# *Introduction*

## Vision and Challenges

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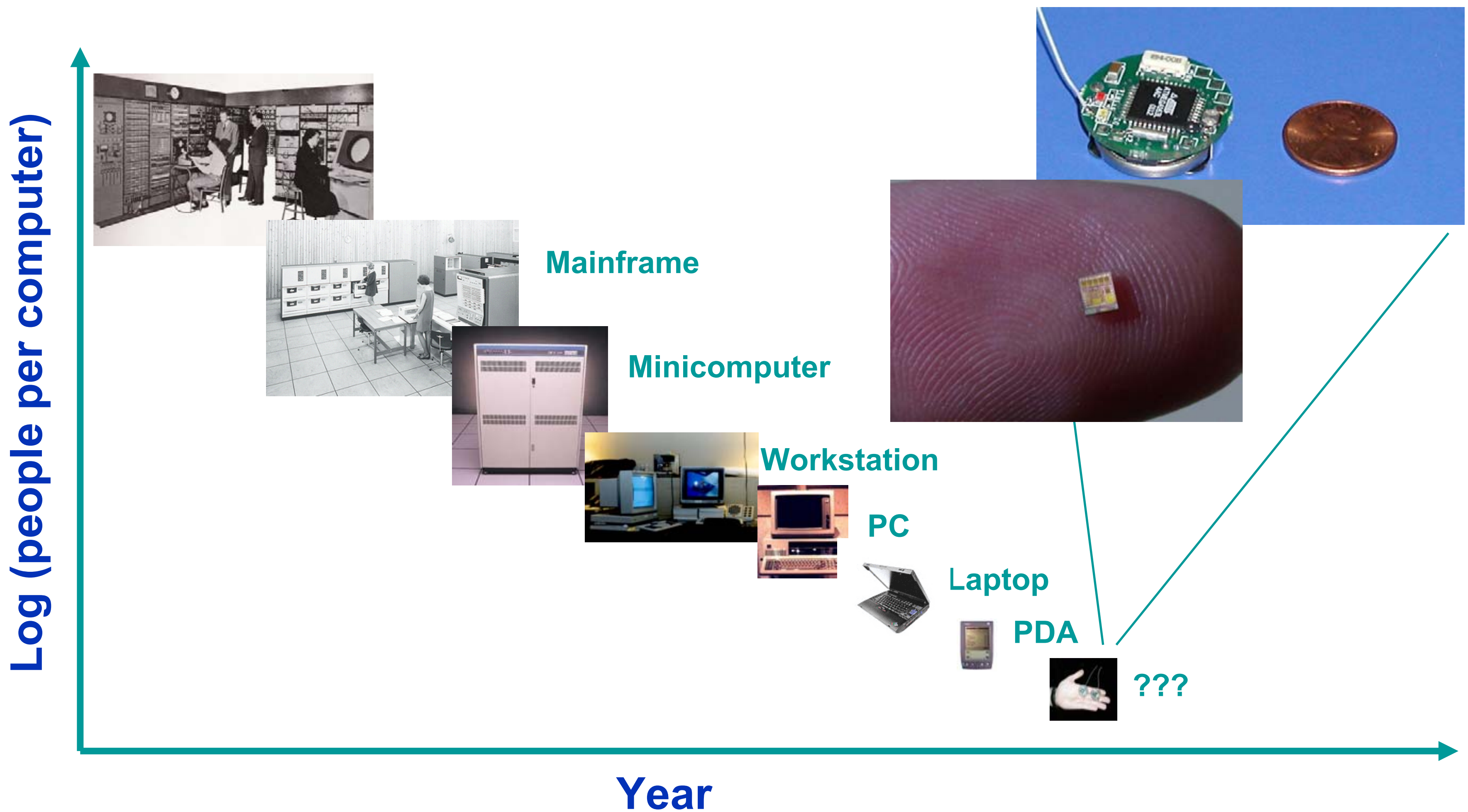
# References (and quotations)

Computer Science


- Mark Weiser, The Computer for the 21st Century. Scientific American, 1991.
- Embedded Everywhere: A research agenda for networked systems of embedded computers, CSTB Report.
- J. M. Kahn, R. H. Katz, and K. S. J. Pister, Next Century Challenges: Mobile Networking for Smart Dust, Mobicom'99.
- M. Srivastava, R. Muntz and M. Potkonjak, Smart Kindergarten: Sensor-based Wireless Networks for Smart Developmental Problem-solving Environments. Mobicom’01
- Akyildiz, Su, Sankarasubramaniam. A Survey on Sensor Networks. IEEE Communications Magazine. 2002.

