The Bat System

Ubiquitous Computing in Action

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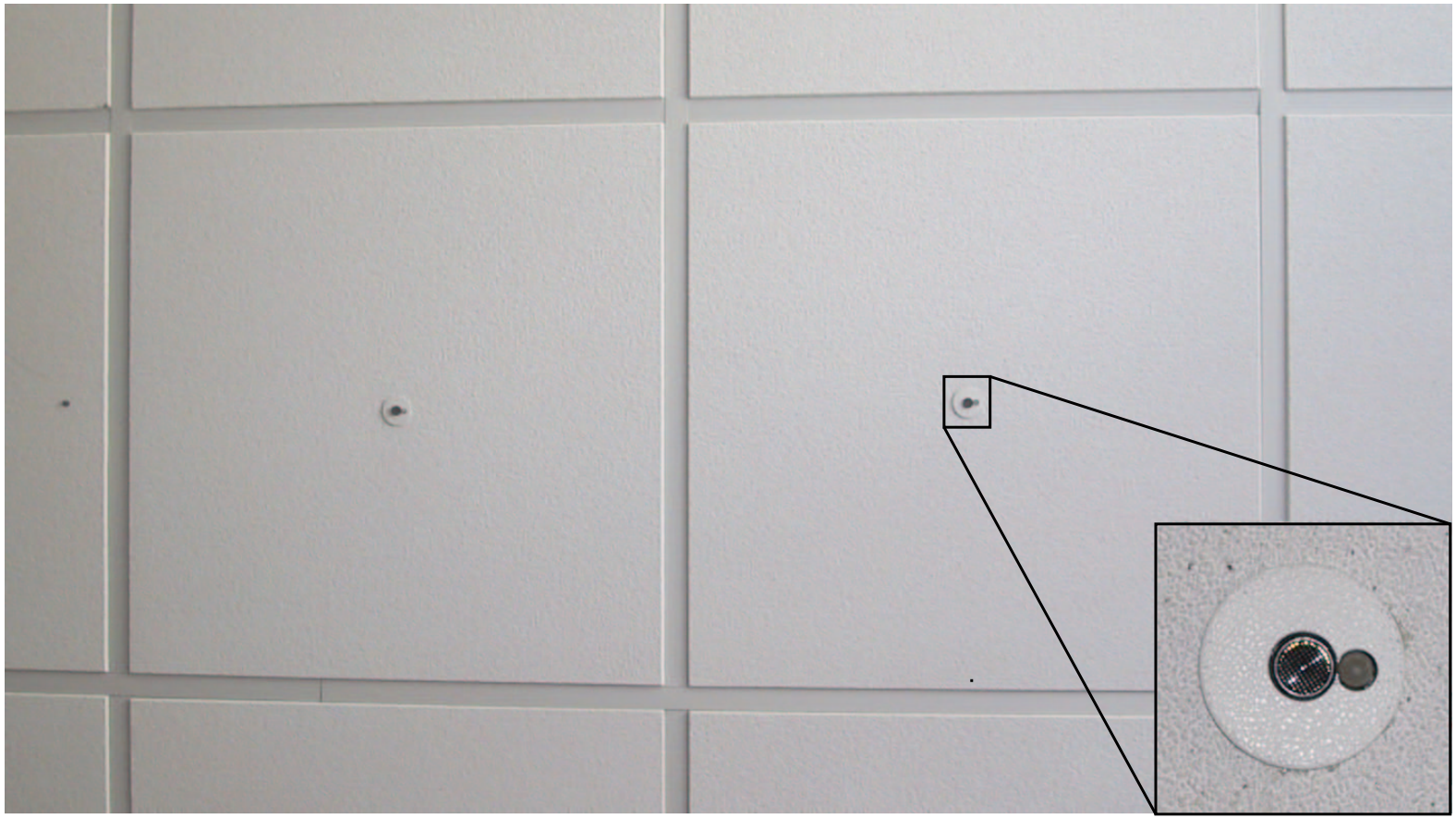
Bat History

- 1992: Initial Active Badge System (ORL)
- 1994: Room Portion Accuracy with Active Badge (ORL)
- 1998: First Bat Prototype (UofC)
- 2000: Flat Bat (AT&T Labs)
- 2002: LCE Installation (UofC)

