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ARTIFICIAL SOCIETIES IN THE ANTHROPOCENE: CHALLENGES AND OPPORTUNITIES FOR MODELING CLIMATE, CONFLICT, AND COOPERATION

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ABSTRACT

Computational approaches to climate modeling have advanced rapidly in recent years, as have the tools and techniques associated with the construction of artificial life, artificial societies, and social simulation experiments. However, the use of computer simulation to study the effects of climate change on human conflict and cooperation is still relatively rare. In this article, we consider some of the challenges and opportunities that face interdisciplinary teams seeking to develop models that incorporate human, ecological, and natural systems. There is an urgency to this task because climate-abetted socio-economic and inter-cultural stress can trigger conflict at all scales, which exacerbates human suffering. We argue that the interdisciplinary community of scholars with expertise in multi-agent artificial intelligence simulation and artificial life modeling have a unique opportunity to collaborate and address these challenges by attempting to develop artificial societies capable of uncovering adaptive pathways that can minimize social conflict and maximize cooperation in the face of climate-abetted social and ecological change.

1 INTRODUCTION

This article calls for a closer dialogue and collaboration between scientists who utilize computational approaches in the "social simulation" (SS) and "artificial life" (AL) academic communities in order to better understand and address potential existential threats facing humanity in the *Anthropocene*. The latter term is increasingly used among climate scientists to refer to the current geological epoch in which human activities have become drivers of climatic and environmental change (Davies 2016, Subramanian 2019). The consensus among scholars who study the Earth system dynamics of the Anthropocene is that we are running out of time to prevent catastrophic human-caused climate change. Although it is important to avoid alarmism, which can sometimes make things worse, we need to focus more attention on the problem and generate practically and politically viable solutions. Given the seriousness of these concerns, it is not surprising that climate scientists have been applying mathematical and computational modeling tools to analyze the relationships among contributing factors and to

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develop alternative climate scenarios. For example, Steffen et al. (2018) recently modeled the potential trajectories of the Earth system as a function of human greenhouse gas emissions, biogeophysical feedback, and degradation of the biosphere. The authors argue that we may be approaching a planetary threshold beyond which a cascade of tipping elements would bring about a "Hothouse Earth" not suitable for human habitation and that sustained human stewardship of the system is necessary to create and maintain a "stabilized earth" pathway in which the human species has a chance to survive as an intentional and integral part of the Earth system dynamics.

The effects of climate change are increasing rapidly across the planet and it is not yet clear whether we will be able to act quickly enough to stabilize the climate and thereby avoid crossing a threshold that will render human life on Earth extremely difficult, if not unsustainable. In recent years, the United Nations, the European Commission, and other international organizations have invested in facilitating dialogue and motivating policy action to prepare for the further effects of climate change as resources (e.g. arable land, clean water and air) become scarcer, fires rage, storms intensify, sea levels rise, droughts and floods shift agricultural practices, and climate-related migration increases. However, climate change is certainly not the only potential existential threat to humanity; one also thinks of other dangers such as future global pandemics, chemical or nuclear war, and widespread famine. This means that exploring adaptation pathways for humanity through the Anthropocene will require trans-disciplinary research on climate change, tracking the varied factors that can exacerbate needless conflict or encourage needed cooperation within and across cultures. Here we encourage practitioners of both SS and AL to peer over the fence at the endeavors of their disciplinary neighbors, and to explore ways of working together to create more advanced "artificial societies" to address some of the adaptive challenges of the Anthropocene more effectively.

2 MODELING CLIMATE, CONFLICT, AND COOPERATION

The application of computational modelling techniques to these topics is nothing new; both the SS and the AL scientific communities have been separately developing models that tackle these issues for several decades. As we will see below, however, at the cutting edge of these efforts is the attempt to construct models that are capable of simulating interlocking human, ecological, and natural systems. The interactions within and among these systems produces climate change at the natural-system level, economically potent agricultural change that threatens food and water for humans and other animals at the ecological-system level, and social stress and existential anxiety at the human-system level. Humans may respond to such stress and anxiety by increasing social cooperation or social conflict (or both). Conflict within or between cultures is often the result of unproductive use of resources and can lead to unnecessary human suffering. Such conflict can be exacerbated by socio-economic stress and climate-driven migration that places large groups of human beings with different cultural norms in close proximity. In some contexts, however, migration and stress can seem to encourage cooperation even (or especially) in culturally pluralistic populations.

What are the conditions under which – and the mechanisms by which – cultural conflict or cooperation increase (or decrease) as climate change occurs? To answer such research questions, we need methods capable of coupling human, ecological, and natural systems in order (1) to produce practical, data-driven cost-benefit analyses of potential policy scenarios that impact climate change, and (2) to identify tipping points where human cultures are likely to abandon cooperation and devolve into conflict under stress exacerbated by climate change. Section 3 below addresses some of the major challenges involved in this undertaking and illustrates how it has been tackled so far in both the AL and SS communities. Section 4 outlines some of the ways in which these neighboring disciplines can inspire each other and possibly work together to construct artificial societies and social simulations that can shed light on adaptive pathways through the Anthropocene. In the remainder of this section, we review some of the literature in this rapidly growing field with special attention on the use of Agent-

Based Modeling (ABM). We focus on ABMs (and especially recent developments in multi-agent artificial intelligence modeling) because this provides us with a point of contact between the AL and SS communities, and a potential avenue for motivating dialogue and collaboration between scholars in these disciplines and both policy professionals and stakeholders in the relevant fields.

