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Abstract

The international system is a complex adaptive system with emergent properties and dynamics of self-organization and information processing. As such, it is better understood with a multidisciplinary approach that borrows methodologies from the field of complexity science and integrates them to the theoretical perspectives offered by the field of international relations (IR). This study is set to formalize a complex systems theory approach to the study of international affairs and introduce a new taxonomy for IR with the two-pronged aim of improving interoperability between different epistemological communities and outlining a formal grammar that set the basis for modeling international politics as a complex adaptive system.

Keywords: international politics, international relations theory, complex systems theory, taxonomy, adaptation, fitness, self-organization

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Una nueva taxonomía para las relaciones internacionales: repensando el sistema internacional como un sistema adaptativo complejo

Resumen

El Sistema internacional es un sistema adaptativo complejo con propiedades emergentes y dinámica de auto organización y procesamiento de información. Como tal, es mejor comprender con una aproximación multidisciplinaria que extraiga metodologías del campo de la ciencia de la complejidad y las integre a las perspectivas teóricas ofrecidas por el campo de las relaciones internacionales (RI). Este estudio existe para formalizar un acercamiento teórico de sistemas complejos para el estudio de los asuntos internacionales y presentar una nueva taxonomía para las RI con el objetivo bipartito de mejorar la interoperabilidad entre diferentes comunidades epistemológicas y esquematizar una gramática formal que ponga las bases para los modelos de las políticas internacionales como un sistema adaptativo complejo.

Palabras clave: política internacional, teoría de relaciones internacionales, teoría de sistemas complejos, taxonomía, adaptación, aptitud, autoorganización

国际关系新分类：重新思考国际关系这一复杂适应系统

摘要

国际系统是一个复杂适应系统，它具备自组织和信息处理的新兴性质和动态。照此，用多学科方法更能促进对国际系统的理解，因为前者借用复杂性科学领域中的方法论并将其合并到国际关系（international relations，IR）领域所提供的理论视角中。本研究致力为国际关系研究提出正式的复杂系统理论方法，并为国际关系引入一种新的分类法，此分类法有两个目标：一是提高不同认识论社区（epistemological communities）间的互操作性；二是概述一种形式语法，为国际政治作为一种复杂适应系统进行建模提供基础。

关键词：国际政治，国际关系理论，复杂系统理论，分类学，适应，fitness, 自组织

Introduction

This study puts forward the idea that the international political system is a *complex adaptive system*, with *emergent properties* and dynamics of *self-organization*. Hence, it suggests that the international system is better understood with a multidisciplinary approach that borrows methodologies from the field of complexity science and integrates them with the theoretical perspectives offered by the field of international relations (IR). The overall scope of this study is to formalize a complex systems theory approach to IR, define a new taxonomy for the discipline to improve interoperability between different epistemological communities, and set the basis for future modeling of the international system as a complex adaptive system (CAS).

IR scholars have embraced theoretical diversity over the past decade and acknowledged the validity of a wide range of different theoretical perspectives in the realm of foreign policy. Many have welcomed theoretical pluralism as a positive development for the discipline. Dunne, Hansen, and Wight (2013, p. 416) argued that if we could use the vast array of positivist and post-positivist theories in a *coherent* and *integrative* way, we would be finally able to make sense of the multifaceted inquiries of international politics. But in reality, coherence is hard to achieve when confronted with an overarching and disorganized menu of theories and claims. And without coherence and method, the whole discipline becomes prone to relativism and loss of critical standards (Dunne et al., 2013, p. 415), transforming academic dialogue in an empty debate of perspectives and mirrors.

A more fundamental problem that affects both general theories and pluralist approaches of IR is a lack of understanding of the subdued nonlinearity of social, and therefore political, interactions among agents. For long, scholars thought they were looking at international politics, but instead, they were only looking at its linear, constant, continuous, and deterministic image. Theorists did not realize (at least most of them) that there was another image of world politics. That image is non-linear, discrete, stochastic, and composite: a chaotic face of the world where there are no general laws or causalities.

At large, IR scholars have deceived themselves and only saw what they were already acquainted with. In the picture of social systems and international politics, they saw the image of linearity (Richards, 2000a, p. 3). Consequentially, they blindly used positivist approaches to come up with general theories based on inductions and deductions rooted in a simple and linear image of the world. However, the real world has never been linear and it has rarely fitted within the general laws and causalities found by social scientists. Repeatedly, new trends and unexpected events have confuted IR theories and required us to seek for new correlations. Eventually, the discrepancy between the real and the theoretical became so vast that IR theorist started to look for new epistemologies beyond positivism during the eighties.

Unfortunately, the pursuit for a new epistemology in IR resulted in a twofold failure. First, it failed to replace empiricism, which far from being dead is even experiencing a resurgence in narrow scope quantitative research (Mearsheimer & Walt, 2013). Second, it failed in finding a coherent epistemology capable of dealing with the nonlinear ontology of social systems and international politics. Scientific realism and critical theory were still fixated on the same linear world that positivist looked at. By assuming that the natural and the social worlds were governed by equal and objective recurrencies, scientific realism and critical theory recurred to a positivist epistemology to study international politics (Smith, Booth, & Zalewski, 2008, p. 35). Conversely, post-modern and post-structural theories, like constructivism, ended up rejecting the *image* of an objective and "external world" to focus on the *observer* or "subjective self" (Smith et al., 2008, p. 30). Yet, by doing so, they focused on ontology and overlooked epistemology, leaving the task of the interpretation to the subjective, and biased, self (Smith et al., 2008, p. 18).

Offering an alternative to general theories or pluralism, this paper suggests that the complexity of politics can only be unraveled using an interdisciplinary research method that incorporates complex systems theory with IR: a method that allows for an ontological closure between the 'real world' and the world of our theories. The consequence of this closure is exciting as it implies that we can advance our knowledge of international politics by making more detailed and holistic analyses of the international system that do not rely on oversimplifications for modeling. The methodology put forward by this study does not fixate on one specific level of analysis, but instead focuses on the multilevel nature of nonlinear dynamics in the international system to find theoretical insights and explain the relationships between agents and system behavior (Downey, 2012, p. 92). Instead of arbitrarily defining the agents of the international system and assuming how they behave, it assumes what are the properties of agents (autonomy, self-containment, and interdependence) and how behavior is generated (through the processes of performance system, credit assignment, and rule discovery).

Over the last two decades, several attempts have been made to use complex systems theory to analyze international politics, see for instance Robert Axelrod's *The Complexity of Cooperation* (1997), Neil E. Harrison's *Complexity in World Politics* (2006a), Diana Richards' *Political Complexity* (2000b), and Emilian Kavalski's "The Fifth Debate and the Emergence of Complex International Relations Theory" (2007). Yet, only a handful of IR scholars have advocated for the use of complexity theory as an overarching theoretical framework of IR, and fewer among them have used its modeling techniques to study the international system. This article hopes to fill a gap in the literature by posing the taxonomical foundations of a theoretical framework of IR rooted in complexity theory. Overall, this study is set to offer a radical reinterpretation of the way we think of international affairs by proposing new ontological, epistemological, methodological, and taxonomical perspectives.