Bat Principles - ToF Measurement

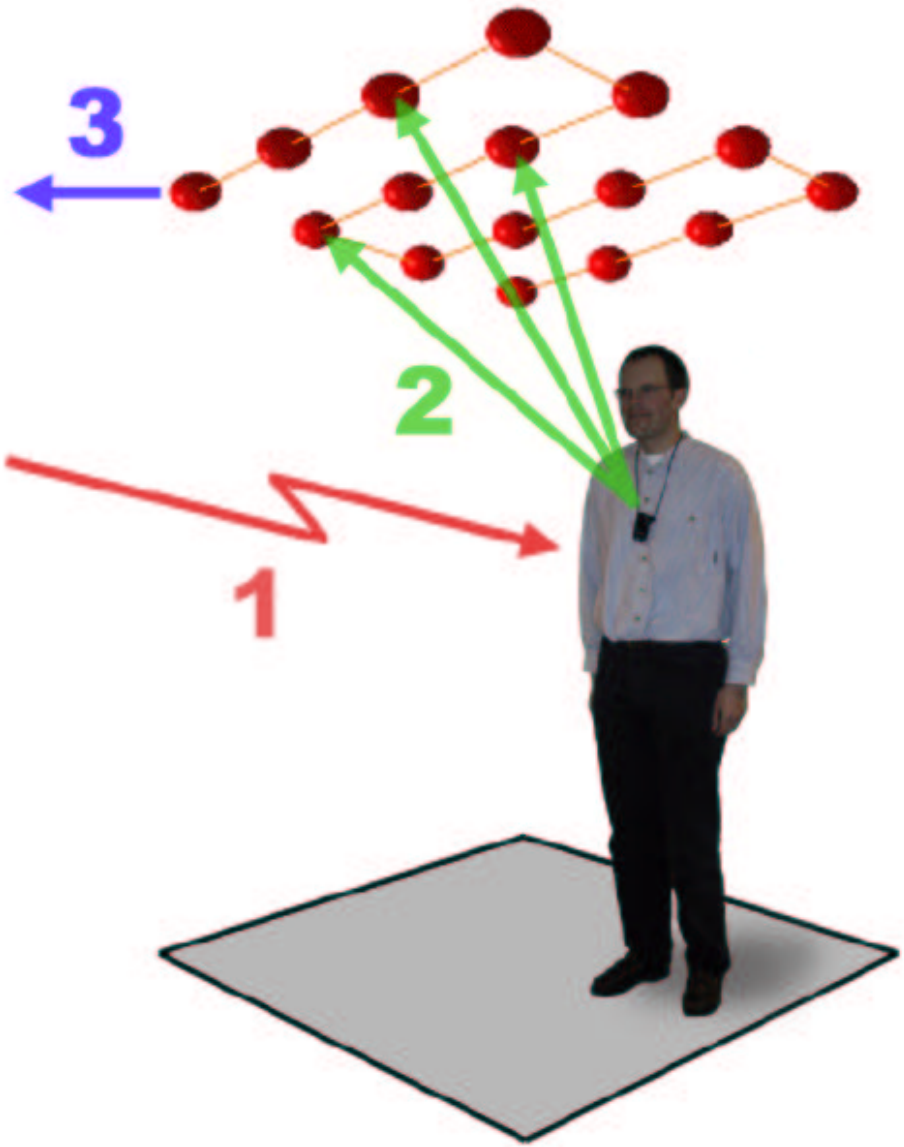


- Matrix of ultrasonic receivers in ceiling tiles

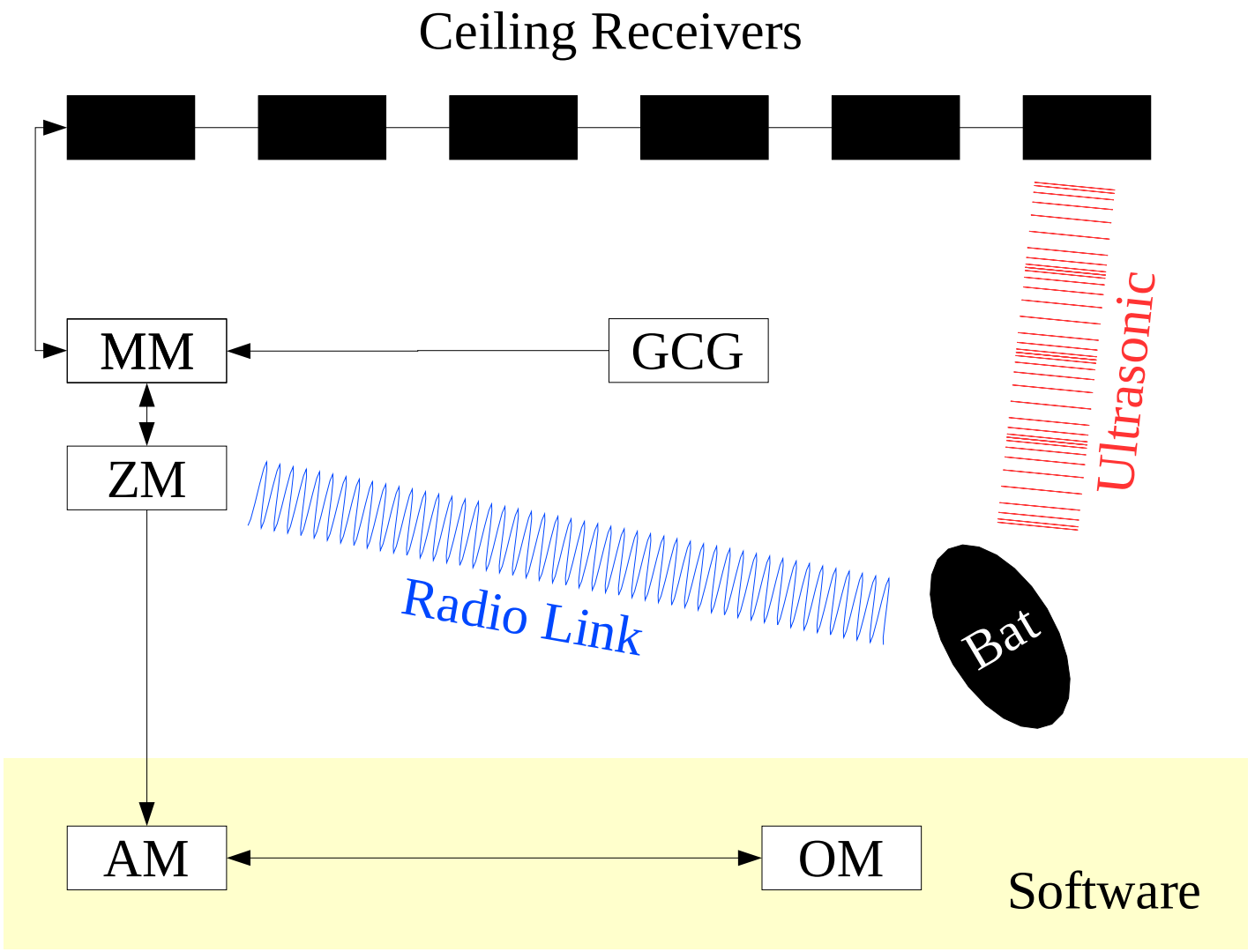
Bat Principles - ToF Measurement

- In building radio transmitter
- Tags or ‘Bats’ are attached to users and equipment
- Bats contain ultrasonic transmitter and radio transceiver
- Radio transmitter polls Bats in turn, triggering ultrasonic emission
- Ceiling receivers measure time from radio poll to ultrasonic reception

