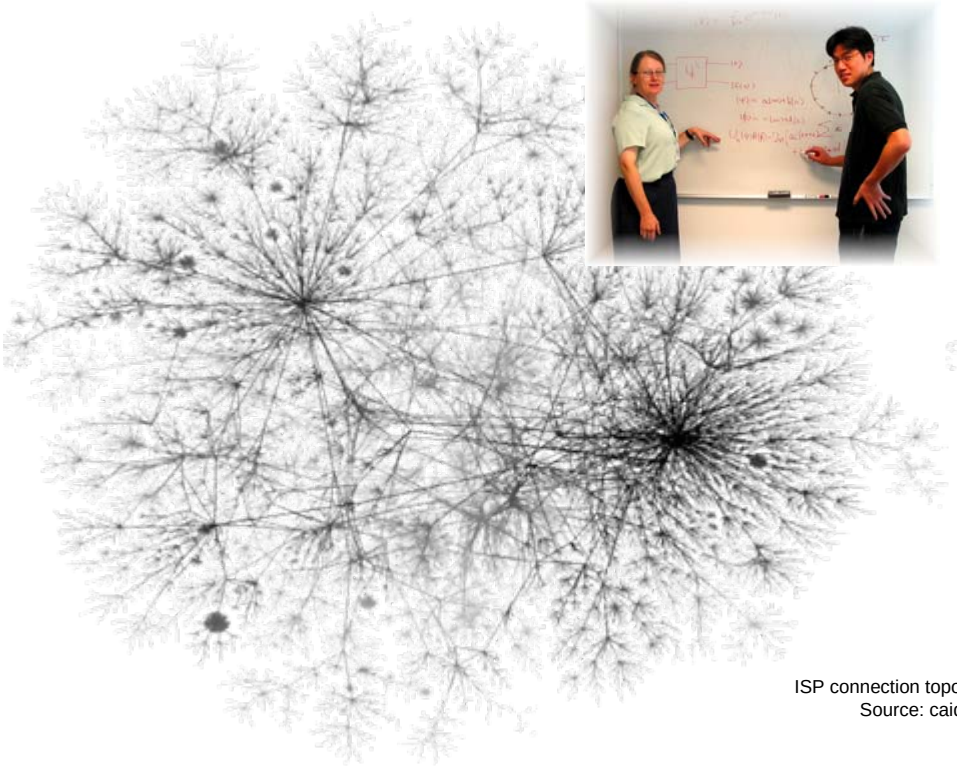
Foundations of Measurement Science for Information Systems

NIST

Information Technology Laboratory

September 2007



ISP connection topology.
Source: caida.org

Ron Boisvert, Chief, Mathematical & Computational Sciences Division

Math & Computational Science

Applied Mathematics
High Performance Computing
Scientific Visualization
Mathematical Software

Ron Boisvert
Division Chief
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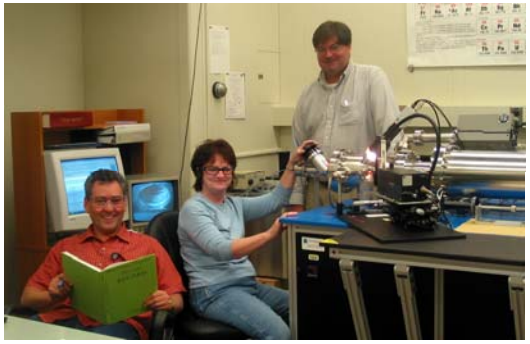
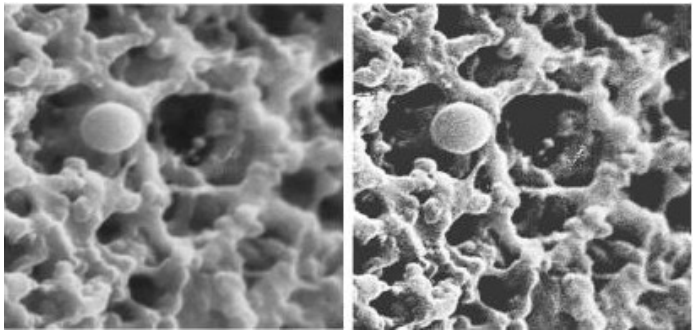
- Collaborative Research
  - within NIST: interdisciplinary, peer to peer
  - bring expertise, facilities / high local payoff
- Underlying R&D
  - research in math, CS anticipating NIST needs
  - tools, facilities to make us, customers more efficient
- Work with community
  - community-based measurement, standards
  - Web-based information services
  - wide distribution of tools

