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Optimizing information flow in biological networks

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The generation of physicists who turned to the phenomena of life in the 1930s realized that to understand these phenomena one would need to track not just the flow of energy (as in inanimate systems) but also the flow of information. It would take more than a decade before Shannon provided the tools to formalize this intuition, making precise the connection between entropy and information. Since Shannon, many investigators have explored the possibility that biological mechanisms are selected to maximize the efficiency with which information is transmitted or represented, subject to fundamental physical constraints. I will survey these efforts, emphasizing that the same principles are being used in thinking about biological systems at very different levels of organization, from bacteria to brains. Although sometimes submerged under concerns about particular systems, the idea that information flow is optimized provides us with a candidate for a real theory of biological networks, rather than just a collection of parameterized models. I will try to explain why I think the time is right to focus on this grand theoretical goal, pointing to some key open problems and opportunities for connection to emerging experiments.