# Tools for Ubiquitous Computing Research

MIT House_n Consortium

PlaceLab:
Proactive Health

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House_*n*
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# Outline

- Motivation: Health care crisis
- House_*n* research agenda
- House_*n* Tools for studying behavior
  - The PlaceLab living laboratory
  - Portable kit of sensors (MITes)

# Some statistics

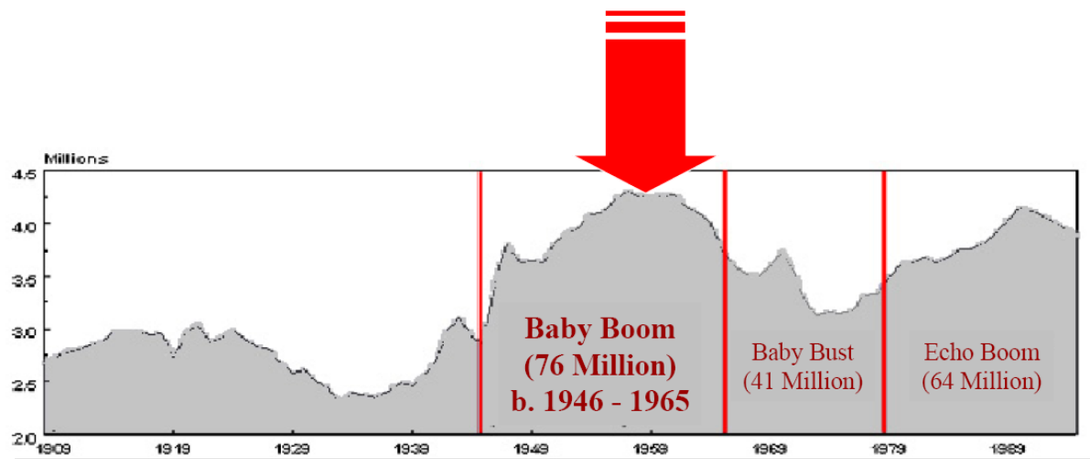
From the 2000 census of population

- Nearly 1 in 5 U.S. residents suffer some kind of disability
- Approximately 40% of people 65 and older have a disability
- Over 20% require continuous monitoring and help performing activities of daily living (ADLs)

# Some statistics

From the 2000 census of population

- In 2030, nearly one out of two households will include someone who needs help performing basic ADLs



# House_*n* research agenda

Goals

- Increase the time that people remain healthy, independent and safe in the comfort of their homes.
- Enable novel context-sensitive applications to be built and piloted

# Health care interventions

**Three levels** (in increasing order of difficulty and importance):

**1. Responding to crisis** (requires a few good sensors) → Medical staff

**2. Early warning of emerging problems** (requires ubiquitous sensors) → Changes in behavior

(dementia/independence)

**3. Proactively keeping people healthy** (requires ubiquitous sensors & communication)` → Encouraging healthy behavior

# Current work: proactive health

- Switch/bend sensors
  - Doors
  - Cabinets
  - Drawers
  - Thresholds
  - Appliances
  - Objects
- Wearable sensors
  - Accelerometers
  - Heart rate monitor
  - Self report
- Multi-purpose sensors
  - People-locator tags
  - Auditory sensors
  - Optical sensors

**new ML algorithms**

- Activity recognition
  - Eating meals
  - Talking
  - Sleeping patterns
  - Taking medications
  - Cleaning
  - Cooking
  - …

**health applications**

Detect **change** in activity;
**Motivate** behavior changes

# House_*n* tools:
# The PlaceLab Living laboratory

# PlaceLab

- Is not to show off “new technology”
- It is a residential observational research facility

Goals
– Run different research studies
– Real people living at PlaceLab 24/7 (weeks/months)
– Collect necessary data for doing research

Design constraints
– Reliable sensing infrastructure
– Add/remove sensors on the fly (Modular)

# Why another live-in laboratory?

Our design benefited from lessons learned by those who created prior “living labs”:

- Georgia Tech Aware Home (Abowd, Mynatt, and others)
- UVA’s Smart Home Monitor (Alwan)
- Smart House (Matsouoka)
- Welfare Techno House (Suzuki)
- Philips HomeLab
- Sleep laboratories
- Others…

# Why another live-in laboratory?

The PlaceLab combines these unique characteristics:

- A unified, extensible, multi-modal, and truly ubiquitous sensor and observational infrastructure
- Designed for shared data generation/distribution and collaboration
- Sensors integrated into architectural aesthetic
- Genuinely live-in

# Goal: Context-aware technologies at home

Three key challenges (among others):

1. Need for complex, naturalistic environments
   *Simulated behavior is overly simplistic*

2. Need for comprehensive sensing
   *Activity occurs throughout environment; realistic datasets costly to obtain; head-to-head comparisions*

3. Need for labeled training datasets
   *Many context-recognition algorithms need labeled example data; annotation required for evaluation*

