



UNIVERSITY OF
CALGARY

SENG 609.22 Agent base Software Engineering
Course Instructor: Dr. Behrouz H. Far

Tutorial Report

Agent-based Simulation for Social Issues
A report on Agent Based Simulation in Integrated Assessment
and Resources Management

Liang Zheng
zheng@cpsc.ucalgary.ca

Agent-based Simulation for Social Issues

A report on: Agent Based Simulation in Integrated Assessment and Resources Management [1]

Liang Zheng

ABSTRACT

An agent is a computer system capable of flexible autonomous action in a dynamic, unpredictable and open environment. Agent technologies and approaches have the potential to greatly impact the lives and work of all of us. Some application domains where agent technologies will play a crucial role include: Ambient Intelligence, the seamless delivery of ubiquitous computing, continuous communications and intelligent user interfaces to consumer and industrial devices; Grid Computing, where multi-agent system approaches will enable efficient use of the resources of high-performance computing infrastructure in science, engineering, medical and commercial applications; Electronic Business, where agent-based approaches are already supporting the automation and semi-automation of information gathering activities and purchase transactions over the Internet; the Semantic Web, where agents are needed both to provide services, and to make best use of the resources available, often in cooperation with others; Bio informatics and Computational Biology, where intelligent agents may support the coherent exploitation of the data revolution occurring in biology; and others including monitoring and control, resource management, and space, military and manufacturing applications, for example.

Social simulation is the idea that one can build a computer program that models the behavior of some social phenomenon. Simulation can be applied in many critical areas and enables one to address issues before they these issues become problems. Simulation is more than just a technology, as it forces one think in global terms, about system behaviour, and about the fact that systems are more than the sum of their components. Simulation can provide insights into the designs of, for example, processes, architectures, or product lines before significant time and cost has been invested, and can be of great benefit in support of training.

DEFINITION

Simulation most general sense means to mimic, to do as if. More specifically it is used in research for any activity in which researchers make models, "simulation models", of the operation of some object of study. The merit of such an approach is that it enables researchers to play with the simulation model: they can enter hypothetical data to see what would happen, without having to let it happen in reality. Usually, simulation involves writing simulation models in a programming language or in a specialized simulation package, and running them on computers. [2]

Agents can be defined to be autonomous, problem-solving computational entities capable of effective operation in dynamic and open environments.

Agents are often deployed in environments in which they interact, and maybe cooperate, with other agents (including both people and software) that have possibly conflicting aims. Such environments are known as multi-agent systems. [3]

Agent Base is an intelligent agent infrastructure, which houses any number of utilities and agents. [4]

Object-Oriented simulation models consist of objects with complex internal dynamics, which interact with each other. The rules of interaction are determined by the properties of the objects. [5]

1. INTRODUCTION

The current challenges in resources management are less characterized by solving well defined problems but rather by building flexible and sustainable resource management regimes. The traditional view of a sequential process of the science policy interface starting with the identification of an environmental problem from the natural science perspective, continuing with the search for a (preferably technical end-of-pipe) solution, and finally leading to the dissemination of this knowledge to decision makers has been replaced by the insight that the human dimension has to be integrated from the very being of the analysis of the problem. However, major conceptual and knowledge gaps exist how to include the human dimension into integrated assessment models and processes.

Approaches derived from economics are not process based and start further from the assumptions of an equilibrium between supply and demand or if a rational expectations equilibrium in a collective of agents. They are in general top-down approaches and the processes / parameters are chosen such that they lead to a new equilibrium state. This is very uncommon for any natural science or engineering approach where one starts with processes and the equilibrium state (if it exists) results from the interactions. Related to the economics approach is the strong normative claim that the market equilibrium results in a Pareto optimal state for the resource allocation and that this state is this the most desirable in terms of maximizing individual and collective welfare given the availability of a limiting resource. Even if it is now readily admitted that market failures exist regarding the visibility and the value of environmental goods, current analytical approaches are yet quite limited in dealing with the complexity of real resource management problems and the dynamics of the interaction between human behavior and the environment. Further, there are basic assumptions about human behavior inherent in e.g. game theoretical approaches that ought to be questioned given the contradicting empirical evidence. The economics perspective covers only a part of the whole breadth of the spectrum of possible approaches to represent human behavior e.g. [10]. The importance of the self-organizing capacities of local communities has for example been noted for quite a while [19] [21].

