25th International Congress on Modelling and Simulation, Darwin, NT, Australia, 9 to 14 July 2023
mssanz.org.au/modsim2023

KEYNOTE

Earth systems to Anthropocene systems: An evolutionary, system-of-systems, convergence paradigm for interdependent societal challenges

J.C. Little [a], R.O. Kaaronen [b], J.I. Hukkinen [b], S. Xiao [c], T. Sharpee [d], A.M. Farid [e], R. Nilchiani [e] and C.M. Barton [f]

[a] *Department of Civil and Environmental Engineering, Virginia Tech, Blacksburg, Virginia, United States*
[b] *Environmental Policy Research Group, University of Helsinki, Helsinki, Finland*
[c] *Department of Geosciences, Virginia Tech, Blacksburg, Virginia, United States*
[d] *Computational Neurobiology, Salk Institute for Biological Studies, La Jolla, California, United States*
[e] *School of Systems and Enterprises, Stevens Institute of Technology, Hoboken, New Jersey, United States*
[f] *School of Human Evolution and Social Change, Arizona State University, Tempe, Arizona, United States*
Email: jcl@vt.edu

Abstract: Humans have made profound and irreversible changes to the Earth. The ensuing societal challenges of the Anthropocene (e.g., climate change and impacts, renewable energy, adaptive infrastructure, disasters, pandemics, food insecurity and biodiversity loss) are usually addressed as if they are disconnected. In addition, when attempting to address any of these challenges, communities, managers, experts and policy-makers do not have strategies and tools to evaluate synergies and trade-offs across multiple complex systems.

To more effectively address the myriad challenges, we are developing an agile, systems-of-systems, computational framework (the SoS framework) to integrate fragmented data and disconnected disciplinary knowledge into a new systemic understanding. There is also an urgent need for a new SoS pedagogy to educate and train communities, managers, experts and policy-makers to think holistically and abstractly, and conceptualize societal problems more coherently. The SoS framework and SoS pedagogy collectively comprise the SoS paradigm. In this critical review we extend the SoS paradigm using geological, biological and cultural evolution, which includes technological evolution, to identify the causal relationships that transformed Earth systems into Anthropocene systems. Focusing on the evolution of the Earth, genetic evolution, the evolution of the brain, and cultural evolution, which includes technological evolution, we identify a nested evolutionary sequence of geophysical, biophysical, sociocultural and sociotechnical systems, and conclude by proposing an evolutionary, system-of-systems, convergence paradigm.

The evolutionary, SoS convergence paradigm must include an SoS computational framework, an SoS decision-support system, and an SoS pedagogy. Unfortunately, because of the large number of systems involved, it will be essentially impossible to integrate computational models of all the systems directly due to their diverse, discipline-specific ontologies. To overcome these limitations, we propose to use system-of-systems engineering and hetero-functional graph theory (HFGT), first translating "real-world" Anthropocene systems into the graphical systems modeling language (SysML), and then using HFGT to algorithmically traverse the gap from the graphical SysML model to the associated mathematical model, and ultimately to the computational model. Both SysML and HFGT are based on the structure of human natural language, relying on a simple ontology with subjects and verb + object predicates that are arranged in a meta-architecture which is independent of discipline. Thus, SysML and HFGT together create a common scientific language and computational framework, providing the means to produce an ontologically-coherent computational model of arbitrary Anthropocene systems. As a result, the proposed evolutionary, system-of-systems, convergence paradigm coherently integrates geophysical sciences, biological sciences, social sciences, engineering and the humanities, providing a potentially quantifiable theoretical framework while enabling behavioral science to derive systemic insights beyond those found in economics, psychology and cognitive science.

REFERENCES

Little, J.C., Kaaronen, R.O., Hukkinen, J.I., Xiao, S., Sharpee, T., Farid, A.M., Nilchiani, R., Barton, C.M., 2023. Earth Systems to Anthropocene Systems: An Evolutionary, System-of-Systems, Convergence Paradigm for Interdependent Societal Challenges. Environmental Science & Technology 57, 5504–5520 https://doi.org/10.1021/acs.est.2c06203.

Keywords: *Cultural evolution, niche construction, norms, resilience, sociocultural systems, sustainability*