From Game Theory to Complexity, Emergence and Agent-Based Modeling in World Politics

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The last lesson of modern science is that the highest simplicity of structure is produced, not by few elements, but by the highest complexity.

—Ralph Waldo Emerson, 1847

... in place of the old local and national seclusion and self-sufficiency, we have intercourse in every direction, universal interdependence of nations.

— Marx and Engels, Communist Manifesto, 1848

Look, you've got it all wrong! You don't NEED to follow ME, You don't NEED to follow ANYBODY! You've got to think for your selves! You're ALL individuals!

— From the "Life of Brian" movie (1979),
http://www.imdb.com/title/tt0079470/quotes

Abstract This chapter examines the complexity of world politics with an emphasis on global environmental issues. Concepts of game theory are reviewed and connected to international relations (IR). Game theoretic models found in IR, such as the prisoner's dilemma, and global environmental negotiations, such as the North-South divide, are presented and discussed. The complexity of world politics, taking place on a highly interconnected global network of actors organized as agents and meta-agents, is presented and discussed as a multiplayer extension of game theory that should not be regarded as a theory alternative to realism but as a novel approach to understanding and anticipating, rather than predicting, global events. Technology, interconnections, feedback and individual empowerment are discussed in the context of the complex world of global politics. Furthermore, evolution and adaptation are related to the concept of fitness and how it may be approached for the case of actors in world politics. Finally, it is suggested that many events of world politics constitute emergent phenomena of the complex international community of state and non-state actors. The presentation is complemented with a review of research problems from the fields of social science, political science, defense, world politics and the global environment that have been

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successfully addressed with agent-based simulation, arguably the most prevalent method of simulating complex systems. This chapter concludes with a recapping of the main points presented, some suggestions and caveats for future directions as well as a list of software resources useful to those who wish to address global problems with agent-based models.

1 Introduction

Lacking a world government, the world is an anarchic community of some 200 sovereign nation-states that strive to survive (Waltz 2008). Wars and conflict erupt as a result of this international anarchy (Waltz 1954). Neorealism (Waltz 2010) asserts that whether the nature of man is flawed (Morgenthau 2005) or not, is of no importance: human nature is not essential to an explanation of conflict. It is the very organization of international relations (IR) rather than the nature of man that determines war (Weber 2009). In response to the international anarchy, states realize that their dominant strategy (to use a game theoretic term) externally is to try to secure their survival by increasing their power; internally, they can afford to focus on quality of life for their citizens (Weber 2009). The Cold War was an example of such a mad spiral in which two global superpowers were trying to outpower one another that as Weber notes, resulted rather surprisingly in a nuclear peace that lasted for almost five decades. Such balance of power arrangements may in fact be more likely to play out in this way when there are only two poles, i.e. the world is a bipolar system. When there are more than two poles, things may become trickier and balances harder to strike.

The unexpected nuclear peace that prevailed in the Cold War and the even more surprising events that have transpired in world politics since then, motivated the author of this chapter to approach the system of world politics from a joint game theoretic and complexity viewpoint. This discussion along with explanation of key elements of game theory is presented in Sect. 2 that contains examples from the field of global environmental diplomacy (Sect. 2.1). In Sect. 3, the author presents complexity science as a multiplayer extension of game theory and argues that many phenomena of world politics may constitute emergent behaviors of the complex global system (Sect. 3.1). Section 4 focuses on simulation and presents agent-based modeling as the premier method of simulating complex adaptive systems (CAS) with a review of key literature publications that have applied agent-based models (ABMs) in problems of social science and world politics (Sect. 4.1). This chapter is rounded up with conclusions (Sect. 5) and a list of resources.

2 Game Theory in World Politics

Cases where a decision making agent is faced with an individual decision and the outcome is not influenced by other agents, are the subject of decision-making. Game Theory examines decision problems where two or more agents (called players) choose between alternative strategies in order to maximize their payoff—this is called rational behavior. Such problems are called strategic games, they can be of simultaneous or sequential movement and they highlight the interactive interdependence of players that together determine the final outcome (Dixit and Skeath 2004). Games are solved when players reach a point of balance, an equilibrium. A small number of equilibrium types constitute frequent solution concepts, including: the dominant strategy equilibrium, consisting of choices that are clearly the best players may achieve; the Nash equilibrium, which is determined by choices that are optimal responses to the selections of the other players; and the focal point equilibrium, which describes an outcome that seems plausible or fair to all players (Schelling 1980). In IR (same source) but also in the business world (Brandenburger and Nalebuff 1996) it has become clear that far fewer games than previously thought are game of pure conflict (called constant or zero sum games), i.e. most games may be directed to outcomes that benefit all players from the distribution of additional value created by smart strategic choices that enlarge the sum of the expected outcomes.

In a newer version of their classic book, Dixit and Nalebuff (2008) present examples from three areas in which game theory is traditionally applied: (a) daily life, (b) business and economics and (c) political science and IR. Attention now shifts to these areas, with emphasis on the latter.

Games in Daily Life

Games are a useful model for the interpersonal relationships of daily life. Stevens (2008) discusses four classic games that he refers to as atomic games, which are particularly suitable for modeling everyday human interaction: the coordination game, the battle of the sexes, the chicken game (in which he who flinches first receives an inferior outcome) and the well-known prisoner's dilemma, a game that illustrates the difficulty of cooperation when individual interests do not match those of the society. Some interesting example games from everyday life that are presented by Miller (2003) include: the interaction between a parent and a rebellious daughter (in which case, it may be advantageous for the parent to pretend that he or she does not love the daughter); the disciplinary style of a young teacher on unruly underage students (where severe disciplinary measures are in conflict with the desire to have them transfer good impressions to their parents); and various negotiation games (in which it may be advantageous, e.g. to discontinue communications temporarily).

Games in Business and Economics

As illustrated in the classic book of Von Neumann and Morgenstern (1944), the broader discipline of business and economic activity is a suitable area for applying game theoretic tools. In their pioneering book, Brandenburger and Nalebuff (1996) analyzed the application of game theoretic models in business and the economy. The basic argument is that when companies try to increase the pie, as when opening up new markets, then it is to their interest to cooperate; when attempting to increase their share of the pie, as when they try to split up existing markets, then it is to their advantage to compete. Hence, the mixed type of business interaction, called co-opetition (i.e. cooperative competition). Other sources analyze numerous examples from the wider field of the economy and businesses at a layperson (Dixit and Nalebuff 1991), professional (McMillan 1992) or college level (Dixit and Skeath 2004). In his video course, Stevens (2008) devotes much lecture time carrying out a game theoretic analysis of pure competition, incentives for increased productivity, oligopolies, bargaining and auctions (a traditional subject of game theory). In an innovative work, Bennett and Miles (2010) show that the approach of one's professional career as a multiplayer game, with the capacity of game theory to model dynamic situations in which the best responses of one player depend on the movements of the other players, allows the extraction of useful conclusions for professionals that are either at the beginning or the end of their career. Finally, in their classic treatise, Fisher and Ury (1999) present a strategic analysis of negotiations as a nonzero-sum game, in which all participants may secure satisfactory payoffs.

Games in International Relations

While Von Neumann and Morgenstern (1944) laid the foundations for the application of game theory in economics, it was Schelling (1980), a Nobel Prize winner that first showed how it may be used as a tool for the analysis of conflict in IR. The Prisoner's dilemma is the best known game theoretic model of transnational cooperation. The original scenario goes like this (Rapoport and Chammah 1965; Axerlod 1985): two suspects, who are not allowed to come in contact, may either keep their mouth shut or confess their crime and give their partner away. If both manage to keep their mouth shut, they are put in prison for a very short time. If only one confesses (the snitch) and the other keeps his mouth shut, the snitch is released while the other goes to jail for a very long time. Finally, if they both snitch, they both go to jail for a moderately long time. Such is the structure of this remarkable game that a powerful outcome emerges in which they both choose to confess, each one in the naïve hope of being released, but since they both snitch on one another, they both go to prison for a moderately long time. An analyst may be pretty confident that they will both select to confess (i.e. snitch) because this is a dominant strategy, and the unfortunate outcome of both snitching on one another is a dominant strategy equilibrium, the strongest solution concept in game theory. This game belongs to the class of social dilemmas (McCain 2004), which are characterized by the existence of a cooperative solution (e.g. both keep their mouth shut) that is distinct from the game equilibrium (e.g. both snitch on one another).

The Cuban missile crisis that transpired in October 1962, is perhaps the international crisis that has been analyzed with game theoretic concepts more than any other crisis in world politics. The governments of John F. Kennedy (from the side of the Americans) and Nikita Khrushchev (on the part of the Soviets) came into conflict for 13 days, which brought the world close to nuclear disaster. In their classical analysis of the Cuban missile crisis, Allison and Zelikow (1999) considered three conceptual policy analysis models for understanding the events: (1) a rational actor model often encountered in the analysis of public policy, (2) an organizational behavior model, which emphasizes the interplay of complex organizational clusters and (3) a governmental policy model that places emphasis on procedures. The authors suggested that all three models are jointly necessary to explain the behavior of the two rival superpowers in the Cuban Missile Crisis. Their innovation lies in the fact that decision-making models are applied to a foreign policy crisis. An elaborate game theoretic analysis of the Cuban missile done by Dixit and Skeath (2004), included a simple-threat model, a model with hard-liner Soviets and a final model with unknown Soviet payoffs. The latter game theoretic model, which was essentially a real-time chicken game (Brams 2005), used Kennedy's estimate that the chances of the blockade leading to war varied from one out of three (0.33) to even (0.5) to calculate the conditions for successful brinkmanship, i.e. gradual escalation of the risk of mutual harm, on behalf of the Americans, rendering a deeper understanding of the crisis and the strategic manipulation of risk it entailed.

Brams (2005) analyzed several cases of national and global politics as bargaining games: the Geneva Conference on Indochina (1954) highlighted the privileged position of the status quo (Zagare 1979); the Cuban missile crisis was regarded a game of chicken (Dixit and Skeath 2004); the Watergate scandal (1973–74) which led to the resignation of President Nixon; the strategy of President Carter at the Camp David negotiations between Israelis and Arabs (September 1978); the role of Kissinger as an arbitrator between Israelis and Arabs during the Yom Kippur war (October 1978); and the role of threats in the conflict between the Solidarity trade union of Lech Walesa and the Government of the Polish Communist Party (1980–1981). Worthy of note is that Noll (2011) favors the use of professional mediation practices in many different types of international conflict. Game theory has also been used to investigate terrorism (Sandler and Arce 2003). Finally, Brams and Kilgour (1988) use game theoretic tools to analyze national security problems, e.g. the arms race (again as a chicken game) or the Star Wars initiative of President Reagan.

2.1 A Game Theoretic Approach of Global Environmental Diplomacy

Having completed the presentation of key game theory concepts, attention now shifts to a game theoretic outline of international negotiations through which the world tries to solve global environmental problems. Such negotiations are usually placed under the auspices of supranational organizations such as the European Union (EU) or the United Nations.

Fiorino (1995) distinguishes three categories of transboundary environmental problems: bilateral, regional and international. As reported by Brandenburger and Nalebuff for the case of businesses (1996), the relationship between national and other agencies of global politics, can best be described as cooperative competition (co-opetition). Transboundary environmental problems such as those related to the anthropogenic contribution to global climate change, conservation of biodiversity, the protection of oceans and the promotion of sustainable development often put countries that are long-term partners and allies, to rival positions on specific environmental issues.

Parties in Global Environmental Negotiations

Susskind (1994) writes that negotiations on global environmental problems take months, years or even decades and eventually culminate in international environmental meetings such as those of Rio de Janeiro (1992, United Nations Conference on Environment and Development, also known as the Earth Summit) or Kyoto (1997, United Nations Framework Convention on Climate Change). Stakeholders in such international environmental meetings include businesses, industries, environmental groups, activists and scientific organizations. Groups not participating in such conferences necessarily rely on representatives to articulate and support their opinion, so meeting participants are under pressure from many interests that want to influence their position. The negotiating committees that represent national agencies receive explicit instructions from the highest levels of their government (such as Brussels or the White House with the assistance of competent environmental government authorities) and often include specialists from these organizations. However, as Susskind mentions, these organizations oftentimes have different agendas and priorities, e.g. Brussels would not want the European negotiating committee to take a position that damages the EU's relationship with allies and partners in other bilateral negotiations such as those on security or economic cooperation. Similarly, an environment ministry wants to ensure that the positions taken by the negotiating committee of its country, comply with applicable environmental laws and regulations and promote the environmental agenda. At the local level, parliamentary or partisan representatives want their opinion to be heard, and may even persist for inclusion in the negotiating committee. When they are present, they may even reject a treaty that could harm their constituency, even if the treaty would benefit the rest of the country or the world, a behavior contrary to the motto of "think globally, act locally".

As pointed out by the same author (Susskind 1994), a host of nongovernmental organizations (NGOs) supplement the actors trying to influence national delegations. Groups coming directly from the grass roots are a strong political force, but rarely exert a direct influence. Extremist environmentalists usually oppose any form of development in areas they consider sensitive. The followers of neoclassical economics and free markets believe that accurate pricing strategies and appropriate financial incentives (rather restrictive regulations) may ensure greater protection of the environment. Consumer protection institutes and left movements seek to ensure that measures to protect the environment do not burden the poor and the weak. Real estate brokers worry that environmental regulations may restrict local investment options in real estate. Bankers are skeptical regarding the impact that actions intended to protect the environmental may have on economic growth. Finally, representatives of scientific groups try to ensure that any political decisions take into account the best and latest research methods and techniques (with a bias towards their own).

To get a sense of the difficulty, it should be kept in mind that global environmental negotiations try to reach an agreement among 170 national delegations, each with its own political agenda, which is in delicate balance with many internal pressures (Susskind 1994). The countries that are represented in the negotiations originate from different geographical regions and political systems: democracies, dictatorships, nations that struggle with poverty and hunger, deprived countries with low per capita income, nations experiencing rapid population growth, newly industrializing countries with little or no enforcement of environmental protection measures and developed countries with elaborate environmental management systems (Rubino 2009). Obviously, the more countries participate, the more difficult it is to reach an agreement. Thus, ambitious plans are often reduced to a small number of real achievements. The conference in Rio, for example, when planned in 1989 by the United Nations General Assembly intended to contain nine individual treaties, which would deal with climate change, transboundary air pollution, deforestation, loss of territories, desertification, biodiversity, protection of the oceans, protection of water resources and, finally, strategies to finance all these measures. Eventually, agreement was reached only on the issues of climate change and biodiversity, with the treaty framework on climate change containing no specific goals or timetable. These are the weaknesses that the 1997 Kyoto summit attempted to correct, although the Kyoto Protocol that was agreed upon, has registered in history as yet another international action in which the world agreed half-heartedly on an extremely costly and inefficient protocol (since the expected delay in global warming by 2100 would be around five years, provided that the Kyoto protocol measures were in full effect until then, as reported by Lomborg 2007), with the United States of America not willing to participate, Canada announcing its retirement on December 12th, 2011 (CBC News 2011) and China and India aware that it was not to their interest to participate. Naturally, the Kyoto accord had strong communication value in local political audiences. Later on, attention shifted to Copenhagen (2009), Cancun (2010) and, lately, Durban (2015), which have undertaken the onerous task of keeping the Kyoto Protocol alive, despite its significant failings (Boehmer-Christiansen and Kellow 2002).

