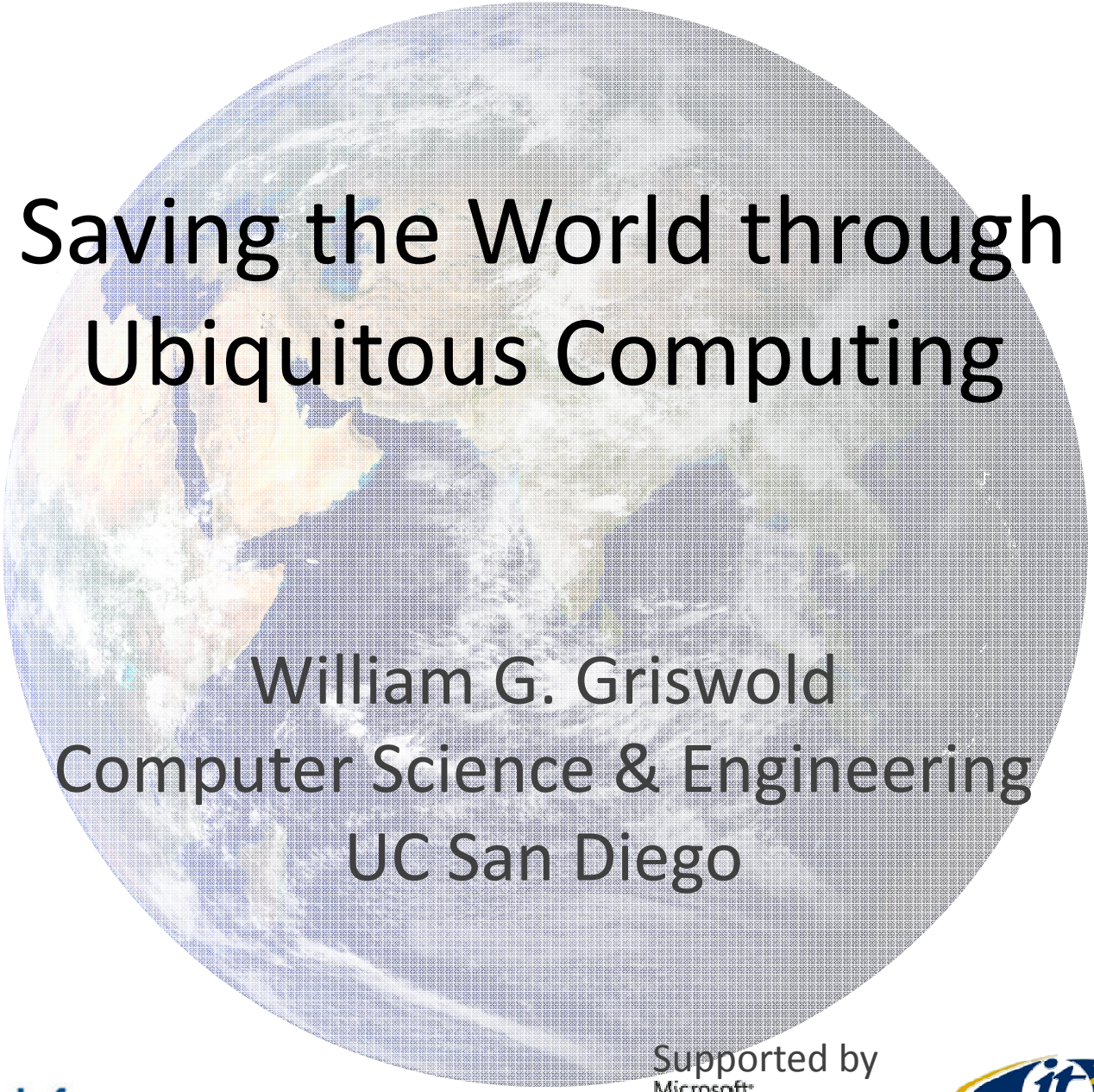


Saving the World through Ubiquitous Computing

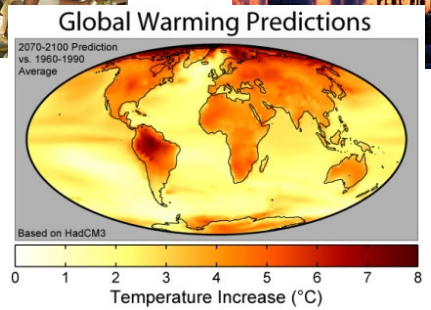
William G. Griswold
Computer Science & Engineering
UC San Diego

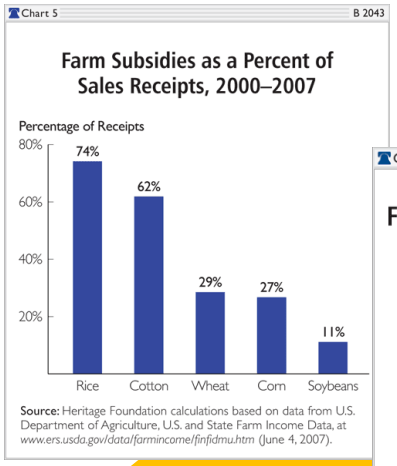
Supported by Microsoft Research

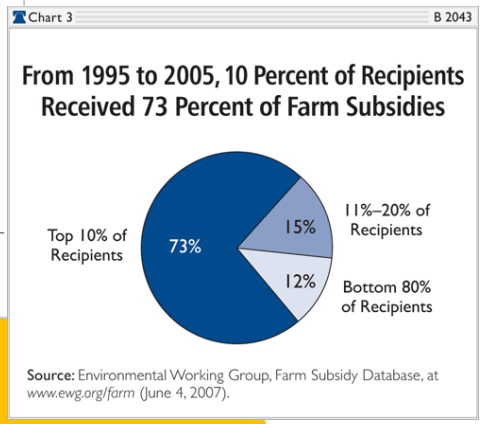
UCSD Jacobs School of Engineering

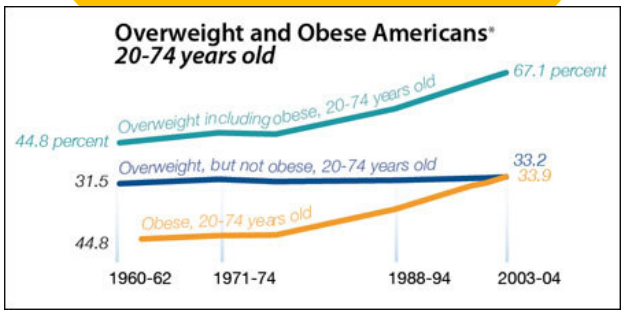
UCSDCSE Computer Science and Engineering

