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An "All Hands" Call to the Social Science Community: Establishing a Community Framework for Complexity Modeling Using Agent Based Models and Cyberinfrastructure

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Abstract

To date, many communities of practice (COP) in the social sciences have been struggling with how to deal with rapidly growing bodies of information. Many CoPs across broad disciplines have turned to community frameworks for complexity modeling (CFCMs) but this strategy has been slow to be discussed let alone adopted by the social sciences communities of practice (SS-CoPs). In this paper we urge the SS-CoPs that it is timely to develop and establish a CBCF for the social sciences for two major reasons: the rapid acquisition of data and the emergence of critical cybertools which can facilitate agent-based, spatially-explicit models. The goal of this paper is not to prescribe how a CFCM might be set up but to suggest of what components it might consist and what its advantages would be. Agent based models serve the establishment of a CFCM because they allow robust and diverse inputs and are amenable to output-driven modifications. In other words, as phenomena are resolved by a SS-CoP it is possible to adjust and refine ABMs (and their predictive ability) as a recursive and collective process. Existing and emerging cybertools such as computer networks, digital data collections and advances in programming languages mean the SS-CoP must now carefully consider committing the human organization to enabling a cyberinfrastructure tool. The combination of technologies with human interfaces can allow scenarios to be incorporated through 'if' 'then' rules and provide a powerful basis for addressing the dynamics of coupled and complex social ecological systems (cSESs). The need for social scientists to be more engaged participants in the growing challenges of characterizing chaotic, self-organizing social systems and predicting emergent patterns makes the application of ABMs timely. The enabling of a SS-CoP CFCM human-cyberinfrastructure represents an unprecedented opportunity to synthesize, compare and evaluate diverse sociological phenomena as a cohesive and recursive community-driven process.

Keywords:
Community-Based Complex Models, Mathematics, Social Sciences

Introduction

1.1
Complex systems modeling may offer important insights into interdisciplinary social science

research regarding self-organization, emergence and hierarchies. Social systems are complex systems, characterized by non-linear dynamics and a high degree of spatial variance in the social and natural parameters that structure them, in the connections among their components, and in the outcomes of socio-ecological processes. They are characterized by self-organization, emergence and hierarchies. Social systems involve complex feedbacks which involve decision-making influenced by an individual's perception of the world, the actions of others and the biophysical consequences of those decisions.

1.2

Such social complexity calls for modeling frameworks that can integrate agent perceptions and behaviors in multi-agent systems such as behavioral ecology, game theory of decision making, and geospatial representations of the world. Such interactions can not be captured by a single dataset or model but rather will only be understood by linking multiple efforts into a community-driven modeling framework capable of being iterated under several parameters to detect emergent phenomena. The rise in the number of research grants, papers and reports using and citing complexity emphasizes that the scientific community recognizes the need to develop modeling frameworks that can integrate non-linear dynamics of complex systems, behavioral ecology and game theory of decision-making, and geospatial representations of the world.

1.3

Over the past two decades, a number of experimental platforms have been developed to begin to meet these needs, generally grouped under the phrases agent-based modeling (ABM) or agent-based models (ABMs). ABMs have rapidly evolved and proliferated. These cellular modeling frameworks are increasingly utilized by groups conducting interdisciplinary research to integrate biological, physical, social, economic, and ecological datasets. Since sophisticated and accurate modeling of the processes governing human socio-ecologial systems is of vital importance to a broad array of issues facing us today, it would seem that ABMs, as both individual and collective processes, would also become a requirement for cutting-edge research in the social sciences. In the "new" social sciences, the systems approach and agent-based modeling are distinguished from the more traditional analytic or qualitative approaches by emphasizing the interactions and connectedness of the different components of a system as a set of feedbacks which result in the emergence of patterns which are not initially predicted (Bentley and Maschner 2003; Scholl 2001; Phelan 1999; Davidsson 2002). By focusing on qualities of complexity, it is well-suited to the study of the adaptive and self-regulating systems which we call "cybernetic". These complex systems require not only currently available mathematical and computation theory and application but also the broader innovation of social science perspectives to capture and identify their unique characteristics. Traditional approaches (i.e., linear algorithm based) to modeling SES, in general have yielded valuable insights toward the interaction of variables with each other, but have failed to capture their more subtle and complex properties and are often not appropriate tools.