Agent based modeling (ABM) is a very promising approach to include the human dimension into Integrated Assessment Models in a more realistic fashion [13]. Agents, in this context, are autonomous software systems that are intended to describe the behavior of observed social entities (e.g. individuals, organizations, governmental agencies). An enormous advantage of agent based modeling is the ability to assess the plausibility of the behavior of agents, the ways in which the agents interact and the consequences of that behavior and interaction. They allow accounting for scaling issues. It is widely recognized that most global change phenomena result from the cumulative effect of numerous activities at regional and local scales. At any scale, decisions are actually taken by individuals or as a result of interactions among groups of individuals. Individuals weigh up the evidence of both their own perceptions and information provided by others. This implies a very different decision making process than was presumed in earlier integrated assessment models.

These issues can be captured with agent based modeling techniques and participatory model building processes where decision making is perceived as a process of social learning. Social learning implies the development of a shared problem perception and an understanding for the complexity of the system under consideration, the recognition of different mental frames, the identification of new rules and strategies. In such a context models have a new role and become part of a process of social learning.

The role of information and information tools in government policy more generally has already been discussed for years, but many questions still remain. This is even truer if we zoom in on the role of information in resources management. The gap between model outcomes and resource management practice has been recognized for years, but there has been little success in bridging the gap. Too often information is seen as objective input into decision making, ignoring issues such as uncertainty and implicit policy choices. Rarely is information and are information tools seen as a means to promote and inform discussions between stakeholders and thus foster social learning. However, it is thus processes of social learning, the development of a shared problem perception, the evolution of shared strategies and perceptions that are crucial for the development of enduring and sustainable resource management regimes. Agent based modeling may both help to improve the representation of the dynamics of social processes in integrated models and to improve the conceptual understanding of processes of social learning and a new role for models as part of a learning process in stakeholder groups. These arguments are now developed step by step by providing first a brief account of the state of agent based modeling and it's potential for an improved representation of social processes.

2. AGENT BASED MODELLING IN A NUTSHELL

Agent based modeling (ABM) allows to capture the behavior of human beings in a more realistic fashion. An enormous advantage of ABM is the ability to assess the plausibility of the behavior of agents, the ways in which the agents interact and the consequences of that behavior and interaction. It is important to emphasize that ABM comprises a wide range of approaches and activities. These range from spatial models with simple rule

based cellular automata to complex cognitive architectures of individual agents such as the BDI framework.

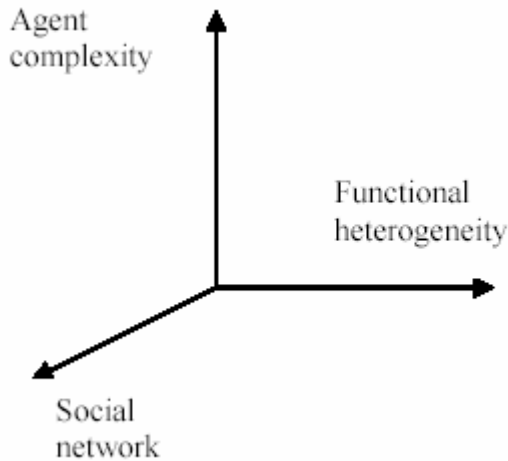


Figure 1: Abstract space for the three dimensions of complexity for an agent based model.

