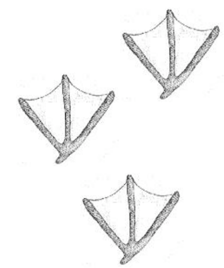
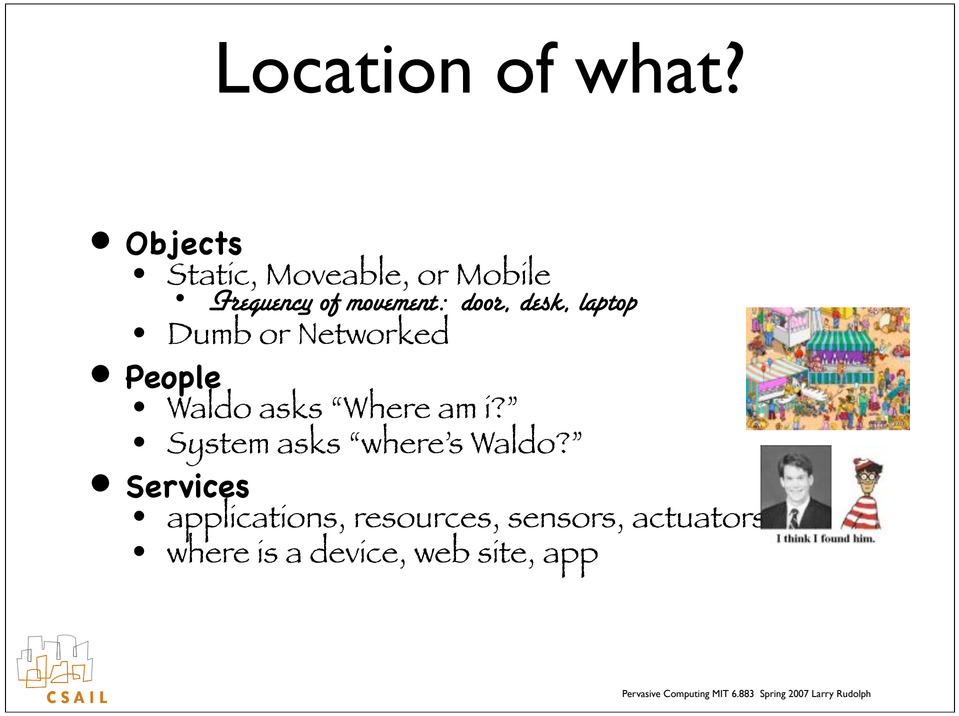
Tracking Indoors

