Sensors meet World Wide Web: searching and organizing world's real-time information

Feng Zhao
Microsoft Research
http://research.microsoft.com/zhao

Keynote at IEEE International Conference on Sensor Networks, Ubiquitous and Trustworthy Computing (SUTC'06), Taiwan, June 5, 2006

Challenges for the Sensornet Community

- Great to see startups begin to tackle practical problems, collecting low-hanging fruits
- But, the research community must set the sight further
  - Every field needs grand challenges to focus energy and drive progress, so does sensornet
  - Here is my take on the grand challenges; you can substitute it with you favorite …

Ubiquitous Sensing Infrastructure and Reality Browser:

Query physical world, live and up close, from anywhere

Potential Apps

- Environment
  - Volcano, underwater, rainforest
- Education
  - K-12 interactive learning, virtual laboratory
- Leisure
  - Virtual travel, sunny spot tracker (for Seattle!), what is the temperature at my favorite beach? what is the water algae level?
- Getting around
  - Where is the nearest available parking space? What is the traffic like on the bridge? How long is the queue at the gas station? Where is the bus?

SenseWeb

- Goal: Simplifying <u>publishing</u> live data on Web and <u>querying</u> that data (from sensors)

Indexing live data
Processing queries on the data

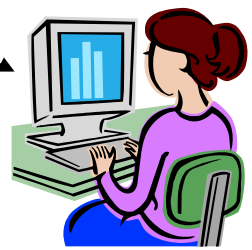
SenseWeb

(Indexing, query processing, caching, scalability, etc.)

Query response

MSRSense

- Generic functionalities implemented
- Programmable



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Monday, May 08, 2006

Microsoft's Plan to Map the World in Real Time

Researchers are working on a system that allows sensors to track information and create up-to-date, searchable online maps.

By Kate Greene

A screenshot of the SenseWeb sensor mapping application. The user highlighted a geographic region (red lines and dots) and typed "Seattle Sensors" to view a variety of real-time data in the area. (Image courtesy of Suman Nath, Microsoft Research.)

Researchers at Microsoft are working on technology that they hope will someday enable people to browse online maps for up-to-the-minute information about local gas prices, traffic flows, restaurant wait times, and more. Eventually, says Suman Nath, a Microsoft researcher who works on the project, which is called SenseWeb, they would like to incorporate the technology into Windows Live Local (formerly Microsoft Virtual Earth), the company's online mapping platform.

By tracking real-life conditions, which are supplied directly by people or automated sensor equipment, and correlating that data with a searchable map, people could have a better idea of the activities going on in their local areas, says Nath, and make more informed decisions about, for instance, what driving route to take.

[For images from the SenseWeb application

"The value that you get out of [real-time da
range from finding a parking spot in a cavern

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Market Overview

DJIA 11,098.35 -0.24% -26.98 click for chart

S&P 1,256.58 -0.43% -5.49 click for chart

NASDAQ 2,158.76 -0.65% -14.10 click for chart

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Microsoft Keeping Web Arsenal Well-Stocked

By Bill Snyder
TheStreet.com Senior Writer
5/3/2006 4:01 PM EDT
Click here for more stories by Bill Snyder

MOUNTAIN VIEW, Calif. -- **Microsoft** (MSFT:Nasdaq - news - research - Cramer's Take) has a not-very-secret weapon in its battle with **Google** (GOOG:Nasdaq - news - research - Cramer's Take) for Web dominance: a 700-person-strong network of labs dedicated to academic-quality research.

Although Microsoft Research is only a part of the software giant's $6-billion-a-year R&D effort, the unit is churning out flashy projects designed to wow users and in the process help vault MSN into a far more competitive position.

On Tuesday, Microsoft opened the doors a bit, putting on a kind of science fair at its campus here, demonstrating 13 of its more promising technologies for an audience of high school students, Silicon Valley residents and journalists. Although the projects on display were positioned as a more or less random

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News articles on our SenseWeb:

- Microsoft's Plan to Map the World in Real Time, *Technology Review*, 5/8/06
- Adding Real-Time Info to Local Searchers, *InternewNews.com*, 5/11/06
- Microsoft Research showcases future technology, *EETimes, InformationWeek, CRN*, 5/3/06
- Microsoft Keeping Web Arsenal Well-Stocked, *TheStreet.com*, 5/3/06
- 135,000 hits on "SenseWeb" and "Microsoft" with Google search

EE Times:

Microsoft Research showcases future technology

Kristen Kenedy
CRN
(05/03/2006 11:55 AM EDT)

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REPRINTS

Those who hate long waits for a table at popular dinner spots may soon get some help from Microsoft.

Thanks to Sense Web, a new Web technology from Microsoft's research group, users may soon be able to find nearby restaurants and then pinpoint those with a shortest waiting list. The technology was one of several

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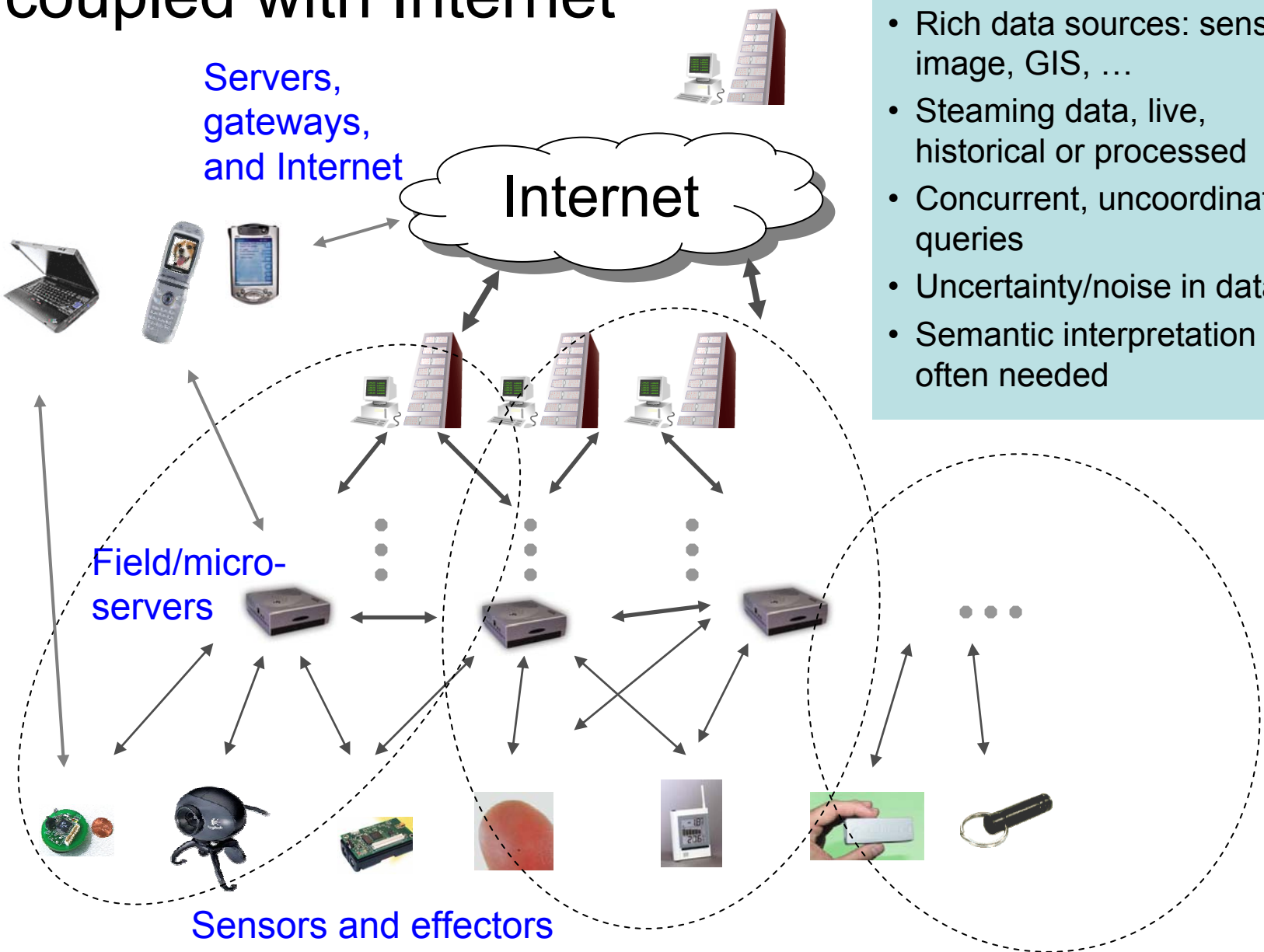
Webcast: Uncover Business Intelligence Growth Opportunities--Join Business Objects and IDC for a discussion on the business intelligence (BI) market outlook and growth opportunities for ISVs and ASPS.

