Abduction, Falsifiability, and Parsimony: When is 'good enough' good enough for simulating history?

Scholarly disciplines can be broken into three directional camps: what is, what was, and what will be. The focus of this article is whether and to what extent simulation can be used in all disciplines which attempt to describe the past in increasingly accurate terms.

Simulation[1] is the functional opposite of historiography[2]. Whereas historiography reconstructs the past from what we know about the present, simulation reconstructs the future from what we assume about the past. Historiography envisions many possible pasts, with the number of credible paths increasing as we reach further back and require more inferential leaps. Simulation mirrors this, with the spread of credible futures widening as time moves forward.

This is a study on the similarities between simulated and historiographic reconstruction, and how the former can inform the latter. I take a discipline-agnostic approach to this endeavor, concerned more about the philosophical limitations and implications of historiographic reconstructions than on whether it is applied to the study of human history, the creation of the universe, evolutionary biology, or language drift. That said, the following work is aimed primarily at scholars of human history, and so the examples will by and large be drawn from that pool.

A number of philosophical and methodological concepts necessarily come into play at the intersection of historiography and simulation. In brief, simulations are often considered proxies for historical experiments because the past itself cannot be recreated. Because simulations can be run in various ways and under various conditions, they are often invoked to distinguish between historically *contingent* and *inevitable*[3] events or processes. Simulations are also used to validate the *sufficiency* or falsify the *necessity* of a particular model. Models are generally developed via *abduction*[4] and chosen via aesthetic, parsimonious, or other para-empirical grounds. Model acceptance is underdetermined by the historical evidence, which itself is uncertain, and the close link between model creation and validation brings it closer as a way of knowing to the humanistic hermeneutic circle than to the tool of scientific certainty its creators often expect of it. This link

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[1] When I refer to models and simulations in this paper, I refer specifically to quantitative and generative models which simulate possible futures from a set of initial conditions and pre-set laws, either top-down via populations and differential equations or bottom-up via interacting agents. There are many other useful flavors of historical models; however they are beyond the scope of this paper.
[2] I follow the lead of Tucker (2009a, 2) in distinguishing between history and historiography, the first referring to past events and processes and the latter to the process of studying and writing about the former. Written accounts and the activities that attempt to reconstruct history are historiography. The scope of the terms both encompass any events of the past, documented or undocumented, social or physical.
[3] Historical contingency is often played against historical necessity. In order to avoid terminological confusion with "necessary and sufficient", I refer to the opposite of historical contingency as historical inevitability, a distinction which is not unprecedented (Inkpen and Turner 2012, 1).
[4] If *a* then *b*. We observe *b*, thus (possibly) *a*.

opens up the possibility of a false sense of confirmation through model *tweaking*, the act of allowing a model to converge on the historical evidence regardless of its relationship to the past. As only one instantiation of history is available as evidence, and controlled comparisons are generally infeasible, it is impossible to know directly whether some historical processes were statistical outliers of likely futures. Conversely, simulations provide a multitude of potential futures. This creates a divide wherein historiography becomes particularly well-suited to the study of causal *tokens* and simulation the study of causal *types*. [discuss nomothetic / ideographic]

While the disconnect between simulation and historiography raises many legitimate layers of methodological and philosophical concern, I argue that there are situations where the benefits outweigh the risks. Just as Winston Churchill famously called democracy “the worst form of government except all those other forms that have been tried from time to time” (1947), simulation is a particularly problematic way of looking at history, but in many cases it could still prove as good as or superior to other historiographic methods.

Simulations, in the form of generative models, have already been invoked in nearly all disciplines which study the past, including historiography (Newman 2006; Craenen et al. 2010), linguistics (Perreault and Mathew 2012; Bouckaert et al. 2012), archaeology (Rubio Campillo, Cela, and Hernàndez Cardona 2012; Bevan 2012; Graham 2007), cosmology (Wesson 1990), evolutionary biology (Arslan and Gaucher 2012), evolutionary psychology (Bowles 2006), econometrics (Marks 2007), informetrics (Bettencourt et al. 2006; Bettencourt et al. 2008; Bettencourt, Kaiser, and Kaur 2009), sociology (Epstein 2006; Epstein 1999; Axelrod and Tesfatsion 2006; Axelrod 1997), epidemiology (Balcan and Vespignani 2011), anthropology (Kuznar 2006), climatology (Grazer and Martin 2012), and paleontology (Schulte et al. 2010), and others.

At stake, then, is not a historian’s knowledge of the past, but rather the possibility of that knowledge in general. If simulations offer some insight into our past, the philosophical ground on which it stands must be clearly defined. This paper provides a sweeping overview of some details concerning epistemological footing of simulations, drawing from the many disciplines which utilize them and contributing specifically to the historian’s plight.