MIT 6.883
March 8, 2007
Larry Rudolph



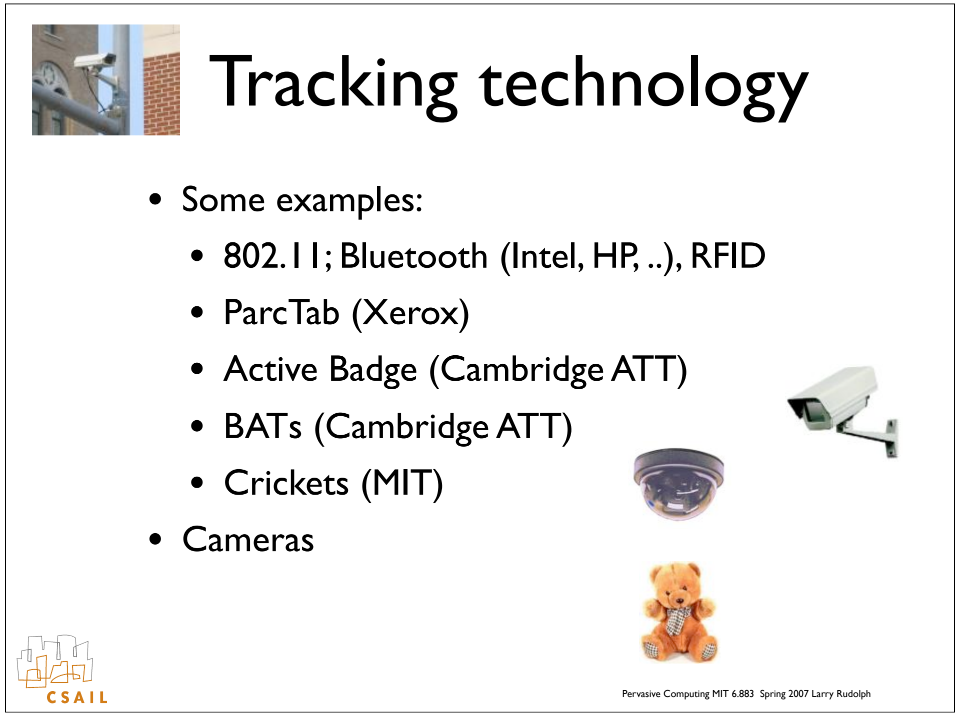
Massachusetts
Institute of
Technology



Last lesson, we realized that latitude, longitude, altitude are not what the user wants to know and when not driving, it may not be right thing even to translate. When indoors,
these values mean even less. One cannot lookup in the architectural plans either because either they are not available or are probably out of date.

Sometimes we want to know our location, location of other people, or location of other things. This can be easy or hard depending on how frequently they move.

Many visual exercises make it clear that, at least for our brains, finding



We have gone over these several times, but now the emphasis is on things that you carry on your person versus things that are embedded in the environment and some combination of the two.

The amount of effort that has gone into this field is incredible. And it is clear that in a few years, most of the techniques will seem silly.

Tangential Note: Larry's conjecture

- Any sensing service in pervasive computing only needs:
  - some cameras
  - lots of computing power
  - some clever algorithms

- Any sensing service in pervasive computing
  - can be done cheaper with application-specific hardware!
  - E.g: Location tracking & recognition

Camera's really are everywhere. Does someone want to find out how many are there? I have heard that New York and London have way more camera's on the street than Moscow.

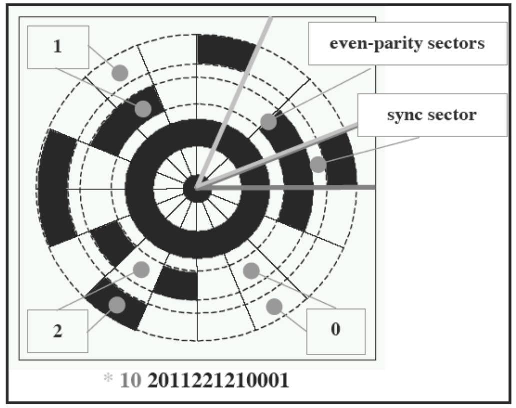


Figure 1. TRIPcode representing number 1,160,407

TRIP constitutes a very cheap and versatile sensor technology. Its 2-D ringcodes are printable, and can therefore be attached even to low-cost items, such as books or office stationeries (e.g. stapler). A TRIPcode (see Figure 1), read in counter-clockwise fashion from its synchronisation sector, represents a ternary number in the range $1\text{-}3^{13}$ (1,594,323). Only off-the-shelf hardware is required, i.e. low-resolution CCD cameras and CPU processing power.

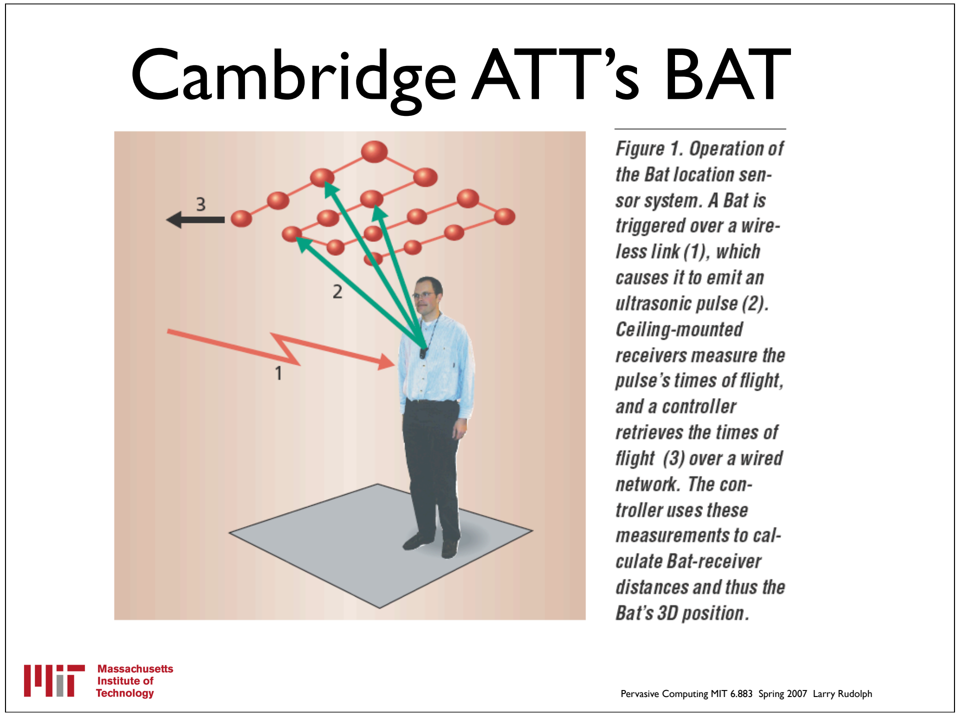
There is a domain in which users have handhelds that should be able to sense where they are in the environment. It would be nice for them to recognize human readable signs, but that often takes too much power.