Games in Global Environmental Negotiations

Having presented and described the participants of international environmental negotiations and highlighted the complexity of the relations among them, the focus now shifts to a few appropriate game theoretic models for these negotiations. International negotiations, trying to solve environmental problems of global concern, target the waste of shared natural resources, such as the oceans, the atmosphere or biodiversity. Like the services provided by a lighthouse or national defense, such common natural resources are pure public goods, i.e. (a) they are not traded in markets, (b) the services they provide cannot be allocated to individual portions nor do they decrease with increasing consumption (because of zero marginal cost), and (c) no one can be excluded from using them (Pirages and Manley DeGeest 2004). The overuse of natural resources, a phenomenon named the Tragedy of the Commons by Hardin in his pioneering work (1968), is understood to be a classical prisoner's dilemma game in which players fail to comply with an agreed cooperative solution (which is the most beneficial to society) because breaking their agreement is a dominant strategy for each of them individually (as long as the others comply with it); the problem is that everyone ends up breaking the agreement and the society is worse off for it. In other words, the nature of this game creates free riders, who enjoy the provision of public goods without fulfilling their agreed obligations. Free riding countries pollute the environment, hoping that other countries will comply with international agreements and bear the costs of remediation. Environmental problems such as air pollution, loss of biodiversity and overfishing (e.g. in South America and Asia) arise in this manner.

The task of analyzing global environmental problems with game theoretic concepts is an interesting task (Finus 2001). Susskind (1994) analyzed the diplomacy of international negotiations on global environmental problems (such as those concerning the ozone layer and global climate change) and found that these negotiations included five specific types of confrontations involving: (1) the rich North against the poor South countries; (2) countries having lax environmental regulations and acting as pollution havens; (3) idealists against realists (as regards their expectations on what constitutes reasonable progress in the solution of global environmental problems); (4) optimists against pragmatists (as regards the improvements in environmental quality); and (5) reformers against conservatives (mainly in reference to the structure of the United Nations). These confrontations constitute games, i.e. interactive decision making by actors that try to maximize their payoffs. Of these, the first four are of importance in the context of this chapter and are considered in the following paragraphs.

The Rich North Versus the Poor South

The first and perhaps the most powerful game governing international environmental negotiations is that in which the rich North is pitted against the poor South hemisphere of the earth. Conflict is caused by the difficulty of maintaining a working relationship among the developed countries of the North and the developing countries of the South because the North seems to deny the dream of economic growth and prosperity to the South for the sake of conserving resources and maintaining the quality of the global environment (essentially in order to ameliorate the global climate change). Developed countries have typically resolved many environmental problems through economic growth, as provided by the theory of Environmental Kuznets Curves (EKCs; Grossman and Krueger 1991). In many of the least developed countries, public interest in environmental quality is not seen as a priority, compared to nutrition and survival problems, a reality no doubt made worse by the global economic recession. This divide between the north and the south makes progress on global environmental issues particularly difficult. The challenge lies in recasting this multi-country (i.e. multiplayer) game of conflict in win-win terms so that a cooperative solution may be arrived at for the benefit of the global man-made and natural environment.

Pollution Havens

The second game that may be distinguished in international environmental negotiations is the phenomenon of pollution havens (Neumayer 2001). Some developing countries deliberately loosen up environmental standards in order to attract foreign investments. Thus, these countries gain a competitive advantage over countries that implement stricter environmental regulations. In this complex multiplayer game, businesses and economically developed countries export their wastes to pollution haven countries that are in a position to provide much more inexpensive environmental compliance oftentimes at the cost of the quality of life of their citizens.

Idealists Versus Pragmatists and Optimists Versus Pessimists

The third and fourth game theoretic models that may be recognized in international environmental negotiations, are these in which idealists confront pragmatists and optimists are opposed to pessimists (Susskind, 1994). Actors characterized as idealists are not in favor of environmental agreements or treaties that fail to promote sound environmental management and achieve substantial improvements in environmental quality. They think that a non-deal is better than a weak and abstract deal that essentially allows politicians to continue communicating empty promises, avoid actual obligations and allow problems to remain unresolved, leading to environmental degradation. From another point of view, actors identified as pragmatists believe that every effort, even a moderate one, is an important step in the right direction and consider even the meeting and commingling of official delegations to discuss environmental issues, to constitute progress even if no agreement is reached at; furthermore, they consider even purely symbolic statements from countries to be valuable because they put pressure on reluctant leaders. A great example of the pragmatist viewpoint was given by an Al Jazeera article (Kennedy 2015) in which Professor Carlos Alzugaray of the University of Havana was quoted as saying "*I am an optimist. If you take out all this noise surrounding these talks, the fact remains that there are officials on both sides engaged in discussions on many different issues. Just to have these people in the same room working towards common goals is a good thing and is hopeful.*" Pragmatists believe that a weak agreement can always be enhanced later—the important thing is to have one, anything instead of a failure to reach a deal. As Susskind mentions, sadly, many pragmatic international agreements have failed to produce any substantial improvement because the cooperation of the international community takes so much time that the environmental protection measures originally proposed, no longer make sense, as when efforts to protect a particular habitat become meaningless when the protected species disappear. The other game, of optimists versus pessimists regarding the range and the prospects of global agreements that aim to improve in environmental quality, is of a related nature and concerns the process more than the substance of such global bargaining.

Deviations from Perfect Rationality

Having introduced a game theoretic perspective to international environmental negotiations, some findings are now reported that shed light into deviations from the assumption of (perfect) rationality, a keystone principle of Game Theory.

Fiorino (1995) mentions four models from the field of administrative theory that are particularly useful in understanding how environmental policy is actually produced: the institutional, the systems, the group process and the net benefits model. The institutional model is the oldest one and it is limited to the examination of the legal aspects of public policy, focusing on institutions, laws and procedures. The systems model is inspired by the analogy between social and biological systems, and analyzes the behavior of an organization by examining its inputs, its outputs and the internal processes that transform inputs into outputs. The group process model, which dominated political science for much of the 20th century, considers special interest groups to be the fundamental unit of analysis, politicians to mediate the competition among these groups, and politics to be the product of this competition. Finally, unlike the group process model that is derived from the field of political science, the net benefits model hails from the field of economics and considers politicians to be analysts who take those decisions that maximize utility to society. Further to these models that put the process of global environmental negotiations in a realistic frame of reference, Fiorino further suggests that the concepts of bounded rationality (Simon 1957, 1991), incrementalism (Lindblom 1959, 1970) and the garbage can model (Cohen et al. 1972) are especially useful in understanding how decisions are taken in practice. All of these conceptual approaches suggest that real decisions are made under conditions of limited rationality and incomplete information, a fact confirmed by empirical findings in areas of social psychology and behavioral economics, as outlined below.

On an individual level, it is impressive to consider than decision making is often done unconsciously (Damasio 1994), which evidently means that neither unlimited rationality nor complete information constitute appropriate assumptions in interpersonal communication and negotiations. The picture is further complicated by the fact that communication is often blocked by the intensity of a conversation (Patterson et al. 2002), or that much of the information is not included in the classic channels of oral or written communication, but transmitted through body language (Navarro and Karlins 2008). Such asymmetries are often created in the communication between people of different gender and constitute additional communication channels that transmit information as meta-messages (Tannen 1990). It is even more impressive to consider that decisions are oftentimes shaped not just subconsciously, but within seconds, and may be more informed than a person would tend to think (Gladwell 2005). An interesting example is narrated by Lehrer (2009): a Lieutenant Commander monitoring a radar in the 1991 Gulf War became subconsciously aware that a radar blip was a hostile Silkworm missile (rather than an American fighter jet) and issued the correct command for the target to be fired upon, long before he realized that this was due to an imperceptible discrepancy in the way the blip appeared in radar sweeps that was indirectly related to its altitude. While the above points concern individual decisions, it is reasonable to assume that they also influence decision-making in groups (Baron 1998), such as those of the actors participating in international environmental negotiations.

A final point of interest regarding deviations from perfect rationality, relates to the influence of individual decisions by some rather unexpected external factors predicted by influence science (Cialdini 2009), which shows that people (and not only animals) make heavy use of automatic responses as a way of dealing with everyday complexity and the demand it places on brain activity for rational analysis on an almost continuous basis. Cialdini writes that such automatic responses are generated by the following six principles of persuasion: (1) reciprocation to those who have already benefited an actor, (2) consistency with the prior commitments of an actor, (3) social validation, i.e. compliance with widespread societal practices, (4) readier acceptance of parties that an actor likes and feels friendly toward, (5) obedience to what an actor perceives as power and authority, and (6) preference for what appears to be scarce. If used strategically by an actor, these influence mechanisms can be quite transparent to other parties so they may well constitute formidable weapons in negotiations (Goldstein et al. 2008), especially in those taking place in the context of international environmental policy where, as mentioned previously, participants are involved in games of incomplete information (Alterman 2004; Mearsheimer 2011).

The aforementioned deviations from the assumption of perfect rationality make a player select outcomes with suboptimal payoffs; in fact, as explained by Ariely (2008), not only do players commit such systematic errors, they repeat them in a predictable way. To the important question of whether such individual judgment errors are conveyed to a collective level, Baron (1998) responded positively by employing concepts of social psychology. Baron showed that several judgmental rules, on which people tend to rely to make decisions at an individual level, have an impact on society and policy making. For example, people prefer inaction to actions that are very likely to generate significant benefits, but have an improbable chance of bringing about gravely negative effects as when, e.g. parents hesitate to have their children vaccinated against influenza. People also prefer to avoid disrupting the status quo or anything that is perceived as environmentally natural. Finally, people tend to decide and act in a way that favors the nations, the tribes or other groups to which they belong, even if that harms third parties belonging to groups that are foreign or unrelated to them. Use of these judgmental rules, affects public life and leads to suboptimal collective decisions. Baron asserts that such systematic judgmental errors play a role in gender issues, religious conflicts, resistance to change, nuclear energy policy as well as global environmental concerns such as overfishing and global climate change.

In closing this section, it is pointed out that international environmental problems such as global climate change are characterized by considerable scientific uncertainty, which surely affects their solution by bargaining. Baron (1998) stresses the uncertainty in the forecasts for global climate change expected from man-made global warming, and compares this problem to that of the ozone layer, where the international community was in possession of actual measurements of the formed hole instead of mere predictions of computer models (as in the case of greenhouse gases).

This scientific certainty may have contributed to the speed and efficiency that characterized the cooperation of the international community on the issue of the ozone hole. On the other hand, global climate change is related to carbon dioxide (CO_2) emissions, which in turn are related to the economic development of countries. Indecision characterizes the global community in its effort to combat global warming which surely has more complex economic and political dimensions than the problem of the ozone layer, despite that fact that, as Schelling (1992) warned, the world should be prepared for adverse consequences possibly even greater than those provided by the models.

3 From Game Theory to Complexity

Game theory that was discussed in the previous sections, typically analyzes games of a few players and then attempts to generalize its conclusions to systems of more actors. Yet, the world is a system of many actors, including some 206 sovereign states (http://en.wikipedia.org/wiki/List_of_sovereign_states), supranational entities such as the EU, North American Free Trade Agreement (NAFTA) and the United Nations (UN) as well as many more non-state actors and institutions. Furthermore, constructing game theoretic models of global problems, i.e. representing global affairs with the payoff matrices of game theory, is not trivial because alternative strategies are not known in advance and specific payoffs may be difficult to quantify. So it is tempting to consider that the global community constitutes a multiplayer arena that operates as a Complex Adaptive System (CAS) and examine whether such a complexity approach leads to a complementary research approach that may be of use in the study of world politics.

The Interconnected World as a Complex System

Based on his past experience at the World Economic forum and the Monthly Barometer, Malleret (2012) writes that the global community of 7 billion people and over 200 nations has become a turbulent arena of volatility, random events, uncertainties and challenges that are impossible to predict. Crises that succeeded one another and propagated beyond national borders include the US subprime lending, the EU sovereign debt, the Arab Spring and the nuclear capabilities of Iran. Malleret warns that the world is changing from a world of measurable (economic, geopolitical, environmental, societal and technological) risks to a world of discontinuous uncertainties that cannot be known in advance and cannot be measured. The world of the mid 21st century will likely bear few similarities with the present.

As noted by the naturalist John Muir, everything is linked to everything else in the universe. Indeed, the overriding characteristic of today's world is its interconnectedness. Global affairs are multidimensional, interconnected, interdependent and dominated by a multitude of cross-border relationships (Harrison 2006a). Social, political, and economic phenomena are increasingly being viewed as CASs. In fact, the global community is considered to have become not just a complex system, but a system of complex systems where everyone is interconnected to everyone else and the whole is greater than the sum of its parts (Christakis and Fowler 2011).

How easy is the study of such a complex global network? Complexity breeds more complexity because an arithmetic increase in the number of system elements leads to a geometric increase in the number of potential links and to an exponential increase in the number of possible patterns (Malleret 2012). It is not surprising then that complexity taxes the capability of analysts to understand systems and overwhelms the capabilities of politicians to analyze problems and suggest appropriate policies to solve them.

Jervis (1997) adopts a systemic approach to international politics and asserts that the social and the political life constitute complex systems with many emerging phenomena being unexpected consequences of complexity. Jervis also suggests that most social phenomena are determined by the choices and interaction of individual actors rather than at a systemic level, thus providing support to a multiplayer game-theoretic, i.e. a complexity science approach to the study of world politics. The anarchic global community may be considered a complex system in which states are agents that compete for power and security. Both regularities and non-regularities may result from such a complex global system, affected by things such as the location and the structure of system components. Furthermore, the global community constitutes not just a complex system, but a complex network, in which states exhibit memory, i.e. their behavior is influenced by their past experiences with the interaction among IR agents (memory or feedback) as well as what takes place in another part of the world (knock on effect).

Complexity, Realism and International Anarchy

In the opinion of the author of this chapter, complexity science does not (and probably cannot) constitute a paradigm shift in IR, i.e. it does not challenge, attempt to modify or even supplant established theories such as realism, constructivism or idealism. If anything, complexity may be useful as a tool that allows a better understanding of the phenomenon of international anarchy explained by realism and neorealism. In fact, an agent-centered approach (in the spirit of CAS) may suggest that, like altruism, the efforts to explain global politics with reference to an idealistic worldview are in fact confusing idealism with enlightened self-interest: unrelated agents may choose to ignore Machiavelli's advice (that a prince must learn how not to be good) and realize that they may benefit from cooperation as long as there are mechanisms in place to encourage reciprocity and punish cheating and free-riding (Harrison 2006a).

Getting into a bit more detail in IR theories, materialistic realists assume that political actors pursue power and wealth while idealists that humans should be guided by ideals. Whichever is the case, complexity science sees the actors of global politics (i.e. agents and assemblages of agents referred to as meta-agents) as closely linked and interdependent, in a position to both aid and harm one another (Harrison 2006a; Keohane and Nye 2012). The links that connect them are multiple and interwoven in a complex way, fostering relations among the actors of world politics that are nonlinear and unpredictable. One could argue that both elements of realism and idealism are required to explain developments in regimes such as environmental protection, where on the one hand Singer's deep ecology has introduced environmental assessment and Environmental Impact Statements (EIS) while, on the other hand, states play a prisoner's dilemma game as they try to talk the talk, but avoid walking the walk, i.e. adopting substantial measures that can curb anthropogenic climate change (Harrison 2006a).