Where Does Complexity Theory Stand?

The fourth inter-disciplinary debate between positivist and post-positivist scholars has succeeded in moving out IR from a strictly positivist ground,[1] but it has failed in creating cohesion over a new philosophical system. On theoretical pluralism, Dunne, Hansen and Wight wrote:

> Only pluralism can deal with a multi faceted and *complex reality* and only pluralism can deliver substantial progress in terms of knowledge. Given the lack of agreed epistemological standards for assessing competing knowledge claims, we should embrace all perspectives. [...] Our view is that we should attempt to move towards a position we will term 'integrative pluralism'. [...] Integrative pluralism accepts and preserves the validity of a wide range of theoretical perspectives and embraces theoretical diversity as a means of providing more comprehensive and multi dimensional accounts of *complex phenomena* [emphasis added]. (Dunne et al., 2013, p. 417)

However, there is an inconsistency in this argument: a sum of not-good-enough theories does not make for a good enough theory. Traditional IR theories are just not equipped with the necessary epistemology and methodology to make sense of complex adaptive systems. Pluralism, in this case, can only lead us to a plurality of errors and misinterpretations. Sure, the more theories we use, the more likely we are to find a tangential explanation for our phenomenon of interest, but none of those explanations will be able to grasp the core dynamics of the international system (adaptation, emergence, and self-organization). For this reason, we

1 There has been a tendency among theory-leaden positivist scholars to shift toward post-positivism, this is the case for example of John Mearsheimer, which in a paper in 2013 wrote that scientific realism offers "a more convincing epistemology" (Mearsheimer & Walt, 2013, p. 433).

should start using complex systems theory also in IR.

Moreover, complex systems theory has the potential of reestablishing agreed-upon epistemological standards and promotes consilience in the field of IR. It does so as a non-positivist theoretical framework that integrates concepts and methods used by both positivist and post-positivist scholars. Where positivist implemented an "outside view" of social sciences and post-positivist an "inside view" of it, complexity theory integrates the two views into an "inside-out" ontology that takes account of the nonlinear dynamics that occurs between agents and system in international politics (Harrison & Singer, 2006, p. 38).

Notwithstanding its potential, IR scholars have largely ignored or misused complexity science. Often, scholars have sloppily borrowed and decontextualized its taxonomy. This is, for instance, the case of Dunne et al. (2013), who, without ever mentioning complexity theory, defined the international system as a CAS.[2] Another scholar that misused complexity theory is Alexander Wendt (1987, 2003), who decontextualized complexity theory as an analogy to support his own arguments; even though his arguments were unsupported from the epistemological and methodological standpoints of complex system theory.[3]

It appears that Wendt and many other post-positivists in IR have, to some extent, grasped the nonlinearity of social systems. However, they missed to follow through the study of nonlinearity with the appropriate modeling methods and instead used hermeneutic and subjective analyses. This trend is pitiful because the computational techniques offered by complex system theory and agent-based modeling would have allowed them to make large-scale models of system dynamics generated bottom up using the "inside view" that they favor.

In sum, whereas positivist scholars bluntly ignored nonlinearity in international affairs, post-positivists ignored the methodologies and analytical tools that could be used to study it. Consequently, both scholarships "missed a lot" by not being able to observe or explain the emergent global dynamics resulting from nonlinear interactions of composite agents in the international system (Richards, 2000a, p. 2). As Diana Richard (2000a) wrote:

2 Dunne et al. give a definition of the international system that seems taken from a complexity theory textbook: "contemporary international political system is best understood as a complex open system, which displays 'emergent properties' and degrees of 'organized complexity.'" Yet, they never mention complexity theory in their paper, and instead advocate that "integrative pluralism" is the most appropriate research framework to study complex systems (Dunne et al., 2013, p. 417).

3 Wendt develops his arguments using, and decontextualizing, a taxonomy drawn from complexity theory. For instance, he refers to emergence, self-organization, negative and positive feedbacks, upward causation, boundary conditions, etc (Wendt, 1987, p. 369; Wendt, 2003, p. 498). However, he does so without using the epistemological framework of complexity theory. Moreover, his studies do not use any form of computational modeling, which is a standard methodological practice to study CAS (Earnest & Rosenau, 2006, p. 145). For these reasons, Wendt's interpretation of the international system as a CAS appears to be subjective and dogmatic.

> No wonder very few clear empirical relationships have been found over decades of political science. If it is a nonlinear world and we are looking with "linear vision," then we can only catch a small portion. Furthermore, our models of constant effects will miss something fundamental about what we are studying; as the saying goes, it's like throwing a dead bird to model the flight of a live bird. (p. 2)

As this paper advocates, it is time for IR to stop missing out. Hence, the need for IR to embrace complex systems theory, pose much-needed ontological and epistemological questions, and develop a new taxonomy that will improve interoperability between different epistemological communities and provide the basis for nonlinear modeling in IR.

IR is a discipline that traditionally does not shy away from importing theories from other fields of studies.[4] Nevertheless, there has been only limited cross contamination with the field of complexity theory. Arguably, lack of dialogue and interdisciplinarity has largely been caused by a linguistic cleavage among different epistemological communities in the discipline. It appears that while all communities deal with the same field of study and use the same language, each of them has a different cognitive understanding of concepts, terms, and vocabulary.

Lack of cross-contamination among the communities is thus fostered by a lack of understanding among them. An effort of "translation" among taxonomies has been attempted in the book *Complexity in World Politics: Concepts and Methods of a New Paradigm*, edited by Neil E. Harrison (2006a). Where the first two chapters, written by Harrison and Singer, provide a seminal taxonomy of complexity science for the use of social scientist. However, communication is not the sole impediment to the spread of complexity theory in IR. The discipline is also divided among methodological communities. The divisions are furthermore aggravated by the fact that, as Richards (2000a) writes, methodologists are known to "suffer change," especially when they are too comfortable with their own methods (p. 3).

As it is today, the IR literature that has used complexity science is mainly found in the book series titled *Princeton Studies in Complexity*, and in two collections of essays; the above-mentioned *Complexity in World Politics*, and *Political Complexity: Nonlinear Models of Politics* edited by Richards (2000b). *Complexity in World Politics* collects ten papers, including: An introductory article by Harrison and Singer (2006) that compares IR systems theory with complex systems theory. An essay on conflict resolution by Dennis Sandole (2006) that uses complexity to reconsider "theories of identity-based conflict in the post-9/11 world." A paper by Walter Clemens (2006) that uses complex sys-

4 IR has borrowed political theory, philosophy, and history from the humanities; economics, sociology, and law from other social sciences; and math, physics, and statistics from natural sciences (Dunne et al., 2013, p. 419).

tems theory to explain why only a few (and fit) ex-Soviet states were able to integrate into the EU. An insightful essay by Matt Hoffmann (2006) that studies coevolution and adaptations in the context of the creation of international regimes. An agent-based model by Ravi Bhavnani (2006) on the spread of violence in the 1994 Rwandan genocide. In addition, lastly, a chapter written by Robert Axelrod (2006), which ponders the role of simulation in IR and social sciences vis-à-vis traditional inductive and deductive methods.