One would want a sign that can be read at different angles, different distances, and different distortions. The camera may not be pointing directly perpendicular to the sign, so there will be some distortion.

There are projects in which users have a 360 degree camera on their head and it can see all around, but there needs to be some improvements until that becomes practical.

Cambridge ATT's BAT

Lets go back to one of the earlier initial experiments. It is instructive to see what they have done and what we can learn from it (if anything). Please think about the strengths and weaknesses of the system.



The building is instrumented and the user wears something. Why is this better than cameras? Is this big-brother watching? Yes, it is but big brother is your employer and that might be ok.

Workers have the most to fear from these systems, but have the least power to fight them. Truck drivers have already lost their fight about having their trucks being constantly monitored as they drive around. White collar workers have more power and so they need an incentive , something beneficial, to buy into the system.

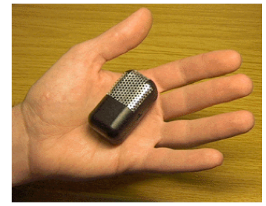
In this early case, there was no real down side since it was the researchers themselves who experimented with the system. Today, the

Cambridge ATT's BAT

Figure 2. Bat wireless tag device. Powered by a single AA lithium cell, each Bat has a unique 48-bit ID, two input buttons, and—for output—a buzzer and two LEDs.

The Bat itself is small, mostly taking up by the size of the battery. It has a small amount of output: an LED and a buzzer and one input, a button. It is amazing how much one can do with a single button. Actually, it has two buttons, one for on/off.

BAT Details



- Ultrasound transmitters
  - 5 cm x 3 cm x 3 cm; 35 grams
  - unique id (48 bit)
  - temp id (10 bit) -- reduces power
  - button (just one)
  - rf transceiver
- Receivers in ceiling
- Base station
  - periodically queries, then bats respond
  - query time, recv time, room temp
    - 330 m/s + .6*temp; >2 receivers ==> location

48 bit id? How many did they expect to build! Even 10 bit was too large :) Notice that there is some factor called "temp" -- this is the temperature of the room.

More on BATs

- Deployment
  - 50 staff members, 200 BATS, 750 Receivers, 3 Radio cells, 10,000 sq ft office space
- 20 ms per bat enables 50 BATs / sec
- Smart scheduling reduces BAT's power
  - while at rest, reduce frequency of query
  - detect activity at PC to deduce "rest"
- Convert BAT location to object locati
- Centralized Datebase
  - less latency than distributed query
  - better filtering and error detection

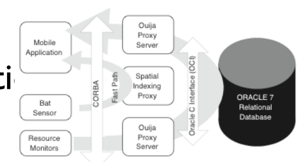
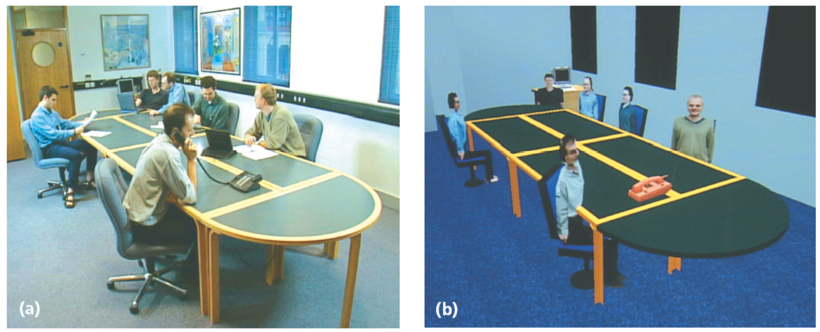