The different IR theories in existence underscore the fact that IR scientists hold different opinions on the identity of the basic actors of world politics, the relevance of their interactions as well as the appropriateness of methods to study them. It is not surprising then that some eminent scholars do not consider that a complexity approach is a fruitful approach to the study of global affairs (Earnest and Rosenau 2006). Nevertheless, important scientists such as Nobel laureates Murray Gell-Mann, Kenneth J. Arrow as well as Schelling (2006) have invested efforts in complexity science, believing it to hold great promise for the analysis of IR (Harrison 2006b). As the various flavors of realism and idealism attempt to describe aspects of IR, they may benefit from attempts to provide a more comprehensive picture, a task made more difficult by the rise of nonstate actors and the interconnectedness of the world that is facilitated by the socioeconomic process of globalization and technology transfer (Binnendijk and Kugler 2006).

The author of this chapter believes that neorealism remains the most convincing conceptual model of world politics. To the state actors of this classical approach, complexity science adds an array of other agents that jointly determine the state of affairs in the world: great individuals, important groups of men as well as aggregations of nonstate actors at various levels (Harrison 2006a). So, complexity may be a fruitful methodological approach to the study of world politics with international anarchy being regarded as an emergent property of the complex global system.

Complexity and Technology

Global affairs are not optimization problems to be solved by a mathematical algorithm (Harrison 2006a). Unforeseen innovations become personal, economic, scientific, technological, cultural and political game changers and make predicting the future impossible. Reductionist approaches are suited to linear systems and are inappropriate in the nonlinear behavior typical of a highly interconnected complex system. As Malleret (2012) points out, radical shifts occurring in the fields of geopolitics, economics, society, energy and natural resources are all underscored by momentous technological advances in the form of waves changing the face of the planet and posing unprecedented challenges to world leaders. As the world becomes more connected in an accelerating fashion, the multiple intersecting links create a highly dynamic decision making context for global political leaders, policy and opinion makers as well as CEOs of multinational companies. The resulting complexity is that of a global network that is beyond hope of understanding with traditional linear thinking.

Technology has played a very important role in making the world a highly interconnected and interdependent complex system. Information and Communication Technologies (ICT) have formed a complex, dynamic global system containing billions of entities that interact over multiple spatial and temporal scales (Malleret 2012). Education and knowledge transfer has been globalized, books have become e-books and are purchased and downloaded instantaneously, product and industry life cycles have been shortened and financial markets react immediately to almost everything that happens. This has resulted in an information overload that has put the modern man in a situation not unlike that of one trying to drink from a fire hydrant, more likely to lead to info-paralysis rather than a solution, as aptly pointed out by Malleret.

Global trends are more often than not difficult to predict and, with hindsight, technology is a factor whose impact on economics and society has always been near impossible to predict, e.g. no one in the 1930s or 1940s could have foreseen how personal computers and telecommunications would change the world (Harrison 2006a). The advent of the Internet and the World Wide Web were momentous developments that opened up new possible futures that contained services like file sharing, email, search engines and social media that catalyzed the occurrence of important regional events such as the Arab Spring. The nature of world politics is such that laws, regulations and policies are mediated by socioeconomic conditions and technology and create adjacent possibilities (i.e. alternative futures) that cannot be known in advance, which means that it is very difficult to govern wisely or select those foreign policies that constitute the best responses to future events (Harrison 2006a).

Complex Systems are Interconnected and Interdependent

Complex systems are predominantly systems of interconnected and interdependent components. Herbert Simon said that a complex system is "made up by a large number of parts that interact in a nonsimple way" (Simon 1962). As Malleret (2012) writes, complexity is analogous to the number of components of a system, the interconnectedness of these components and the nonlinearity of the elements of the system. In a complex system, it is typical for changes in one component of the system to lead to unexpected and surprisingly disproportionate effects elsewhere, e.g. the Fukushima nuclear accident impacted the energy policy of European countries such as Germany. Causality is present although hidden and difficult to establish in complex system.

In the 2007 annual meeting of the World Economic Forum, Tony Blair called interdependence the defining feature of the 21st century while Thomas Freedman of the New York Times called the world hyper-connected (Malleret 2012). Professor and former diplomat Kishore Mahbubani coined an apt metaphor for what he called the greatest transformation ever, saying that the world used to be like 170 distinct ships while now it is like 193 cabins on the same boat at sea (New York Times editorial, August 18, 2011). In such a world, assessing issues in isolation (called silo thinking), a remnant of the past, is part of the reason that major crises such as the current global recession or the Arab Spring were not predicted. One of the consequences of this closely knit interdependence is that a complex system points to so many alternative possibilities that any meaningful prediction of the future is nearly impossible (Malleret 2012). Since prediction is impossible, anticipation is the optimal strategy of world leaders.

World politics take place against the backdrop of an extremely complex web of causal links, connecting a multitude of economic, geopolitical, environmental, societal and technological activities. The fate of any single actor, such as a country, is subject not only to its own choices but to the choices of other actors as well (Malleret 2012). In such a complex network, Malleret writes that risk is systemic, e.g. it is often the weakest link that brings about a system-wide crisis such as Greece (a seemingly insignificant player in terms of size) in the recent Eurozone crisis. Another similar example is provided by the United States and China that are interdependent in a very complex and deep way (Harrison 2006a). On the one hand, China has a huge population of hardworking people, but a poor resource base and possibly a diminished moral and political code. On the other hand, the United States possesses vast hard and soft power assets, but suffers from a growing deficit of wisdom and smart power. As Harrison points out, the two countries could build on their complementary need and maintain peace or enter into conflict, with neither course being predetermined nor predictable.

The web of interconnections among the 206 states of world and the thousands of non-state actors, produces a CAS. What happens at borders is very important for the functioning of a CAS (Holland 2012). Such interconnections include many types of cross-border relations, from individuals to states and the transnational level. Although scholars such as Jervis (1997) have analyzed system effects, the full explanation of cross-border complexity remains a difficult undertaking. In global politics, there are complex multilevel interactions of agents such as individuals, special interest groups, non-governmental organizations (NGOs such as Greenpeace), multinational companies (such as Toshiba or 3M), terrorist organizations (such as Al Qaeda), social classes, entire societies, political parties, governments, states, entire civilizations as well as international and transnational organizations (such as the EU or the United Nations) (Harrison 2006a). The effects of these interactions are further complicated by nonlinear responses and positive feedback loops.

Characteristics of Complex Systems

Many of the observations made in the previous paragraphs are summed up in an interesting fashion by Malleret (2012), based on his experience at the World Economic forum and the Monthly Barometer. Malleret argues that four forces constitute the key characteristics of the global community today: interdependence, velocity, transparency and immediacy. It is through the continuous and cumulative action of these forces that the global community exhibits the nonlinearity typical of complex systems, e.g. shocks propagate surprisingly fast and minor causes bring about major impacts oftentimes in a dramatic fashion. Malleret writes eloquently that velocity and immediacy, mediated by information and communication technologies (ITCs) especially the Internet, have created a "dictatorship of urgency" that runs financial markets, geopolitical upheavals, regional as well as social discontent (e.g. the Arab Spring) fast forward and allow no time to pause and ponder over developments. The effects of velocity and immediacy may be discerned in business and economics (e.g. just-in-time supply chains, high-frequency trading, news traveling around the world instantaneously, electronic books being bought and downloaded immediately) and have even spilled over into social life (e.g. fast food or speed dating). As Malleret says, as the economic value of time has increased, so has its economic scarcity. While technology and the Internet created velocity and immediacy, the social media fathered transparency which, in turn, fostered more interdependence and complexity (by exposing all dimensions and participants of current events, activating even more links). In particular, as Malleret observes, the Internet makes the younger generation (that is more adept at using it) more aware of the corruption of its leaders and facilitates the organization and orchestration of its reactions (as in the case of Tunisia and Egypt). Social media has been vested with the power to transcend occasionally the power of authorities and even the government and that is why anxiety about the social media is evident in countries such as Saudi Arabia and China. Transparency has also limited the confidentiality of many activities, forcing even Swiss bank accounts to divulge information about their clients to inquiring foreign authorities or governments. Not to mention that there can be no privacy on the Internet as long as every move of Internet users is worth something to someone and thus tracked systematically (Malleret 2012). Malleret recaps his presentation by arguing that these four characteristics of today's world have brought about confusion, a multitude of weak signals as well as asymmetry and have underscored the global government vacuum.

The behavior of a complex system emerges from the interaction of its elements (Casti 1994; Holland 1996; Levin 1999). The elements of a complex system adapt to the actions of other elements and their environment (hence such complex systems are referred to as CAS). CASs typically operate several positive feedback loops (based on memory and historical analysis), which cause small-scale disturbances to be amplified to large-scale effects. Because the interactions among the elements of a complex system are nonlinear, study of their components in isolation cannot be used to predict their outcomes (Hendrick, 2010). Harrison (2006a) essentially agrees with Hendrick, arguing that the complexity science approach considers world politics to be unpredictable in part due to chaotic dynamics, positive feedback mechanisms and the surprising power of small events. With the aid of the right tools (such as agent-based modeling, discussed in a following section) patterns may be discerned in the turbulence of world affairs and be used to understand the presence and anticipate (if not predict) the future.

There are quite a few celebrated examples of complex systems such as the weather, a beehive, or the human brain, which appear to defy a reductive approach in part because of the presence of nonlinearities. In most complex systems, outcomes are not proportional to causes and systems cannot be understood by analyzing their parts (Kauffman 2008). Nonlinearities interfere with a linear approach to aggregation and make the behavior of many complex systems more complicated than predicted by summing up the behavior of its components (Holland 1996). While linear systems are near equilibrium, complex systems typically exhibit nonlinear behavior that is far from equilibrium. Data collected from nonlinear systems typically are not normally distributed, i.e. they do not adhere to the familiar bell-shaped distribution associated with linear systems (Rihani 2014) and they tend to render quite a few outliers, making nonlinear systems less predictable. This uncertainty appears to constitute an essential part of phenomena that are now described as nonlinear.

Interestingly, although most complex systems do not exhibit linear behavior, they appear to be characterized by economies of scale, e.g. as cities expand, there are fewer gas stations per capita; and as the number of consumers increases, the length of power lines needed to serve consumers decreases (Harrison 2006a). Holland (1996) argues that another important effect of complex adaptive networks is recycling, which occurs as flows are recycled at some of the nodes of a complex network. The overall effect of many such recycles can be unexpected and contributes to the irreducibility and nonlinearity of complex systems. Furthermore, complex systems oftentimes create situations of asymmetric information, where one party is in possession of much more knowledge of the specifics of a situation than the other party and may use this asymmetry to its advantage (Malleret 2012). Cyber conflict epitomizes the power of asymmetry, which is the reason that much of what happens in the world today is beyond the control of even the most powerful states.

The maxim that complexity is the enemy of control rings true as CASs appear to be both robust and fragile and are characterized by tipping points, i.e. levels after which cascading effects are kick started by connections that used to absorb shocks, but after a certain point become shock multipliers. The behavior after a tipping point is further amplified and accelerated by positive feedback, another hallmark of complex systems. The entire process may be dynamic in a nonlinear and chaotic manner that is typified by the unexpected occurrence of rare phenomena with dramatic impacts. Taleb (2007) uses the term black swans to refer to such exceptional critical events that appear to occur with a probability higher than expected (i.e. they correspond to thick tailed distributions), making successful prediction more difficult. World affairs are often determined by such unlikely and unprecedented critical events that show up unexpectedly (like “fifty-year floods”) like the First World War (Harrison 2006a). The same source describes how in a complex world dominated by chaos and uncertainty, agents and meta-agents (populated by people and institutions) have to face (and try to avail of) shocks caused by such unexpected developments.

Complexity Empowers the Individual

Another important aspect of complexity is that it empowers the individual. It is difficult to deny the influence of individual men on global politics (Harrison 2006a). In their classic analysis of the Cuban missile crisis, Allison and Zelikow (1999) focus on system-level and state-level explanations although it is not difficult to agree that other alternative possibilities might have opened up if Nikita Khrushchev, the Kennedy brothers and Robert McNamara were not present. In a similar vein, it is difficult to imagine how the 20th century would have played out without Hitler, Mussolini, and Stalin, but not difficult to agree that it would not have been the same (Harrison 2006a). A final example of how a personal relationship may have facilitated state politics is given by the evident existence of good chemistry between Papandreou and Netanyahu, Prime Ministers of Greece and

Israel correspondingly (Tziampiris 2015) that appears to have helped move the Greek-Israeli relationship forward. While these examples stress the importance of the actions of individual actors in a complex world, this argumentation is not to say that the complexity science approach to world politics accepts any monocausal model of the behavior of states and other actors (Harrison 2006a): on the contrary, complexity implies that most events are due to multiple causes and it can be very difficult to disentangle the influence of each individual cause.

Evolution and Adaptation

As the Nobel laureate Gell-Mann has reported, complexity has a tendency to grow over time. This happens with small changes that occur in the behavior of individual agents as they interact locally and adapt their rules according to the input they receive from their environment (in order to maximize their payoff, which may equal power or the possibility of their survival or that of their offsprings). As Harrison puts it (2006a), a fundamental pattern of CASs is to evolve by combining new and old building blocks and thus form unexpected emergent properties and new adjacent possibilities, i.e. alternative futures. Evolution itself is complex and even shaped by co-opetition, i.e. the simultaneous cooperation and competition of actors depending on the circumstances (Bradenburger and Nalebuff 1996; Minelli and Fusco 2008; Flannery 2011). Furthermore, the direction of evolution is impossible to predict as each adaptation opens the way to additional alternative possibilities and innovations (Harrison 2006a). As an example, consider how mainframe computers gave rise to portable computers which, in turn, opened the way to mobile telephones, the Internet, social networking and the Arab Spring. As complexity grows and deepens, it tends to breed yet more complexity and it is very difficult to predict how evolution will proceed in technological, social and political systems.

Evolution and adaptation characterizes CASs, i.e. complex systems that evolve and adapt over time. As Holland (1996) reports, the timescale of adaptive modifications varies from one system to another: while in CASs such as the central nervous system or the immune system, adaptation takes seconds to hours or days, in the field of business and economics it takes months to years while in ecology and the environment it takes days to years or even centuries. CASs may be viewed as systems composed of interacting agents whose behavior may be described with stimuli-response rules (Holland 1996). These agents can adapt to their environment, which includes other adaptive agents, by changing these rules as experience accumulates. When agents learn from their environment and modify their behavior, the system itself is modified. A large portion of an agent's time is spent adapting to other agents that are themselves adaptive (Holland 1996). All of the above imply the existence of multiple feedback loops in CASs that beget nonlinearity and the emergence of large-scale aggregate patterns that are impossible to predict by examining the behavior of an individual agent.

Holland (1996) writes that the behavior of CASs is determined more by the interactions among the agents rather than by their individual actions. Also, many CASs display an amplifier effect (related to nonlinearity): a small input can bring about major impacts. Nevertheless, researchers at the Santa Fe Institute believe that there are general principles that rule the behavior of CASs and that these principles may point to the way of answering questions and solving problems related to such systems (same source). Indeed, the world may be thought of as a CAS in which actors, i.e. agents of world politics, continuously adapt their behavior to the external signals they receive. In such a complex world, even a relatively small event may propagate like a contagious disease and end up being the main cause of consequences disproportionately big. In politics, uncertainty (amplified by complexity and fear) and nonlinear dynamics play a significant role as events unfold (Malleret 2012). Important questions must be answered such as: Is increasing complexity a sign of successful adaptation? Is greater complexity good or bad in IR? Is greater complexity a sign of stability, as in biodiverse ecosystems?

