Proactive Computing

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Focus:
• Ad-hoc networks
• Planetary scale services

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Focus:
• Networks and distributed systems

Derek McAuley
Director

Focus:
• Software for widely distributed storage systems

Mahadev Satyanarayanan
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Focus:
• New usage models for ubiquitous computing environments

James Landay
Director
Where Does New Technology Come From?

Universities are the “packet switches” of new ideas

Is the U.S. investing enough in University Research to take advantage of nanotech?
The Research Gap

• Basic Research on Nanotech (NNI) is creating dramatic opportunities to improve productivity & quality of life.

• However … University Applied Research is under-funded
  • Key Example: Computer systems & network research
  • Historic source of today’s productivity gains
  • In general, U.S. government spending on university engineering research has not kept up with its importance to the economy / share of GDP!

→ Time for a thoughtful review of EE/CS funding
Proactive Computing
Proactive Computing

Today: Computers are interactive
• We are always waiting for them or vice-versa

Tomorrow: Computers will be Proactive
• They will anticipate our needs and act on our behalf
Making Proactive Happen

Making It Personal

Machine Learning

Distributed Systems

Ubiquitous Computing

Stats / Cognition
Real-Time Enterprise

Planetary Scale

Get Physical

Intel Research

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Get Physical
CS Research & the DoD

• CS Research was:
  • Stuck working on an old paradigm
  •Disconnected from the physical world (too virtual)
  • Not capturing the hearts of its students
  • Working on an antique model of DoD relevance

• Proactive Computing
  • “Get Physical” with network effects
  • Takes CS to application domains students care about
  • Can amplify inherent strengths of U.S. forces
Making Proactive Happen

- Making It Personal
- Machine Learning
- Distributed Systems
- Ubiquitous Computing
The road to smart dust....

Configurable Silicon Radio

Intel Research

Sensing +
Computing +
Storage +
Communicating

MOTE
(a small piece of silicon)
We are on the verge of:

- a vast increase
- in the spatial & temporal fidelity at which
- we instrument & analyze the physical world.

This will enable real-time proactive computing

- It is starting to happen now
- Nanotech, RFID, etc. will accelerate the process
**Ubiquitous RF: Radio Free Intel**

- Shift the analog / digital balance
- Standard CMOS processes shown to exceed WLAN requirements
- Use reconfigurable digital logic & software defined radio to enhance performance with Moore’s Law

**Ultra Wide Band**
- Moore’s Law Radio: Capacity scales with circuit speeds
- Goal: 500MBPS

**Berkeley Wireless Research Center**
- Low power semiconductor techniques (i.e. multi-threshold VT devices)
- Performance analysis & measurement of reconfigurable architectures
- Modeling techniques for MIMO antenna capacities

Next: Fluidics, Displays, Optics etc.
Networking 8.5B Computers / Year
Building Block: Intel® Mote

- **Arm Core**
  - 12 MHz
  - 64KB RAM
  - 512KB Flash

- **Blue Tooth Radio**
  - Integrated with CPU
  - Up to +4 dBm transmit
  - -80 dBm receive
  - >30m range

- **Antenna**

- **Battery life @ 1% DC**
  - >1 month with coin cell
  - >6 months with single AA
  - Regulator on main board
  - Or on battery board

- **Debug Connector**
  - UART, USB slave, JTAG

- **Sensors/actuator interface**
  - I2C backbone
  - 100kbit/sec

- **Regulator**
  - On main board
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Networking 8.5B Computers / Year

Flat Multi-hop Sensor Network + High-Bandwidth Overlay = Heterogeneous Network

http://www.intel.com/research/exploratory/heterogeneous.htm
Building Block: Stargate

- Intel XScale® based gateway
  - Universal I/O: USB, Ethernet, 802.11, Bluetooth, Serial
  - Connector for motes
  - Battery or line powered
  - Local compute server

- Can control clusters of motes
  - Heterogeneous networking
  - High bandwidth overlay network (e.g., 802.11)
  - Extend Mote battery life
Component Based Programming Model

- Suite of software components
  - Timers, clocks, clock synchronization
  - Single and multi-hop networking
  - Power management
  - Non-volatile storage management

Highly Concurrent

- Single thread of “tasks”, posted and scheduled FIFO
- Events “fired” asynchronously in response to interrupts
“Sensor Net in a Box: Tiny Application Sensor Kit

Motes:
- TinyOS – Network Stack/OS
- TinyDB – Query Processing

Gateway:
- Embedded Linux
- 802.11 Mesh
- TASK Server
- Web Server
- DBMS

External Tools
- Excel
- Matlab
- Enshare
- Etc.

