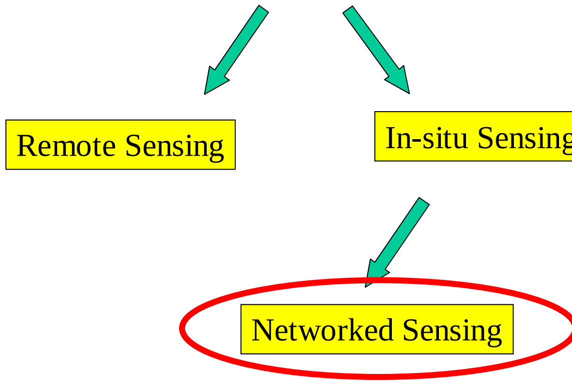
Wireless Sensor Networks

based on a tutorial by Ramesh Govindan

All Three Words Count

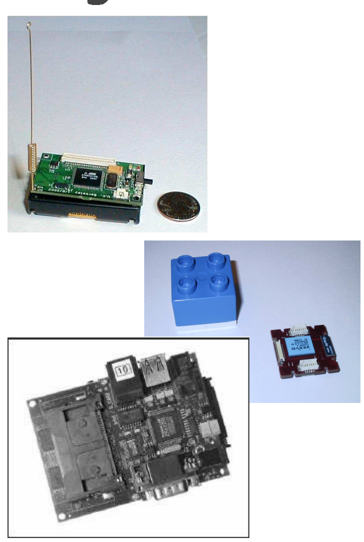
- Wireless: no lines (network or power)
- Sensors: tied to real world
- Networks: not just a single hop

Sensing



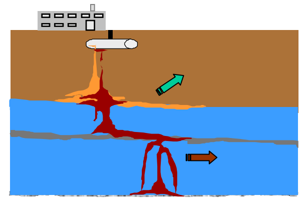
Networked Sensing Enabler

- Small (coin, matchbox sized) nodes with
  - Processor
    - 8-bit processors to x86 class processors
  - Memory
    - Kbytes – Mbytes range
  - Radio
    - 20-100 Kbps initially
- Battery powered
- Built-in sensors!



Application Areas

Seismic Structure response

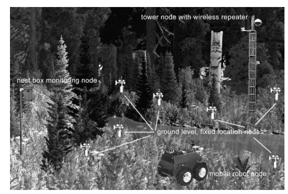


Contaminant Transport

Structural Condition Assessment

Marine Microorganisms

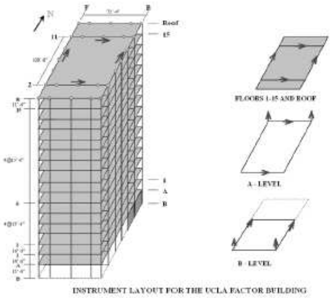
Ecosystems, Biocomplexity

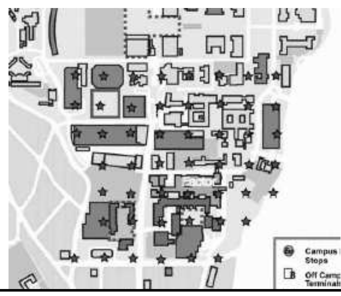


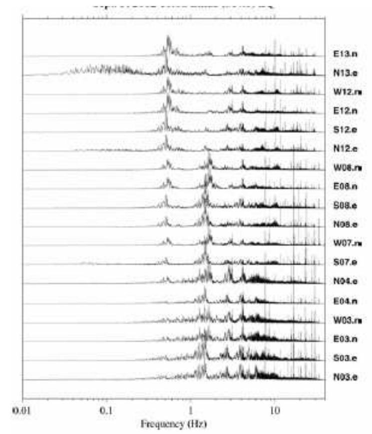
Seismic Structure Response

- Interaction between ground motions and structure/foundation response not well understood.
- Current seismic networks not spatially dense enough
  - to monitor structure deformation in response to ground motion.
  - to sample wavefield without spatial aliasing.

