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Complexity Science: A Mechanism for Strategic Foresight and Resiliency in National Security Decision-Making

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Abstract

Most national policy decisions are complex with a variety of stakeholders, disparate interests and the potential for unintended consequences. While a number of analytical tools exist to help decision makers sort through the mountains of data and myriad of options, decision support teams are increasingly turning to complexity science for improved analysis and better insight into the potential impact of policy decisions. While complexity science has great potential, it has only proven useful in limited cases and when properly applied. In advance of more widespread use, a national-level effort to refine complexity science and more rigorously establish its technical underpinnings is recommended.

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THE CHALLENGE

In the past, analysts could address domestic policy and natural security issues as relatively discrete and bounded problems. However, today's globalization, accelerated technology diffusion, and instant communications have created a rapidly changing, interconnected reality where increased agency and complexity are dominant characteristics of socio-technical systems[1] within which national security problems are embedded. Predictability is replaced by uncertainty as new crises unfold at increasing rates, short-circuiting conventional observe-orient-decide-act decision-making cycles, resulting in compressed, observe-react cycles with little time for sense-making or strategic analysis (whether by humans alone or aided by autonomous systems).

In this environment, national security decision makers seek solutions to each new unfolding crisis, focused on near-term, locally optimal responses. While these solutions -- informed by the best known social and behavioral sciences -- may initially appear satisfactory, effects of individual responses to each crisis propagate collectively in unanticipated, interdependent ways with unintended and often highly undesirable consequences as they multiply across local, regional and global systems. As a result, problems compound and amplify, often unseen until a disaster reveals the overall reduced system resilience. Indeed, at a meeting chaired by the National Intelligence Council (NIC) in fall 2016, members of the community agreed that a critical national security need is understanding how decisions made in the six-month to four-year timeframe (i.e., the effective window of influence of many senior policy makers) effect long term, strategic interests.[2]

THE POTENTIAL

In today's complex, interconnected, and uncertain world, the best policy decisions are those that result in expedient and advantageous solutions in the near-term while avoiding undesirable outcomes in the long-term. To inform such decisions, the goal of the analyst is not to find 'optimal' answers to policy questions, but to reduce uncertainty and risk in their effects. Complexity science has the potential to identify these solutions for both actionable intelligence and strategic foresights from a system-of-systems perspective that accounts for interconnectedness and uncertainty across multiple scales, while helping to avoid unintended, unforeseen, and unacceptable outcomes. Recent advances in complexity science that incorporate advances in social and behavioral research have demonstrated some remarkable successes as well as notable failures. For example, during the U.S. election cycles of 2008, 2012,[3] and 2016,[4] big data analytics helped individual campaigns craft and deliver tightly focused messages for hundreds of disparate target audiences. However, they failed to accurately predict the overall

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[1] Here, socio-technical refers to social and behavioral systems interdependent upon, and highly integrated with, technical systems.

[2] The NIC organized and co-hosted a meeting (with the Assistant Secretary of Defense for Special Operations/Low Intensity Conflict and the New England Complex Systems Institute) on November 19, 2016 to identify analytic challenges of the intelligence community and how research in complexity science can help to meet those challenges. The meeting was attended by over a dozen different intelligence organizations, along with several universities and private consultants.

[3] Dalton, Russell. "The Potential of Big Data for the Cross-National Study of Political Behavior," *International Journal of Sociology*, 46(1): 8–20, 2016.

[4] Hwang, Annie S. "Social Media and the Future of U.S. Presidential Campaigning" (Senior Theses, Paper 1231, Claremont McKenna College, 2016). http://scholarship.claremont.edu/cmc_theses/1231.

outcome of the 2016 presidential elections. It is unclear how successful similar techniques have been to date for shaping strategic communications for countering violent extremism.[5]

EXEMPLARS

Appropriate combinations of theoretical principles from social and behavioral sciences with the associated principles, tools and techniques from complexity science – such as self-organization and emergence of order or nonlinear behaviors; innovation, adaptation, and learning; pattern recognition and network analysis; resiliency in system dynamics; and risk reduction through progressive hedging – have individually proven effective on a wide variety of complex socio-technical problems, providing foundations for strategic foresight and resiliency planning. For example, multi-scale agent-based modeling, a tool for exploring emergent behaviors, is the analytic cornerstone of the U.S. Centers for Disease Control and Prevention (CDC) policy for community response to potential pandemic influenza strains, and the U.S. Department of Homeland Security (DHS) strategic recommendation for national pandemic planning and response.[6] In other cases, dynamic network analysis has provided insights into fragility and resilience of infrastructures for critical national security planning scenarios and emergency response for natural disasters and malicious attacks,[7] and for identifying and targeting national security threats.[8] Combinations of agent based modeling and dynamic network analysis have a long history of providing solutions for situational awareness and courses of action in the evolution of artificial intelligence and decentralized autonomous capabilities for national security applications,[9,10] while combinations of agent based modeling with complex system dynamics have contributed to resolution of international stalemates over policies to control scarce resources.[11]