TASK Field Tools
- Deploy
- Query
- Command
- Visualize

Internet

TASK Client Tools
- Deploy
- Query
- Command
- Visualize

External Tools
- Excel
- Matlab
- Enshare
- Etc.

Intel Research
Mote Applications in Progress

In-Situ Habitat Monitoring

- Temperature
- Humidity
- Pressure
- Infrared

Deployed in habitat
- Great Duck Island, ME
- James Reserve, CA
- UC Botanical Gardens

Workplace / Industrial
- Industrial Automation / Control
- Biology Lab
- HVAC
- Conference rooms
- Parking lots

Environment / Safety / Health
- Micro-climates
- Seismic propagation
- Earthquake damage analysis
- Fire / smoke detectors
- Proactive Health
Sensor Network Application: Habitat Monitoring

From Macro-to-Micro: Surface and Burrow Microclimates

Great Duck Island (GDI) Project Team

Noontime Burrow Temps (cool and uniform)
Noontime Surface Temps (warmer and variable)

GIS data visualizations courtesy of J. Anderson / COA

*Other names and brands may be claimed as the property of others.*
Embedded Networked Sensing

- Micro-sensors, on-board processing, wireless interfaces feasible at very small scale—can monitor phenomena “up close”
- Enables spatially and temporally dense environmental monitoring

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Condition Based Maintenance
Vast Increase in Spatial & Temporal Fidelity

* Ganesan et al.

Increasing spatial resolution

Increasing temporal resolution

Source: Deborah Estrin: UCLA
Common Services/Tools for Robust, Scalable, Flexible, Deployable Systems

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

- Time synchronization, Localization, Calibration, Energy Harvesting
- Routing and transport
- In Network Storage, Querying, Processing, Tasking
- Macro-Programming

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Dimensions: Lossy Multi-Resolution Data Aging in Storage-Constrained Networks

Goal

- Building a long-term in-network storage infrastructure for storage-constrained networks. Exploit spatio-temporal correlation in sensor data, distributed storage capacity and training datasets to achieve goal.

Example Query:

Find nodes along a boundary between high and low precipitation areas.

Only coarsest summary is queried.

Error

30%

5%

All resolutions (coarsest to finest) are queried

Key Ideas

- Construct *lossy wavelet-compressed summaries* corresponding to different resolutions and spatio-temporal scales.

- Queries *drill-down* from root of hierarchy to focus search on small portions of the network.

- *Progressively age* summaries for long-term storage and graceful degradation of query quality over time. Use *training data* to determine aging periods.

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Optimum Sensor Placement

Cramer-Rao Bounding Approach
- CRB of source location error variance
- For 8 fixed sensors, error variance is low when source is inside convex hull of the sensors

Minimum Entropy Approach
- Given locations and sensing certainties, Bayesian method can compute target location distribution
- Bayesian bounds equal CRBs when sensing uncertainties are Gaussian

Smaller error variance inside convex hull of 4 sensors

Larger error variance outside convex hull of 4 sensors

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Network Deployment and Repair from the Air

- Mica2 mote-based sensor network, Mobile robot is an autonomous helicopter
- Results include network deployment and repair
- Significant external collaboration (D. Rus, MIT, P. Corke, CSIRO, Australia)

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Energy Harvesting

• Need distributed methods to learn the environmental energy opportunity at all nodes
• Global task sharing among nodes to optimize performance

HelioMote test-bed
• Recharge batteries from solar
• Track energy received
• Monitor residual battery status
• Provide constant voltage to load as battery voltage degrades

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Vast Increase in Spatial & Temporal Fidelity

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Source: Deborah Estrin: UCLA
Location, Location, Location...

- RFID may be the “killer app” for sensor networks. Think of a location “food chain” ranging from tags to motes to servers.
- However, there are many technologies for determining the location of objects – with varying degrees of certainty.
- Intel Research Seattle has developed a technology neutral approach to location.
  - Common API based on probabilistic model.
  - Information from multiple sources can be “fused”.

