From Agents to Outcomes: Simulation in International Relations

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From Agents to Outcomes: Simulation in International Relations

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This article reviews the use of computational simulations that focus on emergence and complex adaptive systems to model international politics. Computer simulations offer the advantages of focusing on nonlinear interactive dynamics and enabling researchers to explore alternative specifications of a global system. However, current world politics simulations ignore the epistemological and ontological implications that simulation raises. This criticism of current simulations is explored alongside current theories and approaches to international relations in order to highlight inconsistencies in simulations' modeling of political behavior. The article concludes with suggestions for the future development of simulation as a research agenda in world politics.

KEY WORDS ♦ epistemology ♦ IR theory ♦ realism ♦ research design ♦ simulations

1. Introduction

The development of computer simulation as a research agenda in the social sciences has mirrored that of other prominent research agendas. The great debates about epistemology and the philosophy of science have accompanied the development of several predominant methodologies in the social sciences (see S. Smith, 1996). These methodologies, in turn, have spawned further disagreement about the potential for human understanding of the social world. From the earliest works of history and the study of society, advances in the natural sciences led to changes in the way that social scientists viewed the human world. The empiricist epistemology seeks to look at the actions of individuals or groups in order to discover regularities

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in actions (see S. Smith, 1996; Nicholson, 1983; Hollis 1977), often through statistical analysis. Rationalism has provided a logic for rational choice methodologies, which seek to deduce expected social behaviors and interactions through assumptions of rationality and preferences (see S. Smith, 1996; Riker, 1990; Green and Shapiro, 1994). Additionally, the pragmatic epistemology identified with Kuhn and Rorty, as well as post-positivist epistemologies known collectively as critical theory, call for a renewed interest in the discursive methodologies of cultural analysis, thick description, and others (see Kuhn, 1970; Rorty, 1979; Rosenau, 1992; S. Smith, 1996).

Developments in technology and formal mathematics have also affected the diversification of methodologies in the social sciences. With the advent of the electronic computer in the first half of the 20th century, empiricists found themselves able to analyze ever larger corpora of data in ever shorter amounts of time, which in turn has drawn attention from discursive analyses and rhetorical techniques in the social sciences towards positivist modes of inquiry. Applications of combinatorial logic and advances in applied mathematics have similarly led to formal solutions to classic economic problems through mathematics and logical deduction. In the study of comparative and international politics, key insights and further refinements of these methods of inquiry have subsequently led to more specific and applied formal models (see Walt, 1999).

With the publication of Axelrod's (1984) landmark bargaining simulation, the computational simulation of social processes became a widely recognized and potentially valuable research tool available to the social scientist.[1] Johnson suggests that simulation has promise of becoming the fourth methodology available to the social scientist, joining rhetorical logic, empirical analysis and formal or mathematical modeling. Johnson's (1999) review of the history and current application of computer simulations to political science provides an introduction to the use of complex systems and powerful simulation techniques as a methodology to explore politics, but remains largely agnostic regarding their ontological and epistemological entailments. It is on these aspects of simulation in international relations that this article concentrates. Accordingly, the purpose of this article is not to evaluate simulations vis-à-vis other research methodologies for exploring international processes.[2] The advantages and flaws of other paradigms are well known. Rather, this article contributes to the body of research on methodologies for exploring international relations in order to make researchers aware of some of the theoretical and methodological issues that simulation raises for international processes. The argument developed later is straightforward, but heretofore unique — the use of simulation as a methodology in the study of world politics is hampered by two distinct problems, namely its epistemological foundations and its ontological presuppositions. The seemingly ad hoc combination of rationalist, empiricist and scientific realist epistemologies hampers the ability of simulation in world politics to be a Lakatosian 'progressive' research program (Lakatos, 1970). Moreover, a curious neglect of the continually contested nature of the international system as embodied in the rich debates about International Relations theory is discouraging, given the importance of ontology for simulations of world politics. Such a criticism raises the important question of the robustness of findings from international relations simulations to alternative specifications. This argument should not be taken as a signal for researchers to abandon simulation in the study of world politics, but rather as a call for further research into the epistemology of simulation and for attention to ontological debates in the use of simulations in world politics.

2. The Development of Simulation in Political Science

Computer simulation of social processes — particularly international processes — has been influenced by philosophy and technology in the same way as the methodologies discussed above. The term 'simulation' in this article refers to the methodology of creating an artificial representation of a real world system in order to manipulate and explore the properties of that system. Early researchers noted that computer simulations could provide approximate solutions to intractable mathematical problems that are of interest to social scientists. In a classic early example, Klahr's (1966) study of the paradox of voting allows the computer, through running a relatively simple model of voting behavior, to derive approximate answers to the question of the probability of the existence of voting cycles given *m* voters and *n* issues that has no known mathematical solution. The simulation methodology has more recently been influenced by historically minded social science that seeks to avoid the conundrum of the counterfactual — If we posit that event A caused event B, how can we be sure that ~A would have entailed ~B (see Fearon, 1991; see also Brody, 1963; Taber and Timpone, 1996b: 6)? The researcher, being unable to rerun history identically except for the absence of event A, is left unable to confidently reject the possibility that ~A does not entail ~B. Thus, the actuality of social research in the face of immutable historical data results in awkward analytics and, often, rhetoric, arguing the impossibility of B in the case of ~A. By eliminating 'historical noise' (Cederman, 1996: 257) researchers may have found a powerful method to test the sorts of counterfactual claims that often plague the social sciences (i.e. 'if Gavrilo Princip had missed Archduke Franz Ferdinand in Sarajevo, the First World War would never have occurred') and focus on those that truly seem to have made a difference (i.e. 'if Saudi Arabia did not have extensive oil reserves, then the United States would not have liberated Kuwait').[3]

While the purported ability of computer simulations to replicate history and shed light on counterfactual experiments has been influential for the development of this research agenda, refinements in theoretical constructs that originated in the physical sciences have also been important. In particular, researchers have recognized that oftentimes they are unable to correctly model complex phenomena because of their focus on macro-level outcomes rather than micro-level processes. One theoretical result from this realization that has proven quite useful in the physical sciences has been the concept of 'self-organized criticality' (Bak and Chen, 1991). Scheinkman and Woodford offer a precise definition of self-organized criticality in the context of the physical sciences.

