

Embedded Networked Sensing: Overview of Activities at CENS

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Deborah Estrin, Ph.D.

Richard Guy, Ph.D.

rguy@cs.ucla.edu

Work summarized here is that of students, staff, and faculty at CENS

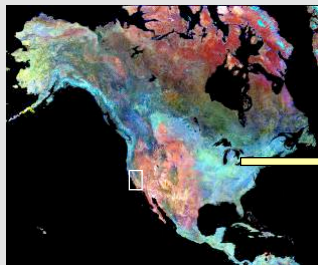
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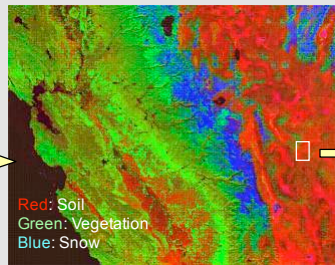


Embedded networked sensing will reveal previously unobservable phenomena

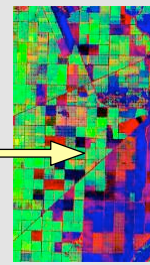
- **Remote sensing** transformed observations of large scale phenomena
- **In situ sensing** transforms observations of spatially variable processes in heterogeneous and obstructed environments



SPOT Vegetation
Daily Global Coverage
SWIR 3 Day Composite



Predicting Soil Erosion Potential:
Weekly MODIS Data



Sheely Farm 2002
Crop map

San Joaquin River Basin
Courtesy of Susan Ustin-Center for Spatial Technologies and Remote Sensing

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Environmental monitoring applications exhibit high spatial variations and heterogeneity



Overflow of embankment



Precision Agriculture, Water quality management



Algal growth as a result of eutrophication



Severe seismic activity & structural response

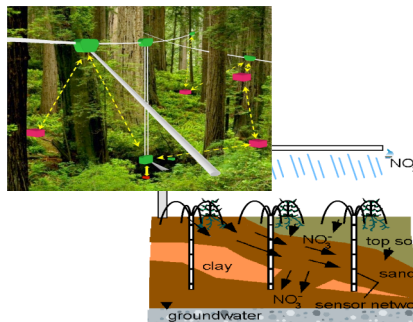
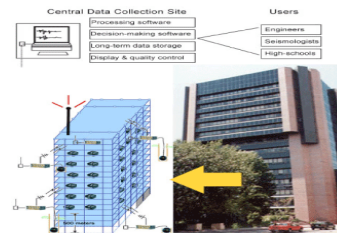
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Approach

- **Embed** numerous, low-cost, distributed devices to monitor and interact with physical world
- Deploy **spatially and temporally dense, in situ** sensing and actuation
- **Network** these devices so that they can coordinate to perform higher-level identification and tasks
- Requires **robust distributed systems** of thousands of devices.



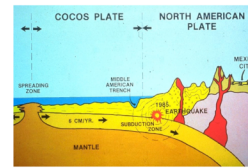
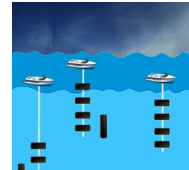
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Environmental Application Drivers at CENS

- Contaminant Transport, Soils
- Marine microorganisms
- Biology/Ecosystem Processes
- Seismic behavior



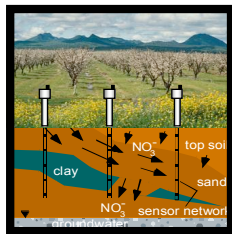
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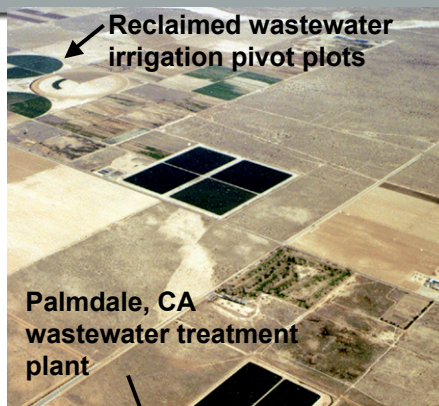
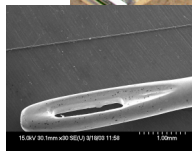


