Wireless Sensor Networks: The Planet's New Skin

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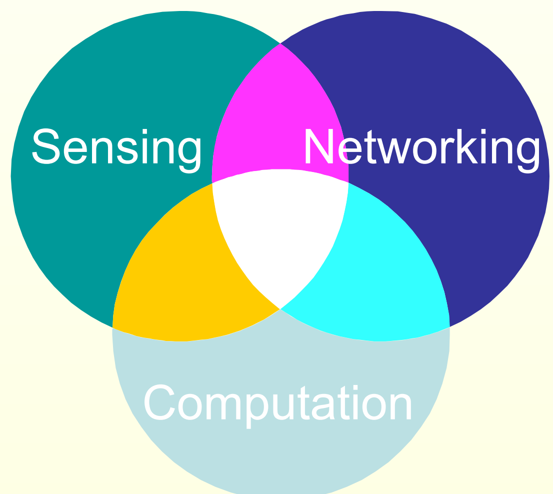
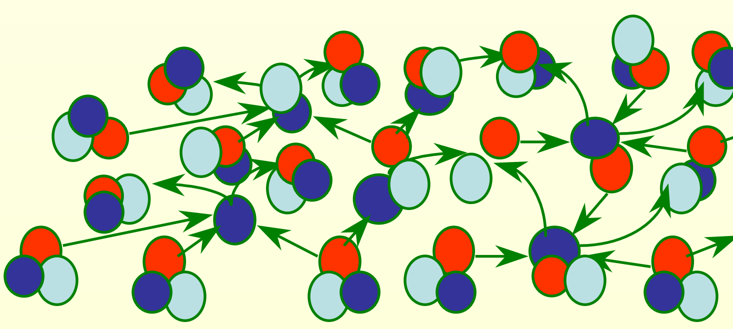
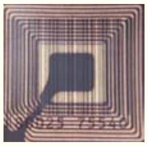




Wireless Sensor Networks

- Distributed systems consisting of small nodes, capable of sensing, processing, and wireless communication
- Often nodes operate untethered, under serious power constraints
- Communication is far more expensive than computation
- Applications in scientific, industrial, commercial, and military settings

motes



RFID

DOT MICA

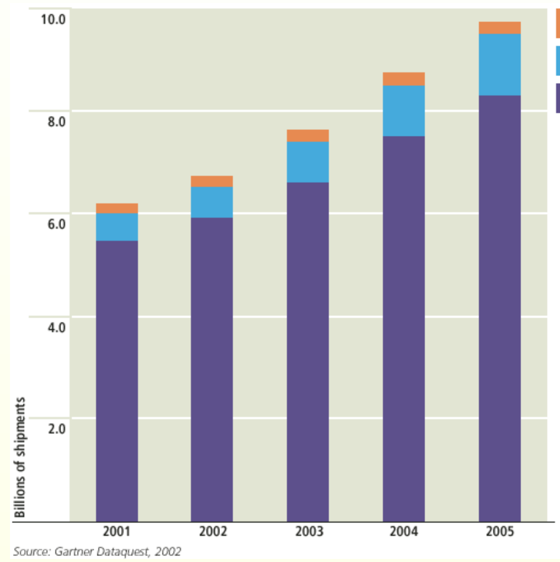
MS Spot Watch

PDA

Sensoria Node

Wireless Sensor/Embedded Processor Trends

- Of 9.6 billion µP’s to be shipped in 2005, 98% will be embedded processors!



- Riding on Moore’s law, smart sensor nodes get:

More powerful

Sensoria WINSNG 2.0
CPU: 300 MIPS
.1 GFLOP FPU
2MB Flash
2MB RAM
ensors: external

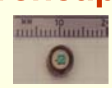
Easy to use

HP iPAQ w/802.11
CPU: 240 MIPS
32MB Flash
64MB RAM
Both integrated and off-board sensors

Inexpensive & simple

Crossbow MICA mote
4 MIPS CPU (integer only)
8KB Flash
512B RAM
Sensors: on board stack

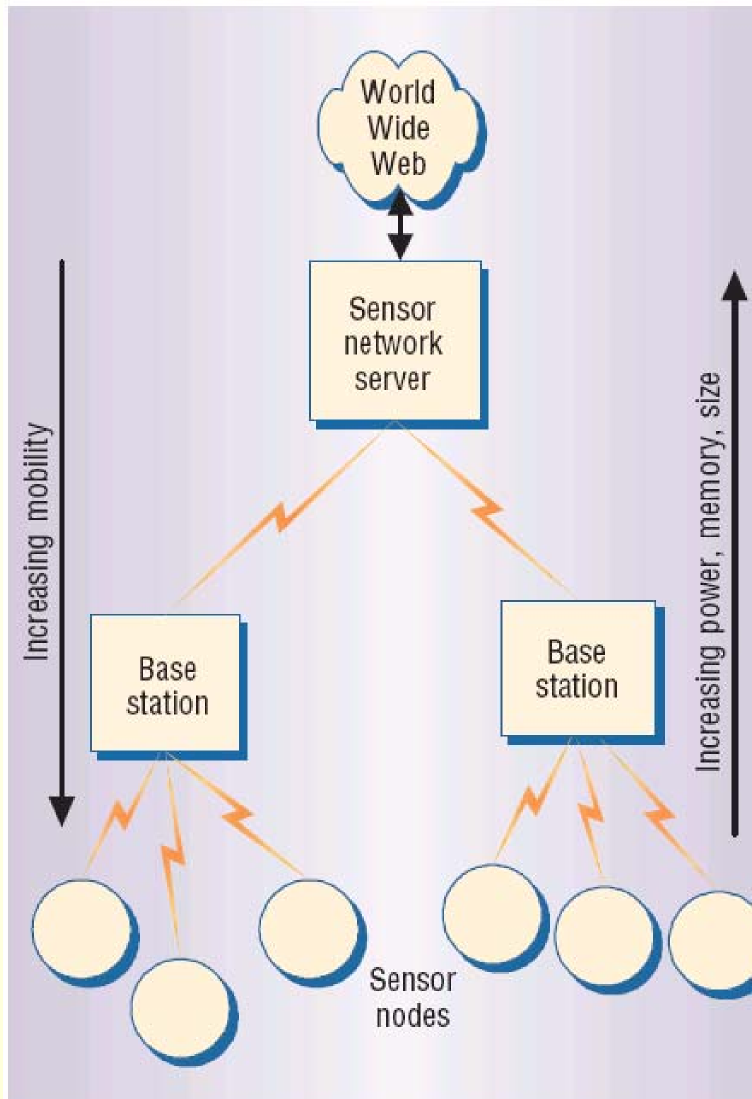
Supercheap & ti



Smart Dust (in progress)
CPU, Memory: TBD (LESS!)
Sensors: integrated

Monitoring the World

- Monitoring the environment and other spaces
- Monitoring objects
- Monitoring interactions between objects, or between objects and their environment



