Cyberphysical systems

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The third generation of control systems

- First generation: Analog Control
  - Technology: Feedback amplifiers
  - Theory: Frequency domain analysis
    Bode, Evans, Nyquist

- Second generation: Digital Control
  - Technology: Digital computers
  - Theory: State-space design
  - Real-Time Scheduling

- Third generation: Networked Control
    - Embedded computers
    - Wireless and wireline networks
    - Software

- Platform revolution: Mechanisms and Policies

- Just in time for the resource-aware system building era of the 21st century

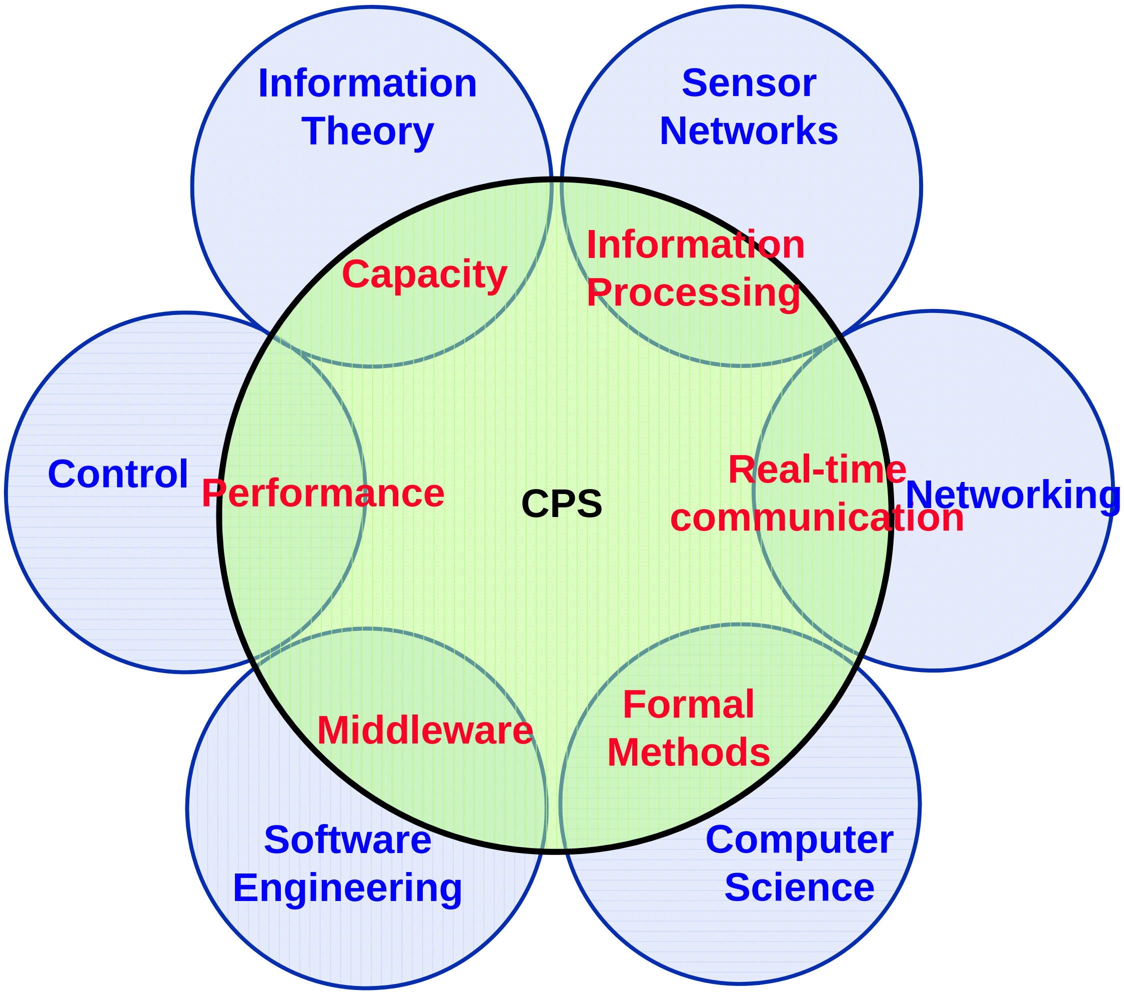
Mechanisms and policies

- Platform revolution

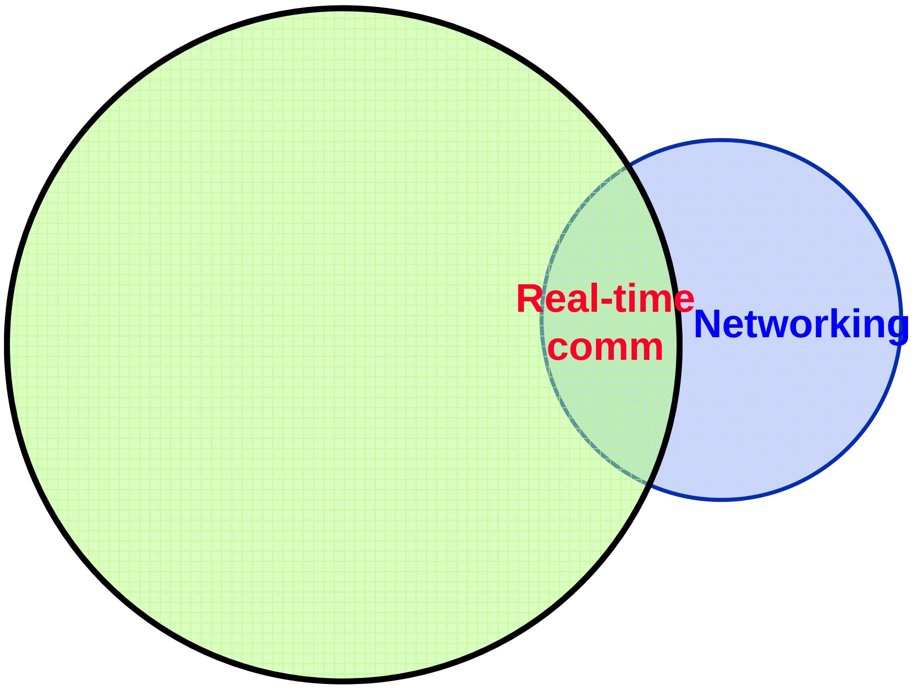
- Mechanisms
