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Agent-Based Modeling and Historical Simulation

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Abstract

This essay discusses agent-based modeling (ABM) and its potential as a technique for studying history, including literary history. How can a computer simulation tell us anything about the past? This essay has three distinct goals. The first is simply to introduce agent-based modeling as a computational practice to an audience of digital humanists, for whom it remains largely unfamiliar despite signs of increasing interest. Second, to introduce one possible application for social simulation by comparing it to conventional, print-based models of the history of book publishing. Third, and most importantly, I'll sketch out a theory and preliminary method for incorporating social simulation into an on-going program of humanities research.

Introduction

This essay will discuss agent-based modeling (ABM) and its potential as a technique for studying history, including literary history. When confronted by historical simulations, scholars first notice their unusual ontological commitments: a computer model of social life creates a simulated world and then subjects that world to analysis. On the surface, computational modeling has many of the trappings of science, but at their core simulations seem like elaborate fictions: the epistemological opposite of science or history. Historical simulation thus straddles two very different scholarly practices. On the one hand are the generally accepted practices of empirical research, which look to the archive for evidence and then generalize based on that evidence. On the other hand is the new and in many ways idiosyncratic practice of simulation, which thinks in the opposite direction. ABM begins with a theory about a real system and then creates a functional replica of that system. When confronted with agent-based models, historians often respond with a knee-jerk (and in many ways, justified) skepticism about the applicability and usefulness of artificial worlds. How can a computer simulation tell us anything about the past? The difficulty of this question should not be understated. Nonetheless, I will propose that these forms of intellectual inquiry can productively coincide, and I'll map out a research program for historians curious about the possibilities opened by this new technique. 1

This essay has three distinct goals. The first is simply to introduce agent-based modeling as a computational practice to an audience of digital humanists, for whom it remains largely unfamiliar despite signs of increasing interest. The second goal is to introduce one possible application for social simulation by comparing it to conventional, print-based models of the history of book publishing. Third, and most importantly, I'll sketch out a theory and preliminary method for incorporating social simulation into an on-going program of humanities research. 2

I: Playing with complexity

Agent-based modeling, sometimes called individual-based modeling, is a comparatively new method of computational analysis.[1] Unlike equilibrium-based modeling, which uses differential equations to track relationships among statistically generated aggregate phenomena — like the effect of interest rates on GDP, for example — ABM simulates a field of interacting entities (agents) whose simple individual behaviors collectively cause larger emergent phenomena. In the same regard, ABM differs significantly from other kinds of computational analysis prevalent in the digital humanities. Unlike text mining, topic modeling, and social-network analysis, which apply quantitative analysis to already existing text corpora or databases, ABM creates a simulated environment and measures the interactions of individual 3 agents within that environment. According to Steven F. Railsback and Volker Grimm, ABMs are “models where individuals or agents are described as unique and autonomous entities that usually interact with each other and their environment locally” [Railsback 2012, 10]. These local interactions generate collective patterns, and the intellectual work of ABM centers on identifying the relationships among individual rules of behavior and the larger cultural trends they might cause.

In this way, agent-based modeling is closely associated with complex-systems theory, and models are designed to simulate adaptation and emergence. In the fields of ecology, economics, and political science, ABM has been used to show how the behaviors of individual entities — microbes, consumers, and voters — emerge into new collective wholes.[2] John Miller and Scott Page describe complex systems: “The remarkable thing about social worlds is how quickly [individual] connections and change can lead to complexity. Social agents must predict and react to the actions and predictions of other agents. The various connections inherent in social systems exacerbate these actions as agents become closely coupled to one another. The result of such a system is that agent interactions become highly nonlinear, the system becomes difficult to decompose, and complexity ensues” [Miller 2007, 10]. At the center of complexity thus rests an underlying simplicity: the great heterogeneous mass of culture in which we live becomes reconfigured as an emergent effect of the smaller, describable choices individuals tend to make. The intellectual pay-off of social simulation comes when scholars identify and replicate this surprising disjunction. As Joshua Epstein and Robert Axtell argue, “it is not the emergent macroscopic object per se that is surprising, but the generative sufficiency of the simple local rules” [Epstein 1996, 52]. In this formulation, to study complex systems is to wield the procedural operation of computers like Occam’s Razor — by showing that simple procedures are sufficient to cause complex phenomena within artificial societies, one raises at least the possibility that such procedures are “all that is really happening” in actual systems [Epstein 1996, 52]. 4

Humanists will be hesitant to accept the value of this (and should be, I think), and I will return to the notion of “generative sufficiency” later. For now I mean only to point out the way complex-systems theory elevates the local and the simple at the level of interpretation: to know about the world under this paradigm is to generate computer simulations that look in their larger patterns more or less like reality but which at the level of code are dictated by artificially simple underlying processes. 5

The basic work of agent-based modeling involves writing the algorithms that dictate these processes. Agent-oriented programs can be written and executed from scratch in any object-oriented programming language, including Python and R. However, scholars looking to incorporate agent-based simulations into their research often rely on out-of-the-box software packages. Some, like AnyLogic, are proprietary toolkits designed for commercial applications, but many are open source. In their comprehensive survey of available packages, Cynthia Nikolai and Gregory Madey point out that “different groups of users prefer different and sometimes conflicting aspects of a toolkit” [Nikolai 2009, 1.1]. Social scientists and humanities-based researchers, they argue, tend to favor easy-to-learn interfaces that require fewer programming skills, while computer scientists prefer packages that can be modified and repurposed.[3] 6

Without presuming to recommend (even implicitly) one toolkit over another, and in the hope that my discussion will be applicable across platforms, I will focus on examples drawn from NetLogo. NetLogo is a descendent of the Logo programming language, which was first designed in the 1960s and became popular in primary and secondary education [Harvey 1997]. Like its ancestor, NetLogo creates sprites called “turtles” and moves them according to unit operations called “procedures”. The turtles circulate in an open field of “patches,” small squares which can be assigned variables that change over time. Like Logo, NetLogo can generate beautiful and intricate visual displays from comparatively simple commands. (See Figure 1.) 7

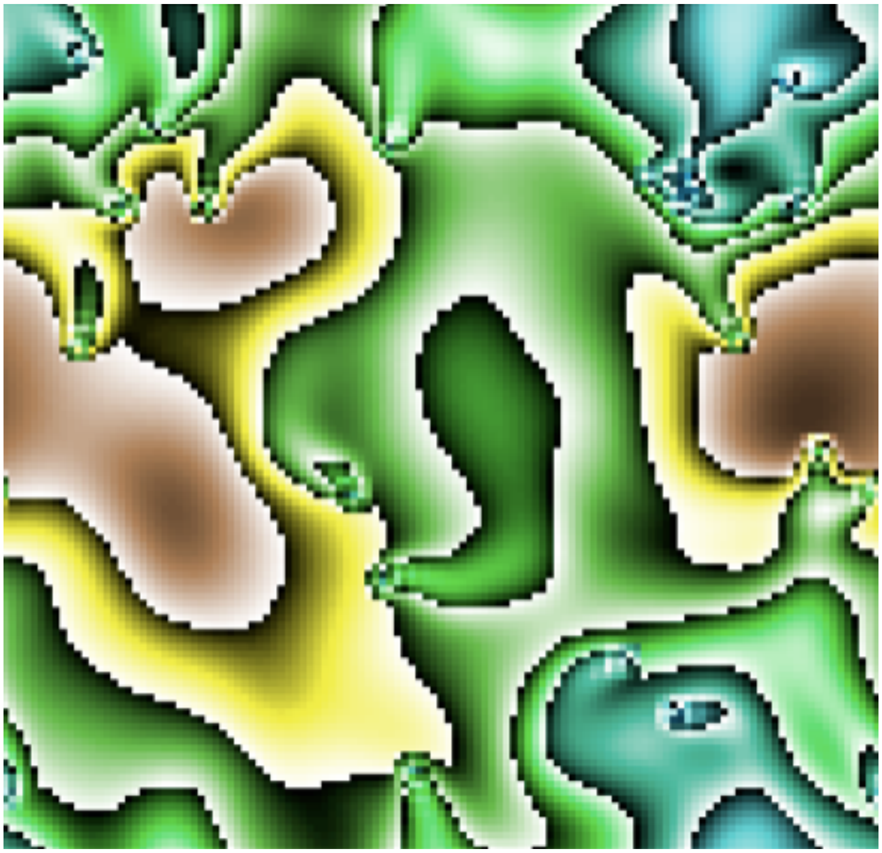

Figure 1. “Diffusion Graphics.” Model created by Uri Wilensky. Screen capture by Michael Gavin, 2013.