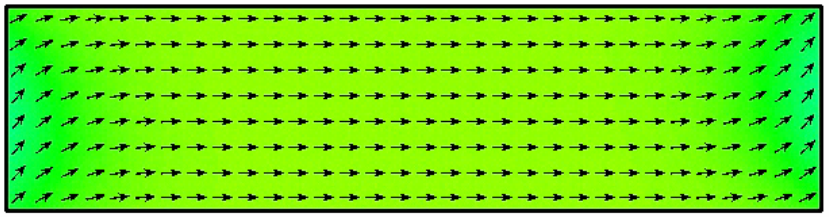


Examples

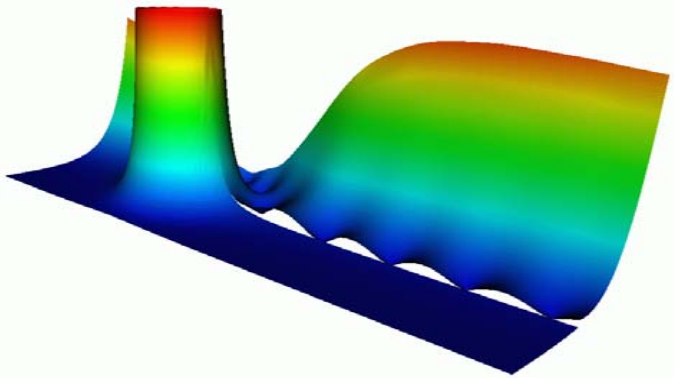
- Deblurring of images from scanning electron microscopes
  - Deconvolution
  - Inverse and ill-posed problems



- Software for modeling in nanomagnetics
  - Applied PDEs, Numerical analysis
  - Problem-solving environments



- Online handbook of special functions of applied math
  - Real and complex analysis
  - Mathematics on the Web



NIST FY07 Cyber Security Initiative

American Competitiveness Initiative

Innovative Technologies for National Security

- The nation's IT infrastructure has grown phenomenally. Critical infrastructures—transportation, financial, power grids, military, intelligence systems, and health and safety—rely on computer, communication networks.
- In spite of efforts to secure, these systems remain vulnerable.
- Today's cyber security efforts are aimed at identifying particular vulnerabilities and determining whether well-known security controls are in place.
- There is no known way to measure the absolute security of a given system. Without metrics and measurement technologies, we can't determine the overall effectiveness of our controls.