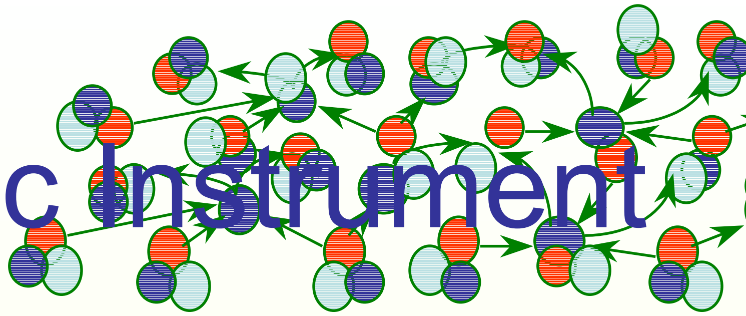
Sensor Network Deployment

- Advantages:
  - sensors can be close to signal sources, yielding high SNR
  - monitoring of phenomena widely distributed across space and time
  - scalable, robust and self-repairing systems
  - significant savings on cabling, etc

British Columbia winery with networked temperature sensors

Other monitoring: temperature in data center, oil tanker vibrations, soil contaminants, etc.

A New Scientific Instrument



- A sensor network can sense the environment and provide information that was impossible to obtain before
- At the same time, a sensor network operates under many processing, memory, communication, and power constraints

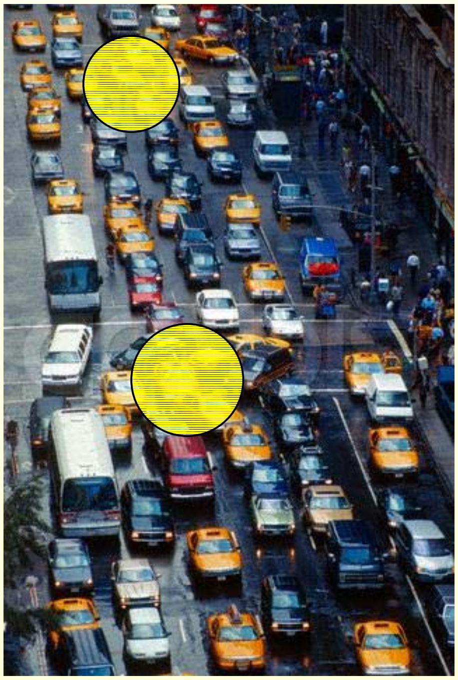
biology

astronomy

ntethered micro sensors will go anywhere and easure anything -- traffic flow, water level, number of ople walking by, temperature. This is developing to something like a nervous system for the earth. -- orst Stormer in *Business Week, 8/23-30, 1999*.

More Demanding Sensor Network Applications

- Beyond simple data collection and aggregation
  - simultaneous tracking of multiple objects
  - distributed, wide-area phenomena
  - many detractors
  - integration of geographically scattered evidence
  - distributed attention: focus and context
- Network must adapt to highly dynamic foci of activity
- Resources must be apportioned between detection, tracking, etc.

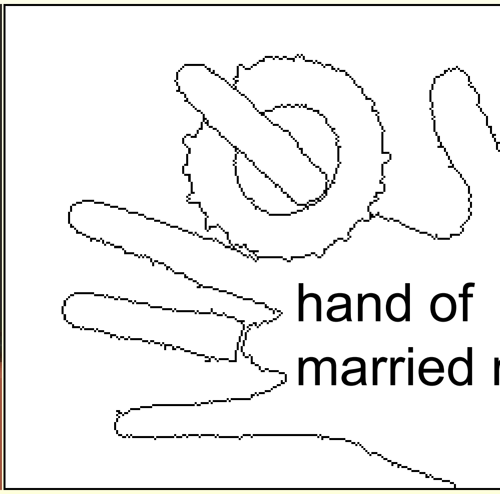


The Challenge of Distributed Sensing

- Data is not all available at once or at the same place
- Data has to be collected only as needed – information acquisition has a cost
- Data may contain errors

nsor data

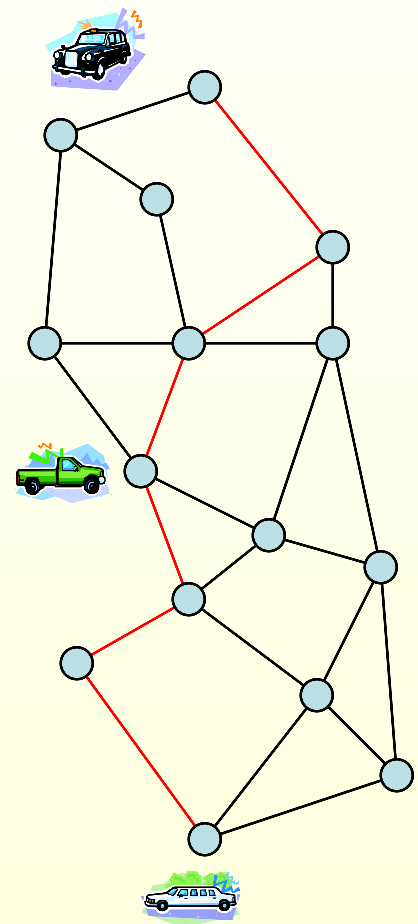
processing: segmentation



recognition

The Challenge of Networking Sensor Networks

- Network support for a small number of collaborative tasks.
- Data-centric, (as opposed to a node-centric) view of the world.
- Monitoring processes may migrate from node to node, as the phenomena of interest move or evolve.
- Communication flow and structure is dictated by the geography of signal landscapes and the overall network task.

