Translating across disciplinary boundaries: Cartography, Math, and Machine-Learning towards more equitable climate outcomes

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Introduction – Maps and Disasters

At present, flooding causes more damage in the United States than any other extreme weather event, with a disproportionate impact on historically and economically marginalized populations. Climate change is already and will continue to exacerbate impacts from flooding and other extreme weather events which destroy transportation networks in ways that isolate communities and disrupt access to essential needs and services, such as food, water, and medical care. Given the growing devastating impacts of flooding and other extreme weather events as well as their disproportionate impact on marginalized communities, accurately modeling and predicting how infrastructural networks decay under extreme conditions is of paramount performance in building resilience and making climate adaptation more equitable. At the same time, wide-scale planning and response to these events increasingly occur through increasingly autonomous machine-learning modeling and analysis. A separation is growing between cartographers and GIScientists who interpret and present the results of said models and the computer scientists and mathematicians that design and automate them with the advent of generative and geoAI approaches offering the possibility of a wholesale elision of the former. This vision paper uses the successful and ongoing collaboration between a team of cartographers, GIScientists, data scientists, and mathematicians to address network decay during climate events as a potential model for transdisciplinary work that keeps cartographer and GIScientists, their insights and expertise, centrally “in the loop” by centering cartography (and GIScience)’s role as the translational science of Geography (Fish et al. 2026). We do so by first explaining the specific methodology that bridges cartographic praxis with a form of machine-learning called Topological Data Analysis (Progin et al. 2025), situating the works’ broader significant; and, then, discussing the specific processes through which the expertise and importance of human level oversight from multiple disciplines remained central to the project.

From a computational and mathematical perspective, Network flows are an abstract framework applicable to a range of real-world problems, including design of infrastructure networks, inventory and logistics management, image segmentation in computer vision, and information flow in neural networks. Traditional combinatorial algorithms (e.g. Ford–Fulkerson) and spectral approximations are the gold standard for static network flow computation. However, these methods become prohibitively expensive when the topology of a large network changes dynamically. During an urban natural disaster such as a flood, a city's road network can change rapidly: roads wash out, capacities fluctuate, and demand spikes unpredictably. Current methods require a full recomputation of the flow whenever even a single high-capacity edge changes state, rendering planning and adaptation computationally intensive. In GIScience, it is common to model road networks as directed graphs, which provide a formal framework for analyzing traffic flow. These analyses tend to focus on computing graph-based metrics as a series of edges are removed from static graphs (Knoop et al., 2012, Loretti et al., 2022). For static graphs, there are alternative algorithms that can determine the maximum flow between intersections across the graph in polynomial time.
For infrastructure networks which contain a very large number of nodes and edges, these algorithms become computationally expensive. Further, in dynamic models, where edges are constantly added and removed, recomputing the maximum flow value becomes highly inefficient.

A Modest Proposal

To address these challenges, we propose a novel theoretical framework for modeling indeterminate flows using sheaves of modules over polynomial rings. While a standard weighted graph captures capacity numerically, a sheaf allows us to attach algebraic structures to the nodes and edges. Sheaf-theoretic treatments of network flows using vector spaces have successfully recapitulated and extended classical results in the context of static networks. By working over polynomial rings, we treat flow constraints as algebraic variables rather than fixed scalars. Coherent flows across the network arise as solutions to a system of polynomial equations, and combining Gröbner-basis methods with recent advances in computational topology, we posit that a one-time "heavy-lift" computation of these indeterminate solutions is feasible. Once computed, queries about how flows behave as the network changes reduce to evaluating precomputed polynomials—an operation orders of magnitude cheaper than re-solving the full problem. Further, to demonstrate the viability of these techniques, we are applying them to simulations of road network degradation during flooding in the Houston metropolitan area.

A Future Vision

What is unique about the above is not only the novel mathematical approach and resulting algorithms, but also the degree to which such an approach was only made possible through the transdisciplinary, human-based collaboration of the full team. Simply put, the application of TDA to geospatial environments was only possible through transdisciplinary collaborations wherein the GIScience expert recognized the computational cost of refactoring networks as they decay and the mathematician recognized the specific application of a technique previously used for modeling neural networks as a potential solution. Such collaborations predicate on the centrality of human experience and expertise, they require mutual respect and built understanding between and across fields; something - as an endeavor deeply rooted in the translation and communication of ideas between audiences and mediums - that cartography is specifically well suited to perform. Rather than retreating into a series of rapidly devalorizing technical processes (the *how* of producing maps) or blindly embracing the deskilling of said processes through new artificial intelligence agents, by embracing the theoretical contributions of Cartography and GIScience beyond their limited application as tools (the *why* of maps; Thatcher and Imaoka 2018), GIScientists and Cartographers become more centrally able to take on their full potential role as the translators across and betwixt domain knowledges. Rather than being automated out of pressing a sequence of buttons in a given software suite, the entwined fields orchestrate collaborations across disciplines using their long-standing praxis of communication. We propose this model as a means of ensuring both the centrality of humans within GIScience and Cartography projects as well as beyond those limits and into the increasingly necessarily transdisciplinary work that forms the cutting edge of geospatial research.

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