Intel Research
Robot Navigation Using a Sensor Network

- Done at Intel in late summer 2003
- Mica2 mote-based sensor network
- Mobile robot navigates based solely on network directives
- Over one km of robot traverses in experiments

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Wireless Sensor Networks: Key Takeaways

- **Vast increase in information concerning physical artifacts / phenomena, including their locations**
- **Wide range of applications**
  - Scientific
  - Commercial / productivity gains
  - National & Homeland Security / Emergency services
- **Rapid improvement**
  - Emerging as a disciplined field of study with large numbers of researchers generating new insights
- **Reduced barriers to adoption**
  - Wireless, ultra low power (software & hardware)
  - ROI driven (vs. mission critical)
  - “Sensor Net in a box” (vs. customized / gold plated)
Making Proactive Happen

- Making It Personal
- Machine Learning
- Distributed Systems
- Ubiquitous Computing
Live Databases

http://berkeley.intel-research.net/tinydb/

- DB-style queries over “live” sources
- App simply issues queries and triggers to the network
- In-network query processing saves power and bandwidth

Intel: D. Gay, J. Hellerstein, W. Hong
Berkeley: D. Culler, M. Franklin, K. Stanek, E. Shvets
MIT: S. Madden

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IrisNet: Architecture for a Worldwide Sensor Web

- The “Seeing” Internet: Internet-connected PCs / PDAs with multimedia sensors
- Exploit processing power near the sensors

Deployments
Coastal monitoring in Oregon

Goals
- Real-time adaptation of collection & processing
- Robustness, data integrity & privacy
- Planet-wide local data collection & storage
- Wide range of sensing services, both physical & virtual

Approach
- Application-specific sensor feed filtering
- Push queries to the sensors and compute answers in-network
- Hide complexities of distributed data collection & query processing
PlanetLab

An open testbed for developing, deploying, and accessing planetary-scale services

- Catalyze planetary scale apps
- >360 instrumented nodes

Key Technologies

- Overlay Nets
- Server Virtualization
- Global Distributed Hash Tables
- More info: www.planet-lab.org/

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- Distributed Systems
- Ubiquitous Computing
- Closing the Loop
- Anticipation
- Dealing with Uncertainty
Probabilistic Methods

Dealing with Uncertainty

Using statistical modeling to deal with uncertainty inherent in the physical world

- Hypothesize cause and effect relationships from raw data

**Simple Bayesian Net Diagram**

```
  Travel     Smoking
   ↓        ↓
Tuberculosis Lung Cancer Bronchitis
   ↓       ↓
Tuberculosis or Cancer Dyspnea
   ↓
X-Ray Result
```

Deterministic → Stochastic

Using statistical modeling to deal with uncertainty inherent in the physical world.
Enabling the Real-Time Enterprise

Closing the Loop

Bridging the gap between anticipating and acting on needs – predictably, and under human supervision

How many agents could you have?

- What is the limiting resource?
- If they “close the loop” autonomously, then how do we engineer the control systems that dampen their behavior?

Straight through processing

- Desirable becoming Affordable
- Potential 10x on transaction volume!
Making Proactive Happen

Making It Personal

Machine Learning

Distributed Systems

Ubiquitous Computing

Get out of the office!
Bring Deep IT to New Sectors of the Economy

Financial

Retail

Health / Life Sciences / Agriculture

Distribution

Government

Environmental

Transportation

Manufacturing
Enabling Transition

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Policy Topics

- Radio Spectrum, Standards, etc.: Anything new?
- Environmental concerns: Consumable computing
- Security: including crypto issues
- Reliability, Authenticity, etc.: “standard of care?”
- Privacy:
  - People vs. physical artifacts
  - Unintended consequences of large-scale and long-baseline correlation
- Infrastructure: Public vs. Private
  - Natural Monopolies?
  - Transparency? Open Data?
  - Unanticipated usage models?
  - Government purchasing of privately collected data?
- Threats to National / Homeland Security …
Do reduced barriers to entry and better understanding of fundamentals create new asymmetric threats? ... Do they mitigate traditional advantages? ... Can they create new advantages?

- What if opponents are trans-national (vs. military)?
- Are counter-proliferation techniques feasible?
- Sources of advantage: Novel sensors, analysis / correlation, etc.

Does civilian adoption of this technology create new asymmetric threats?

- Disruption or tampering with civilian infrastructure
  - Denial of service, forged data, false alarms, etc.
- Targeting / Intelligence gathering / covert command channels?
- Can lightweight mitigation techniques be devised?
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To probe further

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