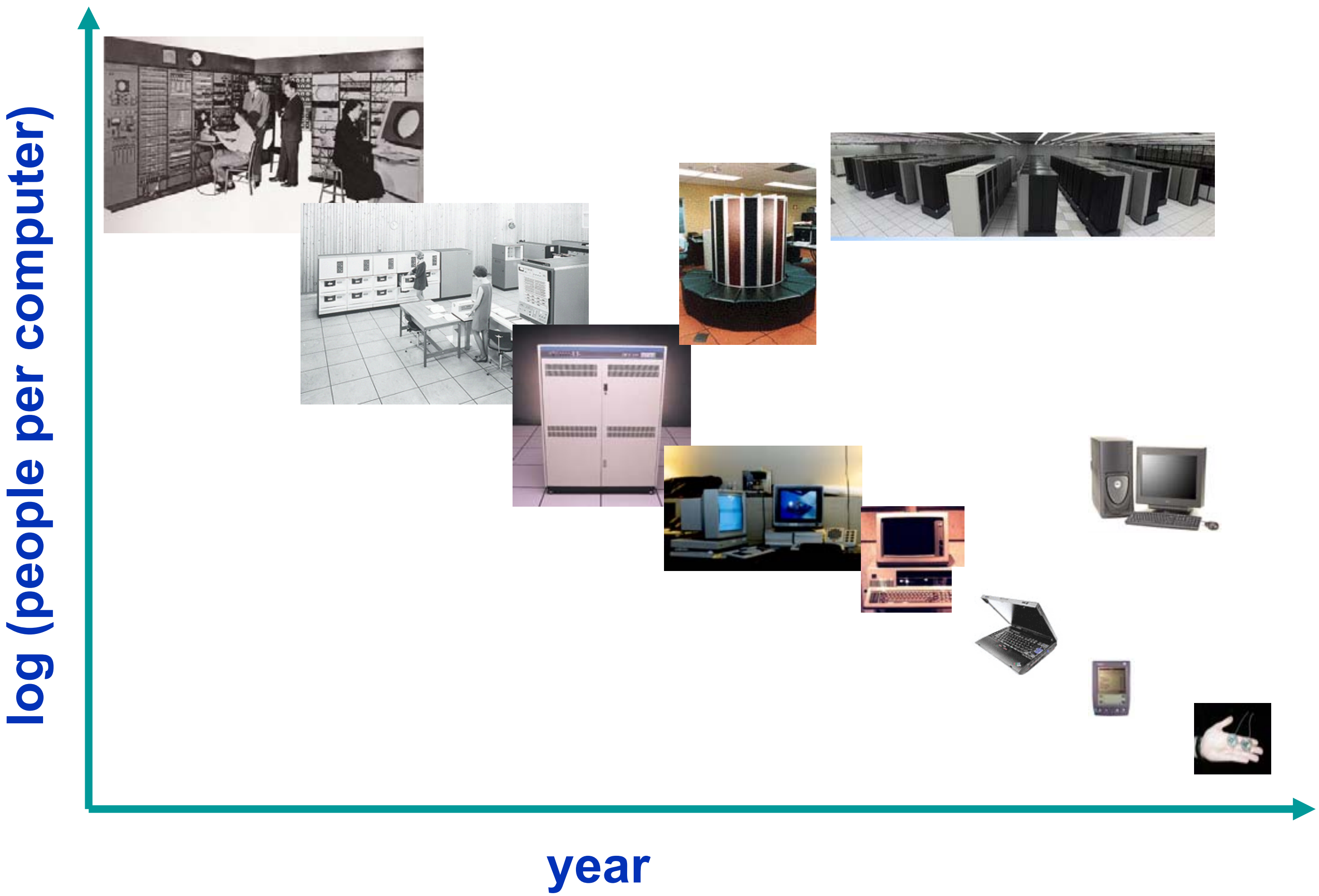
# Scalability: Size and #'s

Computer Science



# New Role for Computing

Computer Science




**Number Crunching & Storage**

**Productivity interactive**

**Streaming information to/from physical world**

# Confluence of Technologies

Computer Science

## Embedded Systems

Small, untethered processing, storage, and control

## Networking

Self-organized, power-aware communication

## MEMS

Mass-produced, low-power, short range, sensors & actuators

Many devices monitor and interact with physical world

Coordinate and perform higher-level tasks

Exploit spatially and temporally dense coupling to physical world

# What is a Sensor?

Computer Science

| Device | Sensor? |
|---|---|
| Keyboard | |
| Mouse | |
| Network monitor | |
| Webcam | |

- Clearly the above devices could be considered sensors—are they?
- What characteristic makes an input device a sensor?

# Input Device → Sensor



- What characteristic makes an input device a sensor?

**UBIQUITY**

| **Device** | **Sensor?** |
|---|---|
| Keyboard | No |
| Mouse | No |
| Network monitor | No |
| Webcam | Maybe! |

# Ubiquitous Computing

Computer Science

## 21st Century Computers (circa 1991)

Embedded in OUR world (*a.k.a.* Ubiquitous/Pervasive):

- *"They weave themselves into the fabric of everyday life until they are indistinguishable from it"* [Weiser, 1991]
- The anti-thesis of *"virtual reality"* and GUI
- Just like motor technology, embedding computers everywhere and having them *"disappear in the background"* is easy—a done deal today
- It's the network stupid!

