Towards a 'pattern language' for spatial simulation models

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1.0 INTRODUCTION

Computational models are widely used in fields from spatial ecology to transportation, and from archaeology to urban geography. Explicitly spatial simulation models are increasingly commonplace, and exhibit a seemingly broad diversity of underlying structures. The challenges of documenting such models are such that it can be difficult to see past details of specific models in order to generalise findings from any particular model. This is a challenge to making progress in computational model-oriented science.

Complexity science (Coveney and Highfield 1995, Mitchell 2008) is one over-arching framework which may be useful in thinking about these issues. However, even two or three decades (perhaps more, see Weaver, 1948) since its inception, complexity remains defined as much by the simulation models that constitute its major objects of study, as by any *a priori* or foundational definition of concepts. Noting the importance of building models to complexity science it is useful to consider one influential approach: *pattern-oriented modelling* (POM; Grimm et al. 2005, Grimm and Railsback 2012). In POM, when building a computational model of a system, the first task is to identify multiple patterns that the target system exhibits, which can serve as filters to inform model assessment. While the term 'pattern' is suggestive of the spatial behaviour of a system, Grimm et al. intend it to be understood to also cover temporal, statistical, or dynamical system behaviours. While POM was originally presented in the context of individual based models in ecology (Grimm et al. 2005), more recently it has been advocated for computational model building generally (Grimm and Railsback 2012).

POM is primarily intended to guide selection among alternative model structures, rather than as a bottom-up approach to model design. The approach we advocate here may be considered a further elaboration of the "patterns for model structure" step in POM (Grimm and Railsback 2012, page 301), where from the very earliest stages of model development attention is paid to general spatial properties of systems so that overall model elements are chosen that are likely to prove fruitful.

2.0 A SET OF BUILDING-BLOCK MODELS

Focusing on the spatial pattern outcomes of models allows us to organize the wide variety of spatial models into a manageable number of categories to use as starting points for model development. Below we briefly sketch a possible categorization of building-block models. These categories will be considered in more detail in our presentation at the conference.

2.1 Aggregation and segregation

A corollary of Tobler's 'first law of geography' (1970; see also Sui 2004) is that many systems consist of regions of similar attributes organized into patches. Many simple spatial processes yield such patterns, among them iterative *local-averaging* and its binary equivalent of *majority rule automata*. The latter is a particular instance of *totalistic automata* (Chopard 1998), many of which also produce subtly aggregated spatial patterns. *Interacting particle systems*, an alternative to cellular automata models, include *contact processes*, *succession models*, *voter models* and *exclusion processes* (Liggett 1999, Durrett and Levin 1994). The last of these is a version of Schelling's model of residential segregation (Schelling 1971, Zhang 2009), and confirms the value of making connections across the literature on spatial models. Whereas the processes above are ‘bottom-up’, an alternative is *iterative subdivision* of a system, either as a spatial ‘tree’ (Morgan 2011), or via a proximity polygon approach (Okabe et al. 2000).

2.2 Random walk

The *random walk* is a fundamental stochastic process, with a natural spatial interpretation (see e.g., Rudnick and Gaspari 2004). Numerous variants on the random walk exist, including *correlated walks* (Bovet and Benhamou 1988). A key distinction is that between diffusive and super-diffusive processes (*Lévy walks* or flights), the latter having attracted considerable attention in the movement ecology literature in recent years (Viswanathan et al. 2011). Consideration of the motivations underpinning movement yields models where walkers decide their next step by choosing among options in a differentiated landscape, most often a target resource. An early *foraging model* was described by Simon (1956). Behavioural rules where the choice of next target location is based on a simple calculation of the benefit-to-cost ratio can yield realistic movement patterns for many plausible spatially structured resources (Boyer et al. 2006). Another family of movement models is provided by various *flocking models*, where interaction among nearby individuals is a key driver (Schellink and White 2011).