1.4

Given the challenges of solving nonlinear processes which describe the evolutionary behavior of complex coupled social-ecological systems, a community-centered, cohesive and systematic discussion is required to create a trajectory for this field of study. Community Frameworks for Complexity Modeling (CFCM), the emergence of critical cyber-infrastructure (e.g., digital archives, computers with robust central processing units (CPUs), large memory capacities and the ability to be linked across broad regions through satellite links and Graphic User Interfaces, GUIs, etc.) have been combined into highly effective tools in many other research domains (e.g., the climate CoP using the Climate Community System Model, CCSM and the biomolecular (Chemistry at HARvard Molecular Mechanics) CoP using CHARMM (http://charm.cs.uiuc.edu/) to establish parallel languages, libraries, conceptual frameworks, and programming algorithms, and ultimately, the culture of the CoP. A comparable effort is largely lacking for the social sciences.

1.5

This paper addresses the urgent need for the development of a community framework for agent-based modeling in the social sciences. It seeks to put out an "All Hands" call for organization within the social sciences in order to gain inclusion in emerging technologies which seek to characterize and understand coupled socio-ecological system dynamics. It is hoped that this will further the discussion for designing a community modeling framework to more effectively integrate ABMs into the social sciences. This "call" to the social science community of practice (SS-CoP) follows a seminal review by the National Science Foundation (Atkins et al 2003) that states:

> The emerging vision is to use Cyber-infrastructure to build more ubiquitous, comprehensive digital environments that become interactive and functionally complete for research communities in terms of people, data, information, tools and instruments and that operate at unprecedented levels of computational, storage, and data transfer capacity.

1.6

This paper also provides an assessment of some existing community modeling frameworks as demonstration of successful efforts in other fields of inquiry, mainly those in the biophysical sciences. The process of designing a community modeling framework to more effectively apply ABMs in the social sciences requires a commitment on the part of multiple SS-CoP practitioners in diverse areas of expertise to form a powerful, realistic, cohesive, accessible and responsive tool.

Community Modeling Frameworks

2.1

While many linear models are interesting and useful, it is now generally accepted that SES systems consist of linked, multi-scale spatiotemporal dynamics resulting in "faster" and "slower" feedbacks. In recognition of these SES features, CFCMs, largely facilitated by the Internet, as both a network and a cybernetic system, as well as by scientists and computer programmers, have developed in parallel with the realization that systems do not exist alone. Community Frameworks for Complexity Modeling are essentially software products that are collaboratively developed by a user community, to be shared, used and accessed via the Internet. Generally such programs are open source and the underlying code and algorithms are transparent (eg., Geographic Resource Analysis Support System - GRASS: http://grass.itc.it). These differ from many licensed software programs that have development sites where users can post their code and extend the analytical and processing capabilities of the basic software program (ESRI Developer Network - EDN: http://edn.esri.com/), but where users make no contribution to the primary program.

Why Use Agent-based Models in the Social Sciences?

3.1

More cohesive, collaborative, sophisticated and accurate modeling of the processes governing human socioecologial systems is of vital importance to a broad array of issues facing us today, from human response to global climatic change (Parker et. al. 2003), to the causes and social consequences of land degradation (Grimm et. al 2005), to the interaction of global and local markets (Holland and Miller 1991), to the progression or reversion to specific forms of economic salience in remote areas (e.g., Robards and Alessa 2004). This underscores the need for concerted investment in the research and development of ABMs within the social sciences.

3.2

The SS-CoP has accumulated a rich and diverse set of data and information from archaeological records, demographics and quantitative survey data to narratives, stories, myths and legends. Agent-based simulation of complex systems can utilize extensive and diverse data simultaneously to create dynamic networks of interacting agents with rules and behaviors which can be refined over time. Agents are autonomous decision-making entities that make decisions based upon a set of rules from which emergent properties result. The definition of emergence, the touchstone of complexity theory, is "macroscale phenomena results from microscale interaction" (Schelling 1978). Interactions between individuals (agents) are complex and nonlinear; agent populations are heterogeneous and outcomes, based on decisions, can result in adaptations (Bonabeau 2002) leading to resilience or vulnerability. Agent based models are termed bottom-up simulations in that they compile information and data about individual agents to observe results of system level properties (Gilbert and Terna 2000; Grimm et. al. 2005). There are significantly fewer data which address such scale (individual to globe) interactions. Computational advances allow for the ability to model agents utilizing large amounts of data while observing measurement and change across scales and variables (e.g., the role of agents in perceiving changing water resources) (e.g., Alessa et al. 2004).

