Marco A. Janssen, Lilian Na'ia Alessa, Michael Barton, Sean Bergin and Allen Lee (2008)

Towards a Community Framework for Agent-Based Modelling

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Abstract

Agent-based modelling has become an increasingly important tool for scholars studying social and social-ecological systems, but there are no community standards on describing, implementing, testing and teaching these tools. This paper reports on the establishment of the Open Agent-Based Modelling Consortium, www.openabm.org, a community effort to foster the agent-based modelling development, communication, and dissemination for research, practice and education.

Keywords:
Replication, Documentation Protocol, Software Development, Standardization, Test Beds, Education, Primitives

Introduction

1.1

During the last two decades agent-based modelling has become an important new tool for modelling the dynamics of complex systems. It is particularly useful for modelling human social phenomena by simulating the rule-based interactions among individuals, allowing researchers to analyze the complex structures and processes that emerge from these interactions. Nevertheless, this potentially powerful analytical protocol has seen comparatively little use among social scientists. Those scholars who have ventured to make use of this tool have often found it necessary to learn and develop agent-based simulations on their own, customized to their specific research projects. This is in part due to the lack of standards and protocols and the rather patchy community of practitioners of agent-based modellers, underscoring the need for a community effort to develop best practices and protocols and exchange information and experience (Alessa et al. 2006).

1.2

About 15 years ago a similar attempt to develop a set of common standards and practices resulted in the development of Swarm (http://www.swarm.org). However, it was centred around a single software platform, one that remained technically challenging for most social scientists to use. As a result, Swarm helped make agent based modelling more visible to a larger number of scientists, but did not generate a broad-based community of practitioners that could embed this methodology and associated concepts in normal social science. The challenges to both widespread and proper use of modelling (especially agent-based modelling) for social science research reach well beyond the capabilities of a single, standard software tool. With support from the National Science Foundation, we are seeking to establish a broad-based community of social scientists and social systems modellers that can collaborate to improve the accessibility of agent based modelling for research and education. At a recent workshop at the Center for Social Dynamics & Complexity (Arizona State University, Tempe, Arizona; http://www.asu.edu/clas/csdc/), participants identified a set of specific challenges that need to be addressed in order to begin to realize this ambitious goal, and proposed a roadmap to do so. In this paper, we review these challenges and possible solutions as discussed during this workshop, including: the need for standardized protocols to describe complex agent-based models in publications and metadata, the lack of a means of archiving published models (i.e., the code and not just textual descriptions) and making them available to other scientists, the desirability of a library of model components that could be reused by scientists seeking to model similar phenomena, the need for improved software tools (especially human interfaces) that could reduce the technical learning curve for these protocols, a lack of test beds with common data sets that could be used to evaluate model efficacy in reliable and replicable ways, and a recognized need to establish training and education programs for both practicing scientists and student scientists in training.

1.3

Community frameworks have been successfully applied in other fields to stimulate collaboration between practitioners at different institutions from different disciplines (Alessa et al. 2006). The participants of this workshop build on these experiences to develop the initial steps towards a community framework for agent-based modelling. While the workshop focused especially on issues related to coupled human-natural systems, the lessons learned are applicable more generally for complex systems research in the social sciences. In addition to reviewing the above challenges discussed in the workshop, this paper describes our initial steps to establish the Open Agent-Based Modelling Consortium, and its collaborative resource and information centre.

Protocol to describe Agent-Based Models

2.1

Common vocabularies and communication standards are essential to the transparency in research protocols and results that is a hallmark of western science. Agent based modelling represents a new research methodology and a new way of conceptualizing research problems. There are currently no common, agreed upon protocols for describing agent-based models, making it difficult, and sometimes impossible, for other scholars to understand the underlying concepts, structure, and algorithms of a published model. This lack of standard communication protocols also makes it problematic to replicate findings of published models (Axtell et al. 1999;Hales et al. 2003); scientific credibility requires the ability, in principle, for others to reproduce the results of one's research. A standard and widely understood descriptive vocabulary is needed in order for agent based modelling to become accepted as an effective and reliable approach for studying complex systems.