Bat Principles - Multilateration



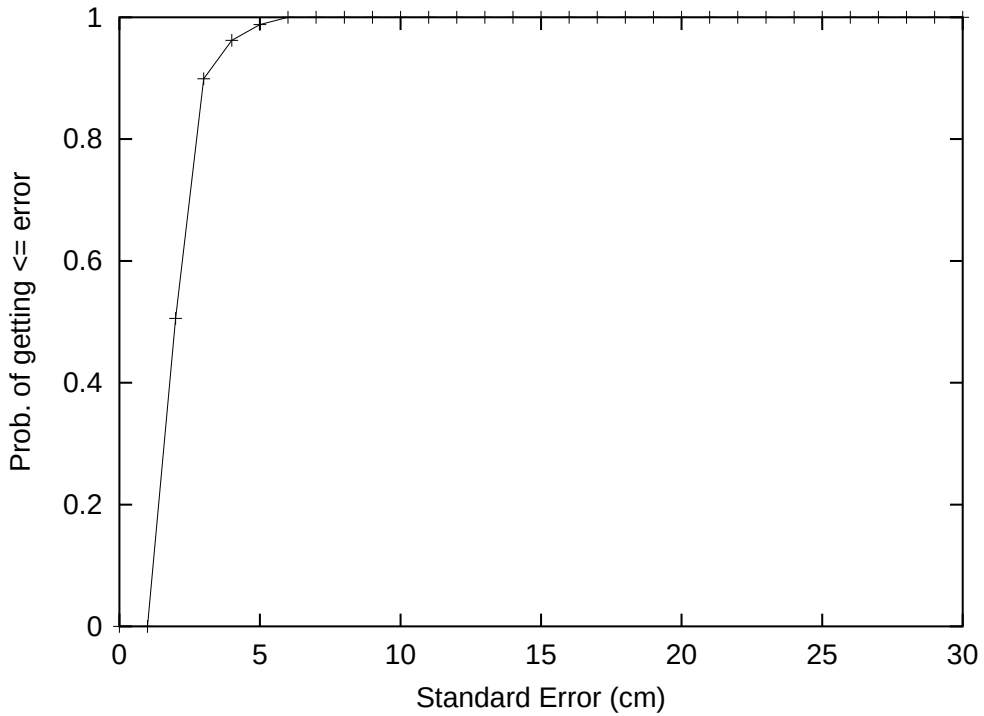
System Implementation



System Scalability

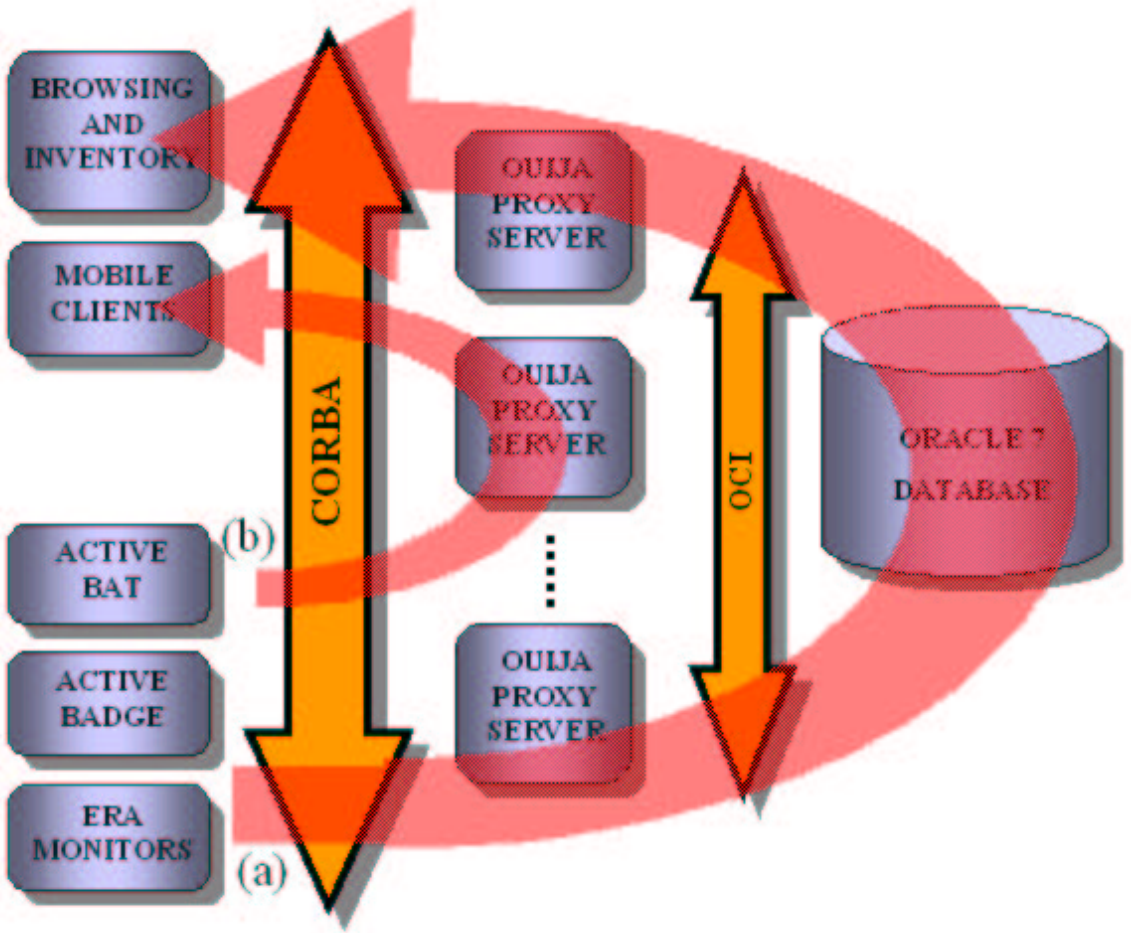
- Average ceiling receiver density 0.6 m^{-2}
- Offload positioning calculation to DSP
- One DSP per average room
  - Scaling is O(n), but no wide-area performance hit
- One radio transmitter zone per floor