  - *How to implement*?

- Policies
  - *What to implement*?

Foundational issues in cyberphysical systems



How can we deliver packets on time in a shared wireless network?



Importance of providing latency guarantees: Wireless Tomorrow

- Current Internet
  - No guarantees – “Best effort”
  - At best – Throughput
- Increasing traffic with delay constraints
  - VoIP
  - Interactive Video
  - Cyberphysical systems
- How to support delay guarantees over an unreliable medium like wireless?

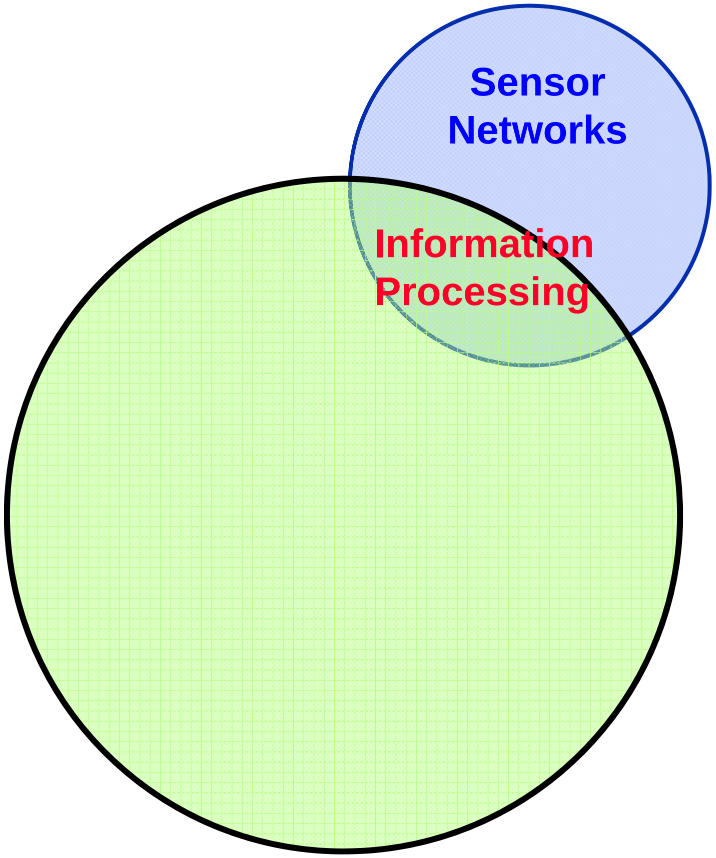
In-Vehicle Networks

- Wiring harness
  - Heavy
  - Complex
  - Costly

Replace wires by an access point

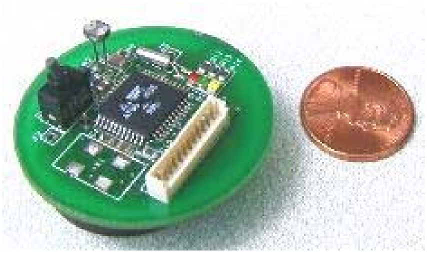
- Fewer mechanical failures
- Easier to upgrade

How do we extract information from networks?

