

# Narrative explanation of agent decision-making

**James D.A. Millington<sup>a</sup>, David O'Sullivan<sup>b</sup>, George L.W. Perry<sup>b,c</sup>**

<sup>a</sup>*Department of Geography, King's College London, UK,  
james.millington@kcl.ac.uk*

<sup>b</sup>*School of Environment, University of Auckland, NZ*

<sup>c</sup>*School of Biological Sciences, University of Auckland, NZ*

**Abstract:** The characteristics of agent-based models (ABM) of decision-making – representing heterogeneous interactions that are context-dependent – mean that contingency will often be important in simulations taking this approach. In particular, here we consider contingency in agent decision-making. Contingent agent decisions are those that neither must *necessarily* be made by the agent in a given model run, but neither are they *impossible*, given the structure and assumptions of the model. We argue here that if decision-making in ABMs is to be comprehensively described, the ways in which model structure can result in contingent agent decisions must be accounted for in protocols of model description. We suggest that narrative approaches are one way to do this and that they provide the benefit of explaining multiple aspects of a model in a coherent manner. We present an example of how such narrative explanation can work for an ABM of land use decision-making.

**Keywords:** agent-based; contingency; model description; land use, ODD;

## 1. INTRODUCTION

This paper contributes to aims to develop a comprehensive protocol for describing decisions in agent-based models (ABM), particularly in the context of natural resource use. As Polhill et al. [2008] highlight, ABMs are different from traditional mathematical models and the only sure way to understand the assumptions in an ABM is to look at the source code. Therefore, standard protocols for describing ABMs – more specifically, for describing both the assumptions of the model and its formal structure (objects, attributes, equations, rules, etc.) – have been proposed, developed and used. For example, the Overview, Design concepts and Details (ODD) protocol was proposed by Grimm et al. [2006], updated by Grimm et al. [2010], and has been used by more than 50 papers in the four years following its initial publication [Grimm 2010], including description of ABMs of land use change (e.g., see Polhill et al. [2008]).

Our argument here is: given that contingency is likely to be important in most ABMs that represent human decision-making, any protocol for describing these models should include some consideration of how model structure has the potential to produce contingent decisions, and that narratives are a useful way to communicate this consideration.

## 2. CONTINGENCY IN AGENT-BASED MODELS

O'Sullivan et al. [2012] argued that ABM will most likely be useful (or at least, more useful than traditional mathematical or statistical modelling approaches) when:

1. the decision-making context of agents is *heterogeneous*;
2. *interactions* between agents are important for agent decision-making, and;
3. the modelled system is '*middle-numbered*'.

The third circumstance could be considered a partial result of the first two. 'Middle-numbered systems' are those that are neither small-numbered (few interacting entities; e.g., balls colliding on a billiard table) nor large-numbered (many, many interacting entities; e.g., air molecules in a room) and consequently are not well described and studied using methods from Cartesian or statistical physics [Weaver 1948]. Rather, middle-numbered systems are composed of many entities, the interactions of which are often heterogeneous and frequently influenced by the state and condition of other entities and their interactions, themselves changing (and potentially distant) in time and space.

ABMs representing natural resource use often have these three properties. A prime example is models of land use/cover change, which couple representation of individual agents that make decisions about land use (e.g., farmers) with representation of biophysical change (e.g., vegetation succession dynamics). Agents are often heterogeneous with respect to personal attributes, such as wealth and age, and also with respect to those that correspond to the biophysical environment, such as land holdings. Furthermore, agents often interact by exchanging land or influencing one another's behaviours, and the number of agents represented is typically in the range  $10^1 - 10^4$ . For example, Millington et al. [2008] presented an agent-based model of agricultural land-use decision-making developed to examine the importance of land tenure and land use on future land cover in Spain. The model results they presented were for simulations that represented 519 agents which interacted by exchanging land and influencing perspectives on the aims of farming.

O'Sullivan et al. [2012] highlight that, given the three properties they describe, contingency is likely to be important in ABMs because a history of events is retained in patterns observed at aggregated levels of organisation (e.g., spatial patterns of land use). Consequently, we can view ABMs as being 'event-driven'. These events might be interactions between entities, or, in the case of an ABM of decision-making, the decisions agents make. Furthermore, these events are often contingent, in the sense that their occurrence is *neither necessary nor impossible* [Sayer 1985] and are dependent on the particular circumstances of entities (e.g., a decision-making agent) at the time of the event. For example, in a model of agricultural land use decision-making (such as Millington et al. [2008]), a farmer may decide (or not) to sow a particular crop in one simulated year dependent on a combination of factors including market conditions, neighbours' decisions on what to sow, their age, and so forth. The structure of the model means that although it is not impossible for the farmer to decide to sow that particular crop in that particular year, it is also not necessarily the case that they will. Whether the farmer does plant this crop in this year depends on the state of the attributes and variables that influence the decision (see section 4 for a more detailed account of a similar example). Thus, contingencies are the simulated outcomes of assumptions encoded in model structure, and so describing model structure without identifying the potential contingencies it may entail is an incomplete description of what the model does.