> Physicists have noted, in several contexts, the possibility of a 'critical state', in which independent microscopic fluctuations can propagate so as to give rise to instability on a macroscopic scale. This is a state in which chain reactions initiated by a local disturbance neither damp out over a short distance (the 'subcritical' case) nor propagate explosively so that the system cannot remain in that state (the 'supercritical case'), as in the controlled nuclear fission that allows a reactor to generate power without exploding. Often this has seemed to depend upon parameters being carefully 'tuned' to exactly their critical values. (1994: 417)

First used in the study of certain fluid dynamic systems, such as sand piles, self-organized criticality has been brought to the social sciences as well, first with economics (see Bak et al., 1993; Scheinkman and Woodford, 1994), and more recently in the field of International Relations (Cederman, 1997). Writ large, the conception of complexity on the social sciences has had a profound impact on the pursuit of social research.[4] By exploiting this revolution in the conceptualization of macro-processes, social scientists — most successfully in the field of economics — have been able to model dynamic systems with complex nonlinear relationships between local inputs and outputs, thus escaping the analysis of equilibria and moving towards a more intuitively satisfying understanding of these complex systems (Bak et al., 1993). It is therefore possible to identify three primary justifications for the use of computer simulation in the study of world politics — to solve problems with no known mathematical solutions, to enable the researcher to investigate counterfactuals, and to model complex systems in social life (compare Taber and Timpone, 1996b: 3–11; see also Timpone and Taber, 1998: 74).

Closely linked to the idea of self-organized criticality and complex systems is the broader idea of chaos and its potential applicability to processes in the social sciences. Defined by Richards as 'nonlinear, deterministic process[es] that . . . [do] not evolve towards a fixed point or a regular cycle' (Richards, 1992: 1049), chaotic systems have been proposed as the underlying mechanisms for arms races (Saperstein, 1984), as well as for determinants of presidential popularity and power in the international system (Richards, 1992). Recent scholarship has suggested that chaos is a defining characteristic of the international system, and some authors explicitly link the ever-changing system of alliances and balancing and the chaotic properties of fluid dynamics (Saperstein, 1984). The relationship between chaos theory and computer simulation is close. Fearon suggests that cellular automata — which are simple structures governed by deterministic or stochastic rules — can serve as analogies to many scientific processes. In particular, cellular automata allow the researcher to model cases where no structural equation can represent the processes that follow from these simple rules. Accordingly, with the adoption of intuitions from chaos theory and its application in the social sciences, cellular automata can show that seemingly random events are not random at all. It is the interactions of cellular automata that serve as the foundation of much work in the field of simulation of world politics.

Applications of social science simulation are found across social scientific disciplines. One of the best-known areas of social scientific inquiry that has frequently and increasingly employed simulation is the study of International Relations. Aside from the field of simulating 'war games', there have been a number of prominent studies over the years that have deal with international political behavior (Benson, 1961), arms races (Plous, 1987), international trade and economics, the global political system (most notably through the GLOBUS Model, see Bremer, 1985, 1987; see also Guetzkow and Valadez, 1981; Schrodt, 1988b), ethnic conflict (Sandole, 1999), escalation (Stoll, 1985; Hollist, 1978), and conquest and war (Cederman, 2003; Bennett and Alker, 1977; Bremer and Mihalka, 1977). Some of these involve an interaction between humans and computers or between groups of individuals (see e.g. Plous, 1987; Guetzkow et al., 1963), while others involve full computational simulations of world politics (see e.g. Cederman, 1997, 2003). Note that this study of computer simulation of world politics does not address work in the area of so-called 'AI in IR', which employs often complex models of individual and group decision-making to 'provide explanations on how individuals and organizations acquire, store, and process information to arrive at decisions on how to act in the international arena' (see Schrodt, 1988a: 82; see also Sylvan et al., 1990; Hudson, 1991; Taber, 1992). Rather, this article concentrates its discussion on simulation methodologies studying complex adaptive systems and emergence approaches to the study of international politics, although reference to models of foreign policy decision-making will be made where appropriate.

3. The Simulation Methodology

To ensure that readers unfamiliar with simulation techniques are able to follow the processes examined here, an illustration of the simulation paradigm will be instructive. An example of an aerodynamics simulation will be developed along with an idealized form of a computer simulation used in the simulation of international processes. Relevant terminology will be introduced and defined with respect to these two simulation examples.[5]

Consider a naïve engineer facing the task of explaining and utilizing the phenomenon of 'lift' in aerodynamics. She has a powerful supercomputer and an advanced laboratory, but she knows nothing about aerodynamics save for the stylized observation that at some speed, a body equipped with wings at a certain angle becomes airborne. How might this researcher explore this problem? She could build a scale model of a vehicle with wings, place it in a wind tunnel of her design, and experiment with different configurations of the wing, wind speed and shape of the vehicle until she observed the phenomenon in question. Having the intuition that perhaps the flow of air over the wing was responsible for this observed lift, she might then put colored particles into the air stream in the wind tunnel, and observe how they flowed over the body of the vehicle at different speeds and with different wing structures. Through repeated experimentation and chance, our engineer will gradually develop a fuller knowledge of aerodynamics, and thus become ever more equipped intuitively to design and describe the phenomenon of lift.