One may identify the three dimensions of complexity for an agent based model outlined in Fig. 1. Any modeler who intends to develop an agent based model for a particular resource management problem is thus faced with choices regarding:

Agent complexity - numerous approaches exist how to represent the reasoning processes of agents. They may be based on psychological theories (e.g. ACTR or SOAR), on microeconomics - rational actor paradigm and modifications thereof based on bounded rationality, complex cognitive agents architectures or simple heuristics and rule based behavior. Any approach deviating from the simplicity of the rational actor paradigm of economics results soon in quite complex models [e.g. 15]. Many conceptual theories on human behavior have never made it to the stage of being included in a simulation model at all.

Hence making here a choice for a specific implementation of an agent based model is not a trivial issue. Functional heterogeneity - what type of functional groups should be included in a model. Economists prefer to work with the representative agent approach where a whole collective of diverse agents is represented by one average type. However, what are the effects of neglecting the diversity of agent heterogeneity, e.g. different consumer groups? Such groups may be for example is based on life-style attributes or on different cultural perspectives [16].

Social network - the interaction among agents is of paramount importance for the diffusion of information or behavior. In the case of the ideal market, information transfer (via price) is immediate, central and without costs. In the real world, interactions are local, information transfer and processing is associated with costs and takes time. Networks have structure - spatial (e.g. neighborhood in geometrical space) and social (different types of relationships, friendship groups). Often interactions are based on

distributing agents on a rectangular grid. However, investigation of voter behavior showed that the network structure based on social interactions was of major influence for simulation results [20]. The existence of such issues is in general acknowledged, the view on their importance and how to account for them differs largely.

The choice of the appropriate agent based model depends on the goal of the modeling approach and on the complexity of the tasks the agents have to accomplish in their environment. Obviously there is a trade-off between modeling complex interactions in heterogeneous social networks and representing the complexity of the internal reasoning processes of individual agents. Up to now these two fields have developed rather independently. Either researcher has been more interested in the emergence of patterns in complex, spatial networks or they have explored in more detail complex cognitive architectures for individual agents. It will be important to foster an intense exchange between these fields to explore the importance of scale, agent representation and aggregation.

One question that should be resolved in such exchanges is for example the appropriate representation of individual and collective agents in spatial settings. Can a representation derived from the cognitive base of an individual be easily transferred to a collective agent and even more so to an aggregated group of agents? Economics assumes utility maximizing behavior for all agents at any scale whether referring to the individual decision maker, the representative household or the profit maximizing firm. A richer framework for the representation of decision making processes at different levels of aggregation and more investigations into the effect of aggregation are urgently needed. Figure 2 show important dimensions that ought to be considered when aggregating agent behavior.

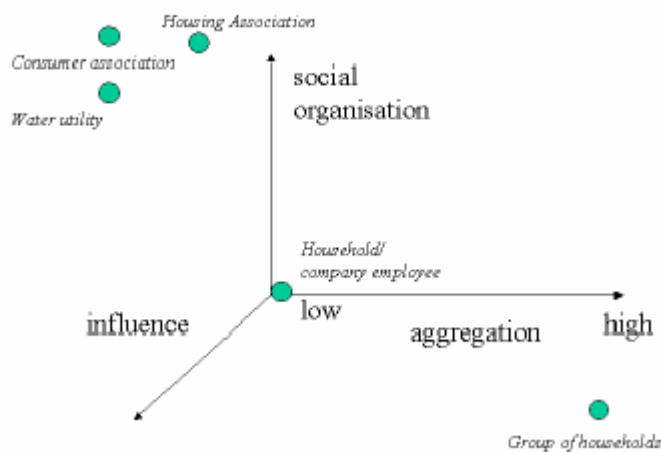


Figure 2 Different levels of aggregation affecting the spatial sphere of influence in an agent based model. "Collective agents" might be associations of companies that comprise a defined communication structure and decision making processes to come to a collective opinion/goal. For aggregations of agents such as a group of households / farms the situation is different. Here the aggregation implies that the properties of individual

households can be represented by an aggregated average. This is an entirely different process of aggregation.