This ability to visualize the behaviors of many turtles as they execute their individually determined procedures is what makes the Logo family of programming languages particularly suited for agent-based simulations. (RePast Simphony has adopted a similar vocabulary, called ReLogo, for novice users.) Researchers Juan-Luis Suárez and Fernando Sancho, inspired by their primary research on the Spanish baroque as a transatlantic intellectual phenomenon, created the *Virtual Culture Laboratory* (VCL) to model international cultural transmission. The VCL (Figure 2) creates a field of individual agents that circulate among each other as they cross artificially abstract cultural boundaries. The world Suárez and Sancho envision is divided geographically and demographically: a green nation is separated from a blue nation, and both are home to agents with a mix of dominant (red) and creative or passive (yellow) personalities. As the agents circulate in these regions, they trade messages and learn from each other. Measuring the agents’ performance under different conditions allows the researchers to test theories of intercultural exchange. Suárez and Sancho write, “Taking the baroque as a cultural system enables us to observe individual works and their interactions with the human beings who create, contemplate and use them, to examine the emergence of ‘cultural’ patterns from these interactions, and to determine the diverse states of the resulting culture” [Suárez and Sancho 2011, 1.11]. In this way, graphically simple programming environments like NetLogo allow researchers to create analytically rigorous representations of complex social systems.[4] 8

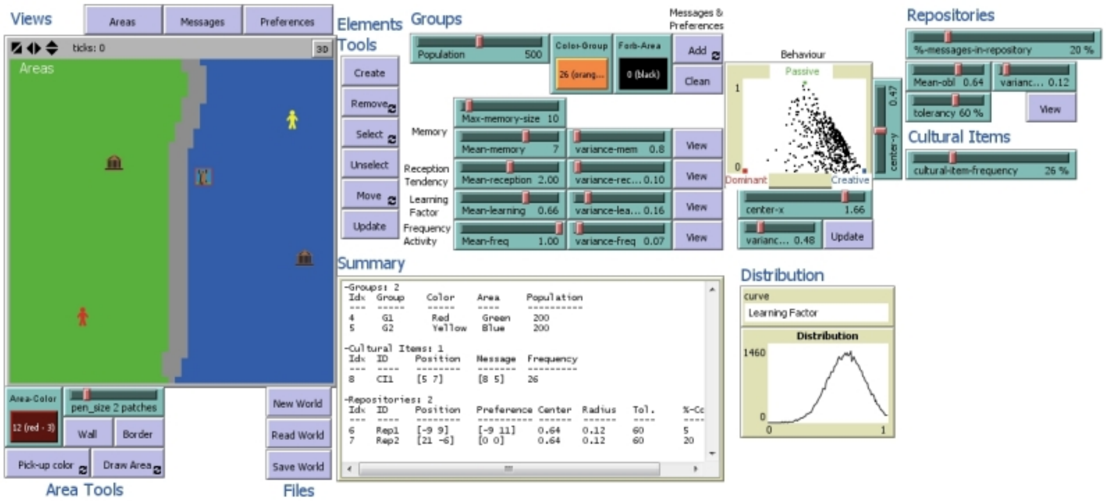

Figure 2. Screen capture from Suárez and Sancho, 2011

Of all the genres of computational expression across the digital humanities, agent-based models might share most in common with games, in particular what are called “serious games.” Like games, models simulate rule-bound behaviors and generate outcomes based on those rules. Ian Bogost has described games’ intellectual function: “Games represent how real and imagined systems work, and they invite players to interact with those systems and form judgments about them” [Bogost 2007, vii]. In this sense, games involve what Noah Wardrip-Fruin has called “expressive processing.” He explains: “When I play a simulation game, author-crafted processes determine the operations of the virtual economy. There is authorial expression in what these rules make possible” [Wardrip-Fruin 2009, 3–4]. Like designing serious games, modeling is a form of authorial expression that uses procedural code to confront complex social and intellectual problems. 9

ABM differs from gaming in three key respects, however. First, it does not usually depend on direct human interaction, at least not in the same sense of games in which players move through a navigable space toward a definite goal [Manovich 2001]. There is no boss to fight at the end of a social simulation. You do not *play* an agent-based model. Instead, you *play with* a model, tinkering with its procedures and changing its variables to test how the code influences agent behavior. [5] I sometimes describe social simulation this way: Imagine a *Sims* game in which the player writes all the behaviors, controls all the variables, and then sets the system to run on autopilot thousands of times, keeping statistics of everything it does. This suggests the second key difference between ABMs and games. With researcher-generated simulations, the researcher is in control of the processes and can adjust their constraints according to her or his interests. [6] A fundamental characteristic of social simulations is that designers can alter the parameters of the model’s function and thereby generate different, often unexpected patterns of emergence. [7] “While, of course, a model can never go beyond the bounds of its initial framework,” Miller and Page write, “this does not imply that it cannot go beyond the bounds of our initial understanding” [Miller 2007, 69]. By pushing against their designers’ expectations, simulated environments are analogous to experimental laboratories where hypotheses are tested, confirmed, and rejected. They join an ongoing process of intellectual inquiry. “Simulation practices have their own lives,” philosopher Eric Winsberg explains. “They evolve and mature over the course of a long period of use, and they are ‘retooled’ as new applications demand more and more reliable and precise techniques and algorithms” [Winsberg 2010, 45]. Here, then, is the third and most important difference that separates simulations from games: they participate in disciplined traditions of scholarly inquiry, and their results are meant to contribute to research agendas that exist outside themselves. 10

II: Models: epistemology and ontology

However, if we are to simulate responsibly, the above discussion raises a number of epistemological and ontological issues that must be acknowledged and dealt with. These issues can be stated as a pair of questions: What is a model? 11

How can models be used as instruments of learning? In the field of humanities computing, Willard McCarty has been a leading voice.[8] Historians have debated the relationship between implicit models of general human behavior and their larger narratives that describe the causes of particular historical events.[9] Outside the humanities, especially in economics and physics, modeling has a long tradition of contested commentary [Morrison 1999]. Against this large and still-growing body of scholarship, it may seem presumptuous or tedious to offer yet another discussion of the philosophy of modeling, but I've found that a very particular understanding of the term is useful when thinking about how computational models can be incorporated into historical research. The thesis I'll argue for, in a nutshell, is that *models don't represent the world — they represent ideas.* The corollary to this claim, as it pertains to history, is that *models don't represent the past — they represent our ideas about the past.*

To begin to show what I mean here and why it might matter for the practice of historical simulation, allow me to back up and survey some of the more common uses of the word. In *Language of Art* (1976), Nelson Goodman describes models in a usefully comprehensive way: "Few terms are used in popular and scientific discourse more promiscuously than 'model.' A model is something to be admired or emulated, a pattern, a case in point, a type, a prototype, a specimen, a mock-up, a mathematical description — almost anything from a naked blonde to a quadratic equation — and may bear to what it models almost any relation of symbolization."[10] Goodman is skeptical that a general theory of modeling is possible, but if we work through these examples, some general patterns emerge. 12

Consider fashion models. It doesn't seem right to say they represent people. Models don't seem to represent actual human bodies. They represent instead normative ideas about how the human body should look, as well as, perhaps, ideas about sexuality and capitalism. Compare fashion models with model organisms, like fruit flies and lab rats, used by geneticists and biologists to study living systems. Mice don't represent human bodies any more than fashion models do, but in the field of medical research they serve as analogues, representatives of mammalian systems in general, including humans. Like beauty, mammalianism is a concept we use to categorize bodies. Theoretical models of the kind used in microphysics represent particles, true, but those particles are usually not directly observable, and in some cases they might not even exist [Morgan 1999a].[11] Mathematical models common in economics are meant to represent real economic activity, but, as Kevin Brine and Mary Poovey have recently argued, economic models remain at several ontological removes from the world they purport to describe [Poovey 2013].[12] Even mimetic objects like physical scale models, such as the papier-mâché volcano, serve to illustrate and visualize ideas about causal forces in geological systems [de Chadarevian 2004]. 13

These different forms of symbolization may have more in common than Goodman acknowledged. They all share a condition of exemplarity. None stand in for reality, exactly. None refer in a straightforward way to the phenomena they purport to describe; rather, they exemplify the formal characteristics of those phenomena. If models represent anything, they describe generic types, categories, theories, and other structures of relation. This is what I mean when I say that models represent ideas rather than things.[13] Models describe the world analogically by representing their underlying theory mimetically. In *Science Without Laws: Model Systems, Cases, and Exemplary Narratives* (2007), editors Angela Creager, Elizabeth Lunbeck, and M. Norton Wise argue that "model systems do not directly represent [phenomena] as models of them. Rather, they serve as exemplars or analogues that are probed and manipulated in the search for generic (and genetic) relationships" [Creager 2011, 2]. As the editors make clear, those generic and genetic relationships — those kinds and causes — are not really intrinsic to anything; rather, they are the concepts and theories that researchers bring to bear, subject to inquiry, and portray as their "conclusions." 14

In the cases of a 3D mechanical replicas or computer simulations, this process of abstraction isolates key characteristics and behaviors — simple things — that can be shown to generate more complex, dynamic structures. For example, the economist and inventor Irving Fisher popularized the use of mathematical equilibrium-based models in economics [Morgan 1999b]; [Morgan 2004]; [Poovey 2013]. He began in the late nineteenth-century by building an actual physical machine designed to represent currency flow. Small hydraulic presses drove water in and out of the machine through different tubes — rising and falling water levels represented the influx or drain of valuable metals in an economic territory whose currency was still tied to the gold standard. Fisher had composed a handful of equations that, he believed, described the flow of currency through an economy, and he built the hydraulic machine to represent that 15 theory.[14] Half a century later, another economist, A. W. (Bill) Phillips, built a similar machine called the MONIAC which he understood as a pedagogical tool [Colander 2011]. By visualizing accepted economic theories of currency flow, the operation of the machine had an analogical relationship to actual economic activity. In Mary Poovey's and Kevin Brine's words, "The analog-machine method could only represent economic processes analogically — only, that is, by producing a simulation that reproduced the theoretical assumptions formulated as equilibrium theory" [Poovey 2013, 72].

