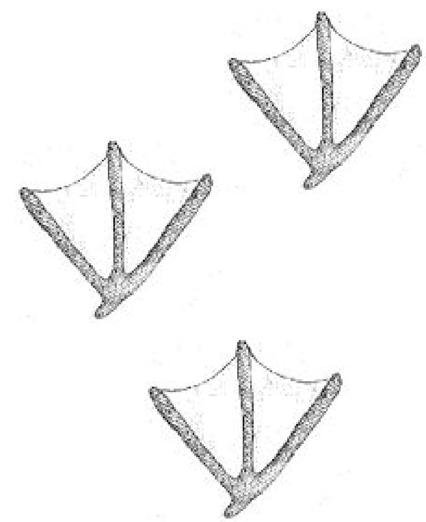
Tracking Indoors



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Location of what?

- Objects
  - Static, Moveable, or Mobile
    - Frequency of movement: door, desk, laptop
  - Dumb or Networked

- People
  - Waldo asks “Where am i?”
  - System asks “where’s Waldo?”

I think I found him.

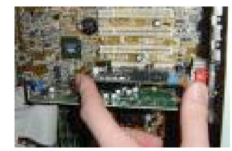
- Services
  - applications, resources, sensors, actuators
  - where is a device, web site, app

Tracking technology

- Some examples:
  - 802.11; Bluetooth (Intel, HP, ..), RFID
  - ParcTab (Xerox)
  - Active Badge (Cambridge ATT)
  - BATs (Cambridge ATT)
  - Crickets (MIT)
- Cameras

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

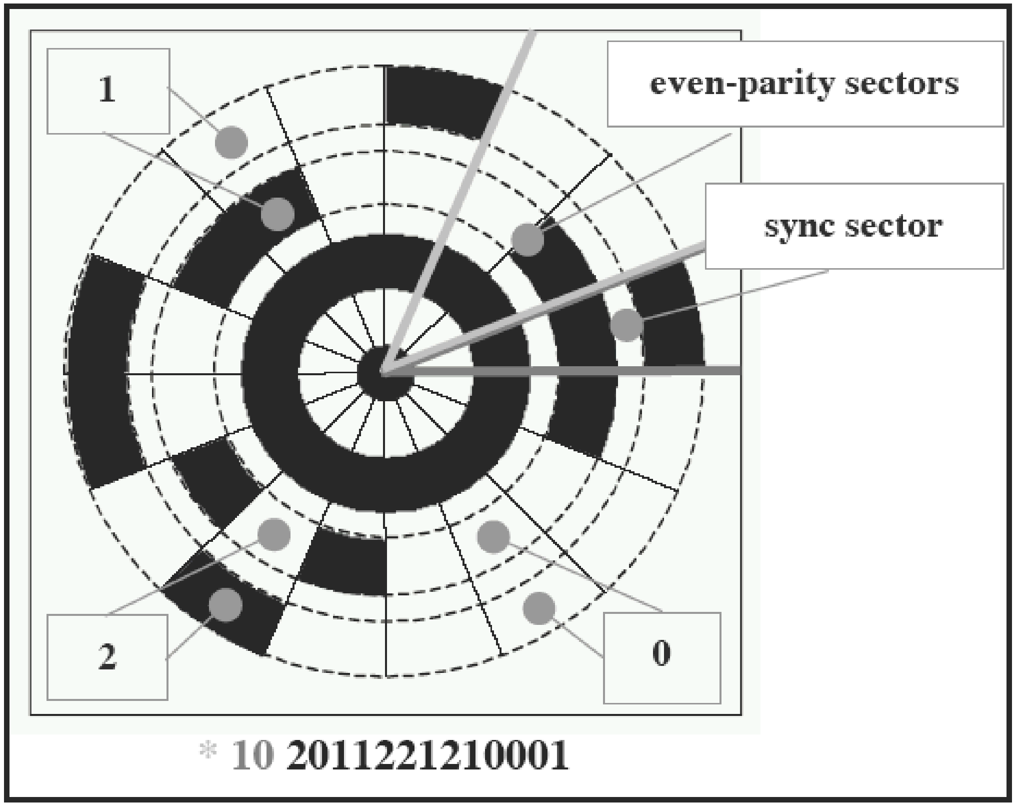


Figure 1. TRIPcode representing number 1,160,407

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 1-3^{13} (1,594,323). Only off-the-shelf hardware is required, i.e. low-resolution CCD cameras and CPU processing power.