Multi-tier net of sensornets, coupled with Internet



Characteristics:

- Rich data sources: sensor, image, GIS, …
- Steaming data, live, historical or processed
- Concurrent, uncoordinated queries
- Uncertainty/noise in data
- Semantic interpretation often needed

Three Challenge Problems

- Need to standardize **interfaces** between apps/db/nw/dsp/hw (e.g., SP link layer abstraction, SensorML)
- Need to treat **uncertainty** (in both data and systems) as first-class entity, for reasoning and system mgmt
- Need (simple) **tools** for sys config/mgmt, for data collection and vis, for in-situ debugging

But the problem is made harder by …

- A great deal of variability
  - Variability in app requirements
    - Use scenarios (data collection, control in the loop, or in-network compression), data rate, hw
  - System dynamism and unreliability
    - Nodes/links come and go
    - Parts of system may be deployed over time by different vendors, using different technologies (e.g., network protocols)
    - Possibly non-replenishable resources
  - Variability in data
    - Uncertain data due to sensor noise, packet loss
    - Incomplete information due to partial observability of the world
- User tasks often specified in high-level semantic queries
  - E.g., “Tell me if you see a red car”, or, “Doing this with that data”.
- As a result, systems are often built vertically
  - With own system abstractions and data models
  - Make sense from efficiency POV, but with relatively small code reuse
  - Phil Buonadonna: “Every sensor net experiment needs 2 PhDs and 5 grad students”, or something like that

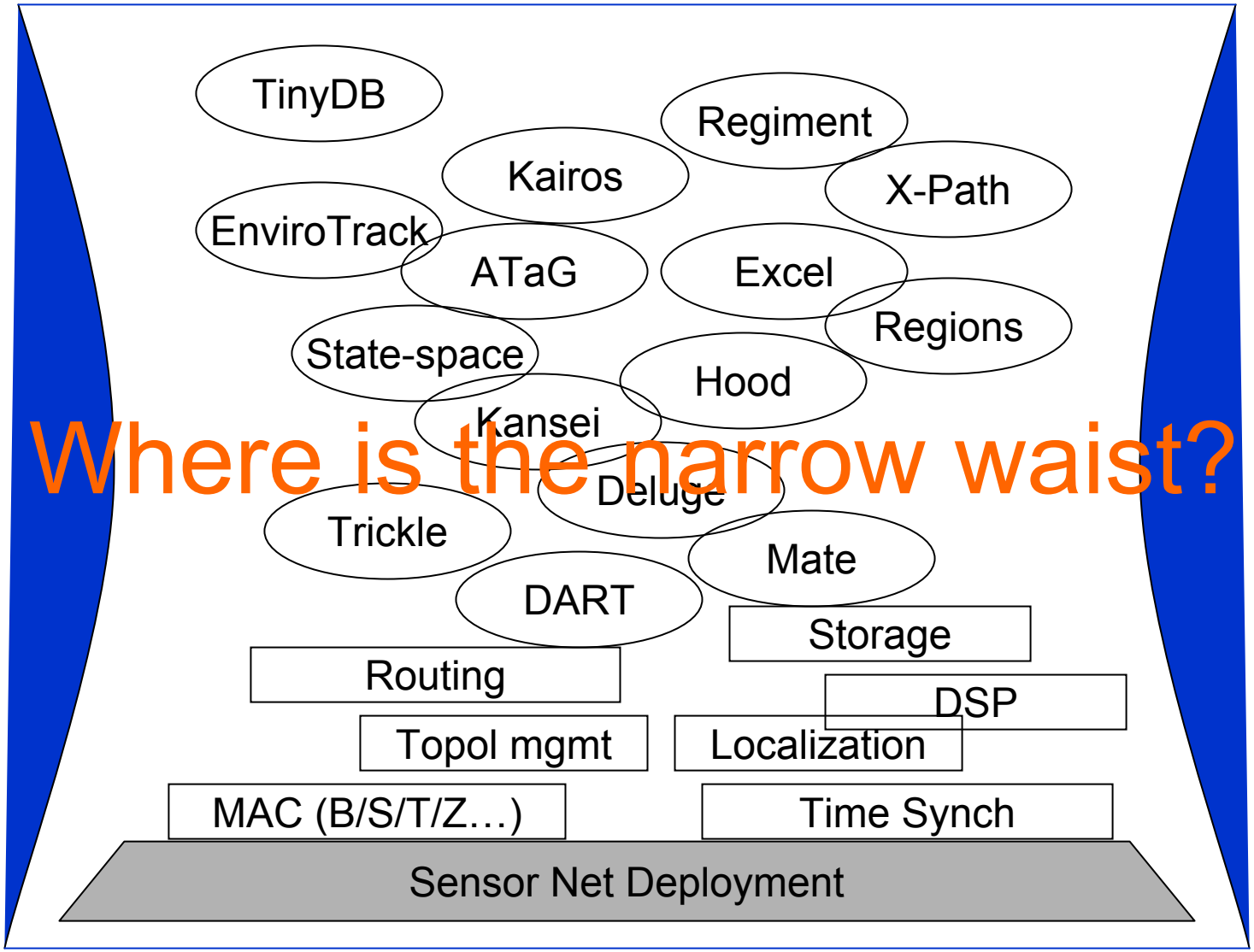
A brief history of sensornet

- 1980: DARPA DSN (PM: Bob Kahn) – sensors are truck-sized, connected via Ethernet using microwave radios.
- 1994: Smart dust (Kris Pister)
- 1994-98: UCLA WINS, Xerox PARC Smart Matter
- 1999-2004: DARPA SensIT (USC/ISI, Cornell, Xerox PARC, BBN, BAE, UCLA, Penn State, Wisconsin, UIUC, MIT, Berkeley, LSU/Tennessee)
- Berkeley motes; Intel Berkeley Lablet
- Startups: Crossbow, Ember, Dust, Sensicast …
- 2001-2005: DARPA NEST (Berkeley TinyOS, Ohio State, UVA, …)
- 2003-Now: NSF NETS/NOSS
- Industrial R&D: Agilent, HP, Intel, IBM, Microsoft, Motorola, Nokia, Sun, Xerox PARC, …

Mobile Node

Equipment Rack

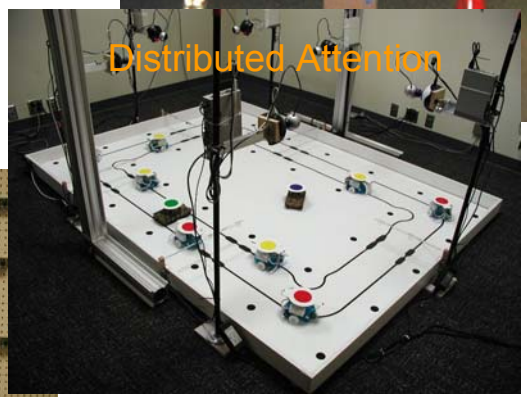
Many systems got built over the past few years …



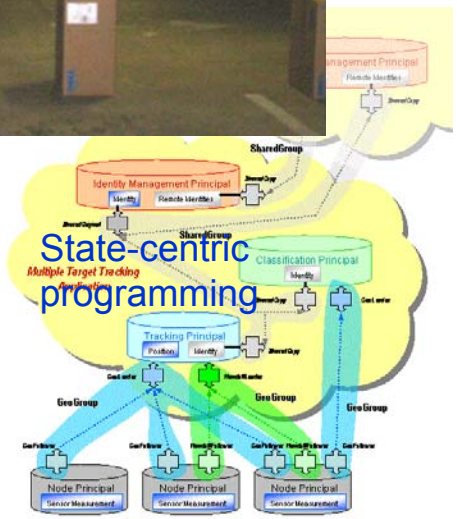
From printer land, Mojave Desert, to parking garage … our own experiences