2.2

One approach to the problem of a standardized communication vocabulary would be a formal language like mathematics to describe agent-based models (Zeigler et al. 2000). However, a highly formal mathematical modelling language may also be very difficult to communicate to the social and natural scientists that comprise a large proportion of the potential users of ABM's. At a more general level, the issue of standardized ways of documenting digital data and the processes that create them are becoming recognized as a critical need of 21st Century science (see for example Kettenring et al. (2006), http://www.ncgia.ucsb.edu/projects/metadata/standard/index.html; http://www.fgdc.gov/metadata). Of more pressing need than a formal modelling language for transparency in ABM research at this early stage in the development of this domain are guidelines for describing models clearly, concisely, and in sufficient detail in publications. This includes agreement on how much detail needs to be published, on which aspects of models, and in which order. Such a communication protocol would make it considerably easier for scholars to understand each other's work, and facilitate the creation of new models that build on the work of others.

2.3

Grimm and Railsback (2005) and Grimm et al. (2006) have proposed a standard protocol for describing individual-based modelling in ecology that could be a useful starting point for agent-based modelling. The Overview-Design-Details (ODD) protocol describes the overall structures first and then moves into the particulars. In the overview component, the purpose of the model is formulated state variables and scales are listed, and the various environmental and individual processes and the scheduling of these processes are described. The design section discusses the high-level design concepts guiding the model developer's creation, covering a wide range of aspects such as emergence, adaptation, stochasticity, fitness, interactions between individuals, etc. Finally, the details on initialization, model input, and submodels are reported. ODD does not communicate specific implementation details, however, and could be expanded in this direction (e.g., http://www.ncgia.ucsb.edu/projects/metadata/standard/index.html)

2.4

The ODD model description standard was applied to 19 extant ecological models to evaluate its usefulness (Grimm et al. 2006). While the protocol can certainly be improved or expanded in a number of ways, it proved a useful starting point for developing a common communication standard for these kinds of models that could be used by journals and model archives to ensure completeness and comparability. Pragmatically, given the potential for rapid growth in the area of ABM research, it may be wise to promote a variant of ODD to be adopted by journals publishing ABMs and their results. As it becomes more widely used, we expect that it will continue to be refined and augmented as needed to cover the range of ABMs for which it is applicable. We have established a discussion forum within the Open ABM Consortium with links to the ODD protocol site to allow the ABM community to collaboratively develop this protocol into a widely useable communication standard for describing ABMs in the social sciences.

Model Archive

3.1

Journal publication has long been the primary means of communicating research protocols and results to scientists and the non-scientific community at large. However, even with a standard descriptive language, such publications are usually insufficient to replicate and empirically evaluate the models described. This requires also publishing the actual source code that operationalizes the conceptual model. It is not uncommon for the actual implementation details to have important implications for the results (Hales et al. 2003). Publishing such code in its entirety would require many pages, making it impractical for journals with fixed space requirements. Furthermore, publishing code in paper form would require the laborious, error prone, and inefficient manual re-entry of the code into a digital format before the model could be tested. The lack of a venue in which the author(s) of a model can make their code available to others considerably hinders the development of ABMs as an effective tool for the social sciences as researchers are forced to reinvent the same or similar models repeatedly rather than building on the published work of their colleagues.

3.2

There is no community-wide, agreed-upon mechanism for archiving the source code of published models, nor well-established avenues to publish efforts to verify and replicate extant models. The Open ABM Consortium developed over the past months a prototype of a general ABM archive to address this issue, and serve as an example for the potential establishment of additional archives in the future. Our goal is to provide a well managed model archive that provides access via the internet to the code (commented and cleaned) and documentation of the model using a standardized descriptive protocol, described above. Additionally, there would be a place to archive relevant associated data, and parameter settings for published experiments.

3.3

Using facilities from the open source community, Open ABM is creating a model archive organized so that authors can upload their models, documentation, and ancillary files. The archive will be based around a combination of content management and version-tracking software, and will offer a collaborative development environment (e.g., CVS or Subversion) to allow models to continue to be enhanced after they are placed in the archive. The author(s) will be able to designate who has access to the code, and specify under which type of license others can use and adjust the code. The archive will also offer discussion forums for each model project and the means to search the archive on the basis of model characteristics. We propose that a model submitted to the archive meet certain minimal levels of description in order to be accepted. From a practical perspective, the minimum level should not be too strict in order to encourage scholars provide their models. However, we are considering a ranking system to indicate how well a model is documented and tested, and the extent to which code and data are made available. We propose a review board for the model archive facility to evaluate submissions to the archive and assign a ranking.