# Ubiquity: Visions and Dreams



“Window Desktops” → “Real Desktops” [Weiser, 1991]

- From Icons, Windows and desktops to Tabs, Pads, and Boards (“widgets”)
- Challenges

  Location:
  - Awareness
  - Adaptation to mobility (which network to use, OS extensibility)

  Scale:
  - Form factor of individual device (e.g., tabs)
  - Number of devices
  - Security and privacy issues

# Ubiquity: Visions and Dreams



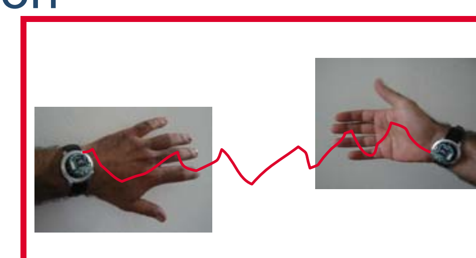
- *"Ubiquitous computing may mean the decline of the computer addict."*

- *"Ubiquitous computers will help overcome the problem of information overload. There is more information available at our fingertips during a walk in the woods than in any computer system, yet people find a walk among trees relaxing and computers frustrating. Machines that fit the human environment, instead of forcing humans to enter theirs, will make using a computer as refreshing as taking a walk in the woods."*

# Example uses

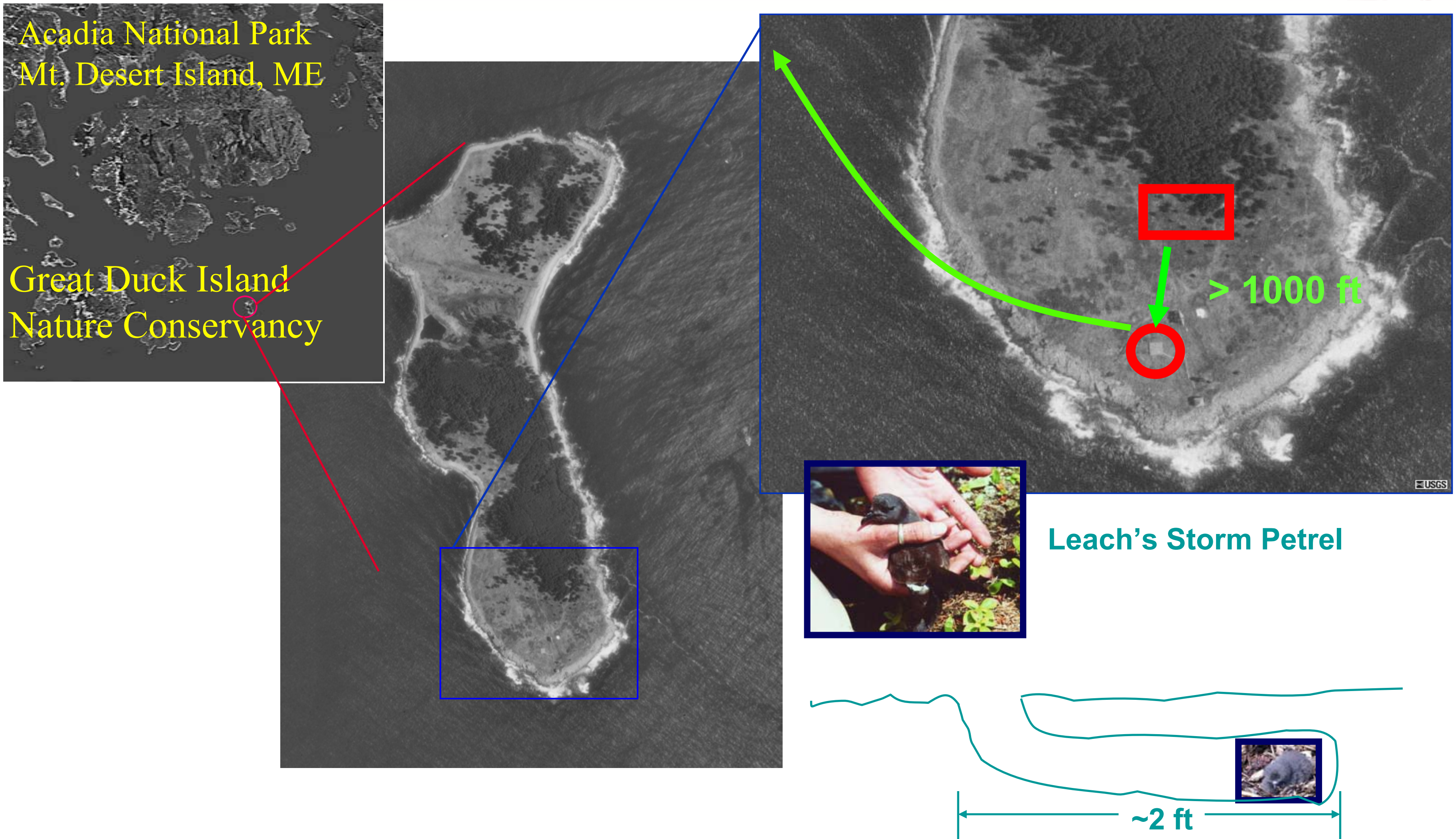


- Environment Monitoring
  - *Precision agriculture, land conservation, ...*
  - *Built environment comfort & efficiency ...*
  - *Alarms, security, surveillance, treaty verification ...*
- Civil Engineering: Structures response
  - *Condition-based maintenance*
  - *Disaster management*
  - *Urban terrain mapping & monitoring*
- Interactive Environments
  - Context aware computing, non-verbal communication
  - Handicap assistance
    - *home/elder care*
    - *asset tracking*



