Agent-Based Modeling (ABM) 17:

A Symposium That Advances the Science of ABM

Science Committee

Position Papers &

Second Survey Answers

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Position Paper

Dan Brown

Extending the Integration Frontier of ABMs for Decision Making on Sustainable Land Use

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Within land system science, ABMs fall on the process end of a pattern-process spectrum of modeling approaches (NRC, 2013). In particular, they provide a means of representing the structure of human decision, social, and institutional processes and how those structures affect social and environmental outcomes. By doing so, they provide the opportunity to construct what John Holland referred to as “flight simulators” for complex systems (Holland 1998, p. 243). A key goal of using models in this mode is to evaluate the consequences of interventions, e.g., through information and communication, institutional structures, regulation and enforcement, and market incentives and penalties, to address social goals. Because of the complexities of these systems, an important intermediate step, for which these models can be helpful, is to understand the consequences of model simplifications in biasing our understanding of complex system dynamics. This approach to reasoning with ABMs can be carried out through model “docking” (Axtell et al. 1996), in which the relational equivalence of models can be determined at the most common level of process specification detail, then ABM can be used to evaluate how the outcomes vary as new complexities are introduced or assumptions relaxed (e.g., Brown et al. 2004).

In the context of understanding the dynamics of coupled human-environment systems, including land systems, agent-based models (ABMs) have facilitated representation of a wide range of human behaviors and their impacts within these systems. ABMs support representation and exploration of non-linear dynamics, tipping points, and cross-scale interactions because of their ability to include heterogeneous, interacting, and context-aware agents. Additionally, agents that learn and cooperate can produce non-stationary behavior that represents regime shifts in social systems. The majority of these applications have been highly context specific. This has both lent a degree of credibility to the models in the context of specific systems, and also limited their generalizability and scalability. In an era globalization, urbanization, and climate change, we need to start to draw the boundaries of the systems we are modeling over much larger and heterogeneous regions. Work aimed at identifying the common inputs, interactions, and decisions across a range of land systems, like that of Magliocca et al. (2013), provides an important step in that direction. Continuing to address generalizability and scalability of ABMs is critical for greater impact on a sustainability science that informs decision making in the face of these broad trends.

Generalizable agent-based models provide the opportunity to interface with both Earth system models and integrated assessment models that provide the global reach needed for sustainability assessments under global change. Brown et al. (2015) outline the needs, as revealed in a workshop sponsored by the US Global Change Research Program, to combine modeling approaches across scales. “Because of the varied scales at which variables drive land-use change, and the multiple scales at which land-use scenarios can be applied, participants at the workshop considered the utility of addressing development of U.S. national land-use scenarios within an architecture that bridges multiple scales and modeling methods. Under a nested architecture approach, amounts of land use at the local to regional scales can be driven by the broader social and economic forces represented at the coarser scales, yet spatially allocated to finer resolutions" (Brown et al. 2015, p. IV). Complex local processes in the context of regional patterns and processes should integrate decision making by heterogeneous actors, interactions with environmental variability, and various interventions should build on the structure of and learning from ABMs.

To be useful in a decision making context, structured approaches to evaluating model responses to interventions, represented as variations in model structures and/or parameters, are needed. Sensitivity analysis certainly plays a big role in our ability to understand system responses in this way. Additionally, however, "substantial opportunities exist in the use of approaches that incorporate human values and goals in the modeling of land systems for design and planning (i.e. normative approaches). Optimization approaches … can be used to evaluate tradeoffs in ecosystem services resulting from alternative landscape patterns, to compare the relative performance of protected areas in providing suitable habitat, to consider alternative possible landscape patterns, and to complement both design-based approaches and process models" (Brown et al. 2013, p. 455).

The forms of integration described here might be advanced through a clearer articulation of standards of modeling practice for ABMs. The flexibility of ABMs is clearly one of their strengths, but model docking and systematic evaluation of interventions requires identification of the specific instances within which that flexibility adds value to understanding a system and is necessary (taking Occam's razor into account). It might be useful for this meeting to continue the discussion of the situations within which ABMs add value, and those in which they do not, relative to other models of land systems. This might allow for definition of practice for both docking to these other modeling approaches and identifying and justifying specific opportunities for integration.

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Keith Clarke

How to Motivate an Agent

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I recently completed a review of agent based and cellular modeling for the *Handbook of Regional Science* (Clarke 2014). This led me to review Helen Couclelis's paper at the original ABM workshop in 2001. One essential difference between cellular automata and ABM is that in CA motivations are "dumb," that is they are part of the structure of the model and its framework, and only rarely externally determined or exogenous. Couclelis's decision not to work with agents was because of their inherent equifinality, that is if the programmer or model designer chooses a particular motivation for the agents, then given enough time, that motivation will shape the agents outcome or spatial distribution. For example, in the classic Schelling model, residential segregation is inevitable in the behavior rules, regardless of the system states and initial conditions, thus the model fails to perform the function of helping to explain how and why segregation happens. Without this explanatory function of models, the use of the model provides no insight into the process, nor any educational value and so has no value for changing the future. After all, we model the future to change it, not to forecast it.

Many ABMs make naïve assumptions about human behavior because they use simplistic economic models about choice. Examples are rational man, profit maximization, utility maximization and prospect theory. Not all agents should be expected to behave the same. Known model uncertainties include the limits of the data, decision-making with incomplete information, copy-cat actions, complex multi-agent interactions that lead to emergence, agent learning and satisficing-based decision making. In my presentation I will discuss some of the more recent models of human decision making, and suggest what impact they could have on ABMs. I will also discuss the critical nature of model validation and verification, aspects of modeling that are paid far too little attention.

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Yue Dou

Quantification of decision making uncertainties through ensembles of agent-based simulations

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Among the modelling attempts to represent the interactions between human and the environment, the agent-based model (ABM) has proven to be an effective bottom-up tool, and has been utilized by analysts who wish to explore societal strategies of adaptation and mitigation for climate change and sustainability. However, for such models to be capable of representing human-environment interactions comprehensively, there is uncertainty possibly being introduced in every modelling process (e.g., the conceptualization and parameterization of the system). Coupling with the internal uncertainty of complex systems, it is essential to understand and quantify uncertainties for planning pathways of a sustainable future. Efforts being made to quantify uncertainties in many aspects, yet the uncertainties from decision making methods have not been investigated systematically.

To learn from climate change models and the previous other land use models, I propose that the ensemble approach should be introduced to the ABM community to acknowledge the uncertainty associated with the models, particularly the uncertainty that comes with the choice of a particular decision making model. Simulation outcomes are very different if different decision algorithms were used, as proved by several studies. However, methods need to be developed to evaluate the variance of outcomes that brought by different decision methods. Ultimately, the probability distribution of internal variabilities from different decision algorithms and scenarios should be established, so that uncertainty of decision processes is embedded in the model outcomes and policy implications can be given with confidence.

To facilitate the ensemble approach, easier efforts to construct ABMs with standardized decision modules (and modules representing other processes) should be promoted. To do this, our community can start to archive existing ABMs and standardize modules of decision algorithms and other commonly used processes. The library of modules gives ABM modelers access to easier modeling and transparent comparison, hence facilitating ensemble approach. In the long run, this can establish a population of agents that being used to represent climate adaptation into global climate models.

Sigrunn Eliassen

Animal decision making and adaptive behavior

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In ecological modelling a major challenge is to link the proximate mechanisms of sensing and decision making to adaptive behavioral responses. Traditional models have often assumed that animals have accurate perceptions and full information about their surroundings and that they are able to optimally respond to a given environment. In nature, animals explore their surroundings and the need to acquire information affects behavioral decisions, distribution patterns and resource consumption. Decisions are often based on multiple cues, in complex, variable and even novel environments, where long-term fitness consequences of behavioral choices are unpredictable. Instead of finding optimal responses to all possible situations animals use simple heuristic and rules of thumb that allow efficient information use in complex environments[1,2]

These decision-making structures can be incorporated mechanistically using an agent-based approach and be allowed to evolve as environmental conditions change. This is essential, especially when studying animal responses to a novel situation or rapid environmental change. To understand why some individuals behave maladaptively while others quickly adjust to change, we need to view behavioral responses in light of conditions typical in the organisms past. An important advantage of agent-based models is that they focus on the most significant biological structure and unit of natural selection: the individual organism. This enables complex description of individual traits and how they change through an animal’s lifetime and vary among individuals. In ABMs, each organism can be traced in space and time, allowing an explicit representation of interactions with other organisms and the physical environment. This approach is particularly relevant when interaction among agents is essential to capture the dynamics of ecological systems for instance in partner choice, competition or cooperation among agents. The flexibility of ABMs relaxes the strong restrictions on individual variation found in game theory models, and of interactions among competitors and environmental feedback in optimality models. This is important because the flexible and diverse behavioral responses that we generally observe in nature are rarely found in simplified models[3,4,5,6].

The agent-based approach can provide tractable tools for communicating theoretical perspectives to empiricists, and an intuitive way for students to explore modelling. Models focusing on individual traits and local interactions make comparisons with empirical measurements possible. In ecology, ABMs have mainly been used to study quite specific ecological systems, with less emphasis on general patterns and relationships. Many models rely on extensive lists of parameters, complex interactions, and processes that are not based in biological mechanisms, reducing the generality of the modelling framework. It is a growing concern that diversity in focus, implementation, and modelling approach makes it challenging to develop generic predictions and coherent theory of how and when key factors are determining the dynamics of complex ecological systems[7].

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Mirta Galesic

Position paper

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1) your area(s) of interest or insight into ABM;

My main interest is in modeling human social interactions, including in particular social learning, spread of beliefs on networks, and cooperation. My approach is to i) design simple but realistic models, based on empirical findings and established theories about sociality of humans and other animals, and ii) test them empirically to see how well they reproduce actual human behavior. I also try to fix as many free parameters by empirical measurement to reduce combinatorial explosion and opacity of underlying mechanisms, which is a frequent problem in ABM.

2) why (in what areas) you like or dislike ABM;

ABM can be a useful tool in almost all areas of science. I learned a lot from my own and others' mistakes in ABM and therefore I find all previous ABM attempts useful, necessary steps in scientific progress.

3) your potential plan or next steps that are related to ABM;

The main obstacle I have now is lack of good empirical data sets that I could use to test my models, in particular longitudinal data on both opinion change and the structure of personally relevant social networks. I am currently designing empirical studies to obtain such data, which in turn should help me to design better models.

4) what you envision the ABM community to accomplish within the next 2-5 years; or

It would be great to develop a better joint understanding for what makes an ABM a theoretically and/or practically useful. It would also be good to discuss how might the benefits of ABM be communicated to scientists using other methods of inquiry, in particular in disciplines that have relatively rigid methodological traditions such as economics.

5) what you expect the ABM 17 symposium to accomplish (specific outcomes the ABM 17 science committee should develop before, during, and after the symposium; the strategy to achieve these outcomes).

I am hoping for a lot of good, open-ended discussions about the current state of the field, problems we're encountering, and the future of the field.

Volker Grimm

Resilience, diversity, and behavior: predictive modeling of agent-based complex systems

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1) My area(s) of interest or insight into ABM

I am an ecologist and have used ABM mostly to analyze all kinds of ecological systems, addressing specific systems, applied problems, and theoretical questions. My main work, though, is on ABM methodology: how to design ABMs in a coherent way, how to communicate ABMs and their development and testing, how to achieve structural realism?

2) Why (in what areas) I like or dislike ABM

We are living in a world of agent-based complex systems where system-level structure and dynamics emerge from the agent's behavior and interactions, but those behaviors are in turn constrained by the structure and dynamics of the system. ABMs are the only way to capture this constitutive, mutual interaction between the parts and the whole. Approaches from statistical physics are not suitable to take into account adaptive decision-making of agents, and network theory has a too strong focus on structure.

ABMs are complex by nature. This makes is difficult, if not impossible, to develop just generic ABMs. To narrow down degrees of freedom in model structure and parameters, we need to relate them to specific systems or classes of systems. As a consequence, distilling general theory has proven difficult. So difficult that it is not tried in a systematic way, but without trying, agent-based modelling will remain case-specific, ad hoc, and too limited to understand and deal with agent-based complex systems.

3) My potential plan or next steps that are related to ABM

We need to link thorough ABM methodology (focusing on structural realism and first principles) with **"big" system-level questions on self-organization** (how does simplicity emerge from complexity) and system **resilience** (the ability to cope with disturbance and stress and still persist). Resilience analysis requires exploring recovery and resistance for multiple state variables, scales, and types of disturbances so that we can identify suitable variables that characterize the entire system, relevant scales, and mechanisms responsible for recovery and resistance that ultimately lead to resilience and persistence.

4) What do I envision the ABM community to accomplish within the next 2-5 years?

A research program and example ABMs for analyzing the resilience of agent-based complex systems in a generic way – independent of the discipline: how does resilience emerge; what are relevant variables and scales; how to define the system of interest; how can we restore, maintain or increase resilience to make systems fit to cope with known and unknown future disturbances and change ("resiliencing")?

5) What do I expect the ABM 17 symposium to accomplish (specific outcomes the ABM 17 science committee should develop before, during, and after the symposium; the strategy to achieve these outcomes).

1. A methodological manifesto, addressing agent-based modelers in all disciplines, outlining a research program and the methodology that is needed to put this program into practice.
2. A programmatic review for Science or Nature that shows: ABMs are beyond the state of just promising, but never really achieving wonderful things. By collecting example of successful predictions and practical solutions we can say: hey, we know how to do it, and from the successful examples we can identify how to do it the right way in general. Successful examples include: forest models, models of wild-life diseases, population models (fish, shore birds), pesticide effect models, - there must be more: traffic, biomedical research, etc. “Yes we can, and yes we must”.
3. Strategy: Collect “success stories”, identify reasons of success. Identify methodological challenges and outline solutions; Initiate a series of review and methods papers which contain the same overall scope and message, but are tailored for specific disciplines: economics, political science, sociology, biomedical research.
4. Discuss fundamental (ontological) differences that might exist between agent-based complex systems that:
    a. Are comprised of agents that are part of a unit shaped by evolution (cells, immune system, social insect)
    b. Are comprise of decision-making organisms, which have no or limited models of the decision making of other agents
    c. Include humans, which behave based on models of themselves, of others, and of the models of others etc.

Marco Janssen

Raising the bar

Marco Janssen

In this brief position paper I provide my background to ABM and what I see as important challenges. I am trained in Operation Research and since the early 1990s I worked on computational models of human-environmental interactions. We now call this agent-based modeling, but to me it was a natural extension of simulation approaches I was trained in. Besides ABM I also use system dynamics and analytical models (ODE). Over the last 20 years I have applied ABM to a wide variety of topics including climate change, malaria, social insects, hunter-gathering, collapse of ancient societies, rangeland ecology, lake management, collective action experiments, evolution of cooperation, land use change, marketing, and cybersecurity. I have combined ABM with other methods, especially behavioral experiments and case study analysis.

In 2007 complexity economist Herbert Gintis (http://jasss.soc.surrey.ac.uk/10/1/reviews/gintis.html) lamented the state of ABMs, their lack of transparency and lack of protocols to develop and analyze models. He concluded "Until this issue is thoroughly investigated and the truth sorted out from the myth, ABM will remain of limited value to the economic research community." Ten years later, this observation still holds. There is no organized professional community, journals do not check on the quality of the model implementation, and scholars do not share their code (http://jasss.soc.surrey.ac.uk/20/1/2.html). This might be a bit exaggerated, and some progress has been made, but with the lack of quality control and transparency, ABM will experience problems in being a widely accepted method. Rightly so, since one needs to be able to distinguish good practices from less desirable practices.

What is needed in the coming years is a change in common practices. If one publishes a paper using an ABM it should be required to archive and document the model code in a public repository and one should document the workflow (scripts) of the model analysis. This is not a technical challenge, but a social one, which is hard to address without an organized community. CoMSES Net (comses.net) is trying to make a modest contribution to this, but more is needed.

The ABM 2017 should not try to pretend to represent the community, especially given the biased sample of representation (land use change) at the workshop. However, it would be useful to have a discussion on the challenges why those interdisciplinary communities can become fragmented. In contrast to statistical, mathematical or operations research communities, we do not research on the method itself, but are mainly users. Nevertheless, we need to develop quality standards for it's use in order to improve the reputation of being a "new method" (something I hear for 20 years now). A possible outcome of ABM 2017 could be a manifesto of guidelines for publishing ABM which we can distribute to journals we are involved in. It would already be a major step if journals start to improve their (review) standards.

Instead of publishing code of complete models, one development that may take off in the coming years is the publishing of model components, nuggets of innovation within a more comprehensive model. Those model components should be citable and could be included in models of model components. Some model components that are core to a sub community might get optimized and could be used much broader. Informally this process is already happening, especially with open source tools like R, but within the ABM “community” not much sharing of model components is observed.