# Testing ubicomp technology in the home

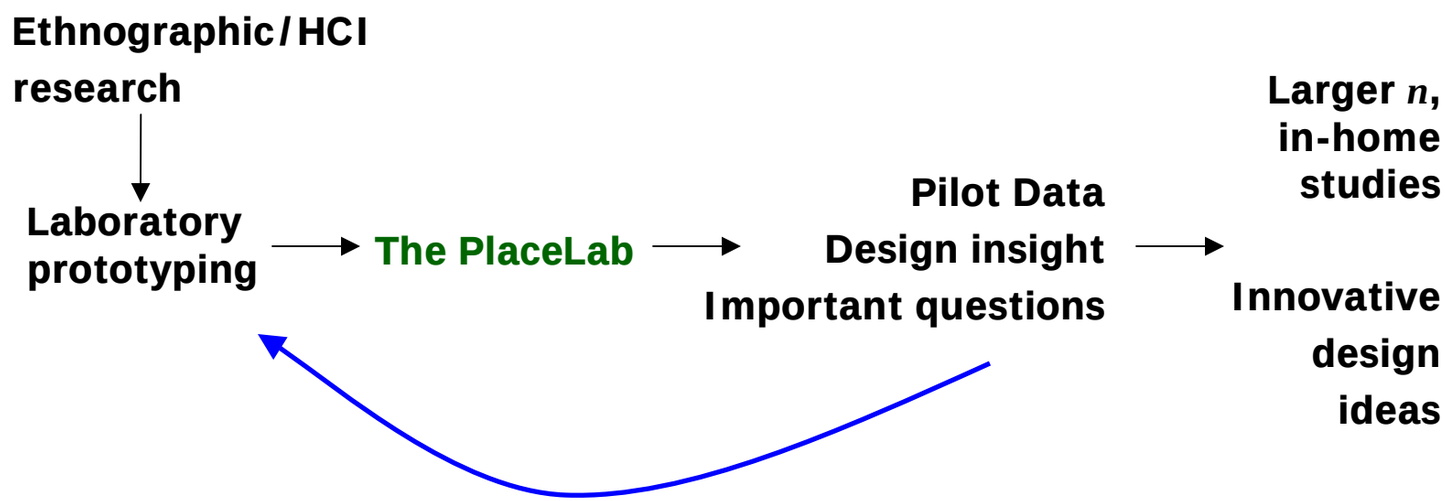
**Ethnographic/HCI research**

↓

**Laboratory prototyping** → **Larger $n$, in-home studies**

**Innovative design ideas**

# The PlaceLab: filling a gap



# PlaceLab can complement…

- Surveys and interviews
- Experience sampling
- Direct observation
- Portable kits of sensors for in-home studies
- Demonstration labs
- Short tests in parts of live-in labs; tests with limited sets of sensors

# The PlaceLab Infrastructure

# PlaceLab

A lower floor unit of full-service condominium building.

The apartment can be entered both from the lobby and from the side yard.

PlaceLab

# PlaceLab

# Interior entrance


House_n

# Living room

House_n

# Living room

- Most visible technology a standard TV

House_n

# Living room

# Kitchen

- Apartment allows the study of natural home behavior
- Interested in complex behavior such as
  - Decision making
  - Interruptions
  - Searching
  - Communication

House_n

# Sensor integration

- Sensors blend into aesthetics of environment (so easy to ignore)