### 3. CONSIDERING CONTINGENCY IN MODEL DESCRIPTIONS

To comprehensively describe decision-making in an ABM, the ways in which model structure can result in contingent agent decisions should be accounted for in some way. In their working paper for workshop H6, 'Human decisions in agent-based models (ABM) for natural resource use - need for protocols' at the 6<sup>th</sup> International Congress on Environmental Modelling and Software, Müller et al. [2012] propose an extension of the ODD protocol [Grimm et al. 2010] to improve description of human decision-making in agent-based social-ecological models. They term this extension 'ODD+D' and suggest adding new categories to the original ODD protocol. These new categories include those that consider agent adaptation and learning, the influences of space and time on decision processes, and heterogeneity between agents. Along with existing categories that consider interactions between agents and stochasticity, the structure of this proposed extended ABM description protocol implies that Müller et al. [2012] acknowledge ABMs have properties similar to those suggested by O'Sullivan et al. [2012]. Hence, if contingency is likely to be important when ABMs have the properties O'Sullivan et al. [2012] suggest, it is likely that contingency will be present in many ABMs of human decision-making that ODD+D seeks to describe.

Consequently, we suggest a question that should be posed in an ODD-type protocol is;

*What decisions are not impossible for an agent make, but neither will necessarily be made, in any given model run?*

By responding to this question the modeller can illustrate how various other aspects of the model (as described in protocols like ODD) combine to influence agent decision-making. First, a response to the question might account for heterogeneity between agents by showing how differences in attributes between agents (e.g., wealth, age, etc.) result in different decisions being made by agents in the same spatio-temporal decision-making context. Second, a response might account for different decisions made by the same agent at different points in time (illustrating the influence of temporal aspects influencing decision-making). This variation in time might, in-turn, be the result of changes in agent attributes due to learning and adaptation, or interactions the agent has had with other agents previously. Third, the response might illustrate how different agents with the *same* attributes might make different decisions at a given point in time due to differences in their spatial context (e.g., spatial configuration of land holdings).

The question we suggest above provides the modeller with an opportunity, therefore, to show how multiple different aspects in the model come together to influence simulated system dynamics. It will almost certainly not be possible to account for all contingencies the model may produce, as by their very nature simulations will produce unexpected or unanticipated interactions and decisions. Consequently, our question should be used to communicate and illustrate examples of anticipated contingencies, or examples observed during model construction and testing. Examples of unanticipated contingencies can be reported later in model analysis.

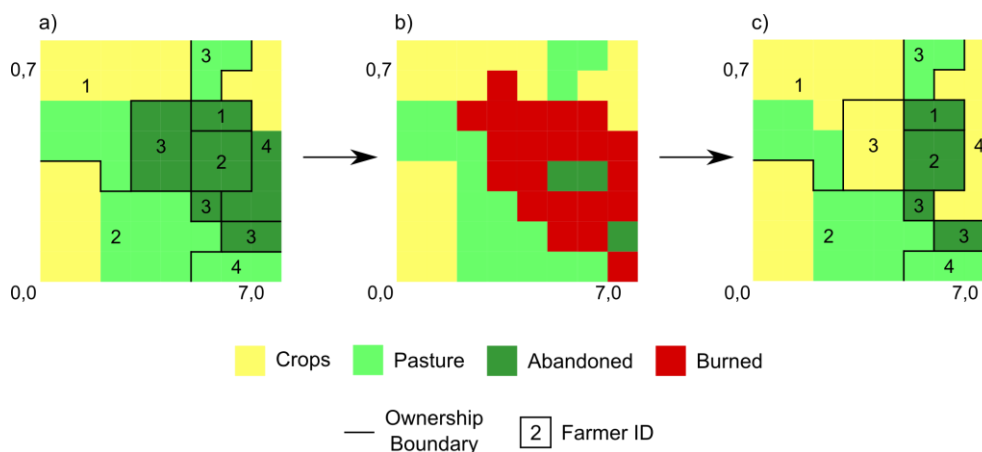
We suggest that these examples can usefully be presented in narrative form (as we discuss and illustrate in the next section). However, we also highlight that in order for the reader to be able to fully understand why particular decisions may or may not have occurred in the examples presented, it will be very useful if they can use the model to reproduce that example model run. This model use can be facilitated by making model code readily available. In order to reproduce the specific examples described in a protocol the reader must know the full details of the model initialization state. This will include the state of any random number generation used in the model code. Therefore, we re-iterate Polhill et al.'s [2008]

suggestion that if model code is to be made available there must be specific provision for the user to be able to set the initial random number seed, and that information about what seeds were used in examples and results presented should be specified.