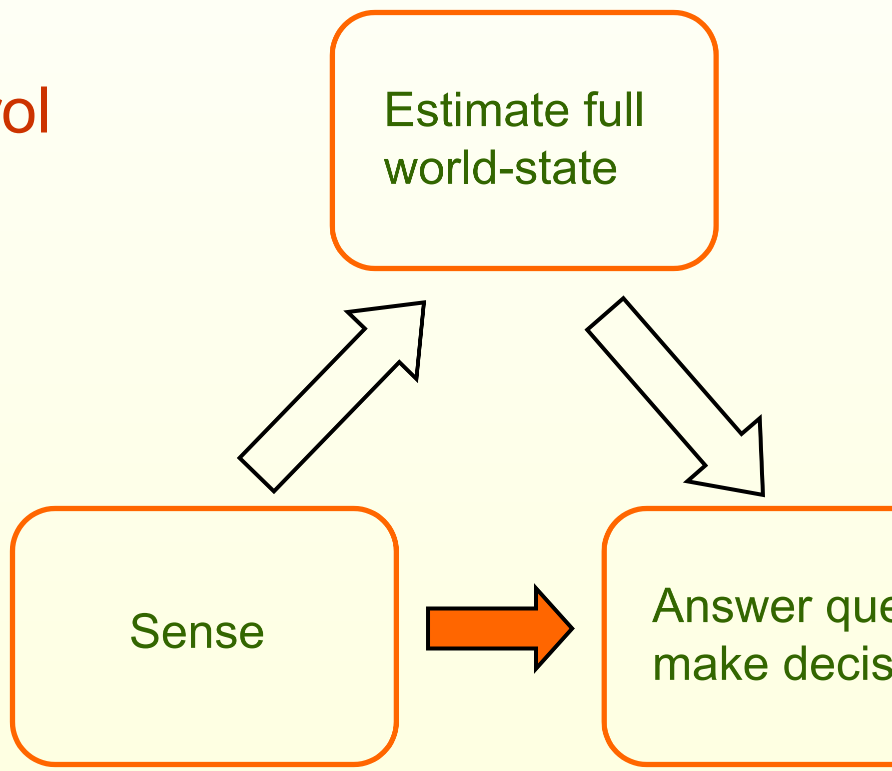


A Conundrum of Disciplines

- Low-Power Hardware Design
- Signal Processing
- Distributed Compression
- Statistical Learning and Estimation
- All layers of Networking
- Distributed Algorithms
- Reasoning under Uncertainty
- Computational Geometry and Optimization
- Data-Bases and Distributed Data Storage
- New Programming Metaphors

Sensor Network Challenges

- power awareness
- sensor tasking and control
- information brokerage
- formation of sensor collaboration groups
- in-network, distributed processing
- node management, service establishment, software layers
- coping with noise and uncertainty in the environment



A key algorithmic problem is how to sense and aggre
only the portions of the world-state relevant to the tas
hand, in a lightweight, energy-efficient manner.

Image Sensor Networks

- CMOS technology enables the production of small, low-cost and low-power integrated image sensors
- Cameras (still or video) and other image sensors are becoming cheaper, smaller, and nearly ubiquitous
- However, truly distributed networked systems of image sensors are still not here

Additional Distributed Imager Challenges

- Imagers are high data rate sensors; therefore data must be compressed and summarized
  - compression must take into account shared data
  - goal of compression need not be reconstruction
- Vision algorithms can be expensive to run on low-power devices
- Visibility is non-local and discontinuous (occlusions, etc)
- Issues of privacy, etc.

The Project

- Use a camera network to obtain information about space occupancy by people.
- Useful for aggregate tracking, counting, etc.
- Crowd density implies multiple occlusions – no one camera by itself can do this.
- No image reconstruction --just high-level distributed spatial reasoning.

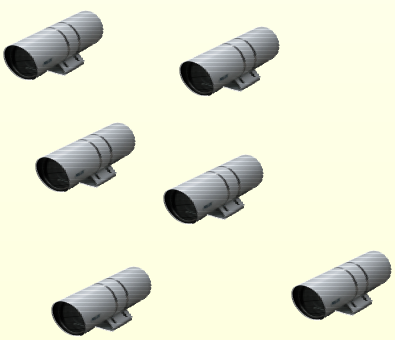
Packard 013

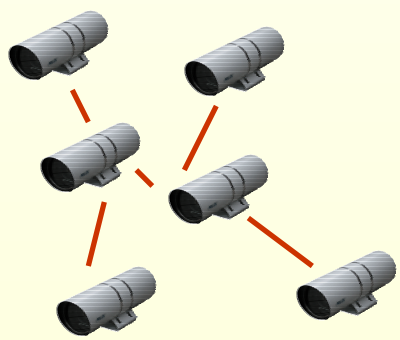
The Current Lab

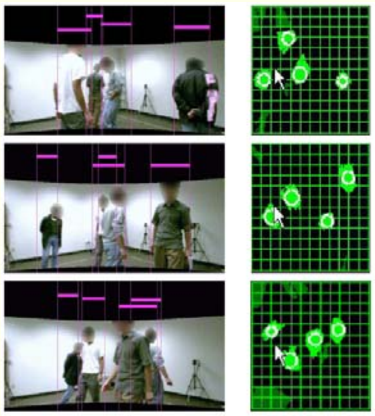
- Web cameras:
  - 16 firewire webcams with 49 degree FOV
  - Placed around a 22 x 19 foot room
- Linux computers
  - Each PC is connected to 2 webcams
  - A separate process is running for each webcam to simulate an individual camera node
  - All processes can communicate with each other over the network

System Architecture

Autonomous Background Subtraction, Data Compression → Collaborative Visual Hull Estimation, Camera Tasking → Problem Solution





