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COMPLEX UNIFIABLE SYSTEMS

The BRIDGE

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Modeling and Envisioning Complex Systems

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Most systems that matter are complex. Common to all complex systems is the fact that they are composed of many different components, whose interaction leads to emergent behavior that is hard to predict.

Human evolution has favored local, short-term thinking and action. We are the children of those who specialized in short-term survival. Not surprisingly, many of the reward systems humans have built so far favor those that win attention and support in the short-term, not those that ask for sacrifices today to avoid major catastrophes tomorrow. Given humankind's capability to change Earth dramatically, this is no longer a winning strategy.

The Power of Models and Visualizations

High-quality data, computer models, and advanced data visualizations can enhance understanding of the structure and dynamics of complex real-world systems. In general, this can be done via conceptual models (e.g., causal loop diagrams to communicate system dynamics), mathematical models (e.g., dynamical equations to capture trends), computational models (e.g., network model algorithms that compute the growth of interrelationships), or physical models developed for real-world experimentation or demonstration (e.g., sand piles to understand avalanches).

Some models use empirical data and algorithms exclusively, others rely solely on expert opinions (e.g., gathered via workshops, panels, or surveys).

Computational modeling approaches employ empirical data, which they mine, model, and visualize using computational algorithms.

Most models are designed by individuals from different domains (e.g., sociology, economics, physics, engineering) and sectors (academia, industry, government). Basic requirements in these collaborations are that user needs are properly communicated and understood to guide model design, coding is done in a correct and efficient manner, and results are transparently articulated—including information on model limitations.

Data visualizations can help communicate model effort requirements, model implementations and runs, as well as model results to different stakeholders. A recent special issue of the *Proceedings of the National Academy of Sciences*[1] presents exemplary models and visualizations that aim to support decision making in education, science, technology, and policy. And the *Places & Spaces: Mapping Science* exhibit features 100 maps and 24 interactive data visualizations, called macroscopes (http://scimaps.org).

Designing Models and Data Visualizations

To support the use of data visualizations when designing, optimizing, and communicating complex systems models, a theoretical data visualization framework (DVL) was expanded to cover model design–specific aspects. The resulting ModelDVL covers analytic and predictive models and their visualization (explained in the forthcoming Börner 2021). The framework explains the steps needed to convert expert or empirical data into actionable insights and includes a typology of key terminology.

The process starts with stakeholders (e.g., those that have questions about a complex system yet must manage it resourcefully). Stakeholder information needs must be identified and operationalized (this is similar to translating a verbal math problem into a formula that can be solved). Based on the stated information needs, which include basic insights (e.g., understanding trends, clusters, relationships) as well as emergent phenomena (e.g., oscillation, synchronization, diffusion, growth, adaptation), appropriate datasets are compiled, descriptive and predictive models are selected and run, and visualizations are designed to help communicate the model design, runs, and interpretation of the results. Visualizations are then deployed (e.g., printed or made available as interactive data visualizations), and results are validated and interpreted.

The framework typology covers key insight needs, data scale types, model types, and visualization types as well as graphic symbol and graphic variable types that can be used to map data variables to visual variables. Last but not least, there is a list of interaction types that might be supported by different tools and required to satisfy a certain insight need (e.g., filter by time is valuable for understanding trends or geospatial diffusion over time).

Expanding Use of Models and Visualizations

Today, more than ever before, it is important that anyone be able to model and visualize real-world or simulated data in support of effective communication among researchers, practitioners, and policy- and decision makers. While many may not be able to read formulas or code, an increasing number of experts can read data visualizations and use them to identify and call out problems and opportunities quickly.

Modeling and visualization efforts are heading toward methods and tools that anyone can use to gain insight, as articulated in recent popular books such as *Elevate the Debate* (Schwabisch 2020) and *Calling Bullshit* (Bergstrom and West 2020). Massive open online courses such as Indiana University's Visual Analytics Certificate (https://visanalytics.cns.iu.edu) empower thousands of students to render their own personal and professional data into actionable insights.

Many models and model visualizations are required to yield a holistic understanding of the world and our place in it. A key challenge is the assembly of models and model results into a mosaic that is larger than the sum of parts. Let's combine forces to model and visualize the complexity of our world!

References

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Schwabisch JA, ed. 2020. Elevate the Debate: A Multilayered Approach to Communicating Your Research. Hoboken NJ: Wiley.

[1] Arthur M. Sackler Colloquium on Modeling and Visualizing Science and Technology Developments (Dec 4–5, 2017), PNAS 115(50), online at https://www.pnas.org/modeling.