The book *Political Complexity* is instead focused on political science and only few of its chapters touch upon international relations. Among those who do, are worth mentioning: Richards' (2000a) paper on nonlinear modeling, which reframes political science under a complexity theory framework, and her paper on nonlinear dynamics in games, which provides an example of modeling for international environmental regimes.

The *Princeton Studies in Complexity Series* has published 14 full-length books on complexity theory that ranges from biology to economics and political science. Those of particular interest for the field of IR are: Axelrod's (1997) book *The Complexity of Cooperation*, which uses agent-based modeling and genetic algorithm to study cooperation and meta-norms. Lars-Erik Cederman's (1997) book *Emergent Actors in World Politics*, which reviews traditional IR scholarship and simulates state formation and "balance of power" in complex adaptive systems. And Joshua M. Epstein's (1996, 2007, and 2013) coauthored books, *Generative Social Science, Agent Zero*, and *Growing Artificial Societies*. Epstein's trilogy provides a foundational framework for studying social dynamics with agent-based modeling. The book *Growing Artificial Societies* uses complex systems theory in a holistic way to recreate in silico an entire society made of composite agents that, with a distributed artificial intelligence, reproduce, create, consume and trade resources. The book is particularly relevant because it provides case studies on how to "discover fundamental local or micro mechanisms that are sufficient to generate the macroscopic social structures and collective behaviors of interest" (Epstein & Axtell, 1996, pp. 12–16).

While there is a growing body of literature in social sciences that uses complexity science, the largest body is still found in natural and computational sciences (Henrickson & McKelvey, 2002). Fortunately, due to the interdisciplinary nature of complexity science, each theoretical advancement in a discipline quickly translates to an overall progress for all the others. For instance, the contribution of Stuart A. Kauffman's (1993) seminal book titled *The Origins of Order* goes beyond the field of evolutionary biology and invests any scholar that uses complexity theory. A social scientist might as well find in Kauffman's elegant use of modeling techniques a source of inspiration for modeling social dynamics. Similarly, John H. Holland's (1995) book *Hidden Order* introduces computational techniques that have been used in several fields of study and for different purposes, including the modeling of aggregate social behavior to the development of artificial intelligence. Among the most recent scholarship focused on the study of CASs are also worth mentioning Nino Boccara (2004), Claudius Gros (2011), and Allen B. Downey (2012), who have published very informative books focused on modeling techniques from mathematical and computational perspectives. These books, together with Uri Wilensky and William Rand's (2015) *An Introduction to Agent-Based Modeling*, provide a comprehensive overview and a good groundwork for any research project that tries to study the international system using complex systems theory.

Only a handful of scholars have advocated for the use of complexity theory as an overarching theoretical framework of IR, and fewer among them have used its modeling techniques to study the international system. Those who did, however, have succeeded in tackling fundamental issues of international affairs, such as the creation of international regimes, cooperative behavior and the emergence of nation-states (e.g. Axelrod, 1997; Cederman, 1997; Harrison, 2006a). Yet, while their findings have been widely acclaimed, their theoretical frameworks and methodologies have never gone mainstream among IR scholars. As advocated in this section, it is time for IR scholars to go beyond analogies on complexity and realize that the international system *is* a complex adaptive system. Only then, under complexity theory's epistemological warrant and methodologies, they will be able to study the international system for what it really is: a system that lacks centralized control and that is composed of a large number of adaptive agents interacting in a nonlinear fashion that gives rise to emergent behavior and principles of self-organization.

Concepts and Ideas for a New Methodological Approach to IR

Complexity science aims to develop cross-disciplinary insights into complex systems by using a methodology that is a combination of experimental, theoretical, and computer simulation (Mitchell, 2015a). Complex systems, which can be either complex adaptive systems (CASs) or complex physical systems (CPS), are studied in several different disciplines, including evolutionary biology, immunology, genetics, information science, dynamics, economics, and sociology.

To define a complex system, it is better to put aside the concept of complexity, and, as Holland (2013, Chapter 1) and Boccara (2004, p. 4) suggest, focus on the properties of the system. Complexity comes in many different forms and shapes, and different disciplines tend to have different definitions and measurements of complexity.[5] Nevertheless, most complex systems share the same properties of nonlinearity, emergent behavior, self-organization, and information processing. Hence, a complex system can be defined as a "system composed of a large number of

5 As Seth Lloyd has catalogued, there are more than 40 different measures of complexity, among which: Shannon information, the degree of hierarchy, and schema length (Lloyd, n.d.).

interacting components, without central control, whose emergent 'global' behaviour—described in terms of dynamics, information processing, and/or adaptation—is more complex than can be explained or predicted from understanding the sum of the behavior of the individual components" (Santa Fe Institute, n.d.). Some of these properties, as lack of central authority, are self-explanatory, but others deserve to be briefly explained.

Nonlinearity in mathematics implies nonadditivity (Boccara, 2004, p. 56). A linear system is one that can be inferred "by understanding its parts individually and then putting them together," but "a nonlinear system is one in which the whole is different from the sum of the parts" (Mitchell, 2009, pp. 22–23). Hence, nonlinear relationships between agents in a system imply "that an independent variable does not have a constant effect on the dependent variable" (Richards, 2000a, pp. 1–2). Nonlinearity is also closely related to the concept of sensitive dependence on initial conditions and chaotic behavior.

The idea of *sensitive dependence on initial conditions* was first formalized by the mathematician Henri Poincaré at the end of the nineteenth century. Poincaré noticed that the initial configurations of a system play a determining role in setting the subsequent states of the system, and "when the sensitivity is high, slight changes to starting conditions will lead to significantly different conditions in the future" (Santa Fe Institute, n.d.). Systems with sensitivity to initial conditions often manifest *chaotic behavior*, which is a specific dynamic where systems change following trajectories that appear to be random (Mitchell, 2009, p. 32). As it has been proved, even a simple and deterministic equation as the logistic map, which is used to describe population growth in the presence of overcrowding, can lead to chaotic behavior even if its parameters are determined exactly. As it can be inferred, sensitive dependence on initial conditions renders perfect prediction in modeling impossible in principle because variables cannot be measured "to infinitely many decimal places" (Mitchell, 2009, p. 33).

Emergent behavior is as well related to the principle of nonlinearity. Emergent properties can be defined as "global-level attributes of a system that arise from the interactions of the components of the system, and that are not explainable by the behavior of individual components of the system or the sum of the components acting as individuals" (Santa Fe Institute, n.d.). It is important to underline that emergent properties at the systemic level are an outcome of the nonlinear interaction of agents, and not of the agent's properties (Boccara, 2004, p. 97). Hence, knowing the rules to which agents obey is not enough to predict the behavior of the system. The system is computationally irreducible, and, for this reason, CASs has neither reductionist explanations nor yield to compact forms of representations (Mitchell, 2015a).

Self-organization, as defined by Melanie Mitchell (2015b), is itself an emergent phenomenon, which can be described as the "production of organized patterns, resulting from localized interactions within the components of the system, without any central control." In other words, self-organization creates stable macroscopic patterns arising from the local interaction of agents with limited information and computational power (Epstein & Axtell, 1996, p. 35). One generic pattern of self-organization is the one of "self-organized criticality," which implies "that from any initial condition, the system tends to move toward a critical state, and stay there, without external control" (Bak, Tang, & Wiesenfeld, 1987, p. 381; Downey, 2012, p. 81). Self-organization, as it will be further explained later, requires the system to signal and process information.