As noted above, models of climate change have become increasingly sophisticated in the last few decades. The urgency of getting these models right – and of allowing resulting insights to influence our actions – increases as we recognize the non-linear dynamics and potentially drastic consequences of climate change, such as the rapidity of sea level rise in areas that will displace human populations. However, as Beckage et al. (2018, p. 83) have pointed out, "*social processes* are important and dynamic components of the Earth system that have been *largely absent* from climate and integrated assessment models" (emphasis added). Linking models of human attitudes and behaviors with models of climate change is not only likely to result in more realistic and comprehensive simulations, but also can actually alter projected forecasts about factors such as the reduction of greenhouse gases (GHGs). These authors' experiments with the Climate Social Model, which involved the coupling of a social model with a carbon-cycle model called C-ROADS, demonstrated that "*perception of risk* from extreme events associated with climate change can *influence emissions behaviors* to reduce GHGs" (2018, p. 83, emphasis added). They suggest that climate modelers should work harder to incorporate human attitudes and social dynamics into their computational architectures.

Social simulations of cultural conflict (and cooperation) have also grown in sophistication and precision over the decades. Given the human suffering caused by armed conflict, for example, it is not surprising that social scientists interested in understanding such conflicts have increasingly turned to computational modeling tools for help in analyzing the conditions under which they are likely to occur (Lim et al. 2007; Neumann 2014). Research using these methods has shed light on a variety of conflicts between or within cultures, such as the tensions caused by migration, and attempts at the integration of immigrants from different cultures (Houy 2019). As climate change alters our environment in increasingly intense ways, trying to avoid conflict will not be enough. We need to proactively foster cooperation within human populations that will be affected by pandemics, drought, fire, hurricanes, and other climate-related events that increase existential insecurity or force migration" (Verburg et al. 2016, p. 338).

The pressing task, then, is to construct empirically validated and policy-relevant computational models that are capable of simulating the causal interactions among natural, ecological, and human systems. Many scholars within SS are working in this direction. The targets of these models are sometimes referred to as "coupled human and natural systems" (CHANS). The coupling yields more than the sum of the parts, with unique emergent properties that "do not belong separately to human or natural systems, but emerge from the interactions between them, and have their own structure, function, and dynamic mechanisms" (Wang et al. 2018, p. 87). For a review and assessment of earlier ABM-type CHANS, see (An 2012). Another common phrase among computational social scientists for the target of models that aim to link climate dynamics and human social dynamics is "socio-ecological systems" (SES). A recent state-of-the-art survey of SES methodologies and models summarized the achievements of the field and articulated persistent challenges, such as the need to represent human decision-making more accurately in light of knowledge from social psychology (Schulze et al. 2017). Most SES models that have explicitly tackled the interaction between climate change and cultural conflict (or cooperation) have focused on particular regions and specific policy intervention options (Hailegiorgis et al. 2010; Granco et al. 2019). For a review of earlier uses of ABMs to address climate change adaptation and sustainability see (Balbi & Giupponi, 2010; Arneth et al., 2014), and for an overview and assessment of more recent developments in this direction see (Köhler et al., 2018; BenDor & Scheffran, 2018).

All of this is good news. There is indeed a growing interest among climate scientists and policy stakeholders in using ABM and other computational modeling techniques to identify "plausible and desirable futures in the

Anthropocene" (Bai et al. 2016), to pursue an "experimental socioecology" that can enhance diverse decision-making strategies in cooperative processes such as land-use (Barton et al. 2016), and to use computer modeling to facilitate "future safe and just operating spaces" (Cooper and Dearing 2019). Such models are needed because it is not obvious how human beings will respond to the effects of climate change. The moral equipment that is part of our phylogenetic inheritance can drive us into conflict or toward cooperation with both in-group and out-group members. Humans can be selfish and antagonistic under threat, but such conditions can also motivate the expansion of altruistic attitudes and behaviors. The behavior of human populations under varying conditions of threat is ambiguous, and critically depends on individual differences in personality and experiential history, underlining the importance of ABMs designed with cognitively complex, psychologically plausible, and heterogeneous agents in artificial societies.

3 THEORETICAL AND PRACTICAL CHALLENGES

Attempts to create models that can help us adapt to the rapidly changing environment of the Anthropocene without devolving into disastrous social conflict are more likely to succeed if they are guided by well-constructed theories, informed by subject-matter experts and stakeholders, and validated by high-quality empirical data. In this section, we identify some of the key challenges facing scholars in AL and SS who are interested in jointly tackling this task. One of the main theoretical challenges is handling the sheer complexity of interlocked natural, ecological, and human systems. A growing number of scholars emphasize the importance of accounting for differences in geographical regions and sociopolitical and economic contexts, which shape the resilience of human populations as they respond to climate change (Von Uexkull et al. 2016; Abel et al. 2019). In some places climate events might challenge resilient socio-economic systems, while in other places the same events could be catastrophic. Moreover, shifts in environmental or social conditions, as well as policy interventions, can alter the likelihood of conflict or cooperation in response to climate change.

