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GeoGame analytics – A cyber-enabled petri dish for geographic modeling and simulation

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ABSTRACT

As researchers start to conceptualize human-environmental interactions through coupled human and natural systems research, the non-linear, dynamic, heterogeneous, feedback loops that are characteristic of those systems challenges a long-standing Newtonian paradigm of systems reducible to component parts, deterministic behavior, and the existence of equilibrium. As an alternative, complex systems researchers often use agent-based models (ABM) or multi-agent systems (MAS) to model and simulate complexity in human-environmental interactions.

This paper briefly reports on the development of a novel cyberinfrastructure portal solution called GeoGames. This computing environment integrates and leverages web-GIS and multiplayer online game technology to enable simulations of real-world scenarios of coupled human and natural systems applicable to anything from cities, urban regions to other human settlements. While there are some similarities between GeoGames and games like SimCity, and Civilization, a fundamental idea underlying the GeoGames approach is the focus on creating an on-line world that mirrors (c.f. Gelernter, 1991) authentic real-world geography, realized by a full range of GIS supported mapping and processing services (Ahlqvist, Loffing, Ramanathan, & Kocher, P).

In the context of our prototype platform we present the emerging area of Spatial Game Analytics (Drachen & Schubert, 2013) that provides an uncharted area for data-intensive geospatial scenario analysis. Our example scenario is a game that models the relationships of land management on hydrology and water quality. Our presentation is illustrated with examples from our own prototype platform that has generated a significant amount of user data on game play decisions and behavior. Exploratory GeoGame analytics are used to mine the spatial behavior of hundreds of players in order to identify how variations in the rules (land use policies) and varying locations (spatial configurations) affect the simulation outcomes.

1. Introduction

1.1. Coupled human-environment systems and agent based modeling

We are living in an era of ever increasing human impacts on the environmental systems. Researchers are increasingly recognizing that important properties of these systems are hard to predict unless we consider the coupling and feedbacks between human and environmental systems (J. Liu et al., 2007). A simultaneous development of complexity theory and research, have led many researchers to adopt approaches that use complex systems modeling techniques that consider aggregate complexity (Manson, 2001). Such complex systems are conceived of as self-organizing systems composed of many heterogeneous entities whose relationships with other entities, their environment, and ability to learn, create emergent behaviors and unanticipated outcomes. Research on such aggregate complexity often adopt computational approaches such as agent-based models (ABM) or multi-agent systems (MAS) because of their ability to model and simulate complexity and emergent behavior (An, 2012; Hare & Deadman, 2004).

An agent based model uses a computer system to model and simulate various decision-making entities such as individuals and institutions. Each software agent has a set of attributes and behaviors that are meant to replicate some important aspects of the real-world entity it represents. A core idea of ABMs is that a system of interacting entities can be modelled as any number of agents and that an agent based simulation can produce aggregate results that would be a possible outcome if the programmed scenario would happen in the real world. In this way ABMs allow for possible scenarios to be studied in a controlled manner by manipulating various configurations of the environment and agent behaviors.

As the geospatial domain saw increasing availability of data and computational power, a variety of geospatial agent models were developed (Sengupta & Sieber, 2007), with sophisticated examples in diverse application areas such as unrest and protest (Pires & Crooks, 2017),

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economic housing markets (Filatova, 2015), and humanitarian assistance (Crooks & Wise, 2013) However, it is generally acknowledged that the formalization of human decision making into software logic is very difficult. Partly because the decision making itself is complex, but also because getting access to empirical data on decision making is resource and time intensive. Consequently, these models typically have to oversimplify real-life decisions into some generalized understanding of what constitutes a rational decision in any given situation. Research is still addressing how to develop generalizable agent based models that can still be case-specific, and how to scale such models to involve interactions among many agents (Janssen & Ostrom, 2006). Some insights into agent heterogeneity have started to emerge (Huang, Parker, Sun, & Filatova, 2013), but it remains a persistent challenge.

1.2. Computer games and simulation

Games and agent based systems share many important characteristics. Games in general can be defined as "…a system in which players engage in an artificial conflict, defined by rules, that result in a quantifiable outcome" (Salen & Zimmerman, 2004). Additionally, games have throughout history had a dual role as both entertainment and 'serious' learning tool (Ahlqvist, 2011). This use is different from so called game theoretic approaches, e.g. in land use change and urban growth simulations (Y. Liu et al., 2015; Tan, Liu, Zhou, Jiao, & Tang, 2015), where the 'game' is essentially a simple rule-based algorithm. Increasingly, games are used in educational and training settings as they have the ability to provide situated experiences where players can engage in complex problem-solving activities (Squire & Steinkuehler, 2005).

