Communication and Inference in Sensor Networks

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NSF Wkshp on Distributed Communications and Signal Processing for Sensor Networks, NWU, Dec 3, 2002

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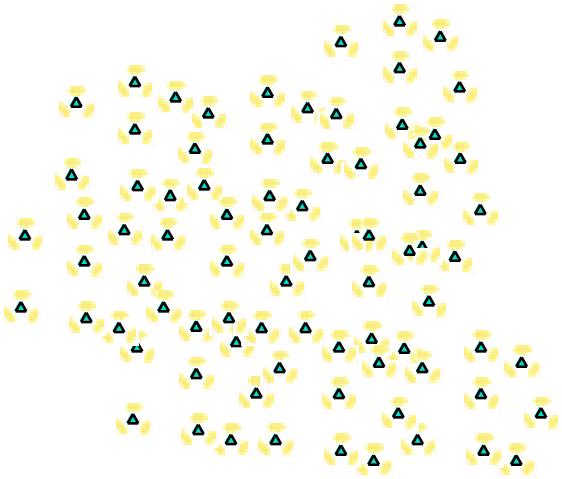
Sensor networks

- Sensor networks
  - Nodes can sense (actuate?)
  - Nodes can compute
  - Nodes can communicate
- Issues and challenges in all three categories separately
- More when you start composing them
- Larger (grand) unification of sensing, inference, communication and computation?

How to transport information over sensor networks?

- How much information can wireless networks transport?
  - Given Energy Budget, Propagation Model
  - Information Theoretic Answer (XK'02)
    - » If Attenuation is exponential or large enough path loss
      - Photons travel approx 1-10m between collisions (F'02)
      - Get absorbed with about 15% probability
    - » Transport Capacity = O(n) bit-meters/sec
    - » Multi-hop transport is order optimal
    - » Transport capacity is bounded by total network power

$$C_T \leq \frac{c_1(\gamma,\delta,\rho_{\min})}{\sigma^2} P_{total}$$



n nodes

Min distance = ρ_{min}

Area = O(n)

- Protocol Development
  - What's a lightweight substitute for an IP stack?
  - How to optimize protocols for information transfer in sensor netowrks?
  - Several protocols
    - » Sleeping - Duty cycle can be very low (1%)
    - » Clock Synchronization, etc

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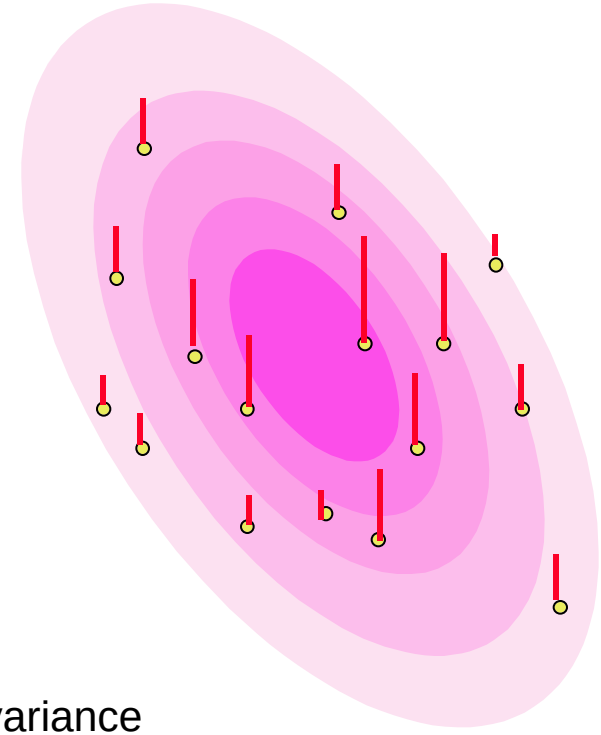
Inference in Sensor Networks

- Given
  - Measurements of a random field
  - Make inferences about the value at a point

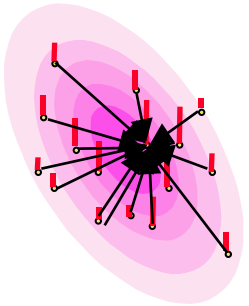


- Algorithms on Graphical Models
  - If graph of dependences is tree, then message passing and BP converge in O(n) steps
  - If graph of dependences is not a tree, then BP
    - » Need not converge even in Gaussian case
    - » If it converges, it is asymptotic
    - » Even then only mean is correct, not conditional variance
  - Other procedures, eg., which converge in O(NL) steps to both correct mean and variance in Gaussian case

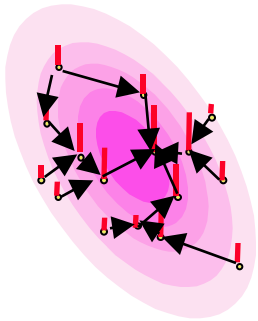
- Need a more general foundation for general inference
  - Calculate variance, median (some statistical, some algorithmic)
  - Need for efficient algorithms

An information theoretic basis for communication and distributed computing

- Example: Compute the mean of a set of measurements



- Can send all measurements to a centralized processor
  - A lot of information needs to be transported
  - Creates communication bottleneck



- Alternate strategy
  - Calculate totals and pass them on
- Issues
  - What is the information theoretically optimal solution?
    - » Combination of Slepian-Wolf type results and wireless network information theory
  - More generally, for other inference problems
    - » What is the right balance between communication and computation?
    - » Eg: Kalman Filtering type estimation to calculate the position of a moving object

Is Communication Computation?