In this example, physical simulation is one option open to the researcher, and history shows that it is a powerful research tool for physicists and engineers studying such problems. Another option, however, is the creation of a computer simulation of this same research question. Due to the impossibility of recreating history in a laboratory, this option has proven attractive to social scientists. Our engineer, instead of building a wind tunnel, could program an *environment* in which all of the relevant aspects of the simulation will take place.[6] A social scientist similarly must create an environment, defined as the locus of interaction for all actors, in which the relevant phenomenon will take place. The environment that our engineer simulates for her exploration of the aerodynamics of lift would closely resemble the wind tunnel — simply a large space in which objects interact. A student of International Relations creating a computer simulation will similarly need to decide how to structure the environment for her simulation, positing a topology and boundaries for the environment that will constrain how actors will behave. Imagine an investigation of war between states. The environment would correspond to a simulated international system, commonly operationalized as a plane upon which states can occupy fixed points within two dimensions. The design of the environment appears comparatively trivial in these cases, but environmental specification will become increasingly important below.

After programming the environment in which the simulation takes place, the engineer will then need to stipulate the relevant *agents* in the system.[7] For her purposes, the engineer knows that there are two types of agents in her simulation — air particles and a winged vehicle. While the term 'agent' here may sound misleading, it simply refers to any entity in the simulation to which behavioral attributes are ascribed. Just as she can be confident that she need not place extraneous inputs (birds, chairs, etc.) in her wind tunnel in order to explore lift, so can she be certain that she need not stipulate them as agents in her simulation. The social scientist using simulation to explore international processes will likewise need to stipulate and program the relevant agents that interact in her simulated environment. Following the example of a simulation of war between states, agents are often squares, exhaustively inhabiting the environment.[8] After stipulating the agents for her simulation, our engineer must now use her knowledge of physics to input the *rules* that govern the simulation, and the *parameters* of these rules. These will include such characteristics as how molecules of air will interact with one another (i.e. they cannot occupy the same space, they are moving at a certain speed through the environment, they exert force on all objects, etc.) and the weight and shape of the structure (i.e. how much force it will take to change its location). The social scientist, like the engineer, will stipulate the rules and parameters that govern the agents in her simulation of some international phenomenon as well. Perhaps the agents in the war simulation 'select' a neighboring agent based on the ratio of resources between the two, 'attack' it, and 'win' with a probability parameter of 0.5. If an agent wins, it 'conquers' the square; if it 'loses', its neighbor conquers it. The process then repeats itself with the newly created agents obeying these same rules in the next time period.

Both scientists are now prepared to begin their simulations, which explore the way that the agents in the environments behave over *time*. At time $t = 0$, the simulated system will appear just as the scientist programmed it, but as t increases the rules and parameters specified may lead to changes in the system. Moreover, different changes will occur with different specifications of the rules and parameters. Our engineer will find that if the speed of the air particles is low and the weight of the structure is high, then they do not exert enough force to change the orientation of the winged structure; that is, lift does not occur. Holding the weight and shape of the structure constant, however, she may find that as she increases the value of the parameter corresponding to the speed of the air particles, the *emergent* property of lift arises. Emergent properties are those phenomena that appear at an aggregate level, based not on specific micro-level interactions of agents but rather on the complex and often unpredicted effects of many such interactions (see Cederman, 1997: 50–1; Lane, 1992). Note that lift is not ‘programmed into’ the simulation; lift is an emergent property of the complex interactions over time of agents in an environment where the parameters of the rules are set at certain values.

A simulation of international processes will proceed similarly. In a simulation of war, rules that the researcher proposes determine why countries attack one another, the behavior that a state exhibits once attacked, and the consequences of conquest. In an attempt to explore the dynamics of a historical process, the social scientist may stipulate certain parameter values and run the simulation from $t = 0$ to $t = n$ to view how nonlinear processes of agent interactions evolve over time, and to witness the emergence of undefined macro-level phenomena. She may then rerun the simulation with the same parameters a number of times in order to assess whether outcomes given certain parameter values are path dependent, discovering whether emergent properties always emerge. Turning to the question of counterfactuals, she may then either add or delete a rule or change one or more parameter values in the simulation in order to assess how specific values of the parameters — or the complete absence of a rule — affects the outcomes and emergent properties observed. She might find that if states always attack one another when the ratio of their capabilities to those of their opponents exceeds 0.5, one pattern emerges. However, the probability of attack varies proportionally to the ratio of capabilities of opponents, another pattern emerges. Similarly, wars may result in conquest of an opponent’s entire territory, or they may result in the conquest of a portion of that territory. War may destroy a fraction f of a territory’s resource endowments, from none of it ($f = 0$) to all of it ($f = 1$), or some value in between ($0 < f < 1$). She also might find that for some values, no patterns emerge — the system is path dependent and never replicates itself.

These two examples that expound on the use of simulation as a research technique show how simulation can be a powerful tool for scientists across disciplines. These examples also highlight the phenomenon of *emergence*, one of the most important insights that have been gained through modeling micro-interactions for the purpose of assessing macro-outcomes. What the reader should notice is how much knowledge the scientist constructing the simulation requires. Simulation forces the researcher to examine deeply the assumptions that she makes about the environment, the agents, the rules and the parameters. It is apparent that our naïve engineer could not have correctly simulated her system for investigating aerodynamics without a comprehensive knowledge of molecular physics and fluid dynamics. The naïve researcher is not naïve at all; she must build on a wealth of earlier knowledge in order to create the correct environment, identify relevant (and irrelevant) agents, and specify the correct rules and parameters. Our extensive knowledge of the physical sciences gives us confidence about how molecules of air will interact with objects in their surroundings. We can also be content with our engineer's decision to include only molecules of air and the winged structure as agents in the simulation, for these are the only agents needed to explore lift. Concerning the environment specified by the simulation, we feel certain that the researcher will design her environment to be large enough to contain the object and a sufficient quantity of molecules of air, and that the nature of the borders of the environment is inconsequential for the simulated experiment.

