The ODD protocol: A review and first update

Volker Grimm [a,*], Uta Berger [b], Donald L. DeAngelis [c], J. Gary Polhill [d], Jarl Giske [e], Steven F. Railsback [f,g]

[a] Helmholtz Centre for Environmental Research-UFZ, Department of Ecological Modelling, Permoserstr. 15, 04318 Leipzig, Germany
[b] Institute of Forest Growth and Computer Science, Dresden University of Technology, P.O. 1117, 01735 Tharandt, Germany
[c] USGS/Biological Resources Division and Dept. of Biology, University of Miami, PO Box 249118, Coral Gables, FL 33124, USA
[d] Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, AB15 8QH, United Kingdom
[e] University of Bergen, Department of Biology, P.O. Box 7803, N-5020 Bergen, Norway
[f] Department of Mathematics, Humboldt State University, Arcata, CA 95521, USA
[g] Lang, Railsback & Associates, 250 California Avenue, Arcata, CA 95521, USA

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ABSTRACT

The 'ODD' (Overview, Design concepts, and Details) protocol was published in 2006 to standardize the published descriptions of individual-based and agent-based models (ABMs). The primary objectives of ODD are to make model descriptions more understandable and complete, thereby making ABMs less subject to criticism for being irreproducible. We have systematically evaluated existing uses of the ODD protocol and identified, as expected, parts of ODD needing improvement and clarification. Accordingly, we revise the definition of ODD to clarify aspects of the original version and thereby facilitate future standardization of ABM descriptions. We discuss frequently raised critiques in ODD but also two emerging, and unanticipated, benefits: ODD improves the rigorous formulation of models and helps make the theoretical foundations of large models more visible. Although the protocol was designed for ABMs, it can help with documenting any large, complex model, alleviating some general objections against such models.

1. Introduction

Ecologists and social scientists have long been faced with the challenge of how to model the complexity inherent in many real-world ecological, social, or socio-ecological systems. One approach for exploring such systems is using agent-based models (we hereafter refer to such models generically as ABMs, and use the terms 'individual' and 'agent' interchangeably). ABMs focus on one or more of the following aspects because they are considered critical for explaining system-level behavior: heterogeneity of and among individuals, local interactions among individuals, and adaptive behavior of individuals (DeAngelis and Mooij, 2003, 2005; Grimm and Railsback, 2005).

ABMs were early criticized as generally being so poorly documented that the models could not be evaluated (e.g., Lorek and Sonnenschein, 1999). These criticisms motivated the ODD (Overview, Design concepts, Details) protocol (Grimm et al., 2006), which attempted to create a generic format and a standard structure by which all ABMs could be documented. The primary purpose of ODD is to make writing and reading model descriptions easier and more efficient. Moreover, ODD is expected to lead to more complete model descriptions, making ABMs easier to replicate and hence less easily dismissed as unscientific.

In the few years it has existed, ODD has been used in more than 50 publications. ODD was also evaluated by using it to compare three different agent-based social simulation models of land-use change (Polhill et al., 2008), and was discussed and included in the portfolio of approaches fostered by the Open ABM Consortium, which was constituted in 2007 (Janssen et al., 2008). Hence a critical mass of experience has been reached, enabling the first update of the ODD protocol. This update was anticipated by Grimm et al. (2006, p. 116): "once initiated, the protocol will hopefully evolve as it becomes used by a sufficiently large proportion of modelers." It was clear from the outset that the first version of a protocol designed to embrace the huge variety of ABM designs, complexity, scopes, or disciplines could not be optimal and that updates of the protocol would be needed.

Here we review the uses to date of ODD. This allows several observations to be made concerning the clarity and completeness of the protocol. An additional observation, however, was that the protocol has had unanticipated dividends that go beyond the expected practical benefits of providing a systematic documentation of models. That key benefit is that the protocol helps to promote a more rigorous formulation of models. The reason for this is that the ODD protocol provides a comprehensive checklist that covers virtually all of the key features that can characterize a model and that should

be described. Because models are vehicles for applying theory to real-world situations, we believe that this also helps communicate clearly the theoretical background and assumptions of the model.

A further observation is that the application of the ODD protocol to model descriptions may be appropriate not only for the ABMs, but for large, complex models in general. The advantages and disadvantages of large, complex models in ecology have been reviewed and debated in many places (e.g., Jørgensen, 1992; Liebhold, 1994; Logan, 1995; DeAngelis and Mooij, 2003; May, 2004; Grimm et al., 2005), the debate often revolving about the level of detail necessary in a model, the tradeoff being between greater realism on the one hand and greater parsimony and transparency on the other. It is not our goal to enter that debate, but to suggest that ODD be used as a thorough and consistent framework for documenting models, which can help to make large, complex models as clear as possible to the reader and user (e.g., Müller et al., 2007). If substantial clarification of large, complicated ecological models can be achieved, then a major disadvantage in such models, that is, the difficulty in understanding them, may be overcome. We will center our comments here on application to ABMs, but broader use of ODD is implied.