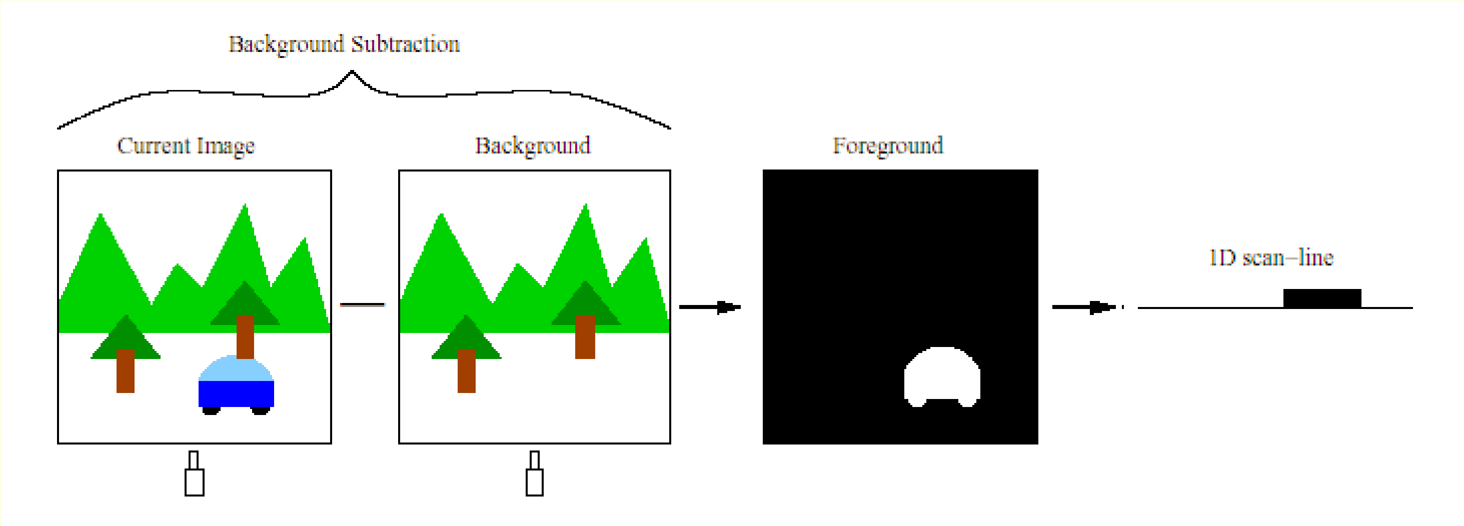


[Yang, Banos, G., ICCV'03]

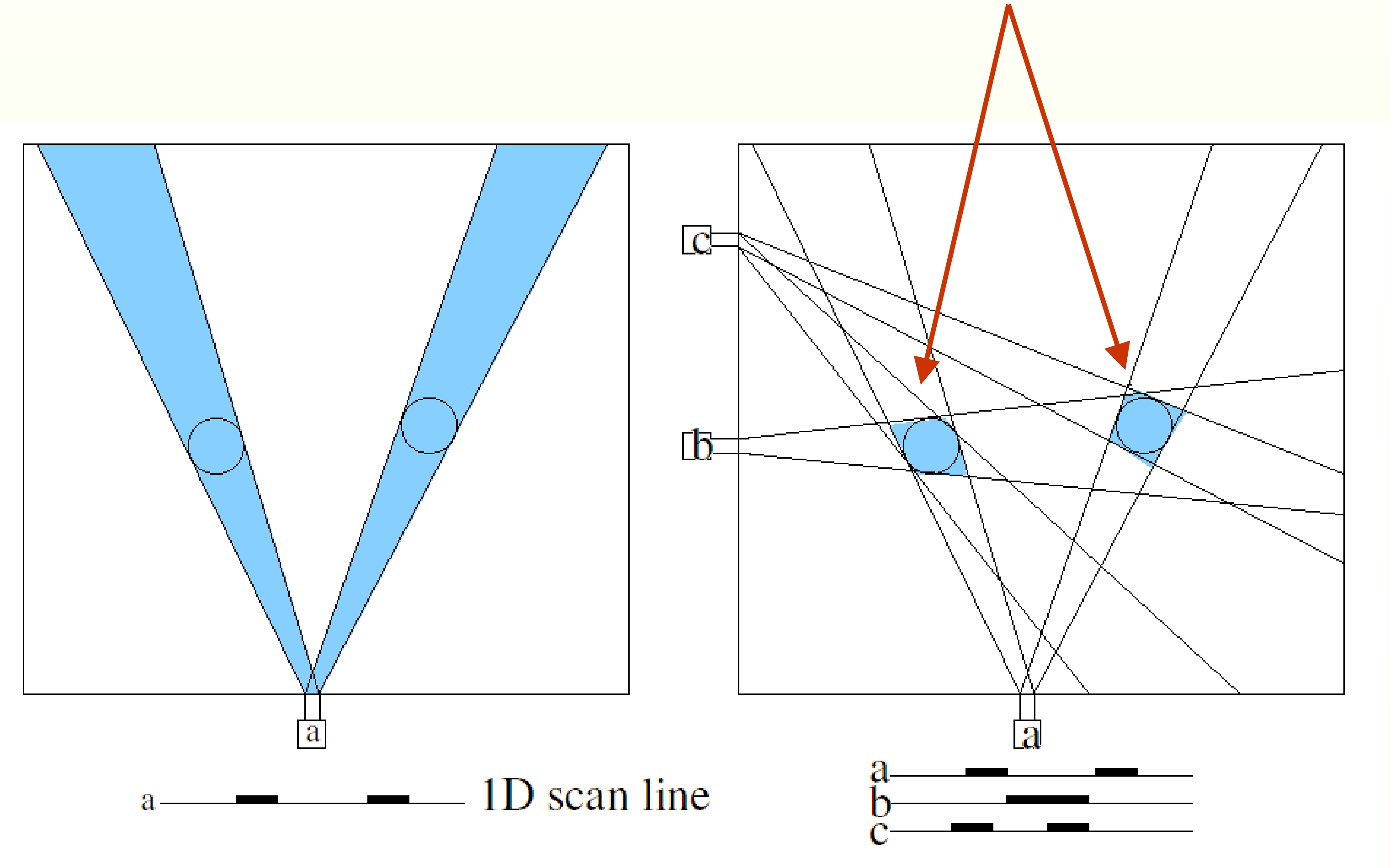
Local Processing

- Perform background subtraction
- Collapse to a single scan-line

- 640x480 RGB image → 640 bit scan-line (which can be further compressed)