Despite their critical and skeptical tone, Poovey and Brine point directly to the value of replicas, whether mechanical or digital. In *Science without Laws*, the editors compare generative models to lab rats and fruit flies. Unlike putatively simple, naive observation, in which the observer passively receives information about the external world, the process of selecting or building models involves replicating one's own *a priori* ideas about how the world does or might work and then subjecting a functional representation of those ideas to close scrutiny. 16

Building from these general observations, I use the word "model" in two closely related ways to describe both the replica or example and the theoretical assumptions that motivate its creation or selection. At the abstract level, a model is *any framework of interpretation used to categorize real phenomena*. It might be specified to the point of being a theory, but it might refer more generally to the categories, structures, and processes thought to drive historical change.[15] In literary theory, model in this sense relates most closely to ideas of form and genre. At the more particular level, a model is *any object used to represent that framework*. Such objects might include a representation, a simulation, a replica, a case-study, or simply an example. 17

The advantage of this definition is that it frees models from the never-realizable expectation that they ought to represent the world empirically. To return to the example of laboratory mice, we can see that they represent human bodies only provisionally and analogically.[16] Their purpose is to represent an interpretive framework — a conceptual model of mammalianism — which is impossible to observe except through particular cases. Like novels, models are fact-generating machines. [17] In Bill Phillips's MONIAC, the waters rise and fall to measurable levels, and those changes are real facts, in much the same way that it's a fact that Elizabeth Bennet married Mr. Darcy. However, artificial data like these are true or false only with respect to their procedural contexts. Out here in the real world, there never was a real Elizabeth Bennet or Mr. Darcy, and if the blue water rises in Bill Phillips's machine, we haven't experienced inflation out here in the real world. Nothing that happens in a simulation ever happens outside the simulation. What happens in a model stays in a model, so to speak. Artificial societies exist on their own terms while providing analogues to the world beyond.[18] 18

So what does this have to do with history? Generative modeling strips away the empirical apparatus of document-based research and creates new facts. It flips and mirrors the hermeneutic circle such that the whole thing looks like a figure-8. (See Figure 3). In the traditional hermeneutic circle the researcher starts with a theory or model, sometimes specified to the point of being a hypothesis, and from there makes observations and experiments out in the real world. The model is then revised to account for those new observations. A researcher who builds simulations begins in more or less the same place, but instead of digging into the archives or querying Google n-grams, builds a simulated world that works or doesn't work according to expectations. The patterns of behavior within the simulation either match or fail to match what the designer predicts, and the model is adjusted accordingly. As a guide to intellectual labor, the hermeneutic figure-8 presupposes a researcher willing to traverse all the contours of this line. 19

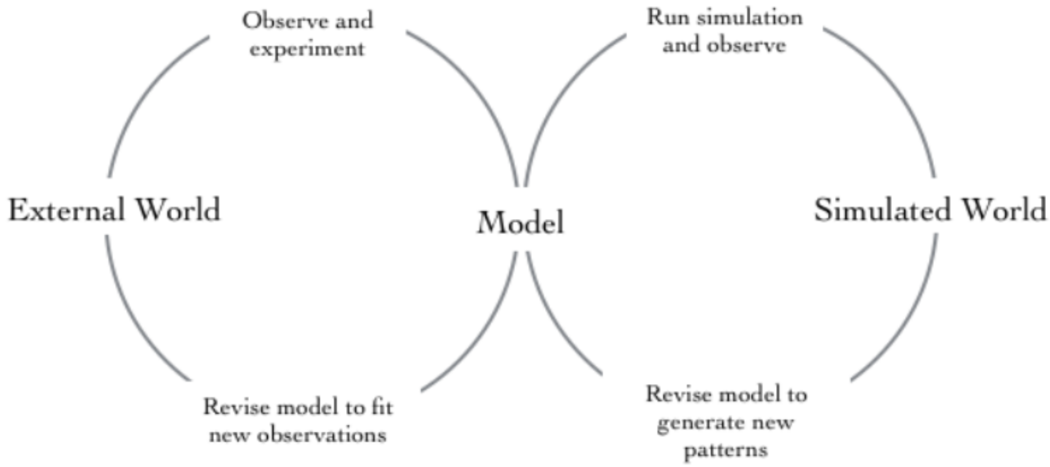

Figure 3. “The Hermeneutic Figure-8.”

III: Models in Literary History

Literary historians use many kinds of models to support many different kinds of claims. The simplest are classification concepts like genre, nation, and period, which provide an interpretive framework against which individual cases are tested. Other models in literary history are more complicated. Biographical contextualization creates a model of some past “context,” usually in the form of narrative description. Contexts are executed when scholars use them to speculate about how people in the past might have interpreted some text or event. [19] These complex models often deploy simpler submodels. For example, Michel Foucault pointed out long ago that “the author” functions as an interpretive model, and much the same could be said about “the reader” as imagined in reader-response theory and book history. The literary canon is itself a great, capacious representative model. Though often compared to the canons of scripture, in practice canonical literature has more in common with the canonical organisms of biomedical research. Rarely is the literary canon read with prescriptive veneration, and never with the authority of law. Instead of “great works” we have a testing ground where new theories are subject to examination. Though journalists and graduate students often wonder what more there is to say about William Shakespeare, that’s like asking what more there is to know about mice or fruit flies. *Robinson Crusoe* is canonical in the same way that slime mold is canonical. 20

Some of these humanistic models are more amenable to agent-based computation than others. Perhaps most promising are those used to describe patterns of social formation, processes of change, and systems of causation. Such models usually appear as two-dimensional diagrams. Pierre Bourdieu’s idea of “the field of cultural production” advanced a highly abstract, schematic picture of art, commerce, and politics. (See Figure 4.) 21

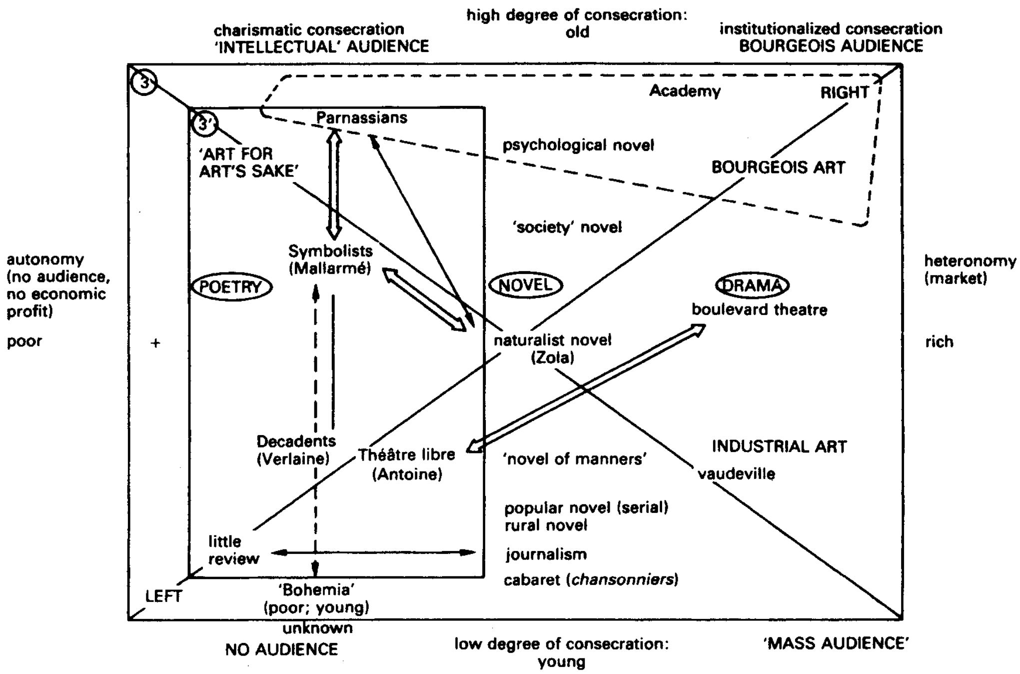

Figure 4. "The Field of Cultural Production" [Bourdieu 1993, 49].

Agents within these overlapping and competing fields jostled for prestige, creating a dynamic and adaptive system highly responsive to the choices made by individual participants. Similarly, Robert Darnton's model of the communications circuit identified structural relationships within the book trade. Ideas and books move throughout nodes in an always-changing network. (See Figure 5).

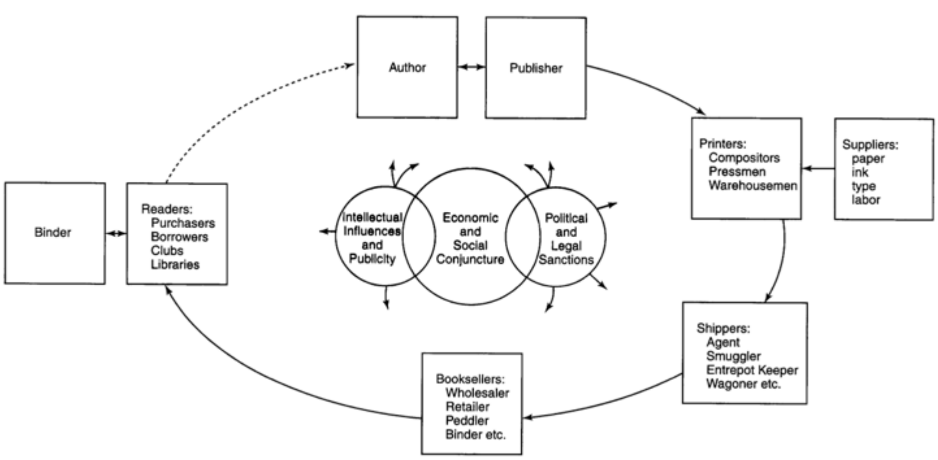

Figure 5. *The Communications Circuit.*[Darnton 2006, 12]

Such diagrams identify kinds of people and a framework that binds them together. These frameworks — the field, the circuit — visualize a web of forces that motivated individual behaviors and caused systems to change over time.

22

Book historians have also collected a large amount of data in the form of statistics, although that data tends to be disconnected and resistant to comparative analysis. It's difficult to aggregate much of the historical records because of inconsistencies and gaps, but some system-level statistics are available. For example, scholars have tabulated the number of new books produced in England annually from the earliest years of the hand-press era. (See Figure 6.)