Theoretical debates about the relation between climate and conflict are played out in journals from the relevant disciplines. For example, in 2012 the *Journal of Peace Research* hosted a special issue with a series of articles addressing the relationship between climate and conflict in a wide array of contexts such as the Israel-Palestine conflict and in relation to a variety of specific challenges such as water management and institutional resilience (e.g., De Stefano et al. 2012; Feitelson et al. 2012). In 2014 the journal *Climatic Change* had a special issue with several articles that critically reviewed the evidence, representing a variety of conflicting interpretations (e.g., Gemenne et al. 2014; Hsiang and Burke 2014). In the same year the journal *Political Geography* published a special issue on climate change and conflict, in which many of the contributions highlighted disparate findings and conflicting messages (e.g., Gleditsch and Nordås 2014; Salehyan 2014). What is striking in these discussions is how little consensus emerges. This may be due, in part, to the complexity of the relationships among climate change and conflict (and cooperation); traditional statistical techniques of the sort typically used by scholars in social science disciplines can model these relationships to some degree, but empirical data are often lacking and they struggle to answer questions about causation. Tackling this challenge will require modeling strategies that are more capable of handling formally complex adaptive systems, such as ABMs, in order to tease out some of the relevant causal mechanisms and the parametric conditions that enable or constrain them.

Modeling climate, conflict, and cooperation also faces practical challenges. Finding suitable data is one (Scheffran et al., 2012). Fortunately, in recent years several groups have been developing datasets that are conducive to the task. One valuable dataset for these purposes is GDELT, which monitors news about conflict from around the world: https://www.gdeltproject.org/. Another example of a useful and accessible dataset is that developed by the European Commission's Copernicus Project, which provides freely available data on climate:

https://www.copernicus.eu/en/services/climate-change. Datasets are oriented toward humanitarian concerns are becoming more common (e.g. Humdata: https://centre.humdata.org/predictive-analytics/).

Another major practical challenge in the construction of policy-oriented artificial societies is securing the interest and maintaining the involvement of policy professionals and other stakeholders in the process of creating and interpreting models. When stakeholders are not adequately engaged throughout the process, it can be difficult for them to understand the value or trust the findings of the model. This helps to explain the increase in popularity of participatory approaches to modeling, which involve far more robust collaboration between simulation engineers, subject matter experts, stakeholders, and policy professionals from inception to implementation. Such approaches can include scenario analysis, design workshops, prototyping, and user panels (Elsawah et al., 2015; Polhill et al. 2019; Moallemi and de Haan 2020). Making the case for participatory modeling requires project leaders and computer-science practitioners to explain to stakeholders and policy experts the benefits of extended commitment in a compelling way, beginning with the practical policy relevance of this type of tool. Despite the difficulties, a growing number of computational social scientists are attempting to construct models that explore adaptive policy pathways in response to climate change (Haasnoot et al. 2013) and support planning for long-term socio-ecological change (Gaube and Haberl 2013). Effective policy evaluations and forecasts rely on moving beyond correlations among measurable factors to plausible claims about causal relations, which is one of the benefits of ABM techniques. However, it is important to emphasize that the future of complex adaptive systems cannot be "predicted" in a strong sense; emphasizing the limitations of these tools is crucial when engaging policy professionals in social simulation strategies.

Another challenge, which is both theoretical and practical, has to do with the difficulty of developing artificial societies whose computational architectures include cognitively realistic simulated agents embedded within socially realistic networks. The Multi-Agent Artificial Intelligence (MAAI) variety of ABMs embraces this challenge. But most ABMs that have tackled issues related to climate change mitigation have tended to be relatively abstract with simple agents, minimizing cognitive, behavioral, and social complexities. Creating realistic heterogeneous agents and accurate agent networks usually calls for cognitive, demographic, ecological, and biophysical variables, depending on the use case, and is even more challenging when the agents and networks must be spatially represented and when multiple overlaying social networks change with time. These complexities multiply when the goal is to simulate across scales: "There is a need for ABM to cross the gap between micro-scale actor and larger-scale environmental, infrastructural and political systems in a way that allows realistic spatial and temporal phenomena to emerge; this is vital for models to be useful for policy analysis in an era when global crises can be triggered by small numbers of micro-level actors" (Lippe et al. 2019, 269).

This review has surfaced a recurring question: how can we adequately include and represent the human agents in coupled socio-economic-political-climate models? That this is important is widely acknowledged, but how (or whether it is possible) to incorporate cognitively and behaviorally plausible human agents and place them within artificial societies with realistic hierarchically structured networks is still an open debate. The MAAI type of ABM is potentially far more complex than ABMs with simple agents and interactions, making MAAIs more difficult to understand and explain, and thereby calling for novel methods of analysis and visualization.

This challenge is illustrated in one of the most promising recent attempts to construct a "coupled socio-climate" ABM designed to chart pathways to climate-change mitigation. In that model, Bury et al. represented individuals as either "mitigators" or "non-mitigators," whose behaviors were guided by utility functions related to social norms and other factors. Optimization experiments on this relatively simple model suggested that, on the pathway to climate-change adaptation, the first step should be "prioritizing an increase in social learning, followed by a reduction in mitigation costs" (Bury et al. 2019, p. 1). While this process produced actionable policy-related insights, the authors acknowledged that their model was limited by its lack of hierarchical social networks and its inability to represent heterogeneous personality variables among its agents. But humans are not all the same, their behaviors are shaped by their shifting social contexts, and those facts are directly relevant to emergent features in complex adaptive social systems. Most of the models we have reviewed here are not psychologically and sociologically realistic. Keeping agents and interactions unrealistically simple helps to make a model easy to understand and explain, but also understandably leads to suspicion both within the academy and among policy stakeholders about the relevance and usefulness of computational simulations.

