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Rethinking the role of Agent-Based Modeling in archaeology

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ABSTRACT

Agent-Based Modeling (ABM) represents a methodology with significant potential for altering archaeological analytical practice. The continued growth in the number of publications that use ABM provides evidence for the significance of this emerging approach. However, the scope of the research topics investigated has not increased accordingly. A consensus exists among ABM practitioners, that once generally accepted by the field, ABM can make revolutionary advances within the overall archaeological research paradigm. Unresolved concerns within the archaeological community center on whether ABMs are sufficiently grounded in empirical data, are aligned with theoretical trajectories, and on the difficult task of mastering the computational systems. It is worth exploring these aspects of the disjuncture between the mainstream and ABM practitioners for two reasons – to frame a discussion of qualities of ABM that make it transformative and to provide guidelines for broadening ABM's applicability. With capacity-building in mind, offered here is a practical reference for the non-practitioner archaeologist considering ABM. A glossary is included of key terms used in the text to describe ABM methods and theory.

1. Introduction

Adoption of a major new methodology by a particular field of study is transformative when it allows the development of new possibilities previously unrealizable. For instance, the implementation of radiocarbon dating from the field of chemistry completely revolutionized the ways archaeologists organize time. More recently, the adoption of user-friendly Geographic Information System (GIS) software developed initially to map modern land use, made it possible to render and analyze multiple data sets and reshape the ways archaeologists conceptualize space. Both radiocarbon dating and GIS are now standard in archaeology.

Observing recent trends toward increased use of Agent-Based Modeling (ABM) in archaeology suggests the beginnings of at least a technological transformation, with the potential for substantial changes in methodology and theoretical frameworks. The annual rate of publications using ABM has increased substantially, especially after 2007, as shown in Fig. 1, based on a review by the authors of publications since 2000. Similar trends have already been noted in other social sciences for the use of ABM, pointing to the emergence of transdisciplinary approaches (Bankes, 2002; Moran et al., 2014). This article explores the reasons for expanded use of ABM, reflects on the challenges inherent in the method, reviews some of the ways ABMs have been used, and provides a practical summary of the modeling process for those not versed in the intricacies of computational approaches.

The sociology of science provides useful examples of how transformations occur in different fields of study. At least since the work of Thomas Kuhn (1962) the patterns that produce major shifts are well-known. Generally, transformations occur as a result of one or more conditions that promote advances: (1) integration of multiple paradigms across disciplines, as in interdisciplinary and transdisciplinary approaches (Cioffi-Revilla, 2014); (2) emergent challenges that galvanize the research community, such as landing humans on the Moon or the current push to understand climate change; (3) development of new technologies, such as larger telescopes or more powerful computers; and (4) research opportunity, as in the social and organizational contexts that may encourage new ideas (Hackett, 2011). Of these four change conditions ABMs most clearly represent a new technology, however, ABMs also offer a methodology to unify long-held discipline-based theoretical disjunctures (Gavin, 2014; Kohler, 2000) and open the path to fundamental challenges to epistemological assumptions (Hayles, 1991; McGlade and Garnsey, 2006).

Even with these potentials, ABM and computer simulation, which have been known in the field for about as long as GIS, have a checkered history of impact (see Lake, 2014, 2015 for a more complete review of the history of computer simulation and archaeology). At the same time that archaeology has witnessed an uptick

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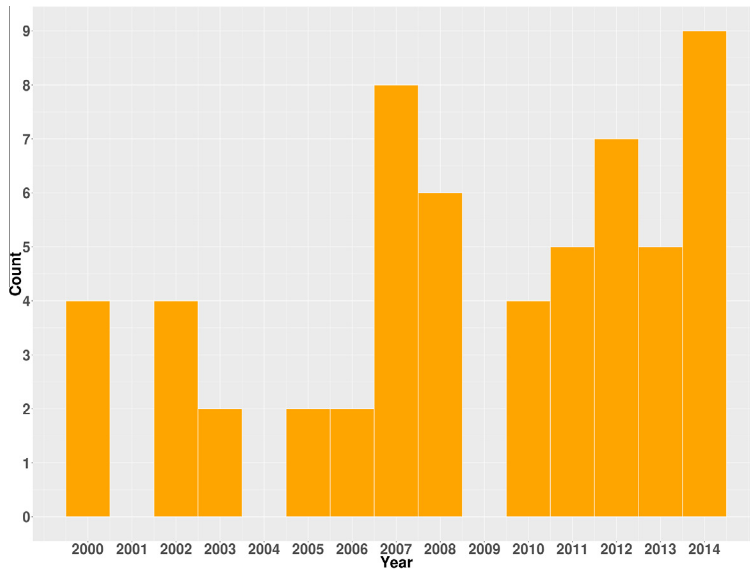