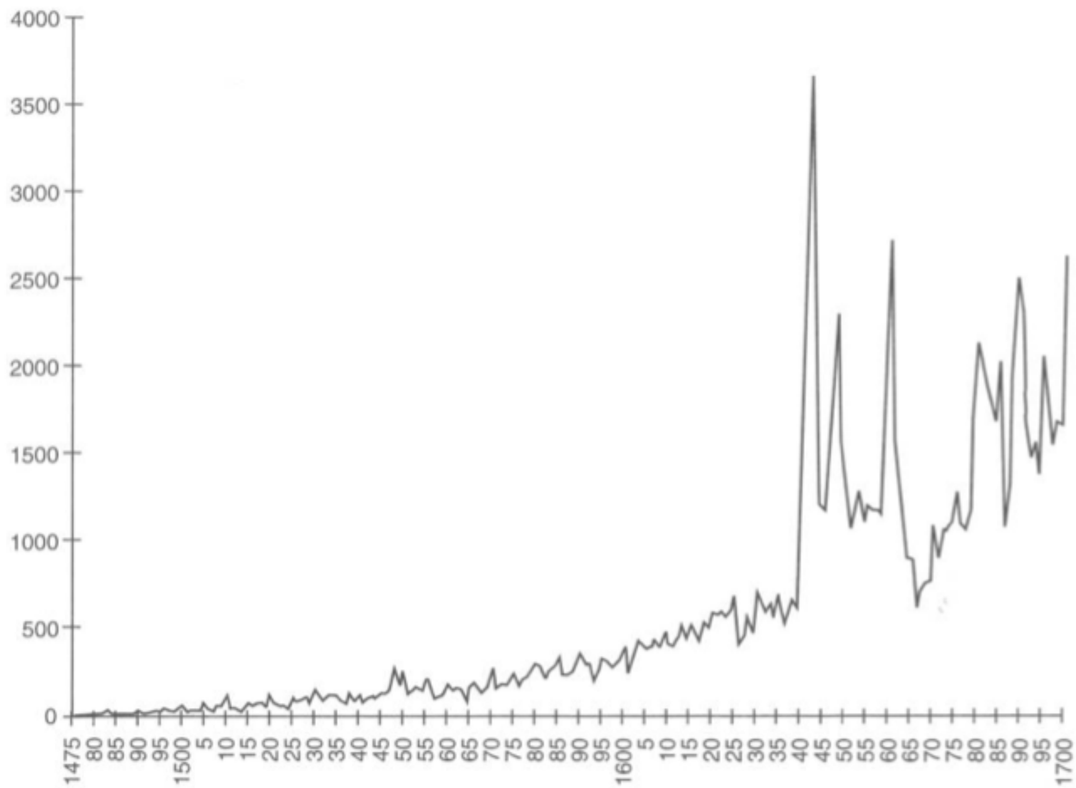

Figure 6. "Annual Totals 1475-1700." *The Cambridge History of the Book in Britain: vol. 4.*

For the first 150 years, book production followed a fairly stable arc of growth. However, this equilibrium was shattered during the civil wars of the 1640s, when the print marketplace exploded with political and religious debates. Historian Nigel Smith has described the event as a "media revolution," and scholars often point to the English Civil War as a key early moment in the development of the free, democratic press [Smith 1994, 24]. On the one hand, the scandal of war and regicide led to a heightened interest among readers and seems to have increased demand for printed books. On the other hand, political instability loosened the stranglehold that state and commercial monopolies had long exerted over the book trade.

What relation is there between diagrammatic models like Bourdieu's and Darnton's and aggregate statistics like these? 23
It turns out, very little. Although economic and political factors appear as forces in both diagrams, the models don't attempt to specify them. Darnton is a prominent practitioner of "microhistory," a technique of historical explanation that performs close analysis of individuals and "everyday life"; in Darnton's case, this means close study of individual members of the book trade [Brewer 2010]; [Darnton 1984]. In microhistory, these often overlooked figures are chosen to exemplify how the print marketplace worked at the local level. Darnton's model is thus designed, not to explain large macrolevel patterns, but instead to provide a heuristic tool for interpreting particular historical events and persons, who then stand in as model exemplars for those larger patterns. The diagrammatic model operates in the service of a bias toward the individual, particular, and contingent event. A model like Darnton's is validated — if "validated" is even the right word — insofar as it helps scholars describe particular pieces of evidence found in the archive.

In this respect, the diagrammatic models often drawn by historians are validated very differently than simulations like 24
those popular among complex-systems theorists. Within the field of complexity science, explanation is "validated" by the model's ability to replicate large system-level patterns within simulated worlds.[20] If the model can produce visual patterns similar to patterns produced by the observed record, the possibility is raised that the moving parts of the model bear some meaningful analogical relationship to the moving parts of real processes. Epstein and Axtell argue that "the ability to grow [artificial societies] — greatly facilitated by modern object-oriented programming … holds out the prospect

of a new, generative, kind of social science" [Epstein 1996, 20]. This newness takes form, not merely as a novel genre of cultural representation, but as a mode of inquiry that fundamentally transforms what we think of as historical explanation. Epstein and Axtell ask, "What constitutes an explanation of an observed social phenomenon? Perhaps one day people will interpret the question, 'Can you explain it?' as asking 'Can you grow it?'"

I will qualify Epstein's and Axtell's dictum below, and I find the notion that agent-based models can be "validated" to be highly dubious, but it's worth pausing over the radicalism of their anti-historical vision. The intellectual mandate to "grow" artificial societies places a wildly different set of demands on models like Bourdieu's and Darnton's. Whereas static models are used as heuristics for interpreting historical records, simulations are designed to mimic macroscopic patterns. A generative model becomes explanatory, they argue, when the simple, local rules that dictate agent behavior can be shown to result in complex patterns: to know something as a complex-systems theorist is to identify this meaningful disjunction. However, such simple rules can never mimic real behavior at the microlevel. Converting static models to dynamic simulations seems to shift the target of explanation away from particular examples and towards system-level statistics. Models are useful, according to complexity theory, not for interpreting particular events but for generating patterns that look like aggregations of things that really happened; modeling complexity thus obviates the need for attention to particulars. Simulations allow us to see through the mystifying complications of historical evidence and see in their place the simple processes that underpin complex systems. Simplicity and complexity are real, and simulations allow us to see them clearly by stripping away the illusory contingencies of actuality. Such is, at least, how I interpret the challenge complex-systems theory poses to historical explanation. 25

In order for generative models to contribute to a larger practice of historical explanation, scholars will need to reject this theory, I think. The value of modeling will need to be placed elsewhere. As a group, historians will never concede that simplicity and complexity are more interesting than nuance, complication, and ambiguity. Nor should they. I'll conclude this essay by arguing that dynamic simulations work much like heuristic models at the level of historical interpretation (but better). We can use agent-based models without taking on board all of complexity theory's ontological commitments. For now though, I want to leave Epstein's and Axtell's challenge suspended in the air, like an unexpected admonition, or like an interdisciplinary dare: Can we take our ideas, written out in regular academic prose or drawn as diagrams, and paraphrase them into functional computer code? Can we generate simulations that behave how the historical record *we created* predicts? If not, maybe we don't know what we think we know.[21] 26

IV: Growing the communications circuit in a digital petri dish

Following through on this dare requires a new historical practice. Generative modeling is very different from archival work (that's obvious enough), but it's also very different from topic modeling and other statistical techniques. Historical simulation completely sets aside the basic empirical project of gathering and analyzing documents from the past. Instead, simulation points back to the theoretical model itself. 27

The task of converting Darnton's model into a functioning agent-based simulation has already been started by literary scholar Jeremy Throne, who breaks the model down to six turtle-types (called "breeds" in NetLogo parlance): authors, publishers, printers, shippers, sellers, and readers. Throne created variables to control how many of each breed are included, and at initialization these turtles are distributed randomly across a standard-sized field of patches. At each tick, the turtles move about randomly, and whenever they bump into each other they perform transactions: authors present publishers with manuscripts, who give them to printers as "jobs," from whom they're picked up by shippers and deposited to sellers. Readers purchase the books and complete the circuit by giving authors encouragement to create more manuscripts. Like clockwork automata, the now-moving parts of Darnton's model create a uniformly bustling field of exchange. (See Figure 7.) 28