Bat System Performance



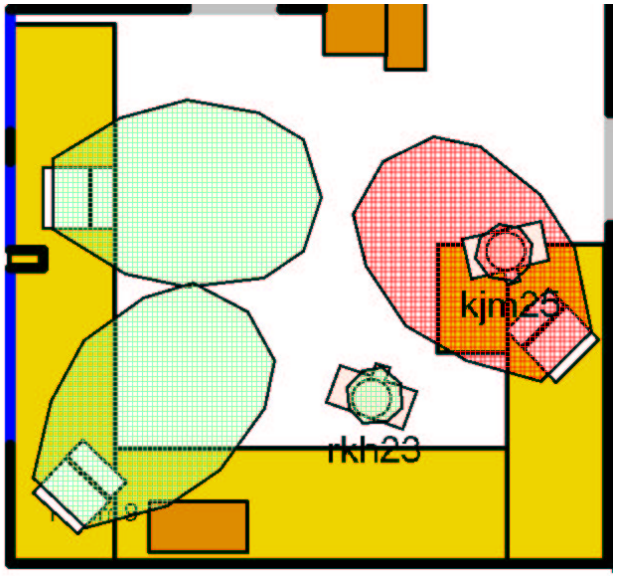
- $3cm$ linear error 95% of the time
- Higher levels of error arise from, poor ceiling receiver geometry, high levels of multipath and ultrasonic noise pollution

SPIRIT



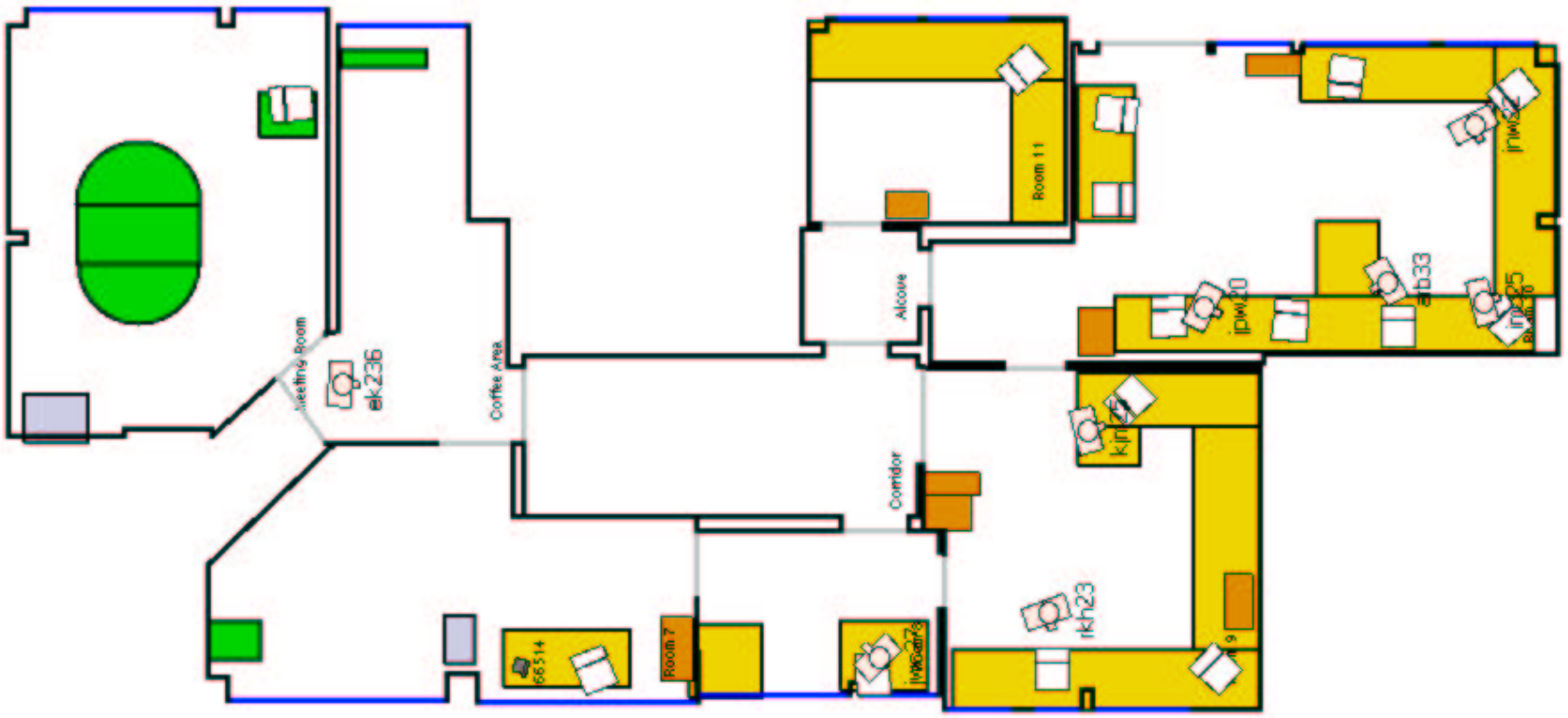
- SPatially Indexed Resource Identification and Tracking