4 OPPORTUNITIES FOR EXPLORING ADAPTIVE BIO-CULTURAL EVOLUTIONARY PATHWAYS THROUGH "ARTIFICIAL SOCIETIES"

We believe that the interdisciplinary community of scholars with expertise in AL and SS has a unique opportunity to address these challenges by developing and designing experiments within artificial societies capable of uncovering pathways that can minimize social conflict and maximize cooperation in the face of climate-abetted social and ecological change. As we have seen, experts in these fields have been working in this direction for some time. Quite early in the development of AL, cellular automata were already being applied to study socio-environmental systems in ways that might help anticipate the effect of climate change in local areas and guide land-use decisions (Engelen et al. 1995; Engelen and White 2008). Other early AL technologies produced insights into conflictual and cooperative relationships by studying the emergence of diverse interacting digital creatures, such as those in the influential Tierra models (Ray 1991). In more recent years, scholars in both disciplines have made rallying cries *within* their communities, calling their colleagues to utilize their skills to address societal and ethical challenges (Penn, 2016; Squazzoni et al., 2020; Conte et al., 2012; Bedau et al., 2000; Aguilar et al., 2014).

Our rallying cry is to (and across) both communities. The daunting complexity of the societal challenges we now face in the Anthropocene calls for a bolder transgression of disciplinary boundaries. But where shall we start? Since the task is to explore possible adaptive pathways in our contemporary environment, it makes sense to begin by taking into account both our shared phylogenetic and diverse socio-historical inheritances, which were shaped by earlier ancestral environments and now condition and constrain any and all potential paths forward. This is also a good place to start for this particular inter-disciplinary endeavor because scholars within the SS and AL communities already have ongoing intra-disciplinary conversations about the importance of developing simulations informed by the sciences that study bio-cultural evolution. Given the history and focus of these fields, it is understandable that AL is stronger on the side of biological evolution while SS is stronger on the side of cultural evolution. In this section we argue that these strengths can complement one another and identify some of the ways in which collaborative efforts might enable the construction of more plausible and more useful artificial societies.

These interdisciplinary efforts can also be facilitated by viewing them within a meta-ethical framework that has been developed specifically for computer scientists working on policy-oriented models (Shults and Wildman 2019). The first aspect of the framework has to do with broader philosophical debates between proponents of consequentialist and deontological approaches to ethics, or realism and non-realism in epistemology and metaphysics. The framework also has a practical aspect that focuses on ways in which philosophical clarity and scientific engagement can help us avoid moral confusion or evasion as we seek to take responsibility for action in the face of challenges such as climate change. While these are important, in this context the scientific aspect of the framework is more relevant. Artificial societies and the networked simulated agents that populate them should be informed by empirical evidence and theoretical insights about the evolved moral equipment that motivates and limits contemporary human attitudes and behaviors. There are of course a wide variety of competing theories about the mechanisms of biological and cultural evolution, but we believe that there are good reasons to think that they all enjoy some empirical support and explanatory power and contribute to a rough consensus about the cognitive and coalitional biases that shape human norms (Shults 2018). We are a hyper-social species, but our capacity to cooperate within groups can also activate anxiety about and antagonism toward out-group members (Johnson and Toft 2014). We cannot fully escape our bio-cultural inheritance, but the more humbly conscious we are of its shaping influence the more likely we will be able to make humanely conscious decisions about adaptive pathways in the Anthropocene.

AL brings critical resources to this endeavor. Unlike most models in the SS community, which focus more on the emergence of macro-level cumulative behaviors from already existing micro-level agents, AL scholars are interested in discovering and creating the conditions for the actual generation and replication of life-like things from non-life-like things. Like biological evolution itself, the results of efforts within AL have often been extremely creative, leading to outcomes that have shocked their developers (Lehman et al. 2020). Many influential models developed within the AL community involve game-theoretic simulations intended to mimic evolutionary processes. For example, models using prisoner's dilemma or public-good games often explore the conditions under which conflict and cooperation can emerge within human populations (Bravo and Yantseva 2018; Teehan and Shults 2019). However, traditional game-theory models typically involve agents with minimal heterogeneity and behavioral rules guided by utility functions presupposing that humans make rational choices. Given the overwhelming evidence for the role of cognitive-emotional inferential biases and ingroup-oriented preferential biases in the motivational reasoning of real human beings, such models are limited in their realism.

Among the "open problems" in AL identified by Bedau et al. (2000), two relate to the issue of bio-cultural evolution. The ninth problem is to "determine the predictability of evolutionary manipulations of organisms and ecosystems." The activities of human beings – like all biological organisms – clearly influence their environment. But can these influences be measured and forecasted? "Speciation and extinction are ubiquitous features of evolutionary history, but the longer-term implications of frequent artificial speciation for biodiversity and sustainability are unknown. Addressing this challenge requires combining an understanding of evolution theory with theoretical experimentation in artificial life models that constructively address hypothetical changes to organisms and ecosystems" (Bedau et al, 2000, p. 371). The thirteenth open problem for AL is to provide "a quantitative understanding of the interplay between cultural and biological evolution" (2000, p. 373). There are significant debates in the literature about the similarities and differences between biological and cultural evolution, but weighing in on these is not crucial for our purpose here, which is to emphasize the need to account for both when constructing artificial societies intended to identify realistic adaptive pathways in the Anthropocene. As these authors note, many cultural-evolution approaches have "the characteristic limitations of analytical population biology, the very limitations that drive the pursuit of synthetic bottom-up models in artificial life." The critical issue in this context, however, is "how biological and cultural evolution are interconnected and influence each other" (2000, p. 374).