3.4

In practice, the development of this public good will be challenging. Scholars may not be willing to invest sufficient effort to document their models, comment the code, and make their code and data available. Human subject regulations could restrict the availability of data. Archives for models and algorithms have been created previously (e.g., http://www.physionet.org/), but have not always been successful in reaching a broader community. We hope to partner with journals like JASSS to use the archive to promote higher standards for publication of agent-based models. For example, journals could require that a model's implementation be made available in an archive for reviewer evaluation as a condition for acceptance of an article reporting model results.

3.5

Journals could also require that a model meets a particular ranking in terms of the completeness of its descriptions and accessibility.

3.6

Another issue identified at the Tempe workshop that could limit the use of a model archive is how to ensure proper credit and acknowledgement for the effort of creating a model that is subsequently made available to others. To stimulate and acknowledge the efforts of scholars to test and replicate model results, the model archive may need to establish a special e-Journal so that individuals who contribute to the quality control of the community derive recognition in the form of formal publications. For example, the replication of a Phyton model in Netlogo might become a separate entity in the model archive and count as a separate publication in the associated e-Journal for the person who did this implementation. Ultimately, the more such an archive is used, the more valuable it will become as a resource to all members of the modelling community.

Library of Model Components

4.1

Problems within particular research domains amenable to agent-based modelling are likely to make use of conceptually similar submodels or agents, but expressed in differing contexts. Currently, scholars developing agent-based models typically start from scratch because there are no reusable submodels that can be transferred from existing, functionally similar models. This is very different from most other science domains, where standardized field or laboratory equipment, statistical procedures, or software components can be reused and composed in a modular fashion. Ideally, we hope eventually to provide a sort of library of model components that can be plugged together to meet varying research needs. However, there are many conceptual and technical challenges to achieving this goal.

4.2

Reusable model components can potentially be operationalized at different scales, ranging from entire models applied to different data sets (see below) to individual agents that may comprise a single class (or analogous coding object). Deciding at what level or levels to make reusable components available is one conceptual challenge. Another is the pragmatics of software platforms. Models and their components are expressed in a particular computer language. It is not clear how these components (e.g., classes and methods) can be made sufficiently generic to be used in multiple ABM platforms and with different data sets, while remaining sufficiently detailed to be of value to researchers.

4.3

We are beginning to explore the possibility of reusable components by deconstructing a set of existing, well-known models, and attempting to rebuild them using a common generic framework of model components. This may represent the next generation of ABM use, in which researchers can modify existing components and assemble them to address diverse questions. To facilitate this, we will need a set of common input/output formats and a structure that will allow model components to be composed (i.e., assembled) in different software platform and with different data constraints. The "MetaModel" framework, discussed below, offers a promising direction toward realizing this.

4.4

There also are some extant starting points within specific domains for this initial work toward developing a new generation agent-based model. For example, Parker et al. (in press) fuse five land-use models into a single framework. At the conceptual ontological level these models have enough in common to be a possible starting point for developing a general land-use model based on generic model components. Within urban simulation, there is the development of a general model framework that can be applied to a diversity of datasets by the broader community. OPUS (Open Source for Urban simulation: http://www.urbansim.org) design is aimed at developing a core architecture with data necessary to validate models, and building blocks for creating new models — independent of a particular application.

4.5

It seems likely that the development of the next generation agent-based models will evolve initially within domain specific communities who may share building blocks and domain specific knowledge to an extent that a common meta-model structure can be used. Over time we hope that this work will lead to a library of tested model components, developed and tested against various datasets. When scholars address new applications, they can build upon accumulated knowledge and develop more reliable models. As with the widespread use of model archives, discussed above, we will need to ensure that there are incentives for scholars to go through the exercise of developing and testing their submodels in a way that can benefit the entire community—e.g., by publishing such work in an electronic journal.