The following article is a synthesis. It begins by defining key vocabulary as it is used here, without any attempt to exhaustively cover the many other terms and definitions often invoked to the same purpose. Part II provides a first pass at why a historian might want to simulate something, along with a brief introduction of associated problems. Part III covers the philosophical and methodological considerations that would be beneficial to keep in mind before setting out to simulate the past. The conclusion, Part IV, raises the question of whether simulations have solid enough methodological grounding to be used in historiographic research, and offers some suggestions of when it might be appropriate. The article avoids technical details or breaking new ground, and instead acts as a map for traditional historians as their discipline begins exploring this new territory of models and simulations.

I. Models and Simulations

It is tricky getting into an in-depth discussion of terms which are used in so many different ways depending on the context. The definitions here attempt to be useful without being exhaustive; they necessarily exclude certain uses that are common, and include some which are not. Still, they provide a backbone with an aim at utility, and should be easily understood if not universally agreed upon.

A complex system is one in which pieces of the system interact to form the whole. Flocking birds, the United States, Earth's climate, and a human nervous system are all examples of complex systems. For the purpose of this article, a model is defined as an incomplete representation of a complex system. A representation can take many forms, such as: a set of assumptions about how a complex system works and what it is comprised of; physical building blocks that are arranged to look like whatever is being modeled; a mathematical formula that describes a set of interactions. Models are by definition incomplete because, if a model were a complete and perfect representation of a thing, it would no longer be a model, but the thing itself. Hence the old adage, "all models are wrong, but some are useful" (Box and Draper 1987).

A simulation is an instantiation of a model (Simpson 2006). It is an activity, performed by a person or a computer or something else entirely, which produces or enacts what a model explains. Taking a simple example, Newton's laws of motion and gravity present a model. If those laws are programmed into a computer game, feeding the computer information about the mass of the earth and the height of an apple tree, we can watch as a simulated apple falls to the simulated ground at 9.8 meters per second per second. What unfolds as the apple falls is a simulation. Physicists can then compare that simulation, that instantiation of their model of how they believe the universe works, to what they observe empirically in the apple orchard. If the simulation and their empirical results match up, they can get some reassurance that their model is accurate.

Models that easily lend themselves to simulated instantiations are generative models. Generative models usually, but not always, separate into two flavors: top-down and bottom-up. Top-down generative models begin with assumptions about how a system works on a large scale, and are often described by differential equations. A common example of this type of model is the SIR (Susceptible, Infectious, Recovered) model in epidemiology, where a population is placed in one of those three S-I-R compartments, and formulas determine the rate at which people move from one compartment to the next. Bottom-up models, on the other hand, usually begin at assumptions at the individual level, and are generally called agent-based models. A famous example is the Schelling segregation model (1971), which begins by assuming that people prefer a certain percentage of their neighbors to be the same race as them, and uses the simulation to reveal the segregational effects of that assumption.

Often, these models include stochastic elements; that is, the simulations may not necessarily turn out the same way when run a second or third or thousandth time. Models are generally encoded with the knowledge that small, seemingly-random events can have a strong causal influence on the evolution of a system. Most of the time, when a power line on the U.S. electrical grid fails, electricity is routed around it and little harm is done. Sometimes, however, if the situation is just right and enough power lines fail in just the right places, a single failure can propagate up the system and generate a massive power outage across a giant region of the country (Watts 2003). This is a rare occurrence, but it can and does happen. Similarly, one out of every few thousand simulations of an accurate enough model of the U.S. electrical grid should result in the same massive failure. It's rare, so a simulation would not result in massive failure every time it is run, but it's programmed to change the conditions slightly each time. Eventually, it too will reach the perfect conditions for failure, and that failure will manifest in a tiny fraction of the simulations.

Generative models generally require not only an understanding of how the system functions, but also in what state the system began. This state is called the initial conditions. Economists could have a perfect understanding of how people react to moving money in the modern world, but if their model begins by assuming that we have an unlimited supply of food and resources, then their simulation will look very little like the modern economy. If the universe is completely deterministic and a historian knew the *exact layout* of the universe in 1900 (the initial conditions), and all the rules that determine the interactions within it, she could accurately predict the present day. This extreme case is obviously absurd, but models of historical communities often assume similar shapes: given some knowledge of how a community was structured and the rules that determined its interactions, the resulting simulations should resemble the actual historical progression of that community.

Any historiographic narratives that are more than mere rote chronologies rely on models, whether implicit or explicit. Kuhn's *Structure of Scientific Revolutions* (1962) is an example of an explicit historical model often used to explain scientific histories by scientists themselves. The model is assumed as truth, or near-enough, and the history of a discipline is contextualized against that model, or explained using it. Other historiographic narratives run on implicit models of how historians believe people or communities or objects interact with one another. Generative models, often necessarily embodied in mathematical formulas or computer programs, can be less nuanced and complex than their conceptual counterparts. However, what they lack in nuance they often make up for in clarity; assumptions and definitions must be made explicit at the outset, for other practitioners to agree with or critique. What often remains unclear or ambiguous in generative models is how various parameters and variables map as proxies to the real world, and intuitive contortionism can sometimes lead to bad models being improperly fit to empirical evidence.