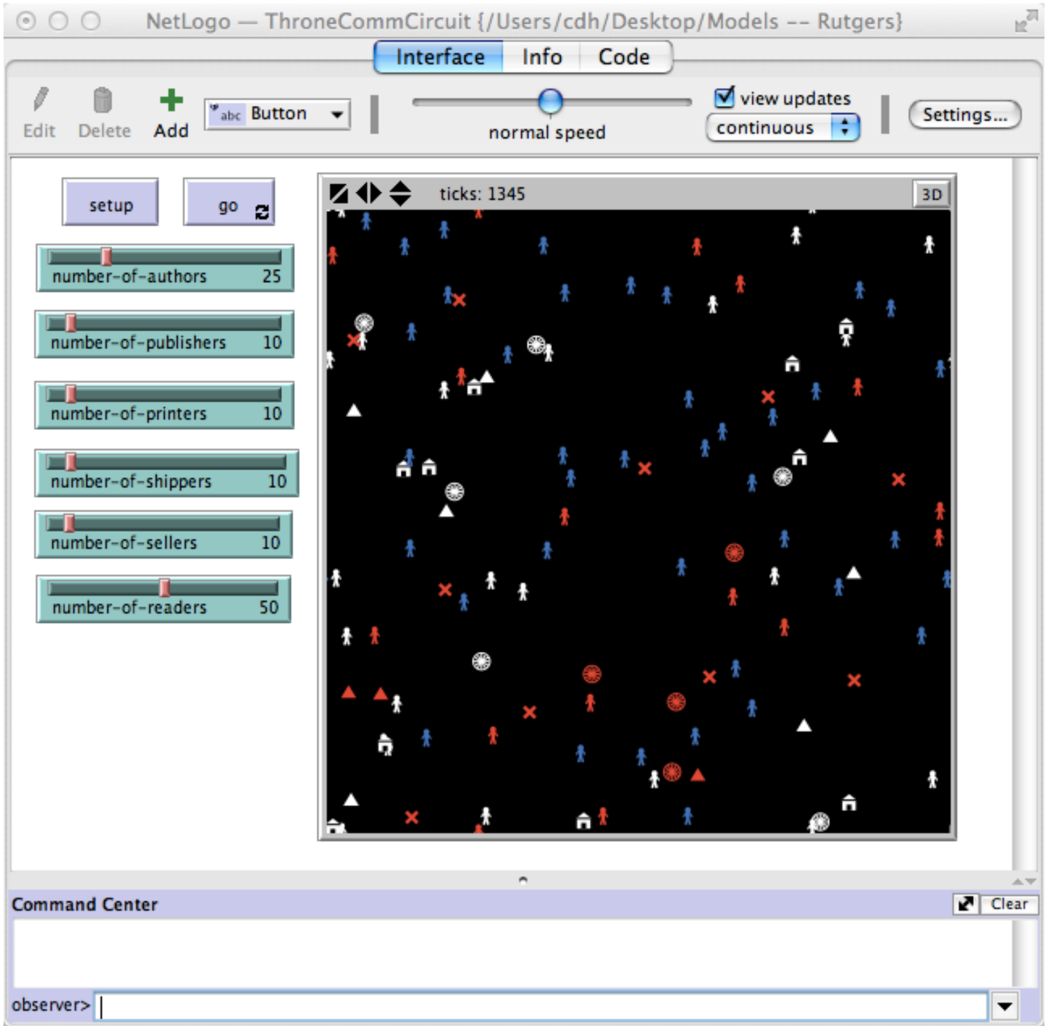

Figure 7. "ThroneCommCircuit.netlogo."Model created by Jeremy Throne. Screen capture by Michael Gavin, February 2014.

Throne concedes that "the homogeneous nature of these businesses is admittedly unrealistic," and indeed the 29
immediate reaction that historians often have when first exposed to agent-based models is to be taken aback by their obvious, even comical artificiality [Throne 2011]. In part this is simply because of the crudity of NetLogo's animations: the figures bounce around the field like chunks of exploded asteroids in *Asteroids*. More deeply, though, the artificiality of the simulation can be traced in the code itself; the procedures that dictate turtle behaviors are radically simplified. For example, here is Throne's code that simulates the activity of book-buying:

```
to buy-book
                     if any? sellers-here with [ inventory > 0 ] ;; if the
reader meets a seller with books to sell
                     [ ask one-of sellers-here with [ inventory > 0 ]
                       [ set inventory inventory - 1              ;; take a
book from the seller
                           if inventory <= 0                  ;; if the
seller is out of books
                           [ set color white ]                  ;; show that
the inventory is gone
                          ]
                          ask one-of readers-here
```

```
                              [ set books books + 1              ;; increase
    the books a reader has read by one
                                set color blue ]
                              ]
                            end
```

These twelve lines of code reduce an enormously complicated cluster of practices surrounding reading to a single procedure. As "readers" move around the patches randomly, they're constantly called upon to "buy-books." Book buying in this context means checking to see if a "seller" turtle happens to sit on the same patch, verifying that the seller has inventory, and then taking that inventory.[22] Already my prose description is more complicated than the procedure itself. In fact, books as such don't exist in the simulation at all. Rather, they appear only as numerical variables owned by turtles. In the above code books exist as "inventory" (for sellers) and "books" (for readers).[23] When a reader bumps into a seller, a seller's "inventory" score is reduced by one and a reader's "books" score is increased by one. That's all that happens. 30

Given its level of abstraction, what relation does this procedure have to actual book buying or real reading? Throne describes the procedure as an activity "that may be thought of as reading, purchasing, or borrowing" — a telling phrase that captures well his model's breadth of imaginative application [Throne 2011]. I say "imaginative" because there isn't anything that existed in history that his readers do, really. They don't read or purchase or borrow: their activities *may be thought of as* those things because they are analogues for those things. Throne's model is less interested in accounting for the particularities of the behaviors imagined here than in demonstrating their function within a larger system of exchange and circulation. That function can be summed up like this: Purchasing, sharing, and reading happen when people encounter media providers, and those activities move content from providers to the reading populace, and these transfers, broadly and abstractly construed, bind consumers to producers in a chain of cultural production.[24] Such abstract ideas require a comparably abstract form of representation. While Darnton's diagram simplifies this process down to an arrow, the NetLogo model represents it as an algorithmic procedure. So, while both models seem unrealistic and over-simplified when compared to actual behavior, if we take the idea to be the models' real subject, rather than the past *per se*, then neither is reductive at all. The code and the diagram are neither less realistic nor less valid than generalizations in prose. Agent-based models don't reduce life to abstractions; they bring abstractions to life. 31

The most salient difference between agent-based simulations and more traditional forms of historical modeling is not, then, that simulations are peculiarly abstract, artificial, or otherwise disconnected from the past. Rather, conventional forms of historical explanation depend on the spatialized logic of print, whether in the form of diagrams, graphs, charts, or simply sequential prose. In such models, sequence and spatial juxtaposition carry much of the explanatory load. Agent-based models use algorithmic processes instead. Alexander Galloway's comment about video games applies to ABM as well: like games, simulations are an "action-based medium" [Galloway 2006]. This means that simulations like Throne's are able to point in both directions of what I've called the hermeneutic figure-8. They retain the capacity to facilitate historical research and explanation, like any static model, but they also can be activated to generate behaviors in simulated worlds — behaviors that may or may not replicate patterns observed in the historical record or predicted by the underlying assumptions. As Willard McCarty has argued, models "comprise a practical means of playing out the consequences of an idea" [McCarty 2008]. In his initial experiments Throne found, for example, that printers and shippers were the surprising bottleneck and that the function of his world is more sensitive to disruptions in production and shipment than he'd anticipated.[25] 32

The challenge then becomes one of reconciling these disruptions with observed patterns in the historical record, and it is at this point in the explanatory process that statistics begin to play a valuable role. Statistics do not "validate" the model, if by validate one means "prove," but they facilitate interpretation by identifying where the model does and does not replicate observed macroscopic patterns [Dixon 2012].[26] To return to Throne's original, what's striking is the lack of change over time: once the turtles are apportioned at initialization, the system runs without constraint or growth. Without feedback loops that alter agent behavior, the communications circuit operates here like a complex system, but not like a 33 complex *adaptive* system, and thus its production, once set, operates at an unrealistically consistent equilibrium.

Happily, agent-based models are easy to modify and extend (surprisingly easy, in fact, to any digital humanist comfortable with basic coding), and gaps in a model can be addressed to facilitate new experiments that ask new questions. In my revision of Throne's original, I wondered how economic growth, state suppression, and the exertion of commercial monopolies might impact book production. My version argues that growth in demand instigates pressure from the state and from commercial interests to restrict production, but that if such restrictions result in too much pent-up demand, constraints break down in moments of crises. The result is a pattern of book production that largely follows economic growth but much more closely matches the punctuated equilibrium observed across the hand-press era. Compare, for example, the pattern of book production observed over a 225-year period in my version (See Figure 8.) with annual book production in England from 1475 to 1700. (See Figure 6.) "Playing with the model" is another term for "sensitivity analysis," and it means adjusting the settings to find out which replicate observed cultural patterns, which cause the system effectively to crash, and to try to figure out why. However, the output of a model never will match the historical data exactly, nor should it. The purpose of historical simulation is not to recreate the past but to subject our general ideas about historical causation to scrutiny and experimentation.[27] 34

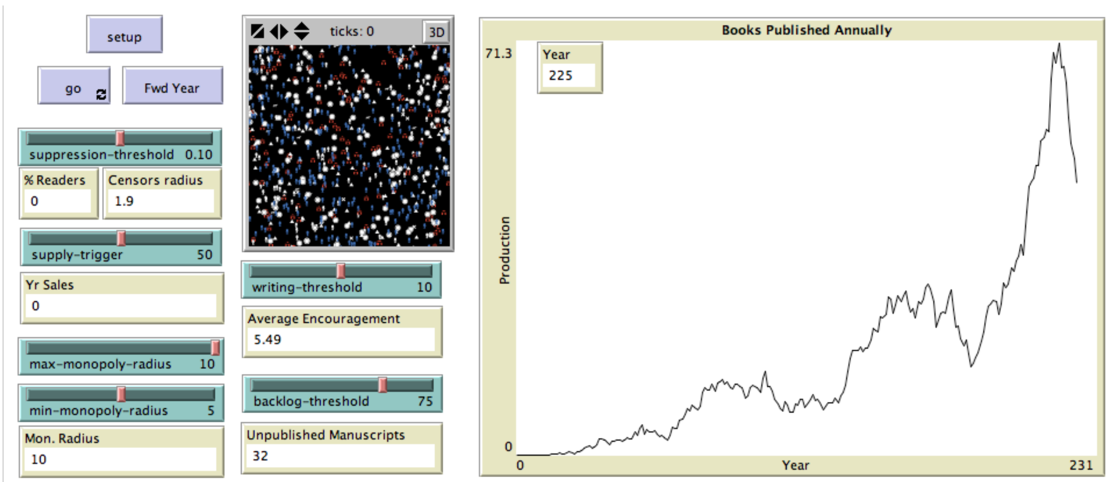

Figure 8. *Print Marketplace.* Model created and screen capture by Michael Gavin, March 2014.