Cambridge ATT’s BAT

Cambridge ATT's BAT

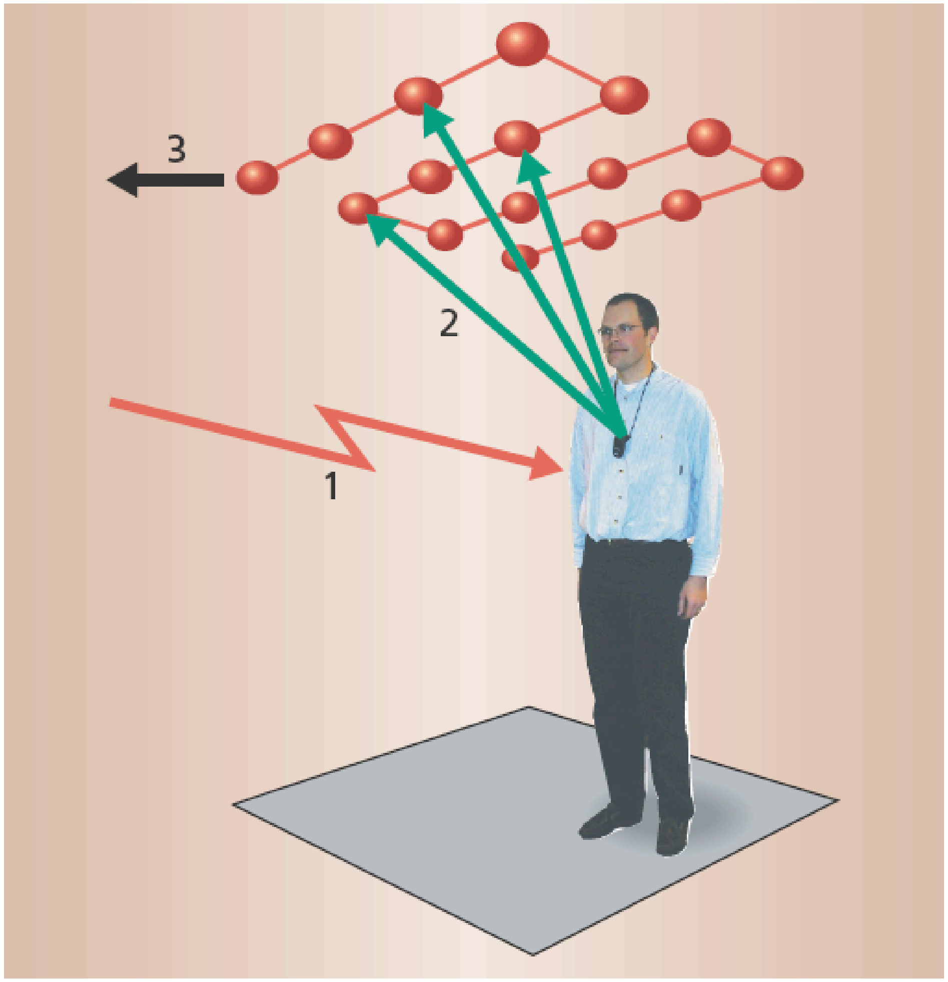
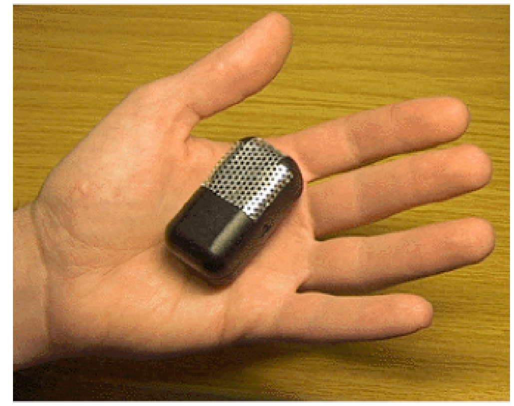


Figure 1. Operation of the Bat location sensor system. A Bat is triggered over a wireless link (1), which causes it to emit an ultrasonic pulse (2). Ceiling-mounted receivers measure the pulse's times of flight, and a controller retrieves the times of flight (3) over a wired network. The controller uses these measurements to calculate Bat-receiver distances and thus the Bat's 3D position.

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.

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

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

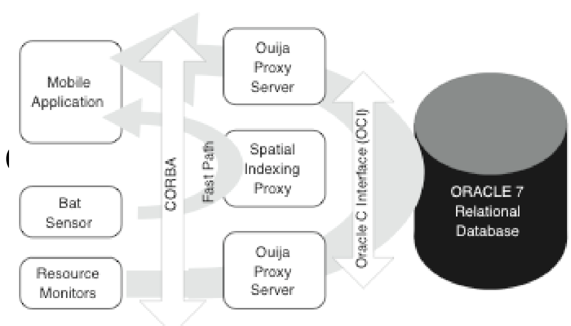
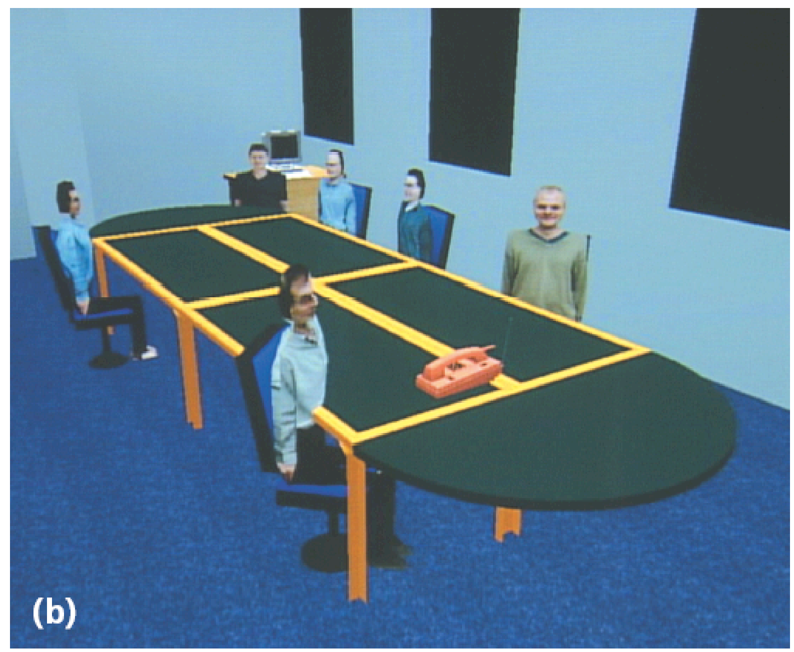


Figure 5. Three-tier architecture

Feedback of Location-service

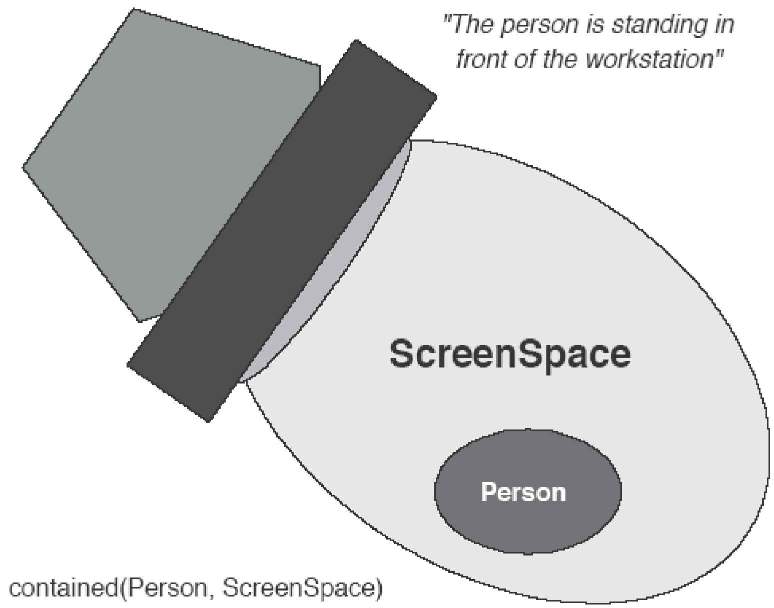
Human-centric view of location information

Cuteness reduces concern over privacy



Programming Model?