Test beds for Agent-based Models

5.1

One commonly mentioned limitation to the use of agent-based models in social science research is the lack of commonly accepted approaches to validating model algorithms and evaluating the effectiveness of different modelling approaches. In part, this is because many agent-based models are developed for specific data sets. But there is also no accepted means of even comparing the results of two different modelling approaches on the same dataset. Nor can we easily assess how well models developed for one application function when applied to another dataset—for example, a model of deforestation in the Amazon applied to

Borneo. Ideally models and submodels can be tested against multiple datasets, to help ensure that validated and verified model components are developed and used within the community.

5.2

It is appealing to have a number of standardized datasets available, which the broader agent-based modelling community can use to compare and test the efficacy of their models. However, there are a number of hurdles to making this practical. First, current agent-based models are often applied to specific domains, making it difficult to define a few datasets that can serve as useful test beds for many diverse models within the broader community. More realistically, test beds can be initially developed within a limited number of specific application domains.

5.3

There are publicly available datasets that might be usable as test beds for evaluating agent-based models, such as *Many Eyes* (http://services.alphaworks.ibm.com/manyeyes/home), *Swivel* (http://www.swivel.com/), and *ICPSR* (http://www.icpsr.umich.edu/). Outside of archaeology, however, there is a general lack of longitudinal data collection in the social sciences. Hence there are limited datasets available with relevant micro-level and behavioural information to test agent-based models that deal with system change. Alternatively, there are ways to collect new test datasets for model testing (Janssen and Ostrom, 2006). However, there may be considerable social and ethical dilemmas and restrictions on making such datasets publicly available. These might be resolvable in some cases by distortion through intelligent randomization, resulting in anonymized datasets that still carry genuine observed data without compromising the identity of the participants that generated the data. Finally, there is the option of creating artificial datasets for use in evaluating and comparing models.

5.4

One of the tasks of the Open ABM Consortium is to begin to compile such standardized datasets, within a limited number of modelling domains and make them available for testing. Once standardized test beds become available, promising directions for evaluation include formal methods to compare alternative models of decision making, such as those discussed in Pitt et al. (2002) and Kruzar (2006). Models that explain more patterns and stylized facts can be considered to be more reliable than their alternatives (Grimm and Railsbeck, 2005). Such datasets might also be useful for testing the submodels discussed earlier. Again, it will be important that researchers are properly credited for the datasets they provide and that other scholarly incentives are provided to encourage scientists to contribute to a community modelling testbed.

Platforms for Agent-based Modelling

6.1

Ideally, agent modelling software should be a tool that researchers use to operationalize conceptual approaches to simulating social dynamics, in order to address social science problems. Modelling-based research should not necessarily require writing software. But in practise today, scientists employing agent-based approaches spend much of their time writing code, and most scholars who have no formal training in programming (the great majority of social scientists) see this as a significant barrier towards the use of agent-based modelling. In addition to the need for programming skills, a further dilemma for a scholar wishing to use agent-based modelling is deciding which platform to use, since there are many different platforms, each with their own pros and cons. Besides the recent developments on meta modelling (see below), it is currently not possible to port a model from one ABM platform (e.g., converting a model from Repast to Mason) to another without manually reimplementing the model, even if the underlying programming language used to implement the model is the same for both platforms (Railsback et al. 2006). This further inhibits the exchange of knowledge and expertise among ABM practitioners.

6.2

New approaches to agent-based modelling software development are focusing on differentiating 'tool experts' and 'domain experts', and recognizing the need for implementation-neutral representations of agent-based models. It is also clear that to encourage more domain experts to use modelling, tools and interfaces need to be available that do not require significant computer programming experience and software engineering expertise. Recent developments in software engineering, such as Domain Specific Languages (DSLs) and Model Driven Software Development (MDSD) tools offer the potential for more accessible modelling platforms to be developed (Parker et al. 2006). For example, Parker et al. (2006) developed a meta-model approach for agent-based modelling and simulation. The idea is that a high level, abstract model of the processes is defined first, and then used to implement a model in a specific software language. Ideally, the abstract representation of such a meta-model is sufficiently detailed that such implementation code can be developed for different platforms.