“The Future Doesn’t Need Us” – Bill Joy









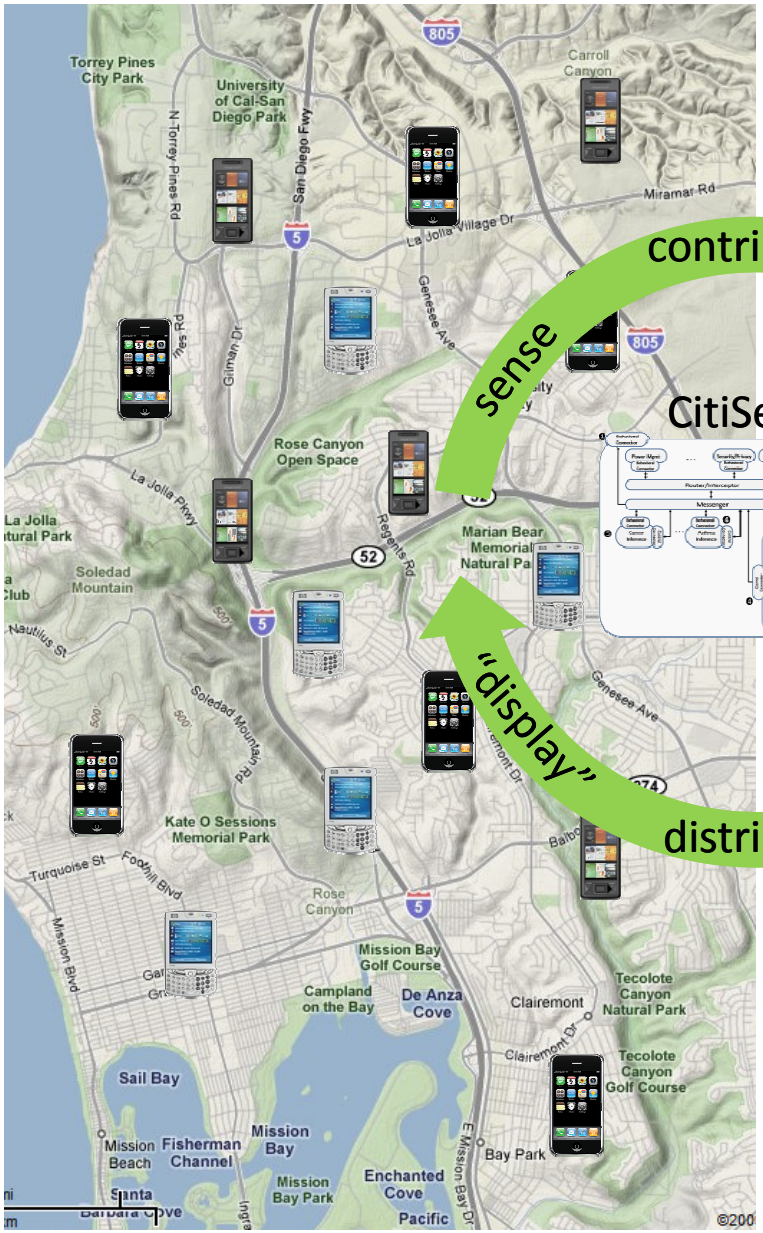
Invisible, Virtual, …Unnoticed

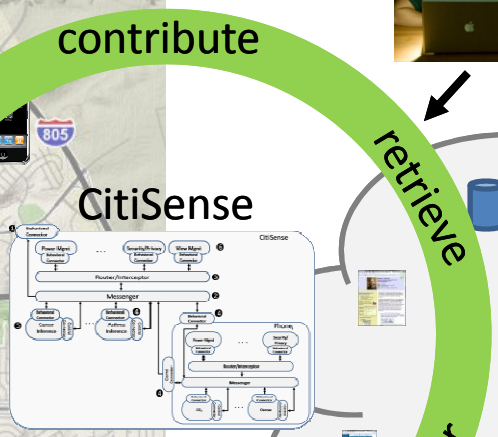
Air Pollution Case Study

- 158 million live in counties violating air standards
  - cancer in Chula Vista, CA increased 140/million residents
  - largely due to diesel trucks and automobiles
    - particulates, benzene, sulfur dioxide, formaldehyde, etc.

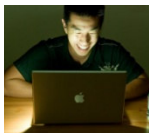
- 30% of public schools are near highways
  - asthma rates 50% higher there
  - 350,000 – 1,300,000 respiratory events in children annually
- 5 EPA monitors in SD Co., 4000 sq. mi., 3.1M residents
  - but air pollution not uniformly distributed in space or time
  - hourly updates to web page; annual reports in PDF form
- Indoor air pollution is uncharted territory
  - second-hand smoke is major concern; also mold, radon

CitiSense - Radical Transparency

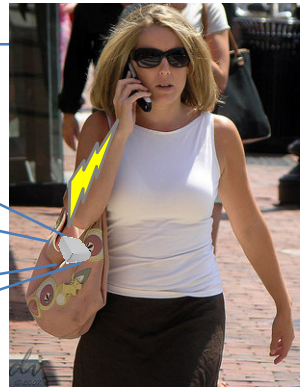


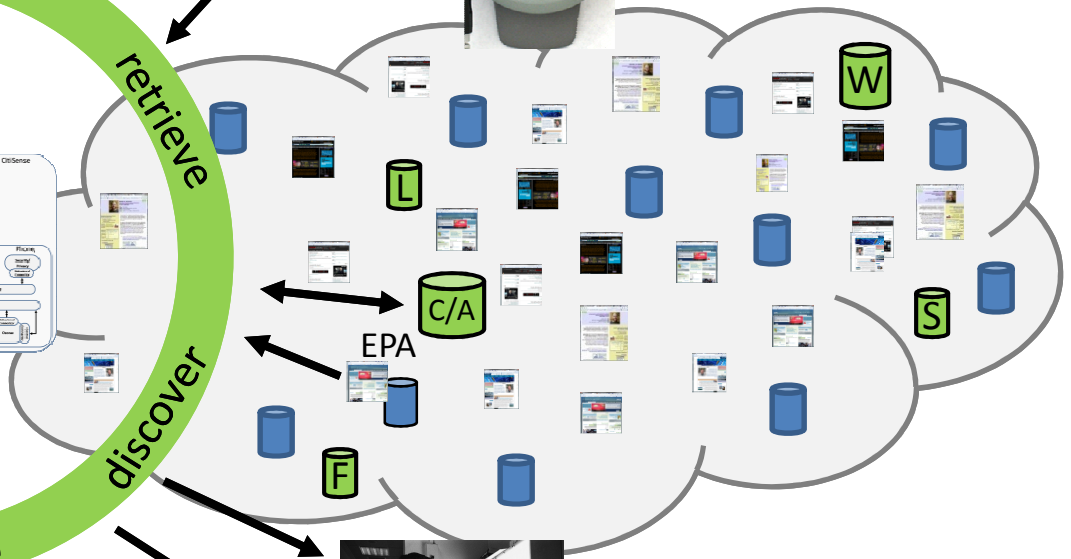


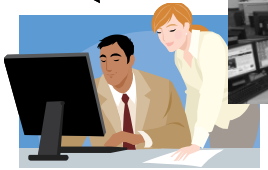
4oz
30 compounds



Seacoast Sci.