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



Application: Follow-me Desktop

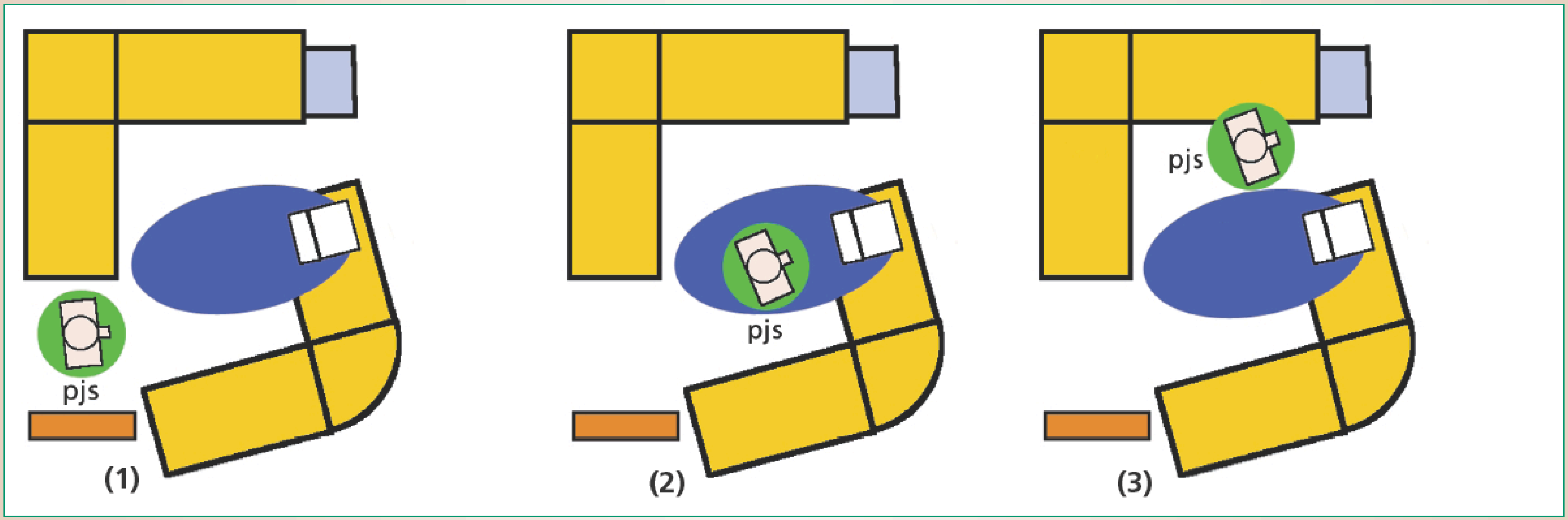
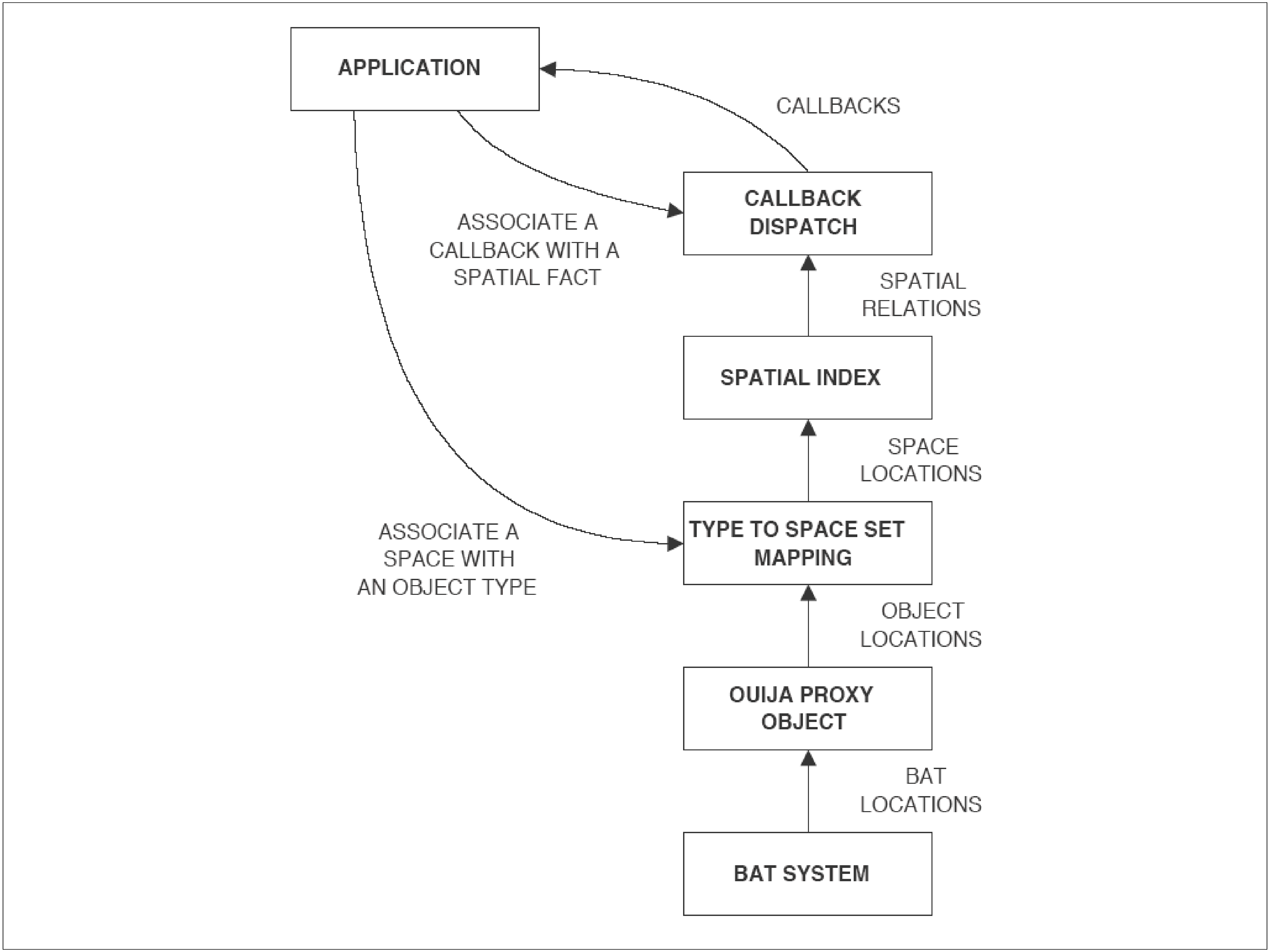