Although AL scholars have typically focused more on the mechanisms of biological evolution, they have by no means ignored issues surrounding cultural evolution and social life. Indeed, some early contributors to the discipline intuited the revolutionary potential of applying AL to cultural evolution, whereby a "culture" might be understood as "a kind of organism built out of individuals and social units" (Farmer and Belin 1990, 20). Other early contributors described their study of complex adaptive systems utilizing phrases such as "artificial social life" (Gell-Mann 1994). In the light of insights derived from anthropology in general and cultural evolution in particular, Gessler has explicitly called for the construction of "artificial cultures," aspirationally describing the latter as extending "the program of artificial societies by adding richer modes of thought, richer social interactions and more richly constructed human spaces" (Gessler, 2002, p. 11). Gessler's vision for artificial cultures would take us beyond traditional artificial societies; the latter explore macro-level shifts emerging from micro-level behaviors, but the former would actually generate artificial cultures. This distinction is crucial because it identifies one of the weaknesses of many models developed in the SS community. Computational social scientific experiments using ABMs have shed quite a bit of light on opinion dynamics and the mechanisms by which norms shift in populations (Conte et al., 2014; Xenitidou & Edmonds, 2014: Elsenbroich & Gilbert, 2014), but they struggle to produce the emergence of normativity itself. This is one of the main ways in which AL could contribute to SS: introducing new techniques and evolutionary computational architectures for artificial cultures in which the actors can "redefine the system in which they are a part" (Gessler 2003, 4).

Are we there yet? No. Neither AL nor SS has yet achieved this goal and it is not clear when they might. However, recent developments in SS have moved in the direction of another goal identified by Gessler as a necessary component of the sort of model of dynamical hierarchical emergence that he envisions. Such a minimal artificial culture would need to "be seeded with a population of individuals, each with the properties of age, sex and parentage, and situated in a physical environment with both space and time." One recent computational model called the "Artificial Society Analytic Platform" (ASAP) includes agents with these variables, as well as other variables such as personality factors (Big Five), social identity, employment status, openness to cultural others, and shared norms. These agents are located in space that simulates the neighborhoods of a major western city and move through time over (at least) four generations as they are born, attempt to find jobs and get married, make friends, interact on social media, and eventually die (Shults et al. 2020). ASAP allows a form of "virtual ethnography" and can be used to explore issues such as immigrant integration in western cities (Puga-Gonzalez et al., 2019).

Conversations about the exploration of adaptive pathways in the Anthropocene inevitably raise ethical concerns. Pathways for whom? And to what end? Which norms shape the criteria for making such decisions? The capacity for misuse of such models is high so it matters who defines and controls their "proper" use. Norms are not distributed universally in human populations, so it matters which norms get attention and which are marginalized. Assumptions about norms operative within social-simulation experiments can significantly impact outputs, which affects the analysis and evaluation of potential policy interventions explored in such models (Diallo et al., 2020). Although it will not eliminate such ethical quandaries, pressing toward computational architectures that are more deeply informed by the bio-cultural sciences about the moral reasoning equipment bequeathed to humans by evolution and fashioned within cultural settings will at least make the task more tractable by surfacing the assumptions and purposes guiding such conversations.

One potentially fruitful direction here would be to link climate models to MAAI models that employ more realistic cognitive architectures informed by social psychology and evolutionary biology and whose agents interact within more realistic social networks. SS is making progress in this direction. For example, an artificial society whose agents have variables informed by "terror management theory" and were placed in environments with various levels and types of threat (contagion, social, predation, and natural) was able to simulate the emergence of increased religiosity in a population and show the way in which it was driven by mortality salience and in-group identification at the individual level (Shults et al. 2018b). This model was also extended to include agent variables related to identity fusion theory and social identity theory, and to incorporate more complex social network dynamics. This expanded model was able to simulate the emergence of conflict between religious groups, and to identify the conditions and mechanisms that drove the mutual escalation of such conflict (Shults et al. 2018a). Simulation experiments were validated using empirical data sets derived from experiments in social psychology and survey and historical analysis from conflicts such as "The Troubles" in Northern Ireland. Because they already include relatively complex cultural agents in realistic networks placed in environments with threats that can be parameterized, these models lend themselves to coupling with more realistic climate models. If successful, such coupling could provide policy-relevant insights into the conditions under which conflict and cooperation are likely to emerge in response to climate-related threats, thereby contributing to the achievement of the UN Sustainability Development Goals (Shults and Wildman 2020).

A partnership between AL and SS could go much further, demonstrating the emergence (not just the mutation) of norms related to social cooperation and conflict, and reflecting the intricately complex society-environment interface. Safely navigating the shoals that lie ahead calls for bottom-up emergence of new norms capable of capturing the imagination of large numbers of people in ways that prevailing norms are failing to do. We should probably think of such emergent norms as life-like organisms that thrive and spread or retract and die depending on reception, which in turn depends on minds, cultures, social networks, cultural circumstances, and top-down socio-political reinforcement. This transition in the normative landscape is an adaptive evolutionary change of the bio-cultural type we have been discussing: mental biases and preferences are just as important as cultural conditioning and nurture, and this type of normative transformation is inconceivable without both. Modelers in the AL and SS communities can work together with policy professionals and ethically concerned stakeholders to specify assumptions about the purposes and design of simulation models. During this process, we should surface our assumptions about whatever ideas or processes are at stake in the model, which in turn can foster dialogue about associated ethical challenges. Moreover, the use of simulation experiments on computational models can prompt users to clarify the purposes of the policies they are interested in implementing. This, too, forces ethical questions into the open, providing an opportunity for dialogue as well as a tool for experimenting with potential scenarios as we pursue pathways toward a sustainable future.