3.3

The literature that defines and describes ABMs is primarily centered in computer science (Zambonelli and VanDyke Parunak 2002), but salient examples also exist for policy (Cioffi-Revilla 2002), organization (Carley 2002), ecology (Bousquet and LePage 2004), and geography (Takeyama and Couclelis 1997). This literature is largely in agreement with regard to the potential and promise of ABMs as offering a "third way" of conducting science through the simulation of complex processes and the refinement of both theory and praxis through 'truthing' real world data as a recursive process through modeling. This is especially relevant for human social-ecological systems, which are quintessential complex systems — and for which there is a critical need to better understand drivers and interactions. Researchers have suggested that ABMs are revolutionary in that they differ from traditional analysis of deductive, mathematical models and inductive, statistical or econometric models (Axelrod 1997; Gilbert and Terna 2000; Cioffi-Revilla 2002). Agent based models provide an environment for new techniques which allow the programming of "intelligent agents," capable of making decisions based on a variety of interactions such as risk aversion and collective benefit. Furthermore, such agents can more closely mimic the types of feedbacks between physical and social systems in that they recognize that human perception, organization and governance, among others, are salient drivers in processes such as landscape geography and hydrological processes. Agent based model simulation of the complex interactions inherent in environmental degradation and socio-economic conditions make it possible to ask (and hopefully begin to answer) provocative questions about the drivers and feedbacks within and between such systems.

3.4

Agent-based models have followed a developmental trajectory similar to that of statistical modeling. The earliest agent-based models were built in a variety of programming languages (eg., C++, JAVA, and SMALLTALK) with no consensus on a particular platform, and often as demonstration projects. Subsequently, standardized libraries were developed in a number of programming environments that included basic, ready-to-use routines (eg., early versions of REPAST, SWARM, and ASCAPE), but which still required the user to be proficient in the underlying programming language. Recently, platforms for ABM teaching and research have begun to emerge that combine collections of routines with a standardized interface (increasingly at least partially a graphical user interface). Examples include: the current version of REPAST, NETLOGO, AGENTSHEETS, and CORMAS. However, these packages require users to master a fairly intricate and complex interface and still require programming expertise (increasingly with object-oriented concepts) (Gilbert and Bankes 2002). Hence, while ABMs are particularly appropriate for social systems (e.g., Bonabeau 2002) they remain elusive to the average SS-CoP user; as a consequence, such a user has been unable to participate in the development and utilization of a rapidly growing and useful tool.

3.5

In spite of these drawbacks, ABMs represent novel ways of conducting science and offer another way to bring the social sciences to the level of consideration and incorporation of that of the biophysical disciplines, particularly in policy and decision making. ABMs are desirable in these contexts to help overcome the limitations of other models (differential equations and statistical modeling) based upon restrictive and unrealistic assumptions (Bankes 2002b) and research questions that demand complex and interdisciplinary approaches. While the fact that ABMs are still in the development stage poses some challenges for adoption by SS-CoPs, this also means that they are highly amenable to directed research and application given sufficient organization by and cooperation within the SS-CoP needed to define the fundamental metrics of emergence and model evaluation. Their organization within a CFCM early in their use by the SS-CoP offers the distinct advantage to structure new data acquisition such that they are broadly useful through synthesis and legacy. In addition, precedents and structures already exist in other CoPs for the SS-CoP to use as potential templates. Table 1 lists some examples of available platforms for developing and executing agent-based models that are potentially useable for research that integrates social, physical, and natural sciences — especially in the domains of land use/land cover change (Parker et. al. 2003), policy development (Bankes 2002b), social organization (Read 2002), ecology (Grimm et. al. 2005) and economics (Holland and Miller 1991).

Table 1: Examples of Current Platforms for Creating Agent-Based Models for Social Science Research

REPAST (Recursive Porous Agent Simulation Toolkit) **	http://repast.sourceforge.net
ASCAPE **	http://www.brook.edu/es/dynamics/models/ascape/
NETLOGO **	http://ccl.northwestern.edu/netlogo/
STARLOGO *	http://education.mit.edu/starlogo/
AGENTSHEETS *	http://www.agentsheets.com/
CORMAS (Software for Renewable Resource Management) *	http://cormas.cirad.fr/indexeng.htm
BREVE ***	http://www.spiderland.org/
SWARM (Multi-simulation of complex systems) ***	http://www.swarm.org
ORGAHEAD (Organizational learning model)	http://www.casos.cs.cmu.edu/projects/OrgAhead/