Spatial Indexing



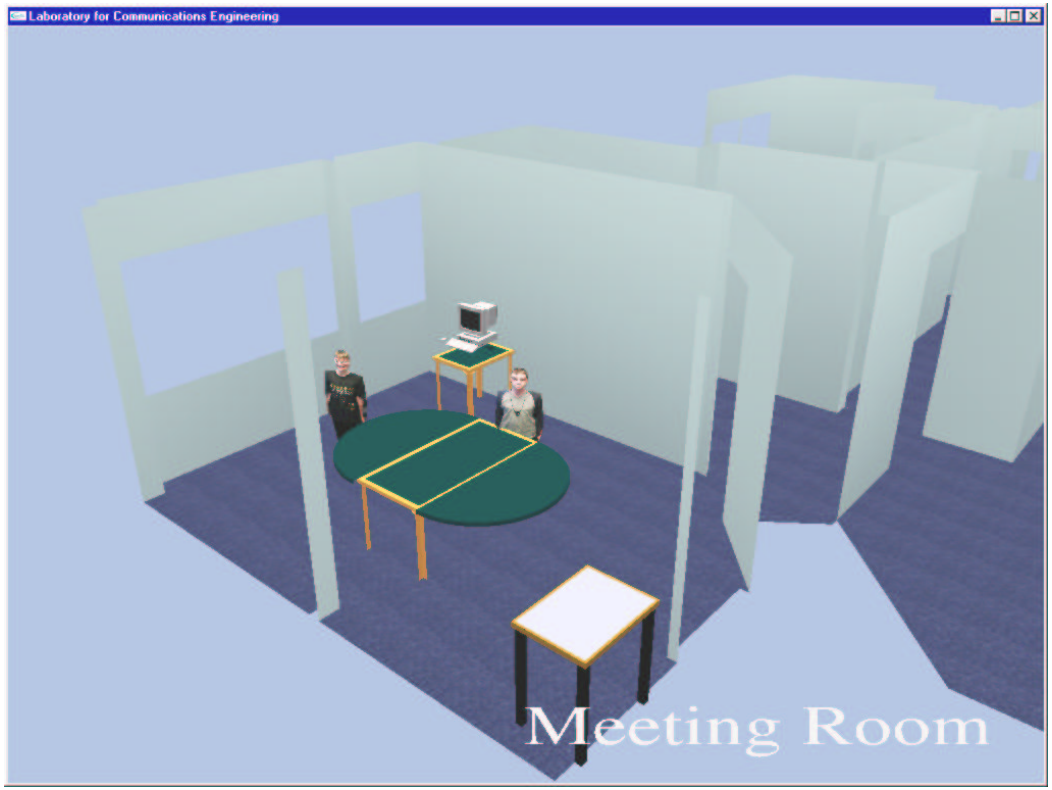
- User defined spatial zones produce CORBA events
- Zone indexing performed with a quad-tree based algorithm

Applications - Visualization



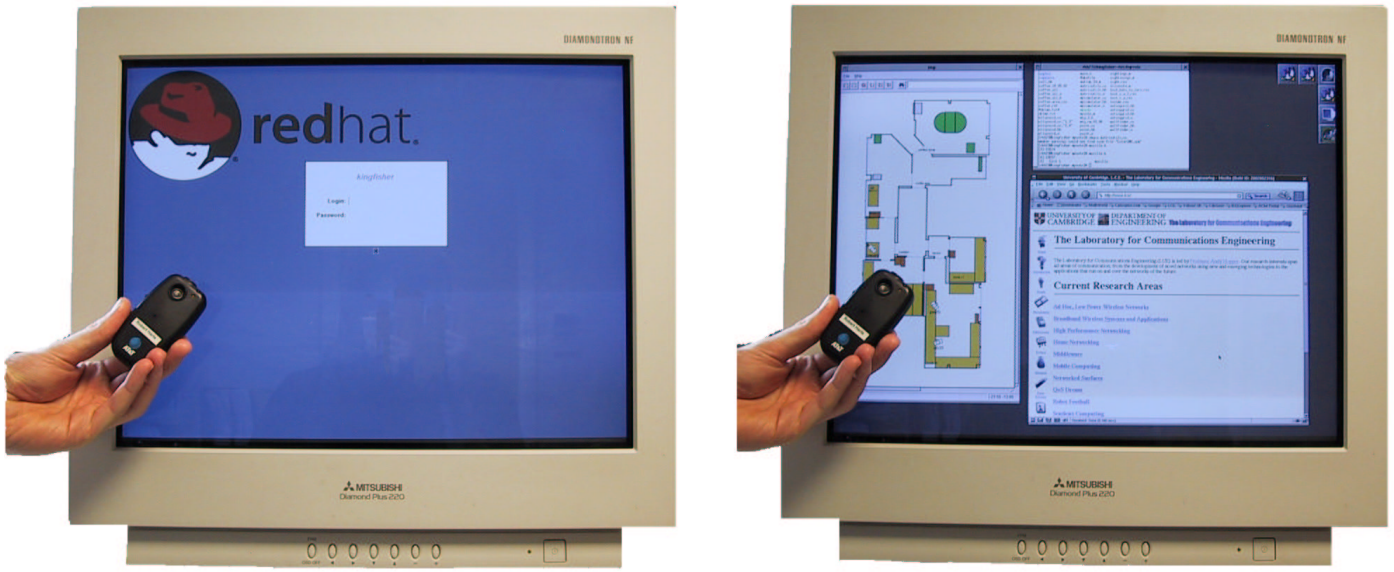
- A map provides human readable context information

