Networks and Information

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A historical view

- Telegraphy is 172 years old
- Telephony 133 years
- Computers 64 years
- Computer networks 39 years
- Cell phones 36 years old

Today

25 years hence?
Another historical view: Third generation control systems

- **First generation: Analog Control Systems**
  - Technology: Electronic Feedback Amplifiers
  - Theory: Frequency domain analysis: Bode, Evans, Nyquist, ...

- **Second Generation: Digital Control**
  - Technology: Digital computers
  - Theory: State-space design, Kalman filter, Optimal control, $H_\infty$, Real-Time Scheduling (Liu and Layland)

- **Third generation: Networked Embedded Control Systems**
  - Embedded computers
  - Wireless and wireline networking
  - Software
    - From registers and variables to libraries, components, messages, remote procedure calls, middleware
Future networks may be revolutionary by today’s standards

- Sophisticated information transfer requirements
  - Collate information produced dynamically by sources correlated in time as well as space
- Network itself must be the information processing fabric
  - Rephrasing Marshall McLuhan
    - Communication fabric will determine the message

Beyond networks to *systems* operating over networks

- Zero vehicular collisions by networked cars
- Wireless systems in operating rooms and hospital environments
Several grand challenges

- Theory, Algorithms and Protocols for Networks
- Provide QoS in networks
  - Throughput, delay and reliability guarantees, Energy, Security
- From data to information fusion
  - In-network information processing: theory, algorithms and protocols

- From Networks to Networked Systems
- Control of distributed systems over not completely reliable networks
- Abstractions and Architecture for convergence of control, communication and computing
- Models and Theories
- Predictable temporal and event behavior
  - Proofs of correctness of large networked systems
  - Verification
Transformations in networking

From
- Ad hoc design
- Simple radios
- Simulation based evaluation
- Fundamentals of single links
- Security as afterthought
- Wireline centric design
- Networks

To
- Scientific design
- New technologies
- Analytical understanding
- Fundamentals of networks
- Security from inside out
- Intelligent cross-layer design
- Systems
Lots of important research themes

- Abstractions and Architecture
- Time
- Information
- Distributed systems
- Reliability
- Overall system analysis

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Source Coding
Channel Coding

Hardware
Software
Lots of important research themes

- Abstractions and Architecture
- Time
- Information
- Distributed systems
- Reliability
- Overall system analysis
- Clocks and synchronization
- QoS for latencies
- Distributed real-time scheduling
- Hybrid systems
- Temporally correct interactions
- ….
Emergence of communication, computation and control

- Perhaps the most exciting developments in the information area relate to the large-scale digital computing machines.”
  – Claude Shannon, 1947

- “I think I can claim credit for transferring the whole theory of the servomechanism bodily to communication engineering.”
  – Norbert Wiener, 1956

- “…the era of cyberspace and the Internet, with its emphasis on the computer as a communications device and as a vehicle for human interaction connects to a longer history of control systems that generated computers as networked communications devices.”
  – David Mindell in “Feedback, Control and Computing before Cybernetics,” 2002
The oncoming re-convergence

1950 — 2000: Substantial progress in several individual disciplines
- Computation: ENIAC (1946), von Neumann (1945), Turing (1936),...
- Actuation/Control: Kalman (1960),...
- Communication: Shannon (1948), Wiener (1953),...
- Signal Processing: FFT, Cooley-Tukey (1965),...

2000 — onwards
- A gradual fusion of control, communication and computation
- But still knowledge of all these fields may be important
- Pedagogical as well as research challenges
Thank you