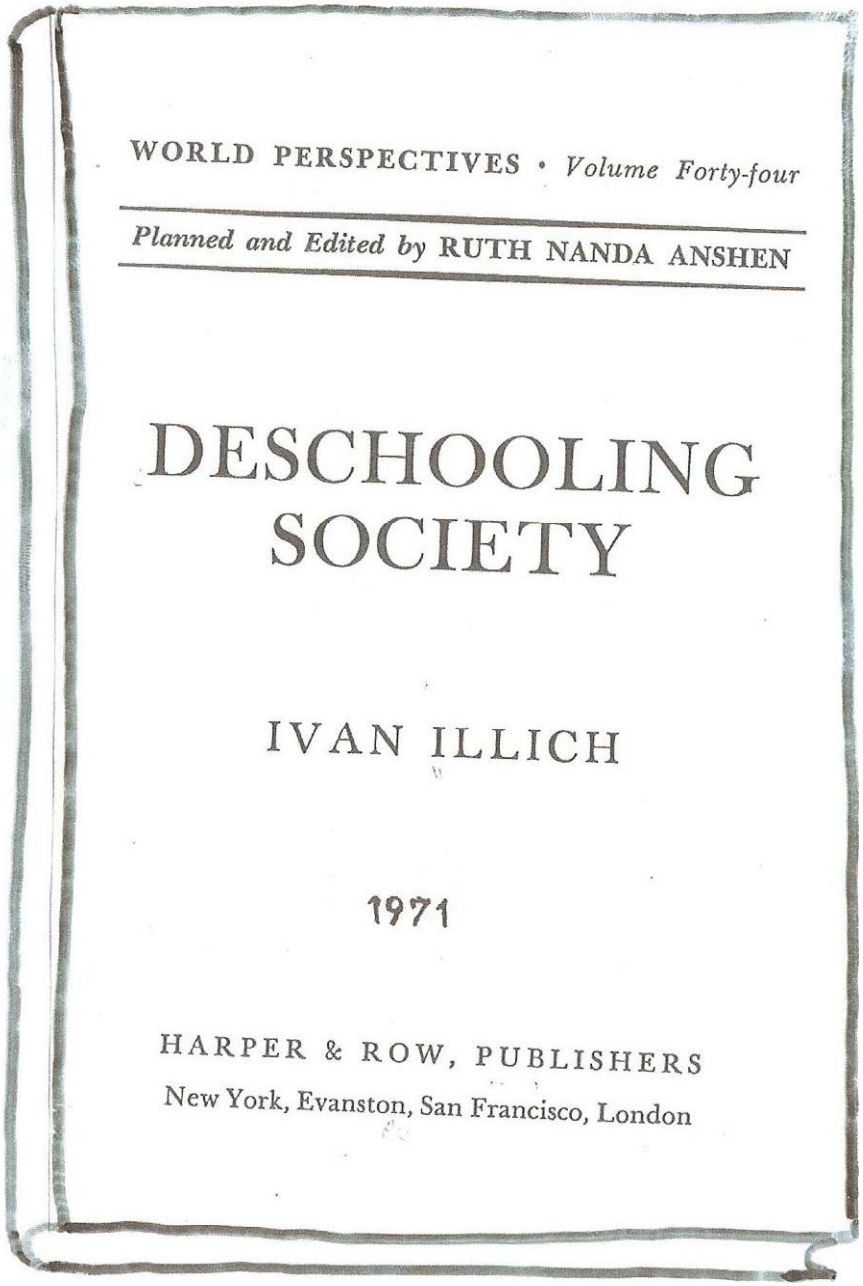
44 YEARS WITH A SAGE OF OUR FIELD

- Reading Sanjoy's Newton Method's paper (early 1960's)
- Memorable first meeting in Cleveland, late 1965
- Joint visits to INRIA, Paris, 1970's
- "LIDS decision" dinner
- Frequent debates, often with George Zames *et al.*
- Visit to a Buddhist temple in China
- Many "philosophical" and some philosophical discussions



PREDICTIONS OF ANOTHER SAGE IN THE 1960s

Chapter 6
"Learning Webs"

described what we recognize today as our virtual INTERNET communities and anticipated technologies to make them possible

A Continuum of Predictions

- Challenges to Control, Santa Clara, CSS 1986
- Future Directions in Control Theory, SIAM 1988
- Future Directions in Systems and Control, Cascais, PT 2000
- Future Directions in Control in an Info Rich World, 2003
- Control Frontiers, Santa Barbara, May 2009
- Paths Ahead, MIT, November 2009

Should we “close the loop” to examine which of our earlier predictions have been confirmed?