*developed in SMALLTALK programming language

** developed in JAVA

*** developed in C (including extensions)

Challenges Posed by a Community Based Modeling Framework

4.1

The perceived resistance among the SS-CoP toward CFCMs and the use of ABMs may exist for several reasons. While familiarity with ABMs is growing, this may be restricted to a relatively small subset of the SS-CoP and within this subset there exists a division between 'theoretical' and 'applied' ABM users i.e., those who work in virtual (controlled) landscapes and those who work in actual (noisy) landscapes, respectively. The mathematical and programming skills required to utilize ABMs is generally outside the expertise of most SS-CoP practitioners and often are too extensive to learn. Additionally, the experimental nature of most ABM platforms employed to model complex social systems prevent them from being readily accessible, even to researchers who are mathematically and computationally savvy, and their isolation within specific projects makes comparisons and theory-testing problematic. Also, the disparate programming code that underlies the diverse ABM platforms employed today often makes it difficult, if not impossible, to compare inter-model parameters. There is likely widespread, albeit anecdotal, suspicion regarding ABMs as a platform for CFCM in that it is feared that rich, qualitative data may be lost in an attempt to "parameterize" information for inclusion in a quantitative model.

4.2

In the converse, limitations in familiarity with social systems by mathematicians, physicists and programmers, can result in a lack of context in programming language, rendering model runs less useful in the 'real world'. Complicating "real" impediments, we posit that the SS-CoP suffers from an "inferiority complex" sustained by many in the scientific community who perceive social sciences to be more divergent and less rigorous than the biophysical sciences. The legacy of Newton and reductionist approaches combined with a lack of "concreteness" in many areas of expertise within the social sciences have relegated them to be under-funded, poorly considered and too "messy" to incorporate into existing predictive models despite widespread rhetoric of the centrality of social phenomena in the SES. In many cases, the nature of data in the social sciences is that they are sensitive and require care in their storage, analysis and dissemination. Ultimately, most SS-CoPs lack the resources to conduct their research, let alone organize toward a CFCM which entails utilizing techniques and technologies with which many practitioners are unfamiliar. No data exist on the perceptions of ABMs and the utility of CFCM for advancing the social sciences nor do they exist for the areas of expertise within them which may be more or less amenable to the establishment of a CFCM. Such data, however, would be helpful for strategic and efficient coordination of the SS-CoP.

4.3

Several reports suggest that simulation modeling in general and ABMs in particular, coupled with advances in computational infrastructure, are precipitating a paradigm shift in science (Atkins et al. 2003, Berman and Brady 2005). Community frameworks for complexity modeling are being touted as the "third way" to conduct science. They are built upon inter-disciplinary research and multi-methodological approaches and their applications to the social sciences have been briefly addressed by computer scientists but no cohesive frameworks for broad applicability have emerged. Increasing computational power and high-speed networks have created an environment in which computer-based modeling and simulation is catalyzing new ways of learning and exploration (Vicsek 2002), and potentially profound changes to scientific approaches and methods. It is important to recognize that such changes will also affect techniques and approaches in computer science — that is, such change will be recursive — and it is important to understand how algorithms affect data, data processing, and model outcomes (Zambonelli and Van Dyke Parunak 2002).

4.4

A CFCM can provide a powerful tool for encouraging wider use of ABMs by the SS-CoP, and also offers the best environment to address several important challenges to the implementation of ABMs as common social science tool. These problems have to do with types of data available, construction of models, mechanistic issues of parallel models, and fundamental issues in the praxis of science in the age of cyber-infrastructure including the attitudes and perceptions comprising the culture of practitioners in the SS-CoP. With regard to the construction of models, there exists insufficient emphasis on analyzing and validating the applicability of models to real problems, compared with simply representing agents (Grimm et. al. 2005). Emergence is a difficult but important concept to articulate and parameterize, particularly in the social sciences. Formal definitions of emergence are needed to recognize, understand, and explain emergent properties (Bankes 2002a). Development of a framework that utilizes ABMs as a common platform beyond visual or numerical representation of agents to model evaluation, the ability to compare multiple model runs, and calibrating models (Gilbert and Bankes 2002) is necessary.