Applications - Visualization



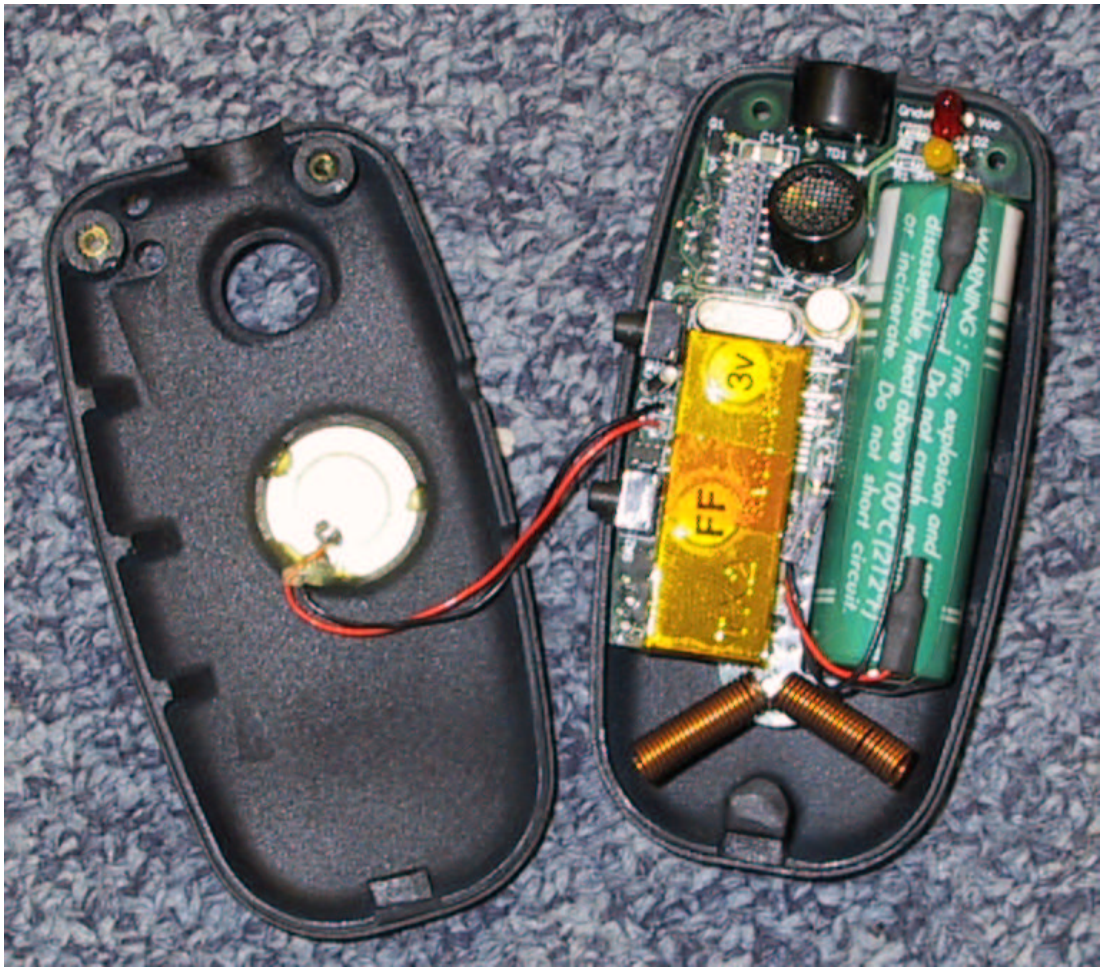
- A map provides human readable context information

Applications - Teleporting



- Hot-desking
- Example of a ‘follow-me’ application
- Other follow-me applications achieved with cameras and sound

Applications - Notification



- Bats contain a simple peizo-electric speaker providing basic feedback

Applications - Security

- Each Bat has a unique identity
- Identity can be used to enforce physical location security
  - Control access to parts of the office environment
  - Enforce health and safety requirements (two members in lab at all times)
  - Access can be both spatial and temporal
  - Current implementation requires trust in users
    - Identity transmitted in plain text
    - No challenge-response protocol

Applications - Active Posters

- Traditional desktop paradigm is not always efficient
- The Bat becomes the mouse, and the environment is the desktop
- Active Posters provide simple and efficient control of the ubiquitous environment
  - Toggle on or off SPIRIT services
  - Control devices, for example, a scanner
  - A plasma display becomes a dynamic Active Poster

