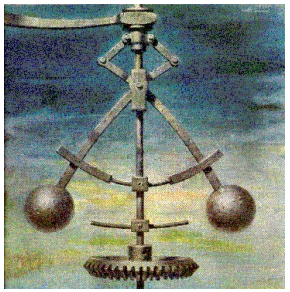
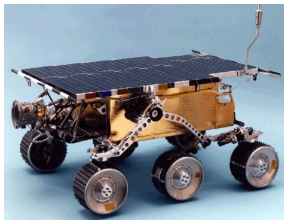
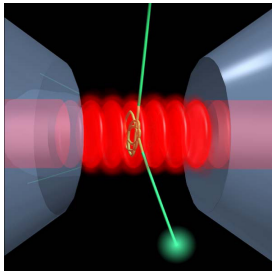


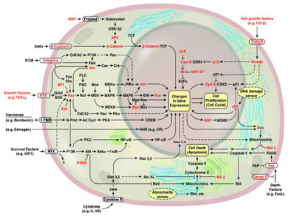


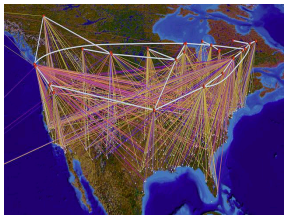
Foundations ∩ Structure

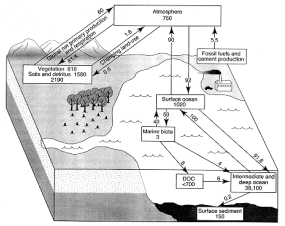
Information and Uncertainty in the Sciences

Richard M. Murray
Control and Dynamical Systems
California Institute of Technology









Outline

I. Dynamics and Feedback in Nature
II. Some Overarching Themes
III. Example: Synthetic Biology
IV. Some Thoughts on Going Forward

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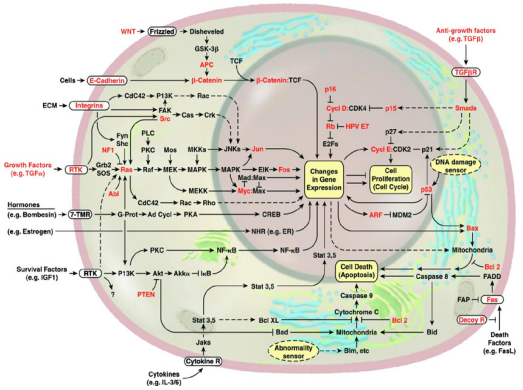
Biological Systems

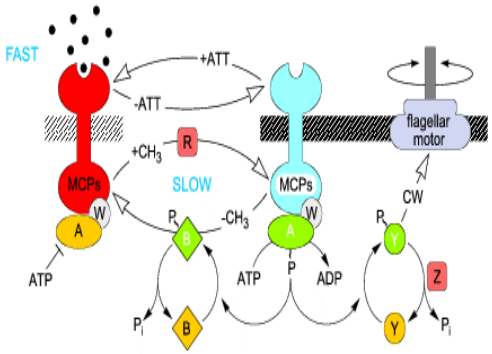
"Systems Biology"

- Many molecular mechanisms for biological organisms are characterized
- Missing piece: understanding of how network interconnection creates robust behavior from uncertain components in an uncertain environment
- Transition from organisms as genes, to organisms as networks of integrated chemical, electrical, fluid, and structural elements



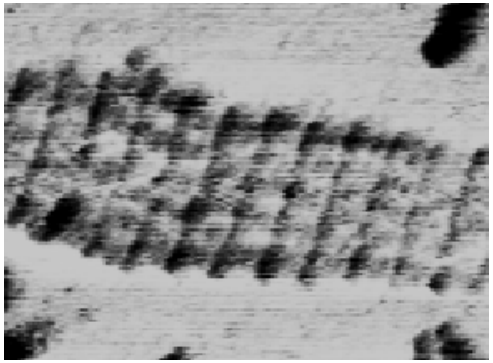
Key features of biological systems

- Integrated control, communications, computing
- Reconfigurable, distributed control, at *molecular* level



