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# New Directions in Networks and Systems

P. R. Kumar

Dept. of Electrical and Computer Engineering, and  
Coordinated Science Lab  
University of Illinois, Urbana-Champaign

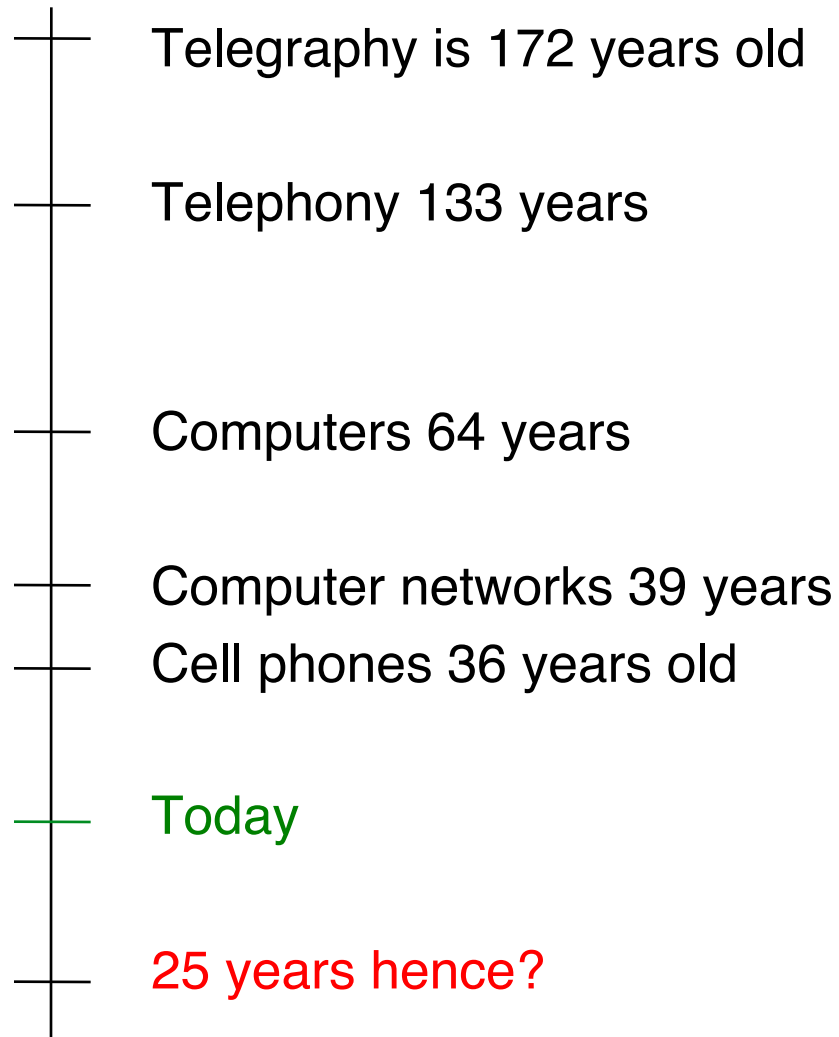
Email: [prkumar@illinois.edu](mailto:prkumar@illinois.edu)  
Web: <http://black.csl.uiuc.edu/~prkumar>

New Trends in Wireless  
Communication and Networking,  
Panel Discussion.  
Tsinghua University,  
Nov 23, 2009



# A historical view

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# Vision

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- ◆ 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



# Several grand challenges

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- ◆ Provide QoS in networks
  - Throughput, delay and reliability guarantees, Energy, Security
  
- ◆ Theory, Algorithms and Protocols for Wireless Networks
  - Currently we are in first generation protocols
    - » 802.11
    - » AODV, DSR, OLSR
    - » TCP, UDP
  - What will the second generation?
  - What will the Third generation be??
  
- ◆ From data to information fusion
  - In-network information processing: Theory, algorithms and protocols
  - We are in zeroeth generation



# Transformations in networking

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## 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



# Vision

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- ◆ Beyond networks to *systems* operating over networks
  - Zero vehicular collisions by networked cars
  - Wireless systems in operating rooms and hospital environments



# Another historical view: Third generation systems

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- ◆ 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 Systems
  - Embedded computers
  - Wireless and wireline networking
  - Software
    - » From registers and variables to libraries, components, messages, remote procedure calls, middleware