In short, a simulation is constructed from a model – a set of rules and initial conditions. If that model is historiographic (that is, it attempts to represent some part of the past), then the simulations it produces are historiographic reconstructions. Historiographic reconstructions (what historians generate for a living) generally begin at the present with surviving evidence and infer their way toward the past. Our certainty of the past decreases with the fidelity[5] and availability of historical evidence, and those generally decreases the further back we look. In other words, historians are generally less certain the further back they reach. Four millennia ago, many possible narratives are consistent with our little historical evidence.

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[5] "Fidelity measures the degree to which a unit of evidence preserves information about its cause. […] Oral transmission has a lower fidelity than written transmission, and […] memorized prose has a lower fidelity than memorized verse." (Tucker 2009b)

Simulations function in the opposite fashion. Historiographic models begin with the initial conditions of the past set in stone, rather than the modern evidence. The dynamical assumptions about how people and things interact can remain constant between a traditional historian's work and a simulated reconstruction, but the arrow of time is flipped.

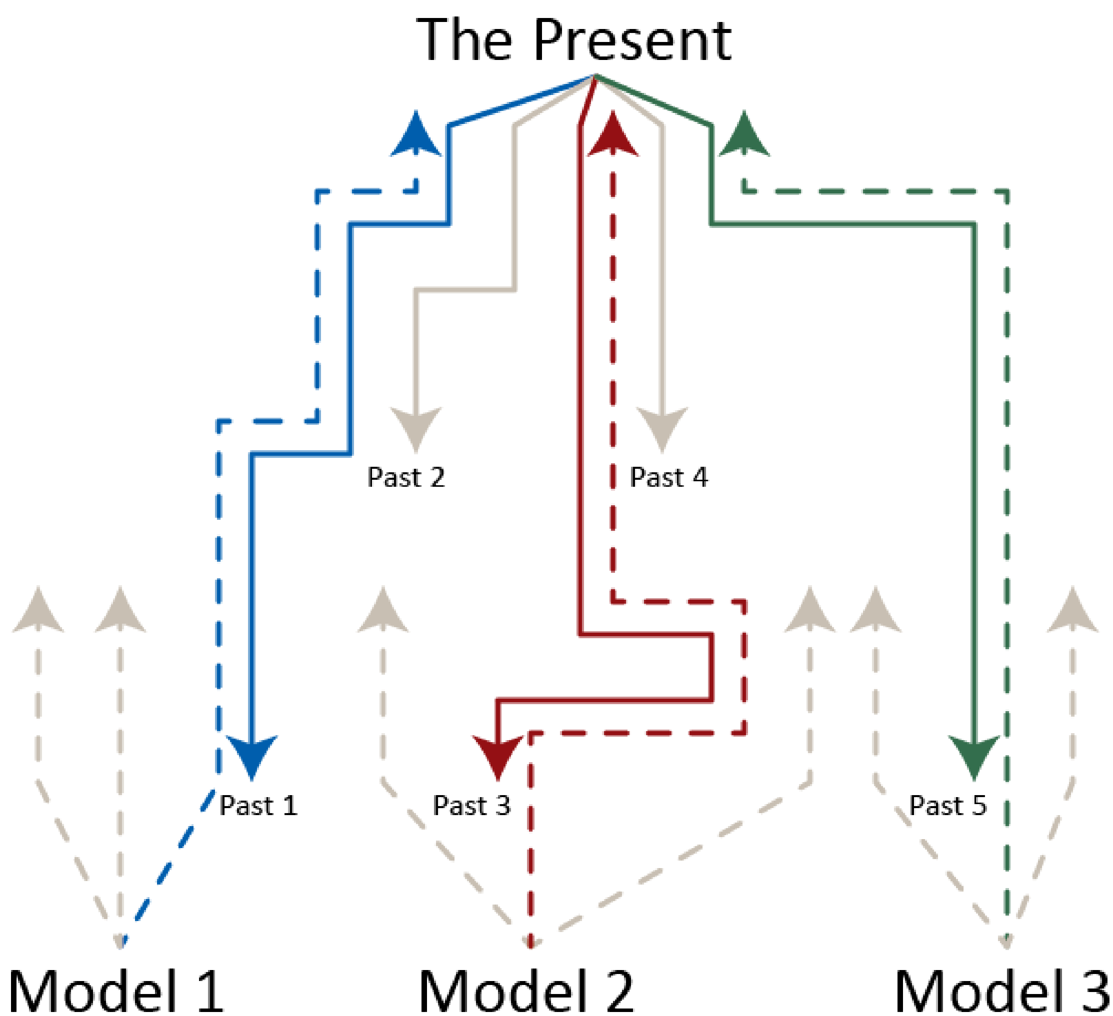

Figure 1. Synchronizing historiographic models with historiographic narratives.