If we want to define the international system as a CAS, we can say that: the international system is composed of many diverse, interconnected, and interdependent agents that iterate non-linear relationships from which multilevel behavior evolves and emerges. Because of non-linearity, lack of central coordination, and the presence of lever points—the international system should not be studied with traditional positivist methodologies that assume linearity (Holland 2013, Chapter 3). Positivist theories are built inductively or deductively, with the previous discovering patterns in empirical data, and the latter specifying a set of axioms and testing them (Harrison, 2006b, p. 139). Complexity theory follows a third way of doing science between induction and deduction.[6] By relying on computational simulation, it deductively sets axioms and generates data that can be studied inductively (Harrison, 2006b, p. 139). Since CASs are irreducible, scholars ultimately need the assistance of simulation to be able to explain those (Earnest & Rosenau, 2006, p. 145).

To conclude, studying complexity does not require a paradigm shift in the way IR is studied. However, it does require some change in the criteria that scholars use to observe the world and build theories. When scholars model complexity, they need to shift from continuous to discrete, from linear to nonlinear, from deterministic to stochastic, from abstract to detailed and from homogeneous to composite (Downey, 2012, p. 4). In addition, also their purposes in research have to change; studies should be explanatory and not necessarily predictive, models should be instrumental and not realist, and theories should be holistic rather than reductionist (Downey, 2012, p. 4).

For a New Understanding of International Relations

A New Grammar and Taxonomy

Ontology and epistemology dictate what can be classified in a taxonomy,

6 "But unlike deduction, simulation does not prove theorems with generality. Instead, simulation generates data suitable for analysis by induction. Nevertheless, unlike typical induction, the simulated data come from a rigorously specified set of assumptions regarding an actual or proposed system of interest rather than direct measurements of the real world. Consequently, simulation differs from standard deduction and induction in both its implementation and its goals. Simulation permits increased understanding of systems through controlled computational experiments" (Axelrod, 1997, p. 4).

and methodology helps to shape the semantics of the language spoken in a discipline. For this reason, positivism, constructivism, and complex systems theory held a different cognitive understanding of basic IR concepts. They use, in other words, different semantics and taxonomies.

The scope of this section is two-pronged: defining a taxonomy of IR rooted in the propositions of complex systems theory to improve interoperability between different epistemological communities, and outlining a formal grammar to set the basis for modeling the international system as a CAS. It is necessary to update IR's taxonomy because the discipline has no standard language for analyzing the agent actions that construct the international system.[7] Actions that are driven by concepts, such as adaptation and coevolution, which are novel to IR and have yet to be systematically contextualized.

In addition, a well-defined taxonomy and grammar are also needed to standardize a language that is both capable of describing emergent phenomena and at the same time following a syntax suitable for computational modeling. As Holland (2013) suggests, a formal grammar for studying CASs should be composed of "a set of generators (e.g. a vocabulary), and a set of operators for combining the generators into meaningful strings (e.g. sentences)" (Chapter 6). The purpose of the grammar is "to generate a corpus (set) that describes the states (sentences) that can occur under the grammar's rules" (Holland, 2013, Chapter 6). Only with this formal grammar, Holland argues, it is possible to deconstruct and understand complex adaptive systems.

Through deconstruction, a system can be divided into Lego-like parts, also called *building blocks*, which serves as generators that can be put together to yield different emergent states of the system (Mitchell, 2009, p. 110). In the spirit of Descartes' (1637) treatise *Discourse on the Method*, the aim of deconstructing a system into building blocks is "to divide all the difficulties under examination into as many parts as possible, and as many as were required to solve them in the best way" (p. 17). In the study of CASs, the *difficulties* are the emergent properties, and the *parts* are the building blocks.

However, knowing what the parts of a system are is not enough to explain how a system behaves. The aggregate properties of the international system, such as migration and war, are "not well-described by summing" or averaging the acts and properties of single individuals (Holland, 2013, Chapter 6). This is because emergent behaviors do not arise from the proprieties of the building blocks, but instead from the iteration over time of adaptive interactions between agents (Mitchell, 2009, p. 6). Knowing the generators of a system is not enough to understand aggregate behavior. Instead, we need to know how the generators are combined together to yield emergent behaviors.

7 As pointed out in the first section, this is true for positivism, but only partially true for post-modern theories of IR. As it was shown, some constructivists take into account the interactions between agents. Indeed, some of the concepts that they use resembles others of complexity theory. Nevertheless, the two epistemological communities still have different semantics (Holland, 2013, Chapter 1).

In conclusion, decomposing a la Descartes is useful only if the deconstruction is orderly and descriptive of the agent actions that construct the international system. Hence, the purpose of a formal grammar is to conduct our thoughts, and modeling procedures, in a given order that is representative of the nonlinearity of the system,[8] with the aims being logical clarity and interoperability with the syntax of programming languages used for agent-based modeling (ABM).

The following sections serve to provide an overview of IR based on complex systems theory. The next three sections will individuate the generators of the international system, explain how these generators combine to yield together emergent behaviors, and infer what these emergent behaviors entail for the international system.

Generators: Agents and the Translevel Nature of International Relations

The concept of agent is instrumental and is used to identify the foundational building blocks of a CAS. Like any other building block, an agent is a generator whose properties and interactions give rise to aggregate behavior. Depending on the discipline, scholars tend to have different definitions of what an agent is; however, there are a few common properties that can be traced among the scholarships.

The first property of an agent is *autonomy* (Macy & Willer, 2002, p. 146). An agent, by definition, exists autonomously from the system. It possesses unique *internal states* and *rules of behavior* that allow him to operate autonomously with the environment and with other agents (Epstein & Axtell, 1996, p. 5). The second property is *self-containment.* An agent has to be bounded, identifiable, and discrete (Macal & North, 2009, p. 87). The third property is *interdependence*. Agents' internal states and rules of behavior are continuously evolving and adapting through interaction with other agents and the environment. Interdependence is also tied to the concepts of adaptation, coevolution, and fitness. Beyond these general properties, there is also a widespread consensus that agents should be adaptive, which means that they should change their internal stimulus-response rules based on a process of learning or evolution (Macy & Willer, 2002, p. 146).

Agents act, think, and process information autonomously based on their *internal states* and *rules of behavior*. Internal states are the attributes of an agent. Humans, for example, have many attributes that define them, such as genes, physical properties, economic preferences, political identity, wealth, and skills (Epstein & Axtell, 1996, p. 4). Rules of behavior are an assortment of simple stimulus-response rules that determine in which ways an "agent can change the state of the environment,

8 This argument differs drastically from the Descartes's view, which claims that the purpose for deconstruction is "to conduct my thoughts in a given order, beginning with the simplest and most easily understood objects, and gradually ascending, as it were step by step, to the knowledge of the most complex; and positing an order even on those which do not have a natural order of precedence" (Descartes, 1637, p. 17).

other agents, or itself" (Wilensky & Rand, 2015, p. 209). We can think of each rule as characterized by a receptor IF and an executor THEN. To make an example, if there is an election, a citizen will use the detector "IF today is an election day" to execute the effector "THEN go to vote." The rule could also be more precise and use multiple detectors and effectors at the same time. Because of adaptive learning, agents do not always execute the same rule when faced with the same input; instead, they learn from their past and "change their behavior in the future to account for this learning" (Wilensky & Rand, 2015, p. 230).