Figure 5. Three-tier architecture

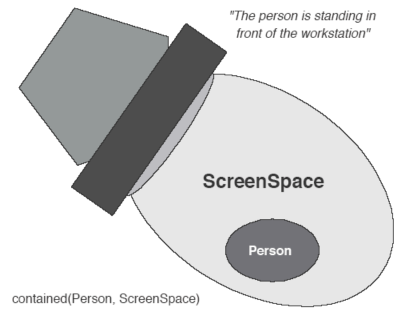
Feedback of Location-service

- Human-centric view of location information
- Cuteness reduces concern over privacy



Programming Model?

- Analogous to window-system. BAT enters workstation space, causes an event call-back



Application: Follow-me Desktop

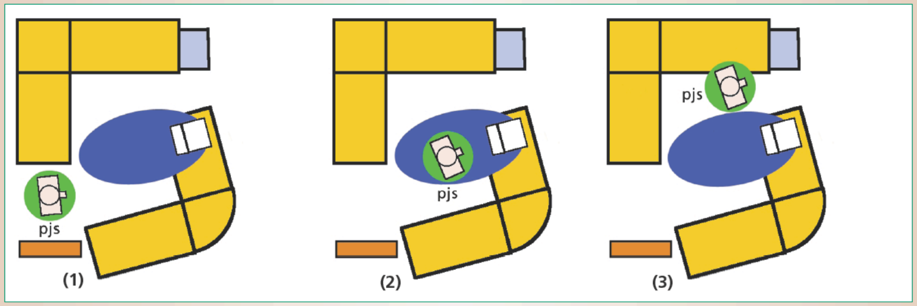
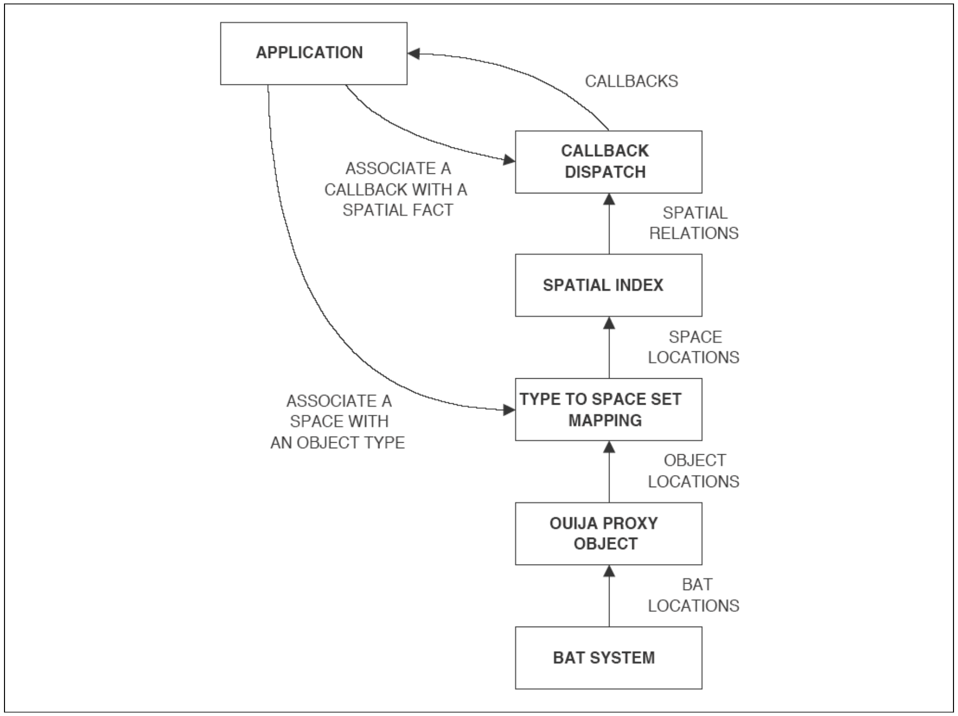


Figure A. Spatial monitoring application that moves users' desktops around with them. The application registers with the Spatial Monitor (1); as the user (pjs) approaches the display (2) or moves away from it (3), the spatial monitor sends a positive or negative containment event to the application that transfers or removes the desktop to or from the screen.