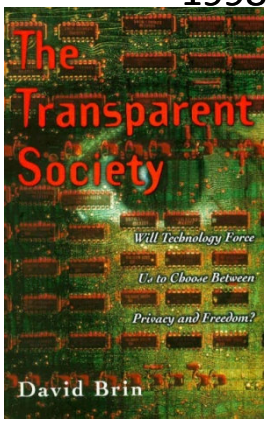


CitiSense Team

Ingolf Krueger
Tajana Simunic Rosing
Sanjoy Dasgupta
Hovav Shacham
Kevin Patrick (Prev. Medicine)

An idea long in coming…

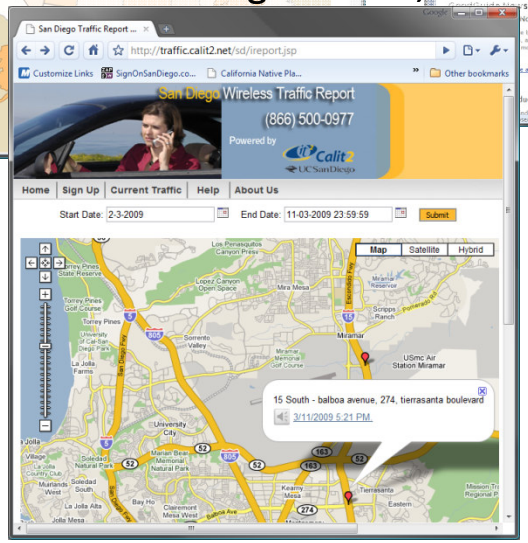
1998



2001

Wattenberg, *et al.* (IBM) 2007

Chockalingam *et al.*, 2007

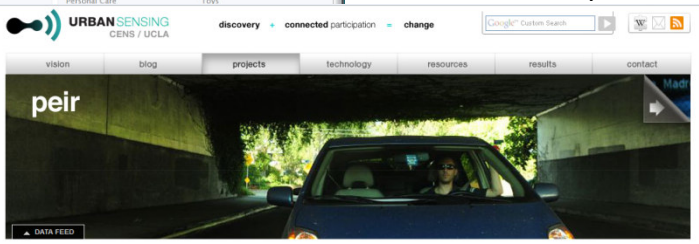


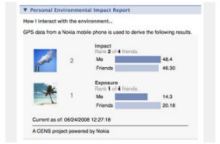
Spanhake *et al.*, 2007

squirrel
adaptable. intelligent. curious.

2008

Estrin *et al.*, 2009





personalized estimates of environmental exposure and impact

PEIR, the Personal Environmental Impact Report, is a new kind of online tool that allows you to use your mobile phone to explore and share how you impact the environment and how the environment impacts you.

What's unique about PEIR? Taking a step beyond a "footprint calculator" that relies only on your demographics, PEIR uses location data that is regularly and securely uploaded from your mobile phone to create a dynamic and personalized report about your environmental impact and exposure. PEIR gives you greater control over your environmental impact and exposure by allowing you to interactively explore how it creates its results from your activity patterns. PEIR analysis starts with your location "trace," a sequence of points collected by a GPS device you carry with you. For each trip you take, we link your location trace with data we collect about thousands of neighborhoods in California, data that include the current weather conditions and estimated traffic patterns on local roads and freeways. All of this information is then analyzed with published scientific models that produce estimates of your exposure and impact in four categories:

1. Smog Exposure (PM 2.5 particulate exposure).
2. Fast food exposure.
3. Carbon impact.

2009

UbiGreen: Investigating a Mobile Tool for Tracking and Supporting Green Transportation Habits

Jon Froehlich[1], Tawanna Dillahunt[2], Predrag Klasnja[3,4], Jennifer Mankoff[2], Sunny Consolvo[4], Beverly Harrison[4], James A. Landay[1,4]

[1]CSE; [3]The Information School
DUB Institute, U. of Washington
Seattle, WA 98195 USA
{jfroehli, landay}@cs.washington.edu; klasnja@u.washington.edu

[2]HCI Institute
Carnegie Mellon University
Pittsburgh, PA 15213 USA
{tdillahu, jmankoff}@cs.cmu.edu

[4]Intel Research Seattle
Seattle, WA 98105 USA
{sunny.consolvo, beverly.harrison}@intel.com

ABSTRACT

The greatest contributor of CO_2 emissions in the average American household is personal transportation. Because transportation is inherently a mobile activity, mobile devices are well suited to sense and provide feedback about these activities. In this paper, we explore the use of personal ambient displays on mobile phones to give users feedback about sensed and self-reported transportation behaviors. We first present results from a set of formative studies exploring our respondents' existing transportation routines, willingness to engage in and maintain green transportation behavior, and reactions to early mobile phone "green" application design concepts. We then describe the results of a 3-week field study (N=13) of the UbiGreen Transportation Display prototype, a mobile phone application that semi-automatically senses and reveals information about transportation behavior. Our contributions include a working system for semi-automatically tracking transit activity, a visual design capable of engaging users in the goal of increasing green transportation, and the results of our studies, which have implications for the design of future green applications.

Figure 1 (left) The UbiGreen Transportation Display shows transit behavior as "wallpaper" on a phone's screen. Here the tree is nearly full of leaves, indicating that the user has completed several green trips for the week. (top) The MSP sensor worn near the waist and the phone's GSM cell tower data are used to semi-automatically infer transportation mode.

and individual change. Given the growing prevalence of mobile phones with sensing capabilities, one compelling opportunity to potentially impact human behavior is to offer immediate feedback about how currently sensed behaviors affect the environment. In this paper, we explore the use of

…and a long way to go (a sampling)

Extensible Architecture

Citizens, policy makers, and researchers should be able to add sensors, displays, and applications easily

Inference with commo

Low cost for ubiquity, competition → noisy

Mobile power

Resources will be scar

Semantic Web

Today mostly untagged, "semi-structure

Security and Privacy

System under multiple authority domair

Attention without disruption

Neither interruption nor passive display

Failure will be the normal mode of operation

The following are examples of problems and current ideas that may contribute to realizing the vision.