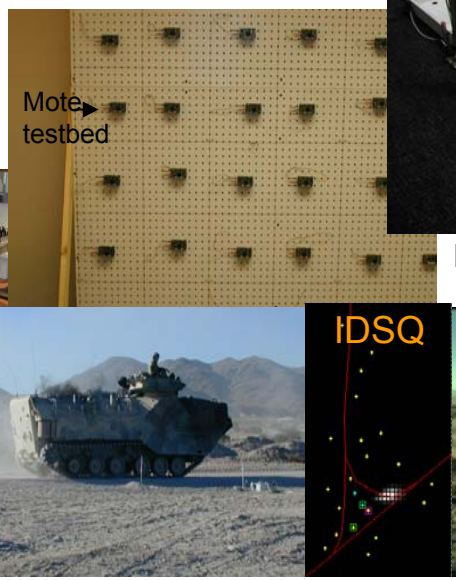
MSR in-building testbed, 2005

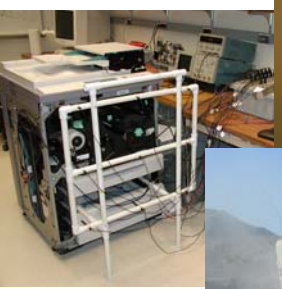
MSR parking garage testbed, June 2004



PARC camera testbed, 2003

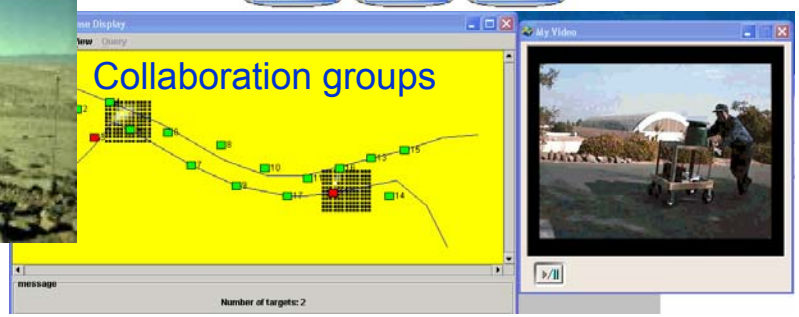






Machine diagnostics, 1997

DARPA SensIT experiments, 29 Palms, 2000-2001



Outdoor experiment, 2002

What we've learned …

- Proposed tracking as a canonical problem for sensornet problem (circa 2000)
  - Dynamic data, close the loop between sensing & decision making (not just data collection)
  - Created SensIT data sets (with ground truth!), app scenarios, experimental testbed (used by others)
  - Many projects since then: SensIT 29P demo, NEST demo, EnviroTrack, …
  - Lesson: a successfull deployment is a function of many pieces that work together - dsp, networking, db, debugging tools, …

- Developed the IDSQ (Information Driven Sensor Querying) framework/Sensor tasking (circa 2001)
  - Pay more attention to data: value of information
  - Interface btw app ↔ routing: value of info and routing decision at each node
  - Move beyond individual nodes: group/neighborhood management
    - Many other work in this space: Hood, Regions, …
  - But ours (and others) were built with it's own interface assumptions and data representation

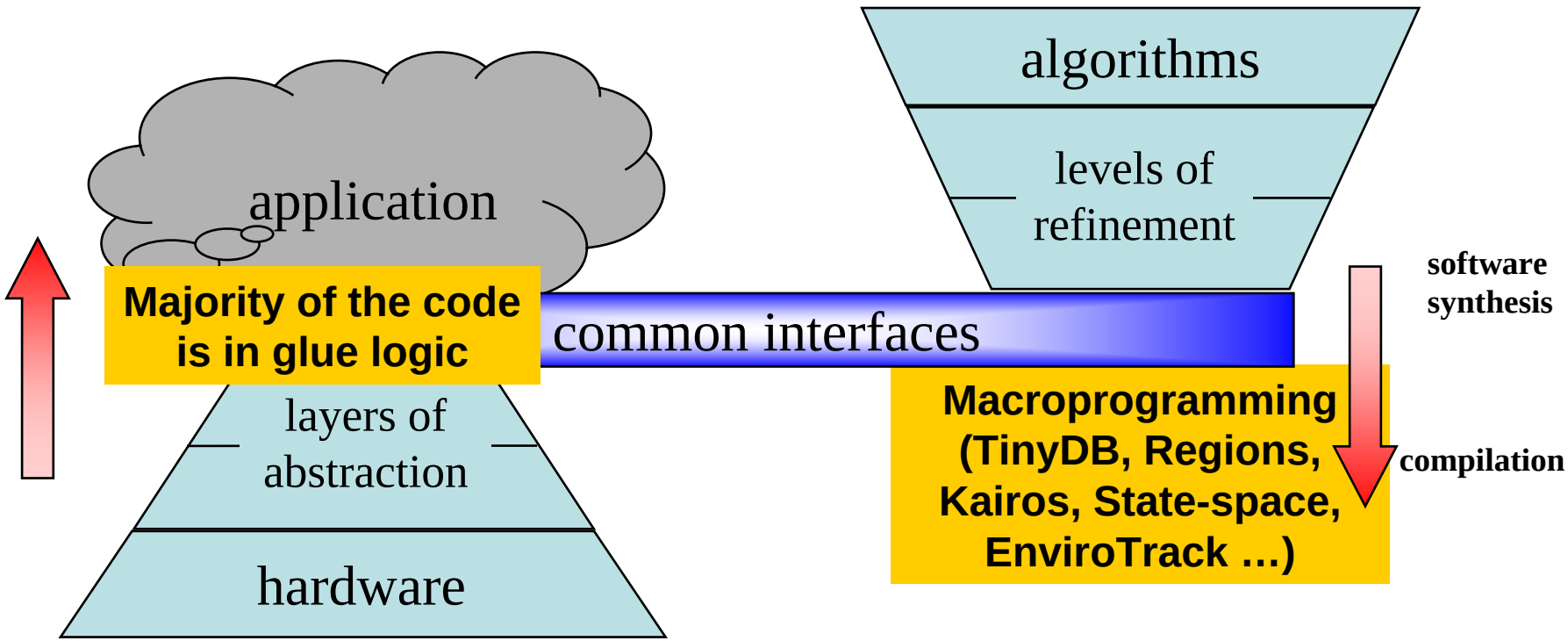
More on Lessons Learned

OS/Network-centric view

Designing component-level abstractions

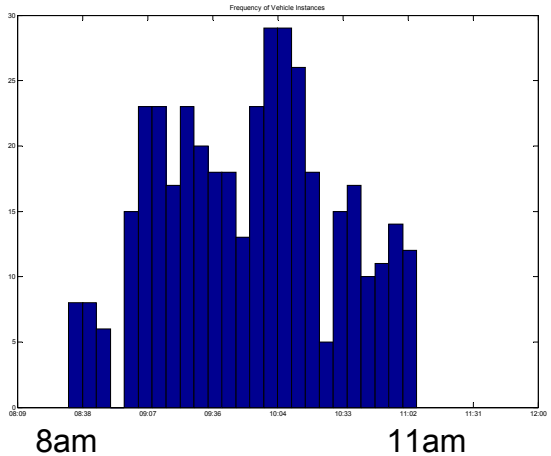
Information-centric view

Designing application-level abstractions



A Scenario: What's happening in the garage?

Arrival statistics



Multiple, concurrent queries:

- Traffic engineering: where can one find a parking spot?
- Security: what is going on down there?
- Corporate health services: when should the air exhaust fan run?

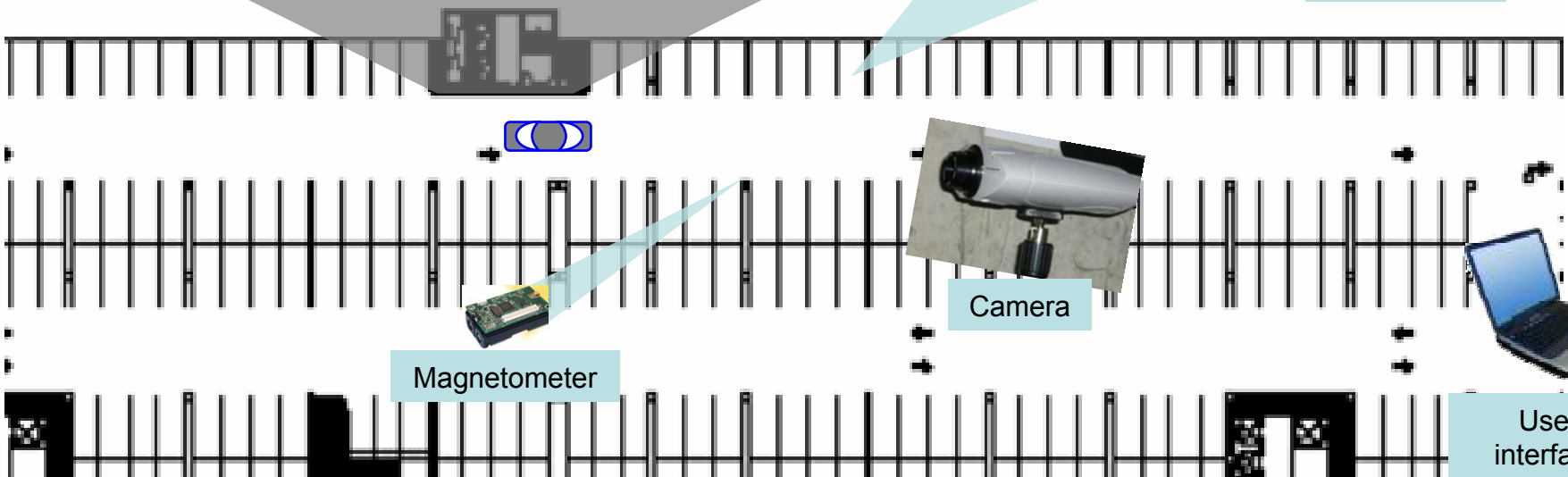
A Parking Garage Example

Break beam sensors

Sense

- Speed, length, and direction of vehicles
- Magnetic signature of vehicles
- Image of vehicles