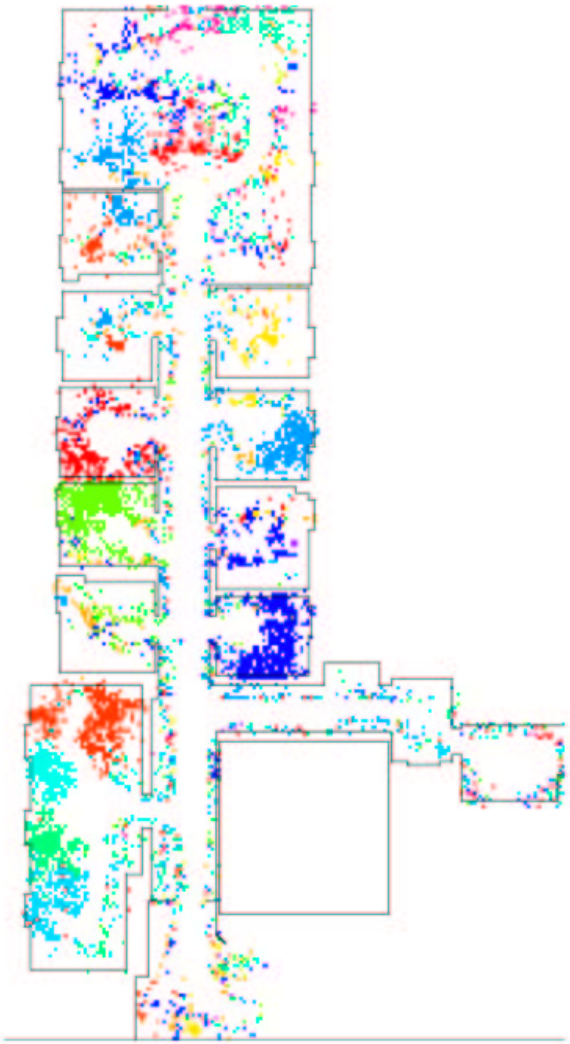
System Experiences

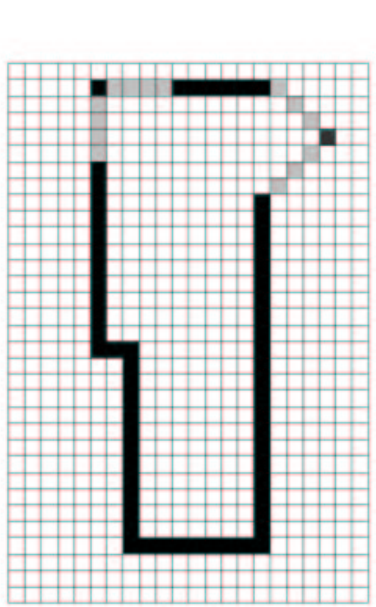
- Minimise wiring requirements—it really matters!
- Use high-quality connectors
- User acceptance
- Do not deploy without applications

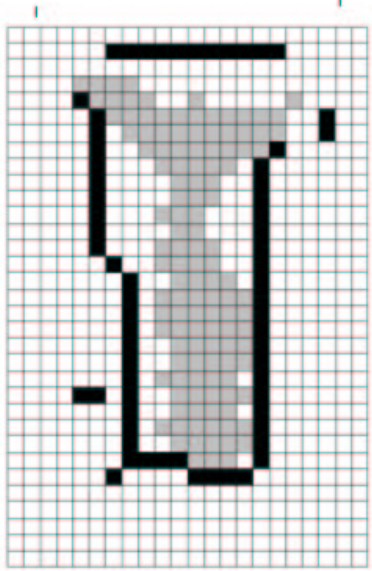
User Experiences

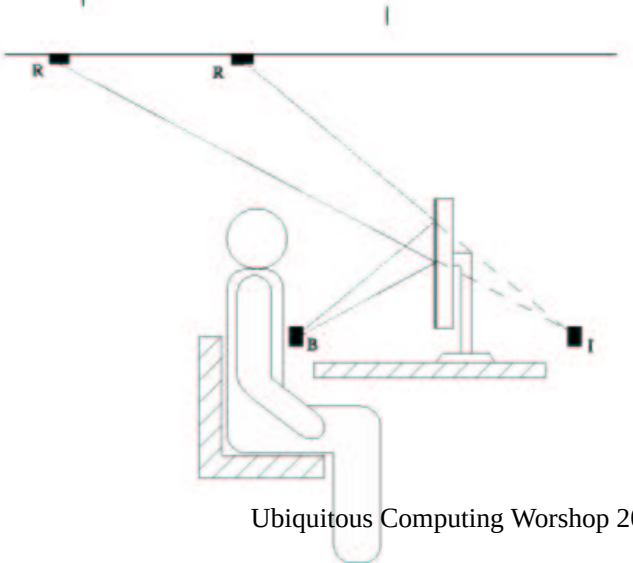
- Day-to-day use in our laboratory has provided interesting feedback:
  - Ultrasonic reflections and noise
  - Radio propagation and power
  - VNC implementation
  - Posters
  - Database
  - Always provide user feedback to button presses