- Is addressing computation?
  - Send a packet to A: Unicast address: A
  - Send a packet to A and B and C and D:
    Multicast address: A B C D
  - Send a packet to one of A,B,C,D and one of P,Q,R,S
    Address: (A B C D) (P Q R S)
  - How to develop communication protocols for such general addressing?
  - Send this packet to one person in each area, except that if region A does not receive it, then send the next message to C …
- Can we compose applications in terms of communication?

Convergence of sensing, actuation, communication and computation

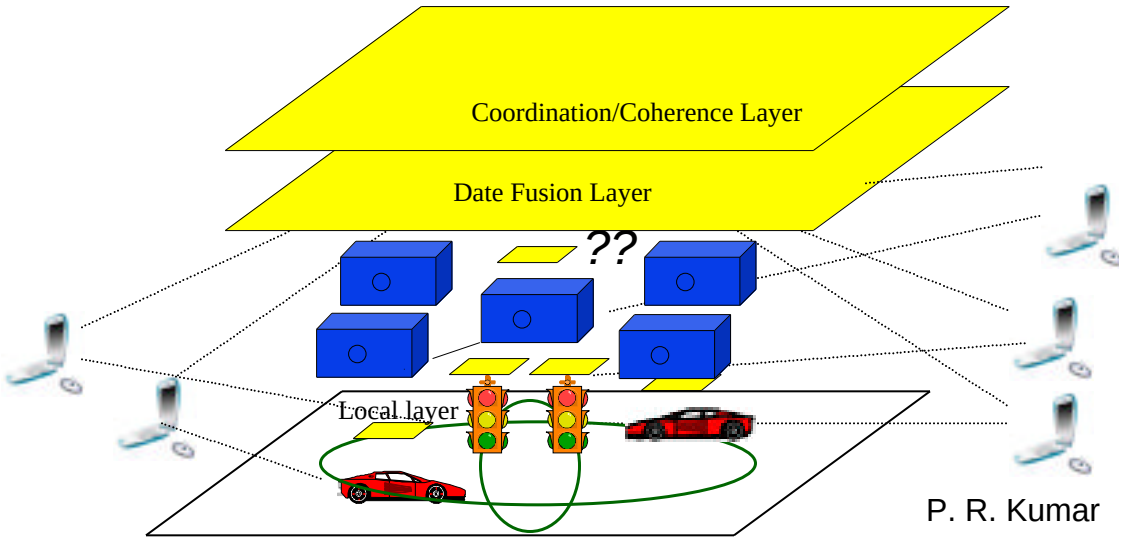
- Systems of wirelessly interconnected sensors and actuators

- Question: How do we organize distributed real-time systems?

- A testbed for convergence at University of Illinois
  - Eg. Suppose traffic lights and cars and sensors can talk to each other
  - What should be the architecture of the system?

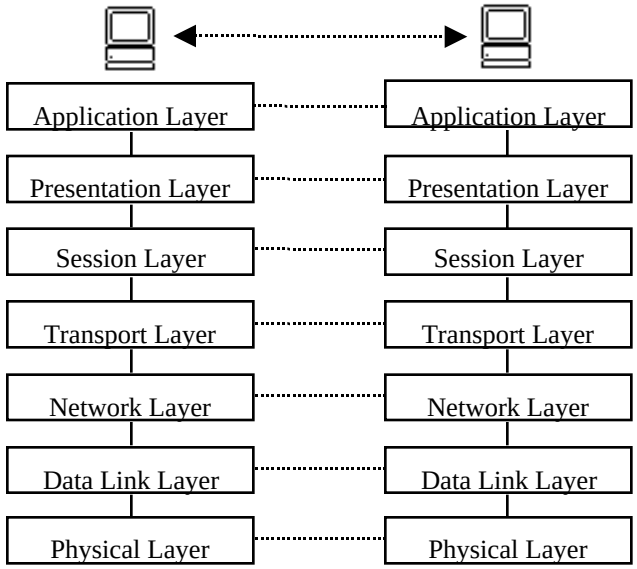
What should be the architecture of such systems?

What are the right abstractions?



The importance of architecture

- Success of Internet is due to its architecture
  - Notion of peer-to-peer protocols
  - Hierarchy of layers
  - Allows plug-and-play
  - Proliferation of technology



- Success of serial computing
  - von Neumann bridge (Valiant)
  - Hardware designers and software designers need only to conform to abstractions of each other

- Control system paradigm
  - Plant and controller separation