As a final note, a branch of simulation modeling of social phenomena described below adopts the so-called *complex adaptive systems* (CAS) approach (Cederman, 1997). CAS models are distinguishable from other types of simulations in that the agents 'learn' from their environment or from the actions of other agents. Nevertheless, in either conventional agent-based simulations that focus on emergence or more advanced CAS simulations, incorrect specification of any one of the four main aspects of a simulation — the environment, the agents, the rules and parameters, and time — will lead to error. Fortunately for the engineer who might want to simulate the motion of a winged structure through the air, we can minimize the risk of misspecification through our knowledge of the physical properties of our world. Unfortunately for the social scientist, this firm knowledge of our social world is largely absent. The implications of this are striking, and the following section explores them.

4. Simulation as a Research Agenda in the Study of World Politics

Although the fundamental concepts and methods of social science simulation are straightforward in theory — albeit often intricate in implementation — the true significance of simulation for the social scientist is often more difficult to observe. In order fully to grasp the implications of adopting the simulation methodology for the continued development of our understanding of international relations, a review of the simulation methodology will not suffice. As with any other research tradition in the sciences, simulation is based on epistemological traditions that license its methodology and legitimate its results through arguments based ultimately on philosophical principles. Moreover, both the methodology and epistemology of simulation rely on thick ontological presuppositions of what agents are relevant, how the environment appears to the agents, and how processes and parameters shape complex systems. In most studies of international relations and general social phenomena that employ simulation, unfortunately, these epistemological issues and ontological presumptions are obscured by the methodology (see e.g. the discussion in Taber and Timpone, 1996b: 2–3).

Simulation as Epistemology

The epistemology that underlies the simulation methodology outlined earlier does not neatly fit with the classifications offered by Steve Smith in his survey of epistemological debates that are of interest to scholars of International Relations (see S. Smith, 1996). Rather, the epistemological foundations of simulation emerge as a selective combination, of sorts, of different epistemological traditions that themselves lead to often conflicting conclusions. Combining insights from scientific realism, empiricism and rationalism, the epistemology of simulation is underspecified and incomplete.

Before proceeding, however, a few words regarding the nature of this critique are in order. It should be stressed that this is not a critique of the use of computational techniques or mathematical modeling *per se* for the study of politics. Representing political interactions on a computer is no more different from a verbal model of political interactions than maximizing a log-likelihood function through a statistical package is different from solving the problem by hand. Conceptually, all that the use of computational techniques contributes is an increase in the speed with which the researcher can reach his or her conclusions, and (ideally) the elimination of the risk of human error. The epistemological critique of simulation advanced here focuses on what the simulation enterprise *in abstract* attempts to do — to create a model of a world too complex for ready analysis in order to make predictions or test hypotheses regarding that world (see Dawson, 1962). If instead of using computers the research described here employed an army of graduate students painstakingly performing calculations by hand, the same critiques would apply.

The epistemology underlying the simulation methodology reflects a variety of influences. With scientific realism (Bhaskar, 1979), it shares an epistemological stance that one of the objectives of scientific inquiry must be to investigate structures that 'exist independently of our perception of them' (see S. Smith, 1996: 26; Wendt, 1999; see also Chernoff, 2002, for a discussion of scientific realism as a 'meta-theory' of International Relations). As Outhwaite contests, 'the realist conception of explanation involves the postulation of explanatory mechanisms and the attempt to demonstrate their existence' (1987: 46). Realist social science presumes the existence of 'actual' structures in the world that may not fall into the realm of the 'empirical', or observable, experiences. That it may not be possible to observe the structures in social phenomena does not preclude their existence; indeed, the organizing principles of chaos and nonlinearity are the scientist's proxies for that which she cannot intricately explain. Taken with the caveat shared by realists and pragmatists alike that unbiased knowledge of the world is unachievable due to the inherently theory-laden nature of observation and inference (Rorty, 1979: 373–9), scientific realism leads to a cautiously optimistic epistemological view of knowledge accumulation in the social sciences. The simulator, like any other scientist, is hampered by her inability to gather unambiguously perfect data or to separate theory from observation. Nonetheless, the scientist begins with imperfect data and inquires into the structural principles — or lack thereof — that organize her observations. If the enterprise of simulation leads to satisfactory results, this by no means verifies that the theories of emergence and complexity are correct, but lends strong credibility to their results in the absence of disconfirmation (see Popper, 1959). However, the de-emphasis of empirical verification inherent in scientific realism is often ignored in complex system simulation. In the quest for more data to compare to the theoretical predictions that simulation is meant to test, simulators create their own. The latent empiricism of many historical studies (King et al., 1994) — where the researcher collects data and then fits theory around these data — is thus evident in the enterprise of simulation as well.

The empiricist epistemology provides a foundation as well for statistical methodologies, where mathematical techniques are adopted to explore reliability and confidence of inferences gathered from incomplete samples of populations. As mentioned earlier, simulation is one attempt to reconcile our poverty of historical knowledge and the impossibility of counterfactual experimentation with the desire to explore data for the purposes of induction. To claim that the 'data' gleaned from a simulation are equivalent to data collected from human experience, however, is highly problematic.[9] The data collected from a simulation necessarily reflect the theory that the simulation is designed to test, and cannot then serve to test the 'empirical validity' of the theory itself. Empiricism and related positivist stances on the social sciences claim that only observable data can serve as the foundations for theory-building. To adopt an empiricist methodology of statistical inference in an environment where the empiricist epistemology itself would disallow the data is inconsistent, and will lead to spurious conclusions.