Hence it must be emphasized that considerable uncertainty is inherent in the simulation of any social system. Hare and Pahl-Wostl [13] investigated the influence of the choice of different types of agent rationality on the outcome of policy options in quite a simple system - nitrate pollution by farming agents. They discovered that the structural model uncertainty inherent in the choice of agent rationality far outweighed any uncertainty deriving from parameter uncertainties or stochastic effects coming e.g. from climate. Uncertainty based on the choice of agent rationality should be explored in a more systematic fashion.

The reasons for uncertainty inherent in any simulation of social systems are manifold. Firstly, a sound theoretical base for representing human systems in an integrated fashion is lacking. And secondly, the predictability of human behavior can be questioned in principle. Molecules follow the laws of nature and a river will not reverse its direction if faced with new information about its state. Human beings, however, may change the rules under which they operate; they may engage in a collective choice process and change their strategies within the constraints of the material boundary conditions. This implies a self-reference that puts any traditional approaches to systems analysis into question. The analyst and the model become part of a process. Hence, social simulation practitioners see model building and scenarios as a route to build a dialogue and a means for a co production of knowledge rather than a means to develop predictive forecasts. The role of a model may be to provide the base for plausible scenarios and finally decisions are made in a process of social learning. This is reflected in the approach of participatory agent based social simulation

3. PARTICIPATORY AGENT BASED SOCIAL SIMULATION

Participatory agent based social simulation deviates in a number of ways from conventional modeling.

The actors themselves whose behavior is represented in the model and who are supposed to later use the models for decision making and strategic planning, participate and contribute to the modeling process. This guarantees that the model captures issues that are of relevance to the actors involved. And the model captures their subjective perceptions and expectations. In any investigation of a system there exist objective components and subjective elements. Decision making is shaped by the perspectives of the decision makers involved. Decision makers have subjective mental models on how the system functions. They base their decisions on their subjective understanding of the world [7] [21]. They have an implicit knowledge about the formal, and in particular the informal rules governing the decision making processes. Hence, any systems analysis for problem solving has to encompass the human dimension explicitly.

Figure 3 shows the two major streams that inform the agent based model - the data from the analysis and the subjective perceptions derived from the participatory process.

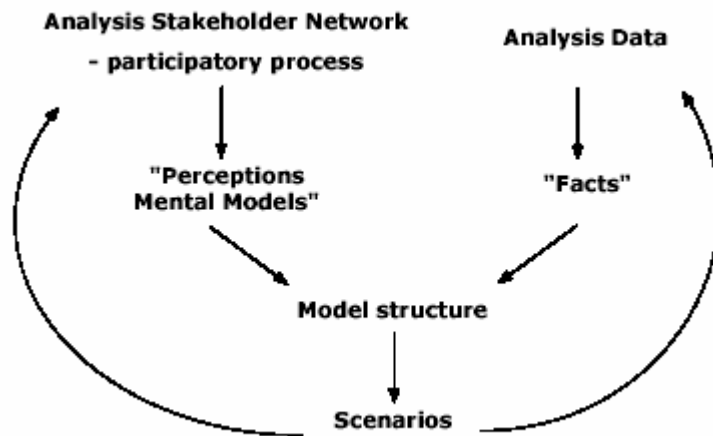


Figure 3 Combination of "hard" and "soft" systems methodologies for analyzing stakeholder networks and for participatory model development and application. The development of the model is informed both by methods of analyzing data and developing systems categorizations based on abstract notions and by the elicitation of mental models and subjective categories derived from individual stakeholders.

In general, approaches to systems analysis in the natural sciences perceive models as a means to capture the processes governing systems behavior. A good model is judged by its ability to simulate phenomena observed in the real world and to make testable predictions about system behavior. Figure 3 emphasizes that an important role of models in processes of social learning is to bridge the gap between the "external" descriptions of a system as derived from the analyst and the "internal" mental models of the system on which stakeholder base their decisions. Model serves processes of learning rather than predictive purposes [17] [21].

In processes of social learning two types of mental models are of major interests

1. Assumptions about cause effect relationships in the overall system crucial for the interpretation of the past, orientation in the presence and for estimating the effects of future actions.
2. Perceptions of the stakeholder network and expectations about other agents' behavior crucial for developing collective strategies and for evaluating the consequences of individual actions.

