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Describing human decisions in agent-based models – ODD + D, an extension of the ODD protocol

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ABSTRACT

Representing human decisions is of fundamental importance in agent-based models. However, the rationale for choosing a particular human decision model is often not sufficiently empirically or theoretically substantiated in the model documentation. Furthermore, it is difficult to compare models because the model descriptions are often incomplete, not transparent and difficult to understand. Therefore, we expand and refine the 'ODD' (Overview, Design Concepts and Details) protocol to establish a standard for describing ABMs that includes human decision-making (ODD + D). Because the ODD protocol originates mainly from an ecological perspective, some adaptations are necessary to better capture human decision-making. We extended and rearranged the design concepts and related guiding questions to differentiate and describe decision-making, adaptation and learning of the agents in a comprehensive and clearly structured way. The ODD + D protocol also incorporates a section on 'Theoretical and Empirical Background' to encourage model designs and model assumptions that are more closely related to theory. The application of the ODD + D protocol is illustrated with a description of a social–ecological ABM on water use. Although the ODD + D protocol was developed on the basis of example implementations within the socio-ecological scientific community, we believe that the ODD + D protocol may prove helpful for describing ABMs in general when human decisions are included.

1. Introduction

It is widely acknowledged that process-based models, and in particular agent-based models (ABMs), can play an important role in fostering understanding of the dynamics of complex systems (see Matthews et al., 2007; Clifford, 2008; Polasky et al., 2011; Schlüter et al., 2012 with respect to coupled human–environmental systems). A number of studies have demonstrated that the appropriate inclusion of human decision-making in models is of fundamental importance (Parker et al., 2003; Bousquet and Le Page, 2004; Jager and Mosler, 2007; Parker et al., 2008b; Le et al., 2012). This is supported by the fact that, in many modelling studies, macro-level patterns are strongly influenced by the assumed human decisions and behaviour at the micro-level (Hare and Deadman, 2004; Rounsevell and Arneth, 2011). However, current modelling practice has two substantial shortcomings: (1) The reasoning behind the choice of a certain human decision model is often not well documented; insufficient empirical or theoretical foundations are given; or the decision model is only assumed on an ad-hoc basis (Feola and Binder, 2010). (2) Often the model is not described in a transparent manner (clear and complete) that would allow for reproducibility and facilitate the communication of the model and its results (Polhill et al., 2008). Consequently, model comparison and advancement is hampered to a large extent.

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Referring to first shortcoming, one has to take into account that decision-making in ABMs can be based on various theories (for an introduction see Baron, 2000): A widely used approach for modelling decision-making in general, especially in economics, is rational-choice theory (Sen, 2008). However, rational-choice theory has been criticised for being overly simplistic (Camerer and Loewenstein, 2004). Various alternative theories of how decision-making is in reality based on a more bounded rationality have been proposed (Simon, 2008; Kahneman, 2003; Gigerenzer and Selten, 2001). For implementation in ABMs, rational choice theory is often represented by an optimisation routine, whereas models based on bounded rationality rely on condition-action rules or on a combination of both approaches (Schreinemachers and Berger, 2006). New opportunities to model bounded rationality are considered to be one of the major advantages of using an ABM approach (Epstein, 2006, p. 6), and there are by now many examples of ABMs that make use of bounded rationality (Jager et al., 2000; Duffy, 2001; Pahl-Wostl and Ebenhöh, 2004).

Referring to the second shortcoming mentioned above, several attempts have been made in the social sciences and land-use sciences to develop frameworks, classification schemes or protocols to represent and communicate ABMs. Hare and Deadman (2004) presented a taxonomic structure to help modellers choose the appropriate model type based on three requirements for social–ecological ABMs: Different specifications for (1) the coupling of social and environmental models, (2) social interactions and (3) the intrinsic adaptation of the agents. Richiardi et al. (2006) criticised the lack of a methodological standard for social ABMs and proposed a three-stage process that could lead to the establishment of such standards in social and economic simulations. The proposed process was based on the development of a questionnaire that includes specific questions on the model structure (including decision-making mechanisms), model analysis and replicability. According to the authors, the evaluation of the questionnaire can then provide the input for a methodological protocol. The MR POTATOHEAD framework, "Model Representing Potential Objects That Appear in The Ontology of Human–Environmental Actions & Decisions", represents key elements of standard ABM and LUCC (Land Use and Cover Change) models in a structured and comprehensive way (Parker et al., 2008a). This "conceptual design pattern" aims first to facilitate a comparison of the structure and functioning of different models and second to assist scholars new to the field with designing their models. Certain facets of human decisions are discussed in all three of these classification schemes and frameworks. However, these studies differ in terms of purpose and none of them puts the main focus on human decisions or elaborates on this topic in a comprehensive way.

