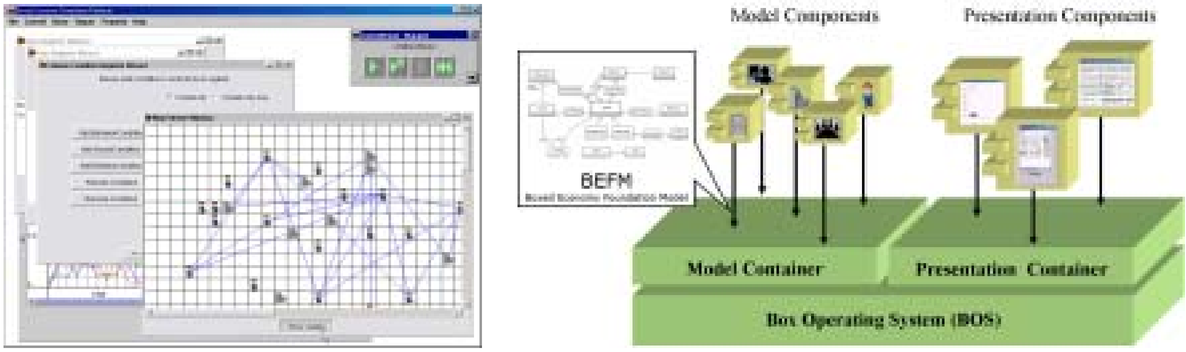

Figure 1: Screenshot and Structure of Boxed Economy Simulation Platform

becomes indispensable. The design rule enables us to divide the model into some piece of modules, which can be reused.

3 Our Approach

3.1 Boxed Economy Simulation Platform (BESP)

We would like to propose a sharable basis for agent-based economic simulations, which we call "Boxed Economy Simulation Platform" (BESP). BESP is a software platform to make, to execute, and to analyze the agent-based economic simulations[1] (Figure 1). BESP is designed to realize an extensible software application with component-based architecture. The user can obtain the simulation environment which suits the needs, only if he/she sets necessary components into the platform. There are two kinds of components built into the platform: that is "model component" and "presentation component". The model component is a software component that implements the model which the user wants to simulate. The model component is made based on the "Boxed Economy Foundation Model", which is mentioned later. The presentation component is a software component for the user interface to operate and to visualize the simulation, and the output into the file. The simulation is executed by setting up the economic model as the model components and the user interface as the presentation components in BESP.

Model components and presentation components are independent each other, communicating indirectly by sending and receiving the events through BESP. Therefore, the user simulates his/her original economic model with existing presentation components even if he/she makes only the model components. In contrast, the user makes his/her original user interface as presentation components that do not specialize in a specific economic model.

From the viewpoint of software program, BESP is multi-platform software which is implemented in object-orientated Java language. BESP is executable on Java Virtual Machine regardless of the operating system. In a word, BESP is executed quite similarly even if the users are using a different computer environment. Moreover, the users who are using different computer environments can share the components, because the component for BESP does not depend on the computer environment in which it is made.

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[1]Boxed Economy Simulation Platform (BESP) is able to be downloaded freely from our web page (*http://www.boxed-economy.org/*). Or please contact us by E-mail to *box-designers@crew.sfc.keio.ac.jp*.

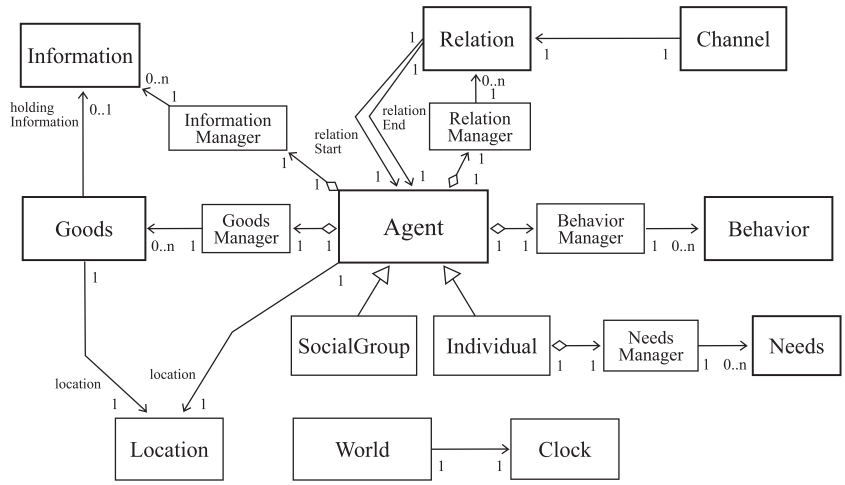

Figure 2: Basic design of Boxed Economy Foundation Model (UML class diagram[7])

3.2 Boxed Economy Foundation Model

In BESP, "Boxed Economy Foundation Model" is provided as a framework of the model component, which is specializing in agent-based model of economic society. The foundation model is an abstraction of the structure of the real economic society by classifying and relating with Object-Oriented analysis [2] (Figure 2).