Evolution and Fitness

The complexity science approach essentially introduces concepts of adaptability, evolution and fitness to the analysis of world politics (e.g. Kauffman 1993 and other works associated with the Santa Fe Institute). Fitness results from evolution and measures the ability of states to cope with the complex global community (Harrison 2006a). As Nye points out (2011), the fitness of states and other global community agents entails the smart power that manages to amalgamate aspects of both hard and soft power into wise policies.

Harrison (2006a) mentions that fitness may be defined as the capacity of an actor to cope with complex challenges, secure its survival and advance other interests. The optimal fitness of every organism, including whole societies and the international system, is located somewhere between rigid order and chaos (i.e. anarchy in politics) but nearer to the edge of chaos (same source). Harrison also argues that fitness results from self-organization and creative responses to complexity rather than from conflictual, zero-sum approaches to problems. An agent or meta-agent that is fit, is one that thrives on the complexity of the global community.

How can fitness be measured? Harrison (2006a) argues that societal fitness may be defined as the ability to cope with complex challenges, which may be closely associated with culture, i.e. the values and way of life of each society. Some cultures may enable outstanding individuals to rise while others may suppress them; some cultures may make excellent use of their resources, while others may waste them. Harrison also suggests that quantitative measures of fitness of countries could be estimated with data such as the United Nations Human Development Index (HDI, measuring longevity, education, and income), rankings of democratization, honesty, the extent of knowledge-based economics from Freedom House, the Bertelsmann Foundation, Transparency International and the Harvard-MIT Index of Economic Complexity. Harrison further suggests that a top-down dictatorial rule with a rigid hierarchy may imply low fitness while a democratic self-organization that fosters creativity and mutual gain may be associated with high fitness. On the other hand, Malleret (2012) argues that the quantification of the fitness of state actors may not always be helpful, e.g. it is difficult to conclude that Italy (that has had about 60 changes in its governmental regime since the Second World War) is less stable than Saudi Arabia that has been run by the same family for the last 40 years.

Complexity and Future Trends of the Global Environment

What about the interplay between anthropogenic activities and the natural environment in the complex global community for the rest of the 21st Century? Malleret (2012) asserts that the following six trends will shape the future of the global community: (1) unfavorable demographics, (2) resource scarcity, (3) climate change, (4) geopolitical rebalancing, (5) indebtedness and fiscal issues as well as (6) rising inequalities.

Unfavorable demographics affect both developed and developing countries, as societies trend towards the feared 4-2-1 paradigm, i.e. one working young adult supporting two parents and four grandparents. A chronic shortage of women along with the arrival of an age wave with no pensions, no health care and no family to support the elderly, is likely to be a recipe for major social turmoil in areas such as Asia and unimaginable ramifications worldwide, considering how difficult the negotiations over retirement age in Europe and Medicare in the US have been.

Resource scarcity is likely to be caused by increased demand for water, food, energy, land and mineral resources and amplified by the complex linkages that exist among them (Malleter 2012). This increased demand will be exerted by forces such as globalization, urbanization, resource nationalism, geopolitical events that translate to negative supply shocks, the rise of emerging powers such as China and India, the prevalence of cheap technology, increased per capita consumption (attributed to the development of developing countries) as well as changes in diet and crop production for biofuels. Malleret also writes about "land grab," an interesting example that shows how resource scarcity may act together with other global mega-trends to produce surprising and serious knock-on effects in an interconnected world. Nowadays, large food importers like China, India, South Korea and Saudi Arabia tend to acquire considerable tracts of land to produce soft commodities for internal consumption. As two examples, South Korea (which imports 70 % of the grain it consumes) has acquired 1.7 million acres in Sudan to grow wheat, while a Saudi company has leased 25,000 acres in Ethiopia to grow rice (with an option to expand further). As Malleret explains, the problem is that the land grabs in Ethiopia and Sudan (which together occupy three-fourths of the Nile River Basin), have affected the flow of the Nile in the Egyptian part, which was supposed to be controlled by the Nile Waters Agreement (signed in 1959) that gave Egypt 75 % and Sudan 25 % of the river's flow. The situation has changed de facto since the wealthy foreign governments and international agribusiness companies that have snatched up large pieces of arable land along the Upper Nile, are not parties to the 1959 agreement. This is another example that shows how unexpected situations may arise in a highly interconnected world in which the power has diffused into many non-state actors.

Anthropogenic climate change, another global environmental concern, is increasingly becoming a source of geopolitical tensions and a security threat, e.g. via the intensification of water balance and water availability issues, which generate tensions and contribute to country failures in regions such as North Africa, the Middle East and South Asia (Malleret 2012). It is unfortunate that problems that are likely to be caused by anthropogenic climate change constitute a long-term threat;

as a result, policy-makers are unwilling to go into the trouble of formulating and implementing sensible climate-change policies now for fear that they will suffer immediate tangible consequences (becoming unpopular and losing the next elections).

Fiscal issues such as indebtedness are global trends that affect the richest countries, but are also likely to have knock-on effect elsewhere (Malleret 2012). Malleret points out that rich countries are likely to face lower growth and higher unemployment compared to the period that started in the mid-1980s and ended in 2007. Nevertheless, debt is likely to deepen the divide between the North, which is mainly composed of surplus countries with solid fiscal positions, and the South, which contains deficit countries with rather unsustainable fiscal positions.

A similar inequality is caused by fuel poverty, i.e. the inability of households to afford adequate warmth at home, one of the most prominent social problems of the 21st century (Boardman 1991, 2010). As pointed out by Preston et al. (2014), fuel poverty constitutes a triple injustice faced by low income households that are fuel poor: they emit the least, they pay the most yet they benefit the least (from pertinent policy interventions). So, while the poor consume and emit less, the cost of energy represents a much higher proportion of their income and their homes are usually poorly built and less energy efficient. As pointed out by the research of Paravantis and Samaras (2015), Paravantis and Santamouris (2015), Santamouris et al. (2013, 2014), fuel poor families (that are literally forced to choose among heating, eating or paying the rent) are caught in a fuel poverty trap that is self-reinforcing and very difficult to escape from, not unlike the digital divide that exists among individuals, households, businesses and geographic areas at different socio-economic levels with regard to their access and use of ICT (Iliadis and Paravantis 2011). Taking tips from complexity and the importance of weak ties (Granovetter 1973), Preston et al. (2014) proposed that energy counselling be done within the community via “green doctors” and “energy champions” that provide advice and support to fuel poor families.

Rising inequality is another global trend according to Malleret (2012) and “the single biggest threat to social stability around the world” according to economist Ken Rogoff, as people at the top have managed to avail themselves of the best educational and professional opportunities, seize most wealth and entrench themselves in privileged position, putting the prospect of a good life for most others beyond reach. On top of that, globalization expands the market and increases the demand for highly skilled individuals, but competes away the income of ordinary employees (Malleret 2012). As this inequality of opportunity and lack of transparency has exacerbated the sentiment of unfairness, Malleret asserts that a tipping point may emerge beyond which social inequality will undermine societal and global cohesion, economies will become unstable and democracy will be compromised.

Complexity and the Future

What kind of games will be played in the future complex arena of the rest of the 21st century? Gideon Rachman of the Financial Times has identified six divides that are likely to constitute fault lines and perturb the geopolitical landscape (Malleret 2012): (1) surplus countries (like Germany, China, Japan and Saudi Arabia) versus deficit countries; (2) currency manipulator versus "manipulated" countries; (3) "tightener" (like the UK) versus "splurger" countries; (4) democracies versus autocracies; (5) interventionist versus souverainist countries; and (6) big versus small countries, pitting the G20 countries against the rest of the world. Instead of one or two superpowers, Malleret thinks that the world is likely to see a number of dominant powers in the coming decades of the 21st century, i.e. China in East Asia, India in South Asia, Brazil in Latin America, Nigeria in West Africa, and Russia being a major resource power (thanks to its oil and gas exports). Malleret asks: Will the US decline? Will Europe fade into irrelevance? Will the BRICS overtake the world? Will the pauperization of the middle class continue and dominate the social arena? In a complex system that is highly interconnected, fully transparent and moving at a very high velocity, such as the global community, it is impossible to know: one can only anticipate and plan ahead.

3.1 Emergence in World Politics

CASs have many interconnected elements that interact locally and support the creation and maintenance of global emerging patterns while the system remains enigmatically coherent (Holland 1996). In fact, Holland (2014) writes that emergent behavior is an essential requirement for calling a system complex. As Rihani (2014) points out, change at the micro level takes place continuously; at the macro level, the system scrolls through many microstates as global patterns or attractors eventually emerge. Emergence occurs across the levels of a complex system (Railsback and Volker 2012) and both regularities and non-regularities may emerge, affected by things such as the location and structure of system components (Jervis 1997).

Emergent phenomena or behaviors appear at the system level. Examples include the anarchy of the international community, the bipolar structure of the Cold War and the collective memory that is oftentimes exhibited by the international community, as if it were an intelligent being (Jervis 1997). It is important to keep in mind that emerging behaviors in complex systems do not require the existence of the invisible hand of a central controller, a fact that agrees with the realist approach and a complexity science approach to the analysis of global politics (Harrison 2006a).

The Emergence of Cooperation

Cooperation is an essential trait in societies, e.g. to build and fly the International Space Station required the collaboration of thousands of people, most of whom never met in person, spoke different languages and lived very differently (Harrison 2006a). How does cooperation emerge in the CAS of world politics? As Axelrod wrote (1985), "Under what conditions will cooperation emerge in a world of egoists without central authority?"

IR and social institutions, like anything that evolves, have likely been impacted by accidental developments caused by novel combinations of ordinary features (Harrison 2006a). This makes it tougher to address several questions pertaining to emergence in world politics. Will conflict or cooperation be more prevalent in the years to come? Is unipolarity, bipolarity or multipolarity of the distribution of international power more conducive to the overall fitness and stability of the global community (Harrison 2006a)? Was the world more stable during the four and a half decades of relative calm of the Cold War and would more nuclear weapons in the hands of even states like Iran be conducive to a more stable world, as Kenneth Waltz has argued (2012)? Is the world better off now, in the era of a relatively undisputed American hegemony and would it be less stable in a likely multipolar distribution of power among the United States, China, India and other actors including smaller states with nuclear capability? Will the complexity that results from global interdependence make war unthinkable and foster peace, as the numerous intersecting interests that link countries render no single interest worth fighting for (Keohane and Nye 2012)? Or do the current troubles of the EU point to a more alarming direction, in which the more interconnected countries are, the easier it is for them to disagree, enter into disputes that are difficult to resolve and end up despising one another? Perhaps it was easier to reach agreement among the six states that formed the European Coal and Steel Community in 1951 than among the 28 EU members at the present time, as Harrison points out (2006a).

While attempting to address such questions with complexity tools may not be trivial, simulating CASs with agent-based models is a worthwhile pursuit in the context of several problems of world politics, as discussed in the next section.

4 Simulating Complexity with Agent-Based Modeling

Problems of contemporary society like inner city decay, the spread of AIDS, diffusion of energy conservation habits or diffusion of the Internet are probably best addressed by resorting to the workings of CAS elements at a micro level (Holland, 1996). CASs show coherence and persistence in the face of change while at the same time they display adaptation and learning. Such systems work based on extensive interactions among their elements. Having borrowed the term from economics, Holland uses the term agent to refer to the active components of CASs.

Agent-Based Simulation

Outside the fields of computer science and engineering, few applications of ABMs are used to solve practical problems (Railsback and Volker 2012). In a historical review and tutorial paper, Gilbert and Terna (1999) suggested that agent-based modeling is an alternative way of carrying out social science research, allowing for testing complex theories by carrying out individual-based numerical experiments on a computer and observing the phenomena that emerge. This contrasts with global politics and IR, fields in which theory is mostly formalized verbally. Axelrod (2003) described simulation as a new way of conducting research that is additional to induction and deduction. Furthermore, he asserted that although the use of simulation in social sciences remained a young field, it showed promise that was disproportionate to its actual research accomplishments at the time of his writing. Agent-based simulation is an important type of social science simulation that is in need of progress in methodology, standardization and the development of an interdisciplinary community of interested social scientists. The addition of regional and world politics to the fields that have traditionally employed decentralized adaptive system approaches (such as ecology, evolutionary biology and computer science), will be a means of advancing the state of the art.

In a colloquium paper, Bonabeau (2002) concluded that agent-based models constitute a powerful simulation technique that had seen quite a few applications at the time of writing and carry significant benefits for the analysis of human systems (although certain issues had to be addressed for their application in social, political, and economic sciences). Bonabeau described several real-world application examples of agent-based simulation in the business fields of flow simulation, organizational simulation, market simulation, and diffusion simulation. It was concluded that agent-based models are best used when (a) the interactions among the agents are discontinuous, discrete, complex and nonlinear; (b) the position of agents is not fixed and space is an important aspect of the problem at hand; (c) the population of agents is heterogeneous; (d) the topology of interactions is heterogeneous and complex; and (e) agents exhibit a complex behavior that includes learning and adaptation. The author suggested that issues that have to be taken into consideration when agent-based models are applied include: (1) a model has to be built at the right level of description (not too general, not too specific); and (2) careful consideration should be given to how human agents (i.e. actors with imperfect rationality, as discussed previously) exhibit irrational behavior, subjective choices, and complex psychology, i.e. soft factors that are difficult to quantify and calibrate. Although the author pointed out that this is a major hindrance in employing agent-based simulations in a meaningful fashion, at the same time he thought it is a major advantage of such approaches, i.e. that they are in fact the only tool that can deal with such hard to quantify applications.

How Agents Behave

As Rihani (2014) writes, a complex regime is a mix of global order and local chaos. Patterns emerge at a system level due to the chaotic interaction of agents locally. The behavior of an agent is determined by a collection of stimulus-response rules describing the strategies of the agent (Holland 1996). Oftentimes the performance of an agent is a succession of stimulus-response events. As Holland pointed out, modeling CASs is done by selecting and representing stimuli and responses. A range of possible stimuli and a set of allowed responses are determined for specific types of agents. The sequential action of these rules determines the behavior of an agent. This is where learning and adaptation enter the picture. Agents also tend to aggregate into higher level meta-agents that themselves can aggregate into meta-meta-agents, which results in the typical hierarchical organization of a CASs. Although the existence of agents and meta-agents is usual in complex systems, the components of CASs are often structured in unexpected and innovative ways (Malleret 2012). Furthermore, the formation of aggregates is facilitated by tagging as when a banner or a flag rallies members of an army or people of the same political or national persuasion (Holland 1996). Tagging is a pervasive mechanism that both aggregates and forms boundaries.