6.3

The meta-model concept is currently being developed for the RePast, Ascape, and Netlogo ABM software platforms (see metascape: http://www.metascapeabm.com/). These software development groups, along with those working with UrbanSim and Mason, are now collaborating within the context of the Open ABM Consortium to address issues of improved usability and portability of ABMs. An important aspect of this, discussed at the Tempe workshop, was the extent to which the inner workings of ABM software should be exposed to users. In general complete transparency in research methods is desirable, and the same is true of model implementation. But 'translucency'—where some aspects of model implementation, but not all the details of the code, are exposed,—is probably a more practical approach for many social science applications. This is the case for a number of other widely used cybertools in social science, including GIS and statistical packages, although in the early stages of their development and adoption, these tools also required high level programming skills. ABM platforms are comparatively young technology, and we hope to encourage their maturation along the lines of other cybertools used in the social sciences. An important point is that the modelling tools discussed here are open source software, meaning that their source code is publicly available. This means that ultimately, regardless of the interface, the underlying code can be examined by anyone ensuring the level of transparency desired in scientific research.

6.4

Graduated user interfaces are another potential approach to making ABM platforms more usable to a wider audience of scientists. There is a lot of detailed software machinery that does not have to be directly user-accessible in order to carry out many simple modelling tasks. For example, a novice modeller could start with a simple interface consisting of a few buttons organized in a simple way. During the development the interface could change to expose more details of the implementation as the user gains more sophistication and the model contains more details. Future software tools for agent-based modelling may offer a range of options to develop models including textual (pure code), visual (like unified modelling language UML) or guided wizard-driven interfaces.

GIS-ABM integration

7.1

As a tool for simulating and studying dynamic complex systems, agent-based modelling can be made even more useful through integration with other software tools such as network analysis software, statistical tools, and geographic information systems (GIS). For scholars who study social-ecological systems, the integration of agent-based modelling platforms with GIS is especially promising, and a number of integration projects have been recently initiated.

7.2

GIS is a highly flexible and mature software technology for processing, analyzing, and visualizing geographically referenced data. Although GIS regularly handles complex modelling tasks, current GIS software is generally less adept at handling dynamic processes and complex scheduling mechanisms. This makes integration with agent-based modelling platforms particularly appealing as most ABM platforms provide powerful abstractions for building scheduling mechanisms and event driven simulations. Conversely, representing socio-ecological phenomena with an ABM involves situating agents and their actions in space, and affecting or being affected by an environment that has spatial relationships. GIS software is optimized to handle such spatial dynamics more efficiently than existing ABM platforms. A further benefit of ABM-GIS integration is that a large user group already familiar with complex modelling using GIS software would be able to make use of integrated ABM tools more rapidly than researchers less familiar with computer-based modelling in general.

7.3

Currently, ABM and GIS integration remains more of a goal than a reality. Brown et al. (2005) distinguish four approaches to coupling agent-based models with GIS: identity relationships (relation between agents and elements of the spatial database), causal relations (agents can process units which can cause change in the spatial features), temporal relationships (especially when updating is asynchronous updating of information can be challenging), and topological relationships (topologically restricted data). Additionally, GIS can be integrated with agent-based models in a loose way (exchange of data), in a tight way (GIS or ABM centric where the functions of ABM/GIS platform are implemented in GIS/ABM platform), or as coupled models. Especially with open source tools, there are pragmatic advantages to the coupled approach. However, there is a need to develop a common ontology and common behavioural primitives to make these couplings more effective and standardized. Ongoing research by Open ABM Consortium members involves implementing bridges between ABM and GIS software.