The user can adopt the policy of modeling provided in the foundation model as a reference when modeling. Moreover, the user does not have to care about details by how those elements are actually executed on the computer. The user describe his/her model only by using the vocabulary in the foundation model, such as "Goods" or "Channel". It can be said that the concept which the foundation model provides is simpler and easier than operating the program directly.

The foundation model also enables us to share and reuse the model components among the model builders, because the granularity and the policy of modeling will be equal if the model components are made based on the foundation model. In addition, efficient communications among model builders become possible because they can use the name of model elements in the foundation model as a vocabulary.

4 What does BESP Bring to Us?

4.1 Providing Integrated Environment for Seamless Research Process

BESP provides the integrated environment by which a whole research process is executed on only a piece of software platform. As a result, the automatic execution with changing the initial settings and to check the behavior of the consequence becomes possible, because all processes are executed on a set of software platform. In addition, systematic management of the models and the programs becomes also possible with the software platform.

4.2 Supporting for Reusing Components

BESP provides the setup to reuse the program components of the models by Boxed Economy Foundation Model and the model components. Reusing the model compo-

[2] Figure 2 shows only the simple diagram of Boxed Economy Foundation Model. See our paper[5] for more detail class diagram and explanations.

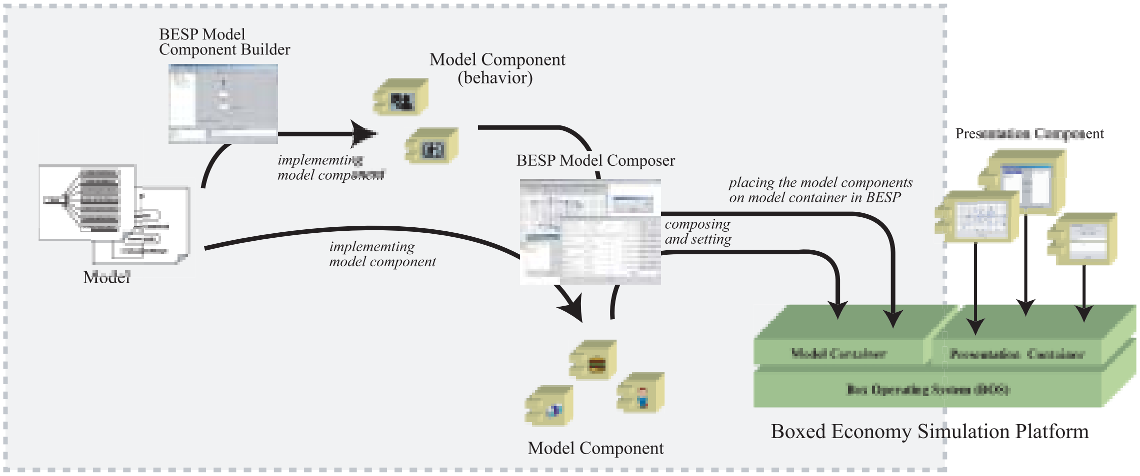

Figure 3: Model Component Builder and Model Composer for building model

nents is realized by the foundation model specialized in the domain of agent-based economic models. In addition, the tools to visualize and analyze the simulation results can be shared as well as the model components, because they are built as the reusable component.

4.3 Breaking Through the Entry Barrier of Programming

BESP provides the setup by which the programming to make the simulation is greatly reduced. As a result, the user comes to be able to make the simulation as long as they have the basic skills of programming, they do not have to make the design and the implementation concerning the structure which make the programming more difficult. Moreover, the user can make and change their simulation promptly, and then can give priority to the analysis of the consequences.

The reduction of the programming is supported by the following three manners. First, many programs that is necessary to simulate an agent-based economic model are already implemented in the body of BESP. Second, the tools which support to make the simulation programs are provided as presentation components[3] . Third, model components and presentation components can be reused, and then the user decreases the amount of the programming if a part of the model which they want to use has already been made. The component-based development, by which simulations are made only by combining and setting the component, becomes possible if the cumulating the model components is enhanced in the future. Thus, many of entry barriers from the social scientist are removed.