Finally, there is a need to pay more attention to model analysis. In recent years we see new methods for model analysis being explored, such as variance based sensitivity analysis, and approximate Bayesian computation. This shows the importance to share not only the model code, but also the scripts and algorithms used for model analysis. Furthermore, the use of those methods will also require more use of high performance computing, a small subfield within our “community”.

Tim Kohler

ABMs in Archaeology

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The Attraction of ABMs for Archaeology

Archaeologists typically resolve and describe the archaeological record in discrete periods of time. How long those periods are depends on the recency and location of that record. In the early Paleolithic temporal resolution is on the order of many millennia; in the northern US Southwest since ~AD 1, where most of my research is, periods vary in length between a century or so and a couple of decades, thanks to abundant tree-ring dates.

The societies we reconstruct for each period are composed of a series of patterns—in household architecture, site locations and size distributions, inferred ritual practices, subsistence regimes, and so forth. What is lacking in our description of these patterns of course is any direct observation of the processes of change intervening between the static snapshots provided by sequences of periods. These processes must be inferred in some way. Often theory employed by archaeologists suggests where to look for mechanisms of change. But even in such cases these processes are typically described in rather vague and almost always verbal ways. It is difficult or impossible to tell if the processes of change sketched in this manner are adequate to account for the changes seen in the record. This makes disproving any theory next to impossible. Even if one doesn't adopt a strict Popperian perspective, it follows that this also makes building convincing, empirically warranted theory equally difficult.

The promise of ABMs in archaeology then is to provide completely explicit models for processes of change. In some cases these might simply invoke some very general theory, such as the notion that human cooperation is fundamentally built on reciprocal social relations. Examining this theory was the point of much of Robert Axelrod's very productive work in the 1980s. So ABMs can operate at very general levels, as in tournaments between various strategies for playing the iterated prisoner's dilemma.

However ABMs can also be less general, and more realistic (to use Levins' terms): fitted to some specific place and time in prehistory, or perhaps simply fitted to examine a particular small set of processes in societies of some particular type (such as "chiefdoms.") My own modeling work has almost always been of this more realistic type. I have some modeling friends in France who contrast these styles as KISS ("Keep it Simple, Stupid") versus KIDS ("Keep it Descriptive, Stupid.") But I don't like the term descriptive too much here, because it can also be used as a contrast to explanatory. But the point of such models is precisely to be explanatory of mechanisms for change. The general strategy of such modeling is to exercise numerous plausible models, or a plausible model with a number of unknown parameters, to see which model (or which parameter set) gives the best fit to the dimensions of the archaeological records that are available for comparison. As a proponent of model-based science, I expect to examine a series of models of increasing complexity and compare their goodness of fit. The interest in this process is not usually to reject some model or set of models (although that could happen), but rather to hone in on increasingly satisfactory explanations for some set of changes perceived in the archaeological record (either through space, or through time).

What do I envision the ABM community in archaeology accomplishing within the next 2-5 years?

For over three decades, theory in archaeology has been dominated by various strands of what is often called "social theory" that typically has a post-modern cast. It is proudly non-explanatory and pointedly interested in answering only questions that have nothing to do with function or adaptation. A great deal of evidence however points to the increasing unpopularity of such approaches, perhaps in part because archaeology is now being called upon to take a serious role in helping to answer questions such as how various kinds of societies respond to various kinds of climate change; whether some styles of social organization are more resilient to crises of various kinds; and how, in a world where coastal and arctic resources are being lost at increasing rates, we prioritize archaeological sites for excavation before they are gone forever.

My opinion is that in this new environment agent-based modeling will come to have an important role not just in recasting general theory into local settings so that it can actually be examined against the archaeological record. We are beginning to do this now. I think that ABMs will have an increasing role to play in *building* theory, not just testing it. As our theories get increasingly sophisticated and precise verbal models will be seen to be increasingly unsatisfactory.

Impediments

The main impediment to this of course is providing the training necessary to make this vision possible. Relatively few anthropology departments make ABM training available to their students; I'm happy to say that my own is one of those. Meetings such as this also have their role. Progress in these directions will be slow, in part because many students are attracted to archaeology because of their perception that it is not a STEM field. But I remain confident that in 10 or 20 years, high-level theory that is not instantiated in a model will not be regarded as fully formed.

Katherine Lacasse

The Future of ABM in Psychology Research

Katherine Lacasse
Rhode Island College

As a social psychologist, I think ABM is useful for linking the individual-level psychological processes that I often study to larger-scale collective outcomes. In psychology, theories are often designed to explain attitudes or behavior at the individual level, and it is assumed that these effects will simply be additive at the collective level. ABM allows researchers to test this assumption and see if the collective outcomes are truly additive or something quite different. ABM also forces researchers to lay out their assumptions ahead of time, which can be useful. For example, do we expect that all people (agents) follow the same rules or are there people (agents) who we expect to respond differently? Finally, ABM is useful in examining dynamic outcomes over time, such as feedback loops. Each variable does not need to either be a predictor or an outcome, but it can serve as both throughout the model run.

My current work with ABM has been as part of an interdisciplinary working group, and ABM is one way we have modeled how human behavior may respond extreme weather events due to the changing climate. Specifically, ABM allows us to model feedback loops to examine how changes in behavior across a group at one time step alter social norms, which can then feedback and influence individuals' behavior at a subsequent time step. My future research will be to use ABM to model potential attitudinal responses to campaigns or laws aimed at altering individuals' environmental behaviors – such as laws banning one-time use plastic bags. This will allow for examination of how top-down policies that cause behavior change may also alter people's attitudes and beliefs relevant to environmental issues.

One future direction for ABM is promoting wider use among psychologists, which I see as an area ripe for growth. Specifically, social psychologists who are interested in interpersonal influence and group relationships would find ABM valuable. A problem is that virtually all current psychology research uses empirical data gathered from human participants - variables measured by self-report measures (survey) or observational measures (observing their behavior). Therefore, many psychologists would be hesitant to accept ABM experimentation in which the outcomes are based upon the "behavior" of imaginary agents with relatively less complex personalities/motivations than actual humans. Additionally, graduate programs in psychology rarely offer training in the coding or programming necessary to run ABM. These hurdles could be overcome somewhat through both education about ABM, and by highlighting how ABM can serve as a useful compliment (rather than replacement) to the survey and experimental research the psychologists are already conducting.

Position Paper

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THE ZEN OF SPATIOTEMPORAL SENSITIVITY ANALYSIS OF AGENT-BASED MODELS

Many agent-based models (ABMs) produce spatially-explicit outputs (maps) like land use change, biodiversity loss due to human activity, or population vulnerability to hunger to name a few. As any other result of simulation, output maps come in different realizations depending on input values. Assuming that a systematic investigation of the input space has been performed, these realizations constitute a three-dimensional distribution of the possible output space (the x and y coordinates and time). Unless lumped into an aggregate statistic (e.g. nearest neighbor index to summarize land use patterning), such outputs produce a major interpretation challenge. For example, a raster map of the size 100 x 100 produced at ten time steps amounts to 100,000 (spatially auto-correlated) output variables to explain where each cell constitutes one variable.

Modelers have resorted to sensitivity analysis to identify the influential drivers of output variability. Numerically, sensitivity analysis generates (a set of) sensitivity indices (SIs) that provide measures of input influence over output variability. Since they are quantitative, SIs afford the means of deriving succinct information on the input-output relationships. In this paper, we summarize **nine principles** for handling the complex issue of sensitivity analysis (SA) in ABMs using SIs as measures of the relative contribution of inputs to spatiotemporal (space and time dependent)[1] results.

[1] Uncertainty analysis (UA) should precede SA. Simply put, UA is the summarization of model outcomes in the form of output distributions and descriptive statistics - especially variance that is used to calculate SIs using variance decomposition. Without UA, we do not know whether there is enough variability in model output to warrant SA. For spatial outputs, UA allows for masking out regions of low variability which speeds up SA computation and simplifies its interpretation [1] – fig.1.

[1] Many of these principles also apply to scalar (spatially independent) outputs.

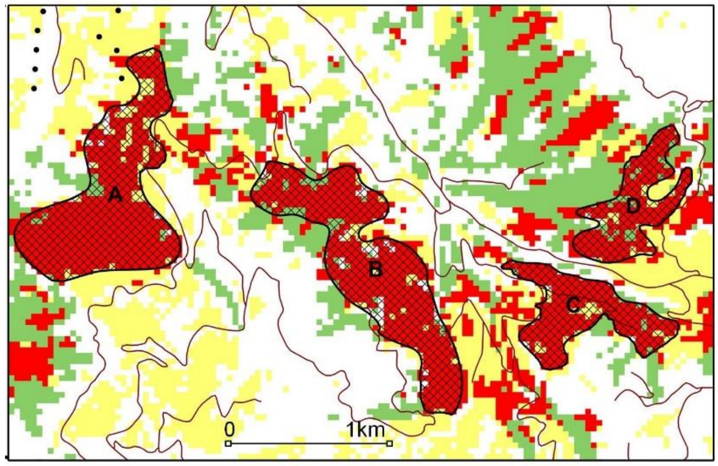

Figure 1 Example of output uncertainty map [2]. Regions of high variance are red.

[2] SA should be global. The most common approach to SA is to change the value of one factor at a time and observe how this change affects the (change in) output. A more general approach requires a systematic value change of a particular factor A in the whole range of its distribution. This is called One-Factor-At a Time – OFAT [3]. If there is an observable change in the results, A is labeled an influential driver of ABM outcome variability. We argue that OFAT has a couple of notable limitations. Since inputs are explored linearly, OFAT is incomplete [4], that is, it does not account for factor interactions. For example, two different factors can have little influence on outcome variability if treated independently, but when analyzed in tandem they can produce variable outputs [5]. In principle, OFAT can be applied to second and higher order factor interactions (e.g. A and B, A and C, B and C, A and B and C). Practically, this approach is computationally challenging as for K inputs we end up with 2^K-1 input-output combinations that need to be investigated. In contrast, while variance-based global SA does require a systematic sampling of the whole multidimensional space, it produces two concise measures (SIs) per each input factor: first-order index for factors treated independently and total-effect index that quantifies both first and higher-order factor contributions to output variability. Since OFAT does not produce SIs, it is difficult to apply when dealing with the large number of output variables, like maps, where the magnitude of change can vary over space (fig.1).

[3] For fast calculation of SIs, one should employ low-discrepancy sequences to sample inputs. Typical simulations use simple random sampling. The modeler uses a set of probability distributions and randomly draws a vector of sample values a pre-defined number of times (N). The disadvantage of this is that, for low N, random sampling does not generate evenly distributed samples (i.e. there are clusters of values for some combinations, and holes for others, fig.2). Since an accurate approximation of SIs requires evenly sampled K-dimensional vectors of sample values, with simple random sampling we need to set N to relatively high values. To reduce the high computational cost of sensitivity index estimation, a quasirandom sampling should be employed that results in more evenly distributed samples for lower N (fig. 2), accelerating the computation of SIs.

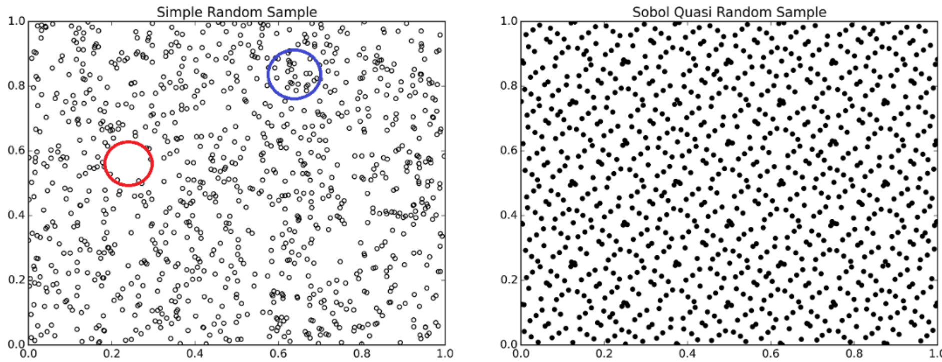

Figure 2 Sample points in a two dimensional input space derived with simple random sampling and quasirandom sampling [6]. Red circle: under-sampled region, blue circle: oversampled region (N=1000).

[4] Sampling, UA, and SA should be decoupled from model execution. Putting sampling directly in the model requires its modification each time we change our experiment. With the decoupled sampling, we can:

- Easily modify input distributions (e.g. move from normal to lognormal or change distribution parameters).
- Keep inputs saved for further analysis.
- Keep output for purposes other than UA and SA.
- Increase model transparency by separating data from execution.

[5] When reasonable, factors should be grouped to speed up computation and ease SA interpretation. ABMs require a large number of variable inputs. Assuming decoupled sampling and independent initialization of agents, with 100 agents each having five attributes we end up with 500 inputs. For variance-based SA the number of model runs is N(K+2) [4]. For N=10,000 the model would require 5,020,000 runs, which is computationally prohibitive. Therefore, it makes sense to group like factors without affecting model objectives. Seldom do we analyze every attribute of every single agent. Instead, we are interested in how agent inputs/attributes as a whole affect model results. So, in our example, we can create five groups of agent attributes, each having 100 values, and then use these groups as factors reducing N to 70,000 runs.

[6] All randomness should be accounted for in inputs. Not all randomness is captured in the distributions of input variables (factors). If unattended, these stochastic components are not the object of SA. In this case, we should try to "factorize" the stochastic components (e.g., keep them under the random seed) in order to account for the undefined randomness. Otherwise, we end up with information that is lost in the model during execution, rendering SA moot.

[7] SA should be used for model simplification. If a factor does not contribute to output variance, it can be fixed (set to constant like mean) to reduce input dimensionality, increase model transparency, and decrease model execution time. The simplified model should have (roughly) the same output variable distribution – fig. 3 [7].

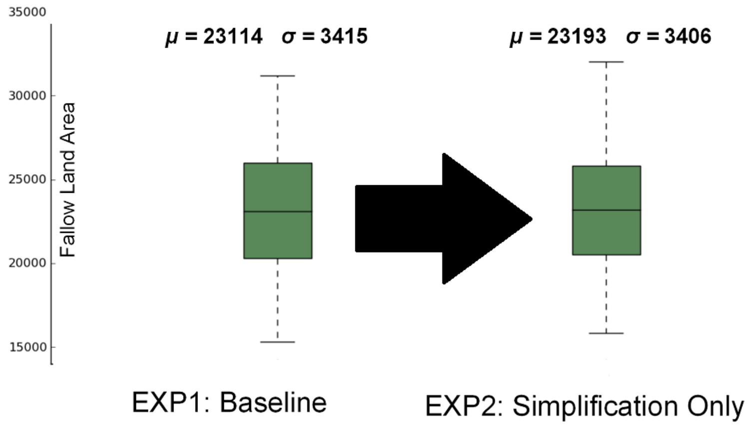

Figure 3 ABM output distribution before (EXP1) and after (EXP2) simplification [7].

[8] SIs should be provided with confidence intervals (CI). Wide CI mean that the SIs estimates are not very accurate, necessitating an increase in model runs. For a relatively low N, the SIs can be even negative. SIs are fractions that represent the relative contribution of inputs to output variability. Negative values are, therefore, meaningless. With the increase in N, negative SIs will ultimately converge to zero. However, setting them to zero without providing CI gives a false sense of precision in relation to other factors that are reported with some degree of uncertainty [3].

[9] For spatially-explicit outputs, multiple sensitivity maps can be substituted with one dominant factor map [2]. Even with a relatively low number of input factors, the interpretation of spatially-dependent SIs may be difficult. For example, for seven (grouped) factors, we end up with 15 output maps to interpret relative to each other (seven first order, seven total effect, and one interactions map). To ease interpretation, we proposed a dominant factor map [7] (fig .4), which partitions the space into regions represented by factors that have the highest SI value at a given location (i.e. a factor 'dominates' other factors).

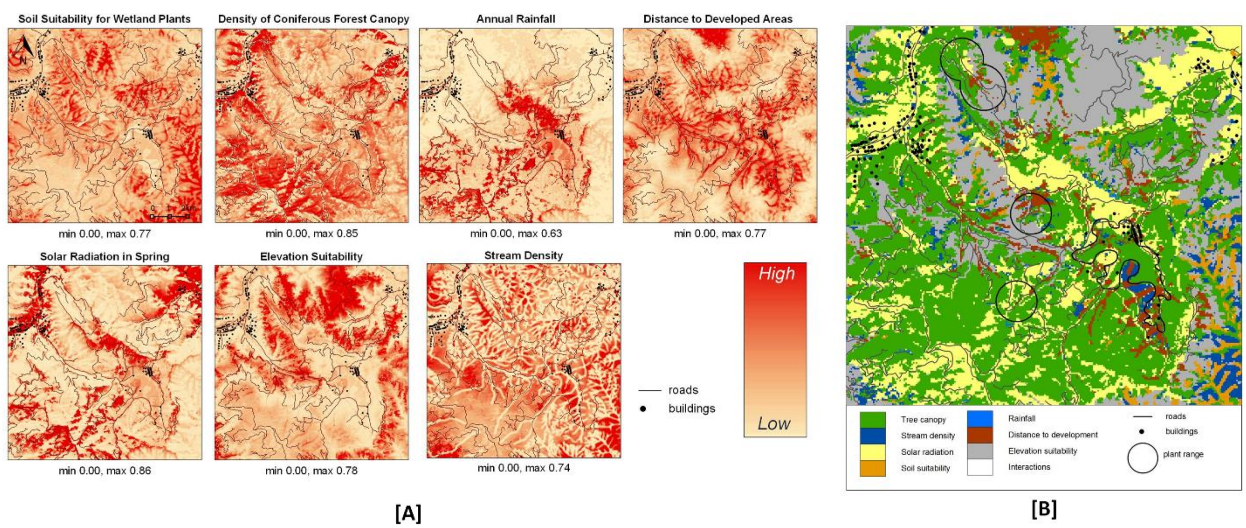

Figure 4 Individual sensitivity maps [A] and dominant factor map [B] (source [7]).