LIMITATIONS

These examples show that the existing observations and theoretical body of complexity science, combined with that of the social and behavioral sciences, can effectively support national policy decision-making. However, to do so reliably, they must be applied appropriately and with a clear understanding of the underlying assumptions and theoretical foundations, and of their limitations. Unfortunately, despite some valuable contributions to national security, theses sciences have at times fallen short, been oversold, or inappropriately applied, contributing to undesirable outcomes rather than helping to prevent them. These cases often involve one or both of two serious flaws: (1) violation of fundamental principles of complexity, such as

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[5] Bunnik, A. (2016). "Countering and Understanding Terrorism, Extremism, and Radicalisation in a Big Data Age," in A. Bunnik, A. Cawley, M. Mulqueen, and A. Zwitter (eds.), *Big Data Challenges: Society, Security, Innovation and Ethics*, pp. 85-96. London: Palgrave Macmillan UK.

[6] http://www.sandia.gov/CasosEngineering/applications/pophealth-apps/pandemic_influenza/index.html.

[7] http://www.sandia.gov/nisac/wp/wp-content/uploads/downloads/2012/03/NISAC-Agent-Based-Laboratory-for-Economics.pdf.

[8] Czeslaw Mesjasz. "Complex Systems Studies and Terrorism," in P.V. Fellman, Yaneer Bar-Yam, A.A. Minai (eds.), *Conflict and Complexity: Countering Terrorism, Insurgency, Ethnic and Regional Violence* (Chapter 2). Springer. file:///Users/nkhayde/Downloads/9781493917044-c1.pdf.

[9] Mitchell, M. (2006). "Complex systems: Network thinking," *Artificial Intelligence*, 170(18): 1194-1212.

[10] The Economist (20107). "Riders on a swarm," *The Economist*, http://www.economist.com/node/16789226. Accessed March 7, 2017.

[11] Passell, Howard et al., 2016. *Integrated Human Futures Modeling in Egypt*, SAND2016-0388, Albuquerque, NM: Sandia National Laboratories.

unpredictability; and (2) misalignment between the types of decisions being supported, knowledge structure, analytic questions, and methodology.

As a rule, the nonlinear, adaptive nature of complex interdependent systems (i.e., all human social systems) means that their behaviors cannot be predicted or optimized, but at best, understood, shaped, and constrained. As a result, a primary contribution of complexity science to national security is to show unanticipated responses and phenomena that, until falsified, add to the possibility space. Such insights prevent national decision makers from being blind-sided and offer new considerations by revealing leading indicators for situational awareness and the underlying dynamics; identifying where the most sensitive interventions points are; generating possible future landscapes based on the dynamics that result from those interventions at a systems level; and enabling progressive hedging to avoid undesirable outcomes.[12] It cannot, with any credibility, be used to accurately predict specific outcomes within socio-technical systems fixed in time and physical space, but to recognize and evaluate new hypotheses and possible singularities.

EVOLUTION

An underlying problem with applications of complexity science is that, it is, itself, complex, relatively new, still evolving. Modern complexity science has its origins in the late 1940s with the introduction of General Systems Theory and Cybernetics.[13] Since then, the field has grown significantly through the deepening and broadening of common theoretical foundations drawn from diverse scientific disciplines (i.e., behavioral economics, evolutionary biology and psychology, thermodynamics, information science, neuroscience, and physics to name a few). New mathematical tools have been introduced alongside these advancements with varying degrees of rigor that attempt to instantiate, test, and apply the new insights from theoretical foundations. However, three challenges remain for the promises of complexity science to be fully realized as a mechanism for synthesizing knowledge and understanding from the social and behavioral sciences into strategic national security analysis:

1. Verification, validation, and uncertainty quantification (VV&UQ) of theories, data, and tools require continued exploration of theoretical underpinnings of – and relationships between – knowledge structures, axioms, invariants, scalability, generalized rules of behavior, data requirements, and epistemological limits in complex, adaptive socio-technical systems.
2. Theories and tools are often complex and hard for all but experts to understand how to apply and interpret appropriately, requiring R&D investments in theory development and training in best practices for learning about, implementing tools for, and communicating results from analysis of complex adaptive socio-technical systems.