The rationalist practice of theoretical deduction rather than empirical induction is further apparent in simulation. While the link between simulation and rationalist epistemology may seem tenuous at first inspection, the two share deep commonalities. The rationalist epistemology emphasizes the necessity of reason and deductive inference, often using formal logic and mathematics, in the development of theory (see Hollis, 1977; Outhwaite, 1987: 36–8; S. Smith, 1996: 21–2). At some level, the rationalist epistemology shares the critique of empiricism made by scientific realists, that observations are not trustworthy sources of truth. Outhwaite sees the difference between rationalism and realism in their acceptance of truth — rationalists assert to uncover truth through deduction, while scientific realists argue for the impossibility of success in such an endeavor (Outhwaite, 1987: 38). The rationalist influence on simulation emerges from the idea of reproducing game theoretic outcomes in a more 'realistic', dynamic environment of interacting agents. Binmore has even argued in response to Axelrod that game theory — one derivative of rationalist epistemology — and simulation are essentially the same enterprise (1998, citing Axelrod, 1997b). While game theory may have the ability to reach many of these same results, simulations allow for more complex, repeated interactions between multiple agents that explicitly model aspects of social interactions that are often too complicated for equilibrium analysis (Marney and Tarbert, 2000). Of course, the most typical, and the most obvious, critique of this rationalist epistemology — a critique equally applicable to the rationalist strain of the epistemology of simulation — is that rationalist deduction requires a full understanding of the knowledge of the agents in a social interaction. Without such awareness, rationalists are left to assumptions and inductions, which contradict the stated deductive purpose of rationalism.

For the researcher defending her use of simulation as a technique for the exploration of international phenomena, the debate over epistemological foundations may be uninteresting. Nevertheless, uncovering the fact that simulation is predicated on an amalgamation of scientific traditions points to the lack of consensus among researchers employing simulation about the correct future of their field. Although Axelrod and Troitzsch comment on some of the tensions between analysis and prediction in their introductory chapters to a volume entitled *Simulating Social Phenomena*, they fail fully to explore the inner tensions among competing epistemological influences (Axelrod, 1997a; Troitzsch, 1997). To claim, as both authors do, that simulation can embrace both deductive and inductive lines of inquiry, simultaneously adopting scientific realist insights, is to neglect the serious questions that such views raise with regard to one another. When should the scientist abandon the model because the data do not match the real world? When does the focus on abstract structure surpass the need for concrete conclusions? These problems of how the researcher should approach the social sciences are endemic to all methodologies, but many find a common home in the field of simulation.

Simulation and Ontology

The question of the epistemological commitments made by theorists of the social sciences, though compelling for the present study of the simulation of world politics, is ultimately a secondary concern. Researchers who adopt simulation as a methodology and accept its epistemological foundations face even greater problems when their ontological presuppositions are examined more fully. Simulation, as it is currently practiced, takes structures — agents and environments — and often relations — embodied in rules and parameters — to be ontologically prior to the emergent properties of the system under investigation. In the earlier example of the simulation of lift in aerodynamics, such claims about the nature of agents and environments and the parameters that govern their interactions is valid because of the overwhelming evidence of their existence in nature. In the case of simulation in the social sciences, an extension of the simulation metaphor to the level of the international system is questionable. Taber and Timpone's discussion of the benefits of simulation in the social sciences falls prey to this very problem; they recognize the need for 'focused realism' in the study of International Relations, but neglect to query just what the implications of this are for simulation (1996a). In order for simulation to be a valid technique for the study of phenomena in the international system, the researcher must assume that the agents, environments, rules and parameters that she stipulates are warranted by substantive theory. In that there is little consensus about the nature of the international system, simulation may not be an acceptable research tool for this enterprise. For this reason, simulations have certainly produced provocative results, but the contributions to the extant literature on International Relations remain rather marginal. This point may seem to 'set the bar' prohibitively high for simulation, but the nature of simulation necessitates caution. Recalling the importance of nonlinear processes, chaos and emergence to world politics simulations, researchers should be wary of the obfuscation of critical dynamics that can arise with the simultaneous processing of vast amounts of simulated data.

The existence and identity of the relevant agents in the international system is an initial point of contention. The realist tradition in International Relations contends that it is possible to develop a theory of International Relations based on the constraints facing states in the international arena, independent of domestic or individual analyses. The agents that interact in international phenomena, according to this 'third image' argument, are states; some theorists contend that states are the only agents relevant for the prediction of outcomes in international politics (Morgenthau, 1978; Waltz, 1979, 2001). It is worth noting that a number of other theoretical works on International Relations that diverge considerably from the conclusions of the realist school, including some of those commonly labeled as liberal institutionalist (see Keohane, 1984) and constructivist (Wendt, 1999), make more or less similar assumptions about the ontology of states as agents in international relations. Inasmuch as this assumption correctly reflects the true nature of the relevant agents in international relations, then simulations of international processes such as those by Bremer and Mihalka (1977), Plous (1987), Cusack and Stoll (1999) and Cederman (1997, 2003) do not encounter problems.

A powerful critique of this assumption, however, has long been made from theorists outside of the realist school. Some emphasize the importance of economic interest groups or transnational social movements (Milner, 1988; Frieden, 1991), arguing that these groups are agents other than states that significantly affect the international system. Others reject the contention that states are unitary actors, decomposing the state into a government and a domestic constituency that interact, often strategically, to produce outcomes (see e.g. Putnam, 1988; Marra et al., 1990; Gourevitch, 1996; A. Smith, 1996; Kaufman and Pape, 1999). Still others examine International Relations from a psychological or sociological standpoint, delving into effects of bureaucratic politics or individual decision-makers on international relations (see e.g. Allison, 1971; Boettcher, 1995; Guttieri et al., 1995; Levy, 1997). What these studies share is resistance to the idea of conflating the notion of the state as the highest level of political organization with the idea of the state as a unitary agent that interacts in world politics.[10] The relevant agents in a simulation of any international phenomenon, following the theoretical alternatives outlined here, therefore include not only states, but also individuals, ethnic groups, corporations and interest groups interacting with one another and with states. This is more than a trivial call to include more agents (or ‘sub-agents’) in grids such as that discussed above, as many IR scholars argue that including sub-national actors does not simply lead to a more complicated realism, but a substantively different set of causal factors in International Relations. Simulations of international phenomena have currently only included states as agents; theory thus pervades the model, and emergence and simulated data are correspondingly tied to theory (Jacobsen and Bronson, 1997). It is no wonder that non-realist International Relations scholarship has yet to seriously question the robustness of results of simulation research, for practitioners of such scholarship may find the research incomplete.