APPLICATION
CALLBACKS
ASSOCIATE A CALLBACK WITH A SPATIAL FACT
CALLBACK DISPATCH
SPATIAL RELATIONS
SPATIAL INDEX
SPACE LOCATIONS
ASSOCIATE A SPACE WITH AN OBJECT TYPE
TYPE TO SPACE SET MAPPING
OBJECT LOCATIONS
OUIJA PROXY OBJECT
BAT LOCATIONS
BAT SYSTEM

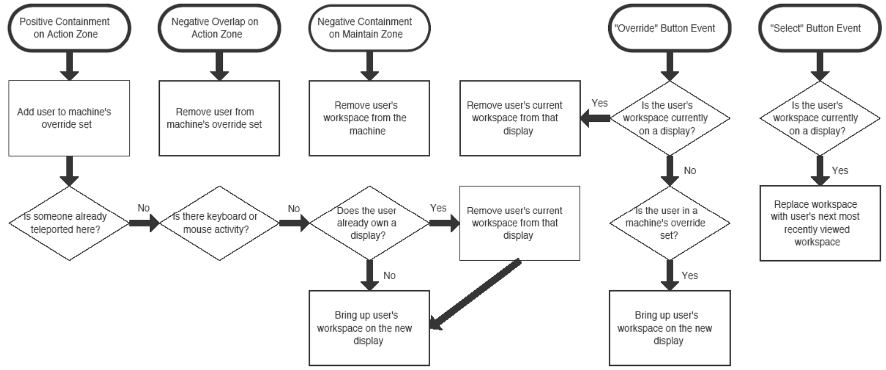


Figure 11. Event-condition-action diagram describing Bat Teleporting

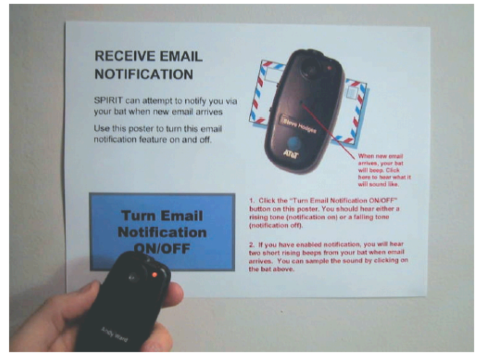
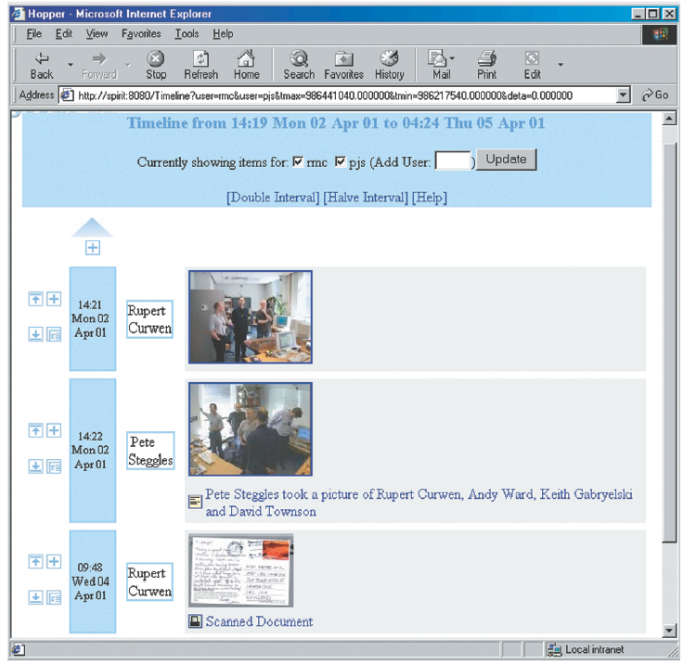


Figure 5. A smart poster. In this example, a user controls an e-mail notification service with a smart poster.