To understand system-wide behavior, it is essential to have a clear understanding of the granularity of the system, which is composed of agents, meta-agents, and sub-agents,[9] with agents being the fundamental generators of the emergent behavior of interest. Meta-agents can be quasi-bounded and possess certain degrees of autonomy; however, their behavior can only be inferred as an outcome of agents' actions and interactions (Harrison, 2006a, p. 9). For example, the behavior of a nation-state in the international system cannot be inferred outside of the context that has generated it. Social organizations are neither self-contained nor autonomous. They are meta-agents generated by the primary agent of social systems: humans. In turn, agents are interdependent , and their behavior can only be understood from a system-wide perspective that takes into account coevolutionary dynamics.

In other words, thinking in terms of adaptive agents requires us to consider the international system as a complex whole. A whole that cannot be divided into levels of analyses, as IR scholars often like to do. As Wilensky and Resnick (1999) wrote, levels of analysis are used to provide three different kinds of views: organization-chart view, container view, or emergent view. The first one is used to think of structural hierarchies within institutions, companies, or organizations. Levels, in this case, serve to conceptualize chains of command and organization-charts. The container view, widely used in IR scholarship, "is based on the idea of parts and wholes" (Wilensky & Resnick, 1999, p. 5). This view "differs from the organization-chart view" because "the lower-level elements are parts of the higher-level elements" (Wilensky & Resnick, 1999, p. 5). For example, a month is part of a year (container view), but an employee is not part of the employer (organization-chart view).

The third view is similar to the container view but focuses on "levels that arise from interactions of objects at lower levels" (Wilensky & Resnick, 1999, p. 5). The difference between emergent and container view is subtle. After all, one might argue that just as a week is made of days, a state is made of people. However, the state–people relationship is significantly different. For a start, the composition of the state keeps changing; people leave, come, and die, so do companies, organizations, institutions, and laws. Furthermore, the state

9 Agents are composed of sub-agents, and meta-agents are composed of agents. In agent-based modeling, it is often said that "it's agents all the way down" (Wilensky & Resnick, 1999, p. 1).

"arises from interactions among" the people, and it is not just a simple accumulation of people (Wilensky & Resnick, 1999, p. 5). As Wilensky and Rand (1999) argued, "months do not interact to form a year; they simply accumulate or 'add up.' A year can be viewed, essentially, as a long month" (p. 5). However, a state is not just a big person. The difference is qualitative (Wilensky & Resnick, 1999, p. 5).

IR theory has largely relied on a container view of the international systems. Usually, dividing the system into three arbitrary level of analysis: the individual level, the state level, and the international level. These levels, also called images, have been used by scholars to study the phenomena of interest in isolation from the rest of the components of the system (Wilensky & Resnick, 1999, p. 5). However, by isolating a single phenomenon in a level of analysis, scholars lose the ability to see the emergent view and individuate the micromechanisms that are sufficient to generate the macroscopic behavior of interest (Vicsek, 2002, p. 131). This happens because these mechanisms are the outcome of cascading effects and chains of causalities that move from the micro to the macro, or vice versa, and therefore, can only be grasped through a multilevel perspective. Consequently, complex system theory breaks the distinction between the realm of domestic and international politics. International politics is the outcome of the interactions of agents and meta-agents at the domestic *and* at the international level. Hence, it is not possible, as explained in the previous section, to understand the international system without considering how it has emerged from it the lower levels of interactions among the people.

To conclude, by conceptualizing international relations in terms of levels of analysis as container views, IR scholars have repeatedly fallen into the trap of "slipping between levels to attribute properties of one level to another" (Wilensky & Rand, 2015, p. 13). Idealists and realists slipped from the individual to the aggregate by giving human attributes to the state (e.g. states have national interests and are power seeking). Neorealist slipped from the aggregate to the individual by deriving the properties of states from the anarchic international system (e.g. states have to self-help and are security maximizers). Both cases are an example of the failure of integrative understanding, which bars to see states as meta-agents qualitatively different from the agents that compose them (people) and the environment that they inhabit (international system).

Operators: Adaptation, the Higher Order Rule of International Relations

Adaptation occurs at the agent level through learning and at a systemic level through evolution. Overall adaptation goes in hand with coevolution. The internal attributes and rules of behavior of an adaptive agent constantly change through interaction with the environment and with other agents. As Hoffman explains:

> When some agents change their behavior, this *alters the system* for the other agents. A new context "forces" agents to alter their rule models as the context determines what goals, interests, and behaviors are appropriate or fit. Adaptive agents are always trying to "fit" with their context. *When their internal rule models fit their context, the agents are successful.* When their rules do not fit, the agents are not successful. System change results when innovation on the part of a subset of agents throws the system rules into flux and other agents then adapt their rule models and therefore their actions and interactions. [...] The system rules, produced by agent actions and interactions, *do more than constrain* potential actions; they become incorporated, through the *evaluation* process, into the agents' rule models [emphasis added]. (Hoffmann, 2006, p. 98)

As it can be inferred from this dense block quote, adaptation is a process that shapes the behavior of agents, meta-agents, and systems. Using the grammar defined in this section, it can be said that whereas agents are the generators of the corpus, adaptation is the grammatical rule under which the generators combine to make a meaningful sentence.

To understand how adaptation works, it is useful to borrow from computer science and look at how adaptive agents are programmed in ABM and other computational models. Agents are adaptive if they can perform three procedures: *performance system, credit assignment, and rule discovery* (Holland, 1995, p. 42). These procedures, which happen naturally and often unconsciously in humans, are useful for the scope of this paper to describe how adaptation occurs at large.

The performance system procedure has already been introduced in the previous section in the form of internal attributes and rules of behavior. To recap, a performance system "specifies the agent's capabilities at a fixed point in time" and what an agent "could do in the absence of any further adaptation" (Holland, 1995, p. 88). In the words of Hoffmann, the internal attributes and rules of behavior:

> Represent the agent's internal (or subjective) understanding of the world (the larger system) around them. They allow the agents to perceive and define their situation, predict the consequences of action, and act. In most applications of adaptive agents, the rules are behavioral, but they can also represent identities, interests, and goals. (Hoffmann, 2006, p. 98)

The second procedure, credit assignment, requires the introduction of the concept of *fitness* in order to be understood. Fitness is a concept that in mathematical genetics is used to represent the "ability of an organism to produce successful offspring" (Holland, 1995, p. 65). In complex systems theory and computer science, fitness is instead used to measure "the overall strength" of an internal rule of an agent (Holland, 1995, p. 65). The underlying idea is that not all stimulus-response rules are equally effective in achieving agents' goals or in guaranteeing their survival. To make an example, if we think in terms of survival of an agent, an "IF I see the cliff, THEN go straight" rule is less fit than one that has an effector that says, "THEN turn 180 degrees."