Instead of the many possible pasts that a historian's work often allows, simulations grant many possible futures, often diverging wildly the further ahead they look. The question is whether simulation is a fruitful endeavor, if it's better at explaining or helping historians understand anything about the past than traditional back-facing historiographic methods. A host of concerns with this approach may already be apparent to the reader, which brings us to the title question: Is 'good enough' good enough? Are simulations still useful in spite of any difficulties which may arise?

II. Using Models

Historians and evolutionary biologists have a great deal in common, and their commonalities prove especially relevant with regard to simulations. Ancestral Sequence Reconstruction (ASR), or paleogenetics, attempts to infer gene sequences of extinct species by reconstructing them from modern evidence; that is, using the genes of modern species and what we know of their ancestry (Pauling and Zuckerkandl 1963; Zuckercandl and Pauling 1965; Thornton 2004; Gaucher, Kratzer, and Randall 2010). This allows biologists to fill in evolutionary phylogenetic trees via statistical techniques to infer the past from the present (often using likelihood or Bayesian statistics (Williams et al. 2006)), although the methods are not without their methodological (Nei 1996) or philosophical (Haber 2009) critiques. Armed with this knowledge, biologists can synthetically engineer proteins in the modern times that match those long-extinct (Stackhouse et al. 1990). Comparative linguistics and classical philology use methods similar in spirit to reconstruct the history of language, as biblical scholars and medieval manuscript scholars do to reconstruct the urtext.

Historians have similar constraints. A past event produces only so much evidence, and evidence tends towards decay or being overwritten. Events are sustained tenuously in the memories of witnesses; impressed upon the physical characteristics of objects in their proximity; documented in texts or manifested as their own physical entities. Some of this evidence survive to the present, along with innumerable potential confounders: forgeries and lies and bits of evidence that looks like it belongs in one place when it really belongs somewhere else. From present traces we reconstruct some of the many pasts which can accurately fit the available evidence, choosing whichever we find the most plausible as the proper narrative: the network of people and things that came together in just such a way to produce the texts and artefacts before us. Implicit in this process are models and selection criteria. Historians have ideas of how bits of evidence might fit together, what sorts of things cause other sorts of things, and what sorts of narratives are ultimately the most plausible. Parsimony is built in, suggesting we steer away from elaborate conspiracy theories when simple solutions might suffice.

Evolutionary biology, however, has another tool which historians rarely utilize. Experimental evolution allows biologists the ability to replay history in a lab, hitting the ‘fast forward’ button from the beginning rather than ‘rewinding’ from the end. Biologists have been working tirelessly on decades-long projects to observe evolution at work in the lab, setting populations in environments where they must compete for scarce resources and letting them do so for tens of thousands of generations (Blount, Borland, and Lenski 2008; Blount et al. 2012; Kawecki et al. 2012). This is, in a sense, a physically manifested simulation; begin with initial conditions, use the universe and the lab environment to set mechanisms and constraints, and let the model run. These physical experiments have a digital proxy; biologists are also working on computational models to watch evolution unfold in software experiments, using what they’ve inferred about the past and the mechanisms of evolution (Lenski et al. 2003; Lenski et al. 1999; Wilke et al. 2001).

The two directional strands of evolutionary biology are beginning to converge, the forward-facing with the backward-facing. Débarre and Gandon (2011) corroborate their selection model with experimental evidence, and even go so far as to suggest other experiments which may aid in future models. Arslan and Gaucher (2012) suggest paleo-experimental evolution, synthetically creating modern organisms from ancient genes and then experimentally evolving them in the lab over thousands of generations. This is a particularly powerful methodology, and one historians would do well to learn from, as it may allow biologists to tease apart historical contingencies from inevitable evolutionary mutations, given the constraints of a system. The ability to recreate the past and let events unfold in lab settings, where the environment can be tweaked at will, would allow historians to explore their theories in ways never before attempted.

If evolutionary biology experienced a shift from backward-looking (reconstructive) to forward-looking (simulative) science, certain areas of cosmology may soon experience the reverse. Traditional cosmology, which focuses on understanding the formation, evolution, and general structure of the universe, starts at the very beginning and works its way forward. Using *a priori* physical laws and a set of potential initial conditions, cosmologists' models rebuild the universe from the ground up (Berry 2009). In a recent paper, Hawking and Hertog (2006) suggest the opposite approach should be taken, beginning with the evidence available in the present and reconstructing potential universal histories given the constraints of the evidence. In some sense, the approach more closely resembles that taken by astronomers who track the history of small groups of or individual objects by the traces they leave. It also relates strongly to historical Bayesian inference as used in other disciplines mentioned above. This theory provides an odd sort of physical manifestation of the historian's dilemma of multiple possible histories; instead of having many pasts to choose from due to the underdetermination of available evidence, these cosmological pasts are on equal existential footing, each being in a state of superposition which reduce to the classical universe as we observe it (Bojowald 2006; Gibbons and Turok 2008). Working from the other end of past-to-present, some wish to computationally recreate the universe from the ground up. Artificial cosmogenesis (Vidal 2012) is one suggested track, where Vidal suggests universe simulations can reveal questions like "what would remain the same if the tape of the universe were replayed?" and "are complex universes rare or common in the space of possible universes?"