The update of the ODD protocol and its description is based on a review of all model descriptions using the protocol that existed by December 2009, checking whether the protocol's terminology was consistently understandable. This assessment had to be based on our subjective assessment on whether or not ODD elements were used as described in Grimm et al. (2006) because a more quantitative assessment seemed not to be possible at this stage.

Our main conclusion from three years of ODD application is that, while the protocol itself does not need a major overhaul, an update of the description of the protocol is needed, as several elements and some important terms have proven unclear or were sometimes misinterpreted. In addition, experience has revealed important potential benefits of ODD that were not foreseen when it was developed. It is worth addressing these benefits to further increase the value of the ODD protocol in the scientific community.

In the following, we first present our review of ODD-based model descriptions. As a result of this review, we then present an updated description and explanation of the seven elements of ODD. We then discuss those features of ODD that have been criticized as well as important benefits that were not anticipated by Grimm et al. (2006).

2. Review of ODD-based model descriptions

2.1. Methods

We searched the 'Web of Science' reference data base (Thomson Scientific) for publications citing the original ODD publication (Grimm et al., 2006). We selected those publications that claimed to follow the ODD protocol in the model descriptions. For each of the publications, we checked whether the ODD format was completely followed, which includes using exactly the identifiers and sequence of all seven elements of the ODD format. Then, for each of the elements of the protocol that was included, we checked whether it was either used more or less as described by Grimm et al. (2006), or whether an incorrect use could be directly referred to a weakness in the original ODD description, or whether parts of the protocol appeared to be inadequate in a given situation.

For the publications that included the 'Design concepts' element we recorded which design concepts were addressed; here, we included a design concept even if its qualifier, for example 'emergence', was not explicitly used, but information relevant to that qualifier was nonetheless supplied. We checked each of the publications for the discipline or field of research, whether the
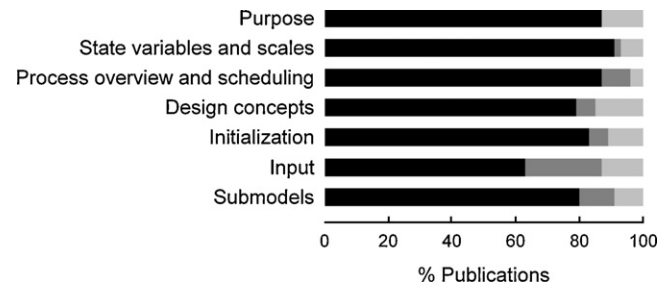

Fig. 1. Percentages of publications using the ODD protocol ($n = 54$) for describing an individual-based or agent-based model that include each of the seven elements described by Grimm et al. (2006), i.e., Purpose, State variables and scales, etc. Black: the element was named and used as described in Grimm et al. (2006); dark gray: the element was included and named correctly, but misinterpreted; light gray: the element was omitted or labeled incorrectly.

model was presented in the main manuscript or in an appendix, whether the schedules were described by using pseudo-code, diagrams, or other means, and whether tables with model parameters were included.

In addition to reviewing existing applications of the ODD protocol, we solicited direct feedback from ODD users, asking especially what they found suboptimal about the protocol. Most of this feedback was given verbally, or via e-mails, so that we cannot provide a solid database of feedbacks from ODD users; therefore, feedbacks are not included in the results section but in the discussion.

2.2. Results

By December 14, 2009, Web of Science listed 87 citations of Grimm et al. (2006). The ODD protocol was used in 54 of these publications; the other publications were reviews, addressing methods, or they just used Grimm et al. (2006) as a general reference to individual-based modeling. In 13 of the 87 publications (24%), one or more of the 28 authors of Grimm et al. (2006) were co-author. The majority of publications is from ecology (70% or 38 publications); other disciplines included behavioral sciences (six publications), epidemiology, forest science, social sciences (two publications each), and archeology, microbiology, biomedical research, and oceanography (one publication each).

Apart from 'Design concepts' and 'Input', the other elements of the ODD protocol were included in more than 80% of the ODD-based model descriptions (Fig. 1). The element 'Input' was included correctly in only 62% of the publications; in 13 cases (24%) 'Input' was omitted, and in 7 cases (13%) it was interpreted as model parameters instead of as input data of driving environmental variables imported from external files or models.

In 75% of the papers ODD was either followed completely and correctly, or only one of the seven elements was missing or was not used as described by Grimm et al. (2006). Six papers (11%) ignored the protocol's terminology or misinterpreted its intention by more than 50% (four or more elements omitted, labeled incorrectly, or misinterpreted).

Variation in the number of publications addressing design concepts was high (Fig. 2) and ranged between 93% (Stochasticity) and 7% (Prediction). If design concepts were addressed at all, often only three or four of the possible nine design concepts were included. 'Emergence', 'Stochasticity', and 'Observation' were used most often, whereas design concepts related to explicit models of adaptive behavior ('Adaptation', 'Fitness', 'Prediction') were listed in less than one third of the papers.

In 12 publications (22%) the entire model description, or parts of it, were presented in an appendix. In seven publications the description of the model's schedule was supported by presenting pseudo-code (12%), in 20 publications (37%) it was supported by