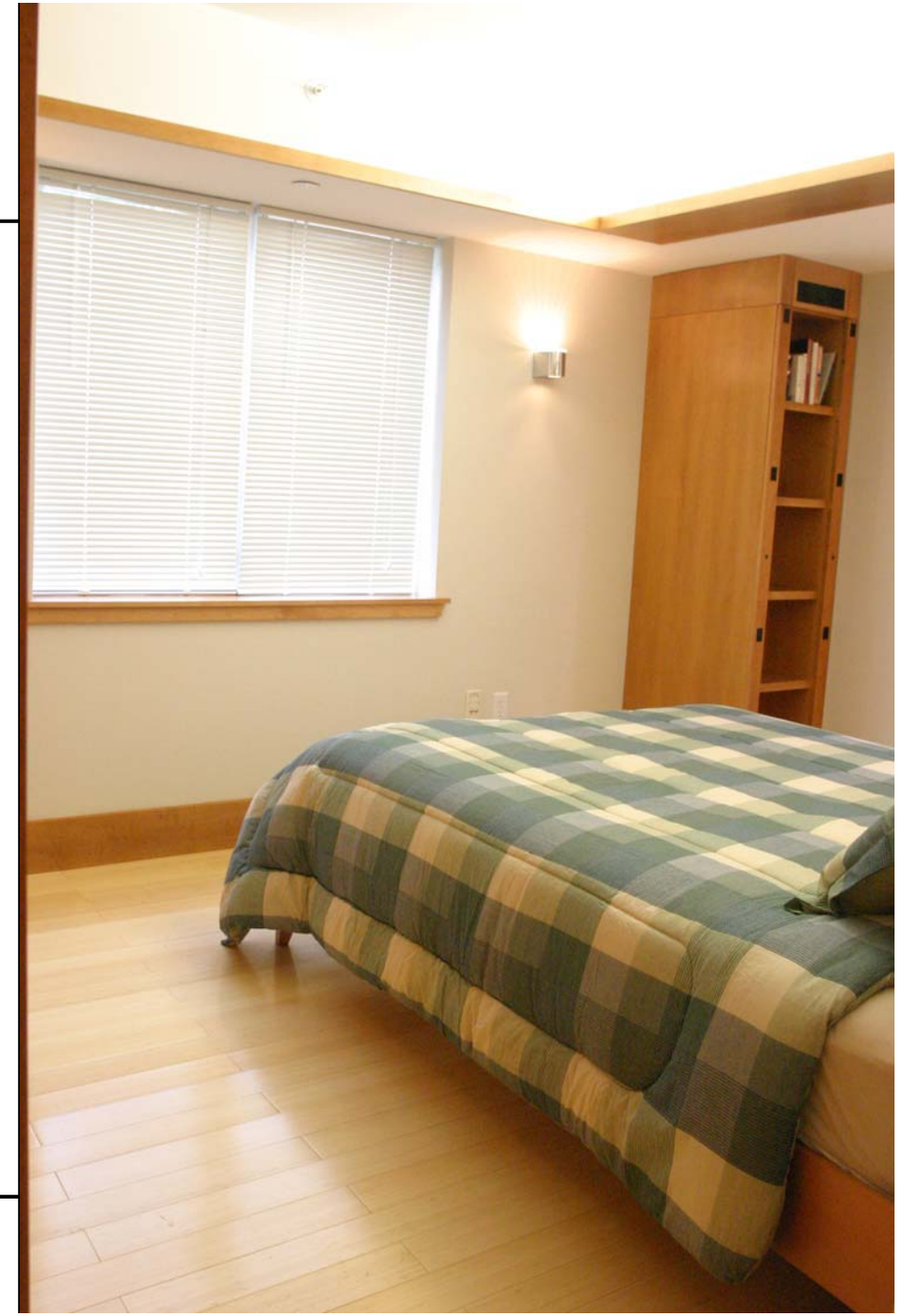
# Kitchen

House_n

# Office


House_n

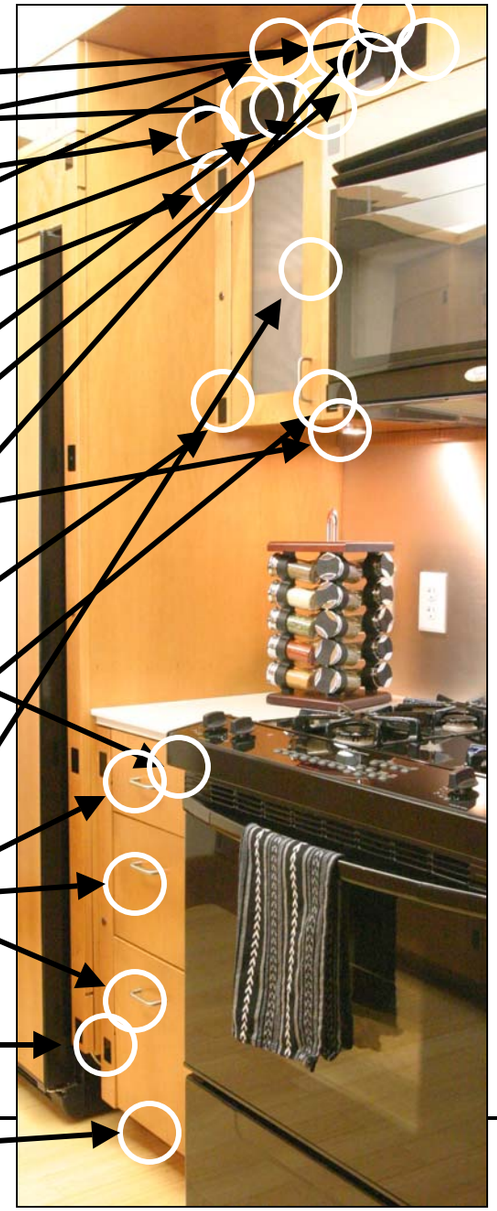
# Bedroom



House_n

# Master bath

House_n




Embedded sensors

Emphasis on ubiquity and quantity over quality

Reasonable locations

House_n

# Easy access to sensor infrastructure

# Wireless object movement MITes

- Real-time, wireless transmission
- Receivers scattered throughout apartment
- 100-200 sensors depending on task