SA has largely been applied in a perfunctory manner using a variety of ad-hoc approaches. A more systematic approach, distilled to nine principles presented in this paper, calls for treating SA as an integral part of modeling, in which SA-obtained insights add value to information derived from ABM models.

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Jianguo Liu

Modeling telecoupled human and natural systems: From ABMs to TeleABMs

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Agent-based models (ABMs) are often developed with the implicit assumption that agents interact with each other within a system. However, agents across distant systems around the world have rarely been taken into consideration even though they are increasingly interacting. To understand and manage such complex distant interactions, an integrated framework of telecoupling has been developed (http://telecoupling.org, Liu et al. 2013). Telecoupling is socioeconomic and environmental interactions between multiple coupled human and natural systems (or human-environmental systems, social-ecological systems) over distances (Liu et al. 2013). It is a logical extension of coupled human and natural systems. As an umbrella concept, it encompasses many processes, such as migration, trade, tourism, species invasion, environmental flows, foreign direct investment, and disease spread. It expands distant socioeconomic processes such as human migration by explicitly and systematically including environmental dimensions and expands distant environmental processes such as animal migration by explicitly and systematically including socioeconomic dimensions simultaneously. It emphasizes reciprocal cross-scale and cross-border interactions (e.g., feedbacks). It also helps to better understand interactions among multiple distant processes (Liu et al. 2015a).

Interest in using the telecoupling framework has been growing rapidly. The framework has been conceptually and empirically applied to address a number of important issues, such as trade (of food, energy, forest products, industrial products, and virtual water; Liu et al. 2014a, Wicke et al. 2014; Liu et al. 2015a,b; Fang et al. 2016; Liu 2014), land use and land cover change (Eakin et al. 2014; Liu et al. 2014; Sun et al. 2017), species invasion (Liu et al. 2014a), species migration (Hulina et al. 2017), tourism (Liu et al. 2015a), water transfer (Deines et al. 2015; Yang et al. 2016a; Liu et al. 2016a), wildlife transfer (Liu et al.2015a), foreign direct investment (McKinney 2014), payment for ecosystem services (Liu and Yang 2013; Liu et al. 2016a), knowledge transfer (Liu et al. 2015a), conservation (Carter et al. 2014; Gasparri et al. 2015; Wang and Liu 2016; Liu et al. 2016b), economic development (Yang et al. 2016b), fisheries (Lynch and Liu 2014; Carlson et al. in review), and the spread of disturbances such as natural disasters (Zhang et al. in review). The Global Land Programme has chosen telecoupling as a research priority. It will be covered in every chapter of the upcoming report on the global assessment of biodiversity and ecosystem services, organized by the UN organization -- Intergovernmental Platform on Biodiversity and Ecosystem Services (similar to IPCC).

Telecouplings have profound implications for global sustainability and human well-being as they can transform structure, function, pattern, process, and dynamics of coupled human and natural systems across local-to-global scales. They pose new challenges and offer exciting new opportunities for the scientific community. To address such challenges and take advantages of the opportunities, it is necessary to develop a new set of AMBs – Telecoupled Agent-based Models (or TeleABMs). TeleABMs would better model and simulate the real world as the entire Earth is a telecoupled human and natural system, made of multiple coupled human and natural systems that are linked through flows of information, energy, people, organisms, and materials. Agents in a system interact with those within the system and in other systems. Incorporating agent interactions across systems over distances would face new challenges. For example, it requires new rules regarding interactions among distant agents, and such inter-system agent interactions would also change rules within a system.

As the first effort, a group of interdisciplinary researchers have proposed developing a TeleABM to simulate international trade as well as its socioeconomic and environmental effects under the telecoupling framework (Liu et al. 2014b). A TeleAMB is being developed using soybean trade between Brazil and China as a demonstration (Dou et al. in preparation). Agents in both Brazil and China are explicitly connected. It is our hope that this TeleAMB can also inspire the development of other TeleABMs for other telecoupling processes such as migration, tourism, and species invasion. Models like this will also be integrated into the Telecoupling Toolbox (Tonini and Liu in review), a suite of spatially explicit software programs that help operationalize the telecoupling framework and integrate various telecoupling processes.

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Steven Manson

Sharing data, sharing models

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There is increased interest around data sharing in science generally and in AMB specifically. Any conversation about data sharing must eventually extend to model sharing. Data and models are growing increasingly inseparable in many fields, and it will therefore be necessary to extend data policies to models that create or examine these data. Below are a few general issues along with some advantages and challenges in model sharing. These lists are meant to be more illustrative than exhaustive.

General issues

The state of model archiving is generally worse than data archiving, although some fields are ahead of others. Some research areas, like climate modeling, have a suite of fairly commonly-held models that are shared in the sense of being readily accessible (if not necessarily understandable to someone without advanced degrees in computer science, mathematics, or physics). Others, like integrated assessment, have shorter histories of sharing a fairly small number of well-accepted models. Some research areas, like mathematical modeling of microbiology, have standards based on commonly held understanding of a specific research domain, but they are in turn tied to this domain.

Other areas have de facto 'sharing' in that the models are simple or widespread. Regression-based models, for example, can be specified in a straightforward way as a mathematical equation or through recourse to a generic description of a well-understood model (e.g., OLS or logistic regression). That said, there are a growing number of cases where researchers have failed replicate seemingly straightforward analyses, even where both data and model formulation have been freely shared. Causes for this failure vary, but can range from obvious problems such as un-reported variable transformations to more subtle issues such as different statistical packages (or versions thereof) having slight variations on how they implement seemingly standard approaches.

Advantages of model sharing

The four reasons for data sharing noted by Borgman (2012) all apply to modeling; in short, to reproduce or to verify research, make the results of publicly funded research available to the public; enable others to ask new questions of extant data; and advance the state of research and innovation.

Some models create terabytes of results, and it may be more efficient or tractable to archive the model and its calibration/initialization conditions than to archive to data. Stochastic models and scenario models in particular may be more useful as test platforms that may be run repeatedly than as one-time generators of data.

There many reasons why models are useful beyond the standard ones of seeking explanation or prediction, and these additional reasons speak to the importance of sharing models. Among these are that models often structure knowledge, in that understanding how a model is constituted is to gain insight into the patterns and processes at play, and can in turn be useful for education and policy-making.

Challenges
Underlying model languages and systems change rapidly, ranging from shifts in underlying operating systems (e.g., there are geostatistical packages that run on DOS), language (e.g., the oft-used language Objective C is dying in the face of Apple spurring the use of Swift), and model-specific languages (e.g., there are a dozen agent-based modeling languages and they constantly evolve). There are countless other related challenges in how software is coded, maintained, and run.

Beyond basic software issues lies the gnarly mess of ontology and knowledge representation more generally. Successful modeling sharing schemes like CellML for cellular biology work in part because the domain is highly specialized and the core concepts are broadly agreed on, unlike many other research fields. We have ways to quantitatively represent abstract notions such as trust and power in models of society but encoding those in a model and then expecting them to transfer to different contexts is extraordinarily difficult. Modeling well known diseases or conditions such as Malaria or Hypervitaminosis relies on capturing a broad array of social and environmental conditions and contexts that are difficult to represent.

Model sharing has a lot to do with the larger culture. Some research cultures see model sharing as essential to scientific discovery, while others see models in proprietary terms, where data may be shared but models are protected for as long as possible.

Moving forward
As noted above, there are several fields that offer examples of model archiving. For example, there are heartening efforts in agent-based modeling (ABM) and they are instructive. Marco Janssen (ASU) and others have pushed for polices such as requiring model archiving at openabm.org for any ABM-based paper (e.g., it is a requirement for submissions at Ecology & Society), a move that has done much to ensure authors share their models. ABM is also home to a modeling documentation format -- Overview, Design concepts and Details (ODD) (Grimm 2010) -- that is becoming a de facto standard for many journals, often at the request of reviewers seeking better model specification.

Nonetheless, these ABM efforts also illustrate various needs for advancing model sharing. For example, ODD is still too abstract for many modelers, in that it can fall short in providing enough detail to facilitate model replication. Extensions are regularly proposed by researchers in sub-fields who feel that the generic ODD formulation is not specific enough (e.g., in how it handles decision making or networks). While this confers flexibility and specificity, it means that the single standard is at risk of fracturing into many sub-standards after only a few years after creation.

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David O’Sullivan

Once more with feeling: persistent challenges in the application of ABMs

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In a recent paper with others (O’Sullivan et al. 2016), I that there are four key areas that research deploying agent-based models in land use science should concentrate on to advance both ABM research and the field most rapidly. These are all topics worthy of more extended consideration in the ABM17 setting. Paraphrasing from pages 183-4 of that article, and adding some additional thoughts:

Sensitivity analysis and model evaluation There is a continued need for low-level methods of model evaluation. However, a more challenging, and persistent concern is how we determine the most appropriate model structures (as opposed to settings of model parameters) in particular cases, since it is comparisons among alternative model structures, rather than fine-tuning of model parameters that tell us most about the systems under study. Developments in the ‘meta-science’ of how models are communicated and reported, and what is considered best scientific practice may need to change in order for progress to be made

Participatory modeling The suitability of ABM for participatory model calibration, evaluation, and translation to policy is both promising and under-explored. Particularly interesting may be the linking of models in laboratory and experimental settings (Evans, Sun, & Kelley 2006

Hybrid modeling Understanding the best ways for linking ABMs to other modeling approaches and structures should be an important priority for the ABM community.

Theoretical engagement More work is necessary to enhance connections from ABM to theoretical concepts in the fields to which they are applied. ABM work in many areas appears biased toward a ‘kitchen-sink’ inclusivity in model structure that works against using ABMs as vehicles for advancing theoretical understanding and intuitions about systems under study. This bias may arise in part from the (relative) availability of funding for complicated applied modeling projects compared to simpler models that tackle theoretical questions of interest. There are exceptions to this generalization (physics and economics most notably) and the problem may be as much about the degree to which abstract theoretical models are deployed in other fields. Nevertheless the central challenge remains of understanding how best to apply ABMs as vehicles for advancing scientific understanding, rather than as one-of-a-kind representations in particular cases (the YAAWN syndrome of O’Sullivan et al. 2016).

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Viktoriia Radchuk

The future of agent-based models in ecology: extending to community and evolutionary perspectives

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Questions in ecology vary greatly. For example, we are asking: 'How individuals of the same and different species can co-exist together in conditions of limited resources?', 'What are the mechanisms supporting the genetic diversity of a single species?', 'How environmental cues affect the movement patterns of individuals?', 'How abiotic and biotic selection pressures affect the evolution of species traits, as a result modifying the composition of communities?'. Despite the apparent diversity, all these questions have one thing in common: the smallest discernible entity they all deal with is an individual organism, which can be described by a set of characteristics. Similarly, Agent-Based Models (ABMs) model individuals as distinct entities that are characterized by a set of traits, and therefore ABMs are especially suitable for tackling ecological questions.

Importantly, individual characteristics do not remain unchanged forever, in nature they may evolve under multiple selection pressures. And, ABMs allow reflecting this process by implementing the evolutionary mechanisms. Further, in reality individuals assemble in groups that can be spatial or non-spatial and may be hierarchically organized. Examples of such groups are families, populations, species, and communities. ABMs enable depicting the higher similarity of individuals within such groups than among them by characterizing the groups by certain properties (so-called 'state variables'). Taken together, ABM's toolkit seems to be especially appropriate for modelling biological systems at different levels of organization, and therefore facilitate understanding the processes acting on these systems.

Whereas early research in ecology focused on describing the patterns of species distribution, later studies increasingly aimed at understanding the factors that affect population dynamics of single species. It is now increasingly clear that in order to protect biodiversity we should go behind mapping species distributions and understand the mechanisms that lead to the observed distribution patterns. Understanding such mechanisms requires investigations of the population dynamics of multiple, instead of a single species, as well as understanding how individuals of different species interact among each other and with their environment. Importantly, recently the emphasis is made on integrating the evolutionary aspect in the community ecology because selection pressure is affecting both the traits of individuals and their interactions with other individuals, as a result shaping the community dynamics.

The majority of ABMs used in ecology until today addressed the issues of behaviour, sociality and movement in changing environments. Many ABMs were developed to assess the population viability of certain species. However, until now only a few ABMs focusing on the dynamics of a single species have explicitly incorporated the evolutionary potential. Moreover, the ABMs used in the community context usually neglect the evolutionary dynamics. However, our future progress in ecology hinges on the unification between community and evolutionary perspectives, and ABM has the potential to accommodate such a development. Indeed, the ability of ABMs to reflect the hierarchical structure of biological systems makes them indispensable in tackling the actual pressing issues in ecology.

In my opinion, the next few years in ecology will experience the rise of ABMs that investigate community dynamics while incorporating evolutionary processes. Such models will enable answering multiple questions that until now could only be addressed in simplified species-poor communities under experimental conditions. Examples of such questions are: 'How change in the inter-specific interactions in one community would affect the inter-specific interactions in other communities within the meta-community?', 'How changes in population dynamics of an influential ('keystone') species in one community will affect the dynamics of other communities within the meta-community?', 'Does temporal change in the genetic diversity of an influential (,keystone') species drive the dynamics of the beta diversity of a metacommunity?'.

Because the main criticism of ABMs concerns their complexity, I see this progress possible only when future models combining community and evolutionary perspectives will be based on the first principles and will re-use existing (sub)models. Building the models from the first principles will ensure the intrinsic links among multiple hierarchical components of the biological systems. And, by re-using already existing (sub)models the time for model development and testing will decrease, while credibility and trust in the model will increase.

Steve Railsback

Theory and Practice in Agent-based Modeling

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My interest in agent-based (or "individual-based", the term we use in ecology) modeling originated with a search for practical methods for modeling animal populations subject to dynamic environments, habitat alteration, and intra- and inter-specific competition. Key to making such models work is adequate representation of adaptive behaviors: the decisions animals make to trade off food intake, predation risk, and reproductive output. We know that these behaviors are very important to population dynamics, and that they cannot be represented adequately by traditional calculus-based population models. However, when we try to model behavior in ABMs we find that traditional models of animal behavior (which neglect competition and feedbacks from the decisions of other individuals) also are not useful. What we need, for all ABMs, is "across-level" theory: theory for what individuals do, in a system of other interacting individuals, that explains the dynamics of the systems. It is important that modelers think of the rules for how individuals behave as the key theoretical basis of ABMs and treat the development and testing of such rules as a major undertaking of theoretical science.

The way to develop this across-level theory is pattern-oriented modeling: using patterns observed in real systems to design ABMs of those systems and then to develop and test theory for agent behavior. Using pattern-oriented modeling means that we must base our models on real systems and include enough of the real system's complexity to explain its key behaviors. Many ABMs so far are "toy models", simplified to focus on one particular idea but too simple to show how important that idea is in reality. To be really useful for understanding and predicting real systems, ABMs often need to be more complex than most now are. It is fun when we can explain important patterns of a real system with a simple ABM, but such situations are rare and usually narrowly confined.

If ABMs need to be fairly complex to be useful, then we need to pay careful attention to methodological issues. One such issue of interest to me, perhaps because I have seen large ABM projects fail because of inattention to it, is software design and quality. Successful implementation and use of ABMs often requires more software expertise than most scientists have. The most common and costly mistake I have often seen is not routinely producing rigorously tested and documented versions of the model and its software as development proceeds.

One conclusion that can be drawn from these opinions is that agent-based modeling perhaps should not be looked at as a simple approach suitable, e.g., as a one person's graduate research project. My experience has been that development and testing of ABMs that are useful for understanding and managing real systems typically requires a team of people with separate expertise in modeling, the system being modeled, and software development. The NetLogo platform greatly reduces the effort needed for software development, but success still requires fairly deep understanding of critical software issues.