Education in Agent-based Modelling

8.1

In order for agent-based modelling to become a regularly used analytical tool in the social sciences, researchers need to be able to conceptualize questions and approaches to answering them in ways that are often quite different from the theoretical and methodological approaches in which they were trained. This includes how to think of problems (especially in terms of generating testable hypotheses) in the kinds of structures and processes that can be readily translated into a simulation environment, how to effectively abstract relevant human behaviours into agents (including data input, internal rules, and external interactions), and how to evaluate the results of simulation experiments. This is in line with the general concept of computational thinking (Wing, 2006). At least with today's ABM platforms, it also involves a more in depth understanding of computer science and software engineering, especially object-oriented programming. Social scientists that are currently developing agent-based models have diverse educational backgrounds, but are often self-taught with regards to this kind of simulation modelling. Furthermore, there are as yet no standard teaching materials or text books available at the graduate and undergraduate level that covers both social science theory and agent-based modelling approach (though some are in preparation). This lack of established training programs in both the conceptual and technical sides of agent-based modelling is a major stumbling block to a more effective use of this important technology for practicing scientists and students

8.2

There are various training workshops and summer schools for the highly motivated and advanced individuals, but we like to see education on agent-based modelling within the curricula of undergraduate programs of the social sciences. In order to train the students who will become the next generation practitioners of agent-based modelling it is important that we develop a critical body of instructional teaching material that is shared within the community, especially in terms of the components of a graduate education needed for adequate skills in agent-based modelling. The participants of the Tempe workshop agreed that students need to gain a broad overview of modelling approaches to understand the differences of agent-based modelling with other modelling approaches like system dynamics, and statistical models. Students also need to learn to conceptualize approaches to research questions in terms of algorithms and pseudo-code. Finally, they need thorough grounding in the domain knowledge and theory of their particular discipline in order to apply these simulation tools effectively in a way that is relevant to their field.

8.3

In order to build this expertise, workshop participants suggested that it would be useful for students to have courses in complexity science, basic programming (especially in object-oriented languages), databases, statistics, and visualization tools, in addition to courses in domain specific knowledge. Given the breadth of knowledge that may be needed to carry out complex simulations, experienced practitioners also strongly recommended that students learn to work closely with students from other disciplines; education of future generations needs to be interdisciplinary.

8.4

Embedding training in agent-based modelling (and other formal modelling approaches) within social science academic programs may require important institutional changes. Many academic programs may find it difficult to encompass the diversity of training needed to acquire ABM expertise within traditional degree tracks, especially when it requires courses not taught within the academic unit. This might be facilitated by more team-taught courses, pairing domain experts and tool experts for example, and graduate supervisory committees that regularly include faculty from outside the main degree program. However, there may well need to be a concomitant shift in university culture at levels above individual academic units for this to take place. In order for administrators to be motivated to change academic policies to favour this kind of interdisciplinary training, we will need examples of successful programs.

8.5

A concerted and unified community initiative will be important to stimulate universities and academic programs to educate the next generation of social simulators. However, we do not think that developing a single, recommended, standard teaching program is realistic, since universities vary with respect to available faculty expertise in the diverse aspects of agent-based modelling and its application areas. A more valuable role for the community of ABM practitioners is to offer guidelines for the skills needed for applying agent-based modelling in scientific research—such as those summarized above—and to highlight best practices in academic programs endeavouring to offer this kind of training.

8.6

Another point raised at the workshop is that students often do not arrive at colleges and universities sufficiently prepared to begin the kinds of interdisciplinary courses needed for attaining initial ABM skills within a four-year degree program. If modelling becomes an important research tool in social and other sciences, it will be important to begin to introduce students to the kind of logic and problem-solving approaches conducive to agent-based modelling at the K-12 level. On an encouraging note, most K-12 students are highly computer-literate (perhaps at the expense of the written word), and are increasingly familiar with some of the concepts of simulation through exposure to video and computer games. Initial trials for beginning education in simulation modelling using Netlogo and similar platforms have been successful at the high school level.

8.7

Finally, it is equally important that established researchers who would like to use ABM approaches in their own work have diverse opportunities to gain necessary skills in ways that can be squeezed into busy professional lives. A community-wide network could have an especially important impact in this setting by providing discussion forums where experienced modellers can advise novices, internet course materials and domain-specific guides to agent-based modelling, and promoting short-courses and summer seminars where scientists could go for intensive training.

8.8
A community initiative is needed to develop such training materials and provide venues for their dissemination. As mentioned earlier, it is important to acknowledge and credit scientists for the intellectual activities related to the development of educational programs of any sort for agent-based modelling, and to ensure that there are publication outlets for reporting such efforts.

