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BIOLOGICAL COMPLEXITY AND ROBUSTNESS

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A surprisingly consistent view on the fundamental nature of complex systems can now be drawn from the convergence of three distinct research themes. First, molecular biology has provided a detailed description of much of the components of biological networks, and the organizational principles of these networks are becoming increasingly apparent. It is now clear that much of the complexity in biology is driven by its regulatory networks, however poorly understood the details remain. Second, advanced technology is creating engineering examples of networks where we do know all the details and that have complexity approaching that of biology. While the components are entirely different, there is striking convergence at the network level of the architecture and the role of protocols, layering, control, and feedback in structuring complex system modularity. Finally, there is a new mathematical framework for the study of complex networks that suggests that this apparent network-level evolutionary convergence both within biology and between biology and technology is not accidental, and follows necessarily from the requirements that both biology and technology be efficient, robust, adaptive, and evolvable. This talk will describe qualitatively in as much detail as time allows these features of biological systems and their parallels in technology, using hopefully familiar and concrete examples. The aim is to be accessible to biologists, and not to depend critically on the mathematical framework. A crucial insight is that both evolution and natural selection or engineering design must produce high robustness to uncertain environments and components in order for systems to persist. Yet this allows and even facilitates severe fragility to novel perturbations, particularly those that exploit the very mechanisms providing robustness, and this “robust yet fragile” (RYF) feature must be exploited explicitly in any theory that hopes to scale to large systems. Time permitting, the mathematical research implications will be sketched of this view of “organized complexity” in biology, technology, and mathematics. This view contrasts sharply with that of “emergent complexity” popular in other areas of science in a way that can now be made mathematically precise.