NSF/ESRC Agenda Setting Workshop on
Agent-based Modelling of Complex Spatial Systems

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Land-use change as an application that challenges capabilities in agent-based modelling and spatial simulation

Modelling and analytical needs of the science land-use and land-cover change present some demanding challenges to agent-based and spatial modelling methodologies. Land-use change is increasingly recognised as an emergent property of interactions of coupled natural and human systems operating as a complex adaptive system (Stafford-Smith and Reynolds, 2002; Lambin *et al*, 2003). Land-use and land-cover change have been related to a variety of direct (proximate) and indirect (underlying) factors[1] (Geist and Lambin 2002, 2004). Observed changes are associated with i) multi-factor explanations, including interaction between factors, ii) complex local- and regional-scale institutional and individual decisions, themselves related to national- to global-scale opportunities associated with new technologies as well economic and other policies, and iii) historical contingency, reflecting development and transition of underlying and proximate factors over time and producing both path dependence and non-stationarity in change (Aspinall, 2004). Additionally, the meta-analysis of case studies of land-use change by Geist and Lambin (2002, 2004) shows that no universally applicable (in space or time) policies or practices for policy-level direction of land-use change are found, and that a detailed understanding of change at a given location is required to evaluate place- and time- specific patterns of change.

Explanation and modelling of change based on driving factors has served reasonably well, both as a basis for comparison across an international suite of case studies and for identifying important sets of influences on land-use change. However, for improved understanding and ability to analyse and model land-use change a factor-based approach must be expanded to include explicit recognition of processes that produce change. Natural system processes influencing land-use change include a set of processes concerned with soil, climate, ecosystems, and hydrology and there has been considerable progress in coupling environmental process models to GIS for scientific study of natural systems at spatial scales from local to global and time scales from short to long. The human system processes influencing land-use change reflect a complex set of individual, group, and institutional decision-making; there are fewer models of these processes despite efforts in economics, and an increase in agent-based modelling as a mechanism for addressing decision-making processes.

These qualities of systems of land-use and land-cover change indicate some of issues that agent-based and spatial models need to be able to address to i) improve understanding of processes producing change, ii) model change, and iii) improve our

[1] Underlying factors include demographic, economic, technological, policy and institutional, cultural factors (Geist and Lambin, 2002, 2004)

ability to predict change and project into the future. Two general requirements relate to the observation that there are no universally applicable policies or practices for direction of land-use change:

1. Place-based analysis and models are necessary for understanding land-use change. The capabilities of GIS to support place-based analysis and modelling provide a foundation for this.

2. Time-based (including historical context and contingency) analysis and modelling are necessary for understanding land-use change. Modelling methodologies and technologies thus need to be able to include characteristics of temporal context and contingency explicitly. This complements the need for place-based analysis to provide models that can adequately reveal local responses to change.

In the context of agent-based models that address individual, group and institutional issues, including decision-making processes, which operate primarily within the set of factors associated with the human systems component of land-use change I identify three related needs:

1. Agent-based models are needed that can represent individual, group, and institutional decision-making, and their interaction, in the context of larger scale economic and other (e.g. technological) opportunities and policies.

2. Management of the spatial representation of landscapes linked to an agent-based model such that the spatial extent, behaviour, and actions of individual agents are adequately located in space. This includes using GIS to provide spatial context and identify neighbours for 'geographic agents' in order to provide potential for peer-group interactions, diffusion of innovation, and shared or common decisions or responses that influence land-use change.

3. Management of the temporal resolution of agent-based models in relation to the temporal application and behaviour of the entity being represented as an agent. For example, many economic policies or technological opportunities effectively operate as constants over some period of time, yet individual, group and institutional responses to these policies and opportunities evolve and otherwise change over time.

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