# Habitat Monitoring @ Berkeley

Computer Science

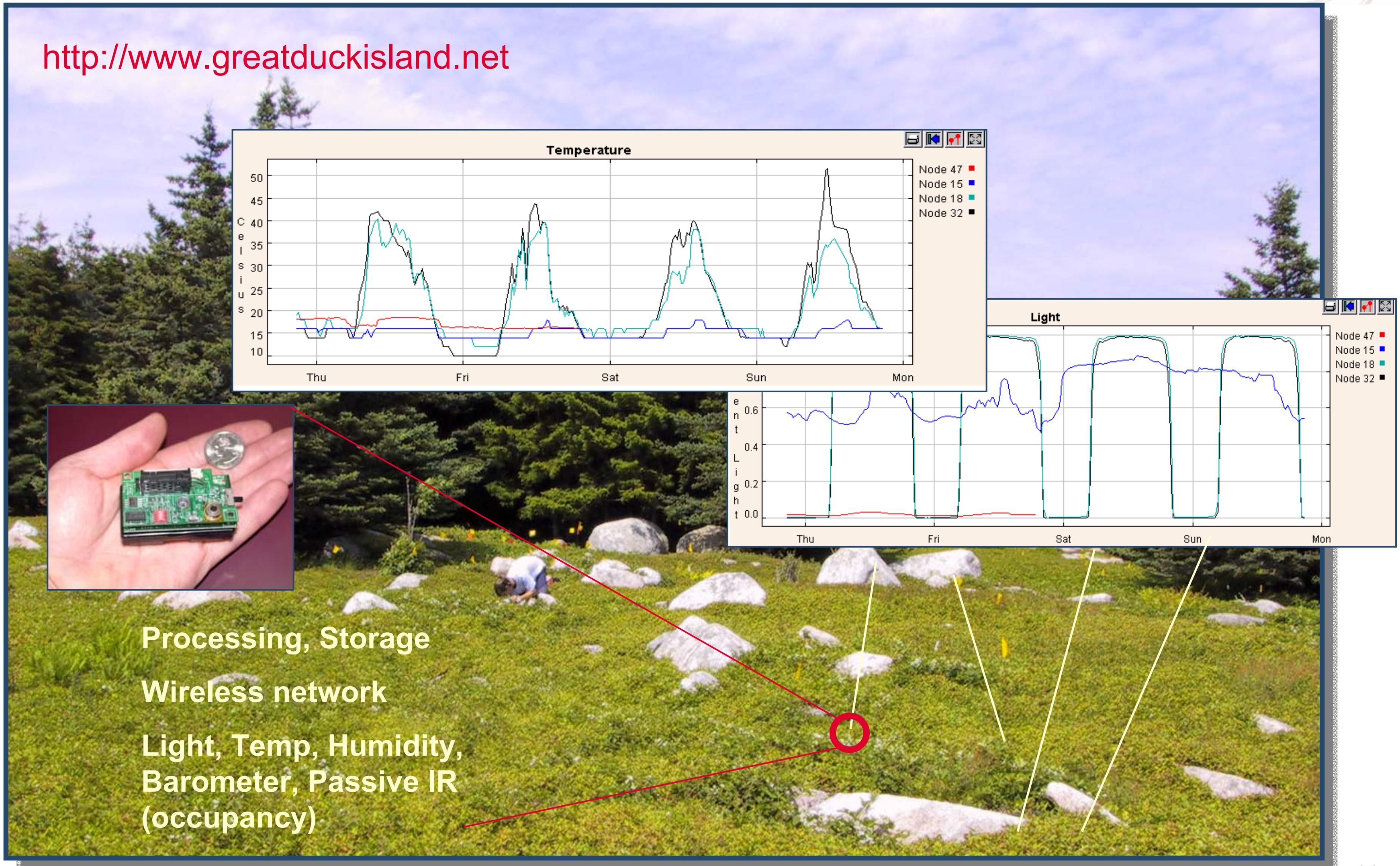


# Current State of the Art



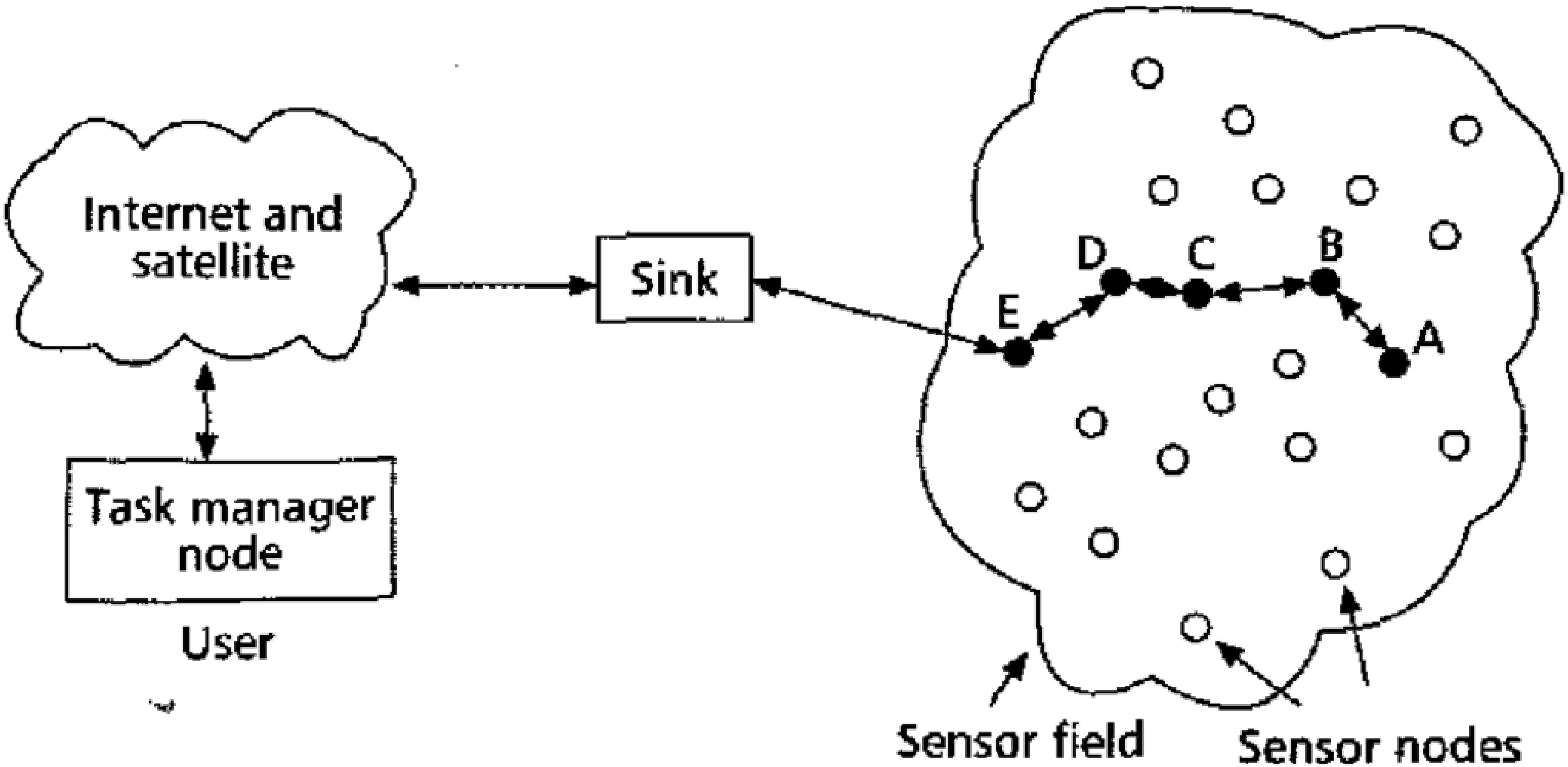
# Sensor Network Solution

Computer Science



# Remote Deployment





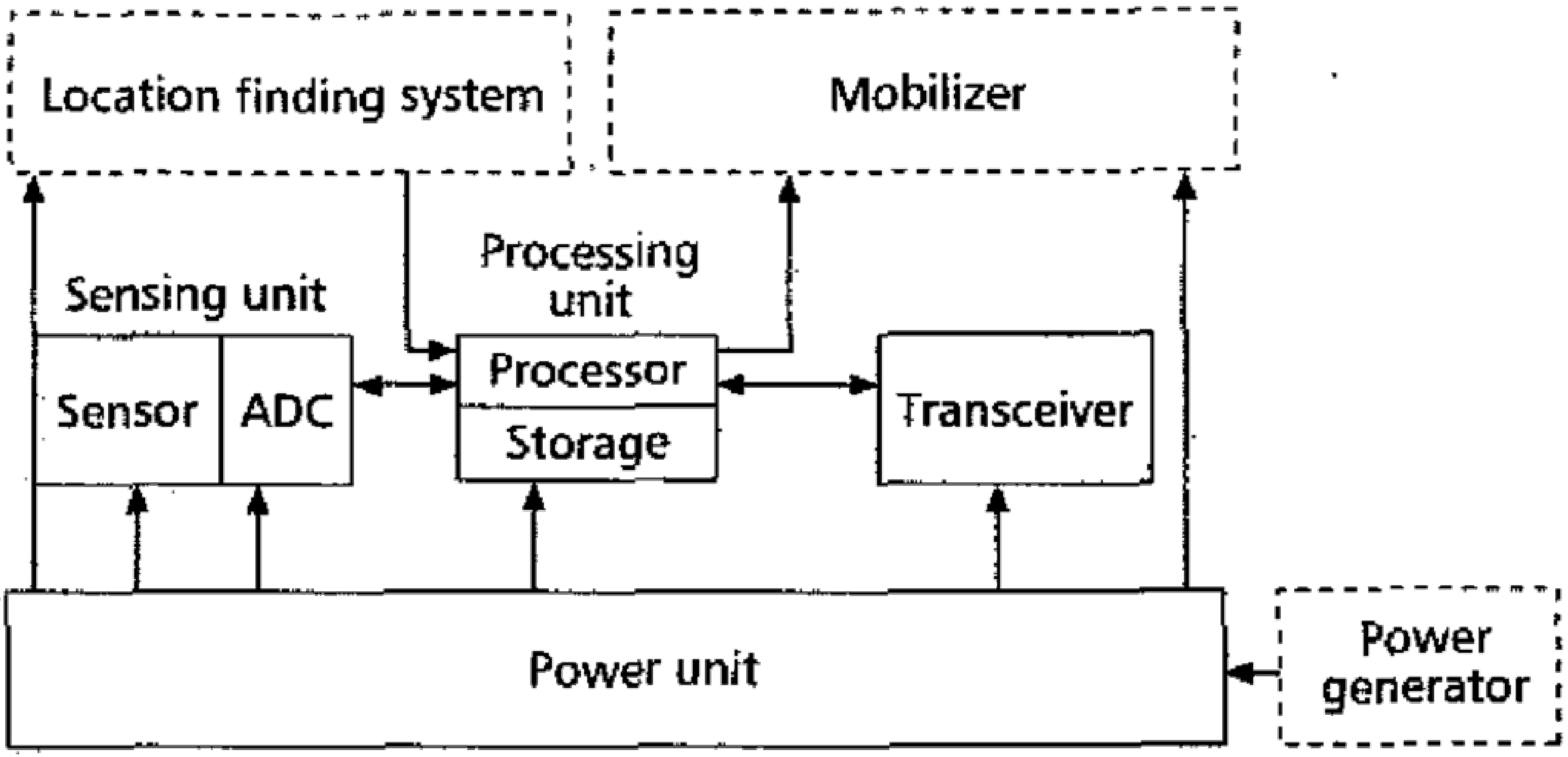
# (Possible) Characteristics

Computer Science

- Number of nodes: Typically large with no unique IDs
- Density of nodes: High and irregular
- Data type: Streaming, periodic, and noisy
- Failure prone: Possibly Intermittent
- Deployment: Prolonged, unattended, and inaccessible
- Power: Energy constrained, possibly scavenge-able
- Operate in aggregate
- In-network processing is necessary
- Mission: What they do changes over time
- Cost: Currently ~ $5/sensor ➔ $0.01/sensor