Agent-Based Networks

Many complex systems are networks with nodes and links that connect nodes (Holland 1996). Nodes represent agents and the links designate the possible interactions among the agents as well as provide transport routes for the flow of various items, e.g. goods or resources, from one node to another. In CASs the flows along the connecting links may vary over time; moreover existing links can disappear or new links may appear as agents adapt. In other words, CASs may be represented with networks and flows that are dynamic rather than fixed in time. As time elapses and agents accumulate experience, changes in adaptation are reflected in different emerging patterns, e.g. self-organization. As flows move from node to node, i.e. agent to agent, their impact is oftentimes multiplied, a phenomenon called multiplier effect that is a typical feature of CASs that may be represented by networks (same source). Holland writes that the multiplier effect is particularly evident when evolutionary changes are present, and it is one of the reasons why long-range predictions are difficult to carry out successfully in the case CASs.

Developing an Agent-Based Model

ABMs are complex systems containing a large number of autonomous agents that interact with each other and their environment (Railsback and Volker 2012). Where in mathematical models, variables are used to represent the state of the whole system, in ABMs the analyst models the individual agents of the system. Agent-based modeling can help find new, better solutions to many problems in the fields of the environment, health, economy and world politics (Railsback and Volker 2012; North and Macal 2007; Sterman 2000). Historically, the complexity of scientific models has often been limited by mathematical tractability. With computer simulation of ABMs, the limitation of mathematical tractability becomes irrelevant so one may start addressing problems that require models that are less simplified and include more characteristics of the real systems (Railsback and Volker 2012). ABMs are easier to employ while, at the same time, more sophisticated than traditional models, in that they represent a system's individual components and their local behavior rather than a mathematical representation of the macro behavior of the system (same source). Railsback and Volker also point out that, because ABMs are not defined in the language of differential equations or statistics, concepts such as emergence, self-organization, adaptive behavior, interaction and sensing are easily recognized, handled and tested when simulating with ABMs.

A model is a representation of a real system (Starfield et al. 1990), as simple as possible, but not simpler, as Einstein famously said. Usually, the real system analyzed by modeling and simulation is often too complex to be analyzed with other means such as experiments. A model is formulated by deciding on its assumptions and designing its algorithms. A decision must be made as to which aspects of the real system must be included in the model and which may be ignored. The modeling cycle is an iterative process of translating a scenario into a problem, i.e. simplifying, designing, coding, calibrating and analyzing models and then using the model to solve problems that are often intractable to solve with analytical approaches. More specifically, the modeling cycle includes the following stages (Railsback and Volker 2012):

(1) formulate clear and precise research questions that are narrow and deep;
(2) construct appropriate hypotheses for testing the research questions, possibly adopting a top down approach;
(3) formulate the model by choosing an appropriate model structure, i.e. scales, entities, state variables, processes, and parameters, starting with the simplest constructs that may test the hypotheses;
(4) implement the model using computer programming, including modern languages such as NetLogo (Wilensky, 1999) or other tools mentioned in the list of resources that may be used to implement and test simple ABMs in a short amount of time;
(5) run the model enough times to analyze, test and revise the hypotheses;
(6) communicate the final results of the simulation carried out with the model (not forgetting that the model is not identical to the real life problem, but a simplification of it).

Agents in ABMs may be individuals, small groups, businesses, institutions, nonstate actors, states and any other IR entity that pursues certain goals (Railsback and Volker 2012) and competes for resources. Agents in ABMs interact locally, meaning that they do not interact with all other agents in the system, but only with their neighbors geographically in the space of the system (same source), which in the case of IR is the highly interconnected network of the global community of states. Agents are also autonomous, implying that agents act independently of each other, pursuing their own objectives, although their behavior is adaptive as they adjust it to the current state of themselves, other agents and their environment.

ABMs may be used to look both at what happens (a) to the system because of the actions of individual agents and (b) to the individual agents because of how the system functions (Railsback and Volker 2012). Modeling and simulation via ABMs allows a researcher to reproduce and investigate emergence, i.e. dynamic phenomena at a system level that arise from how the individual components adapt by interacting with one another and their environment. The recognition of emergent phenomena, offers the only chance of prediction with the case of complex systems although it is not always easy to decide whether a pattern that emerges in an ABM is a regular pattern or a black swan event (same source).

Examples of Simple Agent-Based Systems

To give a rough idea of what may be achieved with agent-based modeling, two examples are now described: a simple educational example and one made famous by Thomas Schelling, its Nobel laureate inventor.

The author of this chapter teaches Game Theory and Complexity regularly to his undergraduate and graduate students in the Department of International and European Studies of the University of Piraeus. Both subjects are well fitted to participatory simulation in class. In one of his favorite in-class activities, the author tells his students to stand up and walk around and then he asks them to disperse so that they are homogeneously scattered in the classroom. In a first version of the activity, the author assigns the role of coordinator to one of the students, who directs each student's movement so that they all are dispersed. In a subsequent version, the author just tells the student to move as they see appropriate so that they are all dispersed more or less at an equal distance from one another and the walls.

The students quickly realize that the easiest way to achieve dispersion is when each moves on his or her own without a coordinator issuing directions. In fact, with the help of the author, they understand that all they need to do to disperse homogeneously is follow a simple rule: see who is closest to you and move away from him or her.

This activity is then demonstrated to the students with the help of a simple agent-based model programmed in the PowerBASIC Console Compiler version 5.0.5 (http://www.powerbasic.com/products/pbcc), running on a 64bit Windows 8.1 notebook computer. BASIC is a procedural language and, just as proposed by Axelrod (1997), despite its age, remains a fine way to implement quick programming tasks especially with social scientists who may not be as well versed in modern object-oriented programming techniques.

The results are shown in Figs. 1, 2 and 3 that depict a population of 160 agents. Figure 1 shows these 160 agents moving randomly, just as students do in the beginning of the in-class simulation.

Figure 2 sort of looks under the hood by having these 160 agents continue moving randomly and displaying the distance of each to its nearest agent as a solid line.

Finally, Fig. 3 shows these 160 agents moving away from the nearest agent (plus a small random jitter so that they never become immobile, for educational purposes).

The students are impressed to see how quickly (instantaneously in fact) the agents disperse in a perfectly homogeneous manner just by moving away from their closest neighbor. It is explained to the students that the homogeneous dispersion of the agents is an emergent phenomenon of this complex system and it is stressed to them that it is simple rules like this that oftentimes effect unexpected system-wide patterns such as self-organization.

Attention now turns to the second and more famous example, Schelling's segregation model (Schelling 1969, 2006). Thomas Schelling showed that even a socially fair preference for half of one's neighbors to be of the same color could lead to total segregation, placing pennies and nickels in different patterns on graph paper and then moving unhappy, ones one by one, to demonstrate his theory.

A version of Schelling's model was programmed in Netlogo (Wilensky 1999), simulating homes of two races, "black" (pictured as the darker color in Figs. 4 and 5) and "white" (pictured as the lighter color in Figs. 4 and 5.) In the version of the

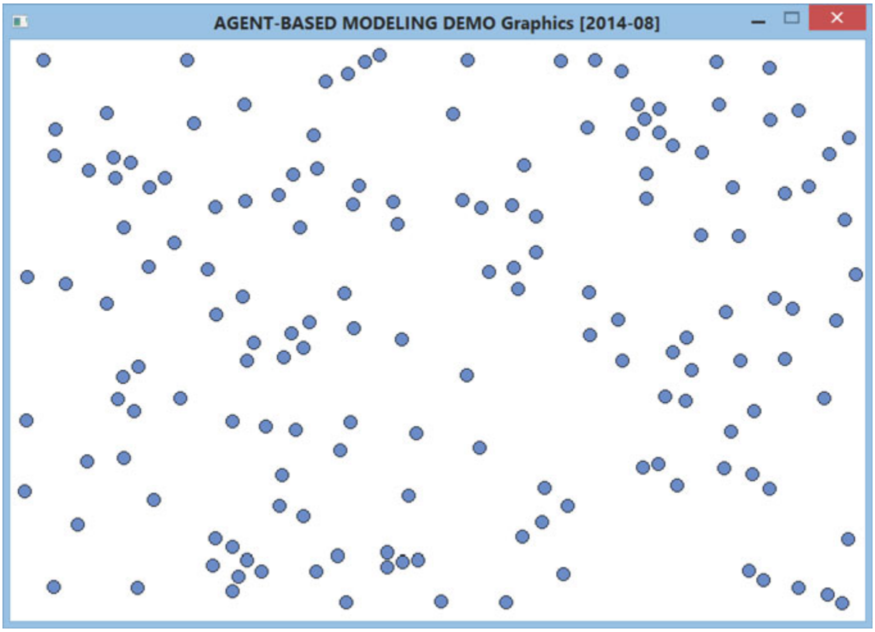

Fig. 1 160 agents moving randomly

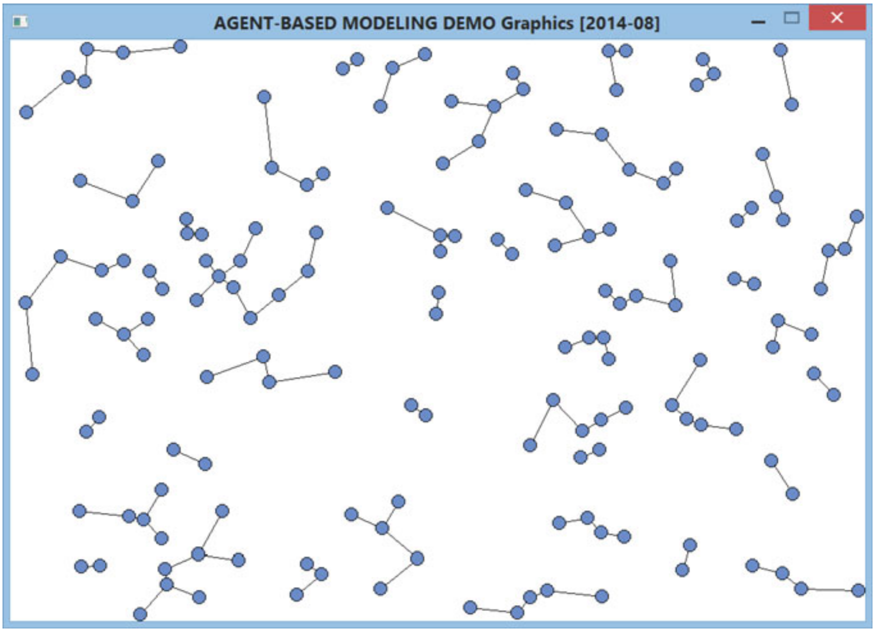

Fig. 2 160 agents moving randomly (distance to nearest agent displayed as *solid line*)

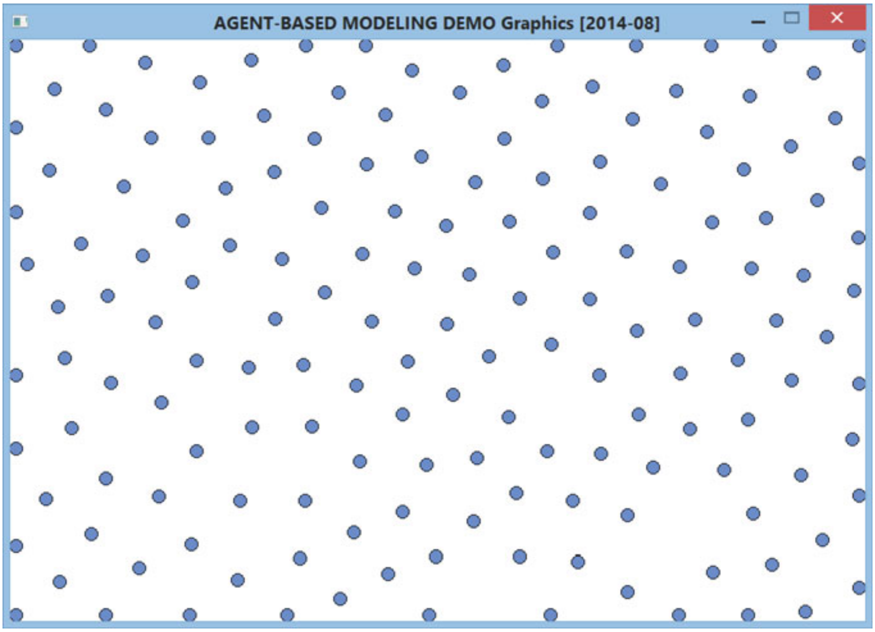

Fig. 3 160 agents moving away from nearest agent (plus a small random jitter)

segregation model simulated herein, homes are placed in a grid (employed in many cellular automata applications) so that each home has eight adjacent homes. A home would be perfectly happy if it had an evenly split number of neighbors of the two different races around it, i.e. four "black" and four "white" ones, and increasingly unhappy as the split moved further away from this socially just configuration. If unhappy, a home swaps places with the unhappiest home among its eight adjacent neighbors (if such a home existed.)

Figure 4 shows the initial random configuration of a neighborhood with one third (33 % requested by the user, 32.28 % achieved by the use of random numbers) "black" homes.

Figure 5 shows the configuration of the neighborhood after about 2500 iterations (taking about 30s at Netlogo's fast speed on an Intel i7, 64-bit Windows 8.1 computer.) One may notice that the swapping of unhappy homes ended up in total segregation, despite the fact that individual preferences were for a perfectly balanced assortment of "black" and "white" neighbors around a home. The resulting total racial segregation is an unexpected emergent phenomenon of this Netlogo model that validates Schelling's proposition and explains (to some extent) the racial segregation observed in many North American cities.

Validation of Agent-Based Models

While the verification and validation of any model is a critical simulation step, it is nontrivial to implement in the case of models describing social and political

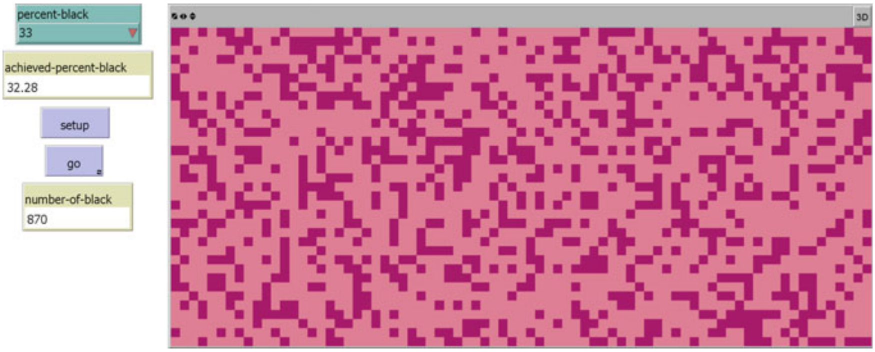

Fig. 4 Random initial configuration of a simulated neighborhood with one third "black" homes

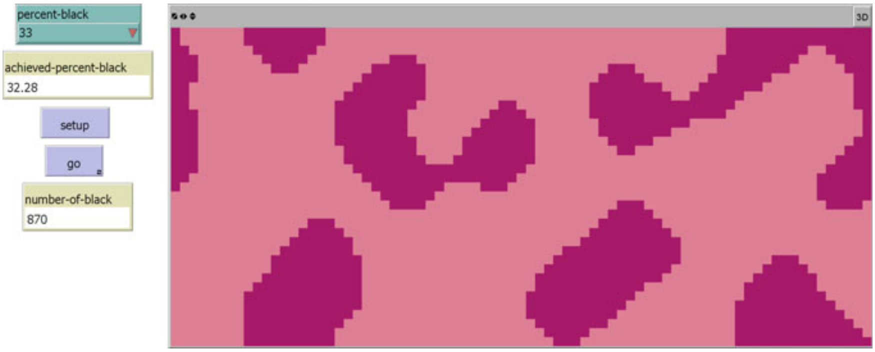

Fig. 5 The simulated neighborhood of one third "black" homes showing total segregation after many iterations

phenomena, where one is often forced to rely (to a large extent) on qualitative information (Bharathy and Silverman 2010). Global politics, in particular, with their complex path dependence and unpredictable emergence, appear to pose insurmountable verification and validation issues to researchers who attempt to analyze them with modeling.