4.4 Supporting for Securing the Software Quality of Simulation

BESP provides the setup to secure the software quality of simulation without enlarging the load to the user. It narrows the range to make the verification, which is the inspection to the correct coding from the model to the computer program. The narrowing the range results from the reduction of the programming, which has been described above.

[3] "BESP Model Component Builder" and "BESP Model Composer" are provided with BESP. These are components to generate the simulation program automatically just by making the state chart diagram and setting the model with a graphical user interface (Fgure 3).

First, each user only has to check the part newly implemented by himself / herself, because the programs provided by BESP are already tested. Second, The user released from a deliberate check on the program if they use the supporting tools, such as "Model Component Builder" and "Model Composer", because human errors at the programming are eliminated by generating the program automatically with these tools[4] . Third, the range of verification is narrowed if they reuse the model components, which have already been tested.

5 Conclusion

In this paper, we discussed how "Boxed Economy Simulation Platform" (BESP) resolves the existing problems in the study of simulating agent-based economic and social models. The tool is used for resolving the following problems in study of agent-based economic models: (1) absence of integrated environment to support a whole research process, (2) difficulty in reusing program components of model, (3) entry barrier of programming, and (4) difficulty in securing the software quality of simulation.

The existing problems are resolved by BESP in the following manners: (1) the integrated environment to consistently support the research process is provided, (2) reusing the program components of models is supported by the Boxed Economy Foundation Model and the model components, (3) programming by user is greatly reduced in BESP, where the tool supports for modeling and implementation of simulation, and reusing of components, (4) the software quality of simulation is improved without enlarging the load to users, because the programming human errors are decreased by BESP, where most of programs for simulation are prepared in BESP.

Creating the foundation for the social simulation researches is an oversized project for our members to complete. We would like to realize this by collaborating with many researchers in various fields. Please contact us on *http://www.boxed-economy.org/*, if you are interested in the challenge.

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[4] It is pointed out that the code generator can describe the code by 10000 times early, and can decrease the error to 1/1000 compared with the human even if the performance is the lowest[8].

Virtual Economy Gaming
- Agent Based Modeling of National Economy -

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Abstract. In this paper we analyze economic systems as agent based bottom up models. For the purpose we introduce small national economy called virtual economy and exchange algebra for state space description. We construct dynamical agent based simulation model and analyze it by agent based simulation.

1. Artificial National Economy

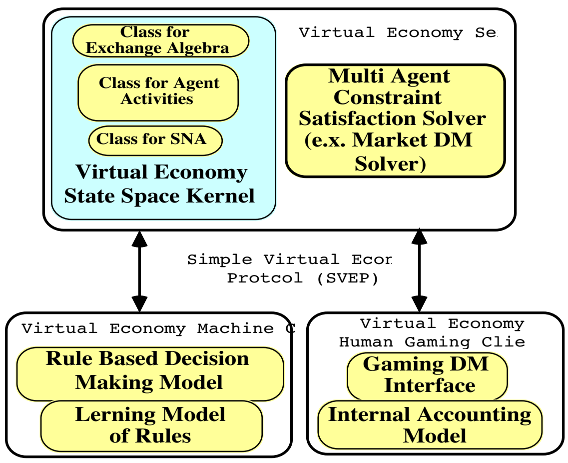
In this paper we focus on simple agent based model of national economy which is called virtual economy[3,4,5]. Virtual economy consists of nine agents such as agriculture ,flour milling industry ,bread industry (bakery), steel industry, machine industry ,government , household, bank and central bank. For describing agent based economic state of stock and flow we give an algebraic abstraction of bookkeeping system which is called exchange algebra. An economic state of each agent is described by the algebra. Exchange algebra is the extension of accounting vector space [1, 2, 3]. By using this algebra we describe systemic properties of economic exchange and properties of economic field which gives a formal model for SNA (System of National Account).

For agent based modeling of national economy we have two different direction of study. The one is constructing huge model which include large number of agents[6]. The other is to give rich description of agents. In the later direction we have to construct suitable state space model for agents. Even in rich description of agent KISS (Keep it simple and stupid) principle for agent based modeling is available if we give essential state description of agents in the target area[8]. In this paper we focus on rich description of economic agent. In economic agents the most basic state description for stock and flow is given by bookkeeping system. Bookkeeping system is usually given in tabular or matrix forms. But these forms are not suitable for abstract modeling. Instead we introduce accounting algebra for our description.
In the model economy agriculture grows wheat, flour milling industry makes wheat flour of wheat, bread industry (bakery) makes bread from flour, steel industry. makes steel and machinery industry makes machinery from steel. In the model we assumed that there is no materials for steel industry. Household purchases and consumes bread. A machine is purchased by each industry as an investment and used for production. A machine is also purchased by government or household. The machines that are purchased by government or household are considered as an infrastructure and a house respectively. A machine is made depreciation on according to a scenario. Population increases by a scenario. Household supplies workers to each industry and a government and household receives a wage. A government can issue national bonds. A center bank issues a bank note and fixes the official bank rate. Household and industry deposit money in a bank. A bank lends money.