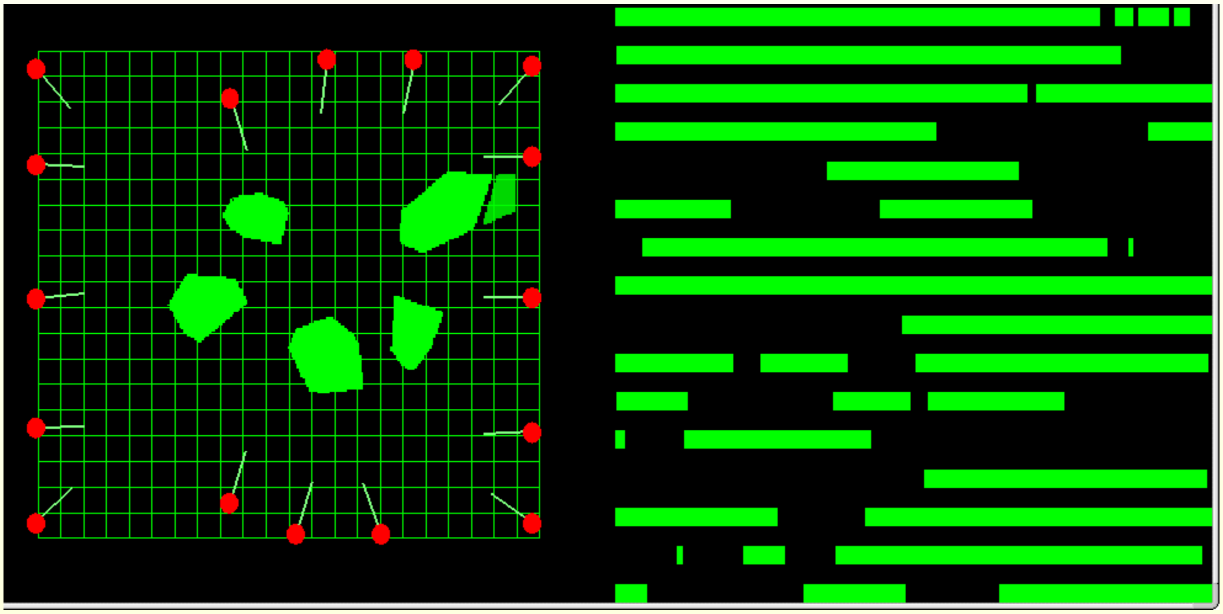


Occupancy Representation: The 2-D Visual Hull



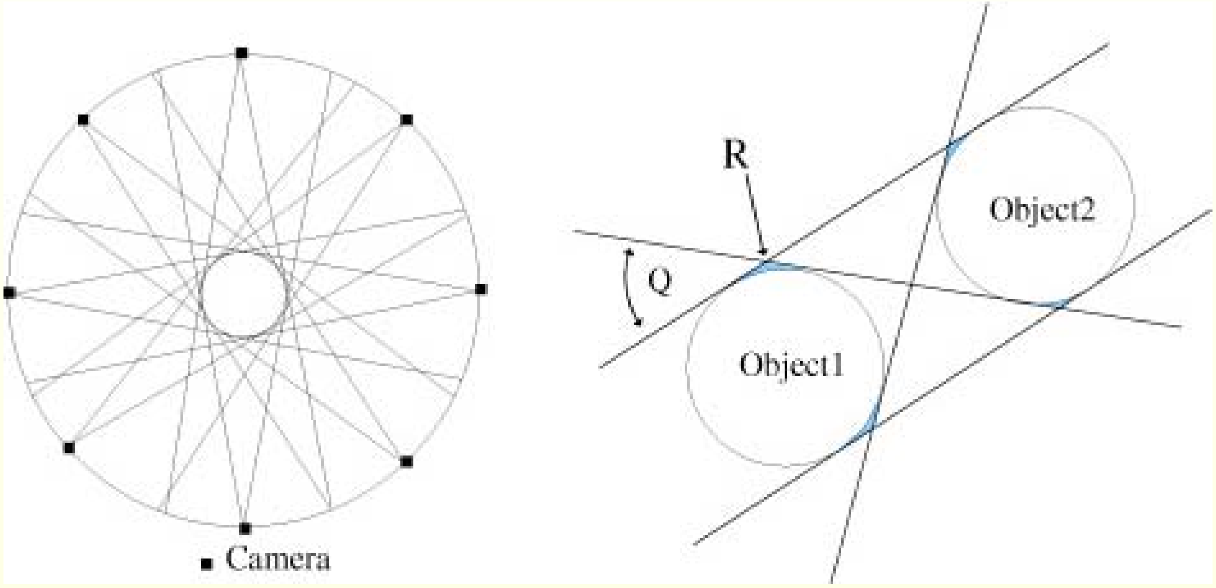
A Visual Hull Example

ew of room
people



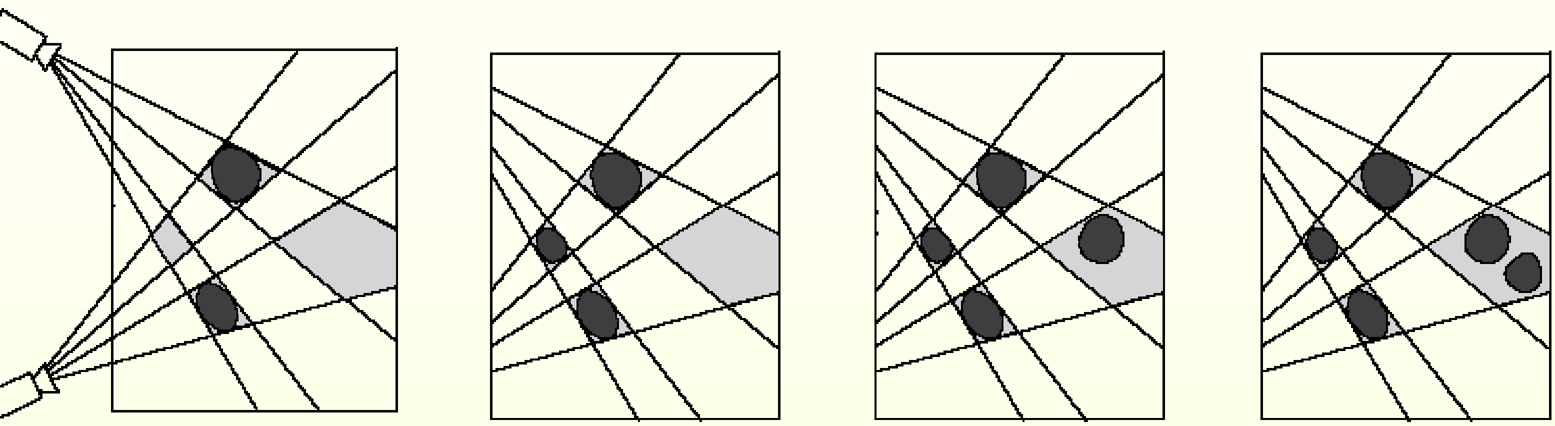
Scanlines
16 camer

The Visual Hull Overestimates Occupancy

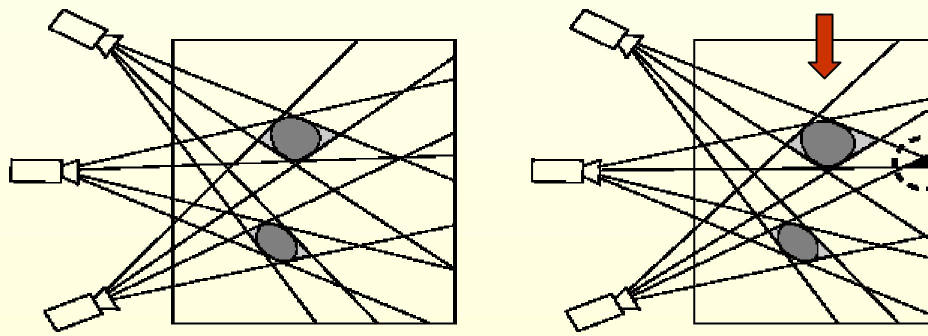


- Visual hull regions surround each object – but there is always wasted space
- Using more cameras reduces the overestimation – but it can never be fully eliminated

And Then There Are Phantom Regions ...