Maja Schluter

Agent-based modeling for developing mechanism-based explanations of SES phenomena

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Social-ecological systems (SES) are complex adaptive systems composed of people interacting with each other and with elements of their biophysical environment. The dynamics that emerge from these complex interactions across multiple scales can be highly non-linear and unpredictable posing significant challenges for SES governance and transitions towards sustainability. Agent-based modeling is a primary tool to study complex adaptive systems, particularly the emergence of macro-level patterns and functions from micro-level interactions of multiple situated agents that adapt and learn. I am interested in developing agent-based models of SES to capture their social-ecological interdependence and enhance our understanding of SES dynamics that result from the many local interactions of people with ecosystems within given social and biophysical settings. By combining agent-based modeling with empirical research in an iterative way I hope to be able to identify critical mechanisms that explain change or persistence in real-world SES. ABM thereby serves as a tool to test empirical hypotheses about key interactions and mechanisms by formalizing them in a model and testing whether the proposed mechanisms can give rise to observed phenomena. However, to effectively use ABM to simulate and explain real world SES phenomena of change (regime shifts and transformations) or lack of change (traps) we need to further develop them, particularly with respect to

1. Better representation of human adaptive behavior in ABMs

SES dynamics emerge from the two way interactions between humans and ecosystems, i.e. human action affects ecosystems and ecosystem change affects human action mediated by social and ecological processes. In order to capture this interdependence we need better representations of human adaptive behavior to social or ecological change. Human behavior, however, is diverse and context dependent. Capturing this diversity and understanding its implications for social-ecological outcomes and governance is only in its infancy. So far SES modeling studies have often addressed this challenge by developing simple ad hoc rules of agent behavior in particular case studies or using the rational actor model. This limits our ability to find patterns of realistic behavior across case studies. The social sciences provide a multitude of theories about human behavior, however, their incorporation in ABMs is still very limited and poses multiple challenges (Schlüter et al., 2017). Important next steps lie in the operationalization of different behavioral theories in ABMs and testing their ability to explain real world SES phenomena. We are currently in the process of developing ABMs that capture empirical insights in the diverse behavior of resource users in common pool resources, such as the Baltic Sea fishery (Wijermans et al., in prep.). The symposium could provide an important step forward by developing an overview of human behavioral theories suitable to incorporate in ABMs and developing a shared understanding of how the field could move forward to systematically address the challenges of doing so.

2. Using ABM to develop mechanism-based explanations of observed SES phenomena

a. Developing ABMs that are grounded in empirical research but not case specific

ABM in SES research are often tailored to specific cases or highly abstract. We aim to explore the middle ground, i.e. develop ABMs that are grounded in empirical social-ecological research but remain at a level of abstraction above an individual case study (e.g. Lindkvist et al., in review; Wijermans and Schlüter, 2014). This raises many questions with respect to how and to what level one can generalizing empirical insights in SES into a valid model. We use a combination of theory and empirical knowledge to approach this middle ground. A discussion I would welcome at the symposium and in the ABM community in general relates to how to develop such semi-stylized models as well as strategies to reuse particular (types of) these semi-stylized models in several contexts to test their validity and use for theory development. Another challenge connected to the process of iteration between empirical and model-based research is the communication of complex ABM to non-modelers.

b. Model analysis to identify mechanism and enhance understanding of cross-level interactions We are developing ABMs that formalize empirical hypotheses about interactions and processes that give rise to observed SES phenomena in order to identify key social-ecological mechanisms (Lindkvist et al., in review; Schill et al., 2016). I see a major area of future research in developing methods to analyze ABMs to identify key mechanisms that give rise to emergent outcomes. These include not only understanding the micro-to-macro link but also macro-to-micro interactions, i.e. the constraints macro-level phenomena pose for micro-level interactions. Furthermore, SES are composed of many levels, so an important next step is moving towards representing multiple (micro-, meso, macro) level and analyzing their interactions. I hope the symposium will provide opportunities for exchange on analysis methods and tools that allow disentangling causal mechanisms operating within ABMs.

3. Improved modeling practices, better validation

There are many examples of poorly developed ABMs of SES that lack a good model analysis, and well documented assumptions and model design. The usefulness of ABMs in SES research depends strongly on the ability of the ABM community to develop rigorous and transparent model development, analysis and documentation procedures. Recent developments of protocols and procedures for ecological and social-ecological ABMs (Grimm et al., 2006; Müller et al., 2013; Schmolke et al., 2010) are very important first steps. More efforts also need to be put into validating ABMs of SES. Given the scarcity of social-ecological data and the fact that there may always be a lack of data regarding particular social dynamics, this is not a trivial task. A next step I would like to pursue and would like the ABM community to engage in is to develop approaches to validate SES ABMs using pattern-oriented modeling (Grimm et al., 2005). The symposium could help advance this issue by developing a position paper on pattern-oriented modeling in social-ecological systems that addresses questions such as what is a social-ecological pattern, when is a SES model good enough for its intended purpose, etc.?

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Eric Shook

Fusing Agent-based Models with Geospatial Approaches and Analytics

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Agent-based Models (ABMs) are a powerful approach for simulating complex spatio-temporal phenomena. As ABMs adapt to meet new challenges and address increasingly complex problems, they began to be integrated into an ecosystem of tools (e.g., (Shook et al., 2015)). Geographic Information Systems (GISs) and data processing tools are used for spatial data preparation, statistics tools for data analysis, geovisualization toolkits for creating animations to name a few. From a user perspective, these computational ecosystems quickly become unwieldy to support, because maintaining a suite of tools, many never designed to be interoperable with each other, can be a time demanding task. From a scientific perspective, these ecosystems make results hard to reproduce, because package dependencies, ever-changing versions, and custom workflows make it difficult to replicate simulation results. From a systems perspective, the use of various tools with overlapping capabilities and features is inefficient and sometimes ineffective. This position paper calls for a rethink of agent-based modeling systems that are fused with geospatial analytics from the bottom-up.

A rethink will help address three challenges facing ABMs today: big data, parallel computing, and handling multiple spatial and temporal scales. First, as geography and many spatial sciences transition from being data poor to data rich, ABMs must cope with the amount of data that is available or being generated on a daily basis (Shook & Wang, 2011). Data are available at higher resolutions, with more individual-level information, and are updated more frequently than ever before. Second, the underlying architectures of desktop computers and computing nodes are changing. Processors in any modern desktop now have multiple cores. In order to use them to speedup simulations requires parallel computing. Performance is not the only reason why parallel computing is important to ABMs, modelers can run more simulations in the same amount of time enabling them to consider more scenarios or conduct more robust sensitivity analyses (Shook, Wang, & Tang, 2013). Finally, almost all ABMs are designed for a single spatial and temporal scale (Shook & Wang, 2015). Yet, scale is recognized as critical for spatial studies. New approaches are needed to enable ABMs to consider multiple spatial and temporal scales much like those used in multi-scale spatial analysis.

My current research involves reenvisioning ABMs, GISs, spatial analyses, and cellular automata not as solitary models, systems, and methods that are individually setup and executed to produce a single output dataset, but rather as an interleaved network of spatial and temporal procedures that together can consume, analyze, model, simulate, and visualize spatial-temporal data. I call this modelytics, which is the fusion of scalable spatio-temporal modeling, simulation, and data analytics. Modelytics goes beyond traditional means of loose, moderate, or even tight coupling between a GIS and an ABM (Crooks & Castle, 2012), which consider GISs and ABMs as separate entities. Instead, modelytics takes advantage of the fact that the basic building blocks of a GIS are the same as the basic building blocks of an ABM system. By creating a single unified system based on those shared building blocks rather than a coupled ecosystem of tools, modelytics is an improvement from the user perspective, the scientific perspective, and the systems perspective.

To realize this new vision, I am leading the development of a domain-specific programming language for modelytics tentatively called Forest. The language is designed For Expressing Spatial-Temporal (Forest) computation in parallel, which includes GIS methods, spatial analysis methods, agent-based models, and cellular automata. The language is based on basic building blocks (primitives), which can be combined in different ways (patterns) to create a method or model. The underlying system is designed to understand spatial data and can automatically distribute computational tasks (primitives) to different processing cores in parallel. Forest development has just started, but initial tests are promising and this new language will provide unprecedented opportunities for GIScientists and agent-based modelers to handle big spatial data, utilize parallel processing, and support multi-scale simulations.

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Abigail Sullivan

Institutions, human-environment systems, and practical aspects of ABMs

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1) Your area(s) of interest or insight into ABM:
I'm an institutional scholar and study environmental governance. As such, I'm largely interested in using agent-based modeling to analyze social-ecological systems from an institutional perspective. In particular, I think ABMs are a useful tool for understanding collective action related to natural resource management and the evolution of institutions (including rules, norms, and strategies). I recently used agent-based modeling to explore different theoretical perspectives related to how norms and strategies associated with invasive species management in Chitwan, Nepal might change over long time scales.

2) Why (in what areas) you like or dislike ABM:
To me, agent-based modeling provides a means of exploring difficult to observe aspects of institutions and is a useful way to understand patterns of change under many combinations of variables (or different scenarios). However, there are downsides to agent-based models. It can be frustrating to validate them, particularly if you lack much empirical data and/or are assessing an abstract ABM. Finding useful information for help during the coding/building process and deciding what language to build your model in can also be tricky. These issues can make replicating and explaining agent-based models difficult.

3) Your potential plan or next steps that are related to ABM:
I am currently working on the initial stages of an agent-based model (with Li An and others) that will explore the conditions under which communism might result in "success" (in terms of natural resource management). In the future, I hope to develop an approachable undergraduate-level ABM course and introduce students to the topics that can be explored with ABMs.

4) What you envision the ABM community to accomplish within the next 2-5 years:
I think the ABM community is shifting towards better communication of their models, results, and applications. In the next few years, I think this trend will continue and the community will produce models and science that are accessible to a wider audience. Additionally, I hope to see more integration of existing human-environment datasets in ABMs.

5) What you expect the ABM 17 symposium to accomplish (specific outcomes the ABM 17 science committee should develop before, during, and after the symposium; the strategy to achieve these outcomes):
I expect that our conversations and sessions on the five or six main topics (such as model verification and validation) will lead to a discussion of existing research and resources in each of these areas, as well as areas for improvement in each topic. It seems like these discussions would be an excellent opportunity to produce articles in each topic area that identify past contributions/progress and future research agendas. Also, I expect that our conversations will involve discussion of readings and other resources for ABM development (including verification and validation). So another natural outcome could be to compile these resources and make them more widely available (I'm not sure of the best place to distribute a resource list- perhaps other people will have ideas).

Wenwu Tang

Model Automation and Acceleration: When Agent-based Modeling Meets Cyberinfrastructure

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Agent-based modeling has been extensively applied to the study of complex adaptive spatial systems (CASS; see Bennett 2007). As a bottom-up approach, agent-based models (ABMs) allow for the representation of decentralized processes (particularly decision-making processes) in CASS. This representational power makes ABM unique for the study of spatiotemporal complexity in CASS in which decision-making processes and associated cognition often play a pivotal role (e.g., land use and land cover change, animal or pedestrian movement). A suite of complex properties, including emergence, path-dependence, self-organization, and adaptation, can thus be investigated through this agent-based modeling approach.

However, the use of ABMs for exploring dynamics in CASS often runs into a computational challenge. ABMs are often regarded as virtual laboratory that allows us to conduct computational experiments to address those questions that otherwise cannot be directly addressed through, for example, physical experiments. Yet, as spatiotemporal extent of interest increases and associated granularity becomes finer, ABMs are often computationally infeasible for answering those questions covering large study areas (e.g., regional or even higher)--thus further becoming a big data challenge. Even for small- or medium-sized problems, the capability of ABMs is limited computationally (e.g., when sensitivity or uncertainty analysis is needed, or intelligent agents are used).

In this position paper, I focus my discussion on the resolution of computational challenges facing agent-based modeling using cyberinfrastructure. As cyberinfrastructure emerged and developed one decade ago, cyber-enabled computing resources and technologies have been increasingly developed that enable and enhance scientific discovery. Cyber-enabled technologies are represented by high-performance computing, service-oriented computing, scientific workflows, and cloud computing (originally from distributed and grid computing). Here, I concentrate on two aspects of agent-based modeling that can reap benefits from cyberinfrastructure-enabled technologies: model automation and model acceleration.

Model Automation

ABMs of CASS are often associated with a suite of data (input, output, and intermediate) and modeling components (e.g., statistical or optimization modeling, or domain-specific models). That is, we need to couple these data and model components within an integrative framework. The integration of ABM and GIS for the explicit representation of spatiotemporal characteristics in ABM has been well studied in the literature. However, seamless integration of these data and modeling components within an integrative

ABM framework is challenging (see Tang et al. 2011). Further, once an ABM is developed, the use of the ABM over cyber-enabled computing resources often requires the further coupling of modeling-level capabilities with computing resources. Cyberinfrastructure-enabled solutions such as scientific workflows and cloud-driven technologies (e.g., virtual machines) hold great promise for implementing the integration needs of ABMs and thus enabling the model automation. Scientific workflows, based on graph theory, assemble the data and modeling components in an ABM by providing interfaces between these components. Thus, once scientific workflows for an ABM are set up, the execution of the ABM (from pre-processing, modeling, and post-processing) can be simply handled by the invocation of the corresponding scientific workflows (e.g., triggered by one-click or one-command operation)—i.e., intra-model automation. Further, cloud computing-based virtualization technologies allow us to recruit virtual machines for 1) extension of ABM functionality (linked to code sharing and transparency), and 2) automated deployment of ABMs over high-performance computing resources (e.g., lowering technology barrier for using these high-end computing resources). Thus, the (re) use of ABM becomes the sharing and use of scientific workflows or virtual machines.

Model Acceleration

The use of ABMs for the exploration of space-time complexity in CASS is often computationally intensive. A series of modeling steps, for example, sensitivity or uncertainty analysis, and scenario analysis, require a sufficient and often considerable number of Monte Carlo runs. Further, agent-based modeling over large spatiotemporal extent with fine resolution leads to more computational requirements (see Tang and Wang 2009; Tang and Bennett 2012; Tang and Jia, 2014). Parallel computing strategies (e.g., spatial domain decomposition, load balancing) provide solid support for utilizing high-performance computing resources available on cyberinfrastructure to accelerate agent-based modeling. An ABM that covers large spatiotemporal extent can be parallelized per se (at the intra-model level). On the other hand, Monte Carlo runs of ABMs can be deployed and run concurrently over multiple computing elements within cyber-enabled high-performance computing environments (e.g., supercomputers). While the barrier of using cyber-enabled computing resources for model acceleration tends to be lower, the estimation of computational demands (i.e., computational intensity) remains as a challenge due to the stochastic nature of ABMs and space-time complexity in CASS.

Concluding Remark

Of course, model automation and acceleration are just two typical benefits that agent-based modeling can directly reap from state-of-the-art cyberinfrastructure (from national, regional, to local). The capability of ABMs in scientific discovery can be expanded substantially with support from cyberinfrastructure. This model-level capability for addressing space-time complexity in CASS is associated with the computing capacity of cyberinfrastructure, which is often several orders of magnitude compared to standalone computing. Therefore, the representation and interpretation power of ABMs for the study of CASS (Bennett 2007) can be further enhanced by cyberinfrastructure. More importantly, an urgent need is to identify those questions 1) that we cannot answer using ABMs (due to computational limits) before the emergence and utilization of cyberinfrastructure, 2) solutions of which can be refined with the use of cyberinfrastructure.

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Leigh Tesfatsion

Modeling Coupled Natural and Human Systems as Locally-Constructive Sequential Games

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Real-world coupled natural and human (CNH) systems exhibit five common features. First, they consist of heterogeneous interacting participants characterized by distinct local states (data, attributes, methods) at each given time. Second, they are open-ended dynamic systems whose dynamics are driven by the repeated interactions of their participants. Third, human participants are strategic decision-makers whose decision processes take into account past actions and potential future actions of other participants. Fourth, all participants are locally constructive, i.e., constrained to act on the basis of their own local states at each given time. Fifth, the actions taken by participants at any given time affect future local states, inducing system reflexivity.

Taken together, these five common features imply real-world CNH systems are locally-constructive sequential games. Two key questions can thus be posed. Do modeling tools exist that permit real-world CNH systems to be represented and implemented as locally-constructive sequential games? If so, can these tools usefully advance our knowledge of real-world CNH systems?

In Ref[1] I answer both questions in the affirmative for economic systems, focusing specifically on Agent-Based Computational Economics (ACE) for concrete illustration. My conjecture is that the answers proposed in Ref[1] for economic systems using ACE can easily be extended to the more general case of CNH systems.

ACE is the computational study of economic processes, including whole economies, as open-ended dynamic systems of interacting agents. The driving concern in the development of ACE has been to provide a flexible modeling approach that enables a researcher to specify and implement a model for a problem at hand with a degree of empirical verisimilitude appropriate for this problem. In particular, modelers should not be forced to rely on a priori model specifications that are clearly falsifiable in terms of available empirical data and whose only justification is analytical tractability.