Currently new approaches from artificial intelligence are explored in the FIRMA project to elicit this type of knowledge and to explore how it affects decision making processes in water supply management [12].

The methodology integrates methods for knowledge elicitation and group learning from management science, clinical psychology and knowledge engineering. Agent-based models are developed in different media in order for the stakeholders to have different levels of involvement with the models, depending on the need for them to learn about

each other's perspectives or to assess a range of possible management scenarios. It allows combining "subjective" knowledge elicited from the stakeholders with "objective" knowledge derived from data. This integration is facilitated by combining a role playing approach with the development of an agent based computer model. The combination of role playing and agent based models has successfully been explored in a number of resource management problems [6]. It seems to be a particularly efficient approach to foster processes of social learning.

4. ROLE OF MODELS AND DIMENSIONS OF VALIDATION

An agent based model in participatory agent based social simulation is informed by different processes and hence has to be validated against these different purposes. This is summarized in Fig. 4.

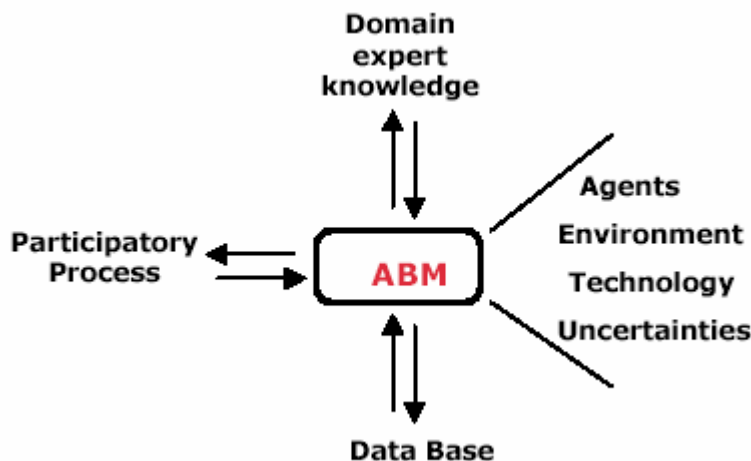


Figure4. Different dimensions in the process of developing and validating an agent based model (ABM).

These dimensions are briefly discussed and illustrated from a participatory process and agent based model in the context of developing new strategies for water supply management [23][12].

1. Data base and coherence with observed factual knowledge.

Any model has an input from factual knowledge as derived from data such as long term monitoring, statistical surveys of consumer behavior, data on water demand and pricing regimes. The outputs produced from simulation runs can be validated against their ability to reproduce empirical patterns.

2. Subjective expert opinion

In this case subjective expert knowledge was used to elicit the rules the govern decision making processes and management strategies in water supply management. These rules were implemented into a model and validated against how they could reproduce behavior in system variables such a total capacity as derived from empirical data and against their plausibility in the assessment of the expert peer group.

3. Input from and the model's role to facilitate a process of social learning.

On the base of previous investigations an extended participatory process was designed where an agent based model in combination with a role playing exercise is currently used to explore processes of social learning and the development of new strategies in a stakeholder group.

Such a stepwise and iterative process allows combining factual knowledge as derived from empirical data, subjective expert knowledge about decision making rules, and mental models about system behavior and social structure. This combination is a prerequisite to engage successfully in a process of social learning where attention is paid to issues such as the development of shared problem definition and shared understanding of the socio-technical and physical system at stake, perception issues and mental frames, negotiation processes and strategies, and the quality of communication.