Figure A. Spatial monitoring application that moves users' desktops around with them. The application registers with the Spatial Monitor (1); as the user (pjs) approaches the display (2) or moves away from it (3), the spatial monitor sends a positive or negative containment event to the application that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


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

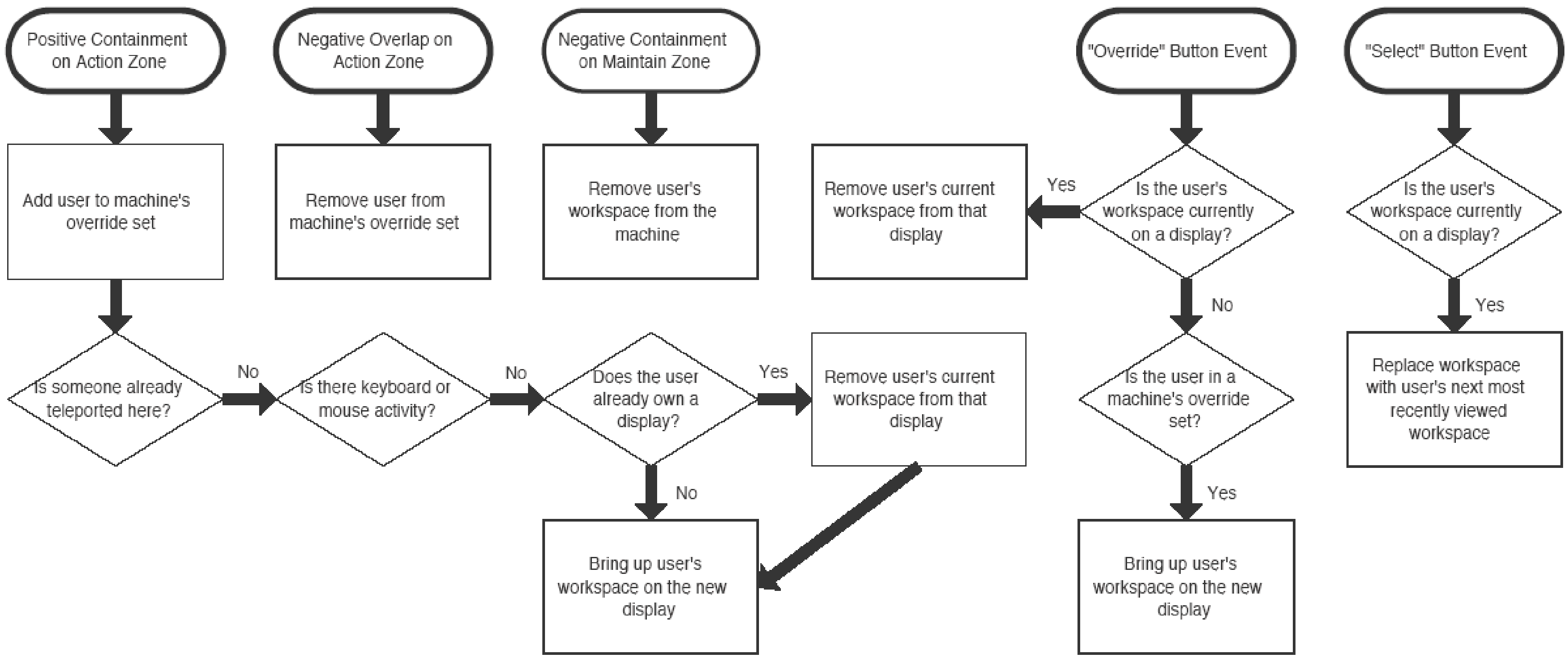
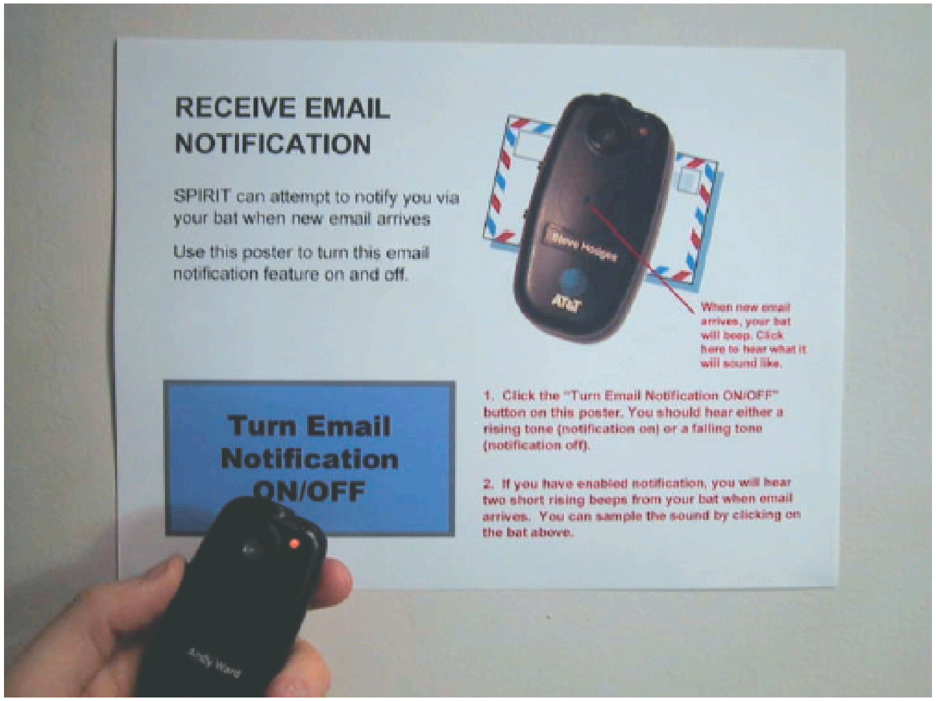
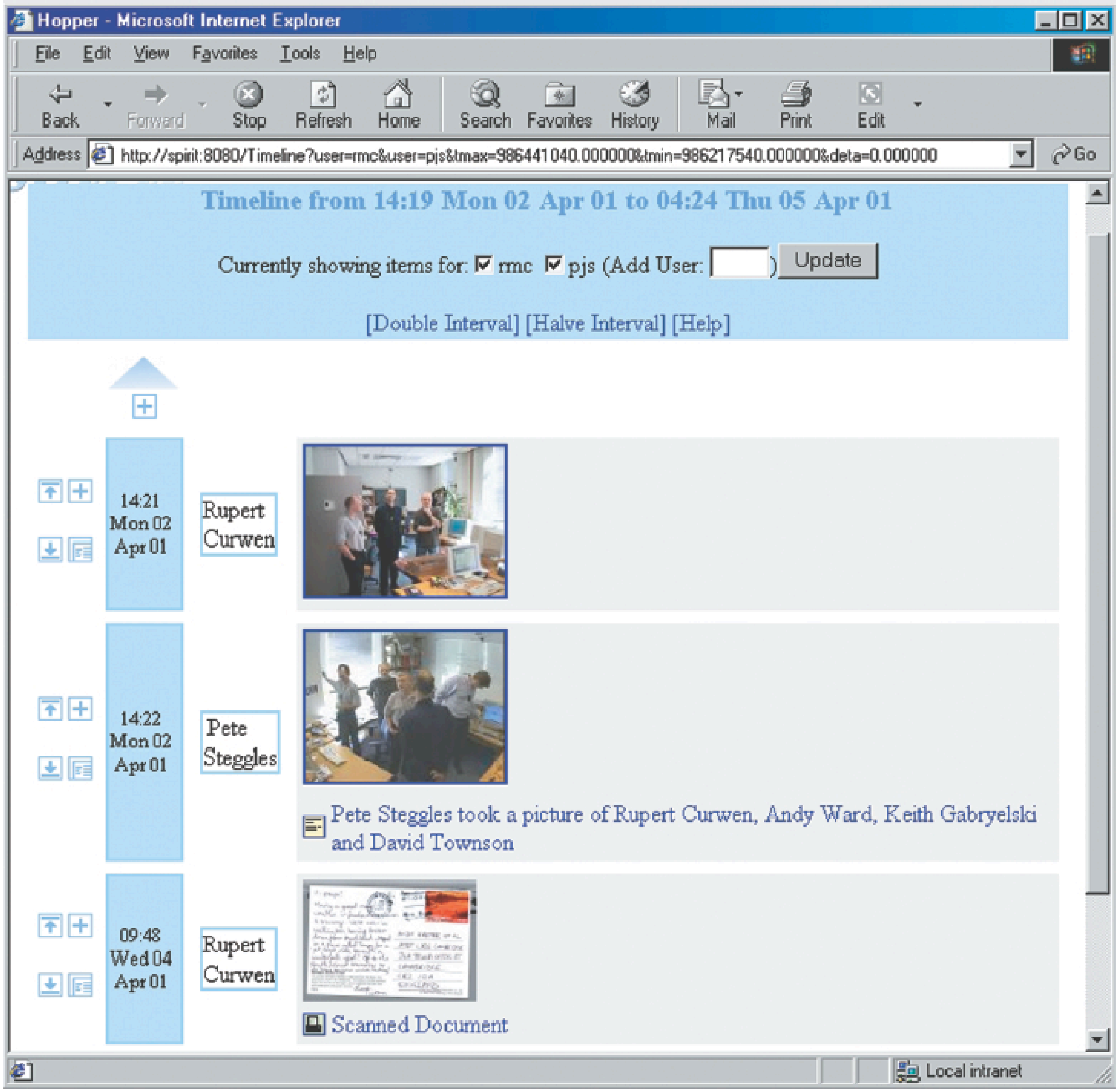


Figure 11. Event-condition-action diagram describing Bat Teleporting

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 http://spirit:8080/Timeline?user=rmc&user=pjs&tmax=986441040.000000&tmin=986217540.000000&deta=0.000000
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?