A Wired Seismic Array







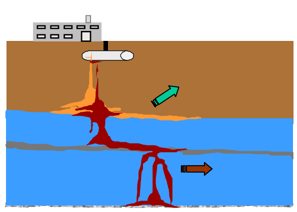
A Wireless Seismic Array

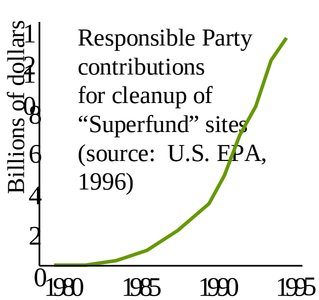
- Use motes for seismic data collection
  - Small scale (10 or so)
  - Opportunity: validate with existing wired infrastructure
- Two on-going experiments
  - Factor building
  - Four Seasons building

Condition Assessment

- Longer-term
- Challenges:
  - Detection of damage (cracks) in structures
  - Analysis of stress histories for damage prediction
- Applicable not just to buildings
  - Bridges, aircraft

Contaminant Transport



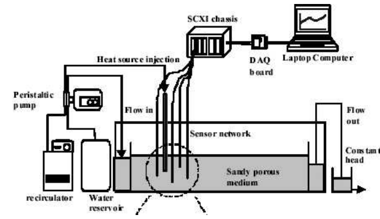


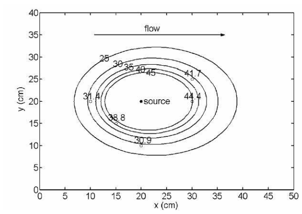
- Industrial effluent dispersal can be enormously damaging to the environment
  - marine contaminants
  - groundwater contaminants
- Study of contaminant transport involves
  - Understanding the physical (soil structure), chemical (interaction with and impact on nutrients), and biological (effect on plants and marine life) aspects of contaminants
  - Modeling their transports
- Mature field!
- Fine-grain sensing can help

Lab-Scale Experiments

[From CENS Annual Technical Report, 03]

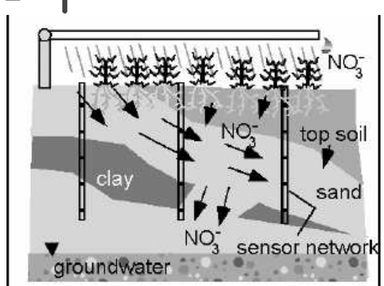
- Use surrogates (e.g. heat transfer) to study contaminant transport
- Testbed
  - Tank with heat source and embedded thermistors
  - Measure and model heat flow





Field-Level Experiments

- Nitrates in groundwater
- Application
  - Wastewater used for irrigating alfalfa
  - Wastewater has nitrates, nutrients for alfalfa
  - Over-irrigation can lead to nitrates in ground-water
  - Need monitoring system, wells can be expensive
- Pilot study of sensor network to monitoring nitrate levels

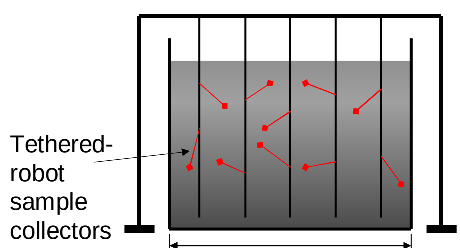


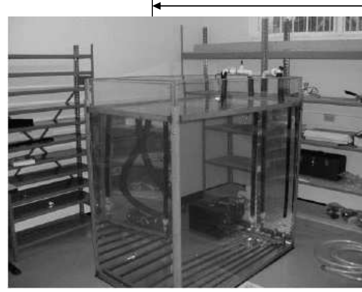
Marine Micro-organism Monitoring

- Algal Blooms (red, brown, green tides) impact
  - Human life
  - Industries (fisheries and tourism)
- Causes poorly understood, mostly because
  - Measurement of these phenomena can be complex and time consuming
- Sensor networks can help
  - Measure, predict, mitigate

Lab-Scale Experimentation

- Build a tank testbed in which to study the factors that affect micro-organism growth
- Actuation is a central part of this
  - Can't expect to deploy at density we need
  - Mobile sensors can help sample at high frequency
- Initial study:
  - thermocline detection