Whereas traditional validation techniques for judging a model in its ability to reproduce empirical observations are well established more work should be devoted to develop techniques that allow to assess the performance of a model in its ability to foster and facilitate processes of social learning

5. COMPARE WITH OBJECT-ORIENTED SIMULATION

5.1 OBJECT-ORIENTED SIMULATION

It is very easy to describe existing simulation languages using object terminology. A simulation language provides a user with a set of pre-defined object classes (i.e., resources, activities, etc.) from which the simulation modeler can create needed objects. The modeler declares objects and specifies their behavior through the parameters available. The integration of all the objects into a single bundle provides the simulation model. Therefore, an object can be described by an entity that holds both the descriptive attributes of the object as well as defines its behavior. For example, suppose you are modeling an exponential random variable in a simulation. The random variable may be described by a standard exponential statistical distribution which has a set of parameters (e.g., a mean in this case). This mean would be considered an attribute of the exponential random variable object. It maybe important to obtain observations from this random variable via sampling. One may want to obtain antithetic samples or to set the random seed. Sampling from the exponential random variable defines a particular behavior.

Modeling and simulation in an O-O language possesses many advantages and has great intuitive appeal in applications because it is very easy to view the real world as being composed of objects. As shown, internal functionality of a language now becomes available to a user (at the discretion of the class designer). Such access means that existing behavior can be altered and new objects with new behavior introduced. The O-O approach provides a consistent means of handling these problems. O-O systems view the world as a set of autonomous agents that interact or work together to solve some complex task. Each object is responsible for a specific task that helps one organize the complexity of complex systems which simplifies the computer programming tasks. O-O designs yield smaller systems through the reuse of common mechanisms. They are more reliant to change and are better able to adapt over time. O-O designs greatly reduce the risk of

building complex software systems because they are developed to evolve incrementally from smaller systems.

5.2 THE DIFFERENCE BETWEEN AGENT-ORIENTED SIMULATION AND OBJECT-ORIENTED SIMULATION

Although there are certain similarities between object-oriented and agent-oriented approaches (both adhere to the principle of information hiding and recognize the importance of interactions), there are also a number of important differences. First, objects are generally passive in nature: they need to be sent a message before they become active. Secondly, although objects encapsulate state and behavior realization, they do not encapsulate behavior activation (action choice). Thus, any object can invoke any publicly accessible method on any other object. Once the method is invoked, the corresponding actions are performed. Additionally, object-orientation fails to provide an adequate set of concepts and mechanisms for modeling complex systems. Individual objects represent too fine a granularity of behavior and method invocation is too primitive a mechanism for describing the types of interactions that take place. Recognition of these facts led to the development of more powerful abstraction mechanisms such as design patterns, application frameworks, and component ware. Although these are undoubtedly a step forward, they fall short of the desired characteristics for complex system development. By their very nature, they focus on generic system functions and the mandated patterns of interaction are rigid and predetermined. Finally, object-oriented approaches provide only minimal support for specifying and managing organizational relationships (basically relationships are defined by static inheritance hierarchies). Agents cannot be directly invoked like objects. However, they may be constructed using object technology.

6. CONCLUSION

Agent modeling, in general and participatory agent based social simulation, in particular, have a great potential for improving the representation of the human dimension in both integrated assessment models and integrated assessment processes. One can thus expect that they will play an important role in resources management in general. The experience up to now is limited and too early to already judge if the agent based approach has fulfilled the expectation it raised [7][9]. The current paper summarized briefly a number of conceptual issues that should be addressed to improve the application of agent based models in resources management and to lay the foundations for a systematic and comparative approach. In particular, it was also emphasized that agent based modeling is more than simply a new technique to represent social processes in integrated assessment models. It paves as well the way for thinking about a new role of models in processes of social learning.

In a word, the use of agents as an abstraction tool, or a metaphor, for the design and construction of systems provided the initial impetus for developments in the field. On the one hand, agents offered an appropriate way to consider complex systems with multiple distinct and independent components. On the other, they also enable the aggregation of different functionalities that have previously been distinct (such as planning, learning, coordination, etc) in a conceptually embodied and situated whole. Thus these notions

provide a set of technology areas that relate directly to these abstractions in the design and development of large systems, of individual agents, of ways in which agents may interact to support these concepts, and in the consideration of societal or macro-level issues such as organizations and their computational counterparts.

