A practical approach to the complex problem of environmental sustainability: The UVa Bay Game

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ABSTRACT

Environmental sustainability is a *complex* problem in the very specific meaning of the word. With many dynamically interacting components in both natural and human dimensions, there are no concise descriptions or solutions to environmental sustainability problems. However, to better understand such problems, an agent-based simulation game of the Chesapeake Bay Watershed was developed. An underlying simulation model captures and represents the natural components of this largest estuary in the United States. Human (agent) behavior is captured through a "serious" game interface. The UVa Bay Game provides an experimental platform to advance the understanding of environmental sustainability in the university classroom as well as to enable policy-makers to discover and appreciate the unpredictable and often *emergent* consequences of their decision-making. The development of the UVa Bay Game is described and its current and planned use is outlined.

***Key Words*:** Complex system; simulation game; sustainability; socio-environmental system (SES); Chesapeake Bay

Introduction

Many problems facing society, from climate change to the worldwide financial collapse to the HIV/AIDS global pandemic, appear daunting because of a large number of interacting elements and the absence of proven theoretical approaches. Problems such as these are often referred to, in the words of C. West Churchman, as "wicked" problems (Churchman, 1967). Those tasked with finding and implementing solutions to such problems are challenged to find effective policies among myriad possibilities.

Problems of this sort, involving the interaction of numerous independent autonomous decision-making entities, are characterized here as *complex* systems (Ottino, 2004). In contrast to *complicated* systems, the behavior of complex systems is often *emergent* in nature, that is, unforeseen and unpredictable. It is these defining characteristics of complex socio-ecological systems that make many of today's problems "wicked."

A complex system of particular importance is the Chesapeake Bay Watershed. This socio-ecological system (SES) (Ostrom, 2007) provides multiple *ecosystem services* – the benefits people receive from nature – and is in danger of severe environmental degradation. Moreover, attempts to maximize the production of one ecosystem service (e.g., agricultural crops) can result in substantial declines of other services (fisheries, coastal protection) (Bennett, 2009). Covering six U.S. states and the District of Columbia and not governed by any one of them, the challenge is one of a *commons* (Dietz, 2003). Restoration and sustainability of this watershed require innovative policy approaches.

One approach to better understanding the nature of a complex SES is via simulation, more specifically, *agent-based simulation* (Axtell, 2000; Macy, 2002; Ottino, 2003; Tesfatsion, 2002). Recently, Farmer and Foley made the case for agent-based modeling and simulation as a means to understand complex system dynamics and to inform policy-making (Farmer, 2009).

The authors realistically describe the challenges facing developers of agent-based simulations in validating and verifying their models. Because there are many decision-making agents in a simulation model, understanding and properly representing their decisions and actions is a critical component. They call for a holistic approach integrating the "close feedback between simulation, testing, data collection, and the development of theory" as well as multidisciplinary collaboration.

The approach described below combines elements of both *natural* and *human* systems. The underlying simulation model captures, at a sufficient level of fidelity, the known dynamics of the natural ecological and environmental processes contributing to the health of the Chesapeake Bay, such as total nitrogen and phosphorous loads, population growth, economic output, the size of the anoxic region, and the sustainability of the blue crab population in light of environmental pressures.

Introducing human decision-making agents in various productive and policy-making roles provides the behavioral dynamics of communities acting in their perceived self-interest. These agents experience the results of policy decisions in a politically neutral environment with limited information and visibility into emergent global outcomes, including possible unintended consequences.

While emergent outcomes are by nature unpredictable (Ottino, 2003), in an agent-based simulation, such outcomes may be realized, especially with direct human involvement and over repeated experimental trials. Combining rich data with derived information and simulated system responses to decisions provides an environment for the exploration of alternatives, learning, and the consequences of policy actions.

The University of Virginia Bay Game

On the assumption that a serious simulation game (a game with learning and policy value rather than merely entertainment value) would provide a constructive platform for integrating disciplinary expertise and to incorporate realistic behavior among the game players, the UVa Vice President for Research challenged a multi-disciplinary faculty group to create a large-scale game and simulation model of the Chesapeake Bay Watershed. Initially skeptical, the faculty group - representing seven schools within the University - quickly confirmed this assumption and discovered that the process of game and simulation model development implicated them in intensive and intensely productive cross-disciplinary collaboration.

A premise behind this effort was, that after years of ineffective policy action with regard to restoration and sustainability of the Chesapeake Bay, the knowledge and technology to do so were available but we lacked the political will. The problem goes deeper than that however as Al Gore pointedly stated: "[w]e have everything we need except political will, but political will is a renewable resource…. The level of awareness and concern among populations has not crossed the threshold where political leaders feel that they must change" (Webster, 2009). The timing of this effort, then, has proven prescient as President Obama issued Executive Order 13508 on 12 May 2009 mandating the restoration of the Chesapeake Bay Watershed.