On an even more general level, the simulation of international systems stipulates an environment that does not map onto the real world. Computational modeling of international relations primarily presents agents in an environment of a two-dimensional bordered plane, as in Zambelli’s model of international trade (1997). This is the two-dimensional grid alluded to earlier. Clearly, such representations do not match the actual environment in which agents in world politics interact, as the world does not have edges and social space is not a plane. Researchers who employ simulation to explore international phenomena are curiously silent about this issue, apparently out of the supposition that the topology of the environment will have no effect on emergent phenomena. This, however, is a theoretical assumption that remains untested, and the robustness of results obtained from such models remains indeterminate.[11]

Beyond the initial presumptions about the existence and ontology of relevant agents in a simulated environment, simulations of international processes require strong assumptions about the nature of the behavioral parameters that the researcher must initially stipulate. In the case of simulations of conflict, researchers often assume that with some probability, an agent 'attacks' a neighbor, and if it prevails, it then 'conquers' that neighbor (Bremer and Mihalka, 1977) or part of that neighbor (Cederman, 2003). In more complex simulations, such as Bennett and Alker's (1977) model of the War of the Pacific that also explores interdependence and alliance formation, agents are given parameters that are meant to capture such notions as dependence, power and international status. Further assumed in many studies is a strict locality of interactions — agents in models such as that proposed above interact with neighboring agents, and not with other agents that are located elsewhere in the environment. Cederman (2003) goes as far as to comment critically on this assumption — noting that conflict researchers argue convincingly that wars with an enemy of an alliance partner are more common than wars between neighboring states (see Siverson and Starr, 1991) — and then to proceed with this assumption intact. Given that neo-realist scholars have maintained that shifting alliance patterns in international relations are a key concern that governs international behavior (Walt, 1987; Waltz, 1979), to assume that geographical contiguity provides the only context for war seems risky. In the example above, this is a critique of the nature of the rules that govern agent behavior, whose potential actions do not include wars with non-neighboring agents.

Again, however, the criticism of the ontological status of behavioral parameters in simulation modeling runs even deeper. From the very outset, the presumption that the relevant behavioral rules, and only the relevant behavioral rules, may be captured in a simulation is questionable. To say that the interactions between agents in the international arena capture the complexity of international politics is to make a profound theoretical commitment. If realist considerations are indeed the only factors that govern international conflict, then only a select few rules need be included. If critiques of realist predictions such as the democratic peace literature are valid (Russett, 1993; Bueno de Mesquita et al., 1999; Russett and Oneal, 2001; Huth and Allee, 2002), then a large number of new rules — which will now include regime type, domestic political conditions, the strategic use of diversionary foreign policy, among many others — must be included as well.[12] All of these are absent from the model discussed earlier. Some simulations are, of course, better than others, as Bremer's model encouragingly admits the influences of different domestic considerations and a plurality of foreign policy outlooks on global political outcomes. It follows that the inclusion and exclusion of parameters is directly tied to the theoretical stance of the researcher, in much the same fashion as the stipulation of relevant agents. It remains unclear to what extent the inclusion of different rules would influence the general results of such models.

Beyond this critique of rule inclusion, there is the critique of parameter specification — what values the included parameters in international simulations should take. Lustick presents a critique of some modeling where parameter values that govern the relations between agents are asserted to be self-evident, rather than problematic (Lustick, 2000). This, of course, is a key problem for all forms of modeling in the social sciences, but in the case of simulating international processes becomes particularly acute, as simulation as presented here is a modeling technique that embraces the power of micro-interactions to lead to macro-outcomes. The sensitivity of parameter specification, as Cederman (1997) recognizes, can therefore present a critical problem for his CAS approach to modeling the emergence and dissolution of states in world politics, as well as for all computational simulations of international phenomena.

One solution to this parameter specification problem is to use the very indeterminacy of parameter values to explore the ways that agents interact. Saam and Harrer (1999), in their presentation of the computational effects of norm specification, adopt this more tenable approach.[13] They demonstrate that different specifications of the relations among agents, and different conceptions of the nature and function of norms, can lead to markedly different outcomes in repeated simulations. Likewise, variation of f — the degree to which war destroys resources — in the example simulation corresponds to different conceptions of the degree to which the destruction of resources affects the propensity of wars to occur, and may serve to illuminate the consequences of changing material incentives for conquest (a subject discussed, for instance, in Brooks, 1999). Along these lines, Cederman (1997: 64) defends parameter specification as being conducive to presenting 'heuristic insights' into the workings of complex processes, a method somewhat related to the examination of comparative statics in game theoretic models. Cederman argues that by 'making the invisible hand visible' (p. 265), computer simulations of world events often highlight faulty logical reasoning and allow the researcher to specify the conditions under which assertions about the nature of actors in the world will hold. Following this logic, the researcher can look at the results of her simulation and compare them to the real world. A simulation whose parameters lead to degenerate outcomes, such as a world free of war or with completely closed economies, may lead to the conclusion that either the researcher has incorrectly specified parameters or misidentified the ontology of the international system. The researcher can then either change the parameter specifications, or change the ontological assumptions of the system, until the desired results — those that map well onto the real world — obtain. In such a case, it would be almost impossible to gauge the success of the simulation as a true explanation of real-world observations. Furthermore, no clear criteria regarding an acceptable sensitivity of parameter specifications exist that can allow researchers to determine the robustness of their findings.[14]