Micro-server

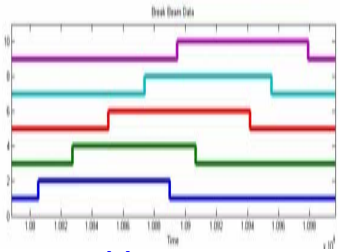


Camera

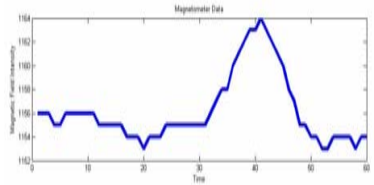
Magnetometer

User interface

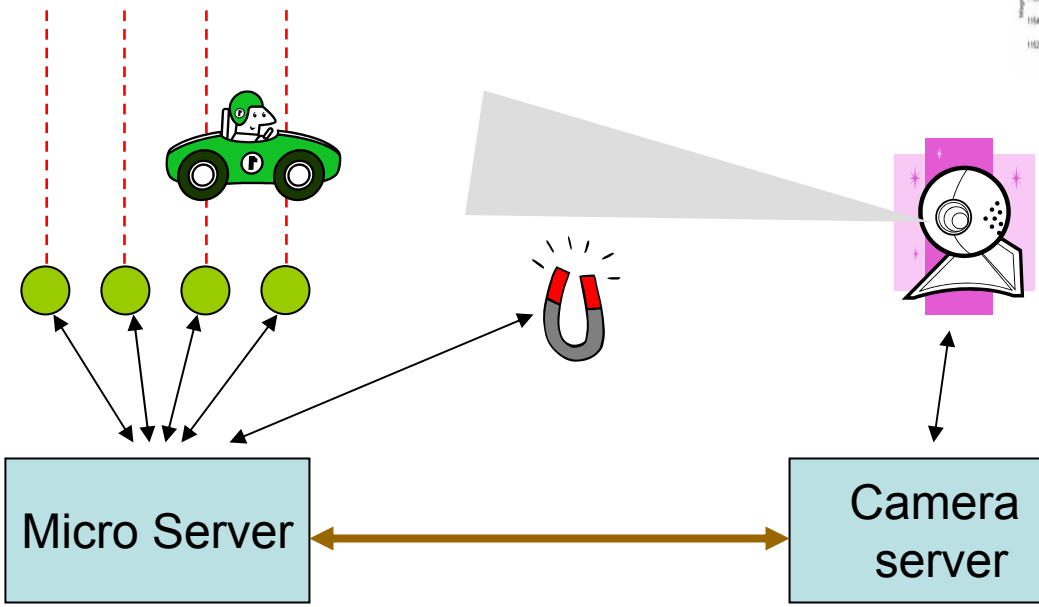
Concurrent Uncoordinated Tasks



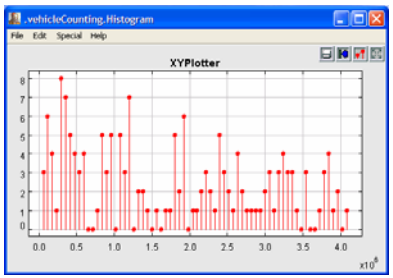
Breakbeam output



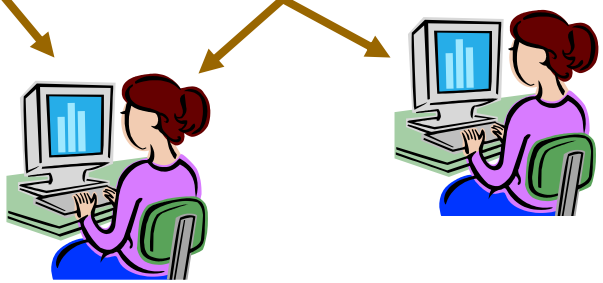
Magnetometer output



Camera image



Report (histogram)



Multiple, concurrent queries

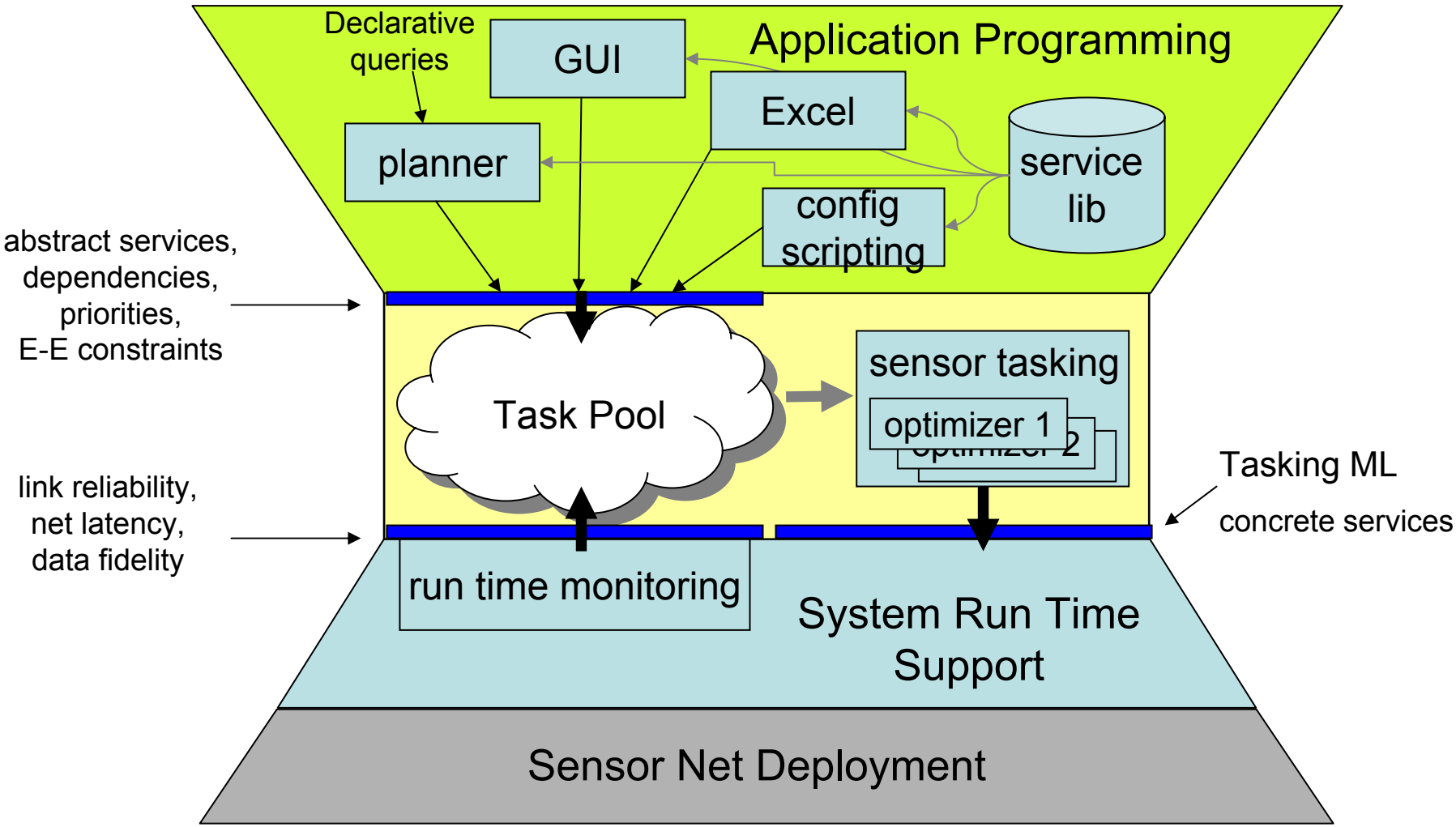
Count vehicles

Acquire magnetic signatures of extra large vehicles

Capture image of vehicles moving in wrong direction

Tasks are sent to microservers at uncoordinated times, running for unpredictable duration. Tasks may partially overlap.