2. Agent Based Modeling of Virtual Economy

In the virtual economy gaming players act such as government, agriculture and so on depending their roles. This virtual economy becomes a multi agent model of a economic system of a country. In the economy players or machine agents act as decision makers. The game needs some basic assumptions. For example we have five products and one currency in this economy with proper units for the products and currency as follows. "MOU" stands for money unit such as dollar. "WHU" stands for wheat unit, " FLU" stands for flour unit, "BRU" stands for bread unit, "STU" stands for steel unit and "MAU" stands for machine unit. Machine is regarded house in the household. We try to construct agent based simulation model for this economy. Figure 1 shows the total design for agent based simulation of virtual economy.

Figure 1 Basic Design of Virtual



Economy Agent Based Simulation Model

Model consists of game server and client. Game server and client are designed depending on MVC and hierarchical lapping architecture. A control class of the server consists of the following feature. (1) Activation of model, (2) Setting environmental variables. (3) Show macro economic state, (4) Show micro economic state of each agent.

Macro economy is constructed by model class. Firm agents (agriculture, flour milling industry, bread industry, steel industry , machinery) are described by the class of FirmAgent.java. Other economic agents are described by EconAgent.java. Internal structure of each agent consist of the class of Exalge.java which described exchange algebra, the class of DMI (Decision Making Items) which describe decision making of agents and the class of BalanceSheet.java for describing balance sheet information of each term. For calculating a change of internal state of an agent as a result of decision making we supplied the class of Transaction.java. MachineStock.java shows state of machine stock and depreciation. All agents are controlled by Veconomy.java.

The communication protocol between client (economic agents) and server is defined as SVMP (Simple Virtual Economy Protocol). SVMP is constructed depending on such three basic protocols as "StateRequest", "DataRequest" and "HashXfer". These basic protocols are implemented by MAEP (Multi-agent Artificial Economy Protocol) .
SVMP (Simple Virtual Economy Protocol) consists of the following handshake.
(1) Server activation confirmation
(2) A term-start protocol:
(2-1) A term-start state demand from agents and send to agents
(2-2) A term-start DMI parameters send to the server
(3) A DMI parameter inquiry from agents and answer
(4) An inquiry of past macro data from agents and the answer
(5) The DMI send to server
(6) Check the local contradiction of DMI data of each agents and return the result
(7) Check the global contradiction among DMI data and return the result

In this paper we try to construct two types of agent based simulations model for single human player and show its results. We introduced two types of dynamic model for this virtual economy gaming. The one is called dictator's view model. In this model a player has to decide all decisions for transactions among agents of this economy in a term like a dictator. Table 1 shows decision making items for a player in a term.

The other is called birds eye view model across the terms. In this model some decision is done automatically depending on hidden decision making rules. A player decide across the time in this model. In the first model decision is done step by step in terms. But in this model a player has a bird's eye view across the terms. A player can observe total period of economic development and decide across the terms for achieving his aim in the economy.
Table 2 shows institutional parameters such as subsidy policy and national bond policy. The decision is shown as true of false. Table 3 shows capital investment of each agent in each term. Table 4 shows management and political parameters.

A player can observe economic development across the terms while he change the these parameters. A player can set up different goals for optimizing depending on focussing social indexes such as the numbers of residents per house, GDP per person and consumption per person.