Environment Discovery





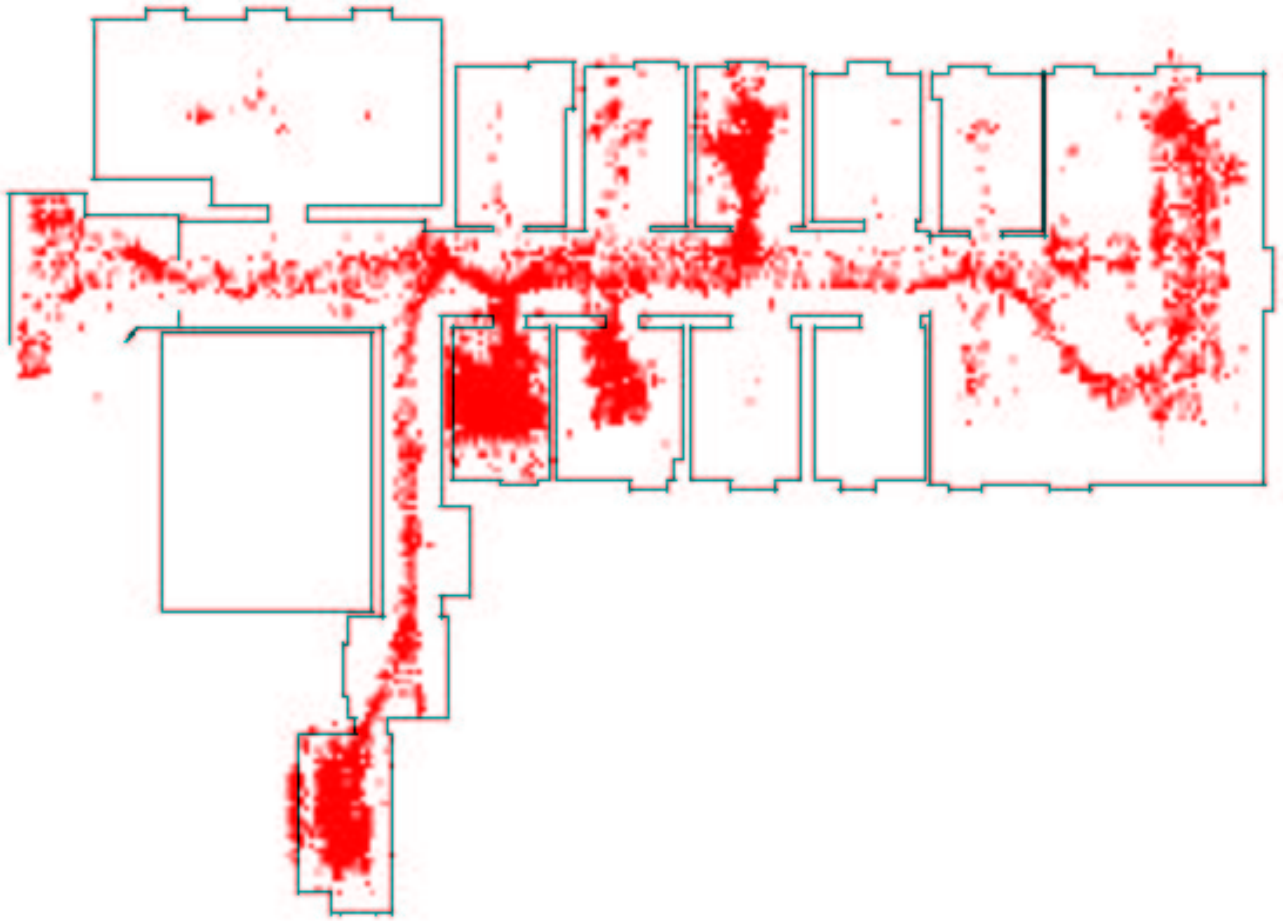




User Location Privacy

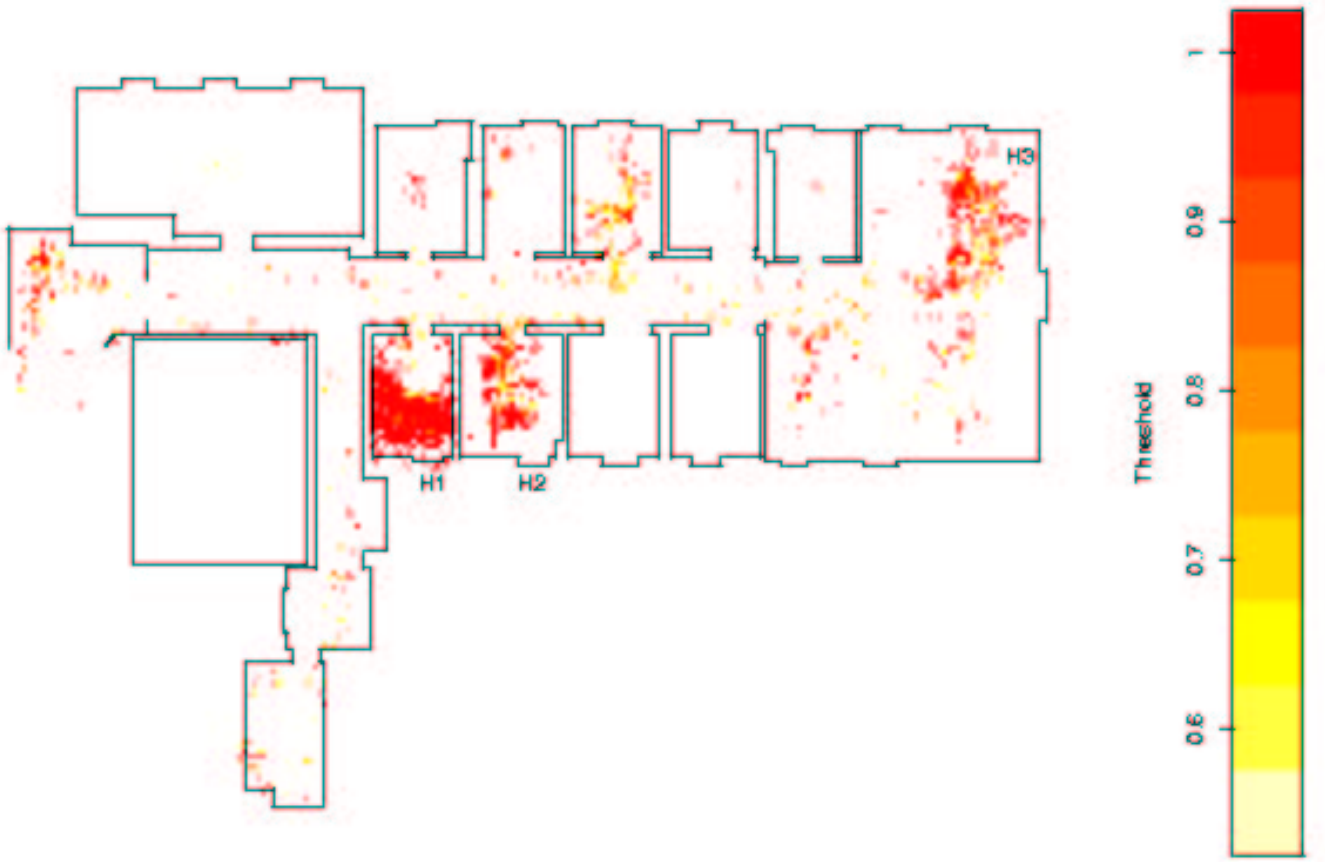
- Allow users to manage their location privacy
- Applies to many domains, not just the Bat System
- Can be done in two overall ways:
  - Access control—*specification difficult*
    - Three domains: location, time and identity
    - Role-based access reduces setting preferences
    - Integration with other apps. helps, e.g. calendar
  - Anonymity—*difficult to guarantee*
    - High-res location data $\Rightarrow$ identity inference
    - Changing pseudonyms and random-walks (spatial and temporal)

Anonymizing Location Information



- Raw data of a single user

Anonymizing Location Information



- Measure fraction of timespent, i.e. $\frac{T_{u,p}}{\sum_{j=1,j\neq u}^{j=n} T_{j,p}} > \tau$

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