A Community Response

9.1
Participants at the Tempe workshop defined a broad set of challenges the scientific community faces if agent-based modelling is to move from a largely experimental technique to a regularly applied methodology, and proposed an equally broad suite of possible solutions. However, in order to go beyond a mere wish list of activities, we also recognized the need to institutionalize the efforts to meet this larger goal, allocate responsibilities toward implementing proposed solutions, and seek the funding to do so in a coordinated way. The grant from the National Science Foundation that made the workshop possible includes modest resources for a pilot study to initiate the work, but a longer-term program is needed if we are to be successful.

9.2
At the close of the workshop the participants took the first steps towards the creation of the Open Agent-Based Modelling Consortium, which aims to foster the agent-based modelling development, communication, and dissemination for research, practice and education related to coupled human and natural systems. We also established the following initial working groups, within the Open ABM Consortium, to begin to implement the initiatives proposed at the workshop:

- **Model archive**: develop archive infrastructure, discuss intellectual property issues, and establish protocols for documenting models.
- **Protocols for communicating models**: description standards, implementation metadata, and getting journals involved with description standards.
- **E-Journal**: coordinate with existing journals and other working groups, and review the options for establishing an e-Journal to focus on publishing model components, educational materials, reimplementation of models, etc.
- **Education and outreach**: compile existing educational activities on agent-based modelling, make teaching material available on the web, and plan workshops for students and professionals.
- **Software tool development**: define best practices among software developers, improve interfaces with input from users, develop model interchange formats, and coordinate tool integration (such as GIS).
- **Data test beds**: define formats for describing data (coordinate with archive and protocol groups), establish criteria for submission, and collect data sets.
- **Next generation ABM**: identify an initial set of suitable models and rebuild them using an agreed upon format of submodels in order to develop a well informed model library of model components.

9.3
Founding Open ABM members agreed that, because transparency and accessibility is especially important in this nascent field, community activities should make use of open source tools and principles to the extent possible.

9.4
We have established a resource, information, and collaboration portal for the community of ABM practitioners at http://www.openabm.org. Although the initial focus of the Open ABM Consortium is on scholars who develop agent-based models for social-ecological systems,

we and our co-participants welcome expanding its mission to other application domains if the initial pilot program is successful. We extend an open invitation to scholars with intellectual and research interests that involve agent-based modelling to participate in the activities of the Open ABM Consortium and to contribute to its working groups. Interested individuals can register at the Open ABM web portal. Some concrete activities are already underway, including the development of a prototype model archive. As this is a communal effort in the open source community spirit, it depends on the voluntary contributions of all of us to make this successful.

List of participants of the Tempe workshop, 1-3 March 2007

(Center for Social Dynamics and Complexity, Arizona State University)

Marina Alberti	University of Washington
Lilian Na'ia Alessa	University of Alaska, Anchorage
Eowyn Allen	Arizona State University
Mark Altaweel	Argonne National Laboratory
Marty Anderies	Arizona State University
Michael Barton	Arizona State University
Sean Bergin	Arizona State University
Daniel Brown	University of Michigan
Douglas Causey	University of Alaska, Anchorage
Robert Cox	Arizona State University
Kathy Galvin	Colorado State University
Randy Gimblett	University of Arizona
Bill Griffin	Arizona State University
Volker Grimm	Helmholtz Centre for Environmental Research, Germany
Ross Hammond	Brookings Institution
Marco Janssen	Arizona State University
Anaru Kliskey	University of Alaska, Anchorage
Timothy Kohler	Washington State University and Santa Fe Institute
Melinda Laituri	Colorado State University
Steven Lansing	University of Arizona and Santa Fe Institute
Allen Lee	Arizona State University
Gary Mayer	Arizona State University
John Murphy	University of Arizona
Michael North	Argonne National Laboratory
Luis A. Nunes Amaral	Northwestern University
Tad Park	University of Arizona
Dawn Parker	George Mason University
Miles Parker	Argonne National Laboratory
Bill Rand	Northwestern University
Hessam Sarjoughian	Arizona State University
Shana Schmidt	Arizona State University
Sander van der Leeuw	Arizona State University

Joshua Watts	Arizona State University
Deborah Winslow	National Science Foundation

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