In order to understand which rules are fit, an adaptive agent assigns credit to each rule based on the payoff received after that the rule has been effected. However, if there is no direct reward after the execution of a rule, an agent is faced with a dilemma regarding credit assignment. If my rival increases defense spending, should I also increase mine in the eventuality of war? If the war never occurs, how do I measure the payoff of rearming vis-à-vis not rearming, or rearming just a little? This is what it is called a credit assignment problem. An agent has to be able to assign credit to rules that (1) have no direct payoff, and (2) are part of a chain of action that is not yet concluded.

In the first case, the problem can be addressed by using a mechanism that in mathematics is described by *bucket brigade algorithms*. This mechanism serves to strengthen the credit of rules that belong to a chain of actions that ends with a good payoff (Holland, 1995, p. 56). For instance, the rule that says "preemptively arm" would be rewarded with a high payoff only if it is part of the chain of actions that has led to the overall survival of the agent. In the second case, since the chain of actions is not yet concluded, an agent has to be able to think and simulate the future. As Holland suggests, he can do so by building internal models and discovering new rules.

Rule discovery creates new internal rules through a process that mimics evolution. This mechanism has well represented Holland's *genetic algorithms*, which serve to combine and crossover rules of behavior to create plausible and fit new rules (Holland, 1995, p. 57). Like in chromosomal crossover, genetic algorithms select couples of high credit rules and then cross them over with elements of randomness to create an offspring rule. In turn, the child rule is evaluated and, if considered strong, crossed over with another rule. Over time, the outcome of this procedure fosters in the selection of new rules of behavior and strategies with high potential.

Explaining in detail how to program an adaptive agent is out of the scope of this paper. The reader will find in the bibliography useful sources that exhaustively explain how to program an ABM with properties of credit assignment and rule discovery. For the scope of this study, what are of interest are the underlying rules of the process of adaptation, which if contextualized to IR can provide novel insights and new understandings. In particular, the concept of adaptation is fruitful to rethink agents' behavior in international politics.

Regarding behavior, one common assumption of positivist IR theory is that humans, and therefore states, are to some extent rational; if not fully, at least in bounded terms. Rationality is in this sense the higher order rule of structural IR theories. For instance, neorealism derives agents' behavior from the system in the assumption that all the units of the system would act similarly if posed is the same situation or under the same system's constraints. Since the assumption of rationality implies that the units of the system share equal internal rules, equal environmental inputs result in equal and static behaviors. As Axelrod argues, rational choice and structural theories assume that behaviors are a given, and do "not worry about where they come from" (Axelrod, 1997, p. 95).

Conversely, in complex systems theory, rationality is not a given, but a construct. Rationality is an abstract concept that agents use to refer to a specific set of rules that they see as fit. However, this specific set of rules is not objective as in structural theories. Instead, it is subjective, or (at best) intersubjective among a defined group of agents that are part of the same breed or niche. Adaptive agents do not share the same set of rules of behavior, nor assign fitness to their internal rules equally. Indeed, depending on coevolution and adaptation, a single rule might have very different levels of fitness among the population (Harrison, 2006a, p. 9). The fitness of rules even changes over time within an agent due to learning and coevolution. In sum, it is devious to talk about rationality, especially in a singular form, because there is no such a thing as a rational or irrational behavior. What we commonly define as rational behavior is a consequence of our actions and not a premise to them. The premise is adaptation: the higher order rule of CASs.

Adaptation allows us to go beyond behavioral assumptions that flatten the heterogeneity of the international system and assume states to be acting under unifying and static principles. Whereas structural theories generalize contextual and particular patterns of behavior to all the units of the system, complex systems theory goes one step deeper and generalizes how behavior emerges among the actors of the system. The difference between the two approaches is fundamental. In neorealism and structural liberalism, maximized power/security and utility are assumed as general behaviors; in complexity theory, they are just some of the emergent behaviors that actors can happen to have. Just as for rationality, those behaviors are a consequence of actions and not a premise to them. They are partially incidental, and partially the outcome of a selection of fit rules made by agents.

In addition, by using the concept of adaptation, agents and systems can be theorized dynamic. Behaviors change over time in a process where evolutionary changes in one agent "induce coevolutionary changes" also in the other agents (Gros, 2011, p. 206). The system itself gains a role that goes beyond the one usually assigned to it by structural IR theories. Not only it acts as a constraint to the agents, as neorealism says, but it becomes a generator for new internal rules of behavior of the agents (Hoffmann, 2006, p. 98; Waltz, 1979, p. 109).

Corpus: Information Processing and Self-Organization

Adaptive agents generate self-organization and entropy-defying behavior at the system level (Mitchell, 2009, p. 40). Self-organization, as previously mentioned, arises from the local interaction of agents with limited information and computational power and creates stable macroscopic patterns at the aggregate level (Epstein & Axtell, 1996, p. 35). It entails that systems themselves compute information.

Organized behavior occurring without centralized control is the outcome of parallel information processing at the individual and aggregate level. Agents process information, as previously explained, by using internal rules of behavior. Information for them is something static and specifically located. It is something that is fed to them or that they retrieve something passive that they can precisely or statically locate in a particular place of the system (Mitchell, 2009, p. 180): a page on the Internet, a book in a library, a law in the civil code. Information, however, comes in another shape and forms at the aggregate and social level.

In biology, information is often referred as "analog patterns distributed in space and time over the system" (Mitchell, n.d.). Instead of being something, static and statistically located, information takes "the form of statistics and dynamics of patterns over the system's components" (Mitchell, 2009, p. 180). Because data are encoded "as statistical and time-varying patterns of low-level components," no single agent "of the system can perceive or communicate the 'big picture' of the state of the system" (Mitchell, 2009, p. 180). In other words, information cannot be retrieved deliberately; therefore, the system has to rely on agents sampling data in a stochastic and decentralized manner (Mitchell, n.d.).

Accordingly, social organizations make sense of system dynamics via agents working together in a "parallel fashion" and acting with elements of randomness (within the boundaries of self-regulation) to sample and explore information across the whole system (Mitchell, 2005, p. 4; Zhong et al., 2005, p. 137). Randomness, in turn, is always adjusted by coevolutionary dynamics and occurs in a back-and-forth of bottom-up and top-down processes that channel agents' behavior. As Mitchell writes:

> As in all adaptive systems, maintaining a correct balance between these two modes of exploration [bottom-up and top-down] is essential. Indeed, the optimal balance shifts over time. Early explorations, based on little or no information, are largely random, unfocused, and bottom-up. As information is obtained and acted on, exploration gradually becomes more deterministic, focused, and top-down, in response to what has been perceived by the system. (Mitchell, 2005, p. 5)

Having discussed what plays the role of information and how information is sampled, the final part of this section addresses what is the meaning of information and why information processing leads to self-organization in the international system. The meaning of information is important because agents decide their course of actions upon it. The meaning is always subjective and contextual; however, agents use shared criteria to assign meaning to information. In biological terms, the meaning of information is tied to fitness and survival. Information *means* something to an agent based on how it affects its fitness (Mitchell, 2009, p. 184). Henceforth, the appropriate response to an input is one that increases the overall agent fitness.