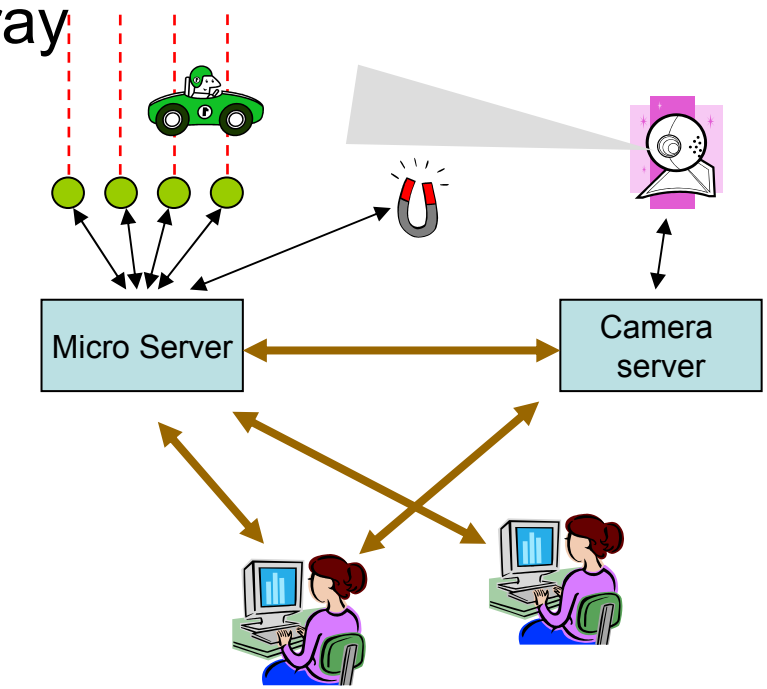
Interfaces Between Apps and Run-Time

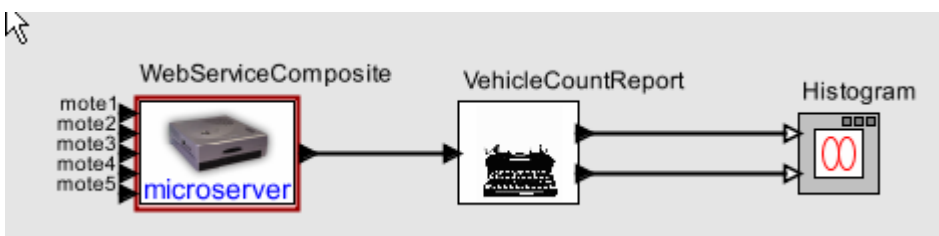


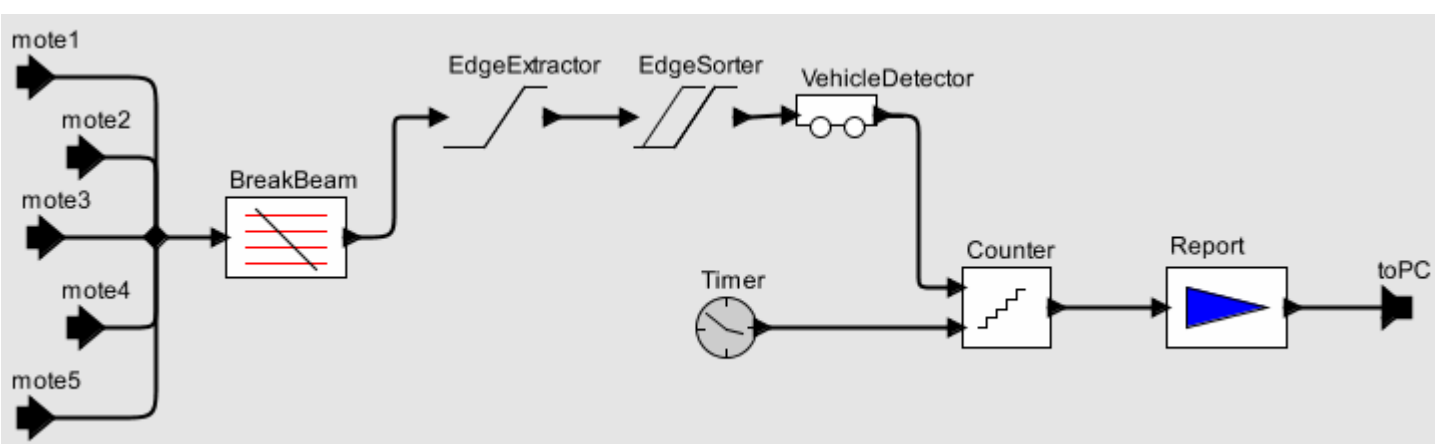
Example of services and their composition

Counting vehicles with a sensor array

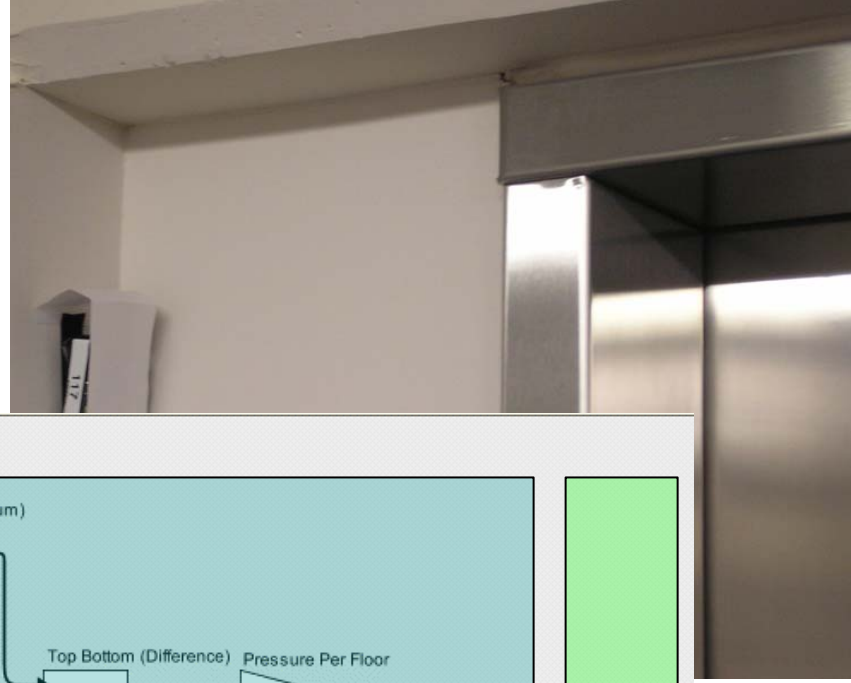
- Extract edges from break beam detections
- Sort edges into consecutive detections
- Detect vehicles based on timing relations among detections
- Count vehicles
- Generate an arrival histogram report