ACE is a specialization to economics of the more broadly conceived approach referred to as Agent-Based Modeling (ABM). Although the precise meaning of ABM continues to be debated in the ABM literature, seven specific modeling principles have been developed for ACE that carefully distinguish it from other types of modeling and that highlight its particular relevance for the study of CNH systems in general and economic systems in particular.

These seven ACE modeling principles are concisely stated in Ref[1, Section 2]. Taken together, they express the fundamental goal of many agent-based modelers: namely, to be able to study real-world systems as historical processes unfolding through time, driven solely by their own internal dynamics. Ref[1, Section 3] succinctly characterizes four basic ACE research objectives: namely, empirical understanding; normative design; qualitative insight; and methodological advancement.

Challenging issues for ACE modelers are addressed in the next three sections. Ref[1,Section 4] considers distinct aspects of empirical validation that researchers tend to weight differently, depending upon their objectives: namely, input validation; process validation; in-sample fitting; and out-of-sample forecasting. It is argued that ACE modeling permits researchers to strive for a comprehensive approach to empirical validation that simultaneously considers all four aspects.

Ref[1, Section 5] discusses the increasingly important role that ACE models are playing as computational laboratories for the development and testing of policy initiatives in advance of implementation. A taxonomy of Policy Readiness Levels (PRLs) is proposed for policy initiatives ranging from conceptual policy formulation (PRL 1) to real-world policy implementation (PRL 9). ACE modeling is helping to bridge the difficult gap between conceptual policy research (PRLs 1-3), typically undertaken at universities, and large-scale policy models incorporating numerous real-world features (PRL 7) that are favored by industry, government, and regulatory agencies as a prelude to field studies (PRL 8) and real-world policy implementations (PRL 9).

An additional potential benefit of the PRL taxonomy is addressed in Ref[1, Section 6]: namely, it could facilitate the development of presentation protocols for economic policy models that appropriately take into account model purpose and level of model development.

Ref[1, Section 7] considers ways in which ACE permits edgier explorations of critical real-world systems. Several ACE studies are briefly summarized to demonstrate how ACE enables the modeling of adaptive communication, strategic choice and refusal of trading partners, endogenous network formation, anticipatory learning, spatially-configured interactions among coupled human, physical, and natural systems, and endogenous growth and change.

In Ref[1, Section 8] it is shown how ACE can be viewed as a limit point of a broad spectrum of experiment-based modeling approaches ranging from 100% human subject to 100% computer agent. By design, any decision-making agent in an ACE model can be replaced by a real person. This opens up huge mix-and-match opportunities to study human behaviors in realistically rendered contexts as expressed both individually and in groups.

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Unlock the potential of agent-based modeling for policy analysis

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Agent-based modeling for policy analysis

Agent-based models (ABMs) simulate decisions of heterogeneous agents in complex systems, and have been used to explain macro-level phenomena in a variety of systems, from economies and markets to social organizations and land use. A number of studies have applied agent-based modeling for policy analysis (e.g., Berger, 2001; An et al., 2005; Happe, Kellermann and Balmann, 2006; Robinson and Brown, 2009; Van Berkel and Verburg, 2012; Schouten et al., 2013; Quang, Schreinemachers and Berger, 2014; Tian, Holland and Brown, 2016; Walsh and Mena, 2016).

A major benefit of using ABMs for policy analysis comes from their ability to capture agents' different responses to policy interventions and their interactions. The particular strength of agent- based modeling lies in its exploratory capabilities (Bankes, 1993; Cioffi-Revilla and Goolsby, 2011), and these can be further unlocked for policy analysis (Tian, in press). In addition to evaluating policy effects, ABMs can be used to explore policy levers, tipping points, adaptive policy, robust policy, unintended consequences, and disastrous future outcomes.

Models are excellent adjuncts to human intellect, and we can combine model experiments with human intellect to better inform policy decisions (Lempert, 2003). A computer is capable of computing a large number of scenarios but cannot capture the richness of human experience. Humans have an incredible ability to recognize patterns and make inferences with limited information. We also possess contextual and qualitative knowledge that is difficult to implement in a model.

We can combine agent-based modeling with other methods to enhance its capabilities for policy analysis (see also O'Sullivan et al., 2016). For example, we can integrate GIS within an ABM to explore spatial effects (see Torrens, 2010; Heppenstall et al., 2012; Malanson and Walsh, 2015). We can combine mathematical tools developed in systems dynamics and bring in data-mining techniques, such as evolutionary algorithms, to explore the model parameter space and data produced by agent-based models. This can help identify conditions that lead to disastrous outcomes, bring insights about robust policy, and inform adaptive policymaking.

We can also integrate social network analysis, another technique for analyzing complex systems, to explore social influences. Network-based interventions have long been used to effect change in the real world (Valente, 2012), and are an important part of "smart" policy. As social media and smart devices become more popular, social networks in the cyberspace will likely exert increasing influence over individual behavior and could be used for policy purpose. However, to make "smart" use of social media for policy interventions, we need to understand how these virtual relationships affect individual behavior in the first place.

Persistent challenges for the ABM community

Agent-based models capture agent diversity, interactions among agents, and the feedback between individual behaviors and global states. This strength of agent-based modeling however also creates challenges for modelers in conceptualization, validation, and communication with “outsiders” (Parker et al., 2003). Despite all the efforts and progress that have been made (e.g., Axtell and Epstein, 1994; Grimm et al., 2005; Brown et al., 2008), these challenges remain for the ABM community. Among them, model conceptualization is crucial: where to draw the system boundaries, what components to represent, what attributes of agents to include, how to represent agent decision making, and most of all, what is the appropriate level of abstraction.

Meeting these challenges is even more critical for policy analysis. To convince policy-makers, we need high levels of confidence in our models. To develop credible models, we need to have a good understanding of the system in question. Understanding how the human agents in a system make decisions is particularly important for policy analysis. This understanding helps us to identify macro-level processes that constrain individual choices and could be improved by policy, and to design “smart” policy to influence individual behaviors, facilitating positive changes in a system. Ultimately, we need broad understanding of a specific issue beyond model experiments to persuade policy-makers.

Looking ahead

I hope in the next few years, agent-based modeling becomes a mainstream tool across fields. Generally speaking, the ABM community needs to demonstrate that agent-based models can bring important new insights about complex systems, (i) contributing to science (theory), and (ii) influencing policy in the real world. We also need to work on advancing the general science of complex adaptive systems (see Holland, 1995, 1998 and 2012).

This symposium will be a great opportunity for agent-based modelers to share individual experiences in addressing persistent challenges as well as emerging ones. There has been an increasing desire to build large-scale, realistic models and to integrate big data and deeper human cognition. These new challenges likely compound the old issues. We might review the progress made by the ABM community on the two fronts (i.e., contributions to theory and influences over policy), and discuss how to move forward.

Such discussions will inevitably touch upon limitations of agent-based modeling. One is obvious: not any single method is sufficient to gain deep, full understanding of a complex system. A variety of empirical research methods can be and have been used to inform the development of ABMs (Janssen and Ostrom, 2006; Robinson et al., 2007). These empirical methods each provide important understanding of certain aspects of a system; it is necessary that we combine them with agent-based modeling to study complex systems.

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Peter Verburg

Limits of agent-based modelling in global land use assessments?

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In the field of land use change agent-based modelling is often claimed as superior to other types of modelling for its ability to distinguish different behaviours of different agent types. Other model types either assume a representative agent (such as most economic equilibrium models) or use land units as units of simulation, hence only implicitly addressing the decision making process. While no one will debate the need to address decision making explicitly and account for different agents the success of using agent-based models beyond relatively small case-studies is limited. Still, all large scale assessments for IPCC and IPBES are made with land use models that ignore agency and are mostly based on either representative, uniform actors or heuristics applied to pixels. So, why, in spite of the large research investments, has agent-based modelling in the field of land use change failed to deliver successful implementations beyond small regional cases? Reasons may include:

1. Computational issues: a full representation of decision making would basically require a representation of the full world population that directly, or indirectly, influences land use. Such may result in increasing complexity and computational needs. Alternative ways may include either using (again) representative agents or 'higher level' agents such as communities rather than individuals. However, both approaches would require a means to represent of agent interactions, either through embedding these within the representative agent-behaviour or through nested models that explain emergent behaviours at the aggregated agent level.

Other ways of simplification, such as the assumption that each pixel represents an agent and agent-types defined by the land use take out the specific advantages of agent-based modelling and, in fact, such models start resembling spatial land use models to a large extent.

2. Behavioural uncertainty: probably the most critical point is that we lack clear information on the (diversity) in behaviours and decision making across the globe. Agent-based models either use assumed profit optimization or alternative models, including fully heuristical models, based on observations, games or surveys within the case study area. Such is simply not possible at global scale and adequate data to make behavioural assumptions are not available. A meta-analysis of behavior observed in case studies across the literature revealed that indeed different behaviours in land use decision making are observed. Rather than fulfilling the archetypical modes of decision making most of the documented studies report behaviours that combine elements of the more archetypical modes often included in agent-based models. Without the ability to specify differential decision strategies the specific advantages of agent-based modelling become obsolete.

3. Data shortages: the strong reliance of land use agent-based modelling on socio-economic characteristics and data to characterize agents causes a high data requirement. Global coverage of many socio-economic essential variables is limited. Without such data simplification of agent-based modelling would need to happen to such a degree that all advantages are gone.

While the above reasons easily explain the lack of success in larger scale applications of agent-based modelling in the field of land use change. However, at the same time we are still faced with a lack of representation of agency in large scale land use models. So, what are alternative ways forward? In my opinion the following avenues all represent potential contributions to making progress in this field:

1. Investment in gathering and synthesizing socio-economic data at global scale. Much more data is collected as part of national and regional surveys that may inform land change modelling and allow better representation of the social dimensions. Census data often contain much information for sub-national units. Large efforts in reconciling and harmonizing the data to a spatial framework are needed to make such data useable and constraints in obtaining the data may be faced.
2. More experimental work and better documentation of case study findings is needed to better understand variations in decision making strategies, the roles of adaptive behavior and behavioural feedbacks on environmental change
3. The development of ways that combine the strengths of agent-based and pixel-based models. Pixel-based models allow the inclusion of agency by differentiating transition rules to specific contexts and land use systems. Rather than modelling land cover, as a symptom of land use change, the changes between land use systems, as socio-ecological system could be simulated, more fully accounting for the differences in agency embodied in these different systems. Further development of 'hybrid' approaches that allow including agency in spatial models could lead to a new generation of land change models.

To achieve the above we would need to overcome the notion of superiority of full-fledged agent-based models while also more strongly recognizing the fact that current large scale models may provide highly biased results by ignoring agency.

Stephen Walsh

Modelling the Transition of Fishers to Tourism in the Galapagos Islands

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Introduction

In the Galapagos Islands of Ecuador, many have long looked to tourism as a vital economic engine to support its residents, while simultaneously protecting its unique and fragile ecosystems. Tourism, however, has created as many problems as it has intended to solve. Nearly 225,000 tourists visited the Galapagos in 2015 as boat- and/or land-based tourists, with differential impacts on the environment, communities, iconic species, and amenity resources of the archipelago. As tourism increases, the number of residents (~30,000 today) expands to provide services through jobs mainly in the burgeoning tourism industry. With nearly two million visitors arriving in the Galapagos since 2000, the tourism sector directly employs 70% of the residents and represents almost the entire economy. Small-scale fishers, however, face very strong forces of change, namely the growing difficulty of earning a living solely in fishing after decades of declining harvests and low seafood prices, and for some, the challenge of integrating into the tourism industry.

Due to its central role in the development of the Galapagos, the tourism industry is the driving force in determining the dynamics of change in all other employment sectors of the islands, particularly, generating high flows of migration from the mainland to the islands, increasing the introduction of invasive species, stressing ecosystem goods and services, accelerating the consumption of resources, and increasing the pressure on basic services. We posit that different arcs of tourism development can create drastically different numbers and types of local jobs, and that this link critically impacts the urban and community structure of the Galapagos. We use fishers to highlight how the effects of tourism on the local economy can vary with policy and economic options.

Complexity Theory guides the development of the GF-ABM and the corresponding spatial simulation used to assess processes and possible outcomes linked to social-ecological dynamics. By formalizing our understanding and knowledge of how systems operate and the manner in which key elements link to other key elements in coupled human-natural systems, rules are specified, relationships are assessed, and rates of exchange between social and ecological features are derived through statistical functions and/or functions specified in theory or practice. By formally modeling how key elements are linked in coupled human-natural systems, we can help articulate the nature of certain social-ecological relationships that are critically impacting the future of these iconic islands, and the role that alternate policies and decisions may play in shaping how the human population and the unique Galapagos ecosystems fare into the future.

Our Galapagos Fishers–Agent Based Model (GF-ABM) considers strategies of household livelihood alternatives with the central proposition that fishers are being “pushed” and “pulled” into the tourism industry, but not all fishers are able to obtain alternate employment nor do all want to transition to part- or full-time employment in non-fishing activities. The processes embedded in our ABM examine fishers as a social-ecological system, where livelihood transitions are modeled and the multi-dimensional drivers of change are examined by integrating processes and relationships between agents, a dynamic environment, and the influence of personal and professional characteristics as well as exogenous dynamics into their employment patterns. The GF-ABM contains a demographic element that models basic demographic changes at the household level (household agents). The model also contains an employment management component in which fisher agents select jobs among three employment sectors – fisheries, tourism, and government. The tourism and government sectors each have three tiers of jobs that require increasing agent skills. Fishers make their employment decisions based on their preference to remain in fishing, the availability of jobs in the three employment sectors, and their personal and professional qualifications that facilitate their movement among the employment sectors. Households contain members that are non-fisher agents, and fishers belong to households. Income and expenses are calculated for both fishers and household agents.

We run the model and generate outputs that describe the model's implications for social and ecological forces of change on household livelihoods and transitions to non-fishing alternatives. The GF-ABM has several parameters that represent key processes related to demographic change and fisher agents skills, for instance, the number and distribution of jobs in fisheries, tourism, and government; the likelihood that the sea cucumber and lobster industries are open in any given year; fisher and fisher household expenses; fisher characteristics and skill levels; the influence of the household within the community; and checks on several fisher and household conditions, such as, sailing certification, job preferences, new births/deaths, cost of living, household expenses and wealth. The model outcomes are interpreted relative to changes in tourism and urban structure in the Galapagos Islands, using demographic projections to establish trends and trajectories of change in tourism and the associated residential population. We discuss the model's implications for the urban structure of communities to accommodate urban expansion and the diversification of fisher households to participate part- or full-time in tourism and government employment alternatives.

Selected GF-ABM Functions & Key Process Characteristics

Power Relationships & Influence in the ***GF-ABM*** use the concept of social networks to create links of individuals and households to key actors and families. Core nodes in the social network represents, for instance, ties to the Director of the Galapagos National Park, Mayor of the community, Governor of the Province, President of the Fishing Cooperative, and Owners and Managers of Hotels & Restaurants, and Guides and managers linked to the airline and tourism industries. We select some number of "power links" in the community, 4-5 families representing perceived power families and organizations and then randomize fisher connections over time. Resident and Tourist Projections are derived through demographic projections of the expanding human dimension, reflected through population census years, social survey, and focus groups.

Memory of Agents are used to simulate human-environment interactions that change as a consequence of "memorable" events that alter human behavior and the development of alternate household livelihood strategies to confront uncertainty and opportunity. ENSO (El Nino Southern Oscillation) events are particularly significant in the Galapagos Islands as water temperature increases, upwelling is disrupted, and marine productivity decreases, with implications observed throughout the food web and the social systems that rely upon fisheries as an economic alternative. Particularly important are the severe events that may redefined human-environment interactions in the Galapagos Islands, including the major ENSO events that occurred in 1982-83 and 1997-98. From 2000 to the present, ENSO events occurred in 2002-2003, 2004-2005, 2006-2007, 2009-2010, 2014-2015, with intervening neutral periods and La Nina conditions that tend to heighten the recovery from El Nino conditions through a deepening of marine upwelling, increase in marine productivity, and recovery of iconic species. Functions are derived that identify contemporary fishers who are active in the fishing industry during major and minor ENSO events. Hypotheses are developed to examine possible mechanisms for developing a propensity for adaptation through knowledge, acquired directly or indirectly, linked to personal traits, such as, education, that may exhibit a time-decay function for memory, adaptation, and change.

Alternate Household Livelihood Strategies involve categories of employment that are accounted for in the model, tourism, fisheries, and government. The capacity to switch among employment sectors, primarily to tourism, is based upon job availabilities, regulatory constraints, individual characteristics, job preferences, and skill levels. While job preferences to transition out of fishing (full or part-time), individual/household income, wealth, and assets are important considerations. For instance, a fisher may choose to switch to tourism during an El Nino event, hire out to work in the highlands in farming, or even out-migrate to the continent and return money to the household through remittances. Job Switching is associated with the learning of English as a highly desirable skill for employment in tourism. Education level, experience in tourism, and intention to leave fisheries are important factors in developing English language skills. We derive a function that determines the probability of increasing a skill based on age, education, and modify that probability based on their job and level of experience.