The underlying simulation model is a result of combining aggregated systems dynamics models with individual decision-making *agents*, both simulated and "live." These models and agents represent agriculture (some 64,000 farms), fisheries (5,000 watermen fishing for blue crab (*Callinectes sapidus*)), land developers, regulators, as well as citizens residing in the watershed, a population of nearly 17 million persons. Live agents interact with the simulation model through a game "dashboard" by which they enter their decisions and review the results of played rounds.

Based on experience to date with students, working farmers, actual watermen, as well as local, state, and federal policy-makers, the UVa Bay Game is an effective platform for basic research into a complex socio/technical/environ-mental system modeling; a medium for exploring and testing policy choices; and an environment for learning and raising awareness of the issues of sustainability among diverse constituencies.

Tests and outcomes

Scholars from the different disciplines brought their scientific, policy, and social science experience to the development of key elements of the simulation model. The process of making the various connections explicit was itself a helpful exercise, as it provided an opportunity for interdisciplinary learning and discourse. The simulation model is initialized with known, published data from the year 2000. To verify the model's accuracy, the simulation model was run without its game interface, meaning it had no live decision-makers. The results of the simulation through the year 2008 were compared with known data (the latest year of published data on the health of the Chesapeake Bay), and the simulation was found to be accurate in tracking key metrics against the known results; for example, the simulation model adequately tracked total nitrogen and phosphorous loads and the Chesapeake Bay Foundation's published "Bay Health" metric.

An initial test with undergraduate students from across the University community offered insight into the impact of unpredictable decision-making. In the test run, students played 10 two-year rounds of the Bay Game through the year 2020. With sensitivity to "doing right by doing the right thing," many students playing the role of farmers quickly abandoned high-yield methods and adopted low-impact or organic farming practices.

The result was a dramatic reduction in the nutrients flowing into the Bay from the agriculture sector – a major source of *non-point pollution* – with a consequent dramatic improvement in overall Bay health and a sustainable blue crab population. This outcome however came with unanticipated costs – there was a profound impact on the economics of the farming sector, suggesting an opportunity for creative policy incentives to support the transition to new practices.

he players, however, developed a better understanding of the complex structure and function of the Chesapeake Bay Watershed and importantly the relationship between human activities and the health of the Bay. Players now have the opportunity to re-play the Bay Game to better understand the nature of a complex system and how their decisions might impact outcomes – that is, to learn.

Informing policy

In addition to providing an environment for classroom use, the interdisciplinary faculty team recognized that an agent-based simulation model is an important tool for raising awareness of the precarious state of the health of the Chesapeake Bay and for informing policy aimed at reversing declining trends.

In a complex system, the results of externally applied policies may be unpredictable and even counter-productive as evidenced by the possibility of unintended consequences. Seemingly rational local decisions can have adverse consequences on geographically distant actors. Policy-makers face risks that their proposals will not achieve stated goals, receive a fragmentary response, or may even exacerbate the problem. An agent-based simulation model, especially with game-like interaction, provides a platform to explore proposed policies *a priori* to better understand possible policy effects. No one game experience, however, will accurately "predict" an outcome. Rather, it enables players to appreciate the *complexity* of the modeled environment; that a complex system does not necessarily respond to policy initiatives as planned and implemented; and that despite due care and consideration, unusual – *emergent* – outcomes may yet arise.

Evidence to date from Bay Game play involving actual stakeholders – farmers, watermen, and local, state, and federal policy-makers – indicates that such increased awareness is achievable, within the simulation game. In experiments with policy-makers, after initial protestations of "this is too simplified," they quickly engaged in effective dialog across agencies and constituencies, something they admit rarely happens in the "real world." But the resultant self-organizing behavior is a potent means for addressing complex SES problems (Ostrom, 2009).

Of more immediate potential impact is the challenge facing policy-makers with the promulgation of the President's Executive Order mandating action to restore the Chesapeake Bay's health. State and local regulators must now propose and implement policy actions to meet mandated targets starting January 1, 2011.

The way forward

Plans to extend the reach of the Bay Game to wider audiences outside the University include forming a regional consortium of universities and colleges to use and collaborate in the further development of the Bay Game. Projects are underway to develop variations of the Bay Game for other regions including outside the United States where issues of water quantity and allocation, in addition to water quality, need to be addressed. In particular, the Bay Game team is working with policy-makers in the Murray-Darling Basin in Australia to adapt a version of the Bay Game to their unique challenges including water allocation and the effects of climate change.

The Bay Game itself continues to evolve. To further refine the agent decision-making models, real farmers, watermen, land developers, and policy-makers are being asked to assist in improving the underlying simulation models and the game interface through structured interviews and actual game-play. Face-to-face communication among these subject matter experts will lead to greater fidelity in model development and will likely lead the building of social capital among groups with diverse and often opposed interests (Ostrom, 2007).