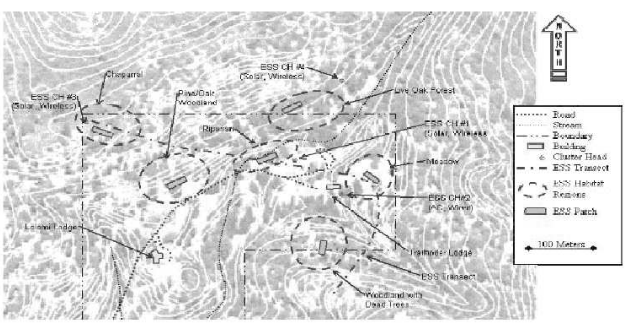




Ecosystem Monitoring

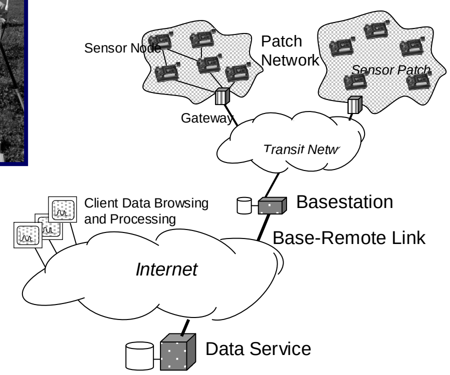
- Remote sensing can enable global assessment of ecosystem
- But, ecosystem evolution is often decided by local variations
  - Development of canopy, nesting patterns often decided by small local variations in temperature
- In-situ networked sensing can help us understand some of these processes

James Reserve



- Clustered architecture
- Weather-resistant housing design
- Sensors: Light, temperature, pressure, humidity

Great Duck Island



- Study nesting behavior of Leach's storm petrels
- Clustered architecture:
  - 802.11 backbone
  - multihop sensor cluster

Challenges

Energy

- Nodes are untethered, must rely on batteries
- Network lifetime now becomes a performance metric

Communication is Expensive

- The Communication/Computation Tradeoff
  - Received power drops off as the fourth power of distance
  - 10 m: 5000 ops/transmitted bit
  - 100 m: 50,000,000 ops/transmitted bit
- Implications
  - Avoid communication over long distances
  - Cannot assume global knowledge, or centralized solutions
  - Can leverage data processing/aggregation inside the network

Can't Ignore Physical World

- Can't hide in the machine room!
- Conditions variable and sometimes challenging

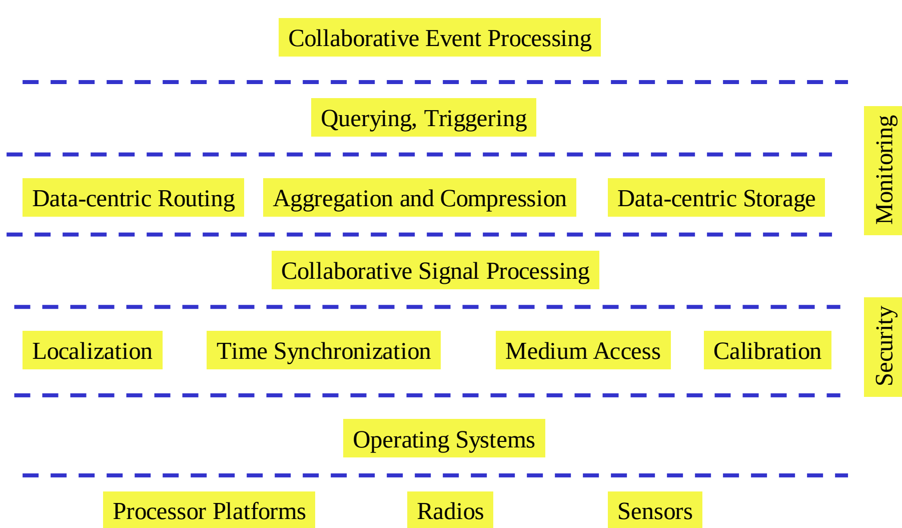
No Configuration

- System must be self-organizing

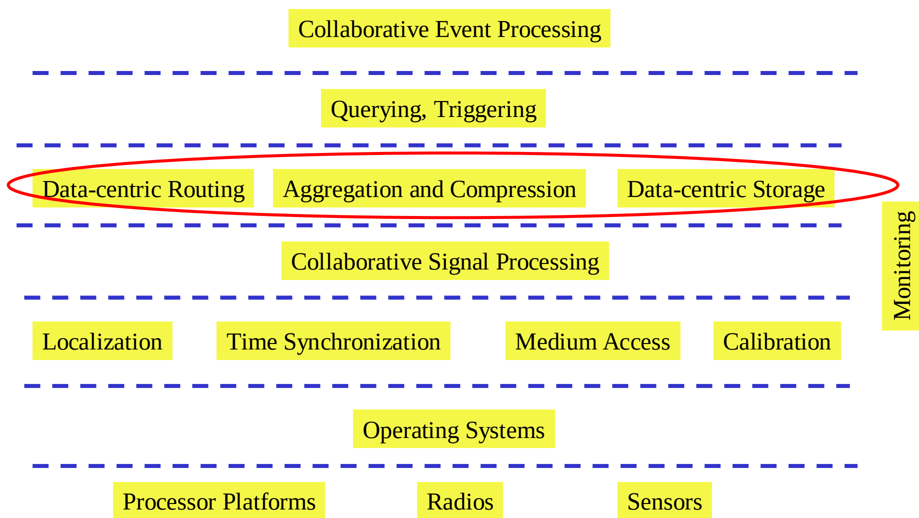
Generality vs Specificity

- Internet: single infrastructure capable of supporting many apps
- Sensornets: each deployment will have limited number of users and limited number of apps
- But basic technology should be general