As Schreiber (2002) explains, the way information is processed by a model, differs from how it is processed in the real world. This is also the case with agent-based models: they produce similar, but not identical output, to their targets, making ABMs paramorphic analogues of the real world phenomena they simulate. Instead of using statistical validation techniques, analysts of global political systems are oftentimes forced to resort to the believability of the output of their analyses. Certainly, it would be wrong of a researcher to expect to derive proof from the analysis of any political and social phenomenon by modeling and simulation, especially in the context of postmodernism. Nevertheless, the verification (of specifications and assumptions) and the validation (of the accuracy of the output) is a necessary endeavor in the modeling of political and social phenomena. Schreiber endorses this view by suggesting that a model-centered approach to science is appropriate for the postmodern epistemological question and discusses the following four categories of tests for the validation of ABMs of political systems:

1. *Theory-model tests* are run to confirm that theoretical concepts are properly operationalized in a model. Of these, face validity is tested by presenting the results of an ABM to scholars knowledgeable in the problem it analyzes, and asking them to confirm that the model is compatible with their informed expectations. Narrative validity is tested by comparing model results to published research accounts, essentially being a more formal version of face validity that is also more amenable to the establishment of a consensus. The Turing test (after the British pioneering computer scientist) examines the believability of the results of a model by testing whether a group of experts can tell the difference between data generated computationally by an ABM and data describing events from the real world of politics. A final form of validation is provided by the surprise test, which essentially refers to emergence, i.e. unanticipated implications arising out of an ABM; if these match some theories of global politics, an interesting form of compelling validation is achieved. All these theory-model tests should be very useful in the analysis of global politics, a knowledge area characterized by narrative theories and eminent scientists embodying key theoretical approaches.
2. *Model-model tests* compare the results obtained from an ABM to results obtained analytically or from other similar models. Of such tests, the docking test cross-validates (Axtell et al. 1996) the results of an ABM by comparing them to those obtained from similar models (some of which may be already validated); alternatively, the results of an ABM may be compared to the results of an identical model formulation, recoded from scratch by another research team (as in Rand and Wilensky 2006, see below). In analytical validity testing, the results of an ABM are compared to the results obtained from analytical methods or even formal proofs (although this is rarely the case in global politics). Fixed values testing is a particular form of such validation, where the results of an ABM are compared to hand calculations, often very easy to compute, as Schelling (1969) did with his aforementioned segregation model (that was initially developed with coins on graph paper).
3. *Model-phenomena tests* compare an ABM to the phenomena that occur in the real political world. Of such tests, historical data validity compares the results obtained from an ABM to historical data while predictive data validity compares the predictions of an ABM to actual outcomes. Out-of-sample forecast tests, mix historical with predictive data validity by calibrating an ABM on one portion of the sample and testing the predictions of the model on the rest of the sample. Experimental data validity mostly refers to the representation of the micromotives of agents in an ABM, which is linked to the validation of the macrobehavior of the entire system (Schelling 2006). Finally, event validity tests compare the occurrence of specific events in the model to their occurrence in the real world.

4. *Theory-model-phenomena tests* examine an ABM in the context of theory and phenomena simultaneously, aiming to establish the robustness of the model. Such tests may include extreme bounds analysis or extreme condition tests (i.e. testing the model under extreme values of its parameters), global sensitivity analysis (of the parameters of the model), degenerate tests (i.e. interrupting some model components in order to see the effect on the system), traces testing (i.e. examining the behavior of individual agents as they operate in the modeling environment) and animation validity (i.e. comparing the visual qualities of the model to what is seen in the real world).

To provide an example, in an ABM model of political party formation that he developed, Schreiber (2002) writes that he employed tests to confirm analytical validity (i.e. whether the model agrees with formal theory predictions), historical data validity (i.e. whether the model output reproduces historical data) and docking (i.e. how the model output compares with the predictions of similar models), at various levels of sophistication. In another ABM, Schreiber ran a model hundreds of times to ensure that the results were robust across a variety of parameter values. Finally, face validity was tested by having subject experts confirm that the results were consistent with their expectations.

An additional example is provided by the makers of Netlogo (Rand and Wilensky 2006, 2007). They mention that, while thousands of ABMs have been published over the last three decades, very few of them have been reproduced, and argue in favor of replication, as an appropriate tool for verifying and validating ABMs. They suggest that with the repeated generation of the output of an ABM, a researcher may be convinced that the original results were not an exceptional case neither a rare occurrence. Rand and Wilensky developed a distinct implementation of a well-known ABM of ethnocentrism (Axelrod and Hammond 2003) in order to study replication, essentially employing a docking test (Schreiber 2002) to validate the original model. Although they had to make numerous modifications in their ABM to match the results of the literature model, they concluded that the replication of ABMs is a necessary endeavor that must be introduced in the ABM practice, despite the fact that it may not be straightforward.

4.1 Agent-Based Modeling Research in World Politics

Having completed an overview of agent-based modeling concepts, attention how shifts to applications of ABMs in a variety of fields including the social sciences, politics, defense, IR and world politics as well as the environment.

ABM in the Social Sciences

In a theoretical work, Walby (2003) argued for the importance of insights from complexity science for sociology, asserting that complexity addresses issues that lie at the heart of classic sociological theory such as emergence, i.e. the relationship between micro and macro-levels of analysis. Walby asserted that in this era of globalization, sociology needs to expand its agenda and develop its vocabulary in order to address large scale, systemic phenomena with the aid of complexity science; such social phenomena relate to connectivity and include the coevolution of CASs in a changing fitness landscape) and path dependency. Differences within complexity (and chaos) theory were discussed, especially those between the Santa Fe Institute and Nobel laureate Ilya Prigogine's approach (Prigogine and Stengers 1984; Prigogine 1997). Finally, the example of globalization was used to illuminate the analysis, especially in relation to the changing nature of polities and how they relate to the economy and culture. This work serves to highlight the linkage between the theory of complexity and social sciences, providing further justification for the use of agent-based models in addressing pertinent problems.

A critical view of the assumptions of agent-based modeling was provided by O'Sullivan and Haklay (2000), who observed that agent-based models were an increasingly popular tool in the social sciences and thought that this trend would continue. The authors examined an overview of examples of such models in the life sciences, economics, planning, sociology, and archaeology and concluded that agent-based models tended towards an individualist view of societal systems (as does the literature), which was considered inadequate for debates in modern social theory that acknowledges the importance of the dual nature of individuals and society. It was argued that because models are closed representations of an open world it is important that institutions and other social structures be explicitly included in them (or their omission be properly justified). O'Sullivan and Hacklay based a tentative explanation for the bias of agent-based models on an examination of early research in the related fields of Artificial Intelligence (AI) and Distributed Artificial Intelligence (DAI) from which the agent-based approach was derived. Although the authors in effect asserted that institutions such as the family, the community, the capital and the state cannot be easily be accounted for in agent-based models, the author of this chapter notes that emergent phenomena are an important characteristic of complex systems and such meta-agents may well emerge from individualist modeling approaches. In closing, O'Sullivan and Hacklay noted that the underlying assumptions of agent-based models are often hidden in the implementation and concluded that such models, although powerful, must be subjected to a critical examination of their assumptions.

Saqalli et al. (2010) documented the behavior of individuals in non-pastoral villages in the Sahel and coded them in an agent-based model simulating three village archetypes that included biophysical, economic, social, agricultural and livestock modules. Social development in the Sahel, an economically deprived and environmentally challenged region with widely publicized crises in the 1970s and 1980s, depends heavily on family organization and social interaction. Simulation results showed several emerging phenomena. Villages specialized in economic activities depending on natural resource availability. Family transition and inheritance systems were implemented and contributed to the population at different sites differentiating into specialized groups according to size, assets and social status. Although validation cannot be easily done with agent-based models, sensitivity analysis was carried out to assess the robustness of parameter values.

4.1.1 Political Applications of ABM

Chakrabarti's research (2000) was motivated by the observation that most theoretical studies of corruption modeled individual acts at the micro level while empirical papers studied corruption at the country level, so the author built an agent-based model to understand the structure of corruption and provide the missing link between these two groups. An example of literature findings was provided by Treisman (2000) who asserted that countries with Protestant traditions, history of British rule, higher level of development, higher level of imports (signifying a more open economy), longer history of democracy and non-federalist structures have lower levels of corruption. Chakrabarti thought that the risk aversion of an individual towards corruption was influenced by religious traditions and cultural factors. Using the model to simulate a multi-generational economy with heterogeneous risk-averse agents showed that societies have locally stable equilibrium levels of corruption that depend upon a small number of socioeconomic determinants such as the degree of risk aversion, the proportion of income spent on anti-corruption vigilance and the level of human capital in society. However, under certain combination of the values of these parameters, there can be situations when corruption rises continuously until it stifles all economic activity. Although as the author correctly pointed out, this work opened more questions than it answered, it constitutes research that would be difficult to carry out without resorting to agent-based modeling.

Defense Applications of ABM

Hare and Goldstein (2010) extended a game-theoretic model by applying an agent-based model to an information sharing network in order to analyze investment decisions and public policies for cyber security in the defense sector. The model was used to analyze the interactions of firms from defense industry trade associations and found that the nature of these interactions (dependent on the scale of the network), driven by the topology of the network, may influence the ability of agents to influence policy makers invest in security. An important public policy implication of this research was that targeted interventions, i.e. centrally coordinated behavior, could not easily influence the investment state of the system. The fact that the characteristics of the agents, the structure of the network and the nature of the agent's interactions were perhaps more important in affecting investments in the security industry, is perhaps a testament to the power of interrelated actors and evidence of the presence and importance of complexity in that industry. The authors suggested that their work may be extended to other sectors that are characterized by intense knowledge sharing of proprietary data such as energy consortiums, the civil aerospace industry and the biotech industry.

Chaturvedi et al. (2013) maintain that the simulation of virtual worlds via agent-based modeling, emerges as an important tool in social sciences including research in the field of economics, society and politics. They present some of the technologies that underlie virtual worlds and describe Sentient World, an ultra-large-scale, multi-agent-based virtual world that has been developed as a geopolitical tool for the US military and has already been used to simulate US military operations in other countries. Demonstrating the capabilities of large agent-based models, Sentient World accounts for the political, military (including terrorist), economic, social (including citizen unrest, epidemics), information and infrastructure aspects of real systems and simulates the behavior of individuals, organizations, institutions (including religion) and geographical regions. The model displays behaviors and trends that resemble those that occur in the real world. The validation of Sentient World showed that such complex modeling systems are capable of converging to the real world and provide decision makers with a tool that helps them anticipate and evaluate potential outcomes in a realistic setting. Clearly, such models are capable of pushing the state-of-the art in global politics by providing a virtual laboratory for testing and validating theory.

ABM in International Relations and World Politics

In an international regime complexity symposium, Alter and Meunier (2008) argued that the number, detailed content and subject matter of international agreements has grown and diversified exponentially in recent decades, resulting in an "emerging density and complexity" of international governance. This phenomenon of nested, partially overlapping and parallel international regimes that are not hierarchically ordered is referred to as international regime complexity and makes it harder to locate political authority over an issue. One of the consequences of this complexity is that international governance takes place via a multitude of complexly interrelated trans-border agreements often characterized by strategic ambiguity and fragmentation. The authors noted that both feedback and competition ensue from this complex governance network, sometimes empowering and other times weakening actors of global politics. Complexity also makes spotting a true causal relationship very hard and forces bounded rationality on the actors of global politics as they have to resort to problem framing and heuristics that may vary over states, cultures and time. Alter and Meunier also argued that international regime complexity favors the generation of small group environments, making face-to-face interaction crucial and having multiple portfolios assigned to individual diplomats or experts. Small group dynamics, more likely to emerge when issues are technical and rely on expertise (opening the door to non-state actors), create depth and strong links, imprinting global politics with the touch of individual actors. The authors also mentioned that feedback effects include: competition among actors, organizations and institutions (i.e. agents and meta-agents), resulting in both positive and negative impacts; unintentional reverberations, where impacts are carried over to parallel domains; difficulty in assigning responsibility and establishing causality; loyalty in the sense that what actors, e.g. states, do in one arena of global politics may carry over into another; and facilitation of exiting, e.g. by resorting to non-compliance. Alter and Meunier concluded that while international regime complexity may empower weaker non-state actors, at the same time it may confer advantages to the most powerful states who possess the resources to sift through the maze or rules and players in order to achieve their goals.

Frej and Ramalingam (2011) examined the connection between foreign policy (which they called a field of few certainties) and CASs. The authors listed 15 global challenges facing humanity in the context of the Millennium Project (http://www.millennium-project.org) including issues related to sustainable development, climate change, clean water, ethnic conflict, population growth, resource usage, democracy, access to ICTs, new diseases, weapons of mass destruction, the role of women, organized crime, energy, science, technology and ethics. The authors discussed what they see as a "quiet revolution in complexity thinking" in foreign policy. Citing Ramalingam et al. (2008), Frej and Ramalingam suggested that foreign policy experts and analysts take into account that (a) the world is characterized by complex systems of elements that are interdependent and interconnected by multiple feedback processes; (b) system-wide behaviors emerge unpredictably from the interactions among agents; and (c) in complex systems, changes are evolutionary, dynamic, highly sensitive to initial conditions, and may exhibit non-linear tipping points. Several principles followed from these, among which that a systemic perspective should be adopted in most cases and "silver bullet" strategies should be avoided in favor of attempting several parallel experiments. The work of Frej and Ramalingam underlined the need to reevaluate foreign policy under the light of the complex interconnected world of the 21st century.

In a true IR application of agent-based modeling, Cioffi-Revilla and Rouleau (2009a) described Afriland, a moderately detailed model of the geographic region of East Africa that was programmed in MASON (Luke et al. 2005) and used to analyze inter-border socio-cultural and environmental dynamics as well as natural hazards across national frontiers that, the authors argue, are questions with scientific and policy relevance in the region. Afriland was built on Rebeland, a previous attempt by the same authors to model a single country with several provinces (Cioffi-Revilla and Rouleau 2009b, 2010), but unlike earlier models, AfriLand is capable of analyzing phenomena that transcend national boundaries. As the authors mentioned, the three basic types of research questions that were addressed by AfriLand revolved around (a) the response of a regional polity system to (anthropogenic or natural) societal stress; (b) the emergence and propagation of insurgency, domestic political instability, or even state failure across borders; and (c) the influence of the condition of the borders on regional (multi-country) dynamics. The model was used to analyze a socioeconomic system of 10 countries impacted by the distribution of resources (such as oil, diamond and gold), terrain morphology (that affected visibility) and climate. The simulation results indicated a range of human and social dynamics such as troop movements, insurgent activity, refugee flows and transnational conflict regions (shown as red dots on a map that helps establish, e.g. the creation of strongholds). Societal satisfaction was tracked and found to vary as a function of the capability of governments to manage public issues. The authors concluded that although agent-based models of international regions composed of several countries were few (at the time of writing), models of the scale of Afriland can be very useful in analyzing and understanding socio-cultural and environmental dynamics that transcend national boundaries.