Design and analysis of biological systems

- Apply engineering principles to biological systems
- Systems level analysis is required
- Processing and flow of information is key



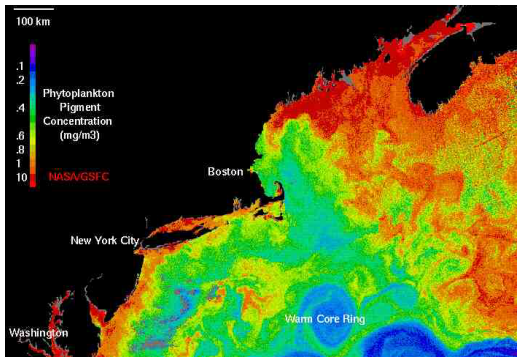
Ecological Systems

Populations and ecosystems

- Example: bacterial networks
- Multiple layers of feedback $\Rightarrow$ complexity
- Get robust functionality to individual cell
- *And* system level robustness for colony
- Q: how does evolution shape this?

Fire management

- Power law distributions $\Rightarrow$ many existing tools are not appropriate
- Multi-scale behavior: fuel to atmosphere
- Q: prevention, planning, policy?



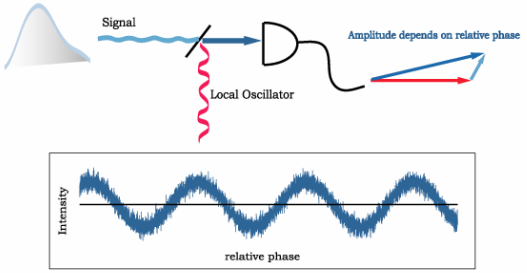
Role of Dynamics and Feedback

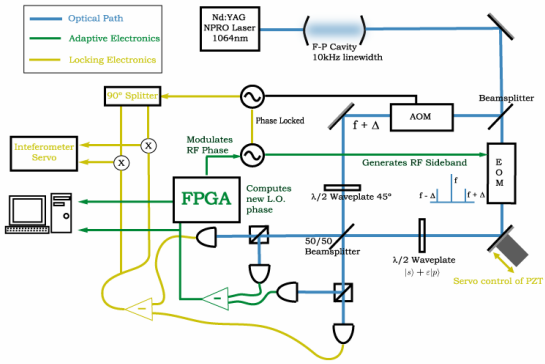
- Multi-scale dynamics
- Robust yet fragile behavior

Physics: Quantum and Geophysical Systems

Quantum Systems

- Rational design and empirical optimization of *open loop* control strategies (eg, NMR)
- Real-time feedback methodology for controlling quantum systems
- Role of interconnection is critical and very different from most engineering applications





Geophysical Systems (earthquakes)

- Reduced order models emerging for non-crystalline solids, soils, and related geo-physical materials that explain complex physical behaviors
- Extreme multi-scale behavior of interconnected components