Wastewater reuse in the Mojave Desert

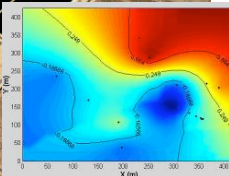
- Where does the County Sanitation District (CSD) of Los Angeles put 4 million gallons per day of treated wastewater in a landlocked region?



Nitrate sensor mimicking plant root fibers



Palmdale, CA wastewater treatment plant

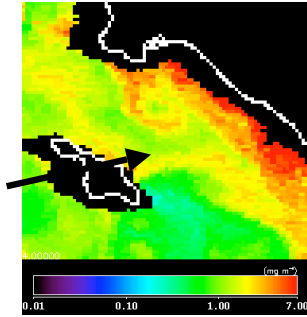


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Plankton dynamics in marine environments



Spatial and temporal distributions of harmful alga blooms (red, green, brown tides) in marine coastal ecosystems



Experimental and observational studies of chemical, physical and biological features promoting bloom events

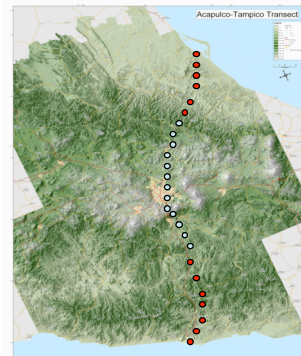
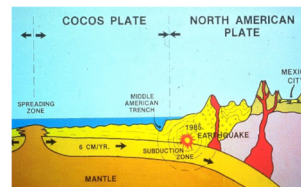


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Seismic behavior across southern Mexico

- Subduction zone structure poorly understood, yet responsible for severe seismic activity in densely populated Mexico City region
- Dense array of seismic sensors across 500km line needed to collect high-fidelity data to infer fine-grained plate structure
- Variety of inhospitable terrain; urban/rural hurdles



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Technical challenges

- Physical environment is dynamic and unpredictable
- Small wireless nodes have stringent energy, storage, communication constraints



WINS node
UCLA (1996)



Smart Dust
UCB (2000)

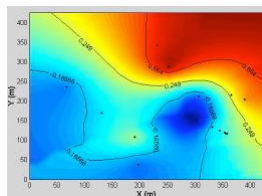
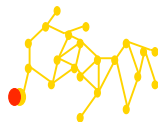
- Large scale deployments call for **in-network processing** and filtering of data close to sensor source
- Embedded nodes collaborate to report interesting spatio-temporal events

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The network is the sensor!

- Requires large distributed systems with adaptive internal behavior that can report spatio-temporal events, and characterize phenomena, not just return individual temporal and spatial data points.
- Model based anomaly detection drives additional data/sample collection, field observation



Model based
anomaly
detection

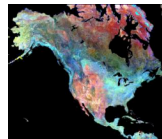
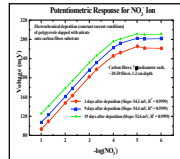
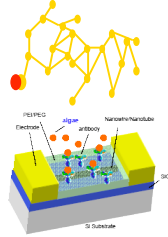
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Current technology research focus

Objectives

- Embeddable, low-cost sensor devices
- Robust, portable, self configuring systems
- Data integrity, system dependability
- Programmable, adaptive systems
- Multiscale data fusion, interactive access



Constraints

- Energy
- Scale, dynamics
- Autonomous disconnected operation
- Sensing channel uncertainty
- Complexity of distributed systems