The Funding Pendulum Disturbance

In the 1970's – early 1980's:

- Hybrid cars, stratified IC engines (Ford)
- Rapid rail transport, people movers (DOT)
- Wind energy, conservation, power systems (DOE)

After that:

- SUV addiction killed car engine research
- Reagan discontinued relevant DOE projects
- Similar situation under Bush Sr., Clinton, Bush Jr.

Now again:

- Renewable energy, hybrid cars, smart grid…

Survival of
intellectually coherent long term research?

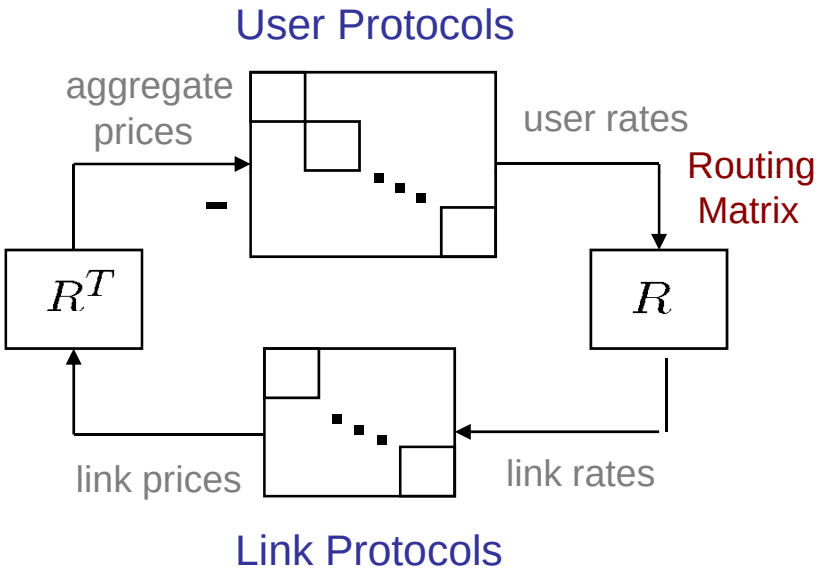
Look at the work of younger researchers…

Input-Output Approach to Networks

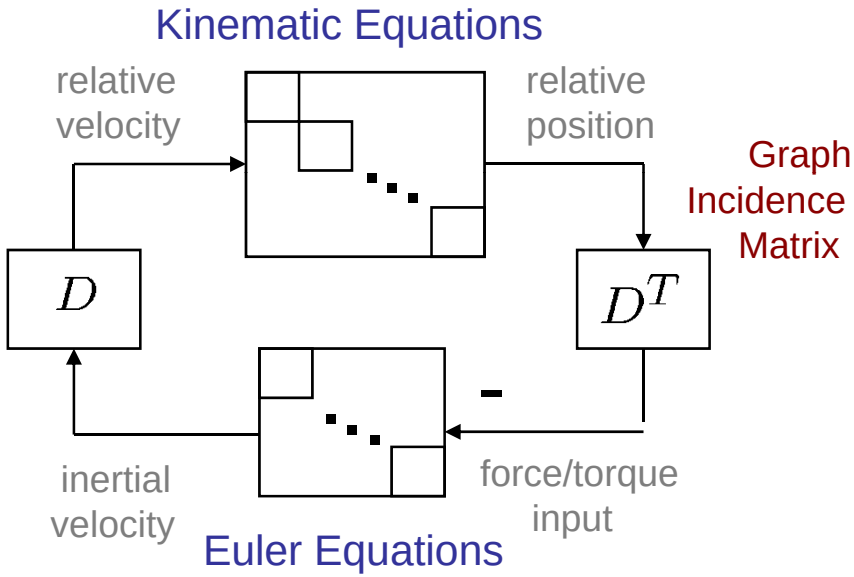
Determine subsystem input/output properties compatible with network structure.

Assign/verify these properties without relying on further knowledge of the network.

Internet Congestion Control



Cooperative Vehicle Networks



Passivity identified as an input/output property compatible with the coupling symmetry in these networks. (Wen & Arcak '04; Arcak '07)

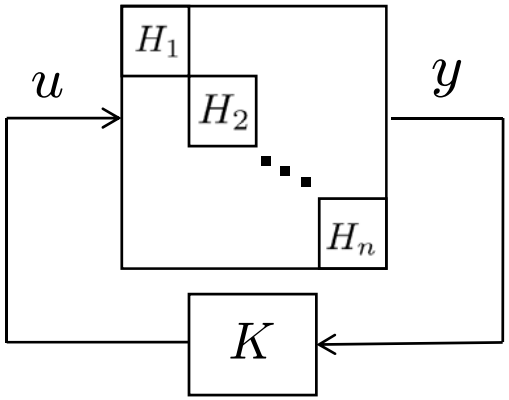
New passivity designs of algorithms offer flexibility for robustness and adaptivity.