REFERENCES

Abel, Guy J., Michael Brottrager, Jesus Crespo Cuaresma, and Raya Muttarak. 2019. “Climate, Conflict and Forced Migration.” *Global Environmental Change* 54: 239–49.

Aguilar, Wendy, Guillermo Santamaría-Bonfil, Tom Froese, and Carlos Gershenson. 2014. “The Past, Present, and Future of Artificial Life.” *Frontiers in Robotics and AI* 1: 8.

An, Li. 2012. “Modeling Human Decisions in Coupled Human and Natural Systems: Review of Agent-Based Models.” *Ecological Modelling* 229: 25–36.

Arneth, A., C. Brown, and M. D. A. Rounsevell. 2014. “Global Models of Human Decision-Making for Land-Based Mitigation and Adaptation Assessment.” *Nature Climate Change* 4 (7): 550.

Bai, Xuemei, Sander Van Der Leeuw, Karen O’Brien, Frans Berkhout, Frank Biermann, Eduardo S. Brondizio, Christophe Cudennec, John Dearing, Anantha Duraiappah, and Marion Glaser. 2016. “Plausible and Desirable Futures in the Anthropocene: A New Research Agenda.” *Global Environmental Change* 39: 351–62.

Balbi, Stefano, and Carlo Giupponi. 2010. “Agent-Based Modelling of Socio-Ecosystems: A Methodology for the Analysis of Adaptation to Climate Change.” *International Journal of Agent Technologies and Systems* 2 (4): 17–38.

Barton, C. Michael, Isaac IT Ullah, Sean M. Bergin, Hessam S. Sarjoughian, Gary R. Mayer, Joan E. Bernabeu-Auban, Arjun M. Heimsath, Miguel F. Acevedo, Julien G. Riel-Salvatore, and J. Ramón Arrowsmith. 2016. “Experimental Socioecology: Integrative Science for Anthropocene Landscape Dynamics.” *Anthropocene* 13: 34–45.

Beckage, Brian, Louis J. Gross, Katherine Lacasse, Eric Carr, Sara S. Metcalf, Jonathan M. Winter, Peter D. Howe, Nina Fefferman, Travis Franck, and Asim Zia. 2018. “Linking Models of Human Behaviour and Climate Alters Projected Climate Change.” *Nature Climate Change* 8 (1): 79.

Bedau, Mark A., John S. McCaskill, Norman H. Packard, Steen Rasmussen, Chris Adami, David G. Green, Takashi Ikegami, Kunihiko Kaneko, and Thomas S. Ray. 2000. “Open Problems in Artificial Life.” *Artificial Life* 6 (4): 363–76.

BenDor, Todd K., and Jürgen Scheffran. 2018. *Agent-Based Modeling of Environmental Conflict and Cooperation*. London: CRC Press.

Bravo, Giangiacomo, and Victoria Yantseva. 2018. “Cooperation and Conflict in Segregated Populations.” *Social Science Computer Review* 38 (4): 405-421.

Bury, Thomas M., Chris T. Bauch, and Madhur Anand. 2019. “Charting Pathways to Climate Change Mitigation in a Coupled Socio-Climate Model.” *PLoS Computational Biology* 15 (6): 1-16. https://doi.org/10.1371/journal.pcbi.1007000.

Conte, R., N. Gilbert, G. Bonelli, C. Cioffi-Revilla, G. Deffuant, J. Kertesz, V. Loreto, S. Moat, J.P. Nadal, A. Sanchez & A. Nowak. 2012. “Manifesto of Computational Social Science.” *The European Physical Journal Special Topics* 214 (1): 325–46. https://doi.org/10.1140/epjst/e2012-01697-8.

Conte, Rosaria, Giulia Andrighetto, and Marco Campennì. 2014. *Minding Norms : Mechanisms and Dynamics of Social Order in Agent Societies*. Oxford: xford University Press.

Cooper, Gregory S., and John A. Dearing. 2019. “Modelling Future Safe and Just Operating Spaces in Regional Social-Ecological Systems.” *Science of The Total Environment* 651: 2105–2117.

Davies, Jeremy. 2016. *The Birth of the Anthropocene*. Oakland, California: University of California Press.

De Stefano, Lucia, James Duncan, Shlomi Dinar, Kerstin Stahl, Kenneth M. Strzepek, and Aaron T. Wolf. 2012. “Climate Change and the Institutional Resilience of International River Basins.” *Journal of Peace Research* 49 (1): 193–209.

Diallo, Saikou Y., F. LeRon Shults, and Wesley J. Wildman. 2020. “Minding Morality: Ethical Artificial Societies for Public Policy Modeling.” *AI & Society* 36: 49-57. https://doi.org/10.1007/s00146-020-01028-5

Elsawah, Sondoss, Joseph H. A. Guillaume, Tatiana Filatova, Josefine Rook, and Anthony J. Jakeman. 2015. “A Methodology for Eliciting, Representing, and Analysing Stakeholder Knowledge for Decision Making on Complex Socio-Ecological Systems: From Cognitive Maps to Agent-Based Models.” *Journal of Environmental Management* 151: 500–516.

Elsenbroich, Corinna, and Nigel Gilbert. 2014. *Modelling Norms*. Dordrecht: Springer.

Engelen, Guy, and Roger White. 2008. “Validating and Calibrating Integrated Cellular Automata Based Models of Land Use Change.” In *The Dynamics of Complex Urban Systems*, 185–211. Dordrecht: Springer.