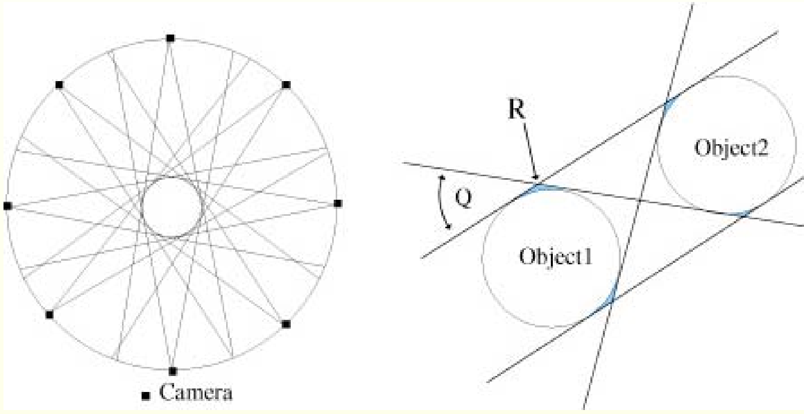
Visual hull regions may also be empty; we call these the phantom regions

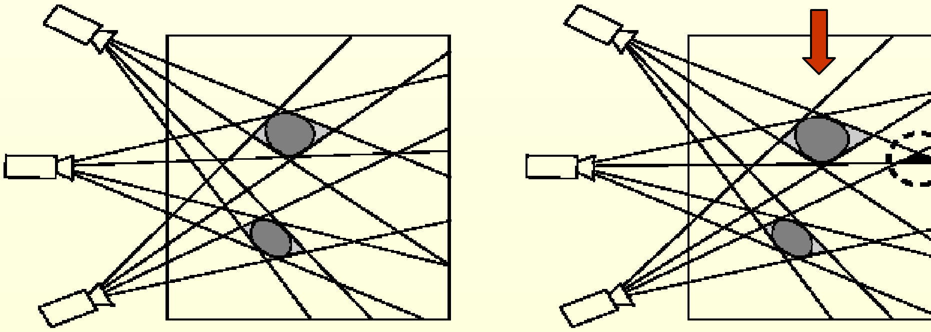


Motion can allow the prunin
of phantom regions

Pruning the Visual Hull

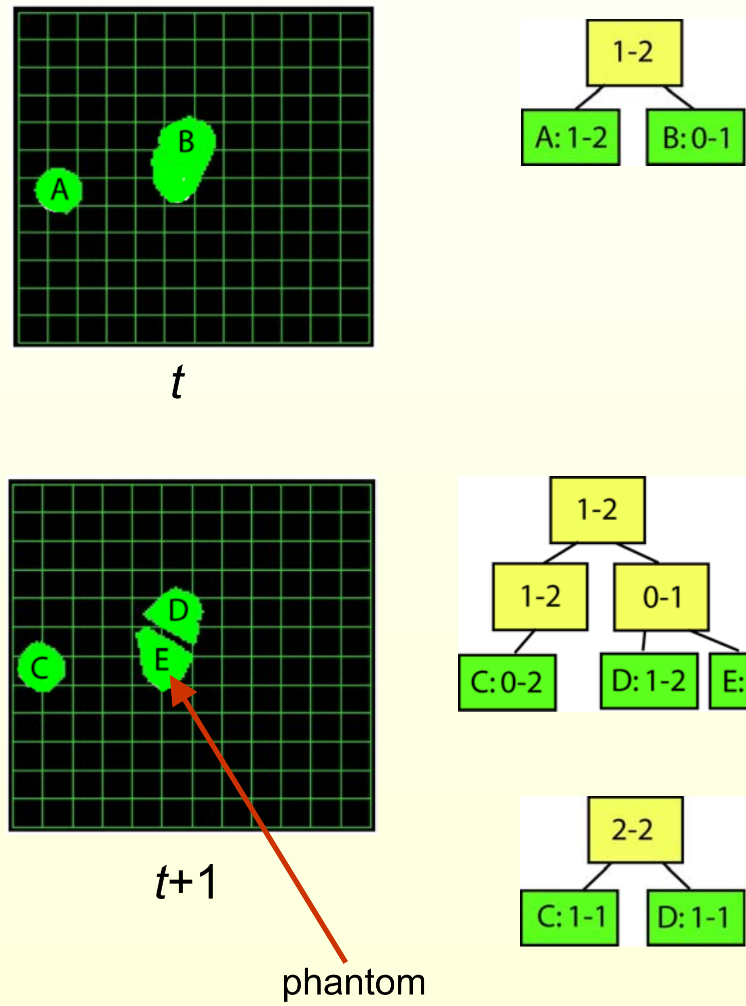
- Using more cameras reduces the overestimation – but it can never be fully eliminated
- Motion can allow the pruning of phantom regions