The examples of historiographic disciplines using the interplay between past-to-present and present-to-past methodologies are too many to list here, but their use should be illustrative. For those who wish to understand what came before, not only the events but the underlying processes, backward- and forward-reconstruction both prove useful. Surely, if these techniques help us understand the evolution of stars and languages and species, they ought also be useful in the human-centric domain of the historian.

Historiographic scholarship of all varieties faces a continuous interplay between the beginning and the end. The present did not appear fully formed and ready for battle like Athena from Zeus' forehead, but nor was the entirety of the present apparent in the energetic and tumultuous cosmic beginning; the interim of history matters from both ends, and either direction scholars face to explore that history can inform the other. This is not a new idea, even for historians. In 1789, Schiller wrote

> World-history therefore proceeds upon a principle which directly reverses the world-order itself. The real series of events descends from the origin of things to their most recent state, while the universal historian moves in the opposite way from the most recent state of the world up to the origin of things […] if he has in this way proceeded step by step up to the

> beginning […] he is then at liberty to return on the path he has made and, guided by the facts he has already marked out, to descend without obstruction or difficulty from the beginning of the record down to the most recent times. (Schiller 1972, 331)

If Schiller missed one element of his anticipation that we might move from now to then and from then to now, first reconstructing and then (at least conceptually) simulating, it is the cyclic nature of this process. This is the historian's hermeneutic circle and the methodologist's circular nightmare. We are unable to reconstruct the past without a theory of its evolutionary processes, and we are unable to theorize on those processes without an initial reconstruction. In the world of quantitative models, this involves the intertwining of premises and conclusions, of construction and validation, and though this process is not unfamiliar in any empirical science, it is rarely so clearly present as it is in the iterative historiographic process of reconstruction and simulation. And to humanists, this logical conundrum is honored.

For historians, past-facing reconstruction is still a far more popular practice than forward-facing simulation. There are a handful of counterfactual historians who look at history from the other side, but they are rarely taken as seriously as perhaps they ought to be (Tucker 1999; Weinryb 2009). With regards to actual quantitative and computational simulations, the ancient past is more-often addressed by historians than other time periods, perhaps because it is the area about which we know the least, and about which models are the least likely to be disconfirmed. Axtell et al. (2002) suggest that it is because archaeology is "the only social science that has access to data of sufficient duration to reveal long-term changes in patterned human behavior."

Thus-far, the parallels drawn between historians of human culture and other related disciplines have been in abstract. Criticisms of this approach often appear much closer to the concrete dilemmas of individual historians. Human culture, it is said, is far too complex for simple models to be useful or even applicable. The rules that determine the modern economy, for example, are so complex that after centuries of research, we cannot even predict whether next week the economy will rise or fall.

The concern is legitimate, but fails to take into account the heterogeneity of human systems. Some, like the economy, are exceptionally volatile and prone to change drastically from even the slightest changes. Many human systems, however, are a great deal more predictable (Castellano, Fortunato, and Loreto 2009): the way people form into networks, the way they communicate, and how communities grow, for example, all follow fairly predictable statistical patterns (Barabási 2005; Mesoudi, Whiten, and Laland 2006; Rybski et al. 2009). Acknowledgement that certain subsets of human activity are more predictable than others opens up the possibility of modeling and simulating many human dynamical systems. Further, and this should be particularly interesting as a new avenue for historians, these simulations can help us determine what sorts of human activities are predictable and what sorts are not; what sorts are highly susceptible to contingent events and which are, for all intents and purposes, inevitably leading in some direction.

III. Methodological and Philosophical Considerations

The goal in matching simulation to historiography is in matching one of the many forward-facing branches of the former to the backward-facing latter, as seen in Figure 1. When both strands align, perhaps, they have converged to say something about *history*. Both work together to extrapolate the causal and explanatory narrative, to make explicit the initial and final conditions and the various states in between, and in the end what comes out is a more full understanding of the past.

There are many pitfalls woven into this process, and promising avenues are not always immediately apparent. Before covering a list of concepts historians should be familiar with before undertaking generative modeling, this section briefly covers overarching themes of complexity theory as they pertain to historiography. Many of the themes mentioned in the overview are covered in more detail below.