Environmental Applications of ABM

In a review of agent-based modeling in coupled human-nature systems, Li (2012) explains that such systems include ecosystems that have been subjected to anthropogenic disturbances and exhibit characteristics of complexity such as heterogeneity, nonlinearity, feedback and emergence. Sites for which such empirical work has been carried out, include the Amazon, Yucatan and areas of China and Ecuador where agent-based models are employed to model human decision making and environmental consequences. Li writes that complex systems exhibit heterogeneous subsystems, autonomous entities, nonlinear relationships and multiple interactions including feedback, learning and adaptation. Complexity is manifested in many forms including path dependency, criticality, self-organization, difficulty in predictions as well as the emergence of qualities and behaviors that are not tractable to the individual system components and their attributes. No orderly and predictable relationships nor causal linkages may be found in complex systems. Li concludes that complexity science is still in its infancy, lacking a clear conceptual framework, unique techniques and an ontological and epistemological representations of complexity. Li calls agent-based modeling a major bottom-up tool for the analysis of complex systems, an approach characterized by methodological individualism rather than aggregation. Cross-pollinated by various disciplines, agent-based modeling constitutes a virtual laboratory in which numerical experiments may be done that would be impossible to carry out without the aid of computers. Nevertheless, agent-based models are difficult to validate and verify.

Angus et al. (2009) attempted to understand the complex, dynamic, spatial and nonlinear challenges facing Bangladesh, a densely populated country of around 145 million people living in a coastal area of just 145000 km^2 that is dependent on the South Asian monsoon for most of its rainfall. The authors considered that a modular agent-based model would permit the dynamic interactions of the economic, social, political, geographic, environmental and epidemiological dimensions of climate change impacts and adaptation policies to be integrated. In addition, such a model would permit the inclusion of nonlinear threshold events such as mass migrations, epidemic outbreaks, etc. The authors formulated their model in Netlogo (the most mature tool in the field) and examined (but did not fully analyze) the dynamic impacts on poverty, migration, mortality and conflict from climate change in Bangladesh for the entire 21st century. Their model combined a Geographical Information Systems (GIS) approach with a district network layer representing the spatial geography, and used level census and economic data with a methodology that allowed national scale statistics to be generated from local dynamic interactions, allowing for a more realistic treatment of distributed spatial events and heterogeneity across the country. The rest of the world was also modeled as an agent, so that exports, imports and migration could be incorporated in the model. The author’s aim was not to generate precise predictions of Bangladesh’s evolution, but to develop a framework that may be used for integrated scenario exploration so their work represented an initial report on progress on this project. The authors concluded that the prototype model demonstrated the desirability and feasibility of integrating the different dimensions of the CAS and hoped that the completed model (which at the time of writing was under development) could be used as the basis for a more detailed policy-oriented model.

Smith et al. (2008) addressed the issue of environmental refugees in Burkina Faso with agent-based modeling observing that even simple such models may exhibit complex emergent behavioral patterns. Burking Faso is one of the poorest countries in the world with an economy heavily based upon rain-fed agriculture and cattle-raising. Migration was considered to occur based on environmental stimuli such as land degradation. Using the longitudinal spatio-temporal data of a social survey conducted in 2000–2001, the authors developed rules of interaction between climate change and migration. Origins and destinations were considered to have push and pull factors while the influence of social structures, individuals as well as intermediate institutions were accounted for. The agent-based approach modeled the cognitive response of individuals to climate change as they appraised the situation (subject to their cognitive biases) and then considered whether to select migration as an appropriate adaptation strategy. Although the paper was limited to a conceptual description of the developed agent-based model and drawing of a few general conclusions, it may nevertheless be considered another interesting application of such models in social problems that would be quite difficult to address with any other method.

Finally, Hailegioris et al. (2010) presented an agent-based model of human-environment interaction and conflict in East Africa using the MASON agent-based simulation software system (Luke et al. 2005). Their model represented a 150 by 150 km^2 area and used a daily time step, in which it updated the regeneration of vegetation (as a function of rainfall and grazing) and activated herders randomly. Annual droughts were programmed to occur randomly with a 15 year cycle. Herders were programmed to adapt to seasonally driven changes in the grazing environment. As the carrying capacity of the landscape varied, conflict was modeled to result from trespassing incidents between herders and farmers; if it were not resolved peacefully (e.g. by cooperation between two herders of the same clan) it could escalate over time, involving more participants and ending up with the infliction of damages. All in all, the model accounted for the complex interaction of pastoral groups (herders and farmers) with their environment and other emerging external factors. Experiments with the model indicated that rainfall was an important factor that was nonlinearly related to the carrying capacity and supported the conclusion that increased seasonal rainfall variability and droughts create tremendous stress on pastoral groups and challenge their long-term resilience and adaptive response mechanisms. This example showcases how environmental complexity research may be valuable in outlining appropriate directions for environmental management policy and measures.

5 Conclusions

This chapter examined the complexity of world politics with an emphasis on global environmental issues. Concepts of game theory were reviewed and connected to the state of world politics. Game theoretic models found in IR included the prisoner's dilemma; game theoretic models encountered in global environmental negotiations included the conflict between rich North and poor South countries, the role of pollution havens and the clash of idealists versus pragmatists and optimists versus pessimists. It was suggested that the complexity of world politics, taking place on a highly interconnected global network of actors organized as agents and meta-agents, is nothing but a multiplayer extension of game theory although a complexity approach to world politics should not be regarded as a theory alternative to realism, but as a relatively novel research tool to aid with understanding and anticipating (rather than predicting) global events. Technology, interconnections, feedback and individual empowerment were discussed in the context of the complex world of global politics. Furthermore, evolution and adaptation were related to the concept of fitness and how it may be estimated for the case of actors in world politics. Furthermore, it was suggested that many events of world politics constitute emergent phenomena of the complex international community of state and non-state actors. Finally the chapter was complemented with a short overview of concepts related to ABM, arguably the most prevalent method of simulating complex systems, and a review of research problems from the fields of social science, political science, defense, world politics and the global environment that have been successfully addressed with agent-based simulation.

Thanks to the work of Nobel laureates that worked at the Santa Fe Institute such as Murray Gell-Man and other celebrated scientists such as John H. Holland and Robert Axelrod, complexity science has emerged as an umbrella science that, in the case of world politics, could be useful as a tool auxiliary to the realist worldview in modeling, understanding and perhaps anticipating the behavior of state and nonstate actors. Axelrod in particular was a key figure in linking game theory to complexity with his two seminal books (1985, 1997). The main aim of this chapter was to suggest that world politics may be considered a CAS with states being modelled as complex adaptive actors, i.e. agents and international organizations such as the United Nations or the EU being meta-agents. Understanding the system rules may be an important aspect of analyzing the international system of states as a CAS (Hoffman 2006).

Nevertheless, formulating theory for CASs is difficult because the behavior of such systems is more than the sum of the behavior of its components as it has been explained time and again in this chapter. The presence of nonlinearities means that tools such as trend analysis are destined to fail to generalize observations into theory (Holland 1996). It is, therefore, suggested that complexity and agent-based modeling may provide a framework that helps understand that entire systems exceed the sum of their parts precisely due to the interaction of their parts with each other. Moreover, it is difficult to envision any causal theoretical paradigm to be of real use in explaining today's complex, interconnected world.

The complexity science approach to world politics (including global environmental and energy policy) will help describe and explain the past and the present although it will not be able to predict future event. Nevertheless, ABMs are a formidable tool that will allow the recognition and investigation of emerging phenomena that are beyond the capabilities of classical IR theory to envision. The understanding of such phenomena though and their use in anticipating the future may best be done by resorting to theoretical and modeling tools in tandem and this is the main conclusion that is drawn from this chapter.

A list of software resources useful to those who wish to address global problems with agent-based modeling ensues after the list of references.

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References

Allan, R.: Survey of agent based modelling and simulation tools. Version 1.1, STFC Daresbury Laboratory, Daresbury, Warrington. http://www.grids.ac.uk/Complex/ABMS/ABMS.html. Last updated 10 Mar 2011

Allison, G., Zelikow, P.: Essence of Decision: Explaining the Cuban Missile Crisis, 2edn. Longman, London (1999)

Alter, K., Meunier, S.: The politics of international regime complexity. In: The Politics of International Regime Complexity Symposium, The Roberta Buffett Center for International and Comparative Studies, working paper no. 07-003, Northwestern University (2008)

Alterman, E.: When Presidents Lie: A History of Official Deception and Its Consequences. Viking, New York (2004)

Angus, S.D., Parris, B., Hassani-M, B.: Climate change impacts and adaptation in Bangladesh: an agent-based approach. In: 18th World IMACS/MODSIM Congress, Cairns, Australia, 13–17 July 2009

Ariely, D.: Predictably Irrational: The Hidden Forces that Shape Our Decisions. HarperCollins e-books, London (2008)

Axelrod, R.: The Evolution of Cooperation. Basic Books Inc.Publishers, New York (1985)

Axelrod, R.: The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration. Princeton University Press, Princeton (1997)

Axelrod, R.: Advancing the art of simulation in the social sciences. Jap. J. Manage. Inf. Syst. **12**(3) (Special Issue on Agent-Based Modeling) (2003)

Axelrod, R., Hammond, R.A.: The evolution of ethnocentric behavior. In: Midwest Political Science Convention, Chicago, IL, 3–5 April 2003

Axelrod, R., Tesfatsion, L.: On-line guide for newcomers to agent-based modeling in the social sciences. http://www2.econ.iastate.edu/tesfatsi/abmread.htm. Last updated on 28 March 2015

Axtell, R., Axelrod, R., Epstein, J.M., Cohen, M.D.: Aligning simulation models: A case study and results. Comput. Math. Organ. Theory **1**(2), 123–142 (1996)

Baron, J.: Judgment Misguided: Intuition and Error in Public Decision Making. Oxford University Press, Oxford (1998)

Bennett, N., Miles, S.A.: Your Career Game: How Game Theory Can Help You Achieve Your Professional Goals. Stanford University Press, Stanford (2010)

Bharathy, G.K., Silverman, B.G.: Validating agent based social systems models. In: Proceedings of the 2010 Winter Simulation Conference, Baltimore, MD, 5–8 Dec 2010

Binnendijk, H., Kugler, R.L.: Seeing the Elephant: The US Role in Global Security. Center for Technology and National Security Policy, National Defense University Press, Potomac Press, Inc., Washington DC (2006)
Boardman, B.: Fuel Poverty: From Cold Homes to Affordable Warmth. Belhaven Press, London (1991)
Boardman, B.: Fixing Fuel Poverty: Challenges and Solutions. Earthscan, London (2010)
Boehmer-Christiansen, S., Kellow, A.: International Environmental Policy: Interests and the Failure of the Kyoto Protocol, London (2002)
Bonabeau, E.: Agent-based modeling: Methods and techniques for simulating human systems. Proc. Nat. Acad. Sci. USA (PNAS) **99**(3) (2002)
Bradenburger, A.M., Nalebuff, B.J.: Co-opetition. Currency Doubleday, New York (1996)
Brams, S.J.: Negotiation Games: Applying Game Theory to Bargaining and Arbitration. Revised Edition, Routledge, London (2005)
Brams, S.J., Kilgour, D.M.: Game Theory and National Security. Basil Blackwell, Oxford (1988)
Casti, J.L.: Complexification: Explaining a Paradoxical World Through the Science of Surprise. HarperCollins, New York (1994)
CBC News.: Canada pulls out of Kyoto Protocol. http://www.cbc.ca/news/politics/story/2011/12/12/pol-kent-kyoto-pullout.html, 12 Dec 2011
Chakrabarti, R.: An agent based model of corruption. In: 2000 Computing in Economics and Finance (CEF) conference, Barcelona, Spain (2000)
Chaturvedi, R., Armstrong, B., Chaturvedi, A., Dolk, D., Drnevich, P.: Got a problem? Agent-based modeling becomes mainstream. Global Econ. Manage. Rev. **18**, 33–39 (2013)
Christakis, N.A., Fowler, J.H.: Connected: The Surprising Power of Our Social Networks and How They Shape Our Lives—How Your Friends' Friends' Friends Affect Everything You Feel, Think, and Do. Back Bay Books, Reprint edition, New York (2011)
Cialdini, R.B.: Influence: Science and Practice, 5th edn. Pearson, London (2009)
Cioffi-Revilla, C., Rouleau, M.: MASON AfriLand: a regional multi-country agent-based model with cultural and environmental dynamics. In: Proceedings of the Human Behavior-Computational Modeling and Interoperability Conference 2009 (HB-CMI-09), Joint Institute for Computational Science, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA, 23–24 June 2009
Cioffi-Revilla, C., Rouleau, M.: MASON RebeLand: An agent-based model of politics, environment, and insurgency. In: Proceedings of the Annual Convention of the International Studies Association, New York, 15–18 Feb 2009
Cioffi-Revilla, C., Rouleau, M.: MASON RebeLand: an agent-based model of politics, environment, and insurgency. Int. Stud. Rev. **12**, 31–52 (2010)
Cohen, M.D., March, J.G., Olsen, J.P.: A garbage can model of organizational choice. Adm. Sci. Q. **17**(1), 1–25 (1972)
Damasio, A.R.: Descartes' Error: Emotion, Reason and the Human Brain. Avon Books, New York (1994)
Dixit, A., Nalebuff, B.: Thinking Strategically: The Competitive Edge in Business, Politics and Everyday Life. Norton, New York (1991)
Dixit, A., Nalebuff, B.: The Art of Strategy: A Game Theorist's Guide to Success in Business and Life. Norton, New York (2008)
Dixit, A., Skeath, S.: Games of Strategy, 2nd edn. W.W. Norton and Company, New York (2004)
Donnelly, J.: Realism and International Relations. Cambridge University Press, Cambridge (2004)
Earnest, D.C., Rosenau, J.N.: Signifying nothing? What complex systems theory can and cannot tell us about global politics. In: Harrison, N.E., Rosenau. J.N. (ed.) Complexity in World Politics: Concepts and Methods of a New Paradigm, State University of New York (SUNY) Series in Global Politics (2006)
Finus, M.: Game Theory and International Environmental Cooperation. New Horizons in Environmental Economics. Edward Elgar, London (2001)
Fiorino, D.J.: Making Environmental Policy. University of California Press, Berkeley (1995)

Fisher, R., Ury, W.: Getting to Yes: Negotiating Agreement Without Giving in. Random House Business Books, New York (1999)

Flannery, T.: Here on Earth: A Natural History of the Planet. HarperCollins, Toronto (2011)

Frej, W., Ramalingam, B.: Foreign policy and complex adaptive systems: Exploring new paradigms for analysis and action. Santa Fe Institute (SFI) Working Paper 11-06-022, 16 June 2011

Gilbert, N., Terna, P.: How to build and use agent-based models in social sci*ence*. Iowa State University, http://www2.econ.iastate.edu/tesfatsi/howtousebuildabmss.gilbertterna1999.pdf (1999)

Gladwell, M.: Blink: The Power of Thinking Without Thinking. Back Bay Books, Little, Brown and Company, New York (2005)