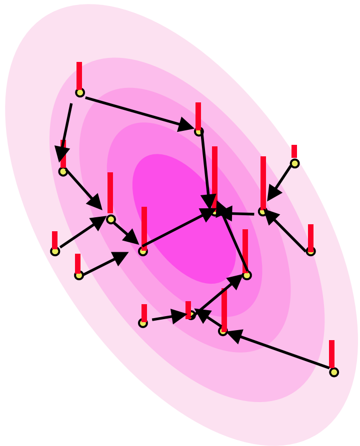


Information processing in networks

- Environmental monitoring
  - n nodes take temperature measurements $x_1, x_2, . . , x_n$
  - Determine the Mean temperature: $(x_1 + x_2 + \ldots + x_n)/n$

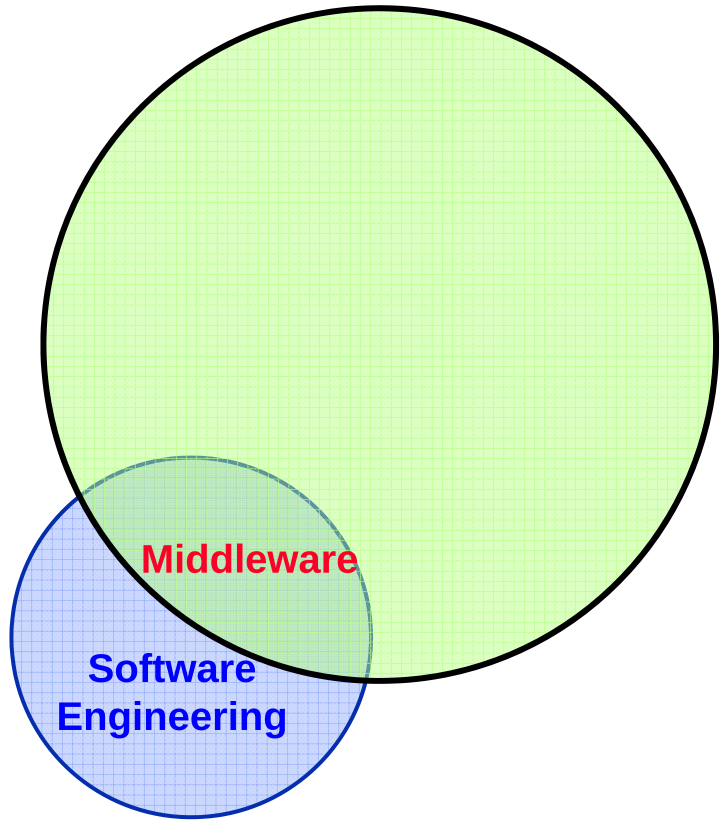


- Alarm networks
  - Determine the Max temperature: Max x_i

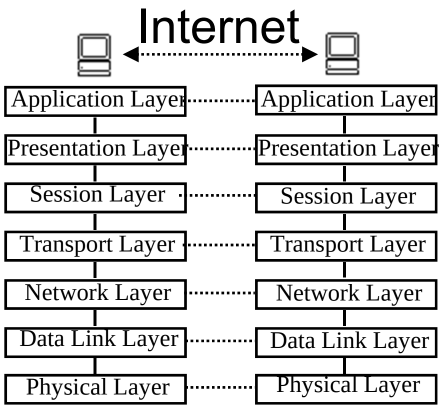


- Sensor networks are not data networks
  - Nodes can change/create/discard packets
- We need to understand how to *process information in-network*

What are the appropriate abstractions and architecture for CPS?



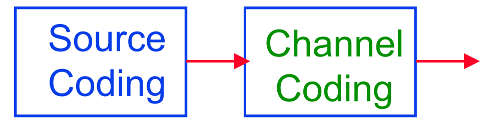
Challenge of abstractions

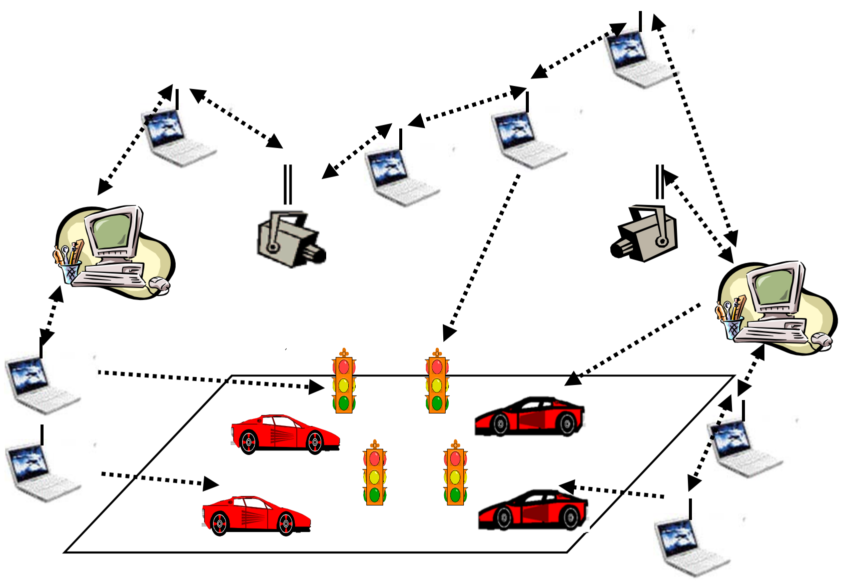


Serial computation

von Neumann Bridge (Valiant `90)