A complex system has been defined in often creative and occasionally helpful ways. For the purposes here the concept is left intentionally vague, simply meaning a set of objects and interactions. The sum of history is a complex system as are its constituent parts, sub-divided in whatever way is functionally convenient to the subject at hand. It is systems all the way down and all the way back up, most interacting with other systems.

The evolution of a complex system is often difficult to predict and its history is just as difficult to untangle. Complexity softly emerges from a critical mass of interacting constituent parts, leading to results that are deeply unintuitive, though perhaps not as mystical as some claim (Peacocke 2006; Ellis 2006). An initially chaotic universe following the second law of thermodynamics should not by rights spontaneously order itself into the paper you're currently reading. The science of complex systems offers a solution to the existence of this document and its author without forfeiting the second law, and it is built around the idea of constraints.

The configuration of any system lends itself to certain stable or unstable states. Most dynamic states of a system are self-undermining; unstable states tend to continuously shift configurations, and the majority of possible configurations are generally unstable. A billiard ball in a salad bowl has a few stable configurations (the ball sitting at the bottom of the bowl) and a multitude of unstable ones. The precise configuration of the few stable states is influenced by the structure of the system itself; the existence of gravity, the shape of the bowl and the ball, and so forth. The constraints and properties of the system determine which types of states will be stable. As a system evolves through a series of self-undermining configurations, it will occasionally happen upon a stable state, and it shall persist in that state specifically because it is stable. Systems with more constituent parts, more boundaries, and more mechanisms defining their interactions also have more difficult-to-predict stable or persistent states, which tend to be stationary, self-repeating, or regular in some other fashion. This occasional and persistent ordering from chaos is emergence, a phenomenon scholars are only now beginning to grasp (Deacon 2006).

Societies are complex systems and, like their basic physical counterparts, have tendencies and boundaries that inform their evolution. Societies are bounded by the basic human condition; our century lifespans and year-long gestations prevent populations from growing above a certain rate. We are bound by the climate and the shape of the earth and the species we interact with (Mesoudi, Whiten, and Laland 2006; Berry 2009). Factors basic to our existence shape our lives in ways that only *seem* trivial because we have lived with them for so very long. As historiographers, evolutionary biologists, complex system theorists, and others flesh out the background factors that affect our lives, we will gain a more nuanced understanding of the interplay between societies and the historical forces that constrain them. In short, understanding people as part of a system can help explain some of their individual and collective actions.

Of course, boundary and systemic properties are nowhere near fully predictive. The initial rise of civilizations might correlate with proximity to water, latitude (due to soil conditions and tropical diseases), and other environmental conditions (Diamond 1999), but that is only half the story. Law-like historical patterns are often upset by seemingly random occurrences which drastically change the course of history. These contingent events, from an asteroid impact 65 million years ago to the shape of Cleopatra's nose (Pascal 1966; Bury 1930; Tucker 1999), prevent the inevitable flow of history from being easily determined. Contingent events are what determine why one particular civilization rises to power out of the many small communities which found themselves near the right latitudes and environmental resources. Dynamical and agent-based models, it turns out, are particularly well-suited to exploring the interplay between contingency and inevitability (Turchin 2011; Axelrod and Tesfatsion 2006).

While the rules of understanding history are far more relaxed than those of formal logic and causal reasoning, many analogs of their concepts still prove useful. The necessity and sufficiency causal relationship is deeply entwined in the relationship between historical contingency and inevitability. It has been claimed that the refinement of clear glass was a necessary precondition for the microscopic, telescopic, and chemical revolutions of the early modern Europe; the Eastern world lagged behind since it did not have the same preoccupation with glass. The existence of this precondition in the West but not the East was largely contingent, an accident of drinking habits, where the Chinese felt porcelain was better suited for their tea and hot liquor while the Europeans opted for fine glass for their wine (Martin and MacFarlane 2003; Rasmussen 2012). Similarly, fertile ground, access to bodies of water, and forgiving climates have been functionally *necessary*[6] for the growth of large civilizations (Diamond 1999). However, these necessary preconditions do not lead inexorably toward civilization, for they alone are *insufficient* to create civilizations.

If water is a necessary condition for civilization, then a civilization will not appear without the presence of water. At the same time, access to water is not a sufficient condition of civilization, because people need quite a bit more than water to thrive. Many paths can lead to the same end. When the available evidence is not great enough to pick between which path led to where we are today, we suffer from the problem of underdetermination. Given the available evidence, a multitude of competing historiographic narratives may be sufficient to explain the present. As will be shown below, models can help untangle necessity and sufficiency.

A models' strength in its relationship to necessity and sufficiency is also one of its weaknesses. Because model creation and validation is often abductive in form (Richiardi et al. 2005; David 2009;

[6] Functionally necessary is taken here to mean necessary for all historiographic purposes. The chance of some great civilization growing in an area near no water, with no access to agricultural lands, and in a completely inhospitable environment is not zero, but it is close enough that the necessity/sufficiency distinction is still useful for historians.