*But then maybe not!*

# (Possible) Architecture



# Wireless Communication

Computer Science

## Radio

- Relatively expensive ~ $5 / Bluetooth transceiver
- Noisy due to interference

## Infrared

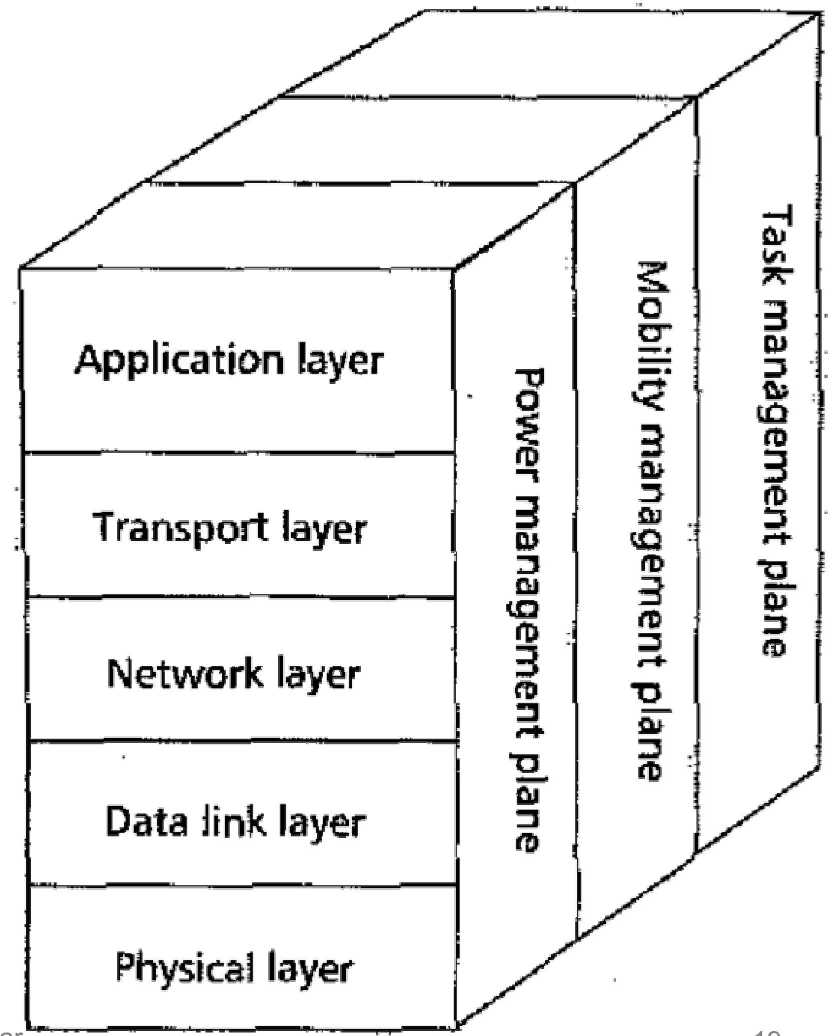
- Cheaper
- Shorter range
- Less susceptible to interference but requires line-of-sight

## Optical

- Cheapest
- Possibly very long range
- Requires line-of-sight

# Networking Stack

- Standard networking layers + management planes
- Management of power, mobility, and resources transcend layering!
- … and interact with each other as well (e.g., power-aware scheduling)



# Physical/Data Link Layers

Computer Science

## Physical Layer

- Signaling, frequency selection, …
- An engineering problem: Another way of saying it is “somebody else’s problem ☺

## Data Link Layer

- Media Access Control (MAC) Issues
  - Infrastructure versus infrastructure-less
  - Need self organization and synchronization
- Power Saving Modes
  - To turn-off or not to turn-off?
- Error Control
  - Retransmission versus FEC; (power) cost of FEC is not insignificant

# Network/Transport Layers

Computer Science

- At play:
  - Power consumption
  - Resilience to failures
  - Congestion management
  - Quality of Data (and not Quality of Service)
- We are not communicating poetry ☺
  - Abstractions such as “flows” and “packets” may need to be revisited
- Routing and data processing cannot be kept totally independent—the network stack abstraction may need to be revisited afterall!