Before concluding, it is worth noting that one possible response to these critiques is to advocate the value of simulation as a heuristic. This response is not without its merits, as the power of the simulation methodology in International Relations has always been its ability to highlight emergent phenomena in international politics. The analogies from the natural sciences of self-organized criticality and nonlinear dynamic systems have widened the field of inquiry in the social sciences, enabling social scientists to focus on more theoretically tractable micro-level interactions in order to explain macro-level behavioral outcomes. With regard to the example model discussed above, ignoring democratic peace research does not mean that its findings are inconsequential, only that the researcher is exploring other dynamics. Researchers, especially scholars of international politics, should be wary, however, of confusing analogy with analysis. Creating a simulated international system based on oversimplifications and numerous theoretical commitments certainly can lead to simulated outcomes that can be interpreted as matching those of reality; the heuristic can sometimes seem to 'work'. It does not necessarily follow that creating an analogy to an international system in a field of polygons serves to analyze correctly the research question of why states erect trade barriers, go to war, or emerge and dissolve.[15] As with any methodology for exploring the complex phenomena of international relations, the researcher must strike a delicate balance between the veracity of her assumptions and her desire to develop powerful and coherent models of international processes. Appealing to the value of simulation as a heuristic tool does not override this concern.

Having reviewed both the epistemological and ontological problems that simulation faces in the field of international relations, it should be apparent that social scientists should hesitate to champion simulation as a 'fourth methodology'. As a methodology for engaging in research in the social sciences, simulation draws on a diverse field of epistemological traditions, including scientific realism, empiricism and rationalism. This diversity of philosophical foundations, while allowing for a highly integrative methodology, also opens simulation to the many valid critiques that philosophers of science and social science have mounted against these competing epistemologies. A more pressing concern for the simulation methodology is its tendency to make sweeping assumptions about the ontology of the system that it aims to study. Seen in this light, simulation reveals its foundational connection with the ontological assumptions inherent in all theories of International Relations. Insofar as simulation tends to adopt realist assumptions about the ontology of international politics, emergent properties and simulated historical data of international systems as modeled through computer simulation are dependent on the assumptions of realist tradition. This is not to imply that simulation must adopt liberal or constructivist assumptions instead of those of the realists; these will present the same sort of problem. Simulation is inherently theory-laden in its construction of models of international processes, a serious critique of its promise to revolutionize our understanding of world politics.

5. Conclusion: Towards Simulation as a Healthy IR Research Paradigm

This study has explored the vibrant field of the simulation of international politics by examining first what simulation is, and then by discussing the often unappreciated consequences of the simulation methodology. In particular, questions of what the enterprise of simulation entails about a researcher's view of knowledge accumulation, as well as the sorts of theoretical baggage simulation appropriates, have been examined and critiqued. Furthermore, this study has built on these intuitions to assess the relative credibility of particular claims — of the dynamic representation of agents, the examination of counterfactuals through simulated history, and others — made by researchers who champion the possible benefits of adopting the simulation framework. While this discussion has shown that the simulation methodology, as with almost all other research paradigms, is fraught with underdeveloped notions of exploration, representation and causation of social scientific phenomena, this study does not aim to critique all of simulation as a research tool in the study of International Relations. Instead, epistemological difficulties and ontological problems, to some extent, might be remedied in future studies that employ computer simulation to enhance our understanding of complex international phenomena. The arguments developed in this study should push researchers who employ simulation in their study of world politics to adopt a broader theoretical framework for understanding the epistemology of simulation and the ontological necessities of the simulation methodology.

Understanding whether or not a particular simulation actually captures the characteristics of the international political phenomena that it seeks to describe is a difficult task. Taber and Timpone adopt the position that simulations must attend to 'process validity', where there is 'correspondence between the model's mechanisms and real world mechanisms' (Taber and Timpone, 1996b: 32). It is clear from the discussion above of simulation's ontological difficulties that Taber and Timpone's concern is critical, but still a second-order issue that international politics simulations must address. Before evaluating whether a simulation gives the right predictions, and that the processes used to arrive at those predictions are correct, modelers must be certain that their simulations are including the relevant pieces of the international political puzzle.[16] The veracity of the implicit claim that only the relevant pieces of the international puzzle appear within a simulation might be strengthened by a demonstration that other pieces — as a particular theory claims — do not influence outcomes. If modelers do not endeavor to include such 'tests' of the robustness of their simulations, they run the risk of promoting simulations that can give accurate predictions for the wrong reasons.

While a fully developed set of recommendations is beyond the scope of this study, several immediate concerns are of note. Researchers who employ simulation might adopt the following suggestions in their studies.

1. Clarity of purpose. Often, the epistemological tension between scientific realism, rationalism and empiricism obscures some of the more powerful insights made through the use of simulation as a research tool. Simulation is a powerful method for exploring the implicit effects of different types of interactions (strategic, local vs global, multi-level) among political actors. Clear epistemological commitments by researchers are always desirable, but for simulation this is especially necessary.
2. Variety in ontological assumptions. The types of simulation reviewed in this study often reveal a covert theoretical allegiance to the ontological assumptions of the various paradigms employed by theorists of International Relations. It has been shown that many of the assumptions about the ontology of states and of the international system itself are biased towards a particularly realist school of thought. Researchers who employ simulation should not shy away from such views if they truly accept them, and should be willing to show how specifications arising from alternative theoretical traditions bear out in similar simulations. This demands an extensive proliferation of the rules governing agents in

simulations such as those discussed earlier in order to establish robust patterns.
3. Concern with reductive modeling. Among the more unfortunate features of simulation in the study of international processes, as it stands now, is the unwillingness of researchers to explore the consequences of their many simplifying assumptions. The belief that the topology of the simulated environment (the grid of agents) in which agents interact does not affect the types of emergent properties witnessed may in fact be valid, but such a statement requires a serious attempt at providing a counter-example. Similarly, the realist presumption of rational and functionally identical actors, while computationally handy, must certainly not serve as the only paradigm through which international relations are simulated. Researchers should make every attempt to ground these presumptions in substantive theory with widely accepted evidence.
4. Focus on cognitive complexity. Many simulations in International Relations, in addition to making potentially invalid assumptions about the ontology of agents, have failed to appreciate truly the notion of complexity in decision-making by agents in the international system. Focused research on this topic must show how any reductive characterizations of non-determinate decision making preserve the necessary complexity of this process, and attempt to broaden the researcher's toolkit for exploring complex decision making across all simulations in the social sciences.