Halas 2011), any particular model that matches historical evidence can only be shown to be sufficient, not necessary, to explain the evidence (Epstein 1999). The process of model creation does not reveal the number of possible models which would also provide sufficiency conditions for the historical evidence, and neither does it show anything concerning the likelihood of that particular model over all other possible models. Thus, unless proven by some external model validation, a model cannot be used as evidence for likely scenarios because the historical evidence is underdetermined. Using frequent path convergence on historical evidence is a tempting criterion with which to test an agent-based model. Unfortunately much of history is contingent and anomalous, thus convergence is not indicative of an accurate historiographic model. History could very well be (and probably is (Wesson 1990; Berry 2009)) the outlying run of some much larger process wherein humans and societies simply tend not to form.

Difficulties also arise in the determination of appropriate boundary and environmental conditions. Those conditions are not static, as with the example of the billiard ball coming to rest in a salad bowl. Instead, as society is embedded in a complex interacting system, we continue to shape and shift our environment at the same time that we ourselves are changing. The result is a species not bound to the same conditions nor influenced by the same environmental factors. Instead of fertile land and water sources, civilizations now grow and thrive off of institutional support, economic conditions, and other features more relevant to modern society (Acemoglu and Robinson 2012). The environment and boundaries are shifting just as quickly as the societies within. Although many of these changes come from within – shifting cultural norms, improving technology, and so forth – external factors are every bit as prevalent, and even more difficult to predict. An asteroid hitting earth, plummeting the world in cold darkness (Schulte et al. 2010) and leading to the extinction of the dominant species, is the prime example of an unpredictable event which changes the environment in such a way that it causes the underlying systems to change with it. It was unpredictable because it came from a separate causal chain; if all a modeler had to work with was the initial conditions of the earth and the physical mechanisms which affected them, she would not be able to predict extra-systematic events like an asteroid impact. Such exogenous events irrevocably affect the evolution of a system.

Much of the previous discussion has danced around the well-trod concept of historical laws without approaching it too closely. The debate on the existence of laws of history is fairly old and not especially fruitful; however, part of the discussion above, on necessary conditions and historical inevitabilities, undeniably revives that debate. At one extreme, the notion that history contains no law-like regularities betrays the function of historiography, falling quickly into a relativism where no single fact is relevant to any other. At the other end, a completely lawful history is an utterly predictable one, with no place for free will or agency. Neither the solid existence nor the total non-existence of deterministic laws, however, is necessary for the hypothesis that systems tend towards stable states. Nor indeed does inevitability imply teleology; a tendency towards stability simply means that minor changes in the causal structure typically won't affect the outcome (Ben-Menahem 2011). When a system shifts enough, however, either gradually via slow social change or quickly via an asteroid, what once was stable may be so no longer, and small contingent factors could result in sweeping changes. History is a balance between regularities and irregularities, contingencies and inevitabilities, chaos and lawfulness.

If the concept of some separate and overarching law, dictating the actions below, seems implausible in the context of historiography, the same issues have been raised concerning the natural sciences (Van Fraassen 1993; Giere 1995). The notion of a natural law is slowly being reconceived in other terms, for example as dispositions, where properties of some object make it predisposed to act in a certain way (Mumford 2003). Historians who stress only the parts of history which are wholly unique and incommensurable risk failing to discern those historical regularities which certainly do exist, and are relevant both to understanding the past and preparing for our future (McCullagh 2009). Equally true, those who focus only on historical patterns will undoubtedly miss what situates historiography in the humanities: the fact that we are all of us human, and simple choices can lead to a world of difference.

Historical Evidence – Availability and Fidelity

[Multiple histories, selective transmission of facts, fidelity]

The past happened singly and unambiguously. Human experience of the past is multifaceted. There is a plenum of legitimate historiographies, angles at which history may be interpreted. No historiographic narrative may hope to capture history unfiltered; like with models, all we can aspire to achieve is utility or relevancy, rather than completeness. A perfect record of the experiences of every person throughout history would not converge on some Structured Whole, because the unique perspective of each historical actor would inevitably lead to conflict.

That said, if our aim is accurate reconstruction of the past, more evidence should help at least to dispel errors and peel-back ever more layers of history. Unfortunately, historical evidence may present itself in such a way that our reading of it becomes systematically biased. A systematic bias in the historiographic record would confound the process of model validation – determining whether or not the model is accurate – as the criteria for testing the model would be flawed. Many evidentiary difficulties leading to systematic bias can be placed in one of three categories: misleading, missing, or uncertain.