Xinyue Ye

ABM on Spatial Meme Diffusion Linking Relational and Physical Spaces

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Human behavior can produce complex patterns in both spatial and virtual systems. A meme is an idea, behavior, or style that spreads from person to person. With the proliferation of social media, information generated and disseminated from these outlets has become an important part of our everyday lives. Thanks for the manifestation of social networks by these online services, observing how information is communicated among people has never been more feasible than ever. With such popularity of online social networks, finding an efficient way to spread information has always been a goal for either businesses or government entities. Social media has become an important emergency information and communication backbone where individuals and organizations request and share information for disaster relief within and outside the affected area (Ye and Mansury 2016).

Space, time, content, and network are all important attributes of social media data and should be fully used to gain insights into situational awareness. There is also ample evidence that people act on the basis of limited information, peer pressure, and political constraints. ABM can be used to predict human behavior like posting, forwarding or replying a message with regard to topics and sentiments. ABM seeks to explain emerging the systems behavior in terms of local interactions among agents as well as between them and the spatial-social environment. Massive and sudden transformations of socioeconomic structures worldwide, which are responsible for the geographic patterns of growth and decline, all point to the increasing importance of individual behavior and human adaptability.

ABM can model complex macro spatial-social phenomena emerged from simple, micro, and individual behaviors that could be aggregated for grouped behavioral patterns. Our ways of examining social-spatial interactions are increasingly transformed by the development of more powerful computing technologies, emerging big and open data sources, and new perspectives on social-spatial processes (Shaw, Tsou, and Ye 2016). It is important to discover, track, summarize, and even predict popular topics and events occurring in the social network in the space-time context. A series of "what if" scenarios can be developed to estimate the meme diffusion. Investigating how information diffuses over online social networks requires the knowledge of human dynamics that create and communicate such information. More toolkits are needed to interface the open source revolution and human/socioeconomic dynamics analysis seeking cross-fertilization between these two fast-growing communities (Ye et al. 2017).

Agents make decisions from where to live and work to what to consume and produce – autonomously according to their present condition, past history, state of the local environment, and rules governing their actions (Ye and Lee 2016). Specifically, we hope to simulate how efficiently meme can flow through spatial-social networks based on the quantity and positions of seed nodes in networks of different structures. Instead of finding a subset of nodes in the network that maximize the influence, however, we are more interested in finding ways to choose the least number of nodes that speeds up the information diffusion the most across space. Comparing different types of networks in terms of the performance of propagating information in the spatial context, we aim to find the kind of network that triggers large cascades of information adoption through ABM, which is a transdisciplinary research field for understanding and analyzing dynamic patterns, relationships, and changes of spatial-social systems where human activities and behaviors occur and evolve (Lee and Ye 2017).

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Second Survey

Dan Brown

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

a. Human decision making in ABM [1]
b. ABM code reusability and transparency [3]
c. Model validation and verification [2]
d. Big data high performance ABM [1]
e. Integrated human-environment ABMs [2]
f. Methodological issues of spatially explicit ABMs [4]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):
I'm interested in how we integrate, dock, or nest ABMs with other models. The opportunities involve integration of ABMs with models of environmental processes, and the challenges of space/time scales and semantics that arise, as well as the cross-scale nesting with other, more aggregate models of human/economic behavior. Integrated in these ways, ABMs can provide a level of detail in the representation of human-environment interactions across scales that both enhance their wider acceptance and improve our understanding of these systems.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [2]
b. Social science [2]
c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

2016. Tian, Q., Holland, J.H., Brown, D.G. Social and economic impacts of subsidy policies on rural development in the Poyang Lake Region, China: insights from an agent-based model. Agricultural Systems,148:12-27. doi: 10.1016/j.agsy.2016.06.005
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2014. Magliocca, N.R., Brown, D.G., McConnell, V., Nassauer, J.I., and Westbrook, S.E. Effects of alternative developer decision-making models on the production of ecological subdivision designs: Experimental results from an agent-based model. Environment and Planning B, 41(5):907-927. doi:10.1068/b130118p

2014. Sun, S., Parker, D.C., Huang, Q., Filatova, T., Robinson, D.T., Riolo, R.L., Hutchins, M., and Brown, D.G. Market impacts on land-use change: An agent-based experiment. Annals of the Association of American Geographers, 104(3): 460-484. doi:10.1080/00045608.2014.892338
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Yue Dou

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

    a. Human decision making in ABM [1]
    b. ABM code reusability and transparency [3]
    c. Model validation and verification [2]
    d. Big data high performance ABM [6]
    e. Integrated human-environment ABMs [4]
    f. Methodological issues of spatially explicit ABMs [5]

(I don't quite understand option e: most ABMs are integrated human-environment models, so what is the issue here?)

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

There is uncertainty introduced at every modeling stage of an ABM construction and simulation. Studies have been done to resolve these challenges, including uncertainties among parameter heterogeneity (Brown and Robinson 2006, Huang et al. 2013), agent typology (Valbuena et al. 2008), components (Parker et al. 2006b, 2008), and key driving forces by meta-analysis (Magliocca et al. 2015). Yet few studies have noticed the fundamental uncertainties associated with the choice of behaviour assumptions. In order to solve this fundamental issue of decision making in ABM, I propose the following issues to be taken into consideration, which at least address the 1, 2, 3 issues that I listed above:

(1) Start to document decision making models for a library

A library of possible theoretical and existing decision making models can be helpful for this. Reviews, agent-functional types, and meta-analysis are good initiatives; however, they need more work to become applicable for modelers to use in the future. A standard procedure for documenting and archiving published models and studies is essential, although it is complicated and hard to draw up rules for classification.

(2) Investigating the uncertainty of the choice of decision making

Similar as the sensitivity analysis for variables in the decision makings and simulations, the uncertainty of the decision making model should also be taken into account. Apart from participatory modeling that modelers could be confident to claim their comprehensive representing of the decision making, other decision making models that are revealed from questionnaire, interview, secondary-data, or theory can bring the underlying assumptions of the model and methods themselves. Therefore, the uncertainty of adopting different decision making models should also be analyzed when using ABM to explore policy and other scenarios.

Another issue worth discussing is how to use agent-based modeling to represent and simulate telecoupled human-natural systems. The biggest challenge is how to define and represent the flows between the sending and receiving systems, and how to design experiments to test and quantify the telecoupling effects to the two systems. The challenge is that causes and effects in telecoupled systems can exchange positions between the sending and receiving systems, and without a simulation model, we are not able to identify the causation. Therefore, the model should be flexible enough to represent this possibility of cause-effect switch but also rigorous to identify the causation through simulations.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [NA]
b. Social science [2]
c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Individual Models
Reviews
Methods that advance the modeling field

An, L. 2012. Modeling human decisions in coupled human and natural systems: Review of agent-based models. Ecological Modelling 229:25–36.
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Magliocca, N. R., J. van Vliet, C. Brown, T. P. Evans, T. Houet, P. Messerli, J. P. Messina, K. a. Nicholas, C. Ornetsmüller, J. Sagebiel, V. Schweizer, P. H. Verburg, and Q. Yu. 2015. From meta-studies to modeling: Using synthesis knowledge to build broadly applicable process-based land change models. Environmental Modelling & Software 72:10–20.
Manson, S. M. 2006. Bounded rationality in agent-based models: experiments with evolutionary programs. International Journal of Geographical Information Science 20(9):991–1012.
Parker, D., D. Brown, and J. Polhill. 2006a. Chapter: Illustrating a new'conceptual design pattern'for agent-based models of land use via five case studies—the MR POTATOHEAD framework. Pages 1–39in A. L. Paredes and C. H. Iglesias, editors.Agent-based modelling in Natural Resrouce Management. INSISOC, Spain.
Parker, D. C., B. Entwisle, R. R. Rindfuss, L. K. Vanwey, S. M. Manson, E. Moran, L. An, P. Deadman, T. P. Evans, M. Linderman, S. Mohammad Mussavi Rizi, and G. Malanson. 2008. Case studies, cross-site comparisons, and the challenge of generalization: comparing agent-based models of land-use change in frontier regions. Journal of Land Use Science 3(1):41–72.
Parker, D. C., S. M. Manson, M. A. Janssen, M. J. Hoffmann, and P. Deadman. 2003. Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. Annals of the Association of American Geographers 93(2):314–337.
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Robinson, D. T., D. G. Brown, D. C. Parker, P. Schreinemachers, M. A. Janssen, M. Huigen, H. Wittmer, N. Gotts, P. Promburom, E. Irwin, T. Berger, F. Gatzweiler, and C. Barnaud. 2007. Comparison of empirical methods for building agent-based models in land use science. Journal of Land Use Science 2(1):31–55.
Schreinemachers, P., and T. Berger. 2011. An agent-based simulation model of human–environment interactions in agricultural systems. Environmental Modelling & Software 26(7):845–859.
Smajgl, A., D. G. Brown, D. Valbuena, and M. G. A. Huigen. 2011. Empirical characterisation of agent behaviours in socio-ecological systems. Environmental Modelling and Software 26(7):837–844.
Valbuena, D., P. H. Verburg, and A. K. Bregt. 2008. A method to define a typology for agent-based analysis in regional land-use research. Agriculture, Ecosystems & Environment 128(1–2):27–36.

Sigrunn Eliassen

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [1]
   b. ABM code reusability and transparency [4]
   c. Model validation and verification [3]
   d. Big data high performance ABM [6]
   e. Integrated human-environment ABMs [5]
   f. Methodological issues of spatially explicit ABMs [2]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit): I hope to be able to contribute to decision making perspectives, although more from a non-human point of view.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [1]
b. Social science [ ]
c. Human-environment science [2]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Tom Evans

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [1]
   b. ABM code reusability and transparency [6]
   c. Model validation and verification [3]
   d. Big data high performance ABM [4]
   e. Integrated human-environment ABMs [2]
   f. Methodological issues of spatially explicit ABMs [5]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [3]
b. Social science [3]
c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

O'Sullivan, D., Evans, TP, and Manson, S. 2016. Strategic Directions for Agent-based Modeling - Avoiding the YAAWN Syndrome. Journal of Land Use Science. 11(2): 177-187.
Evans TP, Phanvilay K., Fox J, and Vogler J. 2011. An agent-based model of agricultural innovation, land-cover change and household inequality: the transition from swidden cultivation to rubber plantations in Laos PDR. Journal of Land Use Science 6(2-3):151–173.
Kelley H and Evans TP. 2011. The relative influences of land-owner and landscape heterogeneity in an agent-based model of land-use. Ecological Economics 70(6):1075–1087.
Evans TP and Kelley H. 2008. Assessing the transition from deforestation to forest regrowth with an agent-based model of land cover change for south-central Indiana (USA). Geoforum 39(2):819–832.
Messina JP, Evans TP, Manson SM, Shortridge AM, Deadman PJ, and Verburg PH. 2008. Complex systems models and the management of error and uncertainty. Journal of Land Use Science 3(1):11–25.
Manson SM and Evans TP. 2007. Agent-based modeling of deforestation in southern Yucatán, Mexico, and reforestation in the Midwest United States. Proceedings of the National Academy of Sciences of the United States of America 104(52):20678–20683.
Evans TP and Kelley H. 2004. Multi-scale analysis of a household level agent-based model of landcover change. Journal of Environmental Management 72(1-2):57–72.

Volker Grimm

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [4]
   b. ABM code reusability and transparency [2]
   c. Model validation and verification [1]
   d. Big data high performance ABM [6]
   e. Integrated human-environment ABMs [5]
   f. Methodological issues of spatially explicit ABMs [3]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

Compile showcases of ABMs: they were actually used to solve complex practical problems, to make predictions that were confirmed. Anything that goes beyond another ABM manifesto:

"Oh, and about Doyne Farmer and Santa Fe and complexity and all that: I was one of the people who got all excited about the possibility of getting somewhere with very detailed agent-based models — but that was 20 years ago. And after all this time, it's all still manifestos and promises of great things one of these days."

Paul Krugman, Nov. 30, 2010, in response to an article about INET housing project in WSJ.

In short: Do not focus on what ABMs can do but on what they already do, plus, of course, that they are indispensible in our agent-based world, and that, of course, we need to develop further. I could think even of a working title like "ABMs: from manifestos to manifestations" – well, maybe not.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [1]
b. Social science [NA]
c. Human-environment science [2]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

I am sending Stillman et al 2015, Grimm and Railsback 2012, Grimm and Berger 2016a/b

Alison Heppenstall

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [1]
   b. ABM code reusability and transparency [6]
   c. Model validation and verification [2]
   d. Big data high performance ABM [4]
   e. Integrated human-environment ABMs [5]
   f. Methodological issues of spatially explicit ABMs [3]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

Human decision making in ABM

I am interested in discussing the following areas:

(i) Identifying and critiquing a range of different behavioural models e.g. fast and frugal, ones based on probabilities through to ones based in psychology e.g. PECS and BDI. There must be many more that can enrich our models that are currently not being used because of our ignorance. How do we translate data into behavioural rules? What do we use each of these models for? Is there a typology we can construct about which model suits which application/behaviour?

(ii) How can we build better behavioural rules i.e. should we be using different approaches such as a casual inference modelling to understand the relationships within our data in much more detail than current methods allow?

(iii) Developing a set of applications of varying complexity to evaluate different behavioural models. Can we develop a repository of code representing different behavioural frameworks? What are they good and bad at representing? What sort of data do they need? What insight do they give?

(iv) Producing guidance: Guidelines for researchers and practitioners alike when wishing to build human behaviour into models.

Model calibration, validation and verification AND Methodological issues

(i) What is the current 'state of the art'? What are we good at doing? What are we bad at doing? What opportunities do we have with the proliferation of 'big data'? What exactly do we need to calibrate and validate – individual movement, behaviour, processes, patterns? Do we need to create new metrics? What would these look like? What spatial and temporal scale do we need to validate at? What other approaches are available from other disciplines that could help?

(ii) How do we generate a confidence value with our simulations? How do we convince policy-makers that our simulations are robust?

(iii) More methodological: how do we create BIG simulations? How detailed should these be? (also links to below)

Big data and ABM

(i) What are the opportunities that BD affords us? What are the potential pitfalls? Is BD just a big distraction from the core methodological issues that need to be addressed?

(ii) How do get value/understanding/insight from big data? Pre-processing and data linkage are massive challenges – is BD worth it? What are the different types of BD and how can these potentially inform ABM e.g. mobile phone data is relatively straightforward and allows a more accurate idea of movement – but it doesn't tell us who a person is and why they are in a particular space.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [NA]
b. Social science [1]
c. Human-environment science [2]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

- Balke, T. and Gilbert, N. (2014), 'How Do Agents Make Decisions? A Survey', Journal of Artificial Societies and Social Simulation, 17(4): 13, Available at http://jasss.soc.surrey.ac.uk/17/4/13.html.
- Benenson, I., Omer, I. and Hatna, E. (2002), 'Entity-Based Modelling of Urban Residential Dynamics: The Case of Yaffo, Tel Aviv', Environment and Planning B, 29(4): 491-512.
- Crooks, A.T., Castle, C.J.E. and Batty, M. (2008), 'Key Challenges in Agent-Based Modelling for Geo-spatial Simulation', Computers, Environment and Urban Systems, 32(6): 417-430.
- Grimm, V., Berger, U., DeAngelis, D.L., Polhill, G.J., Giske, J. and Railsback, S.F. (2010), 'The ODD Protocol For Describing Individual-Based And Agent-Based Models: A First Update', Ecological Modelling, 221(23): 2760-2768.
- Heppenstall, A.J., Crooks, A.T., See, L.M. and Batty, M. (Eds), (2012) Agent-based Models of Geographical Systems, Springer: Dordrecht.
- Kennedy, W. (2012), 'Modelling Human Behaviour in Agent-Based Models', in Heppenstall, A., Crooks, A.T., See, L.M. and Batty, M. (eds.), Agent-based Models of Geographical Systems, Springer, New York, NY, pp. 167-180.
- Macal, C. M. (2016). Everything you need to know about agent-based modelling and simulation. Journal of Simulation, 10(2), 144-156.
- Malleson, N., Heppenstall, A. and See, L. (2010), 'Crime Reduction Through Simulation: An Agent-based Model of Burglary', Computers, Environment and Urban Systems, 34(3): 236-250.
- Manson, S. and O'Sullivan, D. (2006), 'Complexity Theory in the Study of Space and Place', Environment and Planning A, 38(4): 677-692.
- O'Sullivan, D. (2004), 'Complexity Science and Human Geography', Transactions of the Institute of British Geographers, 29(3): 282-295.
- O'Sullivan, D., Millington, J., Perry, G. and Wainwright, J. (2012), 'Agent-Based Models – Because They're Worth It?' in Heppenstall, A.J., Crooks, A.T., Batty, M. and See, L.M. (eds.), Agent-based Models of Geographical Systems, Springer, New York, NY.

