A surprisingly consistent view on the fundamental nature of complex systems can now be drawn from the progress and convergence of three distinct research themes. One is that 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. Also, advanced technology is creating 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 begin with a qualitative description of the parallel organizational features of biological and technological networks, using hopefully familiar and concrete examples. The aim is to be broadly accessible, 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. Then the mathematical progress and research implications will be sketched, including results on a more unified theory of communications, control, and computing.

Time permitting, we can reconsider classical problems such as chaos, fractals, critical phase transitions, power laws, and turbulence, contrasting the traditional “emergent complexity” view with what is enabled by the mathematics of this new “organized complexity” perspective. The idea that proof complexity implies problem fragility offers a more systematic and coherent approach to overcoming the apparent intractability and unpredictability of “emergent” phenomena. A particular interesting example involves new explanations for the nature and origins of organized structures in highly turbulent shear flows.

Selected recent publications
5. Shapiro, BE; Hucka, M; Finney, A; Doyle, J. 2004. MathSBML: a package for manipulating SBML-based biological models, BIOINFORMATICS, NOV 1, 2004
6. Kitano, H; Oda, K; Kimura, T; Matsuoka, Y; Csete, M; Doyle, J; Muramatsu, M, 2004 .Metabolic syndrome and robustness tradeoffs, DIABETES 53: S6-S15 Suppl. 3, DEC 2004
10. Doyle et al, (2005), The “Robust Yet Fragile” Nature of the Internet, P Natl Acad Sci USA. vol. 102 no. 41, October 11, 2005
Biography

John Doyle is the John G Braun Professor of Control and Dynamical Systems, Electrical Engineer, and BioEngineering at Caltech. He has a BS and MS in EE, MIT (1977), and a PhD, Math, UC Berkeley (1984). Early work was in the mathematics of robust control, LQG robustness, (structured) singular value analysis, H-infinity and many recent extensions. He coauthored several books and software toolboxes currently used at over 1,000 sites worldwide, the main control analysis tool for high performance commercial and military aerospace systems, as well as many recent industrial systems. Early example industrial applications include X-29, F-16XL, F-15 SMTP, B-1, B-2, 757, Shuttle Orbiter, electric power generation, distillation, catalytic reactors, backhoe slope-finning, active suspension, and CD players. Current research interests are in theoretical foundations for complex networks in engineering and biology, as well as multiscale physics. His group led the development of the open source Systems Biology Markup Language (SBML) and the Systems Biology Workbench (SBW), which have become the central software infrastructures for systems biology (www.sbml.org), and also released the analysis toolbox SOSTOOLS (www.cds.caltech.edu/sostools). He was the theoretical lead on the team that developed the FAST protocol and shattered multiple world land speed records (netlab.caltech.edu). Prize papers include the IEEE Baker (for the top research paper in all of the IEEE’s ~90 journals, also ranked in the top 10 “most important” papers world-wide in pure and applied mathematics from 1981-1993), the IEEE Automatic Control Transactions Axelby (twice), and the AACC Schuck. Individual awards include the IEEE Control Systems Field Award (2004) and the Centennial Outstanding Young Engineer (1984). He has held national and world records and championships in various sports.