Goldstein, N.J., Martin, S.J., Cialdini, R.B.: Yes! 50 Scientifically Proven Ways to be Persuasive. Free Press, New York (2008)

Granovetter, M.S.: The strength of weak ties. Am. J. Sociol. **78**(6), 1360 (1973)

Grossman, G.M., Krueger, A.B.: Environmental impacts of a North American free trade agreement. National Bureau of Economic Research, working paper 3914. NBER, Cambridge, MA (1991)

Hailegiorgis, A.B., Kennedy, W.G., Rouleau, M., Bassett, J.K., Coletti, M., Balan, G.C., Gulden, T.: An agent based model of climate change and conflict among pastoralists in East Africa. International Environmental Modelling and Software Society (iEMSs). In: 2010 International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada (2010)

Hardin, G.: The tragedy of the commons. Science **162**, 1243–1248 (1968)

Hare, F., Goldstein, J.: The interdependent security problem in the defense industrial base: an agent-based model on a social network. Int. J. Crit. Infrastruct. Prot. **3**(3–4), 128–139 (2010)

Harrison, N.E.: Thinking about the world we make. In: Harrison, N.E., Rosenau, J.N. (ed.) Complexity in World Politics: Concepts and Methods of a New Paradigm. State University of New York (SUNY), Series in Global Politics (2006a)

Harrison, N.E.: Complexity systems and the practice of world politics. In: Harrison, N.E., Rosenau, J.N. (eds.) Complexity in World Politics: Concepts and Methods of a New Paradigm. State University of New York (SUNY), Series in Global Politics (2006b)

Hendrick, D.: Complexity theory and conflict transformation. In: Young, N.J. (ed.) Oxford International Encyclopedia of Peace. Oxford University Press, New York (2010)

Hoffman, M.J.: Beyond regime theory: complex adaptation and the ozone depletion regime. In: Harrison, N.E. (ed.) Complexity in World Politics: Concepts and Methods of a New Paradigm. State University of New York Press, New York (2006)

Holland, J.H.: Hidden Order: How Adaptation Builds Complexity. Helix Books (1996)

Holland, J.H.: Signals and Boundaries: Building Blocks for Complex Adaptive Systems. The MIT Press, Cambridge (2012)

Holland, J.H.: Complexity: A Very Short Introduction. Oxford University Press, Oxford (2014)

Iliadis, M., Paravantis, J. A.: A multivariate cross-country empirical analysis of the digital divide. In: 2011 IEEE Symposium on Computers and Communications (ISCC), Corfu, Greece, pp. 2785–28788, 28 June–1 July 2011

Jervis, R.: System Effects: Complexity in Political and Social Life. Princeton University Press, Princeton (1997)

Kauffman, S.A.: The Origins of Order: Self-organization and Selection in Evolution. Oxford University Press, New York (1993)

Kauffman, S.A.: Reinventing the Sacred: A New View of Science, Reason, and Religion. Basic Books, New York (2008)

Kennedy, R.: Cubans sound off on détente efforts with the US. Al Jazeera, 11 April 11 2015. http://www.aljazeera.com/indepth/features/2015/04/cubans-sound-detente-efforts-150411150513419.html

Keohane, R.O., Nye Jr, J.S.: Power and Interdependence, 4th edn. Longman Classics in Political Science, Pearson, London (2012)

Lehrer, J.: How We Decide. Houghton Mifflin Harcourt, Boston (2009)
Levin, S.A.: Fragile Dominion: Complexity and the Commons. Perseus, Reading (1999)
Li, A.: Modeling human decisions in coupled human and natural systems: review of agent-based models. Ecol. Model. **229**, 25–36 (2012)
Lindblom, C.: The science of muddling through. Public Adm. Rev. **19**, 79–88 (1959)
Lindblom, C.: Still muddling, not yet through. Public Adm. Rev. **39**, 517–526 (1970)
Lomborg, B.: Cool It: The Skeptical Environmentalist's Guide to Global Warming. Cyan Marshall Cavendish Editions, London (2007)
Luke, S., Cioffi-Revilla, C., Sullivan, K., Balan, G.: MASON: a multiagent simulation environment. Simulation **81**(7), 517–527 (2005)
Malleret, T.: Disequilibrium: A World Out of Kilter. Amazon Kindle Edition (2012)
McCain, R.A.: Game Theory: A Non-Technical Introduction to the Analysis of Strategy. Thomson South-Western, Mason (2004)
McMillan, J.: Games, Strategies and Managers. Oxford University Press, Oxford (1992)
Mearsheimer, J.J.: Why Leaders Lie: The Truth About Lying in International Politics. Oxford University Press, Oxford (2011)
Miller, J.D.: Game Theory at Work: How to Use Game Theory to Outthink and Outmaneuver Your Competition. McGraw-Hill, New York (2003)
Minelli, A., Fusco, G. (eds.): Evolving pathways: Key Themes in Evolutionary Developmental Biology. Cambridge University Press, Cambridge (2008)
Morgenthau, H.: Politics Among Nations. McGraw-Hill, New York (2005)
Navarro, J., Karlins, M.: What Every Body is Saying: An ex-FBI Agent's Guide to Speed Reading People. HarperCollings e-books (2008)
Neumayer, E.: Pollution havens: an analysis of policy options for dealing with an elusive phenomenon. J. Environ. Develop. **10**(2), 147–177 (2001)
Noll, D.E.: Elusive Peace: How Modern Diplomatic Strategies Could Better Resolve World Conflicts. Prometheus Books, New York (2011)
North, M.J., Macal, C.M.: Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation. Oxford University Press, Oxford (2007)
Nye Jr, J.S.: The Future of Power. Public Affairs, New York (2011)
O'Sullivan, D., Haklay, M.: Agent-based models and individualism: Is the world agent-based? Environ. Plan. A **32**(8), 1409–1425 (2000)
Paravantis, J.A., Samaras, A.: Fuel poverty in Greece and the European Union. In: Society, Borders and Security Symposium, , University of Siegen, Germany, 24–25 (2015)
Paravantis, J.A., Santamouris, M.: An analysis of indoor temperature measurements in low and very low income housing in Athens, Greece. Special Issue on Indoor Environmental Quality in Low Income Housing in Europe of the Journal: Advances in Building Energy Research, Taylor and Francis, in print (2015)
Patterson, K., Grenny, J., McMillan, R., Switzler, A.: Crucial Conversations: Tools for Talking When Stakes are High. McGraw-Hill, New York (2002)
Pirages, D.C., Manley DeGeest, T.: Ecological Security: An Evolutionary Perspective on Globalization. Rowman and Littlefield Publishers, Lanham (2004)
Preston, I., Payne, G., Bevan, I., Hunt, M.: Fuel poverty: tackling the triple injustice. The green housing forum, Sustainable futures for social housing. http://www.daikin.co.uk/binaries/GHF14_Fuel%20Poverty-tackling%20the%20triple%20injustice_Whitepaper_tcm511-342469.pdf. Accessed on Feb 2015 (2014)
Prigogine, I.: The End of Certainty: Time, Chaos, and the New Laws of Nature. Free Press, New York (1997)
Prigogine, I., Stengers, I.: Order Out of Chaos: Man's New Dialogue with Nature. Heinemann, London (1984)
Railsback, S.F., Volker, V.: Agent-based and Individual-Based Modeling: A Practical Introduction. Princeton University Press, Princeton (2012)
Railsback, S.F., Lytinen, S.L., Jackson, S.K.: Agent-based simulation platforms: Review and development recommendations. Simulation **82**(9), 609–623 (2006)

Ramalingam, B., Jones, H., Reba, T., Young, J.: Exploring the science of complexity: Ideas and implications for development and humanitarian efforts, 2nd edition. Working Paper 285, Overseas Development Institute, London (2008)

Rand, W., Wilensky, U.: Verification and validation through replication: a case study using Axelrod and Hammond's ethnocentrism model. In: North American Association for Computational Social and Organization Sciences (NAACSOS), South Bend, IN, June 2006

Rand, W., Wilensky, U.: Making models match: Replicating an Agent-Based Model. J. Artif. Soc. Soc. Simul. **10**(4), 2. http://jasss.soc.surrey.ac.uk/10/4/2.html. Accessed May 2015 (2007)

Rapoport, A., Chammah, A.M.: Prisoners' dilemma. University of Michigan Press, Ann Arbor (1965)

Rihani, S.: Nonlinear systems. http://www.globalcomplexity.org/nonlinear-systems. Accessed April 2015 (2014)

Rubino, J.: Clean Money: Picking Winners in the Green-tech Boom. Wiley, London (2014)

Sandler, T., Arce, M.D.G.: Terrorism and game theory. Simul. Gam. **34**(3), 319–337 (2003)

Santamouris, M., Alevizos, S.M., Aslanoglou, L., Mantzios, D., Milonas, P., Sarelli, I., Karatasou, S., Cartalis, K., Paravantis, J.A.: Freezing the poo—indoor environmental quality in low and very low income households during the winter period in Athens. Energy Build. **70**, 61–70 (2014)

Santamouris, M., Paravantis, J.A., Founda, D., Kolokotsa, D., Michalakakou, P., Papadopoulos, A.M., Kontoulis, N., Tzavali, A., Stigka, E.K., Ioannidis, Z., Mehilli, A., Matthiessen, A., Servou, E.: Financial crisis and energy consumption: a household survey in Greece. Energy Build. **65**, 477–487 (2013)

Saqalli, M., Gérard, B., Bielders, C., Defourny, P.: Testing the impact of social forces on the evolution of Sahelian farming systems: a combined agent-based modeling and anthropological approach. Ecol. Model. **221**, 2714–2727 (2010)

Schelling, T.C.: Models of segregation. In: The American Economic Review, Papers and Proceedings of the Eighty-first Annual Meeting of the American Economic Association, vol. 59(2), pp. 488–493, May 1969

Schelling, T.: The Strategy of Conflict. Harvard University, Cambridge (1980)

Schelling, T.: Some economics of global warming. Am. Econ. Rev. **82**, 1–14 (1992)

Schelling, T.C.: Micromotives and Macrobehavior. Revised edition, W. W. Norton and Company, New York (2006)

Schreiber, D.M.: Validating agent-based models: From metaphysics to applications. In: Midwestern Political Science Association's 60th Annual Conference, Chicago, IL, 25–28 April 2002

Simon, H.: A behavioral model of rational choice. In: Models of Man, Social and Rational: Mathematical Essays on Rational Human Behavior in a Social Setting. Wiley, New York (1957)

Simon, H.: Bounded rationality and organizational learning. Organ. Sci. **2**(1), 125–134 (1991)

Simon, H.: The architecture of complexity. Proc. Am. Philos. Soc. **106**(6), 467–482 (1962)

Smith, C., Kniveton, D., Black, R., Wood, S.: Climate change, migration and agent-based modelling: Modelling the impact of climate change on forced migration in Burkina Faso. University of Sussex, http://users.sussex.ac.uk/~cds21/infweb/christopher%20smith1.pdf (2008)

Starfield, A.M., Smith, K.A., Bleloch, A.L.: How to model it: Problem solving for the computer age. McGraw-Hill, New York (1990)

Sterman, J.D.: Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin McGraw-Hill, New York (2000)

Stevens, S.P.: Games People Play: Game Theory in Life, Business and Beyond. Parts I and II. The Teaching Company (2008)

Susskind, L.E.: Environmental Diplomacy: Negotiating More Effective Global Agreements. Oxford University Press, Oxford (1994)

Taleb, N.N.: The Black Swan: The Impact of the Highly Improbable. Random House, New York (2007)

Tannen, D.: You Just Don't Understand. Ballantine Books, New York (1990)

Tesfatsion, L.: Repast: a software toolkit for agent-based social science modeling. Self-Study Guide for Java-Based Repast. http://www2.econ.iastate.edu/tesfatsi/repastsg.htm. Last updated on 28 Mar 2015

Treisman, D.: The causes of corruption: a cross-national study. J. Public Econ. **76**, 399–457 (2000)

Tziampiris, A.: The Emergence of Israeli-Greek cooperation. Springer, Berlin (2015)

Von Neumann, J., Morgenstern, O.: Theory of Games and Economic Behavior. Princeton University Press, Princeton (1944)

Walby, S.: Complexity theory, globalisation and diversity. In: Conference of the British Sociological Association, University of York, April 2003

Waltz, K.: Man, the State, and War: A Theoretical Analysis. Columbia University Press, New York (1954)

Waltz, K.: Realism and International Politics. Routledge, London (2008)

Waltz, K.: Theory of International Politics. Waveland Press Incorporated, Long Grove (2010)

Waltz, K.N.: Why Iran should get the bomb. Foreign Affairs, July/August 2012

Weber, C.: International Relations Theory: A Critical Introduction, 3rd edn. Taylor and Francis, London (2009)

Wilensky, U.: NetLogo. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL, USA, http://ccl.northwestern.edu/netlogo (1999)

Zagare, F.C.: The Geneva conference of 1954: a case of tacit deception. Int. Stud. Quart. **23**(3), 390–411 (1979)

List of Software Resources

Lists of ABM software resources may be found at

1. Axelrod's dated but still excellent "Resources for Agent-Based Modeling" may be found as Appendix B in his "Complexity of Cooperation" book (1997). In particular, I strongly concur with his recommendation that a beginner use a procedural language (like BASIC or Pascal) to start working on developing an agent-based model
2. Axelrod and Tesfatsion's outstanding online guide, http://www2.econ.iastate.edu/tesfatsi/abmread.htm. Last updated on 28 March 2015
3. An excellent introductory to the Repast software as well as agent-based models is maintained by Tesfatsion at http://www2.econ.iastate.edu/tesfatsi/repastsg.htm. Last updated on 28 Mar 2015
4. A thorough list of software resources is presented and commented online by Allan (2011)
5. Another list of software resources is given by Railsback et al. (2006)
6. A list of ABM platforms in the CoMSES Network, https://www.openabm.org/page/modeling-platforms
7. The following ABM systems (with an emphasis on open source and free packages) are suggested for social science simulation by the author of this chapter (in order of personal preference)
8. Netlogo, https://ccl.northwestern.edu/netlogo, that has inspired a few other tools that are based on it, such as AgentScript (http://agentscript.org) and Modelling4All (http://m.modelling4all.org)
9. Starlogo at http://education.mit.edu/starlogo, Starlogo TNG at http://education.mit.edu/projects/starlogo-tng, and Starlogo NOVA at http://www.slnova.org
10. Anylogic, which has a free edition for academic and personal use (Anylogic PLE), http://www.anylogic.com/blog?page=postandid=237
11. Repast, which offers the capability of being programmed in Java, Relogo or Python http://repast.sourceforge.net
12. MASON, http://cs.gmu.edu/~eclab/projects/mason (Luke et al., 2005)

13. Swarm, presently at http://savannah.nongnu.org/projects/swarm and MAML, http://www.maml.hu/maml/introduction/introduction.html, that uses easier code that translates to Swarm
14. FLAME, http://www.flame.ac.uk
15. Agent Modeling Platform (AMP), http://eclipse.org/amp
16. Breve, http://www.spiderland.org
17. Cormas, a "natural resources and agent-based simulation" system, http://cormas.cirad.fr/en/outil/outil.htm
18. Agentbase, http://agentbase.org, a tool aimed at educational uses, with the capability of coding models in Coffeescript (a simplified version of Java, http://coffeescript.org) and running them on the browser