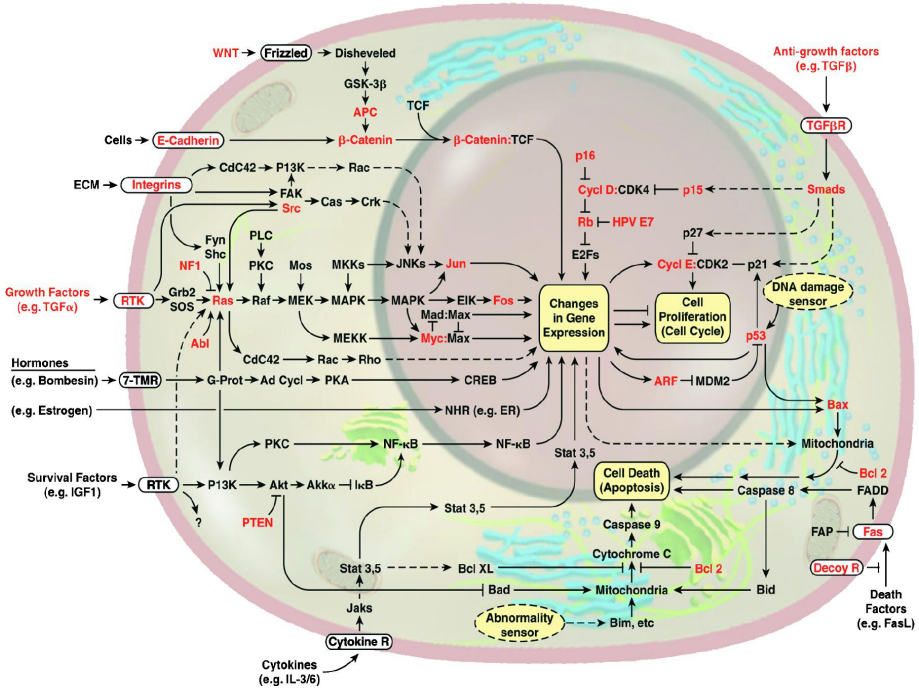
Overarching Themes

Multiscale modeling, analysis and computation

- rigorous techniques for model reduction and efficient, robust simulation becoming essential

Feedback as a tool for uncertainty management

- feedback as a fundamental organizing principle
- enables ``network robustness''

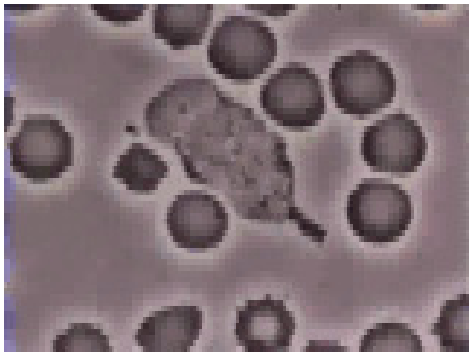


Integrated communication, computing and control

- nature uses dramatically different mechanisms to communicate and process information