Misleading evidence, where the veracity of the individual source is called into question, is a well-known problem in historiography. A source may lie or misremember an event, leading to misleading evidence, and historians have learned to validate facts by looking for multiple sources and learning to trust certain types of accounts over others (multiple authored reports over memoirs, for example). The problem is well-known and will not be addressed further here.

Different historical The dilemmas of historical evidence can be

Necessity and Sufficiency

Contingency and Inevitability

Path Dependence

Internal / External Causal Links / Exogeny

Underdetermination

Tokens and Types

Fidelity

Abduction

Tweaking / Hermeneutic Circle / Overfitting

Model Validation

Falsification

[Duhem-Quine]

Parsimony and Other Criteria

Finding Constraint Space and Regularities

[Historical laws]

Counterfactual History

Connecting operationalizations (proxies) to the real world

IV. Why Model?

[Overview showing the situations when modeling provides good or 'best' way to study history; point out again examples of uses by historians; compare against implicit historiographic models.]

[The conclusion, Part IV, raises the question of whether simulations have solid enough methodological grounding to be used in historiographic research, and offers some suggestions of when it might be appropriate.]

For the historian, a computer simulation offers a laboratory with which to test their theories and assumptions, an avenue for experimentation that was previously unavailable (Dibble 2006; Graham 2012). It allows a much greater exploration of complex systems than a single historian could ever hope for via pen, paper, and thought. Playing with models is *suggestive*; by itself it may not provide evidence for some hypothesis, but it can and often does suggest new and fruitful avenues of inquiry (Grim 2008).

Every historiographic account is theory-laden, each including some aspects in lieu of others and each filled with assumptions. Traditional historiographic method is fairly explicit, though the underlying historiographic assumptions are often difficult to tease out of the narrative. Though models take on a slew of implicit methodological and theoretical assumptions, they are a variety of historiographic argument where assumptions of the past are made explicit. By formalizing these assumptions, they open themselves up for challenge, extension, and enhancement in ways narrative would be hard-pressed to provide (Meeks 2012).

The ills of abduction were made clear above. Far from a weakness, this aspect of modeling is a reinforcement of historiographic norms, as so much of the work of the historian (as well as the natural scientist) is already implicitly abductive. Abduction "depends on our hope, sooner or later, too guess at the conditions under which a given kind of phenomenon will present itself" (Peirce 1958). A historian looks at available evidence and then, using his training and experience, constructs a narrative that fits. After showing his narrative fits and explains more thoroughly than some other narrative, the historian hopes his explanation may be taken more seriously than others'. Modeling is no different; a model is developed to explain some process, and through the modeler's training and experience, she picks the model that explains the most and is the most credible over others.

The criterion for selecting a credible model does not stop when it fits the evidence. As has been explained, myriad models may fit the same evidence. Although it is extra-scientific, it has become standard that parsimony be a criterion on which models are judged. The simpler the model, the better. "Better" may or may not mean closer to reality, and yet simplicity has proven a useful heuristic in the history of science. [This fact about Copernicus is actually sort of wrong – must find a better example] One famous example comes from the Copernican cosmological model, which simplified the mathematics of planetary orbits by displacing the earth with the sun as the center around which other planets orbited. This new system could be considered a usurping explanation of scientific reality, or it could simply be "saving the phenomena," a more convenient (and simpler!) way to calculate orbits without making any additional claims to the actual nature of orbital mechanics. In the end, the simpler model became not only the preferred method of calculation but also the preferred explanation.

A similar example from physics appears a few centuries later with Einstein and relativity. This, however, was not about choosing which mathematics was simpler, but which theory was. The initial predictions and mathematics from Lorentz and Einstein were identical, though the former was based around a complex and *ad hoc* set of theories relating to physical contraction and the luminiferous aether, and the latter on a few simple postulates concerning the speed of light and the relativity of space and time (Miller 1981; Goldberg 1984). Though Einstein's theories were at the time less intuitive, they required a far less complex infrastructure of support. These ideas, like those of Copernicus, were eventually adopted by the scientific majority. [This fact about Copernicus is actually sort of wrong – must find a better example] The parsimonious solution became the accepted solution.

While simplicity and adoption by the majority may be poor criteria for truth (if that is indeed what is sought), and physics and astronomy a poor analogue for history, historians and natural scientists alike still in practice opt for the simpler solution. This is why the cross-section of historians and conspiracy theorists is rather small, even in those cases where the model behind a conspiracy theory is not immediately falsifiable. Generally, conspiracy theories suffer from being too complicated to be believable.

Modeling allows historians to formally represent their historiographic theories in such a way that their simplicity can be measured and their repercussions easily calculated. Far from a problem solely constrained to computer simulations, abductive reasoning is prevalent in all the sciences, and formal models allow us to better utilize and hone our criteria for choosing between and creating new narratives of the past. Models may not get us closer to the truth, but they add to our historiographic knowledge in the same epistemological fashion as traditional historiography, even though the methods are more formalized.

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