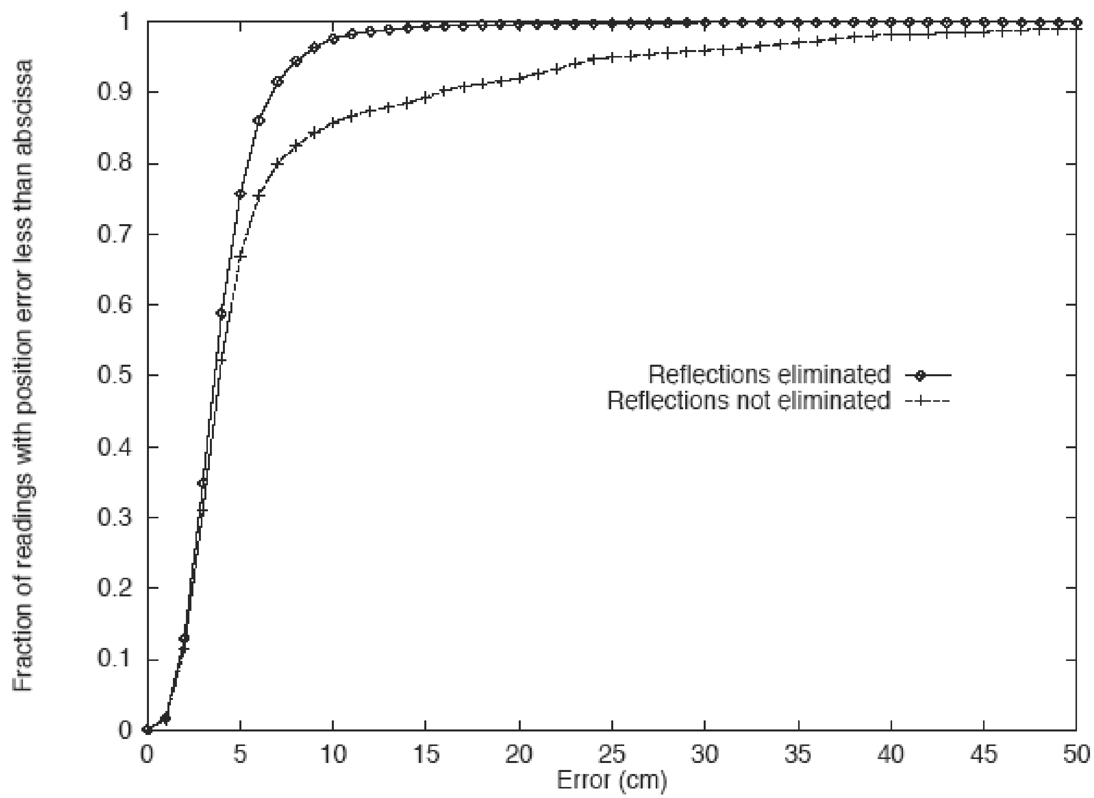


Figure 3. Position accuracy of ultrasonic tracker

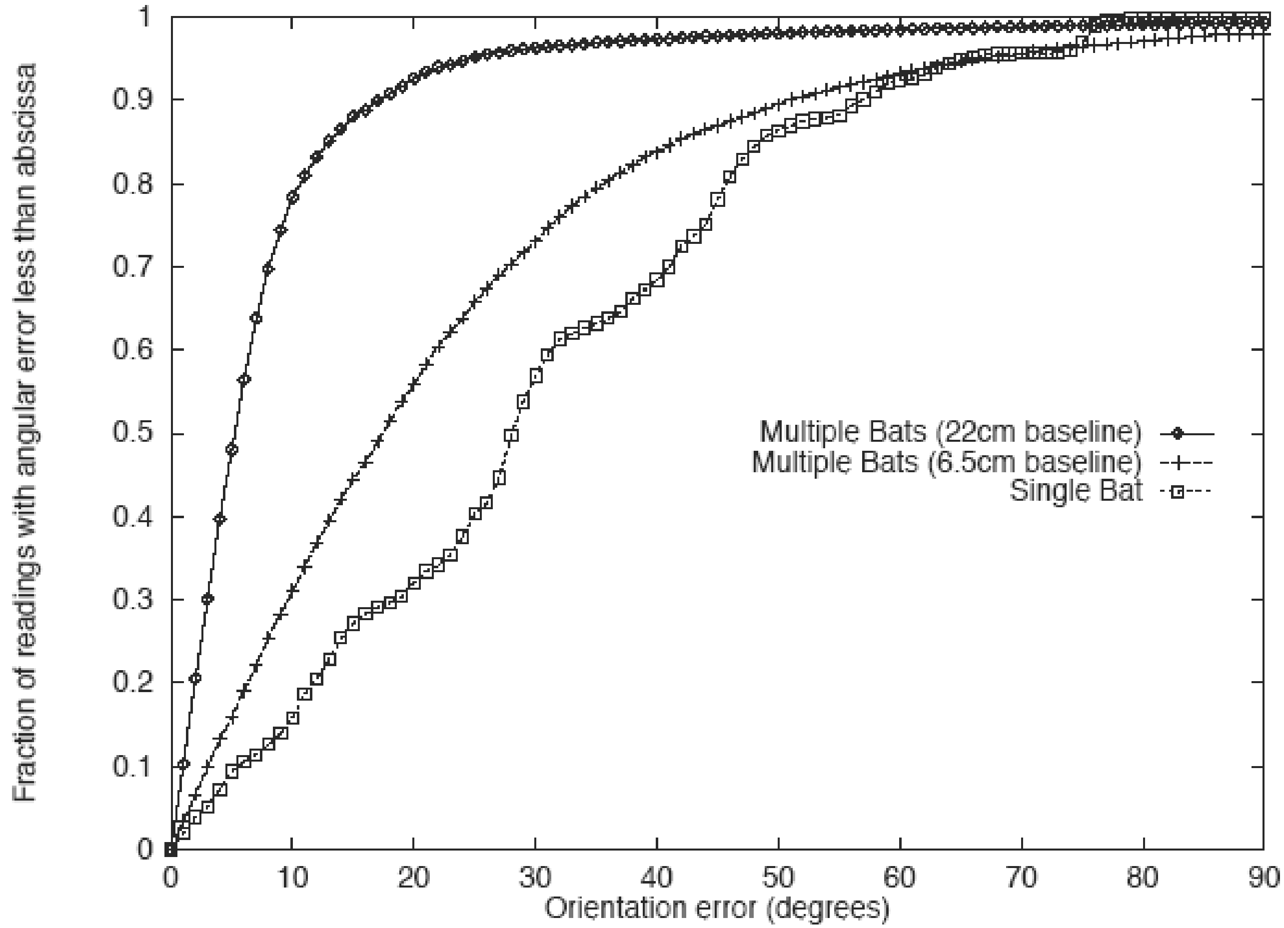


Figure 4. Orientation accuracy of ultrasonic tracker

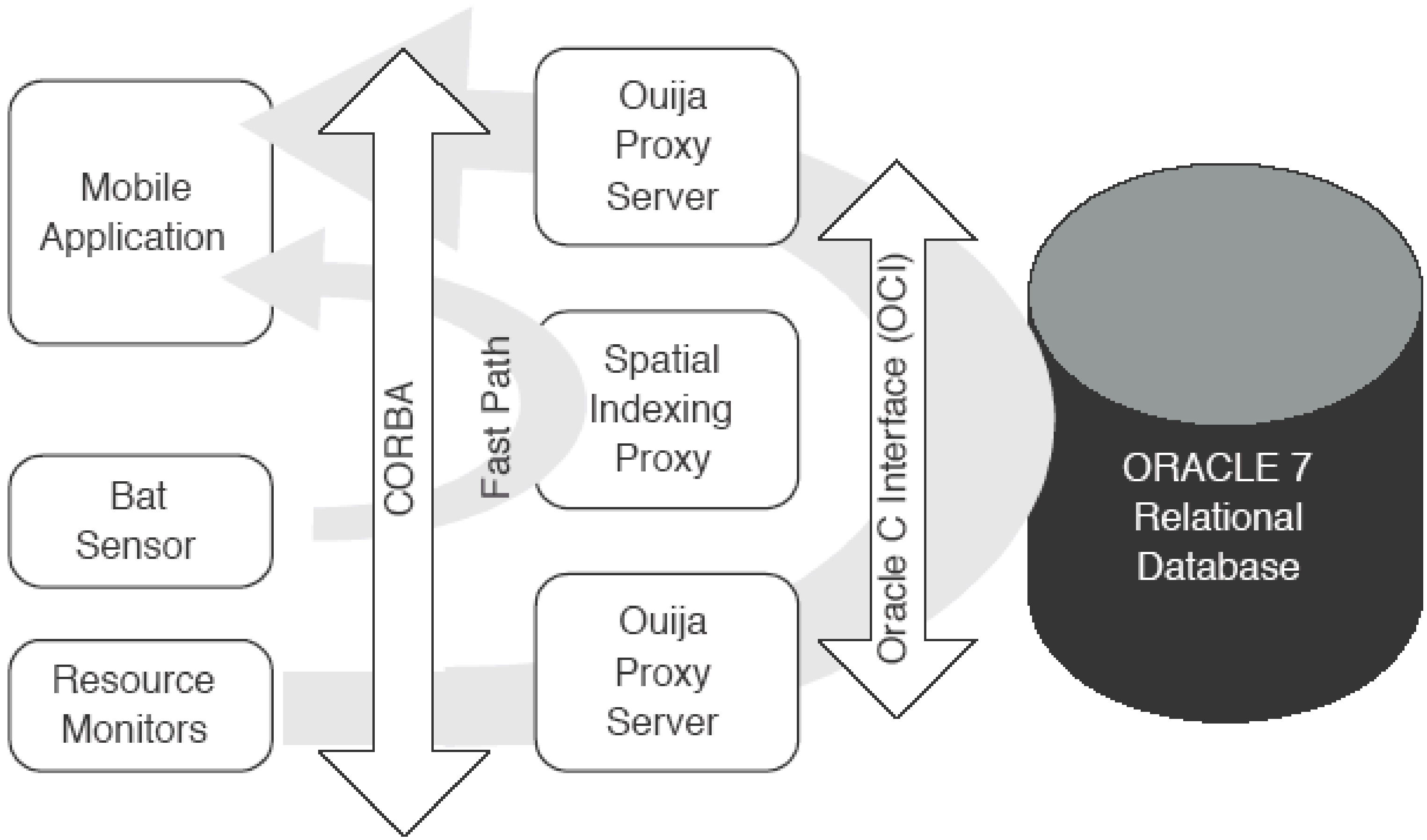


Figure 5. Three-tier architecture

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:

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

See “Voronoi tracking …” Liao, et al.