Current tools not capable of addressing many interesting problems

Example: Synthetic Biology



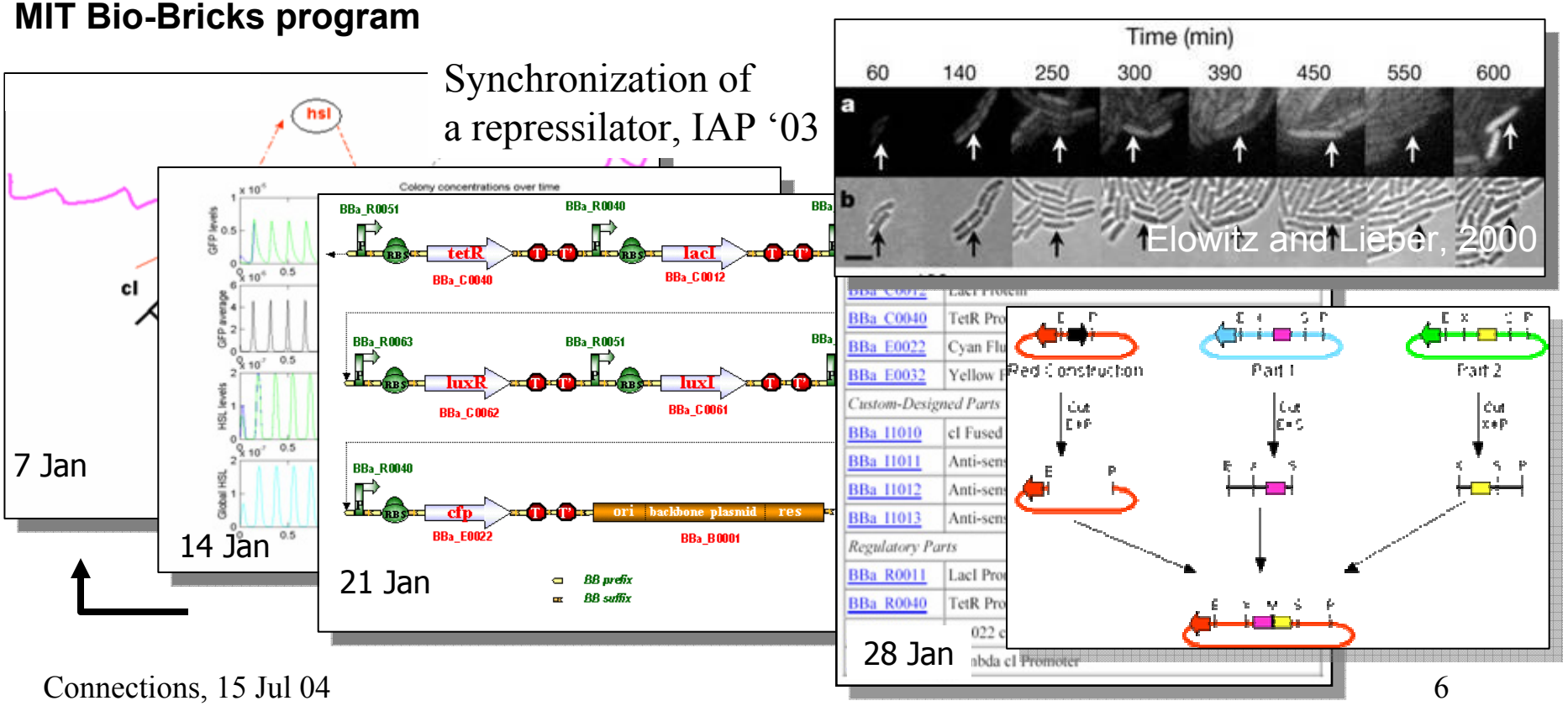
Crawling Neutrophil "Chasing" a Bacterium

- Human polymorphonuclear leukocyte (neutrophil) on blood film
- Red blood cells are dark in color, principally spherical shape.
- Neutrophil is "chasing" Staphylococcus aureus micro-organisms, added to film.

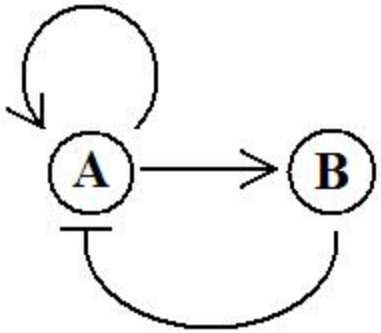
Tom Stossel, June 22, 1999 (John Stossel, 195?)
http://expmed.bwh.harvard.edu/projects/motility/neutrophil.html

