Summary of Proceedings: Special Workshop on Agent-Based Models of Land-Use/Land-Cover Change

An increasing number of scholars are exploring the potential of *agent-based* or *multi-agent system* tools for modeling human land-use decisions and subsequent land-cover change. In an agent-based model, individual agents (representing, for example, migrant populations, land-owner households, or local governments) autonomously make decisions based on internal rules and local information. While agent interactions may lead to recognizably structured outcomes, a set of equilibrium conditions is not imposed on these models, in contrast to modeling techniques such as mathematical programming or econometrics.   Thus, these models potentially offer a high degree of flexibility for accounting for heterogeneity and interdependencies among agents and their environment. Further, when coupled with a cellular model representing the landscape on which agents act, these models are well suited for explicit representation of spatial processes, spatial interactions, and multi-scale phenomena.

In order to bring together scholars with interests in this area for an in-depth discussion of goals, methodological challenges, and needs for research infrastructure, Focus 1 of LUCC (http://www.indiana.edu/~act/focus1/), the Center for Spatially Integrated Social Science (http://www.csiss.org/), and the Center for the Study of Institutions, Population, and Environmental Change (http://www.cipec.org/) jointly sponsored a special workshop on agent-based models of land use, held Oct. 4-7 in Irvine, CA. The workshop was organized by Michael Goodchild (CSISS), William McConnell (LUCC Focus 1), Dawn Parker (CIPEC), and B. L. Turner (Clark University). This workshop occurred in tandem with the U.S. National Academy of Sciences Arthur M. Sackler Colloquium on Adaptive Agents, Intelligence and Emergent Human Organization: Capturing Complexity through Agent-Based Modeling (http://nationalacademies.org/nas/colloquia/). A participants list, meeting agenda, abstracts describing participants' research activities, and copies of participant presentations, are available at http://www.csiss.org/events/other/agent-based/.

An overview paper, "Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review," by Dawn C. Parker, Steven M. Manson, Marco A. Janssen, Matthew Hoffmann, and Peter Deadman provided background reading for the workshop. In this paper, we review existing techniques for LUCC modeling, briefly discussing the strengths and limitations of each approach. We define a multi-agent system model of land-use/land-cover change as a union of agent-based and cellular models that incorporates endogenous links between agent decisions and their environment. We discuss several potential advantages of MAS/LUCC models. First, these models can incorporate mechanisms that generate complexity (heterogeneity and interdependencies) and illustrate complex outcomes (nested hierarchical structures and potentially related "emergent" properties). Second, these models allow the user to examine the path of land-use change dynamics, rather than only examining an equilibrium outcome. Third, these models can interface with geographic information systems models to represent space and link anthropogenic and biophysical processes. We discuss alternative roles for MAS/LUCC models, from generative (exploratory) to fitting (descriptive). We discuss the many challenges of verification and validation in these models, including understanding the behavior of non-linear models, parameterizing models, and comparing model outcomes to real-world data. Finally, we review current applications of MAS/LUCC models, and offer our perspective on ongoing challenges and opportunities in this research area.

The workshop opened with presentations of on-going projects by Jim Opaluch, Alfons Balmann, Thomas Berger, Peter Deadman, Dan Brown, Gary Polhill, Patrick d'Aquino, Steven Manson, and Dawn Parker. Following the NAS colloquium sessions, Michael Goodchild gave a

presentation on issues in spatially explicit modeling, and participants discussed lessons from the NAS sessions. Discussion focused on the concept of emergence and its definition and relevance for LUCC phenomena.

The remainder of the workshop consisted of structured discussions among participants, using a combination of break-out groups and full group discussion. Opening discussions focused on the potential strengths of MAS/LUCC models and what roles these models may play in research. The group identified a range of possible roles, from exploratory to predictive, and agreed that the entire range potentially represented appropriate applications of such models. Continuing discussions focused on issues related to data acquisition, model parameterization, and model verification and validation. Several issues received substantial attention. First, the group agreed that a clear definition of validation was needed. Second, both comparisons with results from alternative modeling strategies and application of existing validation techniques for LUCC models could be useful. Finally, the high degree of complexity in MAS/LUCC models implies special challenges for verification and validation.   The group then moved on to consider infrastructure needs for the MAS/LUCC modeling community, discussing available software tools and communication challenges. While development of a single standard modeling platform was not supported, participants suggested two strategies for more effective communication of model function: meta-data descriptions of model mechanisms, and provision of a pseudo-code version of the programming code used for specific model implementations. The need for integration of ABM, GIS, and validation software tools also was recognized. The group then created a distilled list of open questions that our discussion had not yet touched on. Challenges of modeling individual and group decision making, modeling institutions, and creating land allocation mechanisms were discussed. Additional questions are listed on the conference web site.

Several follow-up activities are planned. A LUCC working paper summarizing the conference discussions will be published through the Focus 1 office. Please contact Focus 1 if you would like to receive a copy upon publication (focus1@indiana.edu). A listserve or bulletin board to enhance communication between scholars in this area will be created, as well as an advanced web site containing background information on spatial modeling, a glossary, links to ongoing projects, model links and meta-data, and a bibliography. The group also discussed possible future conference venues and appropriate publication targets for work in this area across multiple disciplines. Further follow-up activities, including a special journal issue, a hands-on modeling workshop, and a future National Academy of Science colloquium are also being discussed.

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