Components of Infrastructure



Components of Infrastructure



How to Access Data

- Sensornet is useless if one can't access the required data
- Can't send it all to external storage:
  - limited bandwidth
  - limited energy
- How can you get only the data you need?

Name the Data!

- Don’t know which nodes have data
- Don’t think in terms of point-to-point protocols (as in Internet)
- Think in terms of data

Ask for Data!

- Send out requests for data by name
- If nodes have the relevant data, they respond

Three Communication Patterns

- Data-centric routing
- Tree-based aggregation/collection
- Data-centric storage

Components of Infrastructure

Collaborative Event Processing

Querying, Triggering

Data-centric Routing | Aggregation and Compression | Data-centric Storage

Collaborative Signal Processing

Localization | Time Synchronization | Medium Access | Calibration

Operating Systems

Processor Platforms | Radios | Sensors

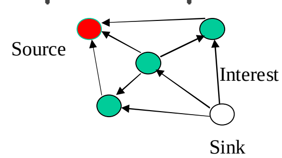
Monitoring

Diffusion messages

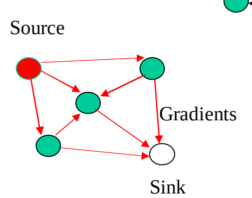
- Messages are sets of attribute-value pairs
- Message types
  - Interest (from sinks)
  - Data (from sources)
  - Control (reinforcement)