Table 1 Decision Making for Dictator's View Model

Decision Making for Dictater's View Model : 2nd T

	Agri.	Flou.	Bake.	Steel	Mach.	House	Gov.	CB	Bank
Income Tax Rate	*	*	*	*	*	*	0.1	*	*
Corporate Tax Rate	*	*	*	*	*	*	0.2	*	*
National Bond Rate	*	*	*	*	*	*	0.01	*	*
Official Bank Rate	*	*	*	*	*	*	*	0.01	*
Deposits in CB	*	*	*	*	*	*	*	0	0
Withdraw from CB	*	*	*	*	*	*	*	0	0
Loan from CB	*	*	*	*	*	*	*	1000	1000
Refund to CB	*	*	*	*	*	*	*	0	0
Receive Subsidy	0	0	10	10	10	0	30	*	0
Deposit Interest	*	*	*	*	*	*	*	*	0.01
Loan Interest	*	*	*	*	*	*	*	*	0.03
Buy National Bond(NB)	0	0	0	0	0	0	0	*	*
Redeem NB	0	0	0	0	0	0	0	*	*
Accept NB by CB	*	*	*	*	*	*	0	0	*
Redeem NB from CB	*	*	*	*	*	*	0	0	*
Loan from Bank	0	300	100	300	300	0	*	*	1000
Redeem to Bank	0	0	0	0	0	0	*	*	0
Deposit in Bank	0	0	0	0	0	0	*	*	0
Withdraw from Bank	0	0	0	0	0	0	*	*	0
Product Price per Unit	0.2	0.5	1	6.25	11	*	*	*	*
Capital Investment (numbers)	2	3	2	4	8	2	0	*	*
Sales of Products (Quantity)	770	580	420	14	21	*	*	*	*
Numbers of Employment	70	70	60	30	65	330	35	*	*
Total Wage	90	90	80	30	90	430	50	*	*

Table 2 Institutional Parameters

Adoption of a Policy : Institutional Parameters

	1	2	3	4	5	6	7	8	9	10
Subsidy for Half the Capital Investment	FALS	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE
Subsidy for the Deficit of Makers	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Subsidy for Half the House Investment	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Issue National Bond under guarantee of Central Bank	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE

Table 3 Capital Investment

Decision Making of Capital Investment										
Term	Machine available	Agri .	Flour	Bakely	Steel	Machine	House hold	Gov.	Sum	Stock of Machine
1	26	2	4	1	7	11	1	0	26	0
2	35	2	5	4	10	14	0	0	35	0
3	44	2	5	6	10	19	2	0	44	0
4	55	2	10	8	10	23	1	0	54	1
5	62	3	15	10	10	22	2	0	62	0
6	75	2	15	17	12	25	3	1	75	0
7	81	4	17	15	10	28	4	3	81	0
8	81	5	21	13	16	24	2	0	81	0
9	88	5	22	13	10	33	3	2	88	0
10	97	3	30	15	13	32	3	0	96	1

4. Result of Simulation

We show an example of results of economic development in ten terms. The following figure shows the results of by birds eye view model across the terms under the parameters of the previous tables. Figure 2 shows the numbers of residents per house.

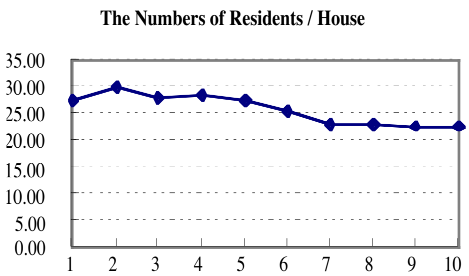


Figure 2 The numbers of residents per house

Figure 3 shows GDP and food consumption per person.

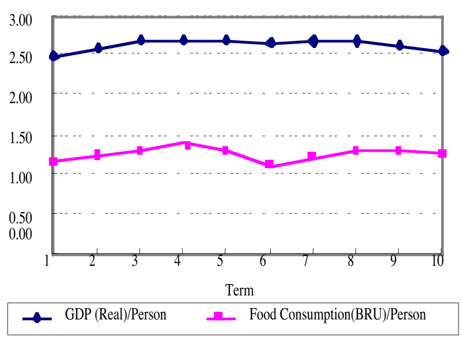


Figure 3 GDP (Real) per Person & Food Consumption (BRU) per Person

5. Conclusion

We investigate agent based simulation model of small national economy. We give bottom up state description of agents by exchange algebra. We can add multi agent decision making mechanism in the model from bottom up point of view. We would like to represent the varieties of institutional and structural change of real economy in the agent based models. This is a first step for our research program.

For virtual economy gaming it is difficult to construct agent based simulation by software agents in this stage. On the other hand virtual economy gaming is useful for human players gaming. For example it was used for the training course of SNA at the Ministry of International Trade and Industry (MITI) of Japan in its educational program on 1995 and 1996. Virtual economy will becomes a good test bed of agent based simulations for complex agent societies. It will also becomes an effective supporting system to learn about the complexity of economic systems.

A human player constructs a certain internal model that represents an understanding of the player and its environment. Internal models are referred to and learned mutually by players. The results of gaming simulation do not converge to the theoretical result of traditional economic theory as actual economy do not converge. The agent based modeling and simulation also help to analyze such a complex interaction among autonomous agents.

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