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Topological phase transition from cyclic to tree structures in evolving transport networks

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Transport networks in nature - such as vascular systems, river basins, and plant xylem - often adapt their structure in response to external flow stimuli. This work investigates the topological transition between cyclic and tree-like configurations in such adaptive networks. Using a model based on the Hagen–Poiseuille equation coupled with a conductivity adaptation law, we simulate network evolution under steady-state flow. A critical transition is identified at the feedback exponent $\gamma = 1.0$, where the system shifts from a highly redundant, looped structure to an acyclic, tree-like topology. We analyze the emergent geometries and their statistical properties, providing insights into how local adaptation rules drive global organization. The findings offer insights into the optimization and robustness of transport systems and have potential applications in the design of human-made infrastructure networks.

Primary author: VASILEUSKAYA, Victoria (Warsaw University)

Co-author: Prof. SZYMCZAK, Piotr (University of Warsaw)

Presenter: VASILEUSKAYA, Victoria (Warsaw University)

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