MIT Bio-Bricks program

Synchronization of
a repressilator, IAP '03

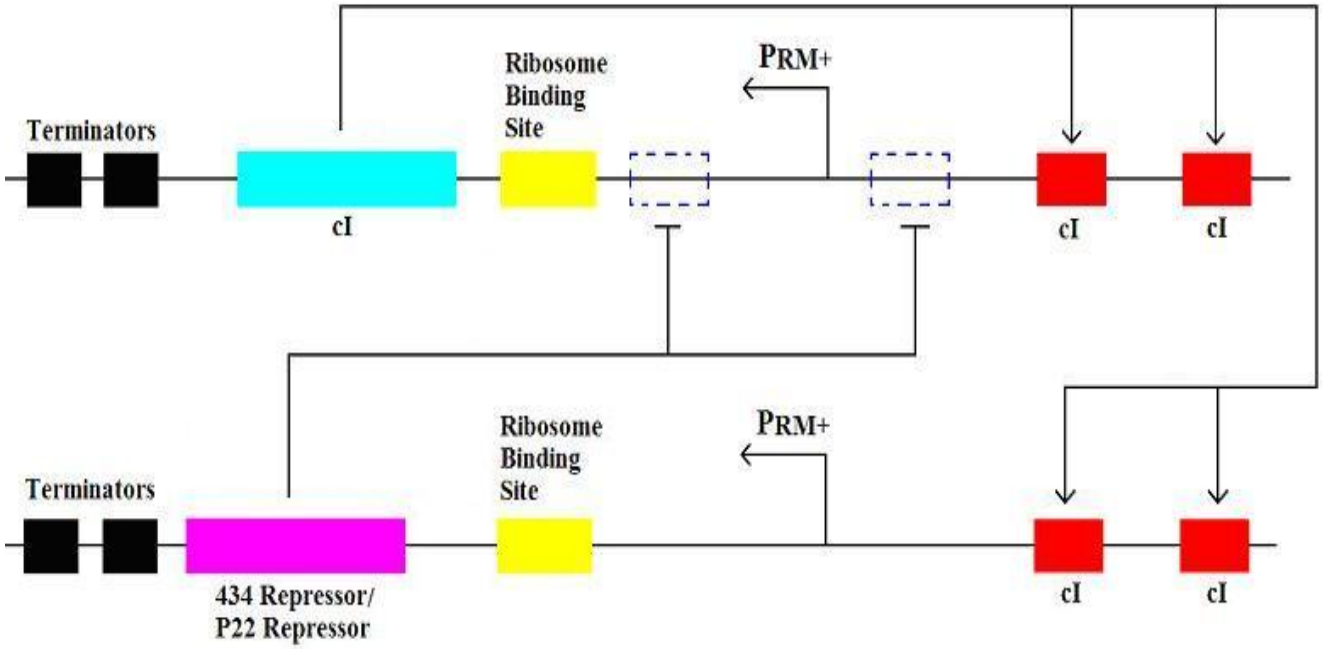


Synthetic Biology Competition 2004



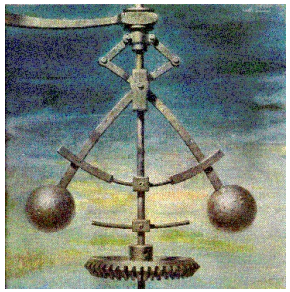
Boston U, Caltech, MIT, Princeton, U Texas

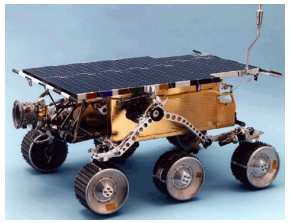
- Caltech: 7 undergrads + 3 grad students + 3 faculty
- Project #1: alternative oscillator designs
- Project #2: serial counter with digital readout



Features:

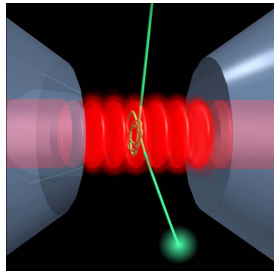
- Multiscale dynamics
- Uncertainty management via feedback
- Integrated communication, computing and control

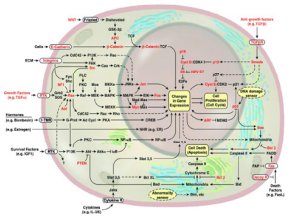


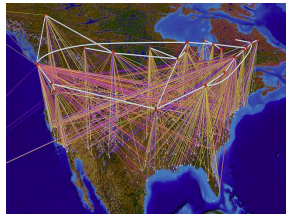


Foundations ∩ Structure

Information and Uncertainty in the Sciences







New CDS research is required

- Integration of computing, communications, control
- "High risk" applications in biology, quantum, geophysics, ecosystems
- Maintain rigorous mathematical approach

New approach to education

- Make CDS tools accessible to broad audience of scientists and engineers
- Provide training required to work on interdisciplinary applications in science and engineering

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