# MITes sensors installation

Installation procedure for stick-on MITes

Single point of contact, no multi-point alignment is required

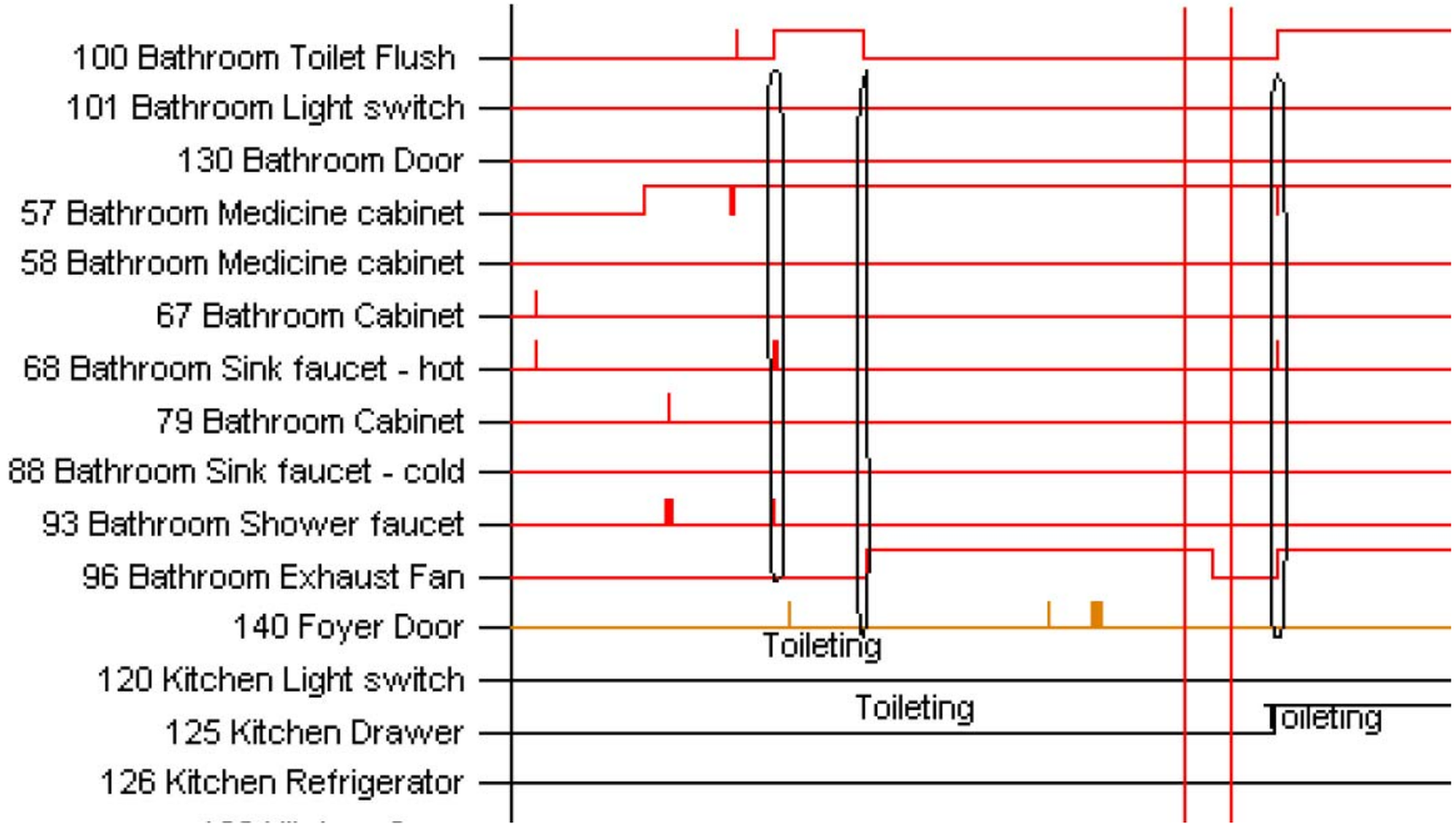
# Object usage MITes

# Activity recognition from sensors in the environment

| | |
|---|---|
| Preparing lunch | 59% |
| Toileting | 71% |
| Preparing breakfast | 45% |
| Bathing | 87% |
| Dressing | 64% |
| Grooming | 89% |
| Preparing a beverage | 36% |
| Doing laundry | 86% |

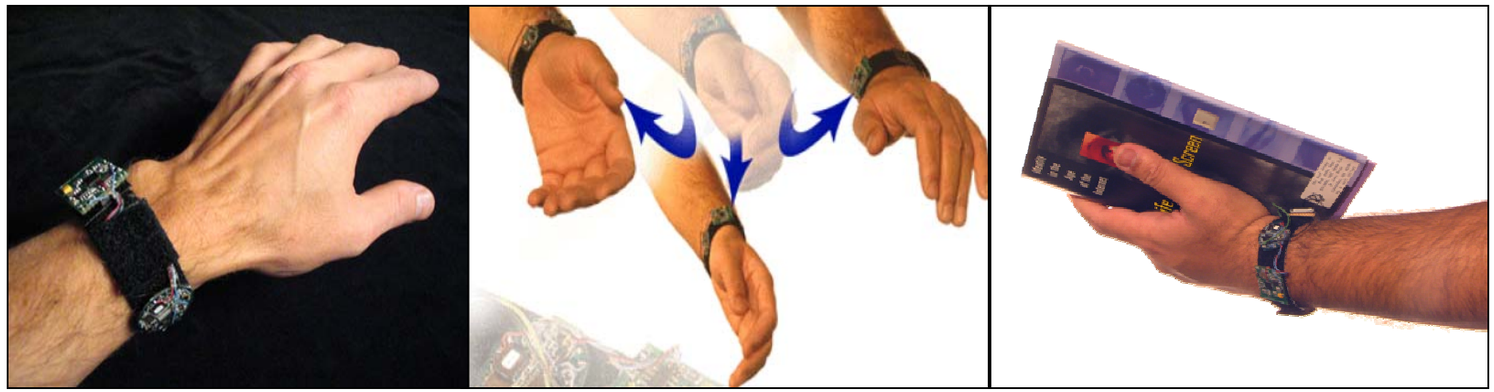
Activity detected at least once criteria

# Example sensor data

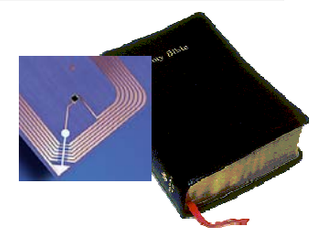


# RFID reader wristband

## Determine motion when holding an object



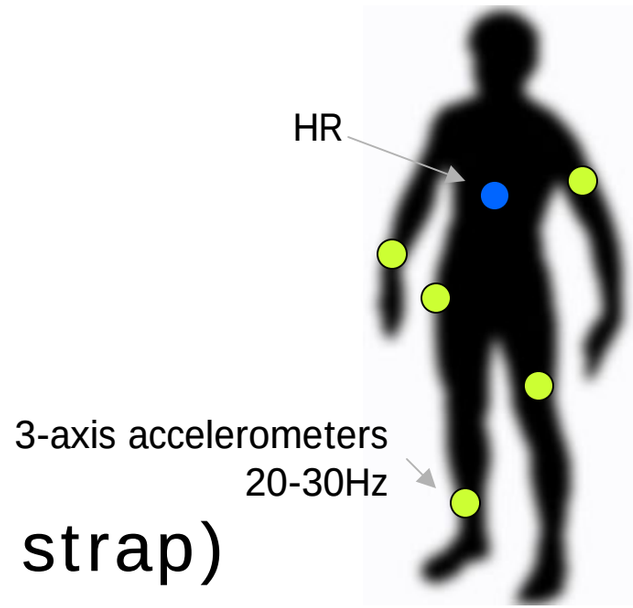
Measures: RFID tagged objects + wrist acceleration
Range: 10cm
Cost: ≈ $181 US