Fitness and versatility in rules of behaviour are what determine the overall fitness of an agent (Holland, 1995, p. 63). Since adaptability is an essential attribute for agents survival, the success of an agent does not derive from its "raw power plus cunning," as social Darwinists and realists believe, but from its ability to cope with the complexity of the system, to process information and discover new fit rules (Clemens, 2006, p. 74). Moreover, agents' fitness are intertwined in a coevolutionary process (Clemens, 2006, p. 75). For instance, in "an arms race, the peaks of a predator and its prey may gain or decline according to changes in their offensive and defensive capabilities" (Clemens, 2006, p. 75). If the attacker gains a new lethal attack tactic, his fitness peak will rise, and the one of the prey will decrease. However, if the prey develops a counter tactic, the peak of the attacker will decrease. Yet, both will be better off than the rest of agents that have not been part of the coevolutionary process, which did not adapt to the new offensive and defensive tactics.

However, the concept of fitness is possible to understand the evolutionary function of self-organization. Self-organization emerges from the coevolution of rules of behavior among adaptive agents as an evolutionary response to the complexity of the system. Via organization, agents are able to process information collectively and increase their computational power. In addition, self-organization increases deterministic and focused behaviors among agents, with the outcome of increasing the overall efficiency of the system (Mitchell, 2005, p. 5). In other words, self-organization acts as a magnifier for coevolution of fit rules among agents.

Social organizations, and in particular the nation-state, are systems with strong self-organization and top-down processes that channel agents into increasingly deterministic and focused behaviors. They have no purpose outside of those defined by their components. Nevertheless, they do have an inherited function, which is one of the favoring coevolutions and promoting fit rules among their population. For example, nation-states execute this function by balancing bottom-up and top-down processes with institutions, unfocused and focused behavior with norms, randomness, and determinism with redistribution.

Conversely, the international system has only a "passive" role in favoring coevolution. Whereas states act as meta-agents to promote fit behavior, the international system is only a place where coevolution takes place: a medium for agents to interact and adapt to each other. System-wide self-organization still subsists, but it is less structured and less resilient. Partially it is so because the system is composed of many different heterogeneous components, each embedded in a different niche and each with its own environmental and social context. In addition, partially it is so because information processing on a global scale is computationally expensive. Which means that information sampling has to rely even more on randomness and loosely regulated explorative behaviors. In this sense, disorder in the international system should not be seen in a negative light.[10] Far from being a source of chaos, self-organized anarchy in the international system bends disorder to generate entropy-defying behaviors.[11]

Conclusion

This paper was set to formalize a complex systems theory approach to the study of international relations. It defined a methodology capable of dealing with the nonlinearity of international affairs and proposed a new taxonomy for the discipline built around core ideas of complexity theory. The study has gone some way toward enhancing our understanding of the international system by proposing an alternative perspective on international affairs that uses the concepts of fitness, adaptation, coevolution, self-organization, and information processing.

The first section looked at the state of discourse in IR and specified why complex systems theory stands out as a viable research method for dealing with the multi-faced complex reality of international politics. As it was pointed out, complexity theory could potentially integrate different IR school of thoughts by using an inside–out view that mixes the ontological perspectives of constructivism and structural theories. Moreover, complex systems theory provides novel analytical tools that could be used to tackle the nonlinearity of social systems, which instead is persistently ignored by traditional IR theories.

The second section introduced the methodology of complex systems theory and agent-based modeling. It defined the properties of a complex adaptive system and described the international system as composed of many diverse, interconnected, and independent agents that iterate nonlinear relationships from which multilevel behavior emerges and evolve. As advocated in this section, IR scholars should make methodological changes in the way they study international affairs. Modeling should shift from continuous to dis-

10 As Walter Clemens writes, fitness is found in the middle ranges of the spectrum between ultrastability (rigid order) and instability (chaos). With "creative and constructive responses to complex challenges [...] more likely to be found close to the edge of chaos than toward the other end of the spectrum" (Clemens, 2006, p. 74).

11 Self-organized anarchy differs from anarchy as conceptualized in neorealism. Whereas both imply lack of central control, only the former assume nation-states to be functionally differentiated within the system. The role of randomness has largely been misunderstood in positivist IR theory and it is one of the reasons why scholars have often been "slipping" between levels. Due to a widespread deterministic-centralized mind-set, there has been a tendency to believe that randomness is disruptive of patterns and that stable organized patters arise under the coordination of a central controller (Waltz, 1979, p. 97).

crete, from linear to nonlinear, from deterministic to stochastic, from abstract to detailed, and from homogeneous to composite (Downey, 2012, p. 4).

The third section introduced a new taxonomy rooted in the propositions of complex systems theory and then used it to reframe the international system. Then it analyzed the granularity of the international system and differentiated between agents (people) and meta-agents (social organizations), explaining that the latter should be studied as structures that have emerged from the adaptive interactions of the former. After having exposed the multilevel nature of adaptive systems, the section criticized the traditional compartmentalization of world politics into levels of analysis, which prevents scholars to see the relationship between microspecifications and macrobehavior.

In the section on the "operators" of the international system, it was inferred that adaptation is the higher order rule that drives agents' behavior. It was suggested that, instead of assuming a unitary (and maybe rational) behavior for all agents, it would be better to assume how behavior is constructed. The section then described how adaptive behavior comes about through the processes of performance system, credit assignment, and rule discovery.

Lastly, the final section looked at the outcomes of adaptive interactions among agents and evaluated what is the function of states and the international system. The research indicated that, in the international system, not only agents process information, but also the system is actively doing so, with the consequence being the establishment of self-organization among agents. One of the more significant arguments made in this study is the one that self-organization is a property of systems that emerges from coevolution of adaptive agents as an evolutionary response that serves to supply for agents' limited resources and foresight.

From this perspective, it was then possible to explain that states are complex systems with strong levels of self-organization and top-down processes that increasingly channel agents into deterministic and focused behavior. Hence, the function of states was suggested to be the one of the favoring coevolutions and promoting fit rules among their population. Conversely, it was noticed that the international system remains only mildly self-organized. With a possible explanation for this characteristic being that disorganized behavior is, to an extent, necessary for the system to process global information, which takes the form of distributed patterns over the system.

Bibliography

Axelrod, R. (1997). *The complexity of cooperation: Agent-based models of competition and collaboration*. Princeton, NJ: Princeton University Press.

Axelrod, R. (2006). Alternative uses of simulation. In N. E. Harrison (Ed.), *Complexity in world politics: Concepts and methods of a new paradigm* (pp. 137–142). New York: State University of New York Press.

Bak, P., Tang, C., & Wiesenfeld, K. (1987). Self-organized criticality: An explanation of the 1/f noise. *Physical Review Letters*, *59*(4), 381–384.

Bhavnani, R. (2006). Agent-based models in the study of ethnic norms and violence. In N. E. Harrison (Ed.), *Complexity in world politics: Concepts and methods of a new paradigm* (pp. 121–136). New York: State University of New York Press.

Boccara, N. (2004). *Modeling complex systems*. New York: Springer.