Diffusion Routing: Two phase pull

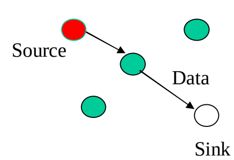
- Flood interest



- Flood data in response

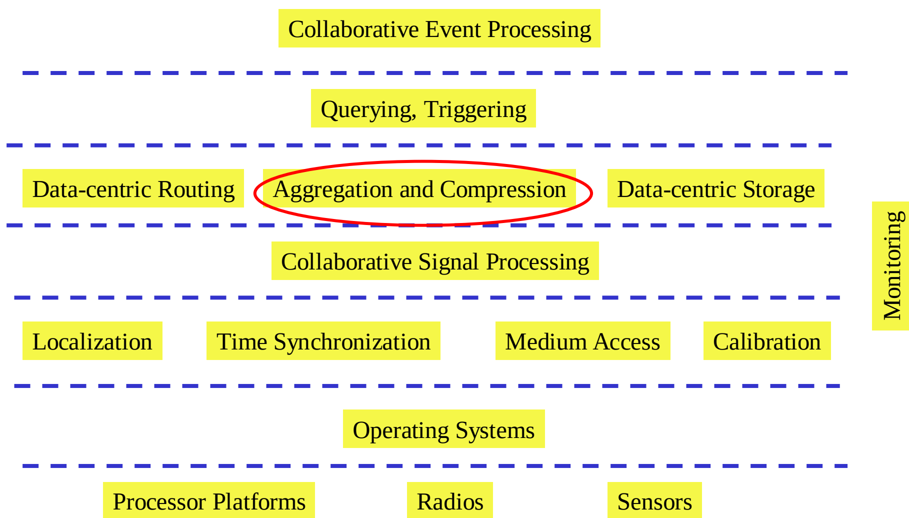


- Sink reinforces



- Forward data along the reinforced paths

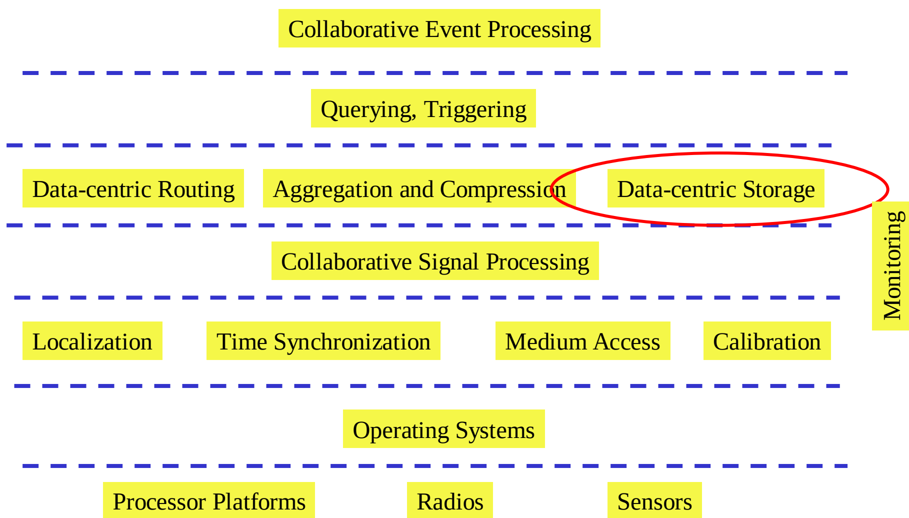
Components of Infrastructure



TinyDB/TAG

- Set up spanning tree from source
  - not as easy as it sounds!
- Flood query down tree
- Data sent back along reverse path
- Apply various aggregation operators

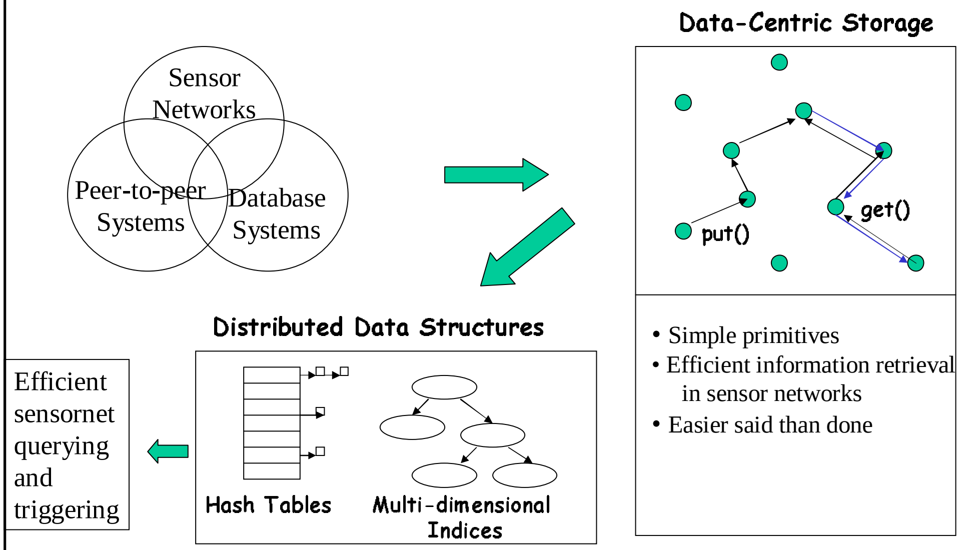
Components of Infrastructure



So Far....

- Data access methods are flood-response
- Good for long-lived queries
- What about one-shot queries?

Data-Centric Storage

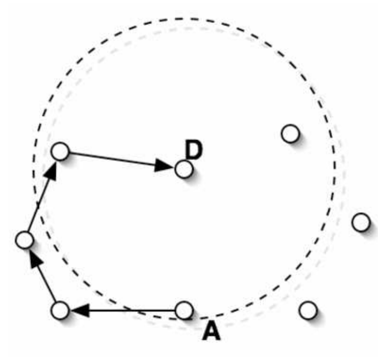


An Instance of Data-Centric Storage

- Geographic Hash Tables (GHTs)
- *Hash* the name of the data to a geographic location
- Store data at the node closest to that locations
  - Use a geographic routing protocol (e.g., GPSR)
- Can retrieve data the same way

GPSR Internals

- Nodes are named by their geographic locations
- Greedy routing as far as possible
- Perimeter routing when greedy fails
  - Fundamentals: Right-hand rule
  - Planarization removes crossing links
- Recover to greedy whenever possible
- Drop a packet when it is going to enter a perimeter along the same route again!



GHT = GPSR + DHT

- Answer queries for exact matched data, just like any other hash tables.

More Sophisticated Queries

- Spatio-temporal aggregates
- Multi-dimensional range queries
- Approach
  - Use hashing and spatial decomposition

- Data-centric storage not yet deployed