Piotr Jankowski

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [1]
   b. ABM code reusability and transparency [6]
   c. Model validation and verification [3]
   d. Big data high performance ABM [5]
   e. Integrated human-environment ABMs [4]
   f. Methodological issues of spatially explicit ABMs [2]

2. In the above topics you want to involve in, identify specific issues that you want to discuss in ABM 17 symposium (no space limit): Spatially-explicit, integrated uncertainty and sensitivity analysis in ABM.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank in what of the following fields you feel you can judge (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [NA]
b. Social science [3]
c. Human-environment science [2]

Marco Janssen

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [2]
   b. ABM code reusability and transparency [1]
   c. Model validation and verification [4]
   d. Big data high performance ABM [6]
   e. Integrated human-environment ABMs [3]
   f. Methodological issues of spatially explicit ABMs [5]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

I am still confused on the goal of the meeting. The meeting seems to be very dominated by land use change scholars, while there is an enormous diversity of at least people in the social sciences that are using ABM (for example, where are areas like marketing , social media studies, and archaeology where there is an enormous uptake of ABM?). This could be fine, but your description of the meeting sounds like it is inclusive, but it is not reflected in the list of PIs or the science committee. So perhaps you need to develop a more narrow focus of your goals, since the current mismatch of stated goals and invited people is confusingly big.

It is also an illusion to talk about a "ABM community" given the fragmented nature of the "community" that use ABM. Is there an ODE community? What connects us is a research method, not a research question.

To have a somewhat fruitful discussion that is not dominated by land use change applications, we may focus on issues related to model analysis and model validation. There are recently quite some papers trying to develop new methods to perform analysis of ABM. This also relates to high performance computing that start to become more available for ABM, and new opportunities arise for model analysis.

Another issue that could be cross topic is reproducibility of the modeling efforts. At the moment there is no norm of transparency in the "community" and the majority of papers get published without the ability to reproduce the work. This is a waste of tax money (assuming most ABM scholars are sponsored by tax money), and does not speed up the learning. Attempts of openabm to get journals to require transparency led to a lot of resistance from journals. Given the increasing discussion in top journals on reproducible science, and the increasing distrust of the broader audience in science it is a shame that we still do not practice the scientific method when we use ABM. (Note that this is not just with ABM, this is a broader issue in Simulation, and in Computer Science).

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [3]
b. Social science [2]

c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.
It unclear what the purpose is here. What is the goal of those readings? Is there a specific question? If one like to "develop an online ABM repository that shared useful ABM resources" why not make use of the efforts of CoMSES Net? If you focus on a bibliometric analysis, a student can do an initial analysis, and you can send around this analysis for feedback.

See http://jasss.soc.surrey.ac.uk/20/1/2.html for some initial results of a database on ABM models that we are developing.

Tim Kohler

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

    a. Human decision making in ABM [2]
    b. ABM code reusability and transparency [4]
    c. Model validation and verification [3]
    d. Big data high performance ABM [5]
    e. Integrated human-environment ABMs [1]
    f. Methodological issues of spatially explicit ABMs [6]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

The "normalization" of the ABM as part of the research portfolio, where ABMs lose the center stage in the research process and become just one of many tools used to understand process in systems

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [3]
b. Social science [2]
c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Crabtree, Stefani A., R. Kyle Bocinsky, Paul L. Hooper, Susan C. Ryan, and Timothy A. Kohler
2017 How to Make a Polity (in the central Mesa Verde region). American Antiquity 82(1):71-95. doi:10.1017/aaq.2016.18.

Cockburn, Denton, Stefani Crabtree, Ziad Kobti, Timothy A. Kohler, and R. Kyle Bocinsky
2013 Simulating Social and Economic Specialization in Small-Scale Agricultural Societies. Journal of Artificial Societies and Social Simulation 16 (4) 4. http://jasss.soc.surrey.ac.uk/16/4/4.html. Published 31 October.

Kohler, Timothy A., R. Kyle Bocinsky, Denton Cockburn, Stefani A. Crabtree, Mark D. Varien, Kenneth E. Kolm, Schaun Smith, Scott G. Ortman, and Ziad Kobti
2012 Modelling Prehispanic Pueblo Societies in their Ecosystems. Ecological Modelling 241:30-41. DOI: 10.1016/j.ecolmodel.2012.01.002.

Katherine Lacasse

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

  a. Human decision making in ABM [1]
  b. ABM code reusability and transparency [4]
  c. Model validation and verification [6]
  d. Big data high performance ABM [5]
  e. Integrated human-environment ABMs [2]
  f. Methodological issues of spatially explicit ABMs [3]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

-How could ABMs be used to examine human risk-perceptions and subsequent behaviors could be impacted in response to local changes in climate?
-How could ABMs be used to examine human attitude change and behaviors change following changes in local laws (regarding environmental or social issues directly related to behavior)?
-In what ways ABM can serve as a useful compliment to the observational, survey, & experimental research psychologists are already conducting on decision-making, attitude change, and group processes?
-What unique collective outcomes could be tested by taking theories of individual-level decision-making or behavior and testing them in ABM?
-How to make ABMs user-friendly to psychologists and/or what kinds of training would be most helpful to engage this group of researchers?

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [3]
b. Social science [1]
c. Human-environment science [2]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

1) Smith, E. R., & Conrey, F. R. (2007). Agent-based modeling: A new approach for theory building in social psychology. Personality and Social Psychology Review, 11, 87-104.

2) Hughes, H. P., Clegg, C. W., Robinson, M. A., & Crowder, R. M. (2012). Agent-based modelling and simulation: The potential contribution to organizational psychology. Journal of Occupational and Organizational Psychology, 85, 487-502.

3) Van Rooy, D., Wood, I., & Tran, E. (2014). Modelling the emergence of shared attitudes from group dynamics using an agent-based model of social comparison theory. Systems Research and Behavioral Science, 33, 188-204.

4) Sohn, D., & Geidner, N. (2016). Collective dynamics of the spiral of silence: The role of ego-network size. International Journal of Public Opinion Research, 28, 25-45.

Jianguo Liu

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [2]
   b. ABM code reusability and transparency [5]
   c. Model validation and verification [6]
   d. Big data high performance ABM [4]
   e. Integrated human-environment ABMs [1]
   f. Methodological issues of spatially explicit ABMs [3]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

How to build telecoupled ABM (ABM for a telecoupled system which consists of two or more coupled human and natural systems)?
How to effectively account for multi-scale interactions in ABM
Would it be possible to identify spillover systems using ABM?
How to account for feedbacks in ABM?

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [2]
b. Social science [3]
c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Steven Manson

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

  a. Human decision making in ABM [2]
  b. ABM code reusability and transparency [6]
  c. Model validation and verification [5]
  d. Big data high performance ABM [1]
  e. Integrated human-environment ABMs [3]
  f. Methodological issues of spatially explicit ABMs [4]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

Status of code-reuse in land change models

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

  a. Life science [3]
  b. Social science [1]
  c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

David O'Sullivan

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [4]
   b. ABM code reusability and transparency [2]
   c. Model validation and verification [3]
   d. Big data high performance ABM [6]
   e. Integrated human-environment ABMs [5]
   f. Methodological issues of spatially explicit ABMs [1]

2. In the above topics you want to involve in, identify specific issues that you want to discuss in ABM 17 symposium (no space limit):

I am particularly concerned with questions of the process by which ABMs are made – from the initial decision to use an ABM at all (often I think ABMs are adopted when other approaches would be equally or more useful or appropriate), the means by which ABMs are iteratively refined to arrive at a 'final' model. My take on modeling is that any modeling method is most useful to the model-builder because of what is learned in the process of building and refining the model, but the ways in which models are communicated scientifically (often dominated by pre/postdiction and goodness of fit of some 'final' model) do not unlock what was learned in the process of developing and exploring the model. Addressing this problem might require innovative thinking about how we communicate models scientifically, what standards we hold modelers to in communicating their models, and also the tools, particularly 'workbenches' that we use to develop models. What role, for example, might version control systems from software development have to play as a routine part of ABM builders toolkit?

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank in what of the following fields you feel you can judge (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

   a. Life science [3]
   b. Social science [1]
   c. Human-environment science [2]

4a. Do you (including your group or students you advise or supervise) have a runnable ABM model, including both code, data (Okay if you want to modify the data to meet the IRB requirements), and documentation, which can be shared to the ABM 17 symposium?

1. Yes 2. No 3. Not sure for now

4b. (If you choose Yes in Question 4a) In what language or platform was the model developed?

[To PIs: For uploading to our website using Jupyter.]

5. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Millington JDA, D O'Sullivan and GLW Perry. 2012. Model histories: Narrative explanation in generative simulation modelling. *Geoforum*, 43(6), 1025-1034.

O'Sullivan, D. 2008. Geographical information science: agent-based models. *Progress in Human Geography* 32 (4):541–550.

O'Sullivan, D. 2009. Changing Neighborhoods–Neighborhoods Changing: A Framework for Spatially Explicit Agent-Based Models of Social Systems. *Sociological Methods Research* 37 (4):498–530.

O'Sullivan, D., T. Evans, S. Manson, S. Metcalf, A. Ligmann-Zielinska, and C. Bone. 2016. Strategic directions for agent-based modeling: avoiding the YAAWN syndrome. *Journal of Land Use Science* 11 (2):177–187.

O'Sullivan, D., and M. Haklay. 2000. Agent-based models and individualism: is the world agent-based? *Environment and Planning A* 32 (8):1409–1425.

O'Sullivan, D., J. M. Macgill, and C. Yu. 2003. Agent-based residential segregation: a hierarchically structured spatial model. In *Agent 2003* "Challenges in Social Simulation." Chicago http://www.citeulike.org/group/8203/article/6651711.

O'Sullivan, D., J. Millington, G. Perry, and J. Wainwright. 2012. *Agent-Based Models – Because They're Worth It? Agent-Based Models of Geographical Systems*. eds. A. J. Heppenstall, A. T. Crooks, L. M. See, and M. Batty, 109–123. Springer Netherlands http://dx.doi.org/10.1007/978-90-481-8927-4_6.

O'Sullivan, D., and G. L. W. Perry. 2013. *Spatial Simulation: Exploring Pattern and Process*. Wiley-Blackwell.

Schelhorn, T., D. O'Sullivan, M. Haklay, and M. Thurstain-Goodwin. 1999. STREETS: an agent-based pedestrian model. Computers in Urban Planning and Urban Management.

Dawn Parker

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

a. Human decision making in ABM [1]
b. ABM code reusability and transparency [2]
c. Model validation and verification [3]
d. Big data high performance ABM [6]
e. Integrated human-environment ABMs [4]
f. Methodological issues of spatially explicit ABMs [5]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit): See my first survey.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [NA]
b. Social science [x]
c. Human-environment science [x]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Viktoriia Radchuk

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [6]
   b. ABM code reusability and transparency [2]
   c. Model validation and verification [1]
   d. Big data high performance ABM [5]
   e. Integrated human-environment ABMs [4]
   f. Methodological issues of spatially explicit ABMs [3]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

Standards and best practices for validation and verification of agent-based models. Expectations regarding the way and level of ABM verification and validation in environmental sciences. Practices for ABM code reusability: how common they are and are we not re-inventing the wheel far too often? How to improve the transparency and reusability of ABM codes? Movement of agents in heterogeneous space: issues related to the scheduling and among-agent interactions. What is the necessary minimum of spatial heterogeneity to capture the realistic agent movement pattern?

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

   a. Life science [1]
   b. Social science [NA]
   c. Human-environment science [2]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Grimm et al. 2006, 2010, 2014, Schmolke et al. 2010

Steve Railsback

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

a. Human decision making in ABM [1]
b. ABM code reusability and transparency [5]
c. Model validation and verification [4]
d. Big data high performance ABM [6]
e. Integrated human-environment ABMs [2]
f. Methodological issues of spatially explicit ABMs [3]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

To me, how to model decisions and adaptive behavior of agents (people, plants, animals, organizations…) is the fundamental question of ABM. I would like us to explicitly use the word "theory" in reference to models of behavior that have been tested and shown generally useful.

The other methodological issues are also very important. The computer science issues could be considered less important because they are basically about doing software development well, which is well-known… but not so well known in many fields of science, so it is worth addressing them too.

One important issue not listed above is model design: how do you design an ABM that has enough complexity but not too much. This question is very critical and also novel to ABMs.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [2]
b. Social science [NA]
c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Grimm, V. 1999. Ten years of individual-based modelling in ecology: what have we learned and what could we learn in the future? Ecological Modelling 115:129-148.
Grimm, V., and coauthors. 2014. Towards better modelling and decision support: documenting model development, testing, and analysis using TRACE. Ecological Modelling 280:129-139.
Grimm, V., and coauthors. 2006. A standard protocol for describing individual-based and agent-based models. Ecological Modelling 198:115-296.
Grimm, V., and coauthors. 2010. The ODD protocol: a review and first update. Ecological Modelling 221:2760-2768.

Grimm, V., and coauthors. 1996. Pattern-oriented modelling in population ecology. The Science of the Total Environment 183:151-166.
Grimm, V., and S. F. Railsback. 2005. Individual-based modeling and ecology. Princeton University Press, Princeton, New Jersey.
Grimm, V., and S. F. Railsback. 2012. Pattern-oriented modelling: a `multiscope' for predictive systems ecology. Philosophical Transactions of the Royal Society B 367:298-310.
Grimm, V., and coauthors. 2005. Pattern-oriented modeling of agent-based complex systems: lessons from ecology. Science 310(11):987-991.
Railsback, S. F. 2001. Getting "results": the pattern-oriented approach to analyzing natural systems with individual-based models. Natural Resource Modeling 14(3):465-474.
Railsback, S. F., and V. Grimm. 2012. Agent-based and individual-based modeling: a practical introduction. Princeton University Press, Princeton, New Jersey.
Railsback, S. F., and B. C. Harvey. 2002. Analysis of habitat selection rules using an individual-based model. Ecology 83(7):1817-1830.
Railsback, S. F., and B. C. Harvey. 2013. Trait-mediated trophic interactions: is foraging theory keeping up? Trends in Ecology & Evolution 28(2):119-125.
Railsback, S. F., B. C. Harvey, J. W. Hayse, and K. E. LaGory. 2005. Tests of theory for diel variation in salmonid feeding activity and habitat use. Ecology 86(4):947-959.
Railsback, S. F., and M. D. Johnson. 2011. Pattern-oriented modeling of bird foraging and pest control in coffee farms. Ecological Modelling 222(18):3305-3319.

Derek Robinson

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

a. Human decision making in ABM [4]
b. ABM code reusability and transparency [3]
c. Model validation and verification [5]
d. Big data high performance ABM [6]
e. Integrated human-environment ABMs [1]
f. Methodological issues of spatially explicit ABMs [2]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

Anything related to Unmanned Aerial Vehicles and ABM

Model Coupling

Agricultural modelling

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [3]
b. Social science [3]
c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Bell, A.R., Robinson, D.T., Malik, A., and S., Dewal, 2015. Modular ABM development for improved dissemination and training. Environmental Modelling and Software, 73: 189-200.

Guillem, E.E., Murray-Rust, D., Robinson, D.T., Barnes, A., and M. Rounsevell, 2015. Modelling farmer decision-making to anticipate tradeoffs between provisioning ecosystem services and biodiversity. Agricultural Systems, 137: 12-23.

Murray-Rust, D., Robinson, D.T., Guillem, E., Karali, E., and M. Rounsevell, 2014. Aporia: an open framework for agent based modeling of land use change. Environmental Modelling and Software, 61: 19-38.

Murray-Rust, D., Brown, C., van Vliet, J., Alam, S.J., Robinson, D.T., Verburg, P.H., and M. Rounsevell, 2014. Combining Agent Functional Types, capitals and services to model land use dynamics. Environmental Modelling and Software, 59: 187 – 201.