2.3 Percolation and growth in heterogeneous spaces

Our third category of models focuses on the interaction between movement and spatial structure. While the literature on *percolation systems* (Grimmett 1999) is primarily concerned with the relationship between top-down random assignment of sites in a system to among fixed categories and the resulting spatial structures, this relationship is also central to the behavior of dynamic processes of growth. The spatial structures in a percolation system control the dynamics of spread in such systems. Closely related to percolation systems is a broad range of discrete growth models, related to the stepwise spread of invasive phenomena (e.g., fire, disease, urbanization). The most basic model is the *Eden growth model* (Eden 1961), along with a number of variants (Herrmann 1986). A related system of interest is *diffusion-limited aggregation* (Witten and Sander 1981). Many of these basic models have informed the development of models of urban growth, particularly work by Batty and Longley (1994).

3.0 CAVEATS AND CRITICISMS

We freely acknowledge that any attempt at a ‘broad-brush’ categorization of models is inevitably open to question. The point is not whether or not our classification is ‘correct’, but that this approach, by systematizing previous work on spatial models, can allow more rapid development of useful models building on that work.

A more substantive criticism is that our building-block models promote a phenomenological approach to model building, focused not on the mechanisms that lead to particular outcomes, but on the outcomes themselves. This might *force* particular patterns to emerge rather than *allowing* them, as advocated by Grimm and Railsback (2012, page 301). Nevertheless, we consider it useful to break system behaviour into categories such as averaging, diffusion, movement, succession, and so on, as part of the abstraction process inevitably demanded by model building. Furthermore, where a complicated model is composed of building-block models, any forcing is likely to be minimal since interaction among the building-blocks will determine overall outcomes. As do Grimm and Railsback, we recommend not blind adoption of building-blocks, but experimentation with multiple alternatives.

More philosophically, the distinction between phenomenological and mechanistic models is not clear-cut. Even the normal distribution can be considered ‘mechanistic’ seen from a particular perspective—as the outcome of an additive process or random walk. Even the most detailed of ‘mechanistic’ models ultimately remains a simplified mathematical model at some level of abstraction (see also Couclelis 1984). In a slightly different context, Scott Page (2011, page 250) argues that “discipline-specific assumptions that enhance realism can extend core models to make them useful within disciplines”, and our approach is in keeping with this view.

4.0 VALUE OF THE BUILDING-BLOCK APPROACH AND FURTHER WORK

The approach to spatial model building we propose, advocates that we attend more closely to previous work in the field of spatial models. Rather than approach every spatial modelling task *de novo* we suggest considering the various spatial processes operating and spatial patterns exhibited at different scales, and using these, along with our knowledge of existing spatial models, expressed in terms of building-blocks, to inform more rapid and effective model development. One way to think of this approach is as a suggestion that we add local averaging, voter models, succession models (and so on) to our ‘modelling toolkit’, alongside the normal distribution and other familiar basic models, which are routinely used when we approach the analysis of any system.

Becoming more familiar with building-block models provides practical benefits in model development. First, is the potential for more rapid development of relatively complicated models. Second, knowledge of building-block models provides a basis for *neutral models* for use as null models, whether for assessment of real world outcomes, or as a testing ground for more central areas of interest in a system. Third, the modular model development that building-block models promote may allow for the structural evaluation of models, building on POM's "patterns for model structure" (Grimm and Railsback 2012, page 301).

An avenue for further work is the development of a more organized classification of our building-block models. In other fields, particularly architecture and urban design (Alexander et al. 1977), but also software engineering (Gamma et al. 1995), well understood components for the solution of complicated design problems have evolved into *pattern languages*. In pattern languages a *design pattern* is a template solution to commonly encountered design problems. We consider our building-block models to be roughly equivalent to such design patterns. Crucially, in pattern languages, design patterns are considered not in isolation from one another but as an *interrelated set of components* that can be combined to solve arbitrarily complicated problems in the domain of interest. Also significant is the idea that patterns are *hierarchically organized* and in a network of interdependencies, so that selection of one particular pattern for use suggests that other related patterns may also be useful. Our building-block models lack hierarchical organization or any mapping of their interrelationships. We will briefly present preliminary thinking on this aspect of our approach, to show how our building-block models might form a basis for development of a pattern language for spatial simulation modelling.

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