http://www.nist.gov/public_affairs/factsheet/cybersecurity.htm

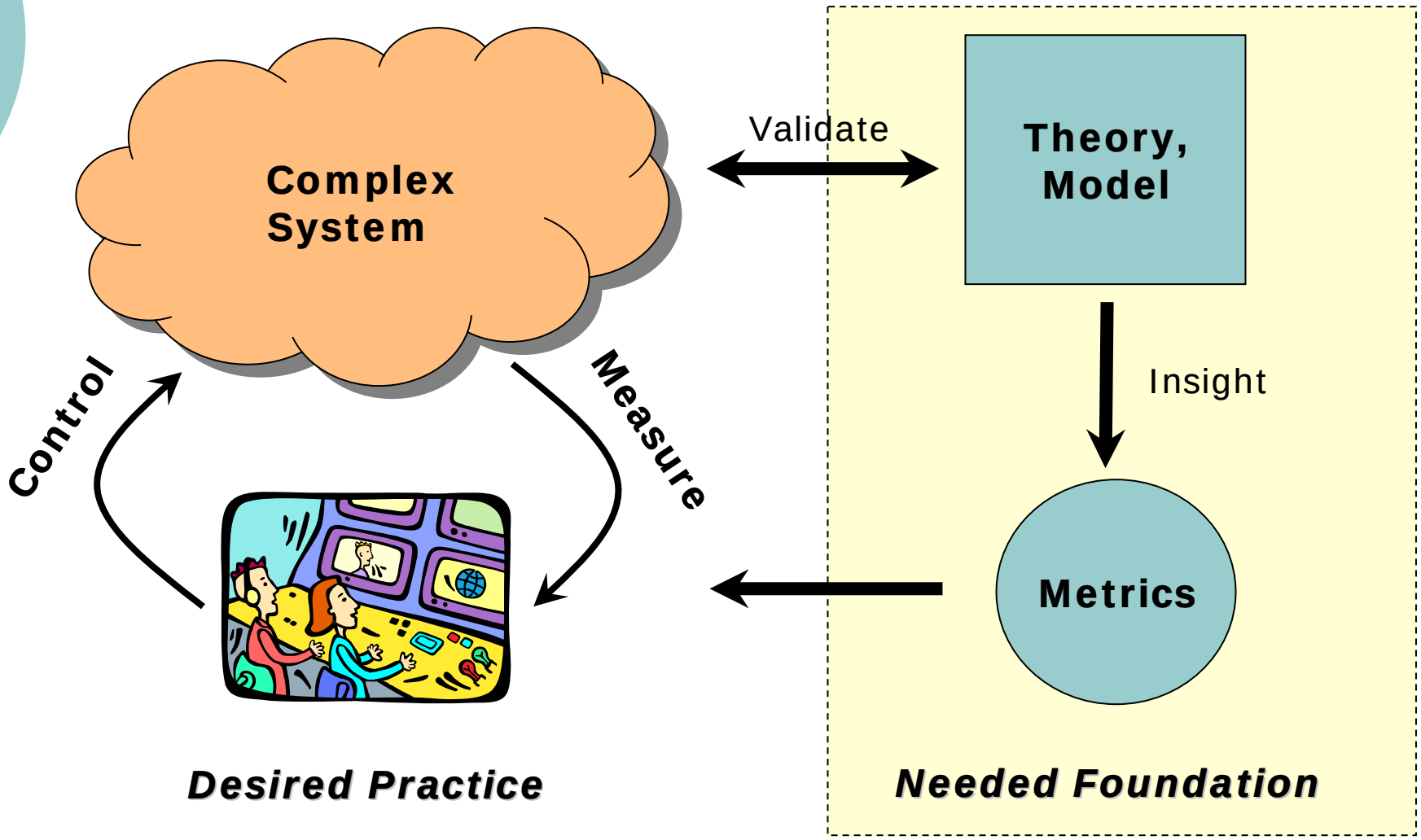
Problem is Fundamental

We build, deploy large-scale information systems without complete understanding of their range of behaviors.

"[Despite] society's profound dependence on networks, fundamental knowledge about them is primitive. [G]lobal communication … networks have quite advanced technological implementations but their behavior under stress still cannot be predicted reliably…. There is no science today that offers the fundamental knowledge necessary to design large complex networks [so] that their behaviors can be predicted prior to building them." — Network Science, National Research Council, 2006

Science Foundation is Prerequisite

Experiment – Model – Understand – Measure – Improve



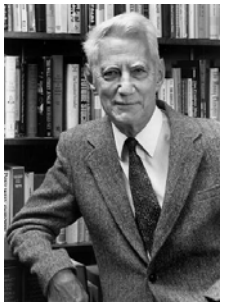
Focus on Foundations

Charge from NIST Director

- To develop metrics we need to know
  - what to measure
  - how measurements relate to properties we care about
- *Need:* a science-based foundation for the understanding / characterization of information systems on par with that of the physical sciences
  - the science behind information technology
  - *challenge*: information systems fundamentally different … man has less discipline than Mother Nature

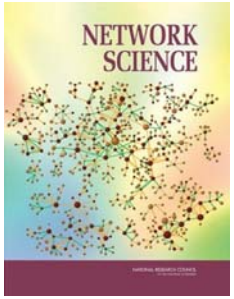
Science Foundations: Examples

- Information Theory
  - Mathematical theory of communication
  - Information entropy, channel capacity
  - Quantum: information is physical
- Theory of Computation
  - What is computable?
  - How hard? … complexity classes
- Network Science
  - How does structure influence function?



Claude Shannon

Alan Turing



Foundations of Measurement Science for Information Systems

- *Mathematics-based basic research program*
- Model, characterize large-scale distributed information systems
  - structure
  - protocols & dynamics
  - feedback & control

Initial Focus

- **Goals**
  - understand relationships among structure, protocols, and performance
  - characterize robustness, fragility
  - identify key (computable) measures

Connection to Cyber Security

- Long-term Research Questions
  - Are there fundamental limits to our ability to design reliable information systems?
  - Can we characterize the absolute security of a system: resilience against threats / vulnerabilities known *and unknown*?

Reality Check

- This is a *really* hard problem: there may be no solution.
  - though any progress in quantitative methods for characterizing information systems is undoubtedly worthwhile
- We have at most $2M/year for an intramural research program*
  - ~6 FTEs
  - new base funding: sustained long-term effort

** $1.3M in FY07, proposed additional $0.7M in FY08*

Non-technical Goals (more realistic)

- Short term (1-3 years)

  Develop mathematical competence within NIST necessary to contribute to the modeling and analysis of information systems

- Mid-term (3-5 years)

  Provide the scientific basis for NIST to begin the development of a measurement science for information systems

- Long-term (5-10 years)

  Work to address fundamental issues related to cyber security

Initial Steps

- Planning workshop (May 31)
  - Help frame mathematical directions
  - Participants: IBM, AT&T, IDA, Dartmouth, UMd, UCSB, UMinn, NIST
- Refocus existing staff
  - Abstract models of network dynamics
  - Computing properties of large-scale graphs
  - Visualization of large-scale networks
- Recruitment (2 new full-time, 2 postdocs)
  - “Long-haired mathematicians” … discrete structures, computational graph theory, stochastic control theory, optimization, game theory, risk analysis, information theory, theory of computation
  - One post-doc on board, another committed

Partnerships

- Leverage internal startups
  - ITL Complex Systems Program
  - NIST Innovations in Measurement Science project
- Connect to applications
  - Collaborate with ITL Divisions: Networking, Computer Security, Software
- Engage external researchers
  - Advice, collaborations
  - Guest researchers