Robinson, D.T., Shipeng, S., Hutchins, M., Riolo, R.L., Brown, D.G., Parker, D.C., Currie, W.S., Filatova, T., and S. Kiger, 2013. Effects of land markets and land management on ecosystem function: A framework for modelling exurban land-changes. Environmental Modelling and Software, 45: 129-140. DOI: 10.1016/j.envsoft.2012.06.016

Luus, N., Robinson, D.T. and P.J. Deadman, 2013. Representing environmental processes in agent-based models of land use and cover change using ecological model approaches. Journal of Land Use Science, 8(2): 175-198. DOI: 10.1080/1747423X.2011.640357

Maja Schlueter

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

    a. Human decision making in ABM [2]
    b. ABM code reusability and transparency [4]
    c. Model validation and verification [3]
    d. Big data high performance ABM [5]
    e. Integrated human-environment ABMs [1]
    f. Methodological issues of spatially explicit ABMs [6]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

Regarding a:

- Development of models of human decision making that build on social science theories
- Building blocks/Reusing code of models of human decision making (relates to topic b)
- Testing the implications of alternative models of human decision making in different social-ecological contexts
- Modeling human decision making on the global scale/ in models of planetary change (How? What can we learn from modeling human decision making on local scales)

Regarding e:

- Various ways of linking integrated human-environment ABMs to empirical research (from parameterizing ABMs with social-ecological data to using empirically derived hypotheses or stylized facts to explain observed SES phenomena and patterns
- Pattern-oriented modelling of social-ecological systems (what are suitable social-ecological patterns?) (relates to topic c)
- using ABMs for theory development in social-ecological systems
- Multi-level ABMs of social-ecological systems, explicitly focusing on cross-level interactions (bottom-up and top-down)

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

    a. Life science [3]
    b. Social science [2]
    c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Hedström, P., Ylikoski, P., 2010. Causal Mechanisms in the Social Sciences. Annual Review of Sociology 36, 49–67. doi:10.1146/annurev.soc.012809.102632

Schlüter, M., Baeza, A., Dressler, G., Frank, K., Groeneveld, J., Jager, W., Janssen, M.A., McAllister, R.R.J., Müller, B., Orach, K., Schwarz, N., Wijermans, N., 2017. A framework for mapping and comparing behavioural theories in models of social-ecological systems. Ecological Economics 131, 21–35. doi:10.1016/j.ecolecon.2016.08.008

Schill, C., Wijermans, N., Schlüter, M., Lindahl, T., 2016. Cooperation Is Not Enough—Exploring Social-Ecological Micro-Foundations for Sustainable Common-Pool Resource Use. PLOS ONE 11, e0157796. doi:10.1371/journal.pone.0157796

Abigail Sullivan

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [4]
   b. ABM code reusability and transparency [3]
   c. Model validation and verification [2]
   d. Big data high performance ABM [5]
   e. Integrated human-environment ABMs [1]
   f. Methodological issues of spatially explicit ABMs [6]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

Related to integrated human-environment ABMs I would like to discuss:

--How to effectively inform human-environment ABMs with social data There seem to be fewer clear standards or protocols for how to incorporate social data in human-environment ABMs. What are the most important considerations?

--Guidelines for when to include different components of a system. In human-environment ABMs, it can be easy to add too much complexity to the model, to the point where it is difficult to understand the results. Have past ABM efforts provided insight into guidelines for essential components of human-environment ABMs?

Related to model validation and verification I would like to discuss:

--How to conduct model validation for theoretically driven or abstract models, particularly when you have limited empirical data or empirical data from only a single time point

--Where/what to consult when stuck on these types of methodological and analytical issues. What resources are available to scholars that have questions related to validation or verification for a specific model?

Related to ABM code reusability and transparency I would like to discuss:

--How and when to share ABM code? Also, issues related to labeling code as available to use (or not) by other scholars

--How and when to share data related to ABMs? Data is shared less often than ABM code and there appear to be more difficulties/hesitations associated with sharing it (such as IRB restrictions on human subjects data or the desire to keep data private until publications have been completed)

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging

them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [3]
b. Social science [1]
c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

I attached several articles with this survey.

Wenwu Tang

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

a. Human decision making in ABM [4]
b. ABM code reusability and transparency [6]
c. Model validation and verification [3]
d. Big data high performance ABM [1]
e. Integrated human-environment ABMs [5]
f. Methodological issues of spatially explicit ABMs [2]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

I would like to discuss large- or multi-scale agent-based modeling in face of big data challenge

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [3]
b. Social science [2]
c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

- **Tang, W.**, and Jia, M., 2014, Global sensitivity analysis of large agent-based modeling of spatial opinion exchange: A heterogeneous multi-GPU acceleration approach, *Annals of Association of American Geographers*. 104(3): 485-509
- **Tang, W.**, 2013, Accelerating agent-based modeling using Graphics Processing Units, edited by Shi, X., Vlad, Yang, C., *Modern Accelerator Technologies for Geographic Information Science, Springer, New York, pp. 113-129*.
- Gong, Z, **Tang, W.**, Bennett, D.A., and Thill, J.C., 2013, Parallel agent-based simulation of individual-level spatial interactions within a multi-core computing environment. *International Journal of Geographical Information Science*, 27 (6): 1152-1170.
- **Tang, W.** and Bennett, D.A., 2011, Parallel agent-based modeling of spatial opinion diffusion accelerated using Graphics Processing Units, *Ecological Modelling* 222: 3605-3615.
- **Tang, W.**, Wang, S., Bennett, D.A., and Liu, Y., 2011, Agent-based modeling within a cyberinfrastructure environment: A service-oriented computing approach, *International Journal of Geographical Information Science*. 25(9): 1323-1346.

- **Tang, W.**, and Wang, S., 2009, HPABM: A hierarchical parallel simulation framework for spatially-explicit agent-based models, *Transactions in GIS* 13(3): 315-333.
- **Tang, W.**, 2008, Simulating complex adaptive geographic systems: A geographically aware intelligent agent approach. *Cartography and Geographic Information Science*, 35(4): 239-263.
- Bennett, D.A., and **Tang, W.**, 2006, Modeling adaptive, spatially aware, and mobile agents: Elk migration in Yellowstone, *International Journal of Geographical Information Science,* 20(9): 1039-1066.

Leigh Tesfatsion

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

  a. Human decision making in ABM [**1**]
  b. ABM code reusability and transparency [**4**]
  c. Model validation and verification [**3**]
  d. Big data high performance ABM [**6**]
  e. Integrated human-environment ABMs [**2**]
  f. Methodological issues of spatially explicit ABMs [**5**]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

The following topic would be of interest to me to discuss at ABM 17:

Modeling economies (or any real-world systems with human decision-makers) as locally constructive games via agent-based modeling tools
NOTE: I have an invited paper titled "Economies as Locally Constructive Games" in progress for the J. of Economic Methodology (JEM). This paper focuses on the use of Agent-based Computational Economics (ACE)" for the modeling of real-world economic systems. ACE is a particular form of ABM, characterized by seven specific model design principles. My JEM paper tentatively includes sections on the following topics:
ACE Model Design Principles
ACE Empirical Validation and Verification
Taxonomy of "Policy Readiness Levels" (PRLs) for Policy-Oriented ACE Models
Standardized guidelines for the presentation of ACE model s

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

  a. Life science [**3**]
  b. Social science [**1**]
  c. Human-environment science [**2**]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

On-Line Guide for Newcomers to Agent-Based Modeling in the Social Sciences
Robert Axelrod and Leigh Tesfatsion
http://www2.econ.iastate.edu/tesfatsi/abmread.htm

Qing Tian

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [2]
   b. ABM code reusability and transparency [6]
   c. Model validation and verification [1]
   d. Big data high performance ABM [5]
   e. Integrated human-environment ABMs [3]
   f. Methodological issues of spatially explicit ABMs [4]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

It seems to me that for ABMs to really make a contribution to science, they have to illustrate new insights about complex systems that conventional methods cannot. And for ABMs to be accepted by the mainstream scientists in any fields, ABM modelers really need to a good job to convince them of the value (i.e, capable of bringing new insights) and the validity of ABMs. How to build ABMs that generate convincing, new insights about complex systems would be important for the future development of ABM and is worth some discussion.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

   a. Life science [3]
   b. Social science [1]
   c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Andrei, A., Comer, K., Koehler, M. (2014). An Agent-Based Model of Network Effects on Tax Compliance and Evasion, Journal of Economic Psychology, 40: 119−133.

An, L., Linderman, M., Qi, J., Shortridge, A., and Liu, J. (2005). Exploring complexity in a human–environment system: an agent-based spatial model for multidisciplinary and multiscale integration. Annals of the association of American geographers, 95(1), 54−79.

An, L., Zvoleff, A., Liu, J., and Axinn, W. (2014). Agent-based modeling in coupled human and natural systems (CHANS): lessons from a comparative analysis. Annals of the Association of American Geographers, 104(4), 723−745.

Axtell, R. L., and Epstein, J. M. (1994). Agent-based modeling: understanding our creations. The Bulletin of the Santa Fe Institute, 9(2), 28−32.

Axelrod, R. (1997a). The dissemination of culture a model with local convergence and global polarization. Journal of conflict resolution, 41(2), 203−226.

Axelrod, R. M. (1997b). The complexity of cooperation: Agent-based models of competition and collaboration. Princeton University Press.

Bankes, S. (1993). Exploratory modeling for policy analysis. Operations research, 41(3), 435−449.

Berger, T., Schreinemachers, P., and Woelcke, J. (2006). Multi-agent simulation for the targeting of development policies in less-favored areas. Agricultural Systems, 88(1), 28−43.

Berger, T. (2001). Agent‐based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis. Agricultural economics, 25(2‐3), 245−260.

Brown, D. G., Robinson, D. T., An, L., Nassauer, J. I., Zellner, M., Rand, W., ... and Wang, Z. (2008). Exurbia from the bottom-up: Confronting empirical challenges to characterizing a complex system. Geoforum, 39(2), 805−818.

Castella, J. C., Trung, T. N., and Boissau, S. (2005). Participatory simulation of land-use changes in the northern mountains of Vietnam: the combined use of an agent-based model, a role-playing game, and a geographic information system. Ecology and Society, 10(1), 27.

Cotla, C. R. (2016). Heterogeneous Preferences and the Dynamics of Cooperation in Networked Societies: A Dialogue Between Experimental and Computational Approaches. PhD dissertation.

Cioffi-Revilla, C. (2014). Computation and Social Science. In Introduction to Computational Social Science (pp. 23−66). Springer London.

Cioffi-Revilla, C., and Goolsby, R. (2011). Advanced Modeling Capability for Rapid Disaster Response', Innovation Beyond Imagination, Vol. 7, September 2011, 12−13.

Crooks, A.T., and Wise, S. (2013). GIS and Agent-Based models for Humanitarian Assistance, Computers, Environment and Urban Systems, 41: 100−111.

Crooks, A. T., Croitoru, A., Lu, X., Wise, S., Irvine, J., and Stefanidis, A. (2015). Walk this Way: Improving Pedestrian Agent-Based Models through Scene Activity Analysis, ISPRS International Journal of Geo-Information, 4(3): 1627−1656.

Deadman, P., Robinson, D., Moran, E., and Brondizio, E. (2004). Colonist household decisionmaking and land-use change in the Amazon Rainforest: an agent-based simulation. Environment and Planning B: Planning and Design, 31(5), 693−709.

Drogoul, A., Huynh, N. Q., and Truong, Q. C. (2016). Coupling environmental, social and economic models to understand land-use change dynamics in the Mekong Delta. Frontiers in Environmental Science, 4, 19.

Epstein, J. M. (2014). Agent_Zero: Toward Neurocognitive Foundations for Generative Social Science. Princeton University Press.

Epstein, J. M., and Axtell, R. (1996). Growing artificial societies: social science from the bottom up. Brookings Institution Press.

Evans, T. P., Phanvilay, K., Fox, J., and Vogler, J. (2011). An agent-based model of agricultural innovation, land-cover change and household inequality: the transition from swidden cultivation to rubber plantations in Laos PDR. Journal of Land Use Science, 6(2-3), 151−173.

Farmer, J. D., and Foley, D. (2009). The economy needs agent-based modelling. Nature, 460(7256), 685–686.

Gilbert, G. N. (2007). Agent-based models (No. 153). Sage Publications.

Grimm, V., Revilla, E., Berger, U., Jeltsch, F., Mooij, W. M., Railsback, S. F., ... and DeAngelis, D. L. (2005). Pattern-oriented modeling of agent-based complex systems: lessons from ecology. Science, 310(5750), 987−991.

Janssen, M. A., and Ostrom, E. (2006). Empirically based, agent-based models. Ecology and Society, 11(2), 37.

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Peter Verburg

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

a. Human decision making in ABM [1]
b. ABM code reusability and transparency [6]
c. Model validation and verification [2]
d. Big data high performance ABM [5]
e. Integrated human-environment ABMs [3]
f. Methodological issues of spatially explicit ABMs [4]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

-empirical parameterization of ABMs

-upscaling of ABMs (ABMs for larger areas)

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

a. Life science [na]
b. Social science [3]
c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

- Verburg PH, Dearing JA, Dyke JG, Leeuw Svd, Seitzinger S, Steffen W, Syvitski J. 2016. Methods and approaches to modelling the Anthropocene. Global Environmental Change 39:328-340 http://dx.doi.org/310.1016/j.gloenvcha.2015.1008.1007.
- van Vliet J, Bregt AK, Brown DG, van Delden H, Heckbert S, Verburg PH. 2016. A review of current calibration and validation practices in land-change modeling. Environmental Modelling & Software 82:174-182. http://dx.doi.org/10.1016/j.envsoft.2016.04.017
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Xinyue Ye

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [4]
   b. ABM code reusability and transparency [1]
   c. Model validation and verification [5]
   d. Big data high performance ABM [3]
   e. Integrated human-environment ABMs [6]
   f. Methodological issues of spatially explicit ABMs [2]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):
We hope to simulate how efficiently meme can flow through spatial-social networks based on the quantity and positions of seed nodes in networks of different structures. Instead of finding a subset of nodes in the network that maximize the influence, however, we are more interested in finding ways to choose the least number of nodes that speeds up the information diffusion the most across space. Comparing different types of networks in terms of the performance of propagating information in the spatial context, we aim to find the kind of network that triggers large cascades of information adoption through ABM, which is a transdisciplinary research field for understanding and analyzing dynamic patterns, relationships, and changes of spatial-social systems where human activities and behaviors occur and evolve.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:
a. Life science [3]
b. Social science [1]
c. Human-environment science [2]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.
Guille, A., Hacid, H., Favre, C., & Zighed, D. A. (2013). Information diffusion in online social networks: A survey. ACM SIGMOD Record, 42(2), 17-28.
Kempe, D., Kleinberg, J., & Tardos, É. (2003, August). Maximizing the spread of influence through a social network. In Proceedings of the ninth ACM SIGKDD international conference on Knowledge discovery and data mining (pp. 137-146). ACM.
Lee, J. & Ye, X. (2017) Obesity Prevalence Simulator: An Open Source Spatiotemporal Model for Simulating Obesity Prevalence. In Thill, J. and Dragicevic, S. (eds.) Springer's Series on Advances in Geographic Information Science.

Rand, W., Herrmann, J., Schein, B., & Vodopivec, N. (2015). An agent-based model of urgent diffusion in social media. Journal of Artificial Societies and Social Simulation, 18(2), 1.
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Shaw, S., Tsou, M., & Ye, X. (2016) Human Dynamics in the Mobile and Big Data Era, International Journal of Geographical Information Science, 30 (9): 1687-1693.
Ye, X. & Lee, J. (2016) Integrating geographic activity space and social network space to promote healthy lifestyles. ACMSIGSPATIAL Health GIS, Newsletter 8(1) 24-33.
Ye, X. & Mansury, Y. (2016) Behavior-Driven Agent-Based Models of Spatial Systems, Annals of Regional Science doi: 10.1007/s00168-016-0792-3
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Weng, L. (2014). Information diffusion on online social networks (Doctoral dissertation, Indiana University).

Moira Zellner

1. According to the survey performed in 2016, we have identified six topics that will be discussed in breakout sessions and (very likely) advance to paper writing. Please rank them based on the level of desirability to you (1 the most desirable, 2 desirable, …, 6 the least desirable) and put the rank number in brackets:

   a. Human decision making in ABM [4]
   b. ABM code reusability and transparency [2]
   c. Model validation and verification [5]
   d. Big data high performance ABM [6]
   e. Integrated human-environment ABMs [1]
   f. Methodological issues of spatially explicit ABMs [3]

2. In consideration of the above list, please identify specific issues that you want to discuss at the ABM 17 symposium (no space limit):

I'd like to cover the big social/environmental questions that we could tackle using ABM, and how we can overcome barriers to addressing them. I feel that all the work we've done with ABM hasn't resulted in many changes. That's probably true of many other modeling techniques, but we could try to address this here.

3. We will have a set of poster presentations from junior ABM scholars, for which we hope you can serve as a judge. Please rank the poster domains below in the order of how confident you are about judging them (1 for most appropriate, 2 for appropriate, 3 for Okay, and NA for not appropriate or not available) and put the rank number in brackets:

   a. Life science [3]
   b. Social science [2]
   c. Human-environment science [1]

4. Please send us a list of recommended ABM related readings (no limit to the max number), including your own or other people's papers, book chapters, reports, etc.

Zellner, M.L.; Campbell, S.; 2015. "Planning for Deep-Rooted Problems: What Can We Learn from Aligning Complex Systems and Wicked Problems?" Planning Theory and Practice 16 (4): 457-478.

Radinsky, J., Milz, D., Zellner, M., Pudlock, K., Witek, C., Hoch, C., and Lyons, L. "How Planners and Stakeholders Learn with Visualization Tools: Using Learning Sciences Methods to Examine Planning Processes" Journal of Environmental Planning and Management (2016): 1–28.

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