# Routing Flavors

Computer Science

## Optimize what?

- Power available (min, total, …)
- Power consumed (max, total, …)
- Number of hops
- Quality of coverage
- Balance supply and demand

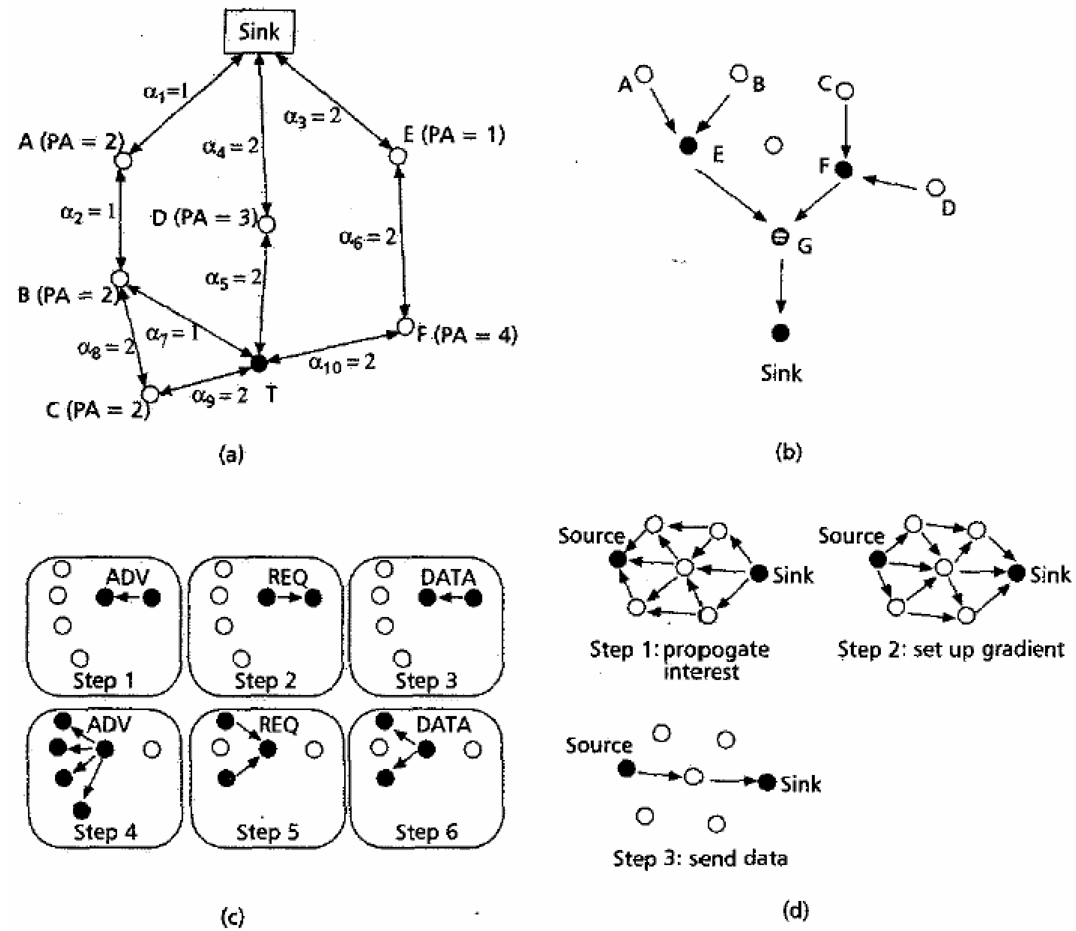



**Figure 4.** *a) The power efficiency of the routes; b) an example of data aggregation; c) the SPIN protocol [15]; d) an example of directed diffusion [5].*