Engelen, Guy, Roger White, Inge Uljee, and Paul Drazan. 1995. “Using Cellular Automata for Integrated Modelling of Socio-Environmental Systems.” *Environmental Monitoring and Assessment* 34 (2): 203–14.

Farmer, J. Doyne, and Ad’A Belin. 1990. “Artificial Life: The Coming Evolution.” Los Alamos National Lab. Report, 1-25. Los Alamos, NM (USA).

Feitelson, Eran, Abdelrahman Tamimi, and Gad Rosenthal. 2012. “Climate Change and Security in the Israeli–Palestinian Context.” *Journal of Peace Research* 49 (1): 241–57.

Gaube, Veronika, and Helmut Haberl. 2013. “Using Integrated Models to Analyse Socio-Ecological System Dynamics in Long-Term Socio-Ecological Research–Austrian Experiences.” In *Long Term Socio-Ecological Research*, 53–75. Dordrecht: Springer.

Gell-Mann, Murray. 1994. “Complex Adaptive Systems.” *Complexity: Metaphors, Models, and Reality*, edited by G. Cowan, D. Pines & D. Meltzer, 17-45. New York: Addison-Wesley.

Gemenne, François, Jon Barnett, W. Neil Adger, and Geoffrey D. Dabelko. 2014. *Climate and Security: Evidence, Emerging Risks, and a New Agenda*. Dordrecht: Springer.

Gessler, Nicholas. 2002. “Computer Models of Cultural Evolution.” Unpublished Report, 1-28. https://www.researchgate.net/publication/229017160_Computer_models_of_cultural_evolution.

———. 2003. “Evolving Cultural Things-That-Think.” *AAAI Technical Report SS-03-02.*1-7. Palo Alto, CA: Proceedings of the AAAI.

Gleditsch, Nils Petter, and Ragnhild Nordås. 2014. “Conflicting Messages? The IPCC on Conflict and Human Security.” *Political Geography* 43: 82–90.

Granco, Gabriel, Jessica L. Heier Stamm, Jason S. Bergtold, Melinda D. Daniels, Matthew R. Sanderson, Aleksey Y. Sheshukov, Martha E. Mather, Marcellus M. Caldas, Steven M. Ramsey, and Richard J. Lehrter II. 2019. “Evaluating Environmental Change and Behavioral Decision-Making for Sustainability Policy Using an Agent-Based Model: A Case Study for the Smoky Hill River Watershed, Kansas.” *Science of The Total Environment* 695, 10 December 2019. https://doi.org/10.1016/j.scitotenv.2019.133769.

Haasnoot, Marjolijn, Jan H. Kwakkel, Warren E. Walker, and Judith ter Maat. 2013. "Dynamic Adaptive Policy Pathways: A Method for Crafting Robust Decisions for a Deeply Uncertain World." *Global Environmental Change* 23 (2): 485–98.

Hailegiorgis, Atesmachew B., William G. Kennedy, Mark Rouleau, Jeffrey K. Bassett, Mark Coletti, Gabriel C. Balan, and Tim Gulden. 2010. "An Agent Based Model of Climate Change and Conflict among Pastoralists in East Africa." *International Congress on Environmental Modelling and Software* 69. https://scholarsarchive.byu.edu/iemssconference/2010/all/69.

Houy, Nicolas. 2019. "Common Dynamics of Identity and Immigration: The Roles of Mobility and Democracy." *Journal of Artificial Societies & Social Simulation* 22 (4): 1-22.

Hsiang, Solomon M., and Marshall Burke. 2014. "Climate, Conflict, and Social Stability: What Does the Evidence Say?" *Climatic Change* 123 (1): 39–55.

Johnson, Dominic DP, and Monica Duffy Toft. 2014. "Grounds for War: The Evolution of Territorial Conflict." *International Security* 38 (3): 7–38.

Köhler, Jonathan, Fjalar De Haan, Georg Holtz, Klaus Kubeczko, Enayat Moallemi, George Papachristos, and Emile Chappin. 2018. "Modelling Sustainability Transitions: An Assessment of Approaches and Challenges." *Journal of Artificial Societies and Social Simulation* 21 (1): 1-28.

Lehman, Joel, Jeff Clune, Dusan Misevic, Christoph Adami, Lee Altenberg, Julie Beaulieu, Peter J. Bentley, Samuel Bernard, Guillaume Beslon, and David M. Bryson. 2020. "The Surprising Creativity of Digital Evolution: A Collection of Anecdotes from the Evolutionary Computation and Artificial Life Research Communities." *Artificial Life* 26 (2): 274–306.

Lim, May, Richard Metzler, and Yaneer Bar-Yam. 2007. "Global Pattern Formation and Ethnic/Cultural Violence." *Science (New York, N.Y.)* 317 (5844): 1540–1544.

Lippe, Melvin, Mike Bithell, Nick Gotts, Davide Natalini, Peter Barbrook-Johnson, Carlo Giupponi, Mareen Hallier, Gert Jan Hofstede, Christophe Le Page, and Robin B. Matthews. 2019. "Using Agent-Based Modelling to Simulate Social-Ecological Systems across Scales." *GeoInformatica* 23 (2): 269–298.

Moallemi, Enayat A., and Fjalar J. de Haan. 2020. *Modelling Transitions: Virtues, Vices, Visions of the Future*. London: Routledge.

Neumann, Martin. 2014. "The Escalation of Ethnonationalist Radicalization." *Social Science Computer Review* 32 (3): 312–33. https://doi.org/10.1177/0894439313511585.