Hopper - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Forward Stop Refresh Home Search Favorites History Mail Print Edit
Address
Go
Timeline from 14:19 Mon 02 Apr 01 to 04:24 Thu 05 Apr 01
Currently showing items for: rmc pjs (Add User:) Update
[Double Interval] [Halve Interval] [Help]
14:21 Mon 02 Apr 01
Rupert Curwen
14:22 Mon 02 Apr 01
Pete Steggles
Pete Steggles took a picture of Rupert Curwen, Andy Ward, Keith Gabryelski and David Townson
09:48 Wed 04 Apr 01
Rupert Curwen
Scanned Document
Local intranet

How well does it work?

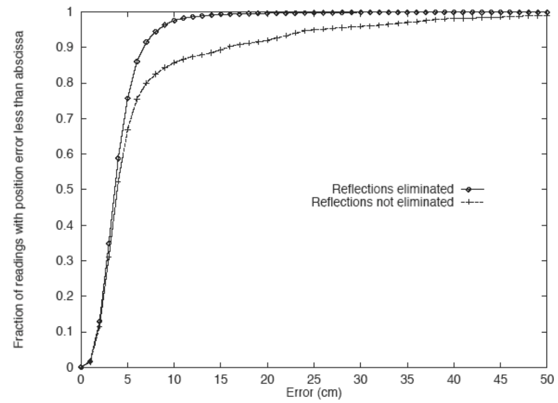


Figure 3. Position accuracy of ultrasonic tracker

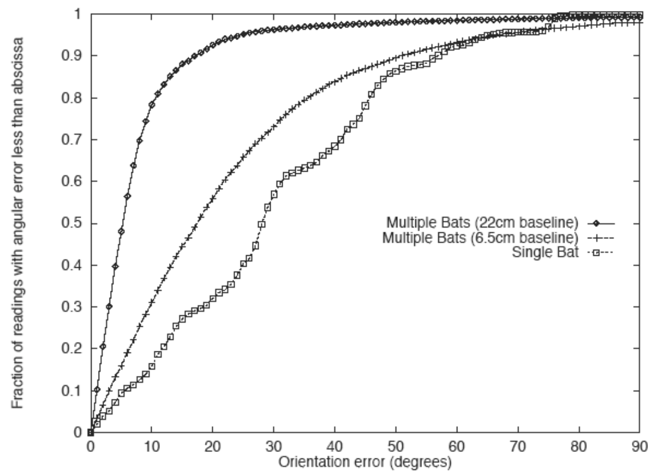


Figure 4. Orientation accuracy of ultrasonic tracker

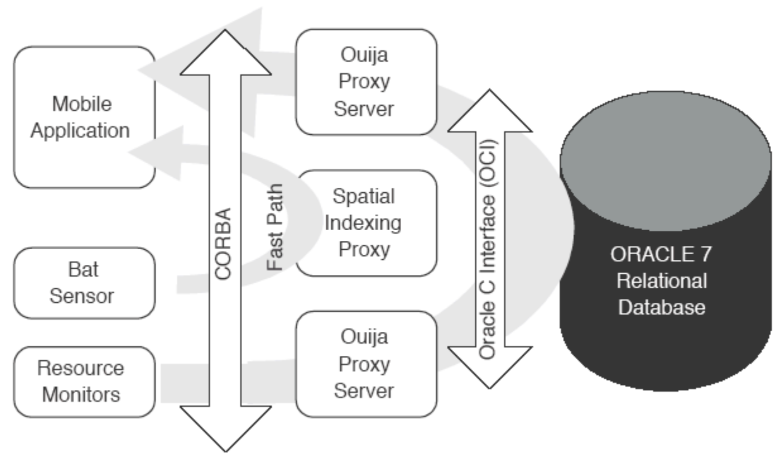


Figure 5. Three-tier architecture

Better Trackers

- Bayesian filtering on sensory data
- Predict where person will be in future.
  - position and speed over near past
  - behavior (avg speed) over long term
- Uses
  - Filter bad sensory data
  - Likely place to find someone
  - Predict which sensors to monitor

A few details of Bayesian Filtering

- Bayes filters estimate posterior distribution over the state x_t of a dynamical system conditioned on all sensor information collected so far:

$$p(x_t \mid z_{1:t}) \propto p(z_t \mid x_t) \int p(x_t \mid x_{t-1})\, p(x_{t-1} \mid z_{1:t-1}) dx_{t-1}$$

To compute the likelihood of an observation z given a position x on the graph, we have to integrate over all 3d positions projected onto x:

$$p(z|x) = \int_{\nu \in \mathcal{S}(x)} p(z \mid \nu)\; p(\nu \mid x)\; d\nu,$$

See “Voronoi tracking ...” Liao, et al.