These, of course, represent only the very beginning of a needed series of reforms in current practices of employing simulation in the study of international processes. The extent to which these suggestions seem foundational to any study of world politics reflects the gravity of problems identified in this article. The purpose of critiques such as these is to encourage research that contributes to the accumulation of knowledge in International Relations research. Further research and detailed analysis of this paradigm can hopefully allow social scientists truly to capitalize on the insights of non-equilibrium dynamics and micro-behavioral analysis, and ever increasing computational power, in the study of International Relations.

Notes

1. Of course, a number of global simulations had existed long before Axelrod's study; see Alker (1985).
2. Other types of simulations are relevant for the study of international relations. These include simulations of the decision making calculi of foreign policy decision makers through different representations of knowledge, and 'machine learning' models that endeavor to learn about international political 'rules'

through induction from empirical data. A capable review of these types of models may be found in Taber and Timpone (1996a), although many of the critiques that I introduce below are applicable to their arguments.

3. Counterfactuals need not be singular events, but may also be characteristics of the world; this is the sense in which computational modeling of social phenomena appears most promising. If A represents the characteristic 'nations attack whenever a neighboring state threatens their security' and ~A is 'nations do not attack when a neighboring state threatens their security,' then it is clear what the result of such characteristics would be for a model for which B is 'war'. See Cederman (2003) for a presentation of such a model. The implications of such a model, however, will be addressed below.
4. See Byrne (1997) for an introduction to complexity theory and its implications for research in the social sciences; see also Sandole (1999: 193–201).
5. A description of the research design behind a 'computational modeling project' may be found in Taber and Timpone (1996: 13–7).
6. Bremer and Mihalka (1977) use 'system' and 'geography' to refer to the environment of their simulation; Cederman (1997) terms this an 'artificial world'. The term *environment* is in predominant use among researchers who simulate social phenomena, especially in the *Journal of Artificial Societies and Social Simulation*.
7. Again, the terminology here is often unclear, as some researchers use 'actor' interchangeably with 'agent'. They are functionally equivalent.
8. Cederman (1977, 2003); Bremer and Mihalka (1977) use hexagons rather than squares. In the jargon of simulation, these are often referred to as 'cellular automata'. See Taber and Timpone (1996: 25–26).
9. See the discussion of 'outcome validity', 'internal validity', and 'process validity' in Taber and Timpone (1996: 71–9).
10. It should be noted that a number of AI in IR studies incorporate cognitive complexity as an integral part of their research design, but they nevertheless map cognitive processes of individuals onto the state as an actor. See eg. Schrodt (1988a, 1988b); Hudson (1991). An interesting exception may be found in Taber and Timpone (1994). However, this model only represents 'U.S. foreign policy belief systems toward Asia', not the global system as a whole.
11. There has been little work, if any, in this area. While it seems possible that the topology of an environment may not play a role in shaping some emergent phenomena, further exploration of this topic is necessary. Indeed, one avenue of useful research would be to compare the results of existing simulations with results where the environment has been stipulated differently. As a further note, it seems intuitive that the social geography of the international system should be modeled as unbounded — perhaps as a sphere, but at least as a manifold in Euclidean space.
12. Cederman (2001) does use insights from the democratic peace in a computer simulation of international politics.
13. It is still difficult, however, to reconcile this conception of norms, and hence preferences, with intuitive thinking about what preferences really are. The three

dominant methods of comparative analysis currently practiced in the social sciences — rationalist, structuralist, and culturalist — share a common conception of preferences as dynamic and problematic. To understand the action of any type of agent, there must be at the very least a quasi-economic calculation of costs, and at most a fully developed knowledge of the culture, discourse, and meaning surrounding all possible actions. Adopting Sil's (2000) broad classifications, it is apparent that social scientists demand a thicker conception of agency than simulation and complex systems analysis, as currently employed in international relations, have provided.

14. A related critique adopts the argument about what parameter specifications actually mean. To say that agents do not act deterministically is a bold assertion. The classic statement of this problem is Almond and Genco (1977); see also Bernstein et al. (2000).
15. Cederman (2003), through manipulating the specifications of the parameters governing his agent-based simulation of the size of wars, obtains results regarding the linear relations between frequency and size of wars that are strikingly similar to those observed in history: as the log of the size of a war increases, the log of the probability of that war occurring decreases. This is often known as Richardson's Law (Richardson, 1948). Using another analogy, it is possible to come up with the same result. Imagine that the leader of every state is responsible for making war and peace — not an unrealistic assumption for much of history. Leaders who enter wars are very likely to fight small wars, but become less likely to continue to fight as the size of the war increases. Imagine further that every leader's preferences in this matter are distributed logistically — again, a rather plausible speculation. The same empirical result would be obtained through this model. As a heuristic tool, though, this model has little value, as the assumptions are so wildly inaccurate that it does not stand to reason that this captures the dynamics involved. Might not the same be said of a simulation where the assumptions are correspondingly false?
16. See Guetzkow (1963; Hermann and Hermann, 1985) for a description of the complexity of international relations simulation and its challenges to researchers.

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