4.5

Mechanistic issues of parallel ABMs and a unified framework (e.g., rules for digital archiving, etc., programming languages, GUIs, regional specificity, etc.) are also challenging. Model simulations differ by the number of agents, the variation in size and what effects changes in number might have on the model. Does variation in size have an impact on model outcomes? The geometry of the agent is another fundamental element of most ABMs which is poorly discussed in the SS-CoP. How could cognitive processes affect decision making? What data are available at what scales and in what areas of expertise? What is the best agent geometry in relation to the referent geometry being studied? Time is an important aspect of physical, ecological and social processes. What is the relationship of model runs to time? How can time be integrated and calibrated in ABMs? (Cioffi-Revilla 2002). Additionally, innovative techniques and approaches to build models to the right level of description are needed. As models are constructed and data is integrated into complex databases, it is important to recognize that such processing will be computationally intensive and time consuming especially for modeling large systems (Bonabeau 2002).

4.6

We propose that, despite these barriers, there are several reasons why a CFCM in the SS-CoP is timely:

1. Increasing acquisition and accumulation of data, including both larger and more complex

datasets (the National Science Digital Library: http://nsdl.org/; US Department of Energy National Collaboratories: http://www.doecollaboratory.org/).
2. Computational and cybernetic technologies enabling the processing of these data (Advanced Computational Technologies: http://www.ad-comtech.co.uk/ACT.shtml; CyberTools: http://www.cytools.com/aboutus.html.)
3. The shortcomings and, in some cases, failure of traditional modeling to be applied to local scales and their inability to detect "surprise" that emerges as a consequence of social, rather than biophysical, system behaviors (Bankes 2002b; Scholl 2001; Read 2002) and the increasing pressures that humankind faces in managing resources under conditions of rapid change, anthropogenic drivers, constraints and feedbacks.

4.7

A CFCM would allow for the inclusion of cross-disciplinary connections and corresponding feedbacks by allowing components of social complexity and dynamic interaction to be added, nonlinearly, to our models across regions both for comparisons and for unifying theories. It could significantly advance the development and application of ABMs within the social sciences as well as identify synergies and contradictions with biophysical systems. Community frameworks for the development of critical cybertools have been highly effective in many other research domains, but not the social sciences. A community framework would encourage more social scientists to participate in the development of ABM platforms, foster collaboration among mathematicians, computer scientists, statisticians, and social scientists wanting to employ ABMs, offer a broadly accepted set of ABM tools designed specifically for social scientists and their research issues, and serve as a central knowledge base for applying ABMs to the complex systems of human society. An excerpt from the National Science Foundation' Report on Cyber-infrastructure (Atkins et al 2003) highlights the consequences of a failure by the SS-CoP to organize:

> The Panel's overarching finding is that a new age has dawned in scientific and engineering research, pushed by continuing progress in computing, information, and communication technology; and pulled by the expanding complexity, scope, and scale of today's research challenges. The capacity of this technology has crossed thresholds that now make possible a comprehensive "cyber-infrastructure" on which to build new types of scientific and engineering knowledge environments and organizations and to pursue research in new ways and with increased efficacy. The cost of not doing this is high, both in opportunities lost and through increasing fragmentation and balkanization of the research communities.

4.8

Agent based models remain experimental and underused (though much discussed) across the social sciences for additional reasons. One is related to the basic mechanics of their use. Unlike other forms of modeling, including differential-equation based non-linear models, there are no standard platforms within which ABMs can be built, evaluated, and disseminated. Even some of the newest platforms, like BREVE and REPAST, require sophistication in computer programming beyond the normal training of many mathematically sophisticated and computer-savvy social scientists. While the next generation of social scientists should learn the conceptual and methodological skills to make effective use of new modeling technology, it is highly unlikely, and possibly unrealistic to expect, that such skills are inherent in the SS-CoP or will be in the near future. At the same time, however, there need to be improvements in the usability of ABM software packages. Although common practice in past decades, it is rare now for a scientist to hire a consultant to program a statistical program, database, or GIS from scratch. But most projects today still rely on building ABM systems from the ground-up mainly through contracts with computer programmers with appropriate skills, while the scientists carrying out the research may have little input to or understanding of the underlying algorithms. This also makes it very difficult to compare different ABM projects or evaluate their relative merits when they differ not just at a conceptual level, but also at the level of computer algorithms, and languages used to implement them. The usability of ABMs platforms must improve or these important cybertools will be in danger of becoming computational black boxes with a loss of confidence in the validity or value of the results of complex system modeling projects. Without leadership and initiative within the social sciences community, sociocultural phenomena run the risk of remaining as secondary peripheral variables attributed within but ultimately excluded from biophysical systems. For example, ecological observation networks which do not incorporate and collect sociocultural data simultaneously with biological and physical data will fail to detect and characterize feedbacks in systems at multiple scales and, ultimately, may not yield useful information.