Readers curious about the model itself are encouraged to download the file and play with its variables to see how its constraints and feedback loops modify agent behavior (http://modelingcommons.org/browse/one_model/4004). As with any new genre of writing, the best way to learn about it is to compare and contrast texts that tackle similar questions and problems. Readers are also encouraged to examine two other models of the historical book trade that I've created. "Bookshops" focuses closely on the finance of seventeenth- and eighteenth-century book-selling businesses to explore how changes in demand and costs might have affected publishers' decisions about price, republication, and edition size (http://modelingcommons.org/browse/one_model/4002). "The Paranoid Imaginarium of Roger L'Estrange" is more subjective and speculative: it attempts to create a working model of how seventeenth-century state censors imagined a print marketplace of scurrilous and seditious publication, where voraciously scandal-mongering readers threaten to disrupt the populace and therefore require strict policing to prevent social breakdown (http://modelingcommons.org/browse/one_model/4003). NetLogo models can also be used to address questions of literary form. For example, Graham Sack has created two models of interest: one that simulates the fictional social networks of nineteenth-century novels and another that adapts models of biological evolution to simulate the evolution of literary genres [Sack 2013]; [Sack 2013]. Surveying these examples, as well as models publicly available at http://modelingcommons.org or the sample library included with NetLogo, may provide scholars a glimpse of this nascent genre's potential as a tool of historical explanation. 35

Humanistic problems that could be tackled with agent-based modeling include (but are not limited to): 36

History of commerce. As the examples of book history above suggest, agent-based computation is well-suited to model production and distribution networks. Indeed, the most important commercial applications of ABM look at systems dynamics and logistics, and there's no reason why ABM couldn't be used to study historical systems. How did communication and transportation networks evolve? How did new technologies (telegraph, railroad) affect commerce, and at what points were those networks most vulnerable? What factors were most important to their development? 37

Political and military history. In the social sciences, ABM is often used to examine phenomena like voter affiliation. Applied to historical cases, it could be used to answer a wide range of questions. What caused the emergence of partisan politics in the eighteenth century? How did the consolidation of nation-states in the nineteenth century lay the conditions for the global wars of the twentieth? How did social movements form and deform? What conditions were needed for twentieth-century political advocacy to manifest as social change? 38

History of literature and philosophy. The material concerns of politics and commerce matter for literature as well. How did competition between publishers, theaters, film companies, authors, editors, unions, typesetters, and other stakeholders affect the production of books, plays, and movies? More abstractly, scholars might use ABM to model interpretive difficulties. Through what process do genres devolve into parody? What is "originality," when is it recognized, and under what conditions is it valued? What factors are the most important drivers of "paradigm shift"? How do ideas change over time? 39

In all of these cases, agent-based models will never be able to establish definitively what happened in the past. However, they could be used in each case to specify scholars' ideas about historical processes while subjecting those ideas to a challenging form of scrutiny. 40

In conclusion, three points are worth emphasizing. First, simulation does not and will never replace document-based research as the historian's primary activity. As hermeneutic tools, agent-based models work much like traditional diagrams: they articulate a cluster of general assumptions and make those assumptions available as a guide to interpretation.[28] However, second, simulation is an action-based medium that makes those assumptions more explicit and enables experiments to test their internal consistency. When agents don't behave how the designer expects them to, debugging, expanding, or otherwise modifying the model becomes a process of intellectual inquiry that subjects the designer's ideas to a frustrating but invigorating process of reformulation. Third, statistical comparison is an important tool for testing that consistency, but such comparisons don't suggest (pace complex-system theory) that simple processes are "all that is really happening." Instead, statistical confirmation and its breakdown identify moments of analogy between the model and the past, as well as (just as usefully) moments of dissimilarity between them. 41

This last point suggests that any historical simulation's success will not be determined by its verisimilitude. Any model that was sophisticated and complicated enough to represent faithfully the multitudinous totality of the past would be every bit as inscrutable as that past. Rather, models should be judged by their capacity to facilitate interpretation and explanation. In practical terms, this means that ABMs targeted toward an audience of historians will need to be thesis-driven and richly documented with primary and secondary sources, demonstrating both the model's macrolevel similarity with historical patterns and its value as a heuristic device for explaining particular events or interpreting historical texts. Ultimately, agent-based models don't need to tell us something new, but they should help us say something new. 42

Notes

[1] In the past thirty years, a number of academic journals devoted to modeling and complex systems have appeared. These include *The Journal of Complexity* (1985), *Complex Systems* (1987), *Complexity* (1995), *Advances in Complex Systems* (1997), and *The Journal of Artificial Societies and Social Simulation* (1998).

[2] For an overview of the intellectual scope of agent-based modeling, the best source is the *Journal of Artificial Societies and Social Simulation*. http://jasss.soc.surrey.ac.uk/index_by_issue.html.

[3] Two oft-compared platforms are NetLogo and RePast, now RePast Simphony. Of the two, NetLogo is more frequently recommended for new users because its programming language is very high-level and comparatively easy to learn [Robertson 2005];[Lytinen 2012]. NetLogo also has thorough documentation and benefits from being featured in Railsback's and Grimm's accessible textbook, *Agent- and Individual-based*

Modeling: A Practical Introduction (2012). However, some users argue that NetLogo's interface and high-level programming language hamper its versatility. Scholars comfortable programming with Java might prefer RePast or other less structured packages, especially for models that incorporate complex geospatial implementation [Robertson 2005].

[4] It is particularly useful in fields like biology and economics, which emphasize the effects of individual behaviors on collective patterns. For example, Craig Reynold's classic "boids" simulation, developed in the 1980s at the Santa Fe Institute, replicates complex flocking behavior in birds and fish with a very short code that executes only three simple procedures. Such simulations were an important part of the "artificial life" movement among computer scientists in the 1980s and 1990s, spear-headed by computer scientists Chris Langton, who believed that programs like these (or, like computer viruses) actually constituted a new kingdom of life certain to evolve and develop over the course of the 21st century. In Reynold's simulation, the "boids" are really simple, but they don't have to get too much more complicated before they meet all the criteria of a living organism, at least, according to the more theological and millennial strands of thinking within computer science [Waldrop 1993].

[5] My phrasing here is meant to suggest the definition of games offered by Jesse Schell: "A game is something you play. ... A toy is something you play *with*" [Schell 2008, 26].

[6] Williard McCarty has made a similar point about computer simulations: "Like game-playing, simulation tends to forgetfulness of the mechanism by which it is created so long as its terms of engagement (expressed in parameters and algorithms) are fixed. Unfix them ... and the simulation becomes a modeling exercise directed to exploring the question of that attitude. Thus simulation crosses over into modelling when the constants of the system become variables. Modelling, one might say, is a *self-conscious* simulation" [McCarty 2005, 35].

[7] The affect of "surprise" is important for a variety of computational methods. As Alan Liu has recently argued, one of topic modeling's most important intellectual ambitions is "to banish, or at least crucially delay, human ideation at the formative onset of interpretation" [Liu 2013, 414]. However, as he suggests, and as we'll see is the case with individual-based simulation, the relationship between human and technological ideation is not simply suppression or delay, but also a give-and-take that vacillates between the expectations and desires of the researcher and the affordances of the simulation software.

[8] Alan Liu summarizes McCarty's contribution to an account of modeling within humanities computing: "Models reveal meaning (recognized in patterns, trends, forms) only by reducing the dimensions and features of meaning. Diagrammatic models, especially the visualizations proliferating in the digital humanities...are comprehensible when their scope or detail is kept low but otherwise grow into beautifully mystifying galaxies of nodes and links." ("Meaning in the Digital Humanities," 412). McCarty's essays on modeling, cited throughout this essay, include chapter 1 of *Humanities Computing* (New York: Palgrave Macmillan, 2005), "Knowing...: Modelling in Literary Studies," in *The Blackwell Companion to Literary Studies* and "Beyond the Word: Modelling Literary Context." http://www.mccarty.org.uk/essays/McCarty,%20Beyond%20the%20word.pdf.

[9] For a theory of history broadly consummate with the view of modeling advanced here, see [Bunzl 1997]. Contra antirealist critiques of history writing that emphasize the inaccessibility of the past, Bunzl argues that causal arguments in history depend (in practice, if not in theory) on the historian's ability to identify and describe implicit models of causal forces that subtend historical explanation.

[10] Cited in [Griesemer 2004, 436]. In this essay, Griesemer argues, "Although recent philosophical literature on models as mediators of world-world or theory-phenomenon relationships has usefully complicated naive correspondence views of scientific knowledge...it has not really come to grips with the dual origins of philosophical talk about models, arising on the one hand from philosophies of language, truth, and logic (particularly model theory), and on the other from scientist's shop talk and use of models as guides for action" (435). One of my ambitions is to bridge this gap between epistemology and "shop talk" as agent-based models are deployed in the digital humanities.

[11] Morgan and Morrison describe models as mediating entities that both separate scientific theories from real phenomena while also providing a tool for understanding those theories in application. In this way, Morrison argues, models are epistemologically "autonomous." Describing the use of abstract models to represent the swinging of a pendulum, Morrison finds that models become objects of inquiry largely divorced from their real basis, but nonetheless valuable to real physical study: "We start with a background theory from which we can derive an idealised model that can then be corrected to provide an increasingly realistic representation (model) of a concrete physical phenomenon or system. The idealised structure/model (this may also occur with certain kinds of laws) can be corrected in a variety of ways depending on the level of accuracy we want. We know the ways the model departs from the real pendulum, hence we know the ways in which the model needs to be corrected; but the *ability* to make those corrections results from the richness of the background theoretical structure" [Morrison 1999, 51].