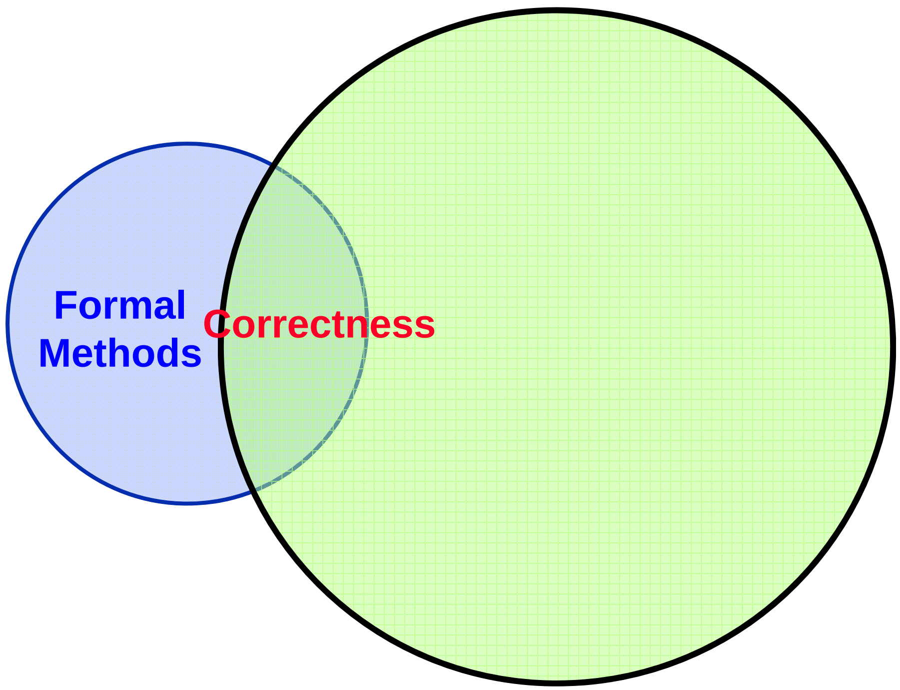
Digital Communication





- What are the abstractions for convergence of control with communication and computing?
- Goal is to enable rapid design and deployment
  - Critical Resource: Control Designer's Time
- Standardized abstractions
  - Minimal reconfiguration and reprogramming
- Hopefully leading to proliferation

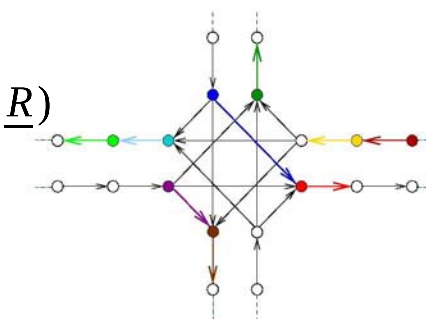
How can we prove that systems behave correctly and are safe?



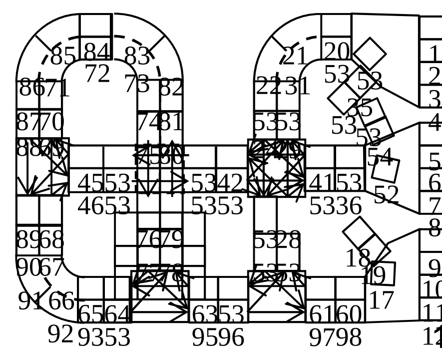
Provably correct behavior

- **Theorem**
  - Directed graph model of road network
    - Each bin has in-degree 1 or out-degree 1
    - System has no occupied cycles initially

  - Road width: $W = R(1 - \cos\beta(2\cos\alpha - 1))$
    - Initial condition: $(d,\theta) : d + R(1 - \cos\theta) < W$
    - Intersection angles $\leq \gamma$, and road lengths: $L = (2\gamma R\underline{R}) \big/ (R - \underline{R})$
    - Multiple cars with appropriate spacing



  - Car control model: Kinematic model with turn radii $\underline{R}$ and R
  - Real time renewal tasks: HST scheduling with $\sum C_i \big/ D_i \leq 1$
  - Then cars can be operated
    - Without collisions (Safety) or
    - Gridlocks (Liveness)



(Baliga & K ’05)

Thank you