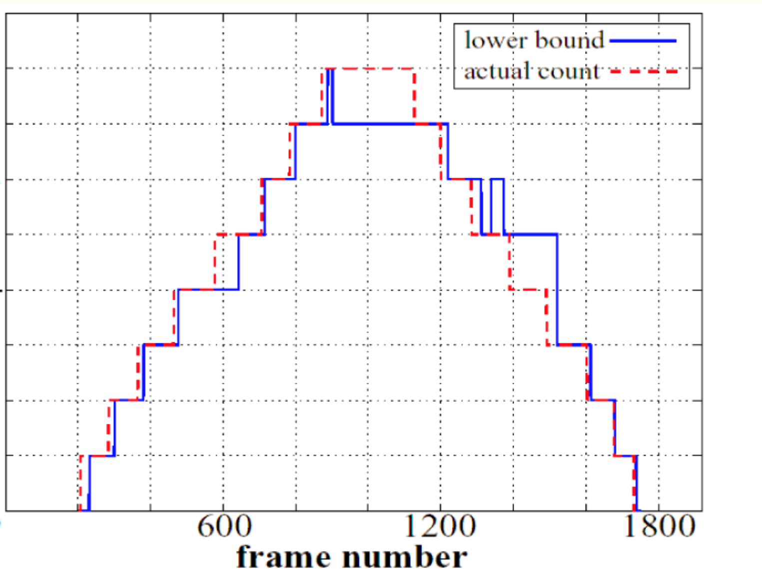


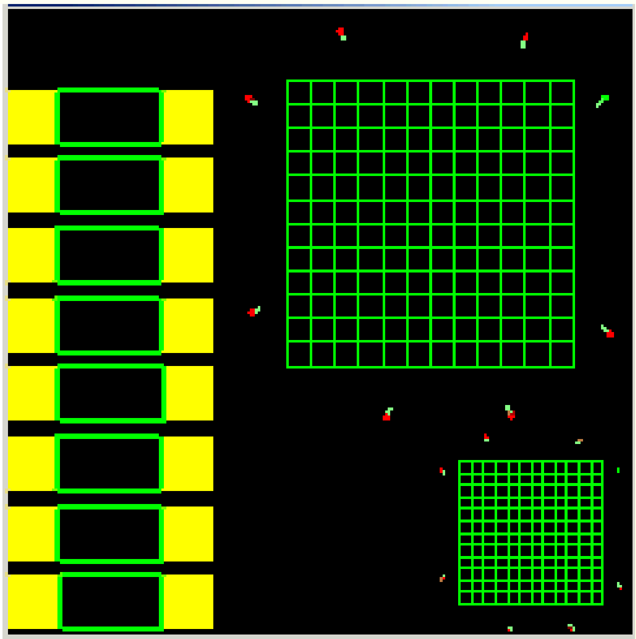
An Application: Counting People

- Given occupancy, bound the number of objects in each polygon of the visual hull
- The bounds over time can be used to constrain the count, using a tree data structure.



A Counting Example

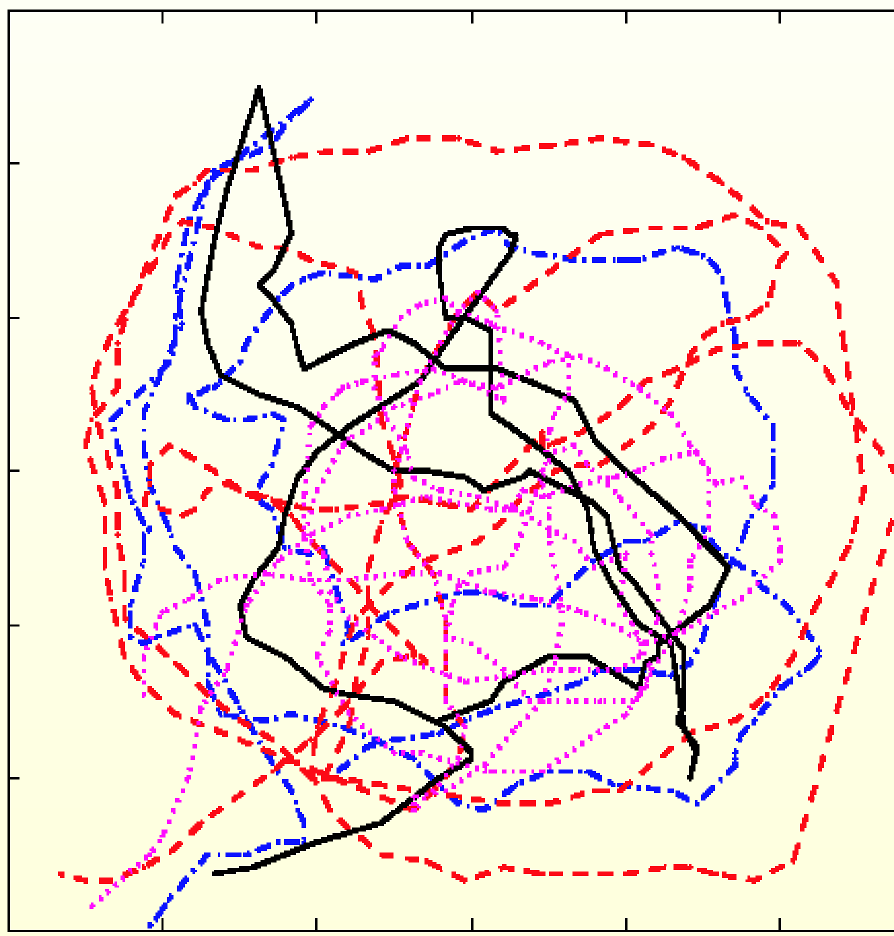




Video

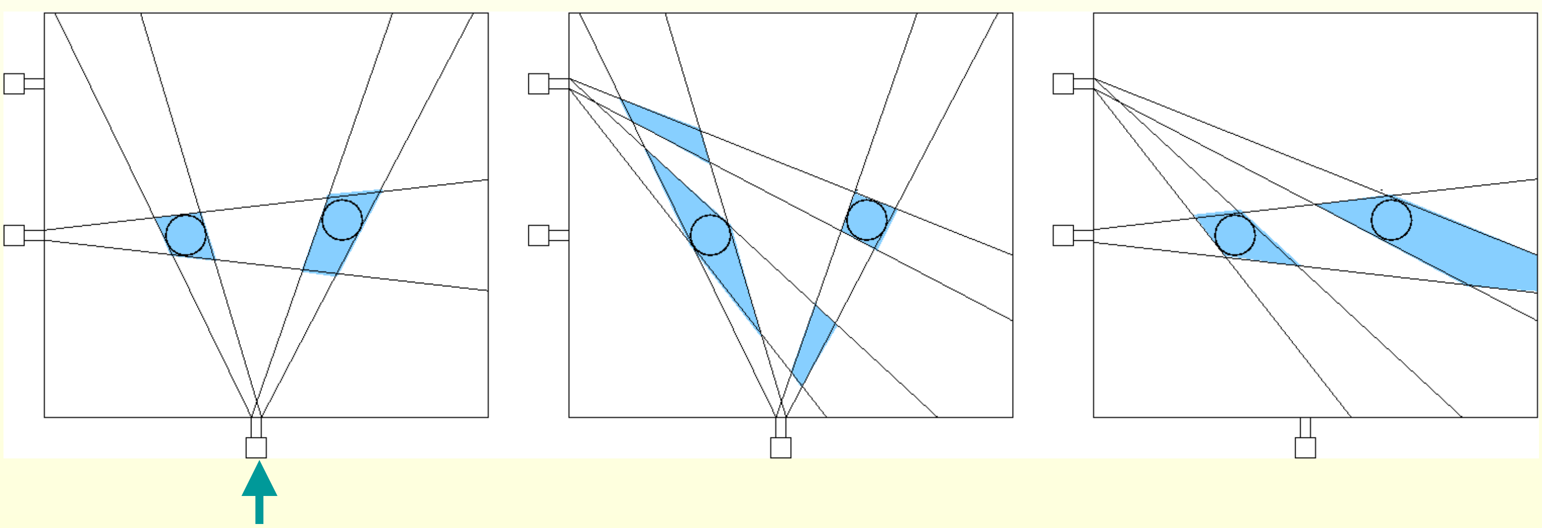
Application: Tracking

track.mov



Tasking Subsets of Cameras

- To scale the system to large numbers of cameras, we must understand how to select appropriate subsets of the sensors to activate
- Using a small subset can save communication bandwidth and energy
- Often it can be done without significant estimation degradation