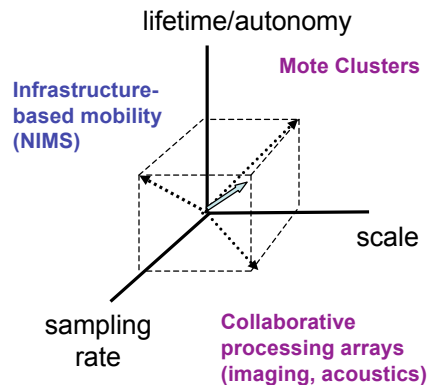
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Heterogeneity is key to deployed systems... and the field as a whole

- Several classes of systems:
 - Mote herds: Scale
 - Collaborative processing arrays: Sampling rate
 - Networked Info-Mechanical Systems: Autonomy
- Achieve longevity/autonomy, scalability, functionality with:
 - heterogeneous systems
 - in-network processing, triggering, actuation

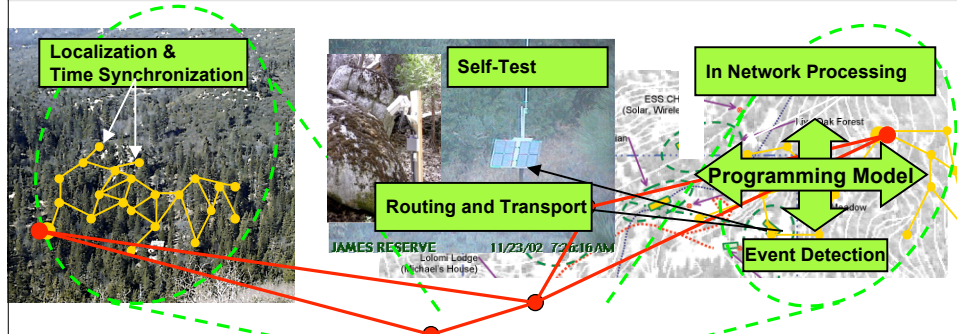


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Application-Driven (not Application-Specific) Common System Software



Reusable, Modular, Flexible, Well-characterized Services/Tools :

- Routing and Reliable transport
- Time synchronization, **Localization**, **Self-Test**, Energy Harvesting
- In Network Processing: **Triggering**, Tasking, **Fault detection**, **Sample Collection**
- Programming abstractions, tools
- Development, simulation, testing, **debugging**

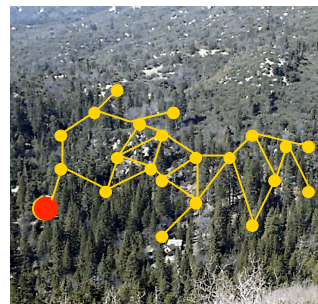
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Status: what's in use

- Platforms:
 - First generation embedded platforms
 - Mica motes (8 bit, chipcon radio or zigbee/18.15.4)
 - Microservers/Masters (32 bit, wifi/802.11, e.g. Intel Stargate)
- Networking:
 - Self-organized tree routing
 - Low power mac
 - Timesync
 - Reliability
- Tasking
 - DB style queries
 - Limited triggering, collaborative processing
- Energy:
 - Energy aware operations
 - App-specific energy harvesting
 - Tiered systems



Microclimate Mapping



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A new S/W environment for 32-bit nodes

- Logistical and environmental issues in deployment
 - Fielded systems tend to degrade more quickly than in the lab
 - Environmental conditions: weather, animals, RF and sensor channel
 - Uniform deployments are difficult to achieve: node replacement
- **Observed Data** can cause unexpected failures, new bugs in the field
 - e.g. Acoustic ranging system encountered new kinds of noise, leading to new kinds of inconsistencies in geometry, crashing Non-Linear Least-Squares (NLLS) algorithm – but not reproducible in the lab



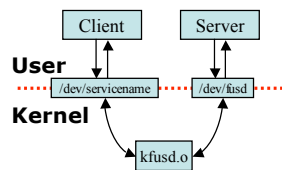
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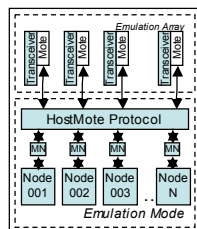