Penn, Alexandra. 2016. ""Artificial Life and Society: Philosophies and Tools for Experiencing, Interacting with and Managing Real World Complex Adaptive Systems." *Artificial Life Conference Proceedings* 28 (September): 15–15. https://doi.org/10.1162/978-0-262-33936-0-ch003.

Polhill, J., Jiaqi Ge, Matthew Hare, Keith Matthews, Alessandro Gimona, Douglas Salt, and Jagadeesh Yeluripati. 2019. "Crossing the Chasm: A 'Tube-Map' for Agent-Based Social Simulation of Policy Scenarios in Spatially-Distributed Systems." *GeoInformatica* 23 (2): 169–99. https://doi.org/10.1007/s10707-018-00340-z.

Puga-Gonzalez, Ivan, Wesley J. Wildman, Saikou Y. Diallo, and F. LeRon Shults. 2019. "Minority Integration in a Western City: An Agent-Based Modeling Approach." In *Human Simulation: Perspectives, Insights, and Applications*. Switzerland: Springer Nature.

Ray, Thomas S. 1991. "An Approach to the Synthesis of Life." *Artificial Life II* 11: 371–408.

Salehyan, Idean. 2014. *Climate Change and Conflict*. London: Elsevier.

Scheffran, Jürgen, Michael Brzoska, Jasmin Kominek, P. Michael Link, and Janpeter Schilling. 2012. "Climate Change and Violent Conflict." *Science* 336 (6083): 869–871.

Schulze, Jule, Birgit Müller, Jürgen Groeneveld, and Volker Grimm. 2017. "Agent-Based Modelling of Social-Ecological Systems: Achievements, Challenges, and a Way Forward." *Journal of Artificial Societies and Social Simulation* 20 (2): 1-18.

Shults, F. LeRon. 2018. *Practicing Safe Sects: Religious Reproduction in Scientific and Philosophical Perspective*. Leiden: Brill Academic.

Shults, F. LeRon, Ross Gore, Wesley J. Wildman, Christopher Lynch, Justin E. Lane, and Monica Toft. 2018a. "A Generative Model of the Mutual Escalation of Anxiety Between Religious Groups." *Journal of Artificial Societies and Social Simulation* 21 (4): DOI: 10.18564/jasss.3840.

Shults, F. LeRon, Justin E. Lane, Saikou Diallo, Christopher Lynch, Wesley J. Wildman, and Ross Gore. 2018b. "Modeling Terror Management Theory: Computer Simulations of the Impact of Mortality Salience on Religiosity." *Religion, Brain & Behavior* 8 (1): 77–100.

Shults, F. LeRon, and Wesley J. Wildman. 2019. "Ethics, Computer Simulation, and the Future of Humanity." In *Human Simulation: Perspectives, Insights and Applications*, edited by Saikou Y. Diallo, Wesley J. Wildman, F. LeRon Shults, and Andreas Tolk, 21–40. Berlin: Springer.

———. 2020. "Human Simulation and Sustainability: Ontological, Epistemological, and Ethical Reflections." *Sustainability* 12 (23): 10039.

Shults, F. LeRon, Wesley J. Wildman, Saikou Diallo, Ivan Puga-Gonzalez, and David Voas. 2020. "The Artificial Society Analytics Platform." In *Advances in Social Simulation: Looking in the Mirror*, 411-426. Cham: Springer.

Squazzoni, Flaminio, J. Gareth Polhill, Bruce Edmonds, Petra Ahrweiler, Patrycja Antosz, Geeske Scholz, Émile Chappin, Melania Borit, Harko Verhagen, and Francesca Giardini. 2020. "Computational Models That Matter During a Global Pandemic Outbreak: A Call to Action." *Journal of Artificial Societies and Social Simulation* 23 (2).

Steffen, Will, Johan Rockström, Katherine Richardson, Timothy M. Lenton, Carl Folke, Diana Liverman, Colin P. Summerhayes, et al. 2018. "Trajectories of the Earth System in the Anthropocene." *Proceedings of the National Academy of Sciences* 115 (33): 8252–59.

Subramanian, Meera. 2019. "Humans versus Earth: The Quest to Define the Anthropocene." *Nature* 572 (7768): 168–70. https://doi.org/10.1038/d41586-019-02381-2.

Teehan, John, and F. LeRon Shults. 2019. "Religion, Empathy, and Cooperation: A Case Study in the Promises and Challenges of Modeling and Simulation." In *Human Simulation: Perspectives, Insights, and Applications*, 157–78. Springer.

Verburg, Peter H., John A. Dearing, James G. Dyke, Sander Van Der Leeuw, Sybil Seitzinger, Will Steffen, and James Syvitski. 2016. "Methods and Approaches to Modelling the Anthropocene." *Global Environmental Change* 39: 328–40.

Von Uexkull, Nina, Mihai Croicu, Hanne Fjelde, and Halvard Buhaug. 2016. "Civil Conflict Sensitivity to Growing-Season Drought." *Proceedings of the National Academy of Sciences* 113 (44): 12391–12396.

Wang, Shuai, Bojie Fu, Wenwu Zhao, Yanxu Liu, and Fangli Wei. 2018. "Structure, Function, and Dynamic Mechanisms of Coupled Human–Natural Systems." *Current Opinion in Environmental Sustainability* 33: 87–91.

Xenitidou, Maria, and Bruce Edmonds, eds. 2014. *The Complexity of Social Norms*. Cham: Springer.

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