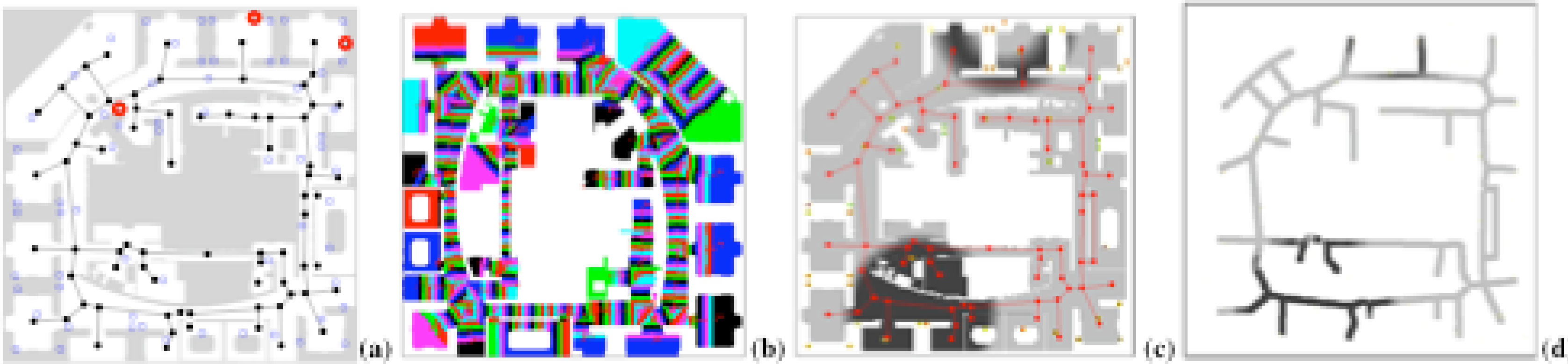


Figure 1: *Voronoi graphs for location estimation: (a) Indoor environment along with manually pruned Voronoi graph. Shown are also the positions of ultrasound Crickets (circles) and infrared sensors (squares). (b) Patches used to compute likelihoods of sensor measurements. Each patch represents locations 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.*

