Networks and Information

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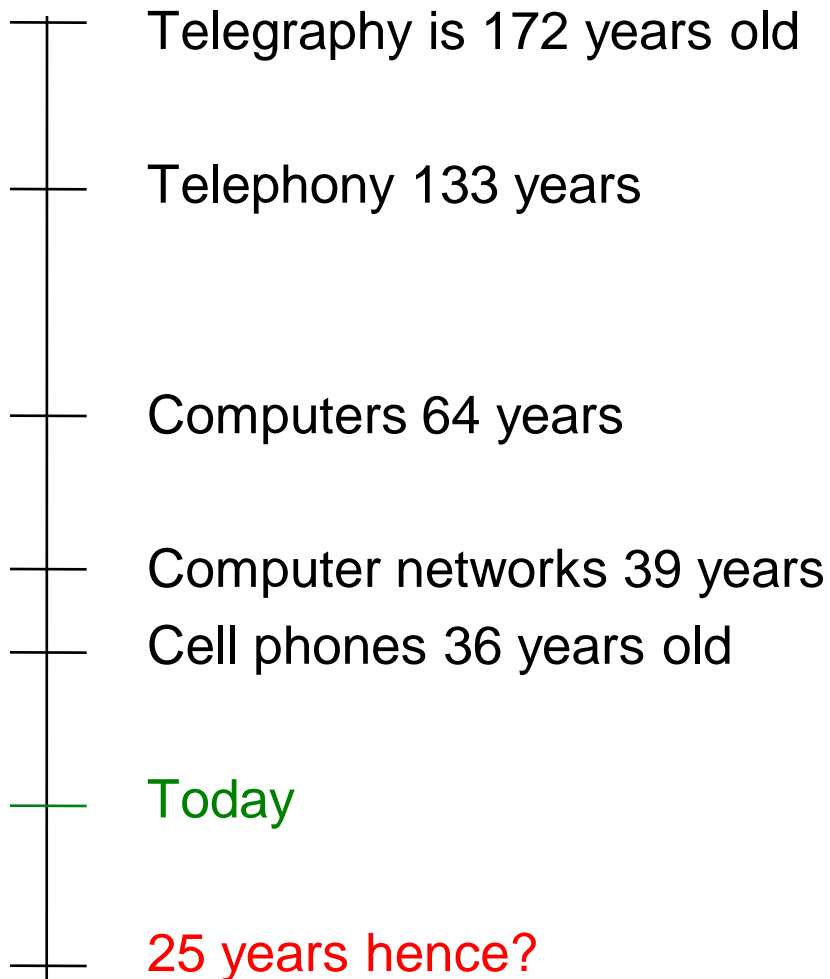
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A historical view

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_∞,
- – 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

Vision

◆ **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	To
Ad hoc design	Scientific design
Simple radios	New technologies
Simulation based evaluation	Analytical understanding
Fundamentals of single links	Fundamentals of networks
Security as afterthought	Security from inside out
Wireline centric design	Intelligent cross-layer design
Networks	Systems

Lots of important research themes

- Abstractions and Architecture

- Time

- Information

- Distributed systems

- Reliability

- Overall system analysis

- ......

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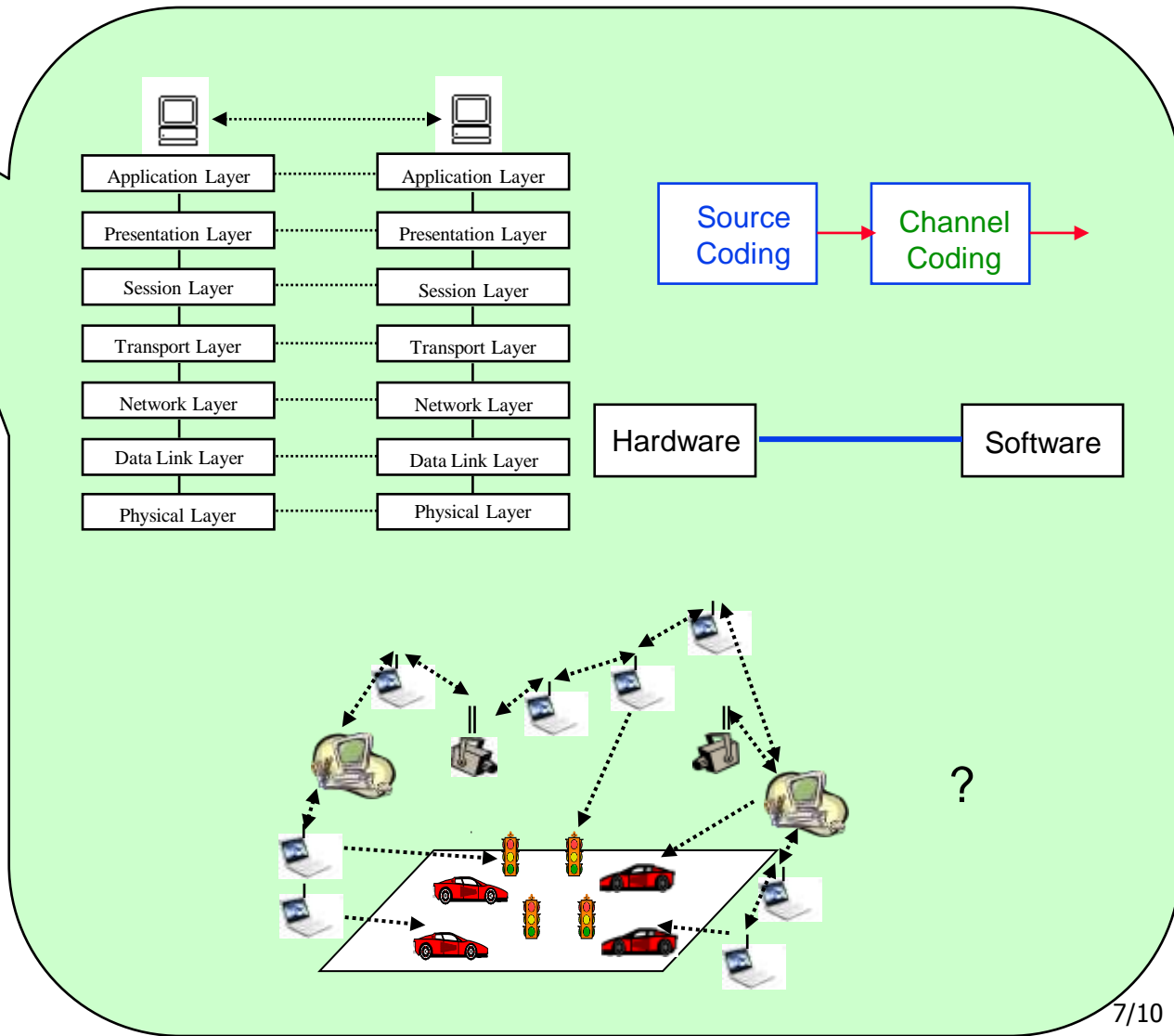
- Clocks and synchronization
- QoS for latencies
- Distributed real-time scheduling
- Hybrid systems
- Temporally correct interactions
- ….

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),…

Post Maxwell,
von Neumann,
Shannon,
Bardeen-Brattain world

Age of system building
    Nodes can Compute
    Communicate
    Sense and Actuate

◆ 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