Modular ABM development in NRM for improved dissemination and training

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Agent-based models (ABM) have become an important tool for natural resource management in recent decades, and for the study of agricultural change in particular (e.g., Becu, Perez, Walker, Barreteau, & Page, 2003; Bell, 2011; Bert et al., 2010). Where household-level decisions, made in interaction with other households and the natural environment, shape outcomes at the landscape scale, ABM can provide insights that coarser equation-based models (EBM) or statistical models may not (Bankes, 2002; Paranuk et al. 1998). ABM provide as well a unique point of entry for non-expert stakeholders into the analytic process because it offers a 1:1 mapping of real-world actors to computational agents, which provides a level of conceptual understanding and familiarity that is not available when EBM or statistical models are used. Furthermore, the actor behaviours that are formalized within the computational code that defines an agent's behavior can be represented in a variety of ways (e.g., heuristic decision trees, utility functions) that are again easier for non-expert stakeholders to than the equations and constraints of other modeling approaches.

While all modelling approaches have trade-offs that make that offer costs and benefits, the benefits of an ABM approach also carry a number of costs or challenges, e.g., parsimony, equifinality, validation, and specificity versus reusability among others. The core of an ABM design is a process-based model of decision making, as well as of agent-agent and agent-environment interactions. The burden on the modeler to decide what processes are relevant, how to model them, and how to calibrate and validate them from data is quite large. In many cases, the appropriate set of social processes and decision modes to include are not obvious without significant primary data collection, making the production of a meaningful ABM a slow, iterative, and potentially expensive process.

A broader issue shaping the pace and impact of ABM research in NRM is that this area of research has yet to explicitly identify a fundamental set of assumptions, laws, and toolkits to use (hereafter we use the term 'soft' discipline) when compared with 'hard' sciences (e.g., geology, biology, physics).The outcome of the lack of structure, synthesis, and consensus is that scientists and modellers lack a clear foundation of agreed-upon approaches and libraries that offer a baseline for problem solutions that characterize other modeling fields. The absence of this foundation has hindered scientific advancement, started to erode the confidence and use of the approach, and limited the capacity for ABM work in NRM to leverage previous development and efforts.

To illustrate this, consider the range of tools commonly available to modelers – such as coding platforms or commercial software packages. Some provide greater or lesser flexibility in developing the complete model, and in fact, these tools occupy different points along a spectrum of 'packaging'. We define several wide bands along this spectrum that help to make this spectrum clear:

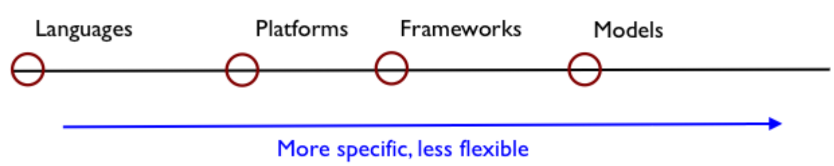

Figure 1: Representation of tool spectrum

- **Languages** – flexible computational grammars, often with much prepackaged functionality, that allow development of complete ranges of software products (e.g., C++, Java)
- **Platforms** – selected range of computational functionality suited to a particular purpose (such as land-use or agent-based modeling), with some programming flexibility and a greater reliance on

prepackaged functional components, integrated in a discrete and somewhat rigid whole (e.g., NetLogo, Cormas)

- **Frameworks** – little or no computational flexibility, and near-complete reliance on choice among a range of prepackaged options for functionality, parameter settings, etc. (e.g., LUDAS, AgriPolis)
- **Models** – a specific representation of a particular system, with little flexibility beyond parameter settings

In the literature on ABM in NRM, many published models arise from well-known modeling platforms – broad platforms such as NetLogo, Swarm, and RePast (e.g., Robinson, Filatova, Sun, Riolo, & Daniel, 2010; Sun & Müller, 2013), which include a range of general tools for representing objects in a two-dimensional space, as well as more specified platforms such as the Cormas platform (e.g., Becu et al., 2003), which includes a range of tools specific to the modeling of socio-ecological systems. Additionally, there are a number of frameworks that have led to multiple publications, and are capable of addressing a broad range of ABM-relevant questions, such as the LUDAS family of frameworks (e.g., Le, Park, Vlek, & Cremers, 2008), and AgriPolis (e.g., Happe, Kellermann, & Balmann, 2006). However, at the same time, we still see through to the present day a great number of models being built from scratch – not from existing frameworks, and sometimes not even from modeling platforms but straight from basic coding languages – C++ , Java, Matlab (e.g., Bell, 2011; Berger & Ringler, 2002; Chen et al., 2012). This illustrates the softness of the science discussed above – it is difficult for any one framework to embed all functionality that a modeler may wish to use, so she must often start from basic materials to develop an appropriate model for her question.