# Major challenges

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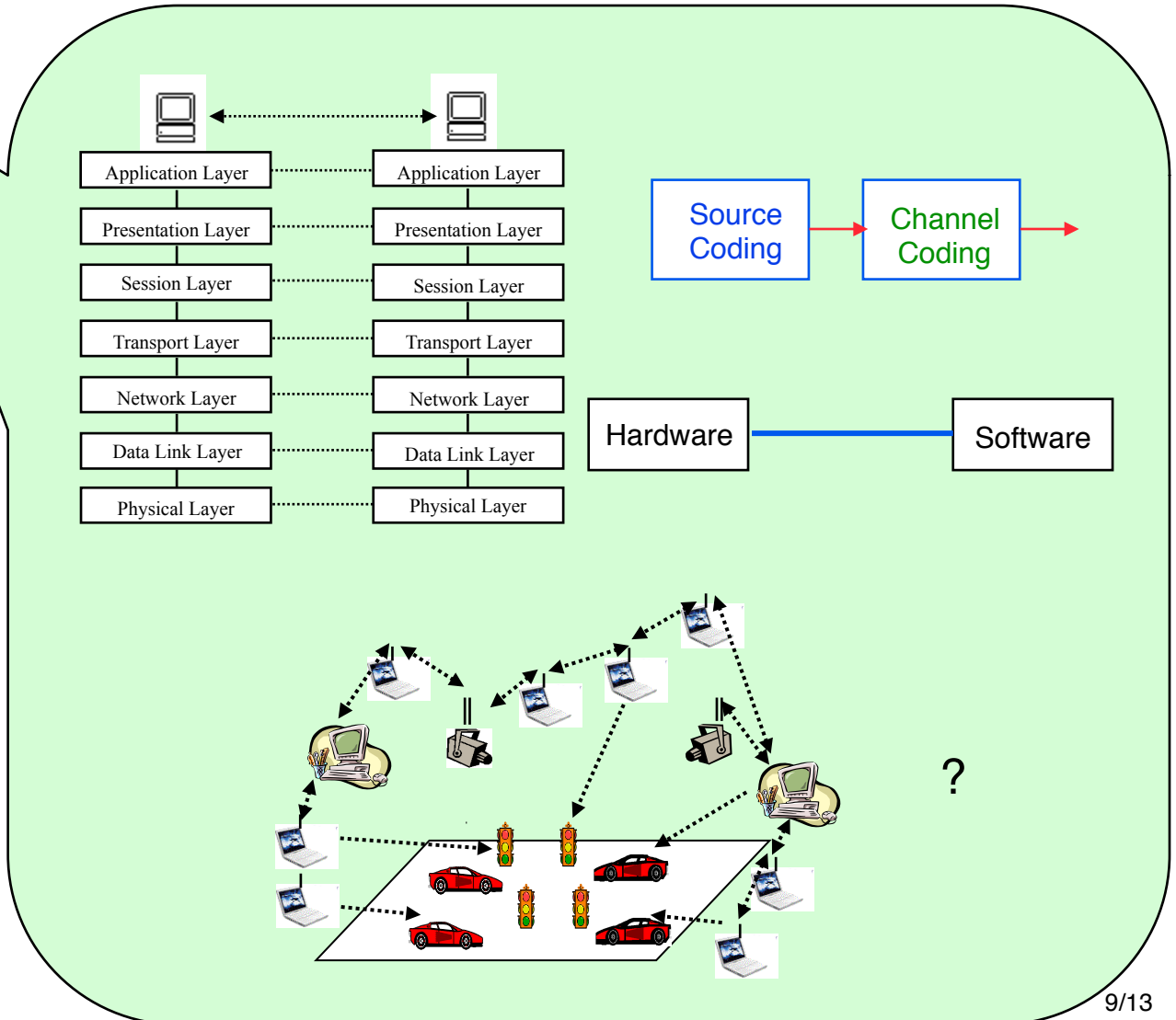
- ◆ From Networks to Networked Systems
- ◆ Control of distributed systems over not completely reliable networks
- ◆ Abstractions and Architecture for convergence of control, communication and computing
- ◆ Models and Theories
- ◆ Predictable temporal and event behavior
  - Proofs of correctness of large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





# Lots of important research themes

## ◆ Abstractions and Architecture





# Lots of important research themes

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- ◆ 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
- ◆ .....



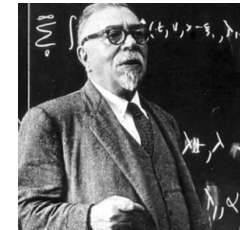
# Emergence of communication, computation and control

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- ◆ *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

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- ◆ 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



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Thank you