EmStar development environment

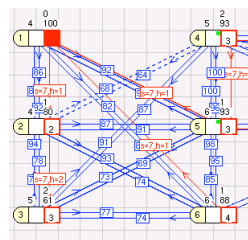
- EmStar is a layer above Linux designed to enable:
 - **Robustness**: Keep system running despite unexpected failures and bugs
 - **Visibility**: Easily debug/diagnose running systems
 - **Simulation, Emulation**: Rapid iteration via real-code simulation tools
 - **Module Reuse**: Leverage existing **libraries, tools, and services**
 - **EmTos**: Wrapper library provides TinyOS API and Services



Robust multi-process,
microkernel architecture



Simulation Framework
with real RF channels



Visualization Tools

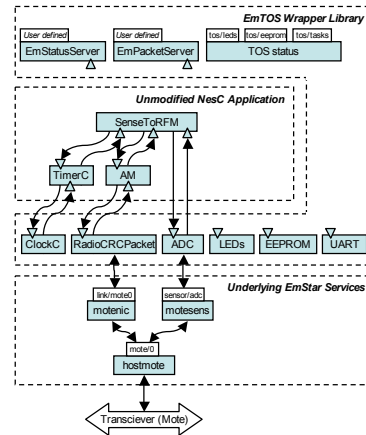
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EmTOS: Support for Heterogeneous Systems

- Wrapper Library
 - Provides TinyOS API and Services
 - Enables NesC to provide new EmStar services
- Compiles NesC Application + EmTOS library into a single EmStar module
- Benefits:
 - Simulate systems of motes and microservers in same “world”
 - Easy “porting” of TinyOS/NesC services to microservers
 - ESS2
 - TinyDB



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Important developments using Emstar and TOS: heterogeneous systems, mobility, sensor diversity, fusion

- Widely-distributed static nodes (smart dust)
 - Limited energy and sampling rate
 - Simultaneous, continuous in time, but costs limit spatial density
- Microservers
 - Provide computational, storage, and communication resources
 - Execute in-network processing, event detection, system monitoring, tasking and gathering
- Mobile and actuated nodes
 - Articulation magnifies effective sensor range
 - Infrastructure-supported mobility enables sensor diversity: location, type, duration
 - Enable adaptive, fidelity-driven, 3-D sampling and sample collection



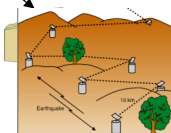
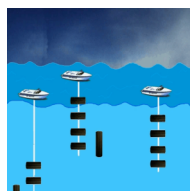
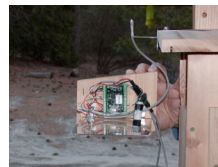
Figure courtesy of Bill Kaiser

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ENS in a box: focus on usability, tools



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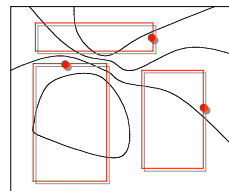
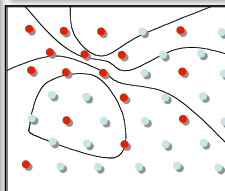
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For further investigation

- Center for Embedded Networked Sensing, <http://cens.ucla.edu>
- TinyOS and Mote platforms: UC Berkeley, Intel, Crossbow, Sensicast, Dust Networks, Ember <http://www.tinyos.net>
- NSF Workshops including Sensors for Environmental Observatories, <http://www.wtec.org/se0/se06.htm>
- National Ecological Observatory Network, <http://www.neoninc.org>
- Principles of Embedded Networked Systems Design, Gregory J. Pottie and William J. Kaiser, Cambridge University Press, Spring 2005

Contact:
Deborah Estrin destrin@cs.ucla.edu
Richard Guy rguy@cs.ucla.edu



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