Existing algorithms, such as Kelly's, appear as special cases.

Analysis of Biological Networks via Passivity

Decompose network into subsystems H_i and verify their passivity relative to network equilibrium x^* :

$$\dot{S}_i \leq (u_i - u_i^*)^T (y_i - y_i^*) - \frac{1}{\gamma_i} ||y_i - y_i^*||^2$$

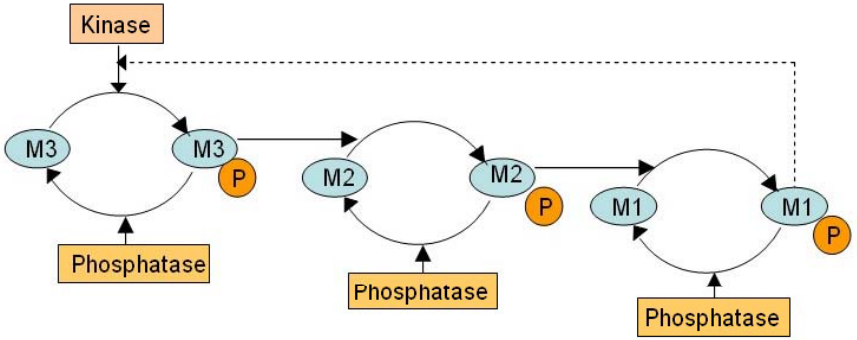


Define matrix: $E := K - \mathrm{diag}\{1/\gamma_1, \cdots, 1/\gamma_n\}$ and ascertain global stability of x^* by finding a diagonal $P > 0$ s.t. $E^T P + PE < 0$

Passivity-based stability test:

Recovers the local "secant" stability criterion used in biology for cyclic structures, and strengthens it to be a global test applicable to other structures.

(Arcak & Sontag '08)



Cyclic feedback structure in cell signaling (Kholodenko '06)

Ensures stability of spatially uniform steady-state in reaction-diffusion PDEs.

(Jovanovic, Arcak, Sontag '08)

Constructive Feedback Design for PDEs

Use **feedback transformations**
to convert an intractable PDE into a well-studied PDE

In 3D Navier-Stokes, this novel closed-loop boundary control design, for the first time

- extinguished turbulence at any Reynolds number
- made mathematics tractable and explicit

Vazquez and Krstic (Birkhauser, 2007)

$$\vec{u}_t = \frac{1}{\mathrm{Re}}\Delta\vec{u} - (\vec{u}\cdot\nabla)\vec{u} - \nabla p$$
$$0 = \mathrm{div}\,\vec{u}$$

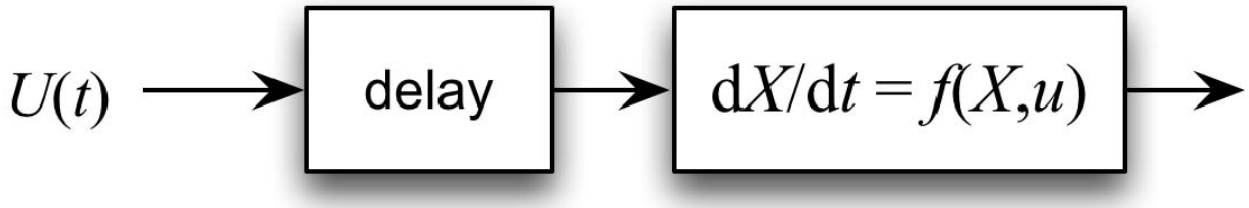
$$v_t = d(x)v_{xx} + a(x)v_x + r(x)v$$

In reaction-advection-diffusion PDEs (Li-ion batteries), functional/spatial coeffs are *uncertain*. The new design

- derives parameterized feedback transformations
- constructs adaptive boundary control with boundary sensing for unstable and inf rel degree PDEs

Smyshlyaev and Krstic (Princeton U. Press, 2010)

Nonlinear control in the presence of **Delays**



- Input delay of *any length*
- Nonlinear fbk laws with *spatially causal* (Volterra) *operators* of actuator state
- Appl.: multi-site hardware-in-the-loop testing over internet

Krstic (Birkhauser, 2009)
Delay Compensation for Nonlinear, Adaptive, and PDE Systems