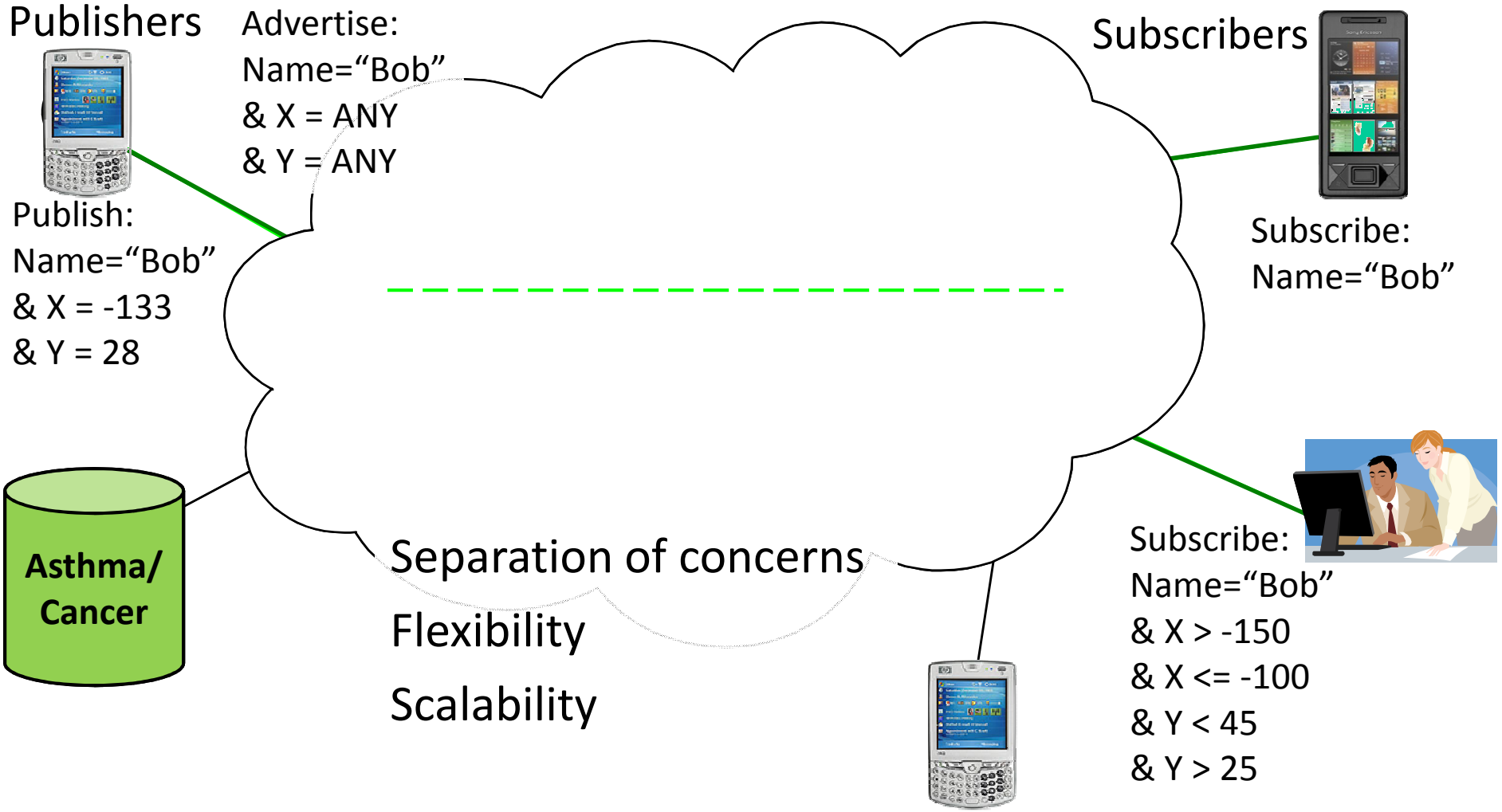
Extensible Architecture

Publish-Subscribe, with a Twist

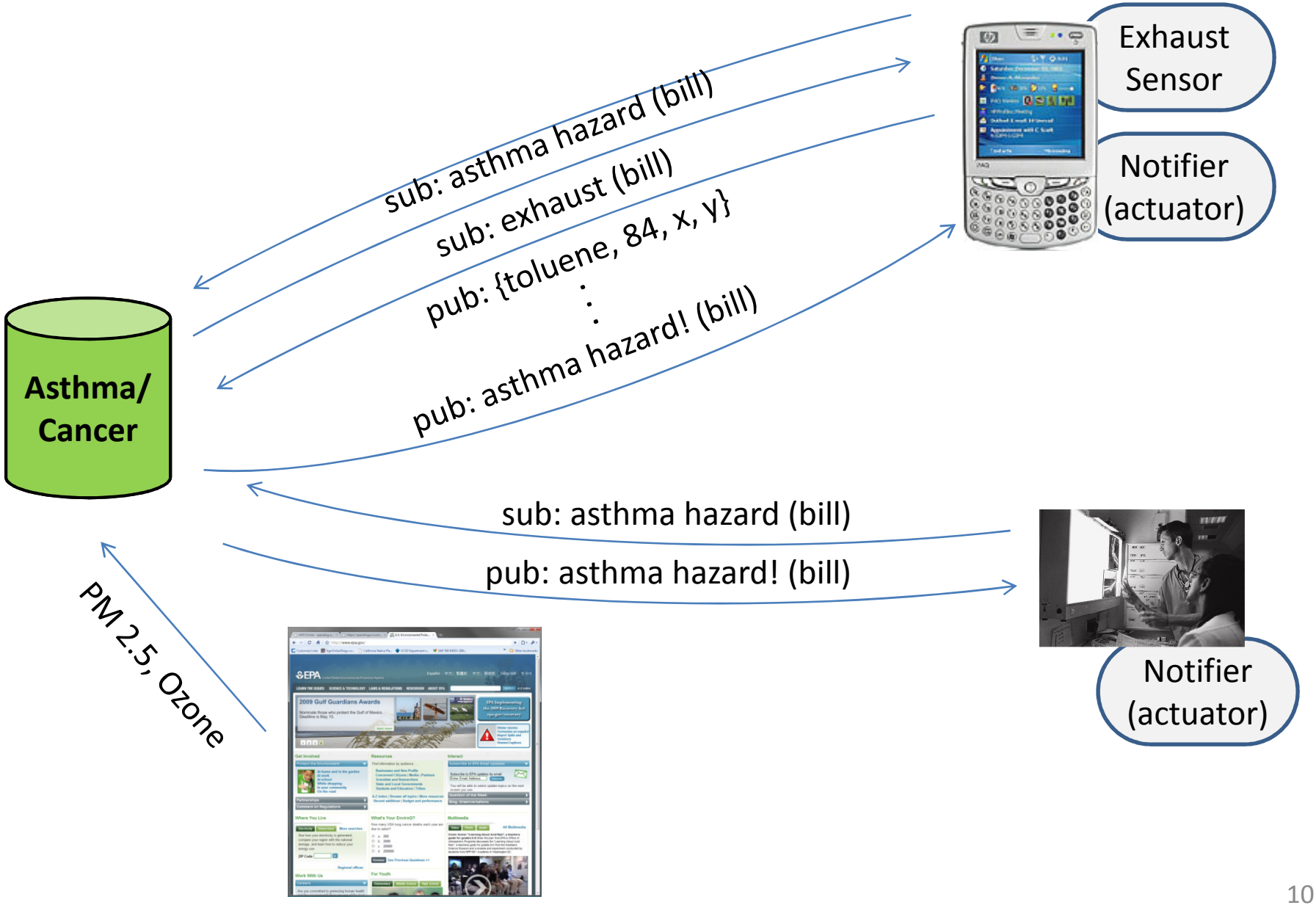
Content-Based Publish-Subscribe (CBPS)

Carzaniga, et al.