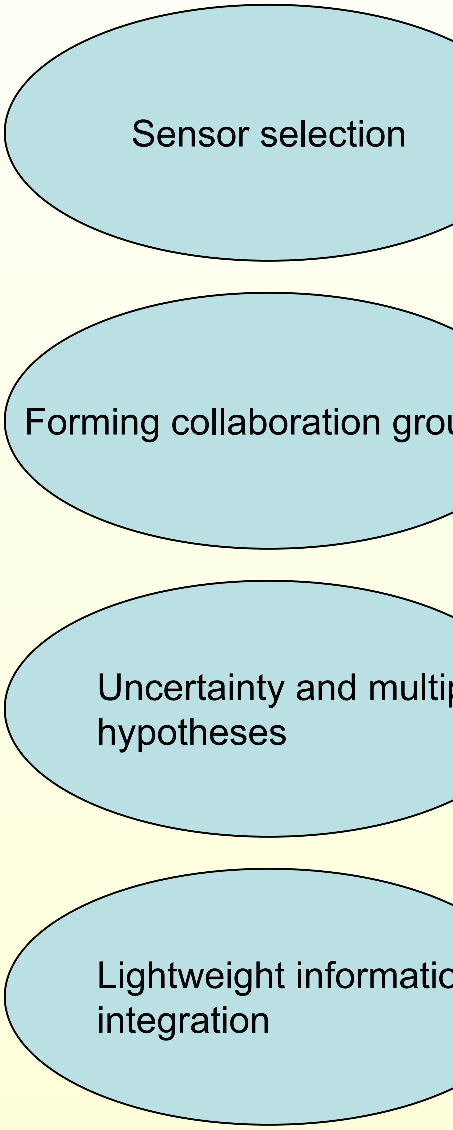


Optimal

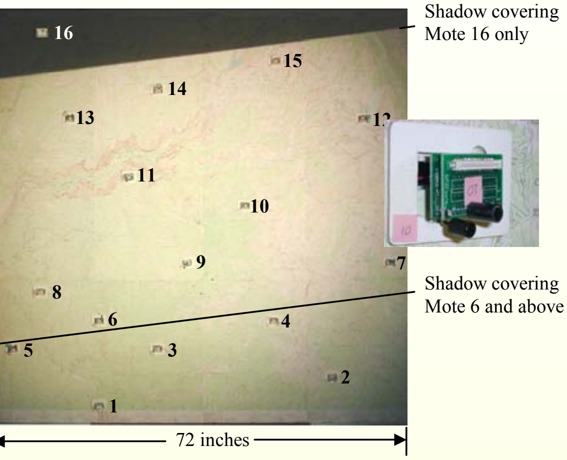
Selection of 2 out of 3 cameras

Some Lessons and Issues

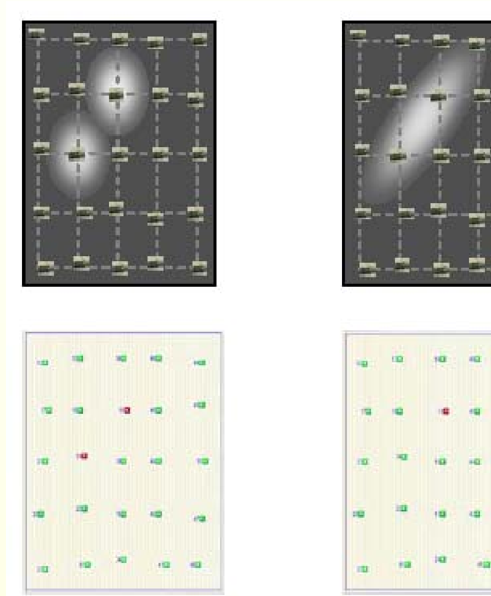
- A surprising amount of spatial information can be captured by cameras sharing very few bits.
- Small subsets of cameras, when appropriately tasked, can provide accurate estimates.
- The system can perform counting without tracking, thus raising no privacy issues.



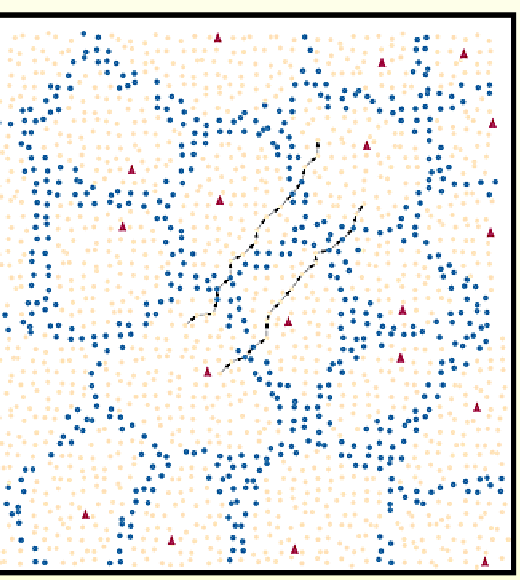
Other Work



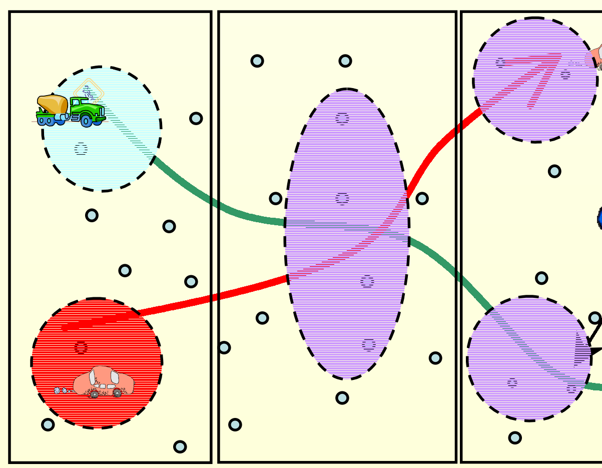
Tracking large shadows over a sensor field



Forming collaboration groups and dealing with identity management



Routing using landmarks, without coordinates



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The End

Another kind of sensor network exhibiting lightweight distributed reasoning