Fig. 1. A review of the use of ABMs in archaeology shows a rapid growth in the number of publications since 2000.

in numbers of ABM applications, the scope of research topics covered has not followed suit necessarily. In addition, its increase is still limited to a small, but slowly growing community of archaeologists targeting a select list of archaeological research interests. As Lake (2014:278) states in a recent review of trends in archaeological simulation, "The skeptic may point out, however, that simulation has only become unremarkable in certain fields of archaeological enquiry, in particular evolutionary archaeology and the study of human evolution, and cannot therefore yet be considered a 'mainstream' tool in the way that, say, geographical information systems are used...." It is worth asking why this is so, since as already illustrated, there should be little reason to doubt the ability of new methods adopted from other disciplines to fundamentally transform our investigations.

In brief, the mixed reception of ABM in the discipline of archaeology may be attributed to three factors: (1) ABM methods are viewed as complex and difficult to use; (2) ABM's theoretical foundations and computing capabilities until recently were not sufficiently developed to address what archaeologists needed and wanted; and (3) trends in archaeological thought had drifted away from quantitative approaches and questioned the ability of computer simulations to capture human complexity. These three factors were arguably legitimate criticisms in the 1970s through the 1990s and it is possible that the frustrations produced still linger when considering ABM as a potential method. Early criticisms of computational simulation also may have led to the absence of computational methods in many university archaeology programs. Additionally, the general lack, or even in some cases rejection of formalism in archaeological models written as if-then statements, has not enabled smooth synchronization between the two. By formalism, we mean the precise listing of logical statements about variables, assumptions about their behavior, and the consequences of these assumptions. We do not argue that ABM is appropriate for studying every aspect of the human condition, but do argue that its potential to make advances especially within post-modernist, anthropological perspectives has been limited by the "computation = reductionism" argument. It may be correct to say that ABMs are reductionist in that they focus on only a few characteristics of a human system, but ABMs are models and just like any other explanatory paradigm, the researcher cannot study all characteristics at once. Therefore, ABMs are no more reductionist than more commonly used explanations in archaeology.

Yet, among practitioners of ABM, there is a clear consensus that ABM, once generally accepted by the field, will make revolutionary advances within the overall archaeological research paradigm (Barton, 2014; Crabtree and Kohler, 2012; Madella et al., 2014; van der Leeuw, 2004). It is worth exploring this disjuncture between the perspectives of the mainstream and ABM practitioners for two important reasons: to serve as a framework to discuss the precise qualities of ABM that make it transformative and to provide guidelines for the changes necessary to broaden ABM's applicability to archaeological mainstream interests.

2. Opening the black box

ABMs are a class of computational models that simulate the behavior and actions of agents (whether individuals, families, villages, or other units of interest) as an integral aspect of interpreting the whole system (Lake, 2015). Railsback and Grimm (2012) have prepared an excellent guide to ABMs and the popular simulation package NetLogo. ABMs were developed in order to vitiate problems encountered by researchers when applying formal mathematical models to complex phenomena (Railsback and Grimm, 2012). Complex phenomena should not be confused with other uses of the word complex or complexity in archaeology (Kohler, 2012). Complex phenomena result from a series of interdependent processes and relationships that cannot be understood by analysis of the individual parts that make up the whole, or even in terms of one empirical instance (Hayek, 1980; also see Glossary). A readily understood example of this is the palimpsest archaeological record. As archaeologists, we readily recognize that palimpsests depend on more than one circumstance, each with its own working details—natural formation process, direct human action, taphonomy, reuse and recycling, and even historical dependency (Bailey, 2007; Holdaway and Wandsnider, 2008). By isolating one of these processes for further analysis, we come to understand it better but never in light of how it is actually related to all of the other circumstances responsible for the palimpsest we see. Or using a non-archaeological example, is it desirable, or even possible to define a basketball team's strategy by analyzing one play of the game?

A long-term criticism of ABMs is that they are too opaque; they are "black boxes" where no one except the programmer can evaluate what goes in and what comes out (Topping et al., 2010; Wobst, 2010). In other words, while the basic concept is intuitively clear to