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[12] Many planning problems for complex systems can be formulated as multi-stage stochastic problems with discrete decision variables in each of the stages. Progressive hedging is a scenario-based decomposition technique for solving such problems in ways. Specifically, researchers have developed algorithmic innovations using progressive hedging for a broad class of scenario-based resource allocation problem in which decision variables represent resources available at a cost and constraints enforce the need for sufficient combinations of resources. See https://link.springer.com/article/10.1007/s10287-010-0125-4.

[13] Sturmberg, Joachim P. "Systems and Complexity Thinking in the General Practice Literature: An Integrative, Historical Narrative Review," *Annals of Family Medicine* 12(1): 66-74, 2014.

3. Adaptive and emergent characteristics of, and problems in, national security require continued development of theory and tools grounded in advances in social and behavioral science research that addresses the dynamic impacts of accelerating rates of emerging technology adoption on human behavior and social systems.

A PATH FORWARD

With appropriate investments and continued research into all the relevant theoretical foundations, complexity science can evolve into a robust, theoretically grounded discipline with a clear understanding of how to structure knowledge, categorize problems, and match them to the specific modeling, simulation, and analysis tools, and produce the type of insight necessary to support informed, resilient policy decisions. Reaching the point where complexity science becomes a trusted mechanism for producing both reliable, actionable intelligence and strategic foresight for domestic and international security policy requires long-term efforts to address the three challenges noted above.

Ideally, such an effort could be centrally supported and administered out of a national-level organization, such as the National Science Foundation, and executed at a combination of publicly and privately funded research centers to include Federally Funded Research and Development Centers (FFRDCs),[14] and University Affiliated Research Centers (UARCs).[15] Both FFRDCs and UARCs have long histories of supporting national security analysis. FFRDCs have the charter and responsibility for solving national security problems in partnership with the intelligence community as both innovators and honest brokers. UARCs generate knowledge from research universities with perspectives different than FFRDCs, while maintaining the dedication to independence found in FFRDCs.

THE BENEFIT

Goals of the recommended research are to (1) yield new discoveries on how complex socio-technical systems behave and how to validly simulate them, while (2) developing the framework for understanding how best to select and apply specific tools and theories from complexity science to different classes of socio-technical problems found in various agencies across the US government. Not every problem is the same, and no single research paradigm, theoretical approach, or analytic methodology will provide meaningful insight into all problems encountered. Indeed, as the previous examples illustrate, multiple tools currently exist, each appropriate to addressing certain aspects and classes of complex problems in the social and behavioral sciences. Applying the wrong tool to a problem is likely to lead to an undesirable outcome, much as trying to solve complex problems without the insights of complexity science would. Alternatively, when applied as a synergistic ensemble of analytic approaches, robust landscapes of possibilities can be generated within which techniques can be applied to increase confidence in strategic foresights and reduce risk of unintended consequences, thereby increasing resiliency in the national security system.

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[14] FFRDCs are public-private partnerships that conduct research for the USG, administered by universities and corporations. There are currently 42 FFRDCs, including the DOE national laboratories, MITRE, RAND Corporation, and the Institute for Defense Analysis.

[15] A UARC is a strategic DoD research center associated with a university.

IN SUMMARY

The current mode of analysis driven by crisis response and decision-making for complex problems of domestic and foreign national security policy risks creates conditions that lead to undesirable and unacceptable strategic outcomes. The interconnected, unpredictable, socio-technical nature of these problems requires new approaches to understanding their dynamics (well-grounded in the social and behavioral sciences), exploring "what if" scenarios, and avoiding short-term decisions that lead to disasters in the long term. Complexity science, when rigorously applied with the appropriate level of understanding of context-specific theoretical social and behavioral sciences and research paradigms, in combination with generalized principles of complex systems, can improve the way in which agencies inform decision-makers, and decision-makers identify and select appropriate courses of action in an uncertain, and ever-changing environment. To realize this vision, more research and development is required in the areas of cross-disciplinary VV&UQ, epistemological limits and knowledge structures, and learning/communication mechanisms. The goal should be to provide strategic foresight for national security decisions that are resilient across timeframes that range from the mid to long term (e.g., six months to more than ten years), and robust to unforeseen circumstances in the future.

Nomenclature

Abbreviation	Definition
CDC	U.S. Centers for Disease Control & Prevention
DHS	U.S. Department of Homeland Security
FFRDC	Federally Funded Research and Development Center
NIC	National Intelligence Council
UARC	University Affiliated Research Center
VV&UQ	verification, validation, and uncertainty quantification

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