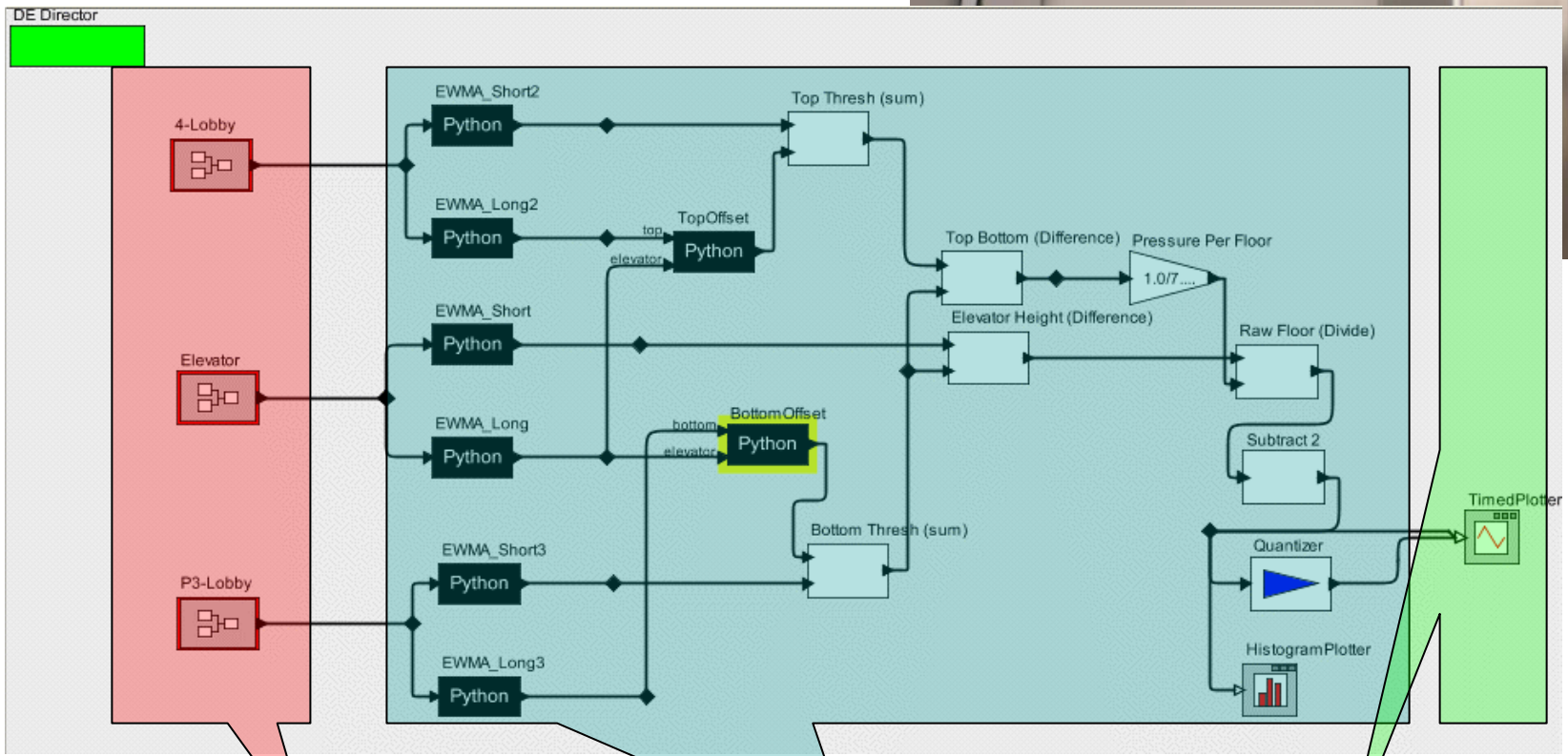






Another Example: where is the elevator?