Advertisements about… Subscriptions for… Publications of… ***Events***

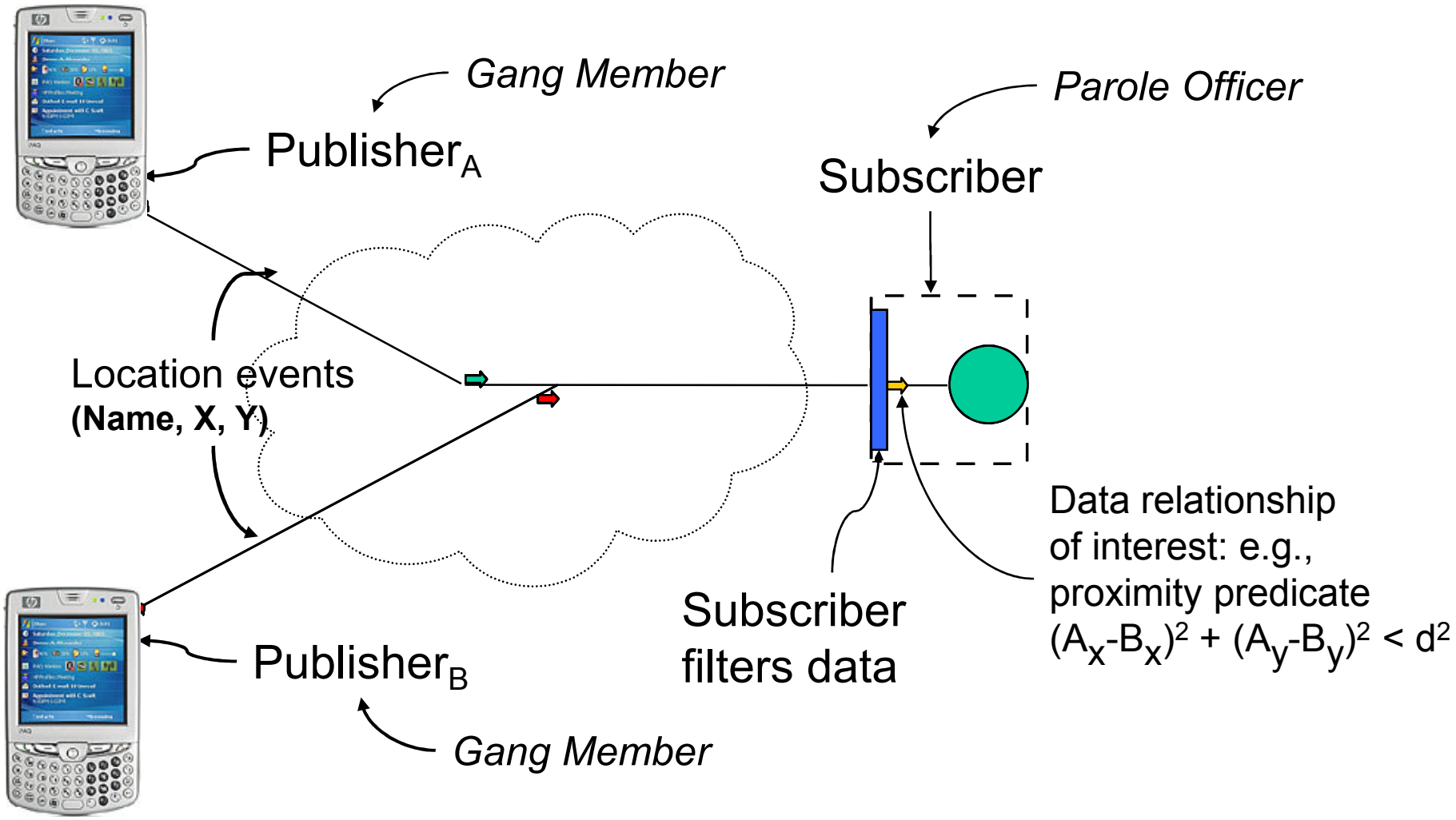


Publish/Subscribe in CitiSense



Context-Awareness is Expensive with CBPS

Example: *Proximity Calculation*



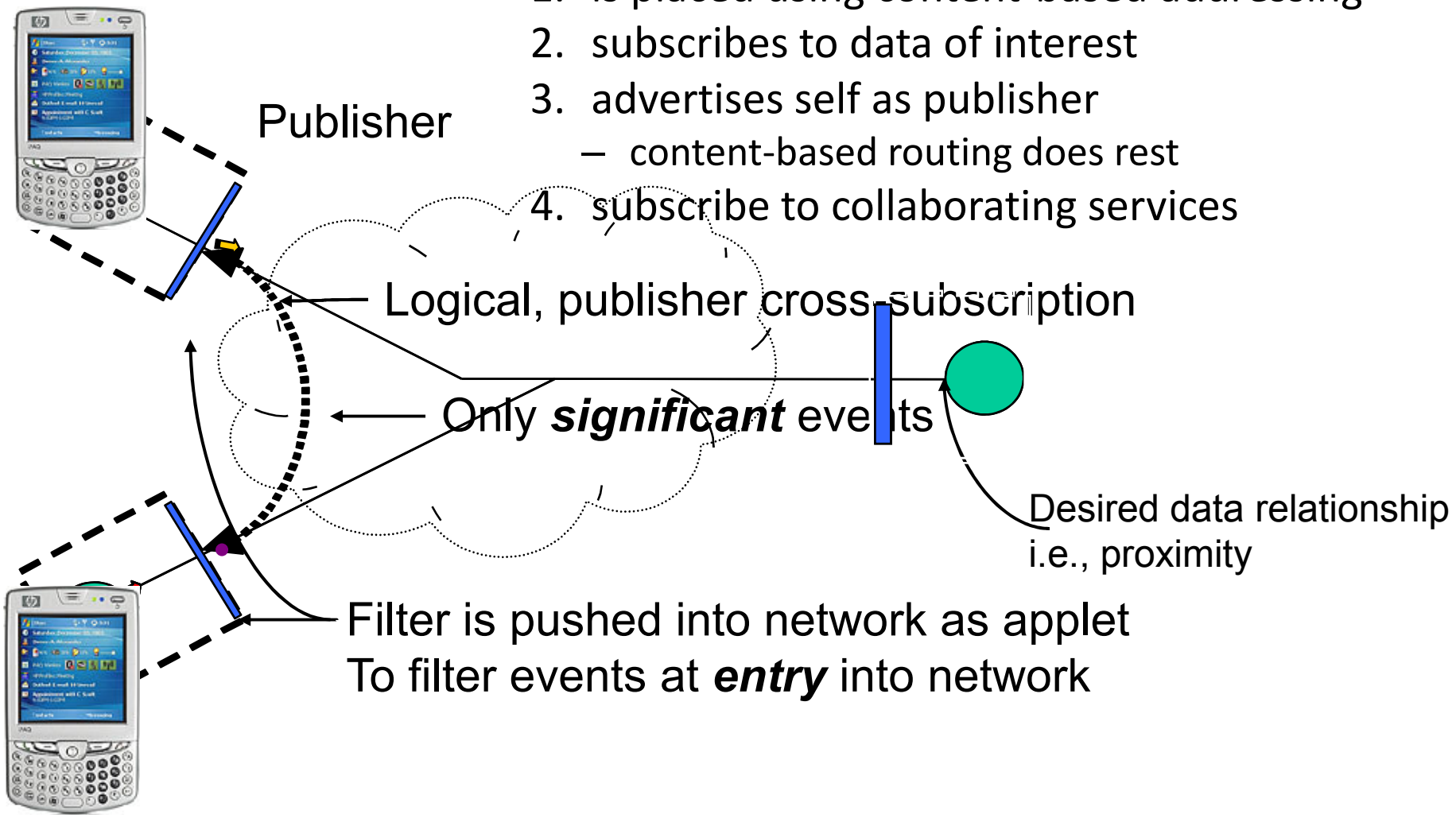
Fulcrum – Internet-Scale Context-Awareness

Boyer & Griswold

What happens here?

The mobile code…

1. is placed using content-based addressing
2. subscribes to data of interest
3. advertises self as publisher
   - content-based routing does rest
4. subscribe to collaborating services



Inference under Multiple Sources of Noise

Ideas contributed by
Sanjoy Dasgupta
CSE, UC San Diego

High-dimensional Machine Learning

- Sensors are noisy, heterogeneous
- Data collection will be sparse and irregular
- How can system determine pollutant level at a given location and time, Z(x, y, t, …)?
- *Gaussian Process Regression* is well-suited
  - treats Z as a random variable to model uncertainty
  - learn a multi-variate regression to capture Z
- High dimensionality makes prohibitively expensive
  - using *random projection trees* to segment problem into smaller lower-dimensional regions