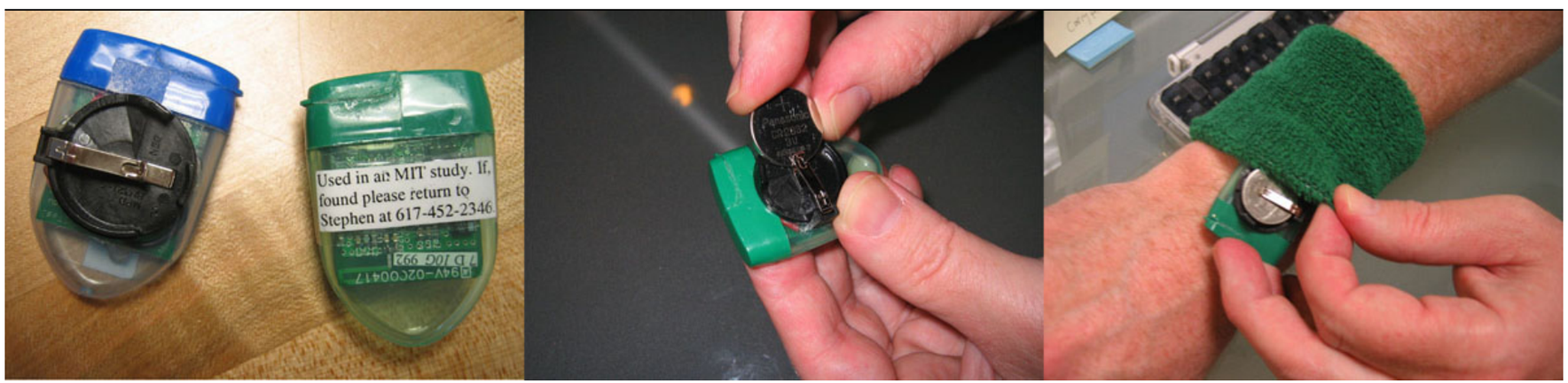


Based on Intel Research Seattle RFID glove **(Perkowitz ETAL '04)**
And in collaboration with Ambient Intelligence MIT Media Lab

# Wireless limb accelerometers and HR

- Real-time, wireless transmission
- Receivers scattered throughout apartment
- Up to 5 locations
- HR monitor (Polar chest strap)



# Activity recognition from wearable sensors

Activity recognition from wearable accelerometers

- 5 points
  - Right hip
  - Dominant wrist
  - Non-dominant upper arm
  - Dominant ankle
  - Non-dominant thigh

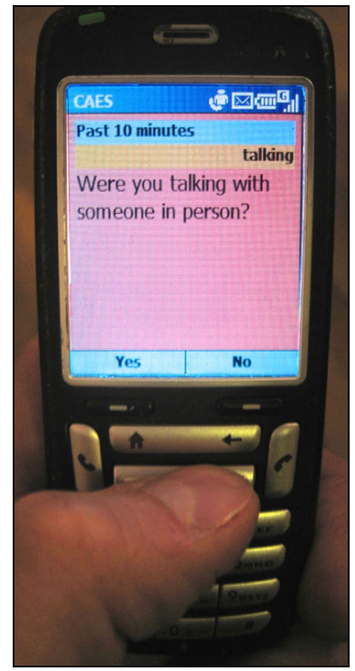
# Recognition results for 20 activities

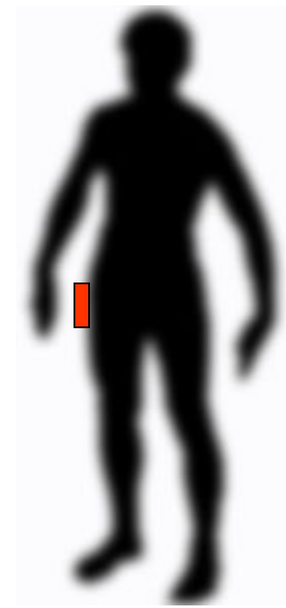
| | | | |
|---|---|---|---|
| • Walking | 89.7 | • Walking carrying | 82.1 |
| • Sitting & relaxing | 94.8 | • Work computer | 97.5 |
| • Standing still | 95.7 | • Eating/drink | 88.7 |
| • Watching TV | 77.3 | • Reading | 91.8 |
| • Running | 87.7 | • Bicycling | 96.3 |
| • Stretching | 41.4 | • Strength train | 82.5 |
| • Scrubbing | 81.1 | • Vacuuming | 96.4 |
| • Folding laundry | 95.1 | • Lying down | 95.0 |
| • Brushing teeth | 85.3 | • Climbing stairs | 85.6 |
| • Riding elevator | 43.6 | • Riding escalator | 70.6 |

Using decision trees and leave-one-subject out crossvalidation

# Subject self report

- Random or context-aware self-report sampling on phone (activities, mood and other states of mind, etc.)