Modelling in general, not only the modelling of human decisions, has to address the challenge of providing transparent and complete model descriptions (Richiardi et al., 2006; Parker et al., 2008a). Standardised protocols for (agent-based) model descriptions and especially the ODD (Overview, Design Concepts and Details) protocol (Grimm et al., 2006, 2010) have been well received by the scientific community. The ODD protocol consists of three parts: First, it provides an 'Overview' on the purpose and main processes of the model. Second, in the 'Design Concepts' block, the general concepts underlying the model design are depicted and third, in the 'Details', all of the necessary information is given that would allow for a reimplementation of the model. However, the original ODD protocol focuses primarily on ecological dynamics (Grimm et al., 2006). The first revision of the ODD protocol has attempted to open the standard for all ABMs (Grimm et al., 2010). Nevertheless, a comprehensive description of the human decision process was not a focal point until now.

First attempts have been made to determine the usefulness of the ODD protocol for describing social–ecological models. Polhill et al. (2008) investigated to which extent the ODD protocol can be applied to LUCC models, considering three ABMs that include human agents as examples. They concluded that the ODD protocol could provide a useful standard to facilitate communication and model comparison. However, refinements are required concerning the definition of terms (such as entities, state variables and parameters). An (2012) took the same line and concluded in his review on modelling and understanding human decisions that the development of protocols similar to the ODD protocol for social–ecological models aimed at modelling human decisions must be put on the future research agenda.

We want to address this gap. The aim of this paper is to provide an extension of the ODD protocol, termed ODD + D (ODD + Decision) which facilitates a clear and comprehensive description of ABMs in a standardised way, with an emphasis on human decisions and which includes the empirical and theoretical foundations for the choice of decision model. The paper is structured as follows: In the next section, the main shortcomings of the ODD protocol, in particular with respect to describing human decisions, are summarised. Then, important terms are defined. The terms *decision-making*, *adaptation* and *learning* are clarified and distinguished. Furthermore, general structural changes in the ODD + D protocol (mainly in the Design Concepts block), as compared to the ODD protocol, are delineated and discussed. Afterwards, we present a detailed description of the revised and new design concepts with an emphasis on human decision-making. In Section 4, we illustrate the application of the extended protocol ODD + D by describing a social–ecological ABM on water use as an example. Given our background in social–ecological modelling, we refer for illustrative purposes in Sections 3 and 4 to examples from that domain, but we believe that the ODD + D protocol may prove to be a helpful protocol for describing ABMs that include human decisions in general. The discussion section focuses on the expected benefits and the efforts required while applying the protocol. The section closes with open challenges for the future. Online Appendix provides a standardised form of the ODD + D protocol that can be used as template to fill in the necessary information about the model to support a transparent and complete model description.

2. Shortcomings of the ODD protocol for describing human decision-making

The ODD protocol is not fully suited to describe how human decision-making has been modelled for the following reasons: (1) Central aspects of modelling human decision-making are not explicitly addressed, such as decision algorithms, the formation of expectation, the temporal characteristics of decision-making and cultural values, amongst others. (2) The theoretical and empirical basis for the chosen decision submodel is not sufficiently emphasised. (3) The Design concepts section does not provide a suitable structure for describing human decision-making.

(1) Central aspects of human decision-making are addressed in related frameworks: In their checklist-type summary, Richiardi et al. (2006) mention the type of agent behaviour (optimising, satisficing, …), the interaction structure, the coordination structure, the formation of expectations and learning with respect to decision-making. In their MR POTATOHEAD framework, Parker et al. (2008a) use the decision algorithm of the agents, their characteristics and cultural values, and the temporal aspects in decision-making and the like as general aspects of decision-making. While the ODD protocol includes some of these aspects (e.g. interaction), other aspects such as coordination, the temporal aspects in decision-making and