# Activity Tracking @ BU

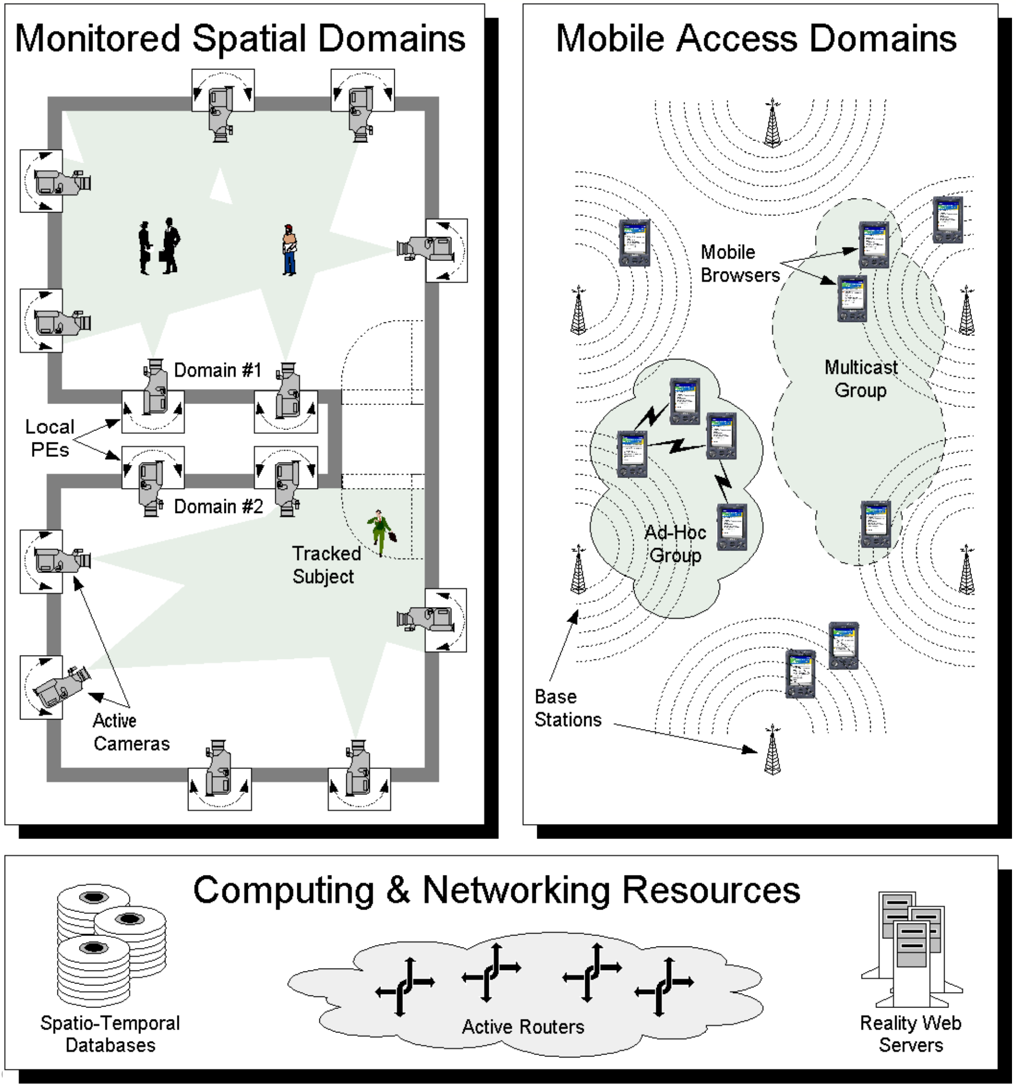
Computer Science

## Sensorium:

A common space equipped with video sensors (VS) for ubiquitous recognition and tracking of activities therein

## Infrastructure:

- Range of VS Elements
- Programmable VS Network
- Backend compute engines
- Backend TByte storage
- Mobile/wireless query units
- Research Engineer



# Why Acquire a Sensorium?



**The proliferation of networked, embedded, and mobile digital video sensors requires a paradigm shift in many areas of CS to address:**

1. The unique spatio-temporal aspects of sensory (video) data acquisition, processing, representation, communication, storage, real-time indexing/retrieval, data mining

2. The challenges of Quality of Service (QoS) management and coordinated resource arbitration of sensory networks, which are both embedded and mobile

**The other extreme in sensor networks research!**

# Sensoria: Deployment

Assistive Environments

- e.g. for home/hospice/elder care/…

Safety Monitoring

- e.g. in factories/pre-schools/hospitals/…

Intelligent Spaces

- e.g. for classrooms/meeting rooms/theaters/farms…

Secure Facilities and Homeland Security Uses

- e.g. at airports/embassies/prisons/…

People Flow/Activity Studies

- e.g. at retail stores/museums/…

# Smart Kindergarten @ UCLA

Computer Science

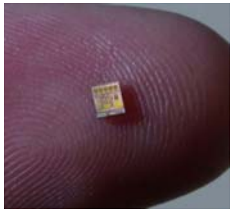
- “A wireless network of toys, composed of toys with embedded modules that provide processing, wireless communication, and sensing capability, would be used as the application platform together with a background computing and data management infrastructure.”
- “Children learn by exploiting and interacting with objects such as toys in their environments, and the experience of having the environment respond (causally) to their actions is one key aspect of their development.”
- “We would use the ability to sense and act on the physical environment to create and evaluate smart developmental problem-solving environments in pre-school and kindergarten classroom settings.”

# Thoughts: Modality Matters

Computer Science

## It is not all about "smart dust" sensor networks!

- A sensor network, where the individual sensors provide a simple measurement (say temperature) is very different from one that provides a real-time high-bandwidth stream of data (say video).



100k sensors * 1kbps

1K sensors * 100kbps

10 sensors * 10Mbps

- *"Are we rushing to very futuristic ultra-scale sensor network research, while many fundamental problems of much smaller (or coarser) sensor networks are yet to be addressed?"*

  [from communication with head of NSF ANI, Feb 2003]

# Thoughts: Tower of Babel



- Today, the term "sensor networks" means different things to different people…
- It is not clear there is even a well-defined community…
- Perhaps we ought to focus on more "down-to-earth" (i.e., more generic) problems, which are inspired by (and have the potential of advancing) specific sensor-network applications.