4.9

Finally, the need for spatially-explicit models makes the coupling of ABMs with geographic information systems (GIS) highly desirable because interactions between humans and their natural environments exhibit complex spatio-temporal behavior (Itami 1994; Brown et al 2005; Gimblett 2002). A fundamental issue in the application of spatially-explicit ABMs is the recognition and choice of the inherent scale(s) of a spatial process - increasingly multiple scale approaches and techniques are being pursued with emphasis needed on bottom-up dynamics. Currently, some (but certainly not all) ABMs simulating human-environmental interactions employ cellular automata theory and techniques for implementing spatial dynamic ecological models that accommodate spatial heterogeneity in base line variables and parameters. However, ABM/GIS links have largely been implemented through loose couplings; much tighter coupling is needed to simulate real-world spatial/temporal dynamics (Brown et al. 2005).

Community Frameworks for Research

5.1

Agent based computer models that are assembled, utilized and amended by a community of practitioners are a comparatively new means of providing critical cybertools for research and the development of cyber-infrastructure (e.g., Axelrod and Tesfatsion 2006). They are very much an outgrowth of the maturation of the Internet and are an example of its collaborative potential, facilitating the development and dissemination of computer-based research tools by a community of scientists working together on a common set of problems There is no clear-cut definition of what comprises a community model. However, a recent NSF-supported workshop for planning a community sediment model offered a succinct set of criteria. "At its most basic, a [community sediment model] may be defined as a community-built and freely available suite of integrated, ever-improving software modules predicting sedimentary basin and landscape evolution over a broad range of time and space scales" (INSTAAR 2002).

5.2

Building on these criteria, there are some features that are common to many CFCMs. These characteristics also are important for developing a framework that will encourage effective use of ABMs in the social sciences. CFCMs have the following features:

- They are designed to solve a set of problems common to research within a domain as well as evolve understanding across domains by detecting consistent versus domain-specific properties.
- They are the work of a collaborative team of scientists rather than an individual, emphasizing the increasingly interdisciplinary nature of scientific inquiry today.
- They are generally freely available, at least for scientific research and education, toward the goal of broad dissemination of knowledge and methods. (However, the software in which such models are implemented may be licensed.)
- The source code for such software is also generally openly available, making underlying algorithms transparent and facilitating improvements and extensions to the modeling environment.
- CFCMs encourage ongoing improvement by users and hence evolve to meet new research challenges — including ones generated by model use.
- They facilitate the education and training of the next generation of integrated social scientists as a cohesive network of scholars and practitioners.

Avoiding the "Re-invention of the Wheel"

6.1

The models and development platforms in Table 2 serve to illustrate features of importance to a community framework for ABMs: all are the products of collaborative teams, most involve collaboration among multiple institutions, and most are linked closely to universities or other long-term institutions with a commitment to science. The listed CFCMs (and the greatest majority of those that exist) are focused on the natural and physical sciences. The social sciences have yet to see a similar benefit from these new internet-based collaborative venues for cybertool development and dissemination.

Table 2: Examples of Community Models in Current Use

Community Climate System Model, National Center for Atmospheric Research
Geographic Resource Analysis Support System (GRASS)
Carbon Community Model, Colorado State University
Chesapeake Community Modeling Program, Chesapeake Research Consortium
Community Modeling Environment, Southern California Earthquake Center
Community Chemistry-Climate Model, Cambridge Universityl
Community Model for Physical Processes in the Nearshore Ocean, National Oceanographic Partnership Program
Centre for Terrestrial Carbon Dynamics, New Community Model
Community Model for Coastal Sediment Transport, USGS
Exposure Assessment Models, EPA Center for Exposure Assessment Modeling (CEAM)
The R Project for Statistical Computing
Evolving Increasingly Complex Neural Networks (NEAT)
Spatial Land Use Change and Ecological Effects (SLUCE)

6.2

Community frameworks for complexity models like these have been made possible by technological and computational advances coupled with new directions of scientific exploration and collaboration across broad domains of inquiry. In these community frameworks, research questions are increasingly focused on the seemingly intractable environmental and ecological problems of our time and their relationship to socioeconomic conditions. Almost all of these problems pose the challenge of embedding sociocultural variables in other systems (such as biophysical and economic ones). A powerful way to accomplish this is to spatially couple them to the environments in which they exist (Alessa et al. In Review). While this represents the "holy grail" of understanding complex and emergent coupled social-ecological systems, it is possible. Cross-disciplinary dialogue, cooperation and results in the biophysical sciences are already evidenced by the multi-disciplinary teams that are currently participating in CFCMs. In other words, the tools with which social scientists may develop robust frameworks for study, both within their domains and between other disciplines, already exist but the organization and mobilization of the SS-CoP does not.