Cederman, L.-E. (1997). *Emergent actors in world politics: How states and nations develop and dissolve*. Princeton, NJ: Princeton University Press.

Clemens, W. C. J. (2006). Understanding and coping with ethnic conflict and development issues in post-Soviet Eurasia. In N. E. Harrison (Ed.), *Complexity in world politics: Concepts and methods of a new paradigm* (pp. 73–94). New York: State University of New York Press.

Descartes, R. (1637). *A discourse on the method* (I. Maclean, Trans.) (2006 ed.). Oxford: Oxford University Press.

Downey, A. B. (2012). *Think complexity* (2nd ed.). Needham, MA: Green Tea Press.

Dunne, T., Hansen, L., & Wight, C. (2013). The end of International Relations Theory? *European Journal of International Relations, 19*(3), 405-425.

Earnest, D. C., & Rosenau, J. N. (2006). Signifying nothing? What complex systems theory can and cannot tell us about global politics. In N. E. Harrison (Ed.), *Complexity in world politics: Concepts and methods of a new paradigm* (pp. 143–164). New York: State University of New York Press.

Epstein, J. M. (1996). Remarks on the foundations of agent-based generative social science. In K. L. J. Leigh Tesfatsion (Ed.), *Handbook of computational economics* (2nd ed., pp. 1585–1605). Amsterdam: North-Holland.

Epstein, J. M. (2007). *Generative social science: Studies in agent-based computational modeling*. Princeton, NJ: Princeton University Press.

Epstein, J. M. (2013). *Agent zero*. Princeton, NJ: Princeton University Press.

Epstein, J. M., & Axtell, R. (1996). *Growing artificial societies*. Crawfordsville, IN: The Brookings Institution.

Gros, C. (2011). *Complex and adaptive dynamical systems*. London: Springer.

Harrison, N. E. (2006a). *Complexity in world politics: Concepts and methods of a new paradigm*. (N. E. Harrison, Ed.). New York: State University of New York Press.

Harrison, N. E. (2006b). Thinking about the world we make. In N. E. Harrison (Ed.), *Complexity in world politics: Concepts and methods of a new paradigm* (pp. 1–24). New York: State University of New York Press.

Harrison, N. E., & Singer, J. D. (2006). Complexity is more than systems theory. In N. E. Harrison (Ed.), *Complexity in world politics: Concepts and methods of a new paradigm* (pp. 35–43). New York: State University of New York Press.

Henrickson, L. & McKelvey, B. (2002). Foundations of "new" social science: Institutional legitimacy from philosophy, complexity science, postmodernism, and agent-based modeling. *PNAS 99*(Supplement 3), 7288-7295.

Hoffmann, M. (2006). Beyond regime theory: Complex adaptation and the ozone depletion Regime. In N. E. Harrison (Ed.), *Complexity in world politics: Concepts and methods of a new paradigm* (pp. 95–121). New York: State University of New York Press.

Holland, J. H. (1995). *Hidden order: How adaptation builds complexity*. New York: Addison-Wesley.

Holland, J. H. (2013). *Complexity: A very short introduction* (e-book). London: Oxford University Press.

Kauffman, S. A. (1993). *The origins of order: Self-organization and selection in evolution*. New York: Oxford University Press.

Kavalski, E. (2007). The fifth debate and the emergence of complex international relations theory: Notes on the application of complexity theory to the study of international life. *Cambridge Review of International Affairs*, *20*(3), 435–454.

Lloyd, S. (n.d.). *Measures of complexity a non-exhaustive list*. Retrieved November 1, 2015, from http://web.mit.edu/esd.83/www/notebook/Complexity.PDF

Macal, C.M. & North, M.J. (2009). Agent-based modeling and simulation. *Proceedings of the 2009 Winter Simulation Conference*, 86-98.

Macy, M.W. & Willer, R. (2002). From factor to actors: Computational sociology and agent-based modeling. *Annual Review of Sociology 28*, 143-166.

Mearsheimer, J.J. & Walt, S.M. (2013). Leaving theory behind: Why simplistic hypothesis testing is bad for international relations. *European Journal of International Relations, 19*(3), 427-457

Mitchell, M. (2005). *Self-awareness and control in decentralized systems* (Working Papers of the AAAI 2005 Spring Symposium on Metacognition in Computation). *Working Papers of the AAAI 2005 Spring Symposium on Metacognition in Computation*. Menlo Park, CA.

Mitchell, M. (2009). *Complexity: A guided tour*. New York: Oxford University Press.

Mitchell, M. (2015a). *Core disciplines, goals, and methodologies of the sciences of complexity*. Retrieved February 1, 2016, from https://www.complexityexplorer.org/courses/27-introduction-to-complexity-summer-2015/segments/2944

Mitchell, M. (2015b). *Models of biological self-organization, introduction*. Retrieved December 31, 2015, from https://www.complexityexplorer.org/courses/27-introduction-to-complexity-summer-2015/segments/3083

Mitchell, M. (n.d.). *Information processing in biological systems*. Retrieved March 19, 2016, from https://www.complexityexplorer.org/courses/27-introduction-to-complexity-summer-2015/segments/3089

Richards, D. (2000a). Nonlinear modeling: All things suffer change. In D. Richards (Ed.), *Political complexity: Nonlinear models of politics* (pp. 1–22). Ann Arbor: The University of Michigan Press.

Richards, D. (2000b). *Political complexity: Nonlinear models of politics*. (D. Richards, Ed.). Ann Arbor: The University of Michigan Press.

Sandole, D. J. D. (2006). Complexity and conflict resolution. In N. E. Harrison (Ed.), *Complexity in world politics: Concepts and methods of a new paradigm* (pp. 43–72). New York: State University of New York Press.

Santa Fe Institute. (n.d.). *Glossary*. Retrieved November 6, 2015, from https://www.complexityexplorer.org/explore/glossary

Smith, S., Booth, K., & Zalewski, M. (Eds.). (2008). International theory: Positivism and beyond. West Nyack, NY: Cambridge University Press

Vicsek, T. (2002). The bigger picture. *Nature, 418*¸131.

Waltz, K.N. (1979). *Theory of International Politics*. Reading, MA: Addison-Wesley.

Wendt, A. (1987). The agent-structure problem in international relations theory. *International Organization, 41*(3), 335-370.

Wendt, A. (2003). What a world state is inevitable. *European Journal of International Relations, 9*(4), 491-542.

Wilensky, U. & Rand, W. (2015). *An introduction to agent-based modeling: Modeling natural, social, and engineered complex systems with NetLogo*. Cambridge, MA: MIT Press.

Wilensky, U., & Resnick, M. (1999). Thinking in Levels: A dynamic systems approach to making sense of the world. *Journal of Science Education and Technology*, *8*(1), 3–19.

Zhong, N., Liu, J., Jinglon, W., Yao, Y., Lu, S., & Li, K. (2005). *Web intelligence meets brain informatics: First WICI international workshop, WImBI 2006 Beijing, China, December 15–16, 2006 Revised Selected and Invited Papers* (J. G. C. Siekmann & J. Subseries, Eds.), *Lecture Notes in Computer Science*. Berlin: Springer.