[12] Poovey and Brine write, "[T]he economist's data always exists at several degrees of remove from the world of actual market transactions. The numbers that prove useful for the economist's calculations, in other words, already embed a set of conventional assumptions, which are

simultaneously reinforced and effaced in technologies like present-value calculations and compound interest tables. When the economist scrubs such data to make it more amenable to the calculations he wants to make, he repeats a process of elaboration and obfuscation that is already implicit in them" [Poovey 2013, 73].

[13] One might ask if any form of representation could escape this condition, and indeed I mean for my discussion of modeling to be commensurate with John Locke's insight in his *Essay Concerning Human Understanding* (1690) that words represent ideas, not things.

[14] Morgan describes the intellectual payoff of Fisher's models: "In using the model, Fisher was able to (i) explore theoretical frameworks, demonstrate the workings of the theory, and conditions under which it holds, and create and explore new theoretical claims as an extension to the older ones; (ii) provide various conceptual indications for measurement purposes and add measurements to map the model onto the world; and (iii) use these measurements to learn something about how the quantitative theory applied to the world and how the world had been during the historical period." (*Learning from Models,* 368-69.)

[15] McCarty uses "model" in this sense when he refers to the "fundamental dependence of any computing system on an explicit, delimited conception of the world or 'model' of it" [McCarty 2005, 21]. See also Ronald N. Griere's *Science Without Laws*: "The fundamental concept in my particular understanding of scientific practice is that of a *model*. Models, for me, are the primary representational entities in science. Scientists, I claim, typically use models to represent aspects of the world. The class of scientific models includes physical scale models and diagrammatic representations, but the models of most interest are *theoretical* models. These are abstract objects, imaginary entities whose structure might or might not be *similar to* aspects of objects and processes in the real world" [Griere 1999, 5].

[16] For geneticists, laboratory mice are sometimes not sufficiently abstract. According to E. Jane Albert Hubbard, "Often studies can be more easily extended in mammalian systems once a genetic, molecular, or biochemical foothold has been gained using simpler model organisms. Therefore a model organism can be used to probe deeply into the function of genes, proteins, and complexes even though the model organism itself does not manifest any of the symptoms similar to human disease" [Hubbard 2007, 61].

[17] A full discussion of the relationship between model theory and literary theory is beyond the scope of this essay, but it's worth pointing out that Catherine Gallagher has advanced a theory of fictionality that parallels closely much current thinking about generative models in the sciences. She writes, "Certainly the novel provided imaginary instances, but it renounced reference to individual examples in the world. The fictionality defining the novel inhered in the *creation* of instances, rather than their mere selection, to illustrate a class of persons. Because a general referent was indicated through a particular, but explicitly nonreferential, fictional individual, the novel could be judged generally true even though all of its particulars are merely imaginary" [Gallagher 2007, 342].

[18] Arguably, one advantage of building simulations is that doing so highlights the artificiality of the simulation's underlying theory and may thus circumvent a lazy essentialism about models. As McCarty has argued, "Theoretical modeling, constrained only by language, is apt to slip from a consciously makeshift, heuristic approximation to a hypothesized reality" [McCarty 2008].

[19] Much like an agent-based simulation generates output that verifies the interpretive value of its underlying model, historical contextualization is tested by whether it generates original and credible claims about how actual people – that is to say, *simulated people*– might have interpreted a play like *Othello*.

[20] I do not mean to suggest here that validation of agent-based models is taken to be a straightforward process in the sciences. Indeed, as Kevin Korb, Nicholas Geard, and Alan Dorin have recently commented, "the theory of how to validate ABMs is vastly underdeveloped compared to its practice" [Korb 2013, 255]. Their Bayesian approach is very similar to the "hermeneutic figure-8" I describe. They write: "The Bayesian approach to philosophy of science explicitly recognizes the distinction between the current understanding of the behavior of a system (prior belief) and the data (likelihood), which provides us with a framework for integrating both qualitative and quantitative approaches to validation. In essence, our prior belief about the model is updated in light of experimental data gathered from our simulations" (256). Whether such an approach could ever achieve "validation" in the colloquial sense of "confirm to be true" remains unlikely. In fact, Joshua Epstein has exhibited considerable defensiveness on this point: "I am always amused when … people challenge me with the question, 'Can you validate your model?' The appropriate retort, of course, is, 'Can you validate yours?'" [Epstein 2008]. As one of the authors of the "Artificial Anasazi" project, which was built on decades of careful archeological and environmental research, his frustration is understandable. Their simulation of an early American Indian civilization showed how its population might rise and fall in relation to the area's changing water levels, and they were able to show that their artificial society closely replicated the archeological evidence [Dean 2000]. However, the problem they run into is that no amount of data-based confirmation can prove that the procedures written into the model accurately represent what actually happened at the local level. Agent-based simulations represent our ideas about causation, and, as we have known since David Hume, causation cannot be observed. Nothing about agent-based modeling will solve this dilemma. Nor should it be expected to, and this, perhaps, is Epstein's point. Critics of modeling betray considerable naiveté when they brandish the incommensurability of ideation and mind-independent reality as a criticism of any

particular genre. I share Epstein's frustration insofar as this naiveté manifests as a double standard: when written out in sequential prose or drawn in diagrams, models generally do not face the same kind of skepticism similar models receive when executed computationally, and there is no philosophical justification for this difference. In any case, like Epstein, I am wary of the term "validation" and prefer not to use it.

[21] This dare is stated even more provocatively in Fred Dretske's essay, "If You Can't Make One, You Don't Know How It Works" (1994).

[22] This description is slightly inaccurate. The reader does not necessarily take the book from the seller, nor does it necessarily give the book to itself. The NetLogo command "one-of," which appears in the third and eighth line of the code snippet cited above, means that the reader looks at the entire field of readers and sellers that happen to sit on the same patch. If more than one seller or reader exists in the same place, this procedure dictates that one of each will perform a transaction without specifying which turtles will do so. This ambiguity could be understood to mimic a social process like gift-giving or recommendation-making. It has the added advantage of making the code run more efficiently.

[23] Interestingly, one of the criticism's famously leveled at Darnton's model is that its focus on human agents weirdly effaces the actual existence of books. Thomas R. Adams and Nicholas Barker argue that "the weakness of Darnton's scheme is that it deals with people, rather than the book. It is concerned with the history of communication" [Adams and Barker 2006, 51]. Nowhere do books as such appear in Darnton's model, an effect, it seems, inadvertently replicated in Throne's simulation.

[24] In Darnton's words, "So the circuit runs full cycle. It transmits messages, transforming them en route, as they pass from thought to writing to printed characters and back to thought again" [Darnton 2006, 11].

[25] Throne concludes, "My exploration suggests that for the given population of authors and readers, movement of texts through the circuit appears to be more closely connected to the presence of printers and shippers than it is to the number of publishers or sellers in the environment."

[26] Dixon argues that "patterns can be justified as part of the process of inquiry in any type of research, but not by themselves as an ends; they are process not product." In the field of complex-systems theory, "repeated, physically-observable features are recognised as emergent and convergent principles that reveal underlying forces and processes."

[27] Dan Dixon calls this intellectual procedure of deciding among potential prior causes "abduction": "seeing patterns where there are patterns and creating the correct interpretation." "Analysis Tool or Research Methodology?" by John Bonnett has similarly identified abduction as the core explanatory mechanism of counterfactual history and agent-based simulation [Bonnett 2007]. See also Weingart and Düring. At this early stage in thinking about humanistic applications of ABM, I am less interested in pointing out differences than identifying areas of common ambition, but it's worth mentioning that I find the idea of "counterfactual history" to be a bit of a red herring. All history writing deploys models, and all causal explanations imply counterfactuals. The particular value of ABM is in the execution.

[28] Ted Underwood has recently made a similar argument: "The point of model-building is actually to address the reservations and nuances that humanists correctly want to interject whenever the concept of 'measurement' comes up. Many concepts can't be directly measured. In fact, many of our critical concepts are only provisional hypotheses about unseen categories that might (or might not) structure literary discourse. Before we can attempt to operationalize those categories, we need to make underlying assumptions explicit. That's precisely what a model allows us to do" [Underwood 2013]. Underwood here echoes the argument made by Epstein toward the scientific community: "Anyone who ventures a projection, or imagines how a social dynamic — an epidemic, war, or migration — would unfold is running some model. But typically, it is an implicit model in which the assumptions are hidden, their internal consistency is untested, their logical consequences are unknown, and their relation to data is unknown" [Epstein 2008].

Works Cited

Adams and Barker 2006 Adams, Thomas R. and Nicholar Barker. "A New Model for the Study of the Book," in *The Book History Reader, 2nd ed.*, ed. David Finkelstein and Alistair McCleery (New York: Routledge, 2006).

Barnard and McKenzie 2002 Barnard, John and D. F. McKenzie, eds. with the assistance of Maureen Bell. *The Cambridge History of the Book in Britain: vol. 4.* (Cambridge: Cambridge University Press, 2002).

Bogost 2007 Bogost, Ian. *Persuasive Games: The Expressive Power of Videogames* (MIT Press, 2007), vii.

Bonnett 2007 Bonnett, John. "Charting a New Aesthetics for History: 3D, Scenarios, and the Future of the Historian's Craft," *L'histoire Sociale / Social History* 40, 79 (May 2007): 169–208.

Bourdieu 1993 Bourdieu, Pierre. *The Field of Cultural Production: Essays on Art and Literature* (New York: Columbia University Press, 1993).

Brewer 2010 Brewer, John. “Microhistory and the Histories of Everyday Life,”*CAS eSeries* 5 (2010).