A Community Framework for Complexity Modeling (CFCM) in the Social Sciences.

7.1

A parallel and collective cyber-infrastructure consisting of both cybertools and SS-CoP expertise (e.g., such as in the design of GUIs which allow input in real time from remote locations through the Internet) would help mitigate many issues faced by the social science community by providing an environment in which social scientists could collaborate with mathematicians and computer scientists to improve the usability of a common set of transparent ABM algorithms, could evaluate alternative ABM protocols against a common set of test data, and develop middleware to more tightly couple ABM output with GIS and visualization software (e.g., GRASS, ArcGIS, GNU-plot, and R). We feel that the convergence several important factors presents the SS-CoP with an opportune moment to develop a Community Modeling Framework for ABMs and complexity theory.

7.2

There is now a critical mass of practitioners, including those who practice in social sciences, mathematics, computational theory and application and cybernetics, linked through digital networks. Many of these individuals did not receive "formal" training in complexity theory but have emerged as a self-organized group of researchers. These practitioners are a potential core community of scientists needed to develop and support such a framework and develop introductory educational materials that can help other social scientists begin to understand and apply ABMs in their research. Forming networks of practitioners who communicate on a common goal of developing and evolving a CFCM allows interactions that cut across diverse applications and scales. As such, the next logical step in emergence is organization.

7.3

Case studies of the application of ABMs in social systems studies are now becoming available (e.g., Lansing 2002; M. Janssen, personal communication). If representative case studies can be archived within a community modeling framework, they can serve as the kernel for a test-bed, where alternative ABM protocols can be evaluated in terms of their efficacy in addressing research questions in social complexity.

7.4

A developing set of partial methodologies for ABMs in the social sciences is beginning to emerge (e.g., Lansing 2002, Epstein and Axtell 1996), but still lags behind those applied in the biophysical sciences despite the criticality of social phenomena to system dynamics. This is the time to develop a community framework that could begin to integrate these methodologies and use outputs and conceptual results from prior workshops, symposia and research. Establishing a community framework at this stage in the growth and elaboration of ABM protocols (when they are also beginning to attract attention for industrial and military applications) can help ensure that a suite of these cybertools remain transparent and accessible to social scientists, and can evolve in response to research needs through ongoing contributions by these scientists.

Challenges to be Addressed

8.1

In addition to the conceptual issues described above, there are a suite of more pragmatic issues related to more effective implementation of ABMs in social-science research, including the framework for a community-based approach to such modeling. These areas include the following:

Working with appropriate spatial scales and understanding heterogeneity

8.2

It is critical to understand changes in local scale sociocultural and economic systems that may result in cumulative effects which, in turn, are manifested at the regional and global scales. An integrated approach to the challenges of accurately modeling a heterogeneous system at local scales can aid in the prediction of long-term changes in coupled social-ecological dynamics related to diverse issues.

Linking the continuum of time and space: historic, contemporary and future systems

8.3

All social systems demonstrate continuity of some type throughout space and time. In other words, they have an origin, a history and current status and a trajectory. The application of complexity theory can aid our understanding of these patterns (e.g., deterministic chaos) by assessing the types and numbers of agents, their individual behaviors and their collective actions based on the types, number and strengths of their linkages.

8.4

Historic, archaeological, and palaeoecological datasets represent a rich source of information reflecting the cultural, behavioral, socioeconomic and biophysical environments in which societies existed (Redman 2005, Tainter 1988). Using them, we can develop both continuous and comparative types of contemporary research that can address a remarkably diverse set of questions and contexts. It is with both of these types information that we will be able to sort and program relevant data into prospective models.