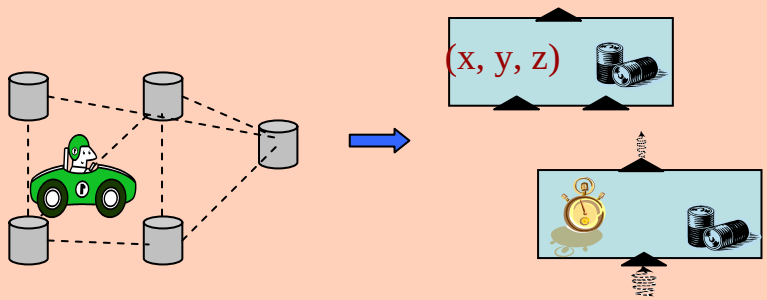
Data Sources

Intermediate Processing

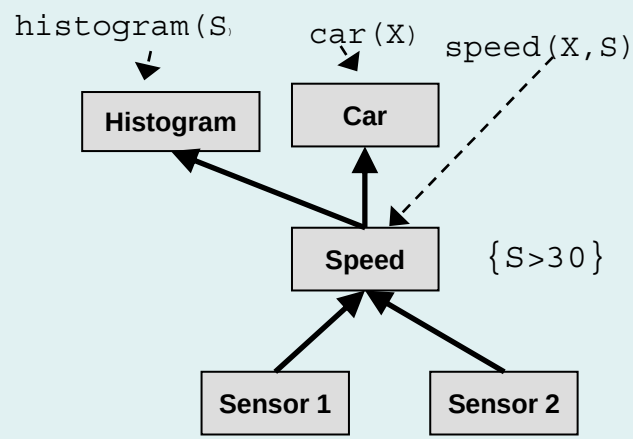
Output

SONGS: Service Oriented Networked ProGramming of Sensors

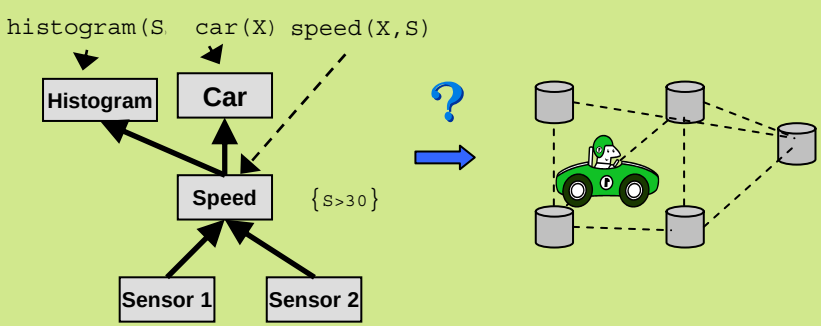
Service Abstraction and Interface



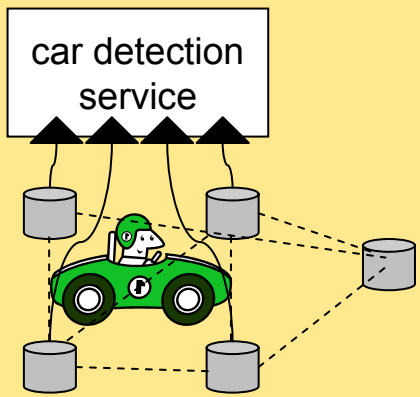
Service Planning



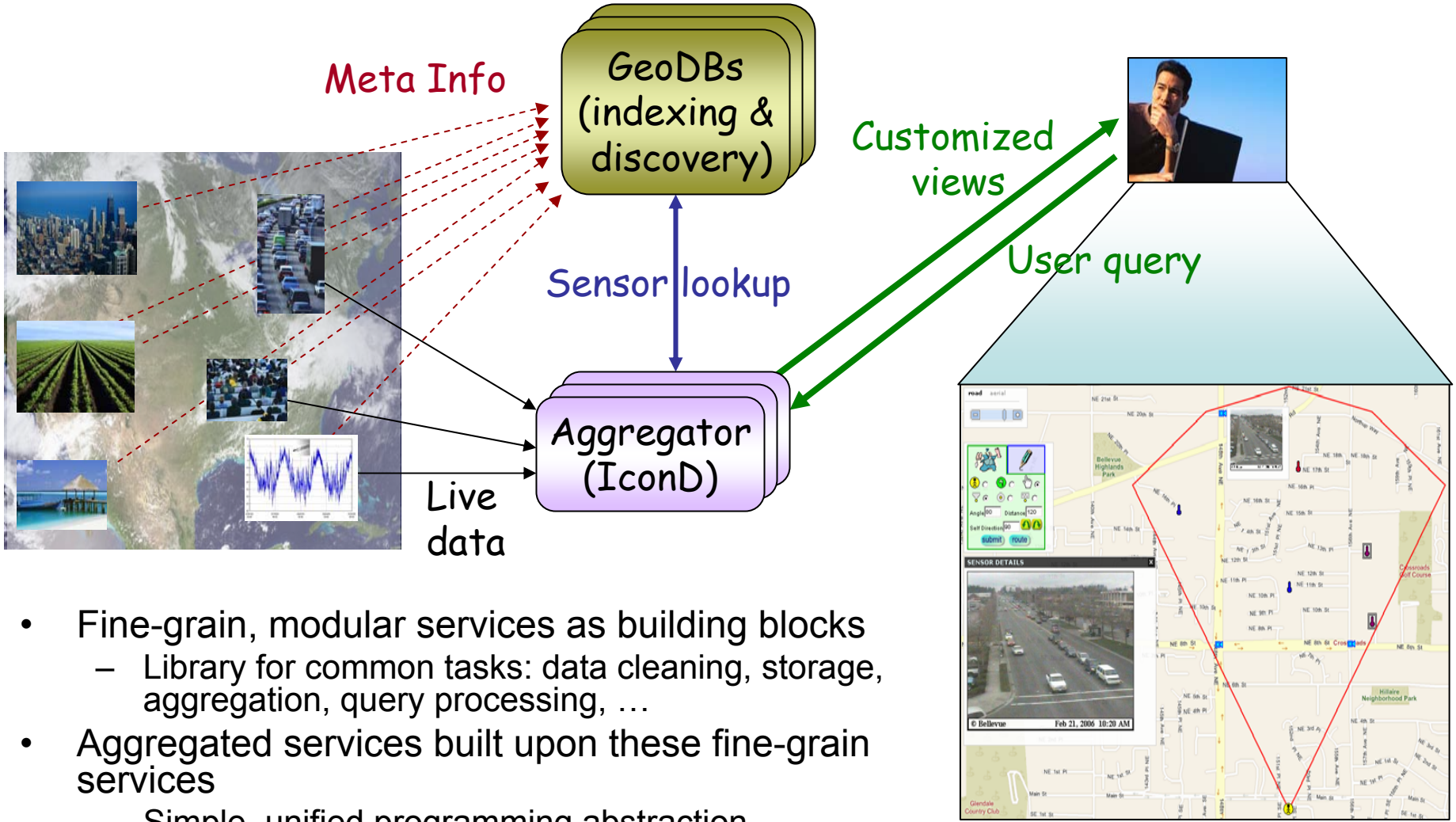
Service Embedding



Service Scheduling and Execution



SenseWeb Architecture

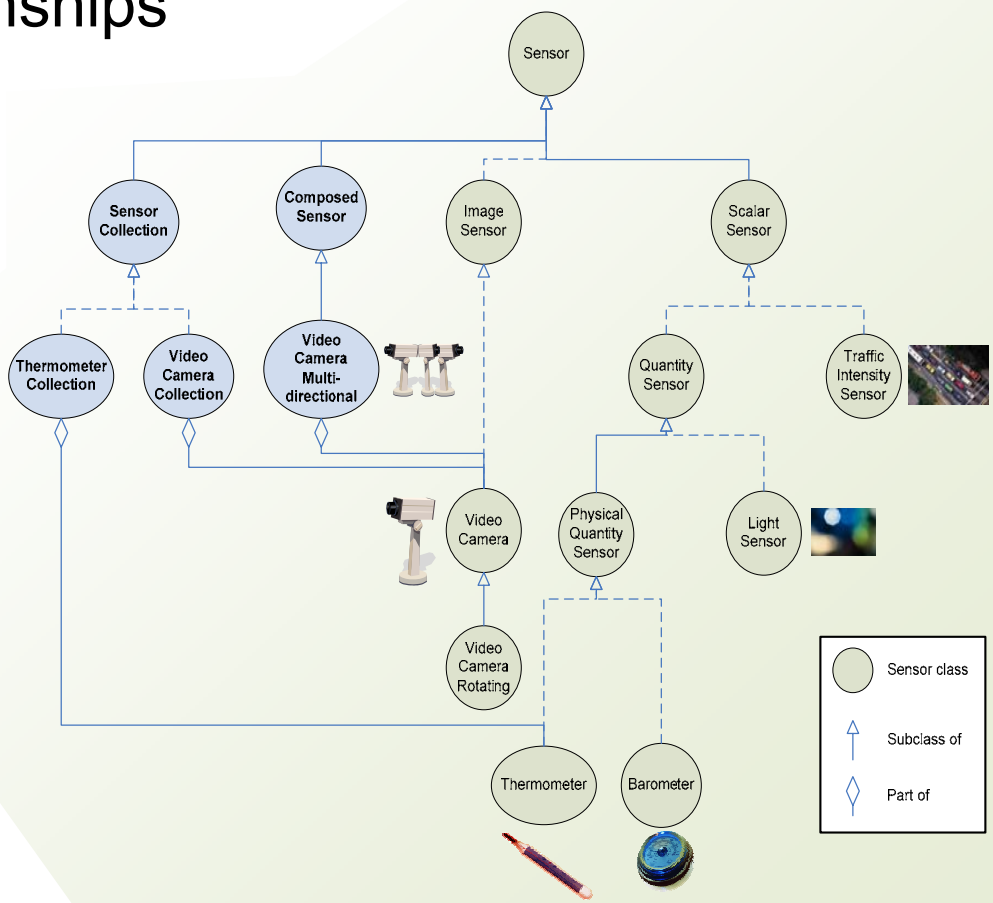


- Fine-grain, modular services as building blocks
  - Library for common tasks: data cleaning, storage, aggregation, query processing, …
- Aggregated services built upon these fine-grain services
  - Simple, unified programming abstraction
- Extensible, friendly to 3rd party services

Sensor Ontology

- OWL sensor ontology exposes the semantics associated with sensor types, groups and relationships

- The ontology provides high-level interoperability at syntactic and semantic levels



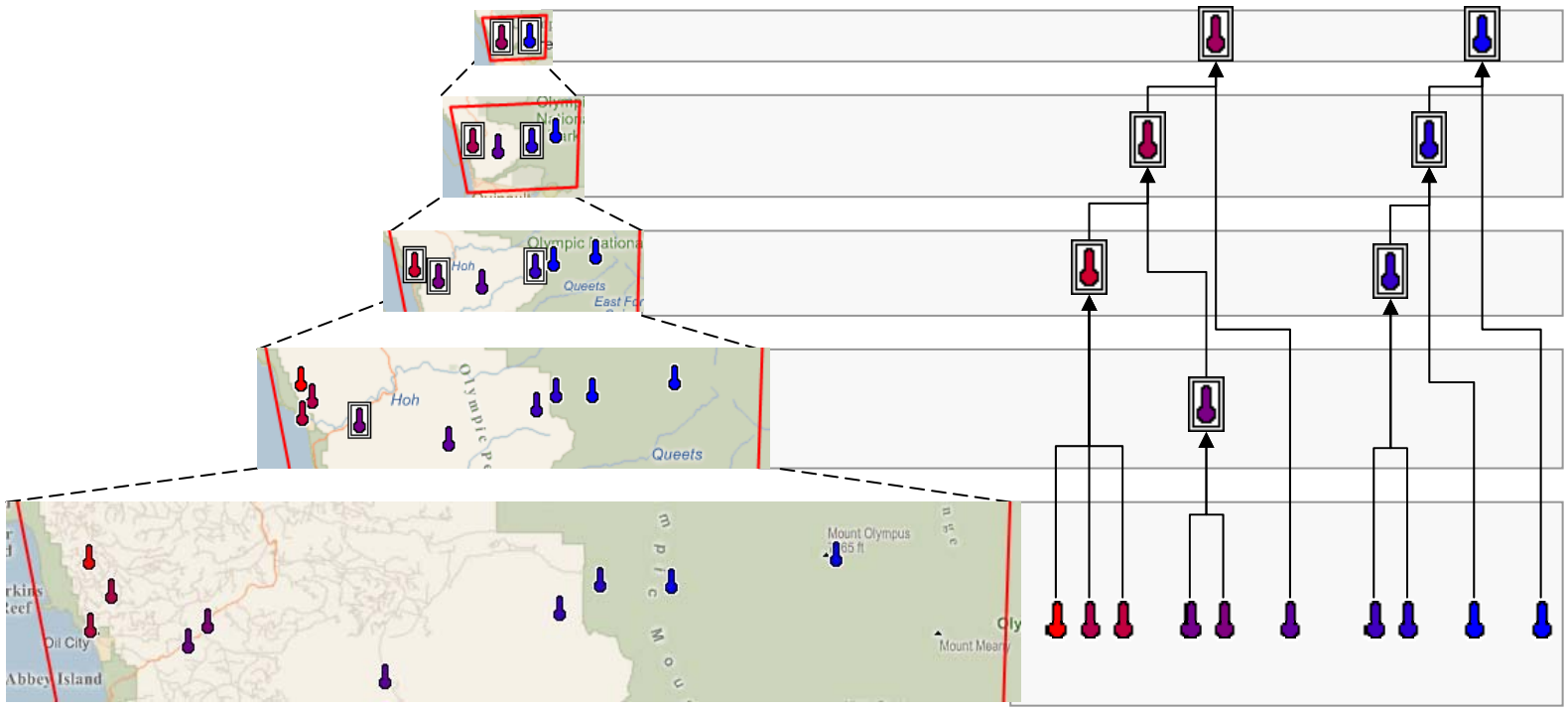
GeoDB

- Processes queries on geographic data
  - E.g., cameras inside a region, near a route
- Sensors register themselves
  - Single rendezvous point for sensors and users
- Data indexed with Hierarchical Triangular Mesh (HTM)

  - Proximity-preserving 1D mapping of Lat/Long
  - Implemented as table valued functions in SQL Server 2005 + external library
- Simple APIs and Web Service interface to store, modify, and query the database

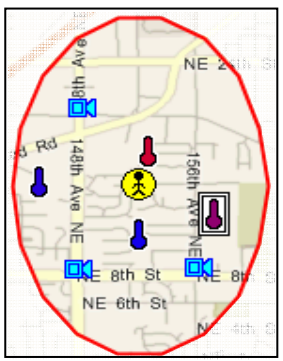
Aggregator (IconD)

- Aggregates sensor data, produces icons
- Aggregation at different granularities
  - Dynamically, e.g., based on zoom levels