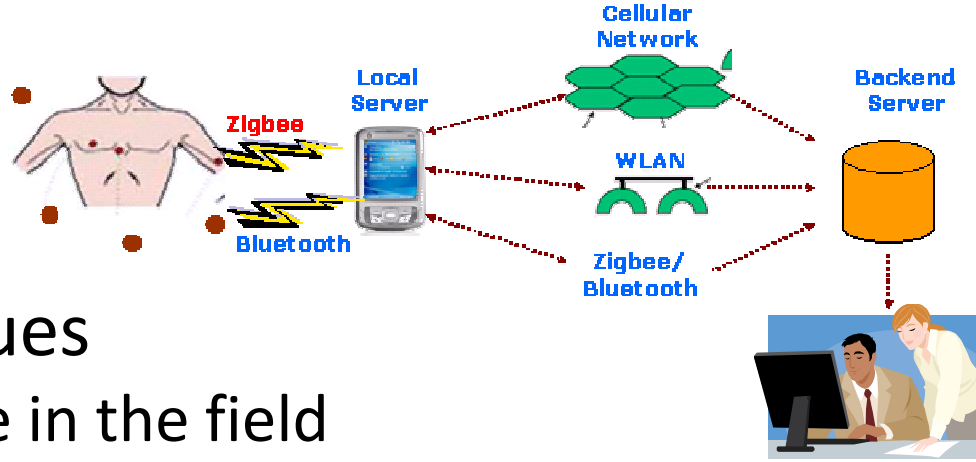
Mobile Power - Balancing Power Consumption and Data Criticality

Ideas contributed by
Tajana Simunic Rosing
CSE, UC San Diego

Power Management is Game of Tradeoffs

Limited energy & computation

Fast response time



Ample energy & computation

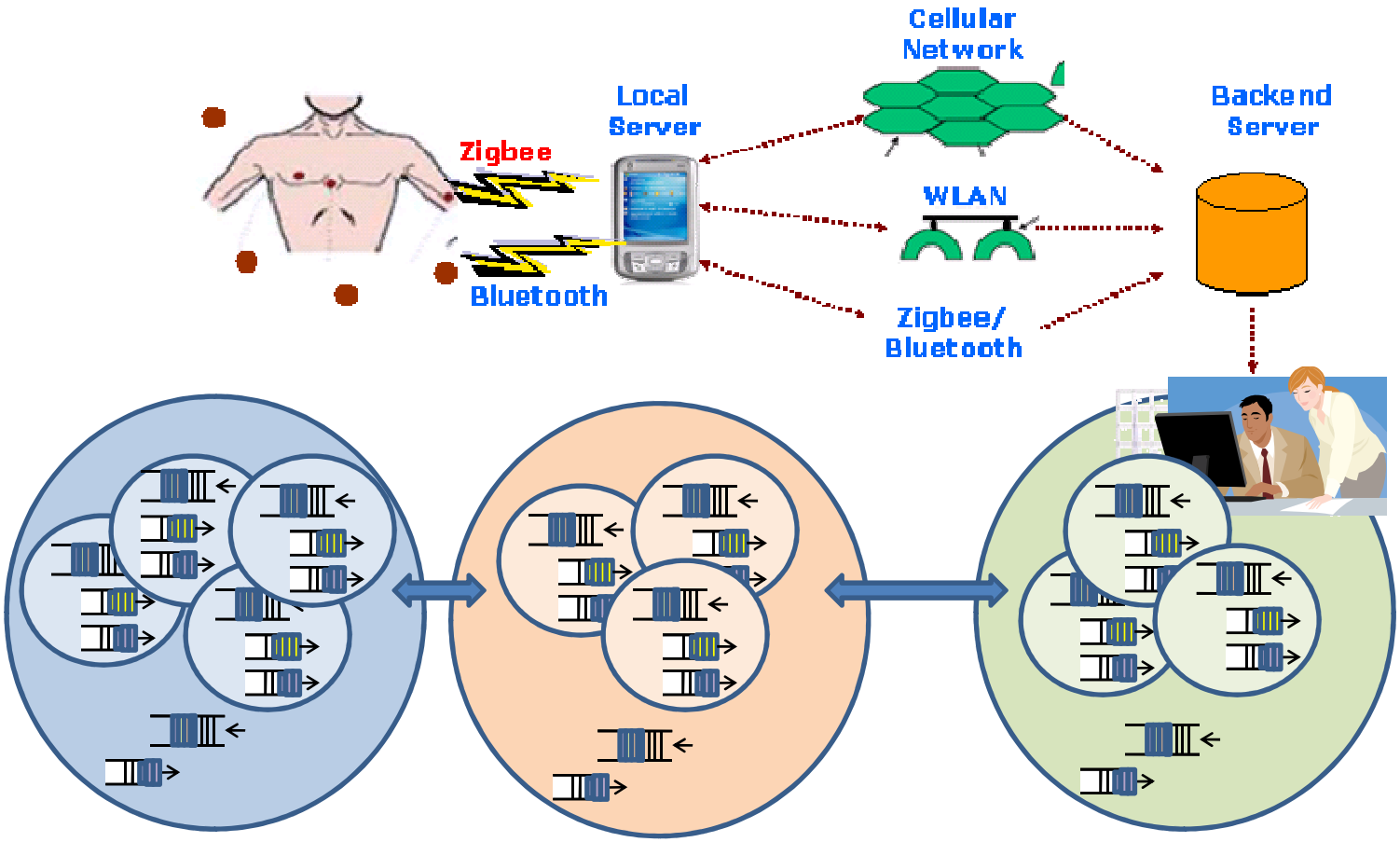
Longer latencies

- Several issues
  - device life in the field
  - data capture in critical situations (pollution levels rising)
  - notification when needed (timeliness)
- Optimizing these tradeoffs influences:
  - sensor sampling rate
  - way that data is reported (e.g., summarized)
  - local vs. remote computation
  - precision of estimation
- Employing *queuing model* approach
  - naturally describes rate of data capture and processing

Queuing Model Composition

Compose individual component models of sensors, phone, and server for global performance and energy tradeoff analysis

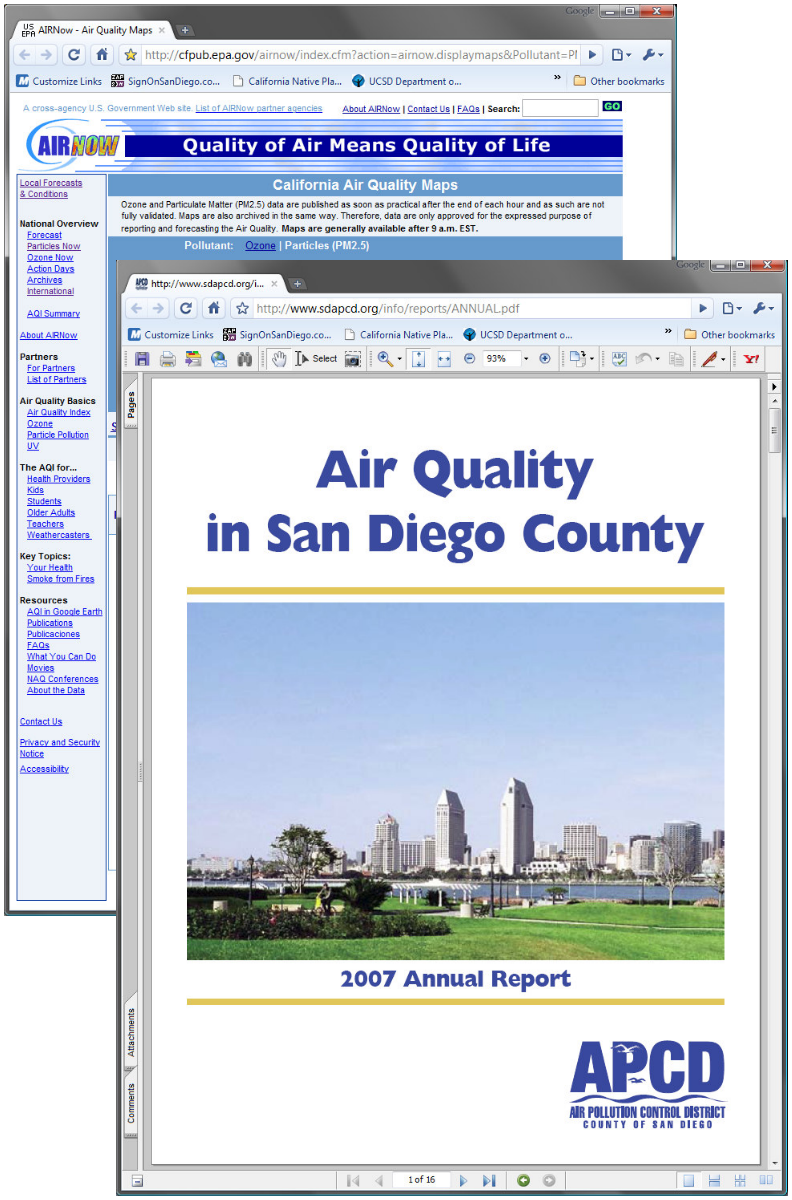
Answer questions about when, where, how much computation & communication should occur at what energy cost