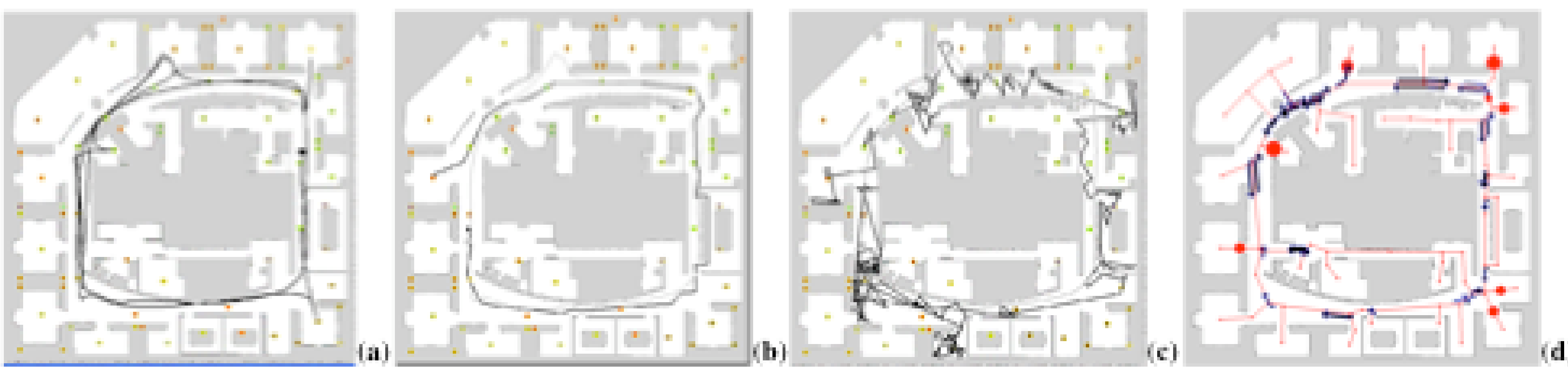


Figure 3: *(a) Trajectory of the robot during a 25 minute period of training data collection. True path (in light color) and most likely path as estimated using (b) Voronoi tracking and (c) original particle filters. (d) Motion model learned using EM. The arrows indicate those transitions for which the 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

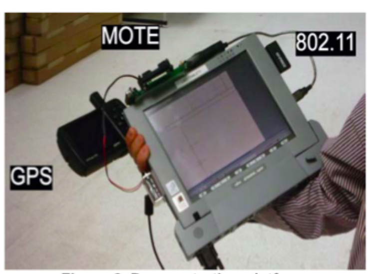
Stack: Sensor, Measure, Fusion, Application

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



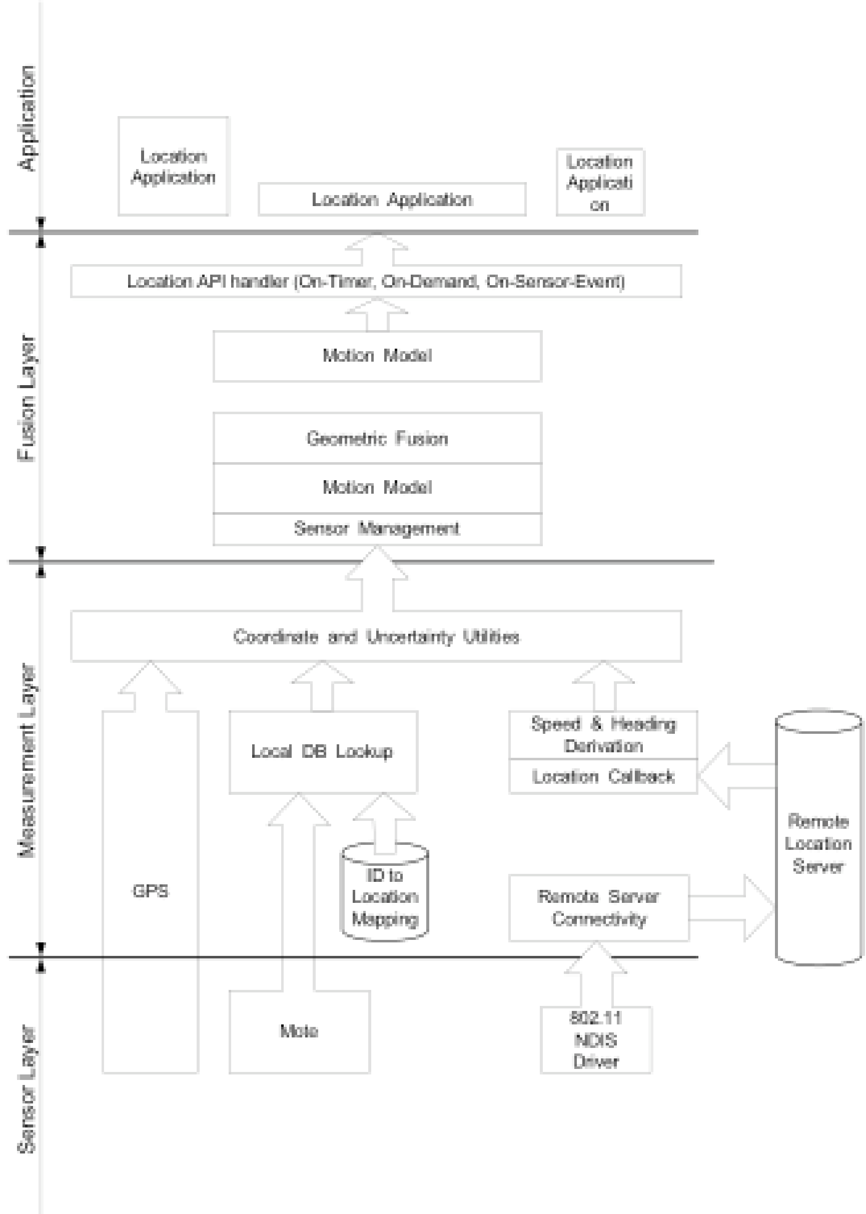


Figure 3. Universal Location Framework block diagram.

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

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