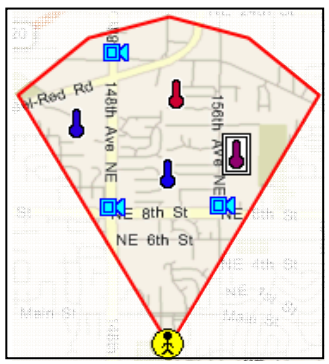


Client-side GUI library

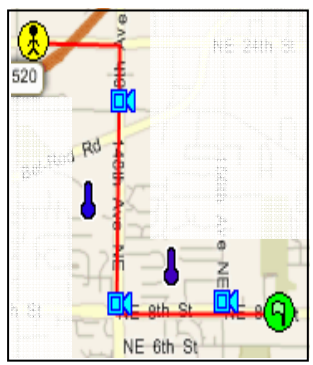
Java-script library to develop web-based GUI with more controls to interact with data



region



orientation



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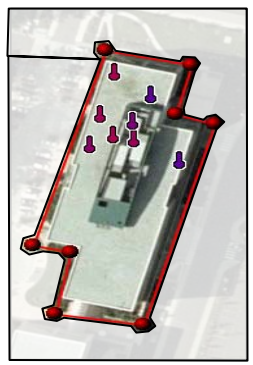

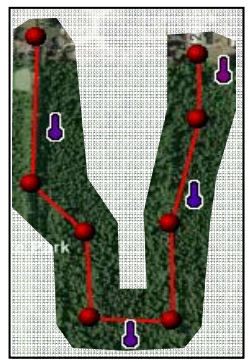


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Microsoft Research
road aerial
Show labels
submit
clear
filter
favorites
Filter Sen
Help
last update: 58 s (update now) [active]
Seattle Sensors
Search
road aerial
Magnuson Park
Kirkland
Redmond
Redmond Way
WASHINGTON
Marymoor Park
Yarrow Point
Hunts Point
Clyde Hill
NE 24th St
Bel-Red Rd
NE 8th St
Main St
Medina
Bellevue Way SE
Roanoke
Beaux Arts
Mercer Island
SE 40th St
W Mercer
S Jackson St
Adelaide
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minimum 12
maximum 20
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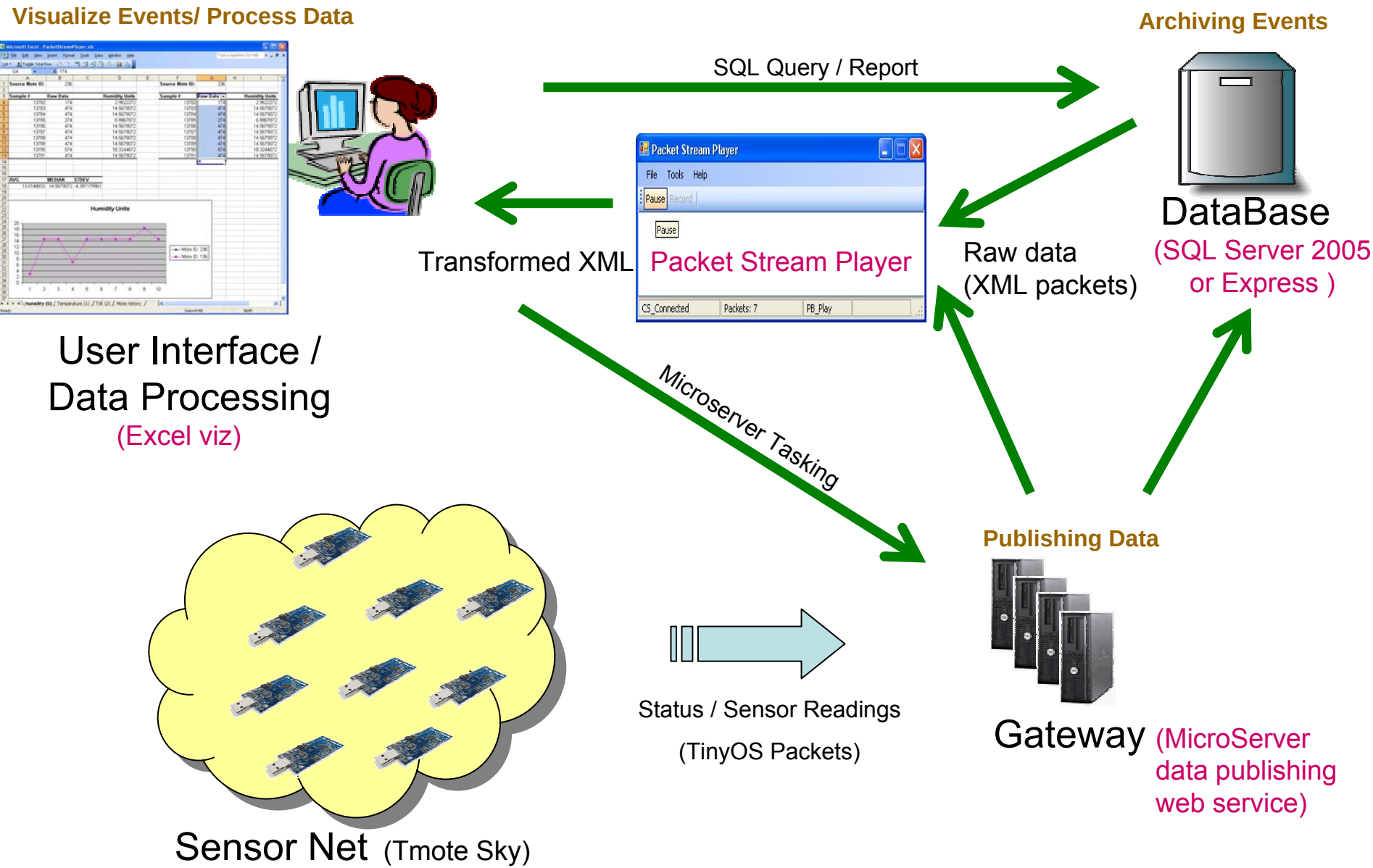
May 4, 2006 3:18 PM
close
NEW SENSOR
Sensor name: Thermometer_112_3347
Sensor type: thermometer
Latitude: 47.640750056505716
Longitude: -122.14115919289585
Description: A thermometer in the 112/3347 room.
URI: http://necomp4/SensingService/Service.asmx
Insert
Cancel

MSRSense: A toolkit for data publishing, archiving, visualization



Software release

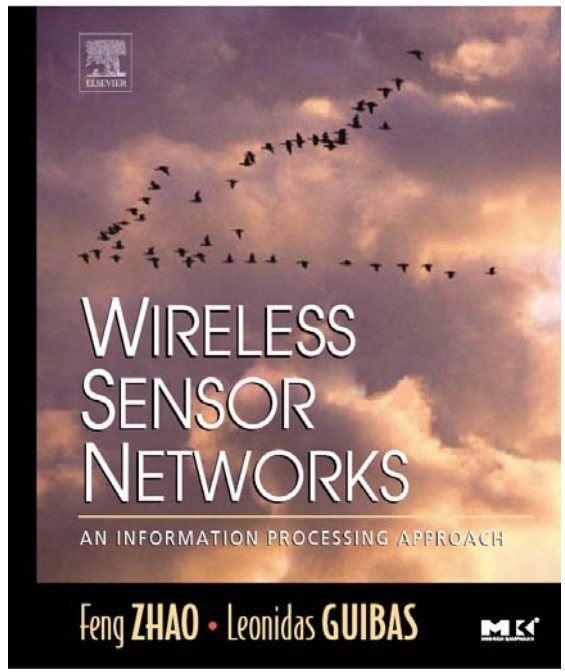
- MSRSense toolkit available (in source code) from http://research.microsoft.com/nec/msrsense
  - Over 5,000 downloads since the 12/14/05 announcement on TinyOS mailing list
- SenseWeb portal will be publicly available in July, 2006
  - http://research.microsoft.com/senseweb
  - With webcam, traffic, weather, city street parking, soil, lake data being added right now

To probe further

- Papers from our group:
  - "Semantic Streams: a Framework for Composable Semantic Interpretation of Sensor Data." EWSN'06.
  - "A Spreadsheet Approach to Programming and Managing Sensor Networks." IPSN SPOTS'06.
  - "Kinetically Stable Task Assignment for Networks of Microservers." IPSN'06.
  - "Semantics-Based Optimization Across Uncoordinated Tasks in Networked Embedded Systems," EMSOFT 2005.
  - "Towards Semantic Services for Sensor-Rich Information Systems," Basenets 2005.

- A few related conferences/Journals
  - ACM Sensys06, Boulder, Nov 2006
  - ACM/IEEE IPSN07, MIT/Boston, April 2007
  - EmNets, DCOSS, EWSN, SECON, …
  - ACM Trans. Sensor Networks, http://www.acm.org/tosn

- MSR Project: http://research.microsoft.com/nec



Wrap up: Challenge Problems

- As a community, we need grand challenge problems
- Three focus areas:
  - A community effort to standardize **interfaces** between various sensornet components/layers
  - Build models for **uncertainty** that can be utilized by data and system management
  - Create more **tools**, for sys config/mgmt, data collection and vis, debugging

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