7. REFERENCES

1. Claudia Pahl-Wostl "Agent Based Simulation in Integrated Assessment and Resources Management" *Institute for Environmental Systems Research, University of Osnabrück*
2. <http://www.cis.upenn.edu/~hms/home.html>
3. <http://www.agentlink.org/roadmap/roadmap.pdf>
4. http://industry.java.sun.com/solutions/products/by_product/0,2348,all-656-18,00.html
5. <http://milpah.com/~bill/output/oom.htm>
6. Barreteau, O., F. Bousquet, et al. "Role-playing games for opening the black box of multi-agent systems: method and lessons of its application to Senegal River Valley irrigated systems." *Journal of Artificial Societies and Social Simulation* 4(2), 2001.
7. De Geus, A. Modeling to predict or to learn? *European Journal for Operational Research*, 59, 1, 1992.
8. Downing, T.E.; S. Moss, and C. Pahl-Wostl. "Understanding climate policy using participatory agent-based social simulation", In S. Moss and P. Davidsson, eds. *Multi-Agent-Based Simulation*. Springer Verlag, New York, 2001.
9. Ferrand, N. Modèles es systèmes multi-agents pour la gestion de l'environnement et des territoires. Cemagref Éditions, Clermont Ferrand, 1999.
10. Gigerenzer, G. and R. Selten. (2001). Bounded Rationality: The Adaptive Toolbox. MIT Press, Cambridge MA.
11. Hare, M. P., P. Deadman, et al. (2001). Towards a taxonomy of agent-based simulation models in environmental management. Integrating models for natural resources management across disciplines, issues and scales. MODSIM 2001. 10-13 December. F. Ghassemi, M. McAleer, L. Oxley and M. Scoccimarro. Canberra, Aus, MSSANZ. 3: Socio-economic systems: 1115-1122.
12. Hare, M. and Pahl-Wostl, C. *Integrated Assessment*. The categorization of stakeholders in participatory integrated assessment, in press.
13. Hare, M., and C. Pahl-Wostl. Model uncertainty derived from choice of agent rationality - a lesson for policy assessment modeling. In Giambiasi, N. & C. Frydman. (Eds) *Simulation in Industry: Proceedings of the ESS2001 European Simulation Symposium*, Marseille, October, 2001, SCS Europe Bvba, Ghent. Pp. 854-859, 2001.
14. Hare, M., J. Heeb., and C. Pahl-Wostl. The Symbiotic Relationship between Role Playing Games and Model Development: A case study in participatory model building and social learning for sustainable urban water management. Proceedings of the ISEE 7th Biennial Conference on Environment and Development, Sousse Tunisia, 2002.
15. Jager, W., M.A. Janssen. et al. Behaviour in commons dilemmas: Homo economicus and homo psychologicus in an ecological-economic model. *Ecological Economics*, 35, 357-380, 2000.

16. Janssen, M.A. and H.J.M De Vries. The battle of perspectives: a multi-agent model with adaptive responses to climate change. *Ecological Economics*, 26, 43-65, 1998.
17. Lane, D.C. "Modeling as learning: a consultancy methodology for enhancing learning in management teams". *European Journal of Operational Research*, 59, 64-84, 1992.
18. Ludwig, D., R. Hilborn. and C. Wolters. Uncertainty, resource exploitation, and conservation: Lessons from history. *Science*, 260, 17-18, 1993.
19. Ostrom, E. *Governing the Commons: The Evolution of Institutions for Collective Action*. New York, Cambridge University Press, 1990.
20. Pahl-Wostl, C. *Integrated Assessment*. Participative and Stakeholder-based policy design, evaluation and modeling processes, in press.
21. Pahl-Wostl, C. The dynamic nature of ecosystems: Chaos and Order entwined. Chichester: Wiley, 1995.
22. Tillman, D., T. Larsen, T. C. Pahl-Wostl, and W. Gujer. Interaction analysis of the stakeholders in water supply systems. *Water Science and Technology*. 43, 319-326, 2001.
23. Tillman, D. Stakeholder analysis in water supply systems. Zürich, ETH: 165pp, 2001.