The UVa Bay Game is now in its third version incorporating numerous enhancements and extensions. This process of revision is informed by numerous game play events ranging from small classroom use to large public plays (over 120 concurrent players). Current information about the state of the UVa Bay Game's evolution can be found at www.uvabaygame.org. There is also a short, five-minute video highlighting the game's features at that site.

While the current Bay Game employs levels of aggregation above that of the individual citizen, a full agent-based model of the Chesapeake Bay Watershed, called UVa Bay Game/Analytics, is now under development to model decision-making at the level of the individual, all 16.7 million of them. At this scale, this is simulation-only version presents a significant computational challenge. But, as is the general case with large-scale agent-based models, the computational effort is inherently parallel, meaning that a grid computing architecture can be employed. The project was recently selected by IBM to run on its World Community Grid, a worldwide collection of nearly 1.5 million individual servers, thus solving the computational challenge.

Research questions exploring whether this experience leads to measurable, tangible policy action are currently being defined. To this end, our original faculty team has been expanded to include a social psychologist and an anthropologist.

Although the research agenda for the UVa Bay Game remains focused on improvement and extension of the underlying game and simulation models (e.g., an airshed model has been added and an oyster model is under development), research questions about the broader impacts of the Bay Game are being developed.

Challenges currently under consideration include:

- developing further experience with game-play in controlled experimental trials across diverse groups of players;
- assessing any impacts on policy- and rule-making activities;
- correlating game-play experience with personal behavior change (for example, reducing one's nitrogen-footprint analogous to one's carbon-footprint); and
- implementing a simulated market for tradable pollution credits.

Two final challenges on which research has started are linking changes in the health of the Chesapeake Bay to overall measures of public health. For this challenge, preliminary research indicates a significant linkage between the health of the Bay and the incidence of pulmonary diseases, for example, in the population.

And, as external groups have been introduced to the UVa Bay Game, the issue of the impact of climate change is inevitably raised. Including climate change was not a design element in the original development of the Bay Game but is now a matter of increasing importance. Including climate change effects in the Bay Game will present a significant challenge, as the science, policy, and politics of climate change are currently a topic of heated public debate.

Conclusion

The complex problems facing society today, while perhaps daunting and intractable with conventional approaches, lend themselves well to agent-based modeling and simulation. The UVa Bay Game's achievements echo the recommendations in a recent report by the National Science Foundation's Advisory Committee for Environmental Research and Education (NSF, 2009), which identifies three key goals for a reinvigorated initiative in the environmental sciences: "to provide a better understanding of complex environmental systems, a higher level of environmental literacy in the public, and a stronger foundation for informing policy decisions for addressing global environmental issues."

When combined with interdisciplinary expertise and interactive serious game features, agent-based modeling and simulation can serve as a platform for basic research, as an instructional tool, and importantly as a vehicle to examine and test policies that seek to alter and direct complex system behavior.

The key to the success of the UVa Bay Game is not simply the use of agent-based modeling and simulation, but rather the newfound spirit of interdisciplinary collaboration across traditional academic units. Through the combination of distinctively deep and diverse domain expertise, research universities are uniquely positioned to deliver innovative tools for solving our most challenging problems.

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Gerard P. Learmonth Sr. is Research Associate Professor in the Computational Statistics and Simulation Group of the Department of Systems and Information Engineering at the University of Virginia. In addition to the UVa Bay Game, Learmonth is engaged in agent-based modeling and simulation research efforts related to water and health issues in rural South Africa; a national study of the potential impacts of the recent U.S. healthcare legislation; and the spread of multidrug resistant infections in medical intensive care units.

David E. Smith is Professor of Environmental Sciences at the University of Virginia where his research interests are in the ecological processes occurring in coastal environments, conservation issues, and the intersection of policy and science. Prior to assuming this position, Professor Smith served as the Associate Director of the Virginia Sea Grant Program and as staff to the US Senate Commerce, Science and Transportation Committee in Washington DC. Dr. Smith graduated from the College of William and Mary with a BS degree in Biology and from Texas A&M University with a Ph.D. degree in Oceanography.

William H. Sherman is an Associate Professor of Architecture, Associate Vice President for Research and the Founding Director of the OpenGrounds initiative to promote cross-disciplinary research at the University of Virginia. As an architect and educator, his teaching and design research explore the relationship between architectural design, local ecologies and dynamic global systems.

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Jeffrey Plank is Associate Vice President for Research at the University of Virginia where he leads the UVA Bay Game and other related projects. He recently completed a three-book series on Louis Sullivan and architectural photography, building restoration, and architectural history.

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