This has led some researchers to look at role-playing games (RPGs) as a way to generate empirical data for the calibration of agent attributes and behaviors. A prime example is the so called Companion Modeling approach (Étienne, 2014) that employs stakeholders to role-play various land use scenarios and provide feedback on the elicited rules. Role-play is a particular form of game where a participant assumes the role of some character or object in a scenario of interest. Because a significant amount of decision-making is left to the player, guided by the imposed rules and circumstances, the applications of role-playing games range from business, planning and policy simulation (Becu, Neef, Schreinemachers, & Sangkapitux, 2008; Forssén & Haho, 2001; Poplin, 2012) to various educational games (Hays, 2005; Rieber, 1996).

The appeal of role-playing games to complexity research is how they allow researchers to study real human stakeholders involved in a realistic decision scenario. Face-to-face role play also has an added advantage of encouraging discussions among the players. All this could potentially be used as input to better understanding and modeling of agent based systems, but the translation of a few sample interactions into a general, yet diversified, ABM remains problematic. Formally representing human decision making, particularly when social interaction, negotiation, and adaptation affects actual decision-making, is not as predictable as what is generally expected from the rational "homo-economicus" of classical economics (Hare & Deadman, 2004). Hence, a key remaining challenge of ABM development is to generate decision knowledge from a representative yet heterogeneous sample of actual humans in various situations.

In light of the preceding overview, we see a possible convergence of online gaming and GIS technologies that leverage the analytical and data management strengths of GIS with the social collaboration and knowledge creation capacity of online games (McGonigal, 2008; Steinkuehler & Duncan, 2008). While computer games, GIS and agent based models, all exhibit some amount of overlapping capabilities and features, there has been limited efforts to integrate all three approaches. The Cormas framework is one effort along these lines and it has been an active area of research for the past decade or more (Le Page, Becu, Bommel, & Bousquet, 2012). It uses a multi-agent system for participatory modeling of socio-ecosystems to help stakeholders understand various resource management scenarios. While Cormas supports GIS data import and exports, it does not implement direct integration with a GIS and its underlying geospatial processing capacity. In another example effort Forrester and colleagues (2014) used Netlogo simulation to elicit additional knowledge from local stakeholders to build a model of ecosystems and livelihoods of artisanal fishers in a coastal water environment. While their approach used schematic map-like graphics, it did not integrate with a GIS, and the final outcome was a non-spatial process model. Netlogo has fairly recently been enhanced with some basic GIS functionality like import/export of GIS data and some simple spatial operations, so there is reason to assume that newer approaches with Netlogo will become more spatially advanced. To date, the most advanced integration of GIS into an agent-based simulation framework is GAMA (Grignard et al., 2013; Taillandier, Vo, Amouroux, & Drogoul, 2010) that provides substantial support for spatial analytical operations, a robust modeling language, and GIS data import/export functions. All of these diverse efforts have taken big strides in developing sophisticated models of real world systems by encoding both the environment and the agents and run computer simulations to study various scenarios in-silico. In our work reported here, we seek to explore the opportunity to replace coded software agents with actual people in simulations that could take place anywhere in the world and involve as many participants as a game can attract. With enough player data, we can then analyze the spatial behavior of actual human players/agents engaged in spatially situated decision making and environmental simulation, opening for the inclusion of widely heterogeneous decision-making where both rational and irrational behaviors are represented. Using an existing online GIS-based educational game called GeoGame – Green Revolution (geogame.osu.edu), we describe and analyze data generated from 419 participants playing a similar game, but with small variations. While currently small in size, our data illustrates how this approach opens an uncharted area for data-intensive geospatial scenario analysis.

A related idea is exemplified by how crowds of people can be leveraged into crowdsourcing systems (Brabham, 2008; Doan, Ramakrishnan, & Halevy, 2011) that produce massive amounts of geospatial information that can be turned into actionable knowledge, simply by using the Internet as a platform together with location based services for sharing and distributing content (Goodchild & Glennon, 2010; Zook, Graham, Shelton, & Gorman, 2010). In the case of our system, the crowdsourcing is characterized by a system that enlists a large number of participants to take part in a structured geospatial activity where we, as system owners and activity designers, are interested in how participants behave in response to different configurations of the activity.

2. Coupled land management and environmental model

In previous research (Ahlqvist et al., 2012) we have developed software that combine online GIS and multiplayer online game technologies to create a simulation environment called "GeoGame". Through several subsequent iterations we have further developed the technology to a browser-based, client-server architecture that allows for multi-user interactions with real-time map interactions, the use of multiple distributed data sources, and the incorporation of feature geoprocessing services. Using this novel cyberinfrastructure portal solution, we have developed a multi-player farming game that is used to let students in an introductory Geography course explore the concept of the Green Revolution by becoming a farmer in a developing country. After a signup process, players become the head of household and start farming on digital plots of land located in Punjab, India. Each turn represents a single growing season, and students play through 20 turns where they must decide, in each turn, how to manage their land and resources: Irrigate and fertilize plots of land to varying levels, plant either land race or high-yield seeds on each plot, sell surplus grain yield on the market, buy more parcels of land, purchase oxen to increase productivity, and purchase or sell additional labor. An overview of the game interface is presented in Fig. 1.