Bunzl 1997 Bunzl, Martin. *Real History: Reflections on Historical Practice* (London and New York: Routledge, 1997).

Carmichael 2013 Carmichael, Ted and Mirsad Hadzikadic. “Emergent Features in a General Food Web Simulation: Lotka-Volterra, Gause’s Law, and the Paradox of Enrichment,” *Advances in Complex Systems* (April 2013).

Colander 2011 Colander, David. “The MONIAC, Modeling, and Macroeconomics,”*Economia Politica* 28, 1 (2011): 63–82.

Creager 2011 Creager, Angela N. H., Elizabeth Lunbeck, and M. Norton Wise, eds. *Science Without Laws: Model Systems, Cases, Exemplary Narratives, Science and Cultural Theory* (Durham: Duke University Press, 2007).

Darnton 1984 . *The Great Cat Massacre and Other Episodes in French Cultural History* (New York: Vintage Books, 1984).

Darnton 2006 Darnton, Robert. “What is the History of Books?” in *The Book History Reader, 2nd ed.*, ed. David Finkelstein and Alistair McCleery (New York: Routledge, 2006).

Dean 2000 Dean, Jeffrey S., George J. Gumerman, Joshua M. Epstein, Robert L. Axtell, Alan C. Swedlund, Miles T. Parker, and Stephen McCarroll, “Understanding Anasazi Culture Through Agent-based Modeling.” In *Dynamics in Human and Primate Societies : Agent-Based Modeling of Social and Spatial Processes: Agent-Based Modeling of Social and Spatial Processes*, edited by Timothy A. Kohler and George J. Gumerman (Oxford: Oxford University Press, 2000), 179–206.

Dixon 2012 Dixon, Dan. “Analysis Tool or Research Methodology? Is There an Epistemology for Patterns?” in *Understanding Digital Humanities,* ed. David Berry (Basingstoke; New York: Palgrave Macmillan, 2012), 191-209.

Düring 2011 Düring, Marten. “The Potential of Agent-Based Modeling for Historical Research,” forthcoming in *Complex Adaptive Systems: Energy, Information and Intelligence: Papers from the 2011 AAAI Fall Symposium*.

Epstein 1996 Epstein, Joshua and Robert Axtell, *Growing Artificial Societies: Social Science from the Bottom Up* (Cambridge: MIT Press, 1996).

Epstein 2008 Epstein, Joshua. “Why Model?,” *Journal of Artificial Societies and Social Simulation* 11, 4 (October 2008), http://jasss.soc.surrey.ac.uk/11/4/12.html.

Gallagher 2007 Gallagher, Catherine. “The Rise of Fictionality,” in The Novel, ed. Franco Moretti, vol. 1, 2 vols. (Princeton: Princeton University Press, 2007).

Galloway 2006 Galloway, Alexander. *Gaming: Essays on Algorithmic Culture* (Minneapolis: University of Minnesota Press, 2006)

Griere 1999 Griere, Ronald N. *Science Without Laws* (Chicago: University of Chicago Press, 1999).

Griesemer 2004 Griesemer, James. “3-D Models in Philosophical Perspective,” in *Models: The Third Dimension of Science*, ed. Soraya de Chadarevian and Nick Hopwood (Stanford: Stanford University Press, 2004).

Harvey 1997 Harvey, Brian. *Computer Science Logo Style: Symbolic Computing*, 2nd ed. (MIT Press, 1997).

Hubbard 2007 Hubbard, E. Jane Albert. “Model Organisms as Powerful Tools for Biomedical Research,” in *Science Without Laws*, ed. Angela N. H. Creager, Elizabeth Lunbeck, and M. Norton Wise (Durham: Duke University Press, 2007).

Korb 2013 Korb, Kevin, Nicholas Geard, and Alan Dorin. “A Bayesian Approach to the Validation of Agent-Based Models,” in *Ontology, Epistemology, and Teleology for Modeling and Simulation*, ed. Andreas Tolk,(Berlin: Springer, 2013).

Liu 2013 Liu, Alan. “The Meaning of the Digital Humanities,” *PMLA* 128, 2 (2013).

Lytinen 2012 Lytinen, Steven L. and Steven F. Railsback. “The Evolution of Agent-based Simulation Platforms: A Review of NetLogo 5.0 and ReLogo,” *European Meetings on Cybernetics and Systems Research* (2012).

Manovich 2001 Manovich, Lev. *The Language of New Media* (Cambridge: MIT Press, 2001).

McCarty 2005 McCarty, Willard, *Humanities Computing* (Basingstoke; New York: Palgrave Macmillan, 2005).

McCarty 2008 “Knowing...: Modelling in Literary Studies,” in *A Companion to Digital Literary Studies*, ed. Susan Schreibman and Ray Siemens (Oxford: Blackwell, 2008). http://www.mccarty.org.uk/essays/McCarty,%20Beyond%20the%20word.pdf

Miller 2007 Miller, John H. and Scott E. Page, *Complex Adaptive Systems: An Introduction to Computational Models of Social Life* (Princeton: Princeton University Press, 2007).

Morgan 1999a Morgan, Mary S. “Learning from Models,” in *Models as Mediators: Perspectives on Natural and Social Sciences*, ed. Mary S. Morgan and Margaret Morrison (Cambridge: Cambridge University Press, 1999), 347–88.

Morgan 1999b Morgan, Mary S. and Margaret Morrison, eds., *Models as Mediators: Perspectives on Natural and Social Sciences, Ideas in Context* (Cambridge; New York: Cambridge University Press, 1999).

Morgan 2004 Morgan, Mary S. and Marcel Boumans, “Secrets Hidden by Two-Dimensionality: The Economy as a Hydraulic Machine,” in *Models: The Third Dimension of Science*, ed. Soraya de Chadarevian and Nick Hopwood (Stanford: Stanford University Press, 2004)

Morrison 1999 Morrison, Margaret. “Models as Autonomous Agents,” in *Models as Mediators: Perspectives on Natural and Social Sciences, Ideas in Context*, ed. Mary S. Morgan and Margaret Morrison (Cambridge; New York: Cambridge University Press, 1999).

Nikolai 2009 Nikolai, Cynthia and Madey, Gregory, “Tools of the Trade: A Survey of Various Agent Based Modeling Platforms,” *Journal of Artificial Societies and Social Simulation* 12, 2 (2009). http://jasss.soc.surrey.ac.uk/12/2/2.html

Poovey 2013 Poovey, Mary and Kevin R. Brine, “From Measuring Desire to Quantifying Expectations: A Late Nineteenth-Century Effort to Marry Economic Theory and Data,” in *“Raw Data” is an Oxymoron*, ed. Lisa Gitelman (MIT Press, 2013), 61–75.

Railsback 2012 Railsback, Steven F. and Volker Grimm, *Agent-based and Individual-based Modeling a Practical Introduction* (Princeton: Princeton University Press, 2012).

Ramsay 2003 Ramsay, Stephen. “Toward an Algorithmic Criticism,” *Literary and Linguistic Computing* 18, 2 (2003).

Robertson 2005 Robertson, Duncan, “Agent-Based Modeling Toolkits,” *Academy of Management Learning and Education*, 4, 4 (2005): 525-27

Sack 2011 Sack, Graham. “Simulating Plot: Towards a Generative Model of Narrative Structure,” in *Complex Adaptive Systems: Energy, Information and Intelligence: Papers from the 2011 AAAI Fall Symposium.*

Sack 2013 Sack, Graham. “Character Networks for Narrative Generation: Structural Balance Theory and the Emergence of Proto-Narratives.” *Proceedings of 2013 Workshop on Computational Models of Narrative (CMN 2013)*, ed. Mark A. Finlayson and Bernhard Fisseni and Benedikt Lowe and Jan Christoph Meister. August 4-6, 2013.

Schell 2008 Schell, Jesse. *The Art of Game Design: A Book of Lenses* (Taylor & Francis US, 2008).

Smith 1994 Smith, Nigel. *Literature and Revolution in England, 1640-1660* (New Haven: Yale University Press, 1994).

Suárez and Sancho 2011 Juan-Luis Suárez and Fernando Sancho, “A Virtual Laboratory for the Study of History and Cultural Dynamics,” *Journal of Artificial Societies and Social Simulation* 14, 4 (2011). http://jasss.soc.surrey.ac.uk/14/4/19.html

Throne 2011 Throne, Jeremy. “Modeling the Communications Circuit: An Agent-based Approach to Reading in ‘N-Dimensions’,” forthcoming in *Complex Adaptive Systems: Energy, Information and Intelligence: Papers from the 2011 AAAI Fall Symposium*.

Underwood 2013 Underwood, Ted. “Measurement and Modeling,” *The Stone and the Shell*. 20 December 2013. http://tedunderwood.com/2013/12/20/measurement-and-modeling

Waldrop 1993 Waldrop, Mitchell M. *Complexity: The Emerging Science at the Edge of Order and Chaos* (New York: Simon & Schuster, 1993)

Wardrip-Fruin 2009 Wardrip-Fruin, Noah. *Expressive Processing: Digital Fictions, Computer Games, and Software Studies* (MIT Press, 2009).

Weingart Weingart, Scott. “Abduction, Falsifiability, and Parsimony: When is ‘good enough’ good enough for simulating history?”” (unpublished draft)

Wilensky Wilensky, Uri. “What is NetLogo?” http://ccl.northwestern.edu/netlogo/docs/.

Winsberg 2010 Winsberg, Eric. *Science in the Age of Computer Simulation* Chicago: University of Chicago Press, 2010

de Chadarevian 2004 de Chadarevian, Soraya and Nick Hopwood, eds., *Models: The Third Dimension of Science*

(Stanford: Stanford University Press, 2004).