#### 4. NARRATIVES FOR ILLUSTRATING CONTINGENCY

Given the nature of contingent events and decisions (as described above), we suggest that it is useful to look to narrative approaches to answer our proposed protocol question. 'Narrative explanation' is a form of explanation that is commonly used in fields such as sociology and ecology that study middle-numbered systems and in which history is important for understanding observed patterns (e.g., Abell [2004], Brown [2011]). Narrative explanation shows how patterns are produced or events came to rise by presenting a coherent account of the sequence of preceding decisions and states that led to the pattern or event of interest. This account can be composed of text, figures, tables, maps, and movies. The narrative can refer back and forth between model structure and the kinds of decisions and events it results in to illustrate why decisions are contingent.

We present an example of how a narrative approach can do this in Figure 1. This example is derived from the Special Protection Area SIMulator version 1 (SPASIMv1) integrated socio-ecological landscape simulation model described in Wainwright and Millington [2010] and using modules presented in Millington et al. [2008, 2009].



**Figure 1. Narrative illustrating the importance of individual agent context in an agent-based model of agricultural land-use decision-making and wildfire.** (a) An example landscape extract made up of 8 × 8 pixels contains land holdings of four farmers with heterogeneous land ownership and socio-economic circumstances. (b) Fire preferentially burns more densely vegetated pixels (e.g., abandoned land). (c) Following a fire event, subsequent use of burned pixels for crops varies between farmers dependent on their individual circumstances and the location of burned pixels as well as their assumptions, such as that burning acts to improve potential crop yields. For example, to increase income whilst minimizing costs of farm fragmentation, Farmer 3 converts six conterminous burned pixels (at coordinates 3,3 to 4,5) to crops, but not individual pixels (at coordinates 5,2 and 7,1). Already with much land under cultivation (in conterminous pixels), Farmers 1 and 2 do not convert their pairs of burned pixels (at coordinates 5,5, 6,5 and 5,4, 6,4, respectively) as the added production does not outweigh the costs of their fragmentation from the remainder of the farm (but if all four of the conterminous abandoned pixels owned by Farmer 2 had burned it may have been worthwhile converting all four to crops), while Farmer 4 finds the fire makes coterminous pixels

of formerly abandoned land profitable for cultivation, and so expands from their existing cultivated area. Figure and caption reproduced with permission from Wainwright and Millington [2010].

Our example (i.e., Figure 1) shows how contingent circumstances (e.g., the configuration of land holdings, the ignition point of the fire), when combined with the other rules and relationships specified by the model (e.g., greater fragmentation of land holdings incurs greater management costs), led to a sequence of specific events (e.g., changes in land use). In doing so, the narrative approach offers the potential to overcome some perceived problems with current model description protocols. For example, when discussing their use of ODD to describe their ABM of land use decision-making one modeller in the case studies Polhill et al. [2008, 3.33] present, stated;

*“I struggled with a perceived mandate by ODD that model components be taken apart and presented separately, as I was then not sure as to how to coherently explain how they could be put back together.”*

As we have argued, and shown in our example, taking a narrative approach allows several aspects of the model description protocol to be accounted for and explained more coherently. Although our discussion of contingency and narrative here has focussed on agent decision-making, there will likely be other types of ABM in which contingency will be present in producing, and narratives therefore useful for describing, model outcomes.

## 5. CONCLUSION AND RECOMMENDATIONS

We have argued here that the characteristics of agent-based models of decision-making mean that simulated decisions will often be contingent on the context in which they are made. That is, simulated decisions may be neither necessary nor impossible in a given model run. This contingency arises because of the heterogeneity of agent decision-making contexts a model structure implies. We argue that contingency should be explicitly recognised and accounted for in protocols that describe these models. Narrative approaches are well suited to explaining contingencies and are able to communicate how several different aspects of model protocols (such as heterogeneity, agent learning, temporal and spatial influences on decision-making) combine to influence simulated dynamics. Narrative approaches such as the one we present here will therefore likely be useful for explaining and illustrating the contingencies a model structure implies.

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