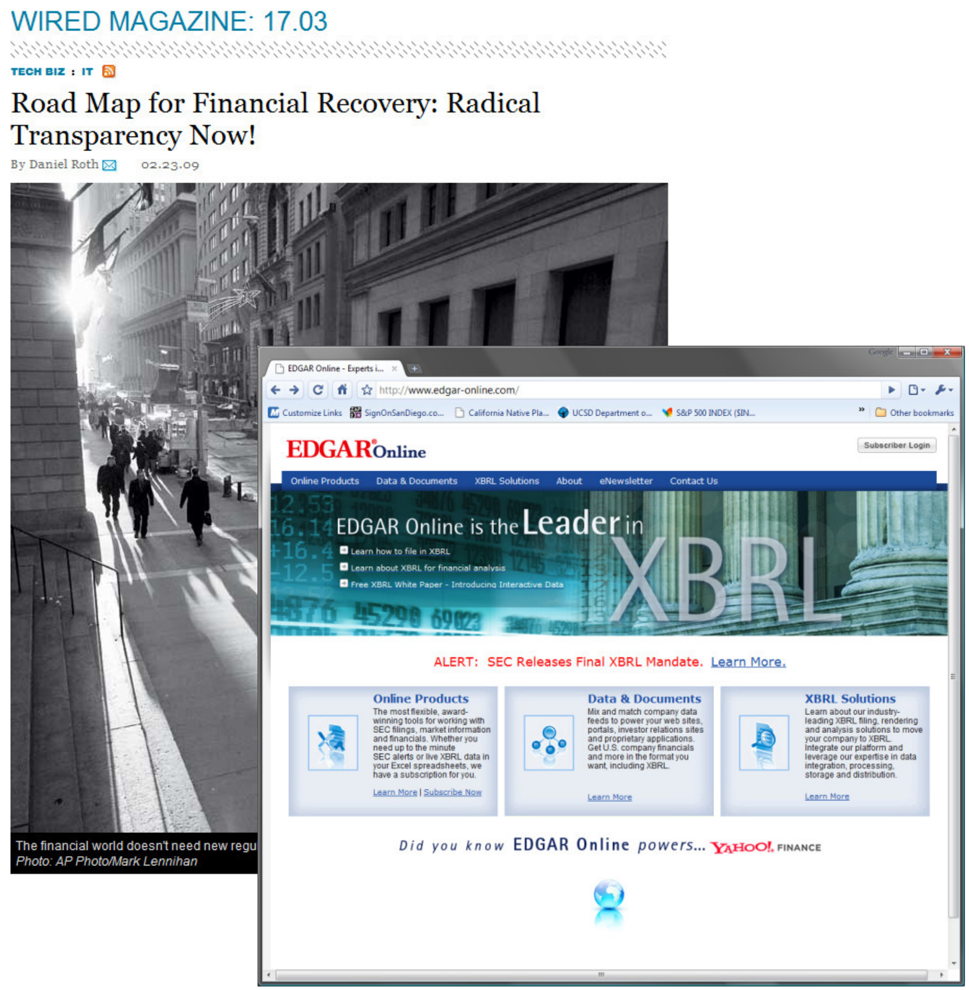


Semantic Web

Today's information sources are a largely unstructured collection of HTML web pages and PDF documents

Challenge of discovery, retrieval





200[illegible] pages)

Security and Privacy

With guidance from
Hovav Shacham
CSE, UC San Diego

Architecture Inference Power Semantic Web **Security & Privacy** Attention

Very Hard Problems

- Cannot secure or tamper-proof sensors
  - expensive to “harden”, still must be exposed world
  - can attempt to *detect* suspect data, maybe using GPR
- Hard to achieve privacy through anonymization
  - *k*-anonymity proof asserts that *k* pieces of personal data needed to uncover identity [Sweeney, 2002]
  - *k* is often lower than calculated due to characteristics of data sources [Narayanan & Shmatikov, 2008]
- How about we encrypt everything?
  - problems: selective access, multiple privacy domains
  - functional encryption, multi-party encryption

Brent Waters et al.

Functional Encryption

- Encrypt sensor data using capability-based access controls – a predicate stored with encrypted data
  - e.g., owner(d) | (law-enforcement ^ has-warrant(d))
- Can build on secret sharing and public-key encryption
  - SS: split secret over parts of predicate
  - PKE: encrypt with public key, decrypt with private key
  - requires “personalization” to avoid collusion attacks
- Extensions for revealing certain attributes to those holding subset of capabilities
  - compute average or similar (many adds, one division)
    - i.e., e(x) + e(y) = e(x+y)
  - Performance and generality remain challenges

Attention Technologies

Proactive, Rich, Non-disruptive

Design Requirements

- *Proactive* – best to know when it's most relevant (e.g., when you're being exposed)
- *Peripheral* – shouldn't divert attention during "critical" tasks
- *Unobtrusive* – shouldn't cause social problems
  - sound will be out in many cases
- *Rich* – don't have to get out phone to look at it
- *Adaptive* – changes according to your task, etc.
- *Redundant* – if you're busy, miss a notification, or don't understand it

Multi-Scale Visual Displays

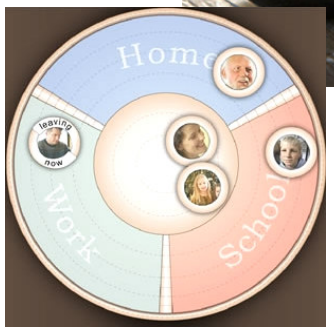
peripheral, persistent, redundant

UbiGreen

8MP CSE display ($15,000 + labor)

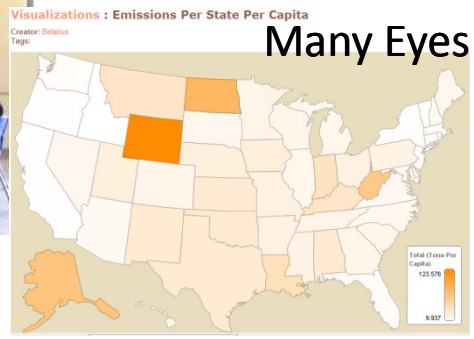
Chumby ($200)