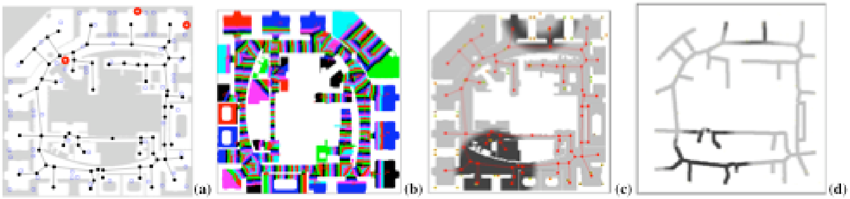


Figure 1: *Voronoi graphs for location estimation: (a) Indoor environment along with manually pruned Voronoi graph. Shown are also the positions of ultrasound Crickets (circles) and infrared sensors (squares). (b) Patches used to compute likelihoods of sensor measurements. Each patch represents locations over which the likelihoods of sensor measurements are averaged. (c) Likelihood of an ultra-sound cricket reading (upper) and an infrared badge system measurement (lower). While the ultra-sound sensor provides rough distance information, the IR sensor only reports the presence of a person in a circular area. (d) Corresponding likelihood projected onto the Voronoi graph.*

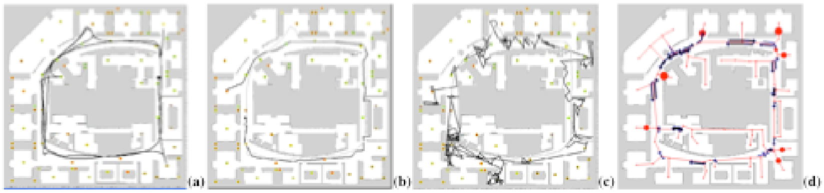
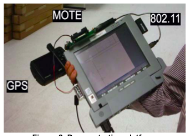


Figure 3: *(a) Trajectory of the robot during a 25 minute period of training data collection. True path (in light color) and most likely path as estimated using (b) Voronoi tracking and (c) original particle filters. (d) Motion model learned using EM. The arrows indicate those transitions for which the probability is above 0.65. Places with high stopping probabilities are represented by disks. Thicker arcs and bigger disks indicate higher probabilities.*

Universal Location Framework

- Stack: Sensor, Measure, Fusion, Application
- Location API (preliminary)
  - What: timestamp, position, uncertainty
  - When: Automatic (push), Manual (pulll), Periodic
- 802.11 base station location
  - Calibrated database of signal characteristics
  - 3 to 30 meter accuracy



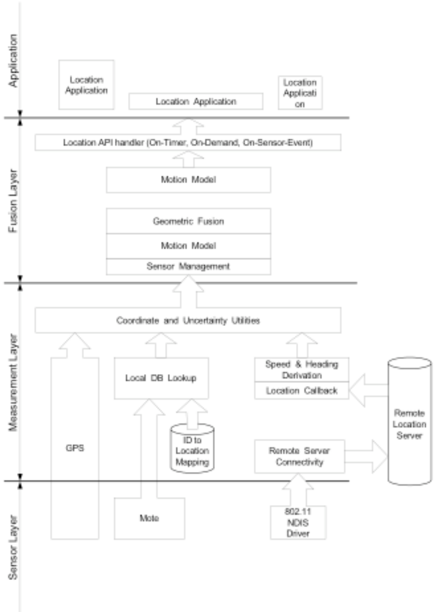


Figure 3. Universal Location Framework block diagram.

Division of Labor

- Determining the location of object
- Associating name with location
  - Object (or person) has name
  - Object has a location
    - physical or virtual (instantiation of program on some machine)
- Need scalable solution to connect them
  - RFIDs demand scalability

CSAIL

Critique

- **Pro's**
  - one button, one device
- **Con's**
  - infrastructure: expensive, poor maintenance
  - only does one function: location
- **Modern version**
  - wireless sensor networks (with or without wires)