Coupling Social and Natural Systems

8.5

An increasing number of social scientists recognize that we are, either wholly or in part, components of a coupled social-ecological system where sociocultural values and infrastructures often govern how humans interact with the biophysical environment (e.g., Alessa and Watson 2003). It is through these interactions, which are reflected primarily as qualitative data, that modifications occur in the biophysical space and produce feedbacks, which are generally measured as quantitative data. A coupled social-ecological system must thus be examined using innovative approaches that enable the meaningful combination of both qualitative and quantitative datasets. Such a combination requires appropriate mathematical frameworks which allow the programming of agents, their behaviors, and networks as complex systems. Without the ability to link local and regional ABMs which examine specific phenomena we cannot capitalize on the power of comparison within and between systems at different scales. The use of cyber-infrastructure, particularly in the form of a community modeling framework, allows researchers in the CoP to access this process regardless of their physical location and, in many cases, regardless of the resources they have available to conduct studies, including surveys. In addition, a CFCM could result in the emergence of novel questions which only become apparent once on-going and diverse efforts are linked through cyber-infrastructure.

Standardizing approaches while building flexibility into programming

8.6

A social science community modeling framework must be able to accommodate diverse and sometimes unpredictable research designs and datasets. However, these diverse datasets also need to be comparable over space and time. To do this may require coupling mathematical theory with applied computational tools and historic and contemporary social science data in order to evaluate the precision and robustness of ABMs.

8.7

Extensibility is also important for ensuring that a community modeling framework can be usefully applied across diverse research designs and datasets. Architectures that promote such extensibility, by permitting user-contributed modules to interact with core processes, not only allow a community model to evolve and meet changing needs, they also broaden the user/contributor base by encouraging new applications of ABMs.

8.8

Furthermore, the emerging field of complexity and social systems science needs standardized, accessible user input and output media into which different ABM algorithms could be inserted, methods tried, and concepts implemented and reiterated as an open process. This would allow social scientists to experiment with and evaluate the potential for ABMs, both alone and in parallel, to address a broad array of issues.

Creating interfaces, both for diverse models and for the users of those models

8.9

To move beyond the experimental design of current ABM platforms, which often require programmers for even simple implementation, will require innovative graphical user interfaces (GUIs) that can be manipulated by social scientists, while still retaining much more flexibility than is required of GUIs in most other software. It will be important to consider new approaches to interface design (e.g., graphically chaining model elements and 'intelligent interfaces') that could serve as more accessible front ends to existing platforms and facilitate the use of ABMs by social scientists for both self-interested and CFCM purposes.

Educating social scientists in modeling complexity and bringing social science to focus

8.10

The ability of practitioners to use mathematics, computer science and statistics in social science research varies tremendously across the social sciences from economists who spend most of their career developing and implementing computer models of market dynamics to cultural anthropologists who focus on qualitative assessments of personal interviews. Compounding this is that ABMs are a relatively new and experimental platform, thus few of even the most mathematically adept and computer-savvy social scientists are competent in their use from a conceptual standpoint — let alone a programming basis. These, among others, underscore the critical need for new standards for educating the next generation of social scientists. Even with reduction of software interface difficulties of access to ABM systems, the lack of training in the research-appropriate use of such analytical frameworks remains as an impediment to the wide-spread application of ABMs to complex SES.

8.11

Concurrently with a CFCM, there needs to be a concerted effort by the SS-CoP to train both active researchers in the field today and the future researchers who are currently students in the social sciences, complex systems and other cross-disciplinary fields such as geography. As importantly, we need to organize, as a community of practice, to realize a unique and timely opportunity: using emerging technology to move the social sciences into the forefront of understanding complex and coupled SES. A systematic, comprehensive and accessible tool and training program that utilizes but goes beyond existing resources (e.g., Axelrod and Testfasion 2006) is needed for all constituents to ensure that ABM tools are utilized effectively to further social science research as a community legacy.

Conclusion

9.1

For years the SS-CoP has often been viewed as insulated and/or peripheral disciplines with little relevance to more "concrete" biophysical phenomena and the authors posit that this condition lies squarely in the failure of the community to organize and capitalize on cybertools. If we fail to realize the opportunities provided by emerging technologies and improved access to information, we run the risk of being poorly incorporated into ABMs and ultimately the frameworks on which decisions are made. At worst case, the rich data provided by the social sciences are completely omitted from such decision frameworks seriously limiting the applications of the latter and further marginalizing the social sciences. Without an open and thorough discussion of how agent based models and a community framework for complexity modeling can serve the SS-CoP, our ability to elucidate the feedbacks and couplings between human and biophysical systems is severely restricted. This requires that the SS-CoP organize in an unprecedented way to develop a community-wide tool. Without the decisive recognition of the contribution of sociocultural variables to the function and trajectories of ecosystems our prediction of 'future outcomes' may be fatally flawed.

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Return to Contents of this issue