2MP display ($4,000 + labor)



Whereabouts Clock

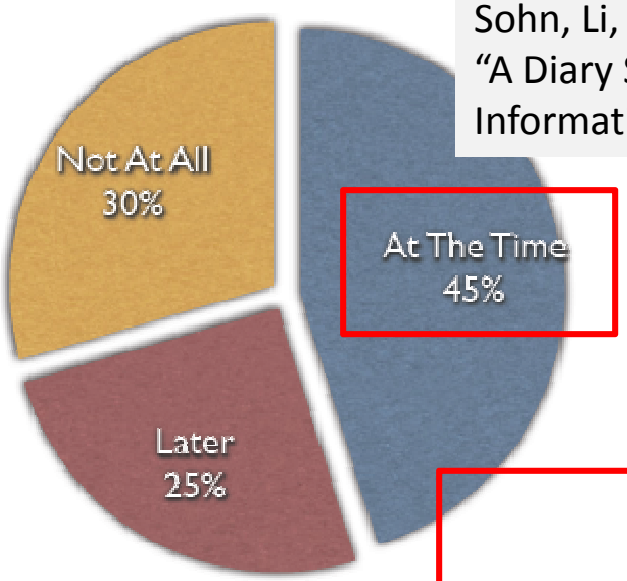
Many Eyes



Delta E-Paper

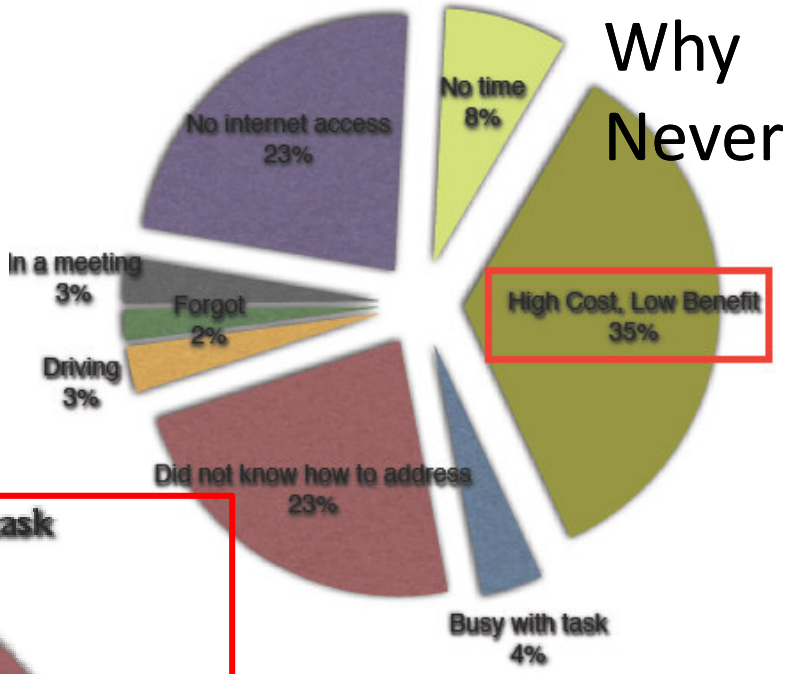
Task contexts demand proactive eyes-free

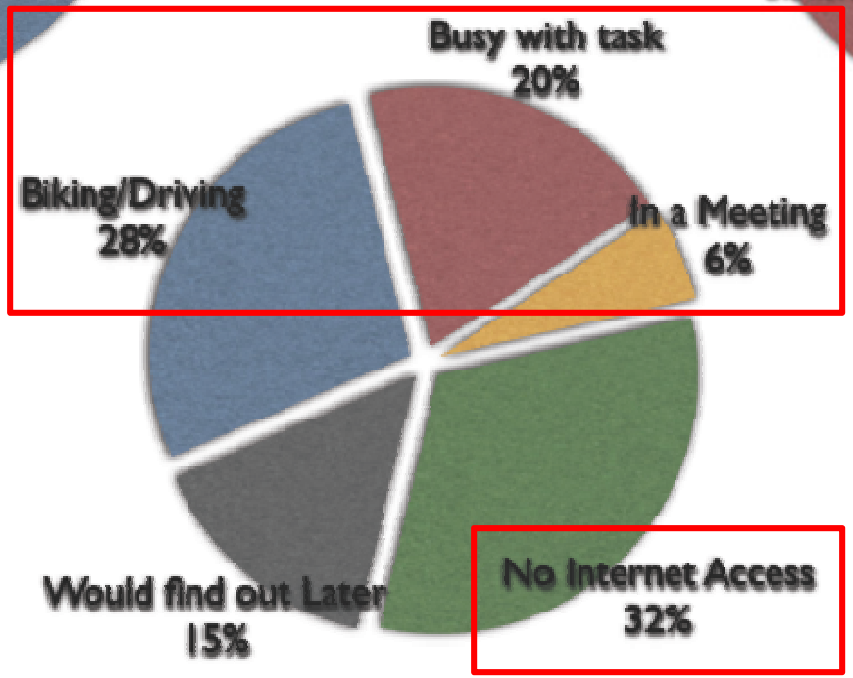
Sohn, Li, Griswold, and Hollan, "A Diary Study of Mobile Information Needs", *CHI '08.*



When do you satisfy information needs that arise out of the office or home?

Why Never?





Why Later?

If people can't pursue *known* information needs, what about *invisible* needs?

Requires proactive eyes-free notification

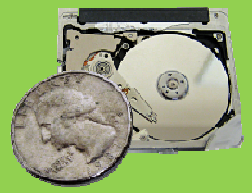
How about vibrations that feel like sound?

MobiSys'08, Li et al.

- Low learning curve, eyes-free
- Need vibrations of varying intensity
  - but phone's $0.50 vibrator only turns on and off
  - at a single frequency and amplitud
- Pulse-width modulation approac
  - how light dimmers work
  - for vibrotactile motors, decreases
    - perceived as lower intensity
    - can produce 10 intensities
    - amounts to 50Hz dynamic range
  - rather than use beat, convey energy in music
    - Example: Beethoven's 5th (requires imagination)

Next:

Translating the spoken word using prosody



Alternative implementations of commodity haptics

Many problems, a few ideas

Extensible Architecture

- Programmable content-based publish-subscribe

Inference with commodity sensing

- Model uncertainty, decompose into lower dimensional problems

Mobile power

- Queuing models are natural for streaming systems

Semantic Web

- Establish XML standards

Security and Privacy

- Sharing with functional encryption and multi-party encryption

Attention without disruption

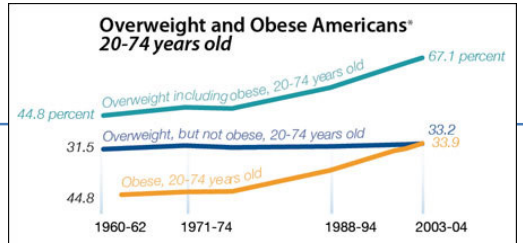
- Peripheral, proactive, redundant – visual and eyes-free

Many challenges I didn't touch on

- Bootstrapping the vision
- Programming models and languages
- Networking
- Databases
- Cloud computing
- Social dynamics
- Policy

…

Conclusion



- We can no longer delegate our moral and health responsibilities to government agencies
- And we no longer need to
  - technology is here, and it's affordable
- Advocating an open framework for citizen sensing, analysis, & presentation
- Many challenging research problems
  - applications
  - basic computer science
  - social and individual consequences