In many cases this is reinvention of the wheel – particular algorithms present in a published modeling framework, but needing to be developed anew in the modeler's project because of the difficulty in extracting and understanding code within the bigger, more rigid framework. We suggest that there is a way around this, and a means to promote the speed at which model functionality is exchanged over this period as the ABM in NRM discipline hardens – that is, we need to work more at publishing our wheels separately.

To illustrate what we are suggesting, we look first at how ABMs are described in review articles (Table 1). It is clear that there are common dimensions that authors use to represent ABMs - key components they all possess and thus a good basis for comparison. In particular, we note the agent decision mode, social interactions, and environment structure as common components the reviews use for

Table 1: Structure of ABM in NRM Reviews

Review	Model motivation	Agent type	Agent Decision Mode	Environment Interactions	Social Interactions	Environment Structure	Time Scales	Agent Learning and Response
(Matthews, Gilbert, Roach, Polhill, & Gotts, 2007)	x							
(Hare & Deadman, 2004)					x	x		x
(Parker, Manson, Janssen, Hoffmann, & Deadman, 2003)	x	x	x			x	x	
(An, 2012)			x					
(Kremmydas, 2012)	x	x	x	x	x	x	x	
(Robinson et al., 2007)		x	x	x	x	x	x	
(Bousquet & Le Page, 2004)			x	x	x	x		
(Athanasiadis, Mitkas, & Tzima, 2007)		x				x		

comparison. In a sense, these components are genes within an ABM genome, with particular choices (such as rational optimization, bounded rational optimization, or heuristic rules as choices for the agent decision mode) representing traits of these genes.

Extending the analogy, we note that the code and sets of functionality that describe many of these components can be packaged conveniently in modular ways, and plugged in and out of modeling tools (e.g., an agent decision module, a social interaction module, an environment structure module). Sometimes this is implicitly a part of ABM development, as models are coupled loosely to third-party software for the calculation of water transport, crop growth, etc. In truth, many of us as programmers build this way to begin with – leaving simple placeholders for a variable of interest as we build structure in other parts of our models. These placeholders are often good indicators of what might break off into a useful module.

Our premise is that efforts to build modeling tools in a modular way, and to make these modules – the 'wheels' (and other parts) – available independently offer a range of benefits:

1) Encourage better coding practice
2) Enable faster assembly and multi-purposing of one's own code in new modeling tools
3) Improve dissemination of modeling parts among researchers and reduce reproduction
4) Make meaningful tasks in a larger model accessible to students at the masters' thesis or class project scale

This last point is of particular interest. Many introductory courses in ABM are restricted to the development of simple models from a NetLogo or RePast starting point. The availability of modules could provide a pedagogical inroad at the intermediate level to allow students to contribute to more engaging projects – drawing together existing modules, and developing the one or two that need to be written from scratch. This is an important training introduction to the collaborative model development process that will surely be an increasingly important skill among modelers in future.

The lynchpin to make this work is researcher incentive in the form of citation. We propose that a modules library be developed, as part of the website OpenABM.org (which provides peer review for complete models, and with whom we have been in contact through the writing of this paper) or other location, with modules submitted for peer-review to include the following:

1) A clear description of module inputs and outputs
2) A complete pseudocode description of the algorithm
3) One well-commented implementation of the algorithm, in any language/platform
4) Sufficient data, and any necessary supplementary scripts, to test the algorithm
5) A list of key algorithm benchmarks and expected results, for testing purposes

Submitted thusly, modules could be linked to OpenABM models of which they are components. As is the case for models on OpenABM, the process of peer review allows the module to be cited formally.

We already observe a great number of forums on the internet serving up scripts and functions written by helpful programmers, to accomplish a range of common tasks. We observe as well sites like OpenABM.org, that serve up complete models, free for us to use but often not well suited to the questions we have in mind. What we are proposing here is to work harder at filling the gap between these two scales, and make the innovative knowledge products that are the various modules within our finished tools, better available for our peers.

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