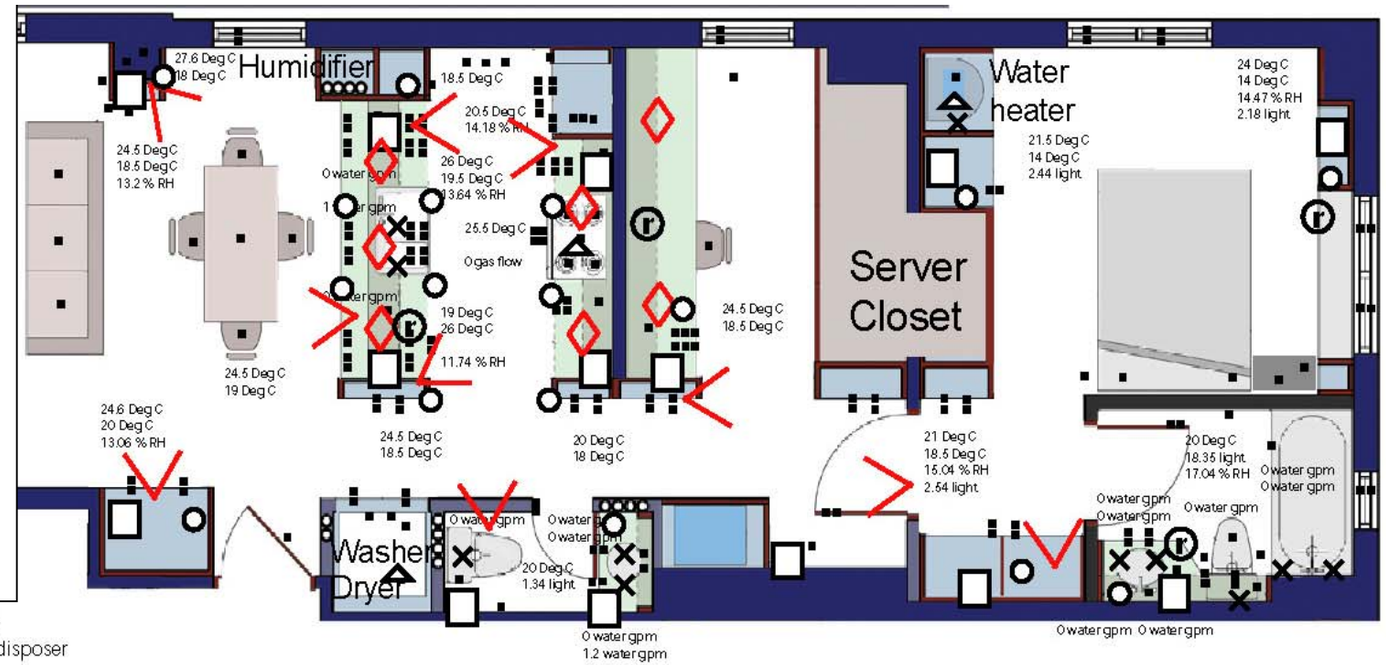


- Apps on phone can respond to PlaceLab sensors

- Standard surveys or ethnography can also be used

- Microprocessor
- Camera
- Top down camera
- Microphone
- Wireless receiver
- Gas flow
- Water flow
- Switch sensor (wired & wireless)

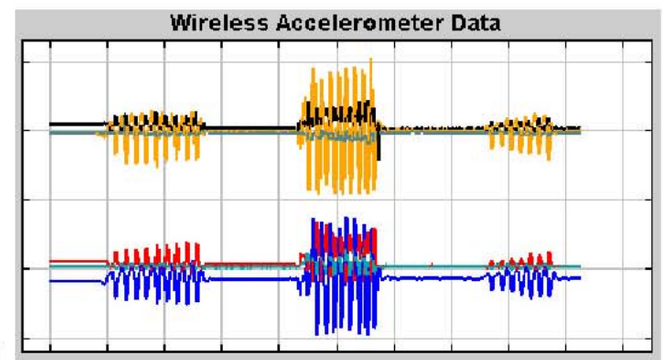


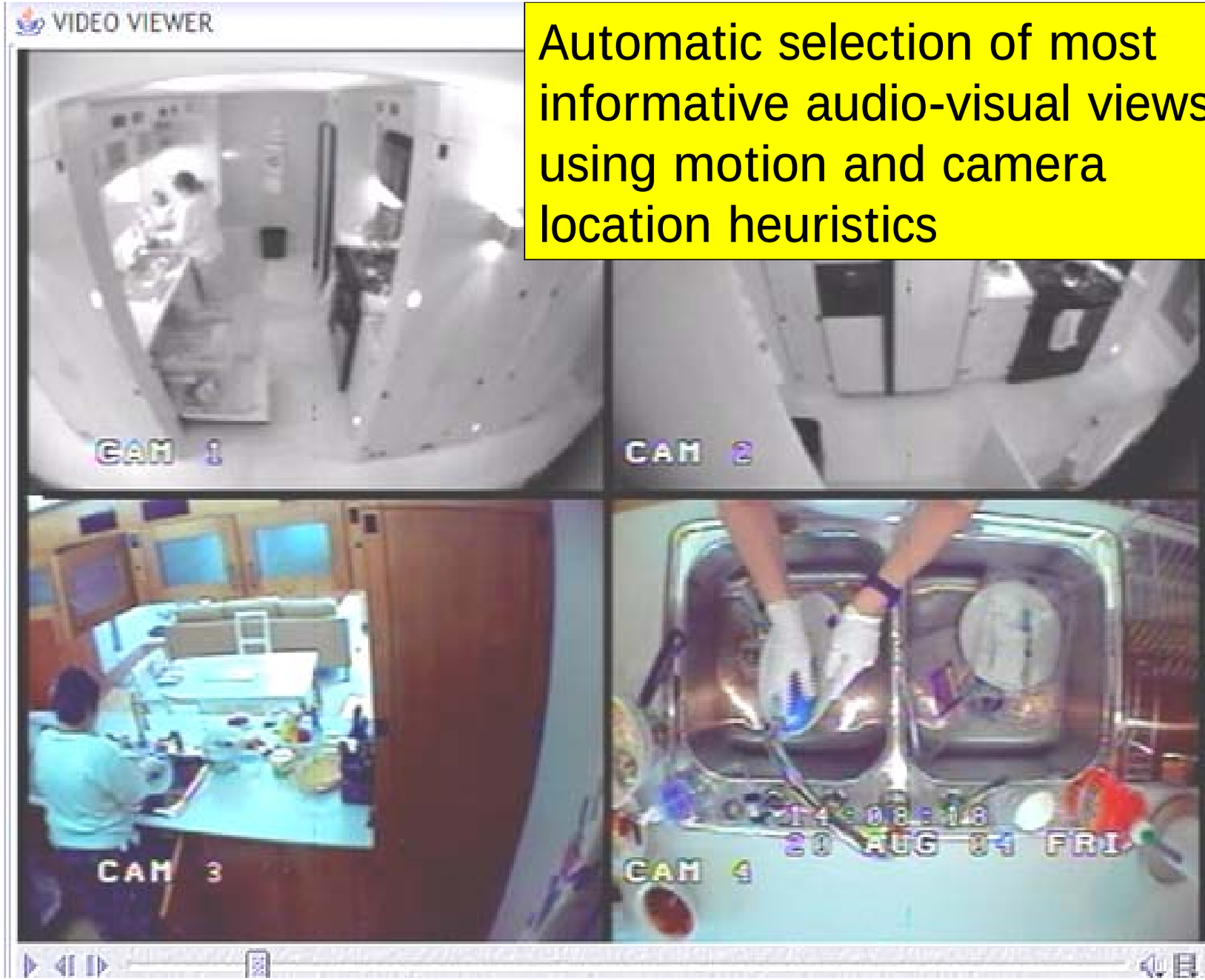

| | |
|---|---|
| 0 Amp | Living Room lighting |
| 0 Amp | Kithen sink garbage disposer |
| 1.68 Amp | Kitchen lighting |
| 0 Amp | Study lighting |
| 0 Amp | Microwave oven |
| 0 Amp | Dining Room receptacles |
| 0 Amp | Powder Room receptacles |
| 0 Amp | Residential condensation unit on roof |
| 2.36 Amp | Residential fan coil unit |
| 0.82 Amp | Energy recovery ventilator unit |
| 0 Amp | Corridor and Utility Closet lighting |
| 0 Amp | Kitchen receptacles on island |
| 1.14 Amp | Dining Room lighting |
| 0 Amp | Entry lighting |
| 0 Amp | Exterior receptacle |
| 0 Amp | Bedroom and Water Heater Closet lighting |
| 0 Amp | Bedroom computer controlled lighting |
| 0 Amp | Living Room computer controlled lighting |
| 0 Amp | Washer |

Participant Heart Rate 80 BPM

Video received from Cameras 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18

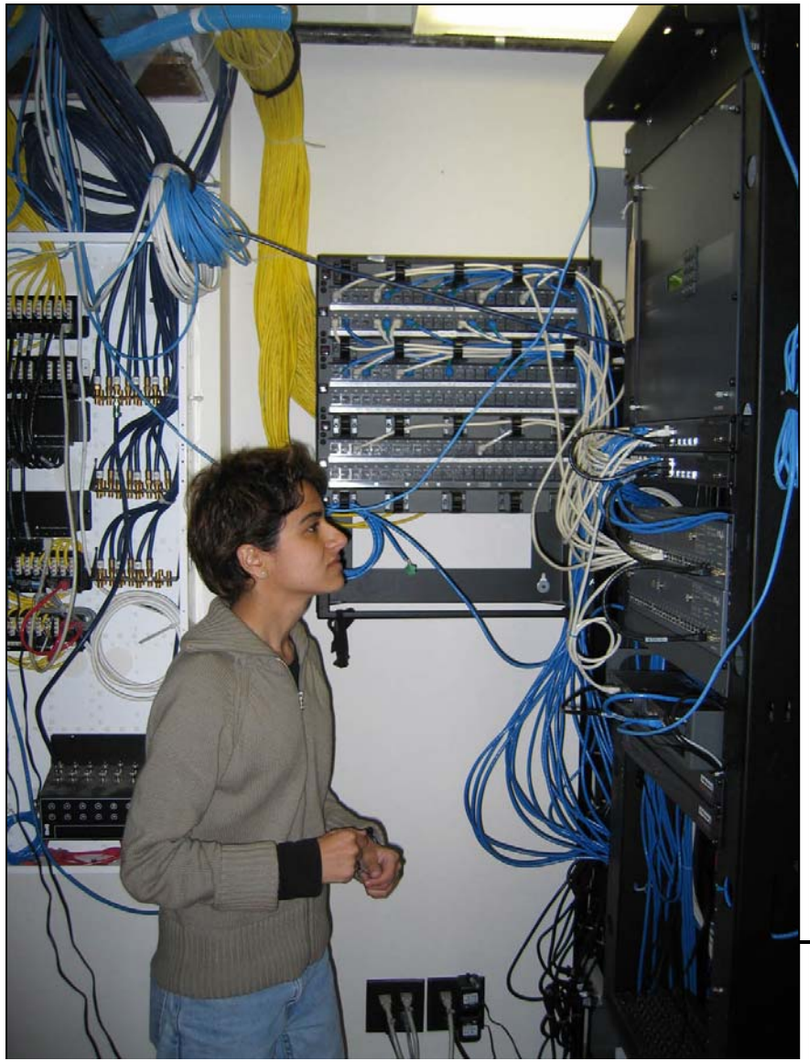
| | |
|---|---|
| 0 Amp | Bedroom computer controlled lighting |
| 0 Amp | Living Room receptacles |
| 0 Amp | Entry receptacles |
| 0.54 Amp | Bathroom lighting |
| 0 Amp | Kitchen receptacles on north wall |
| 0.68 Amp | Refrigerator |
| 0 Amp | Kitchen computer controlled lighting |
| 0.42 Amp | Study receptacles |
| 0 Amp | Stove/Oven |
| 0 .68 Amp | Hot water heater |
| 0 Amp | Corridor receptacles |
| 0 Amp | Bathroom receptacles |
| 0 Amp | Dryer |
| 0 Amp | Powder Room lighting |
| 0 Amp | Dining Room computer controlled lighting |

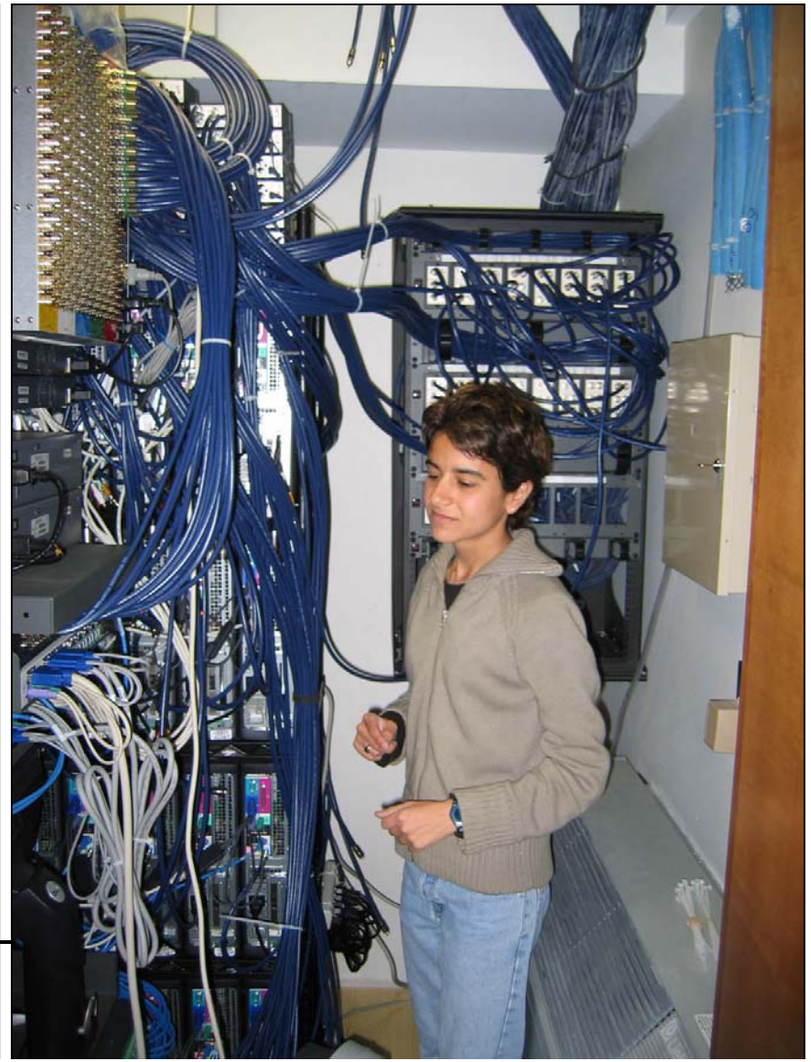





Automatic selection of most informative audio-visual views using motion and camera location heuristics

# Control “closet”



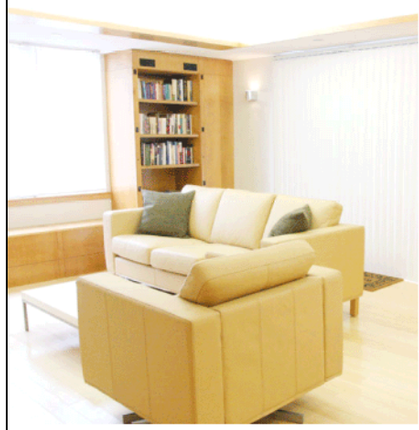


# Running an experiment

- Recruit participant(s)
- Participant(s) move in
- Home disconnected from Internet (data saved to portable disk)
- Minimal interaction with researchers during stay
- At end of stay, data is collected and stored
- Data annotated for items of interest
- Datasets become more valuable as more researchers annotate them

# Recruiting

## Teach MIT Researchers about Your Everyday Life



Ever get the feeling that today's technologies and homes are not designed for you and the way you live? Help MIT researchers design better technologies and homes (with fewer frustrations!) by sharing your everyday experiences.

Live in a comfortable one-bedroom apartment for 10 days. Researchers will capture your activities and experiences and apply lessons learned to developing technologies for better health and living.

For more information, contact Jason at placelab-volunteers@mit.edu or (617) 452-5679

**PlaceLab** AN **MIT** + **TIAX** INITIATIVE

# Take away

- The PlaceLab is a live-in residential home laboratory developed for health and ubiquitous computing research
- Unlike prior facilities, the home has a truly ubiquitous, synchronized, and multi-modal sensor infrastructure built non-obtrusively into the architecture
- The lab can be used as a hypothesis generation and testing facility and can help projects transition from laboratory testing to larger-*n*, in-home studies with portable sensors
- We are trying to operate the facility as a shared resource

# Thank you!

Questions? Contact: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- Kent Larson
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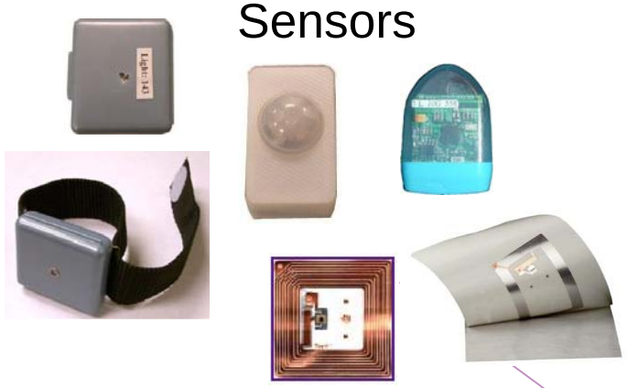
## House_*n* sensing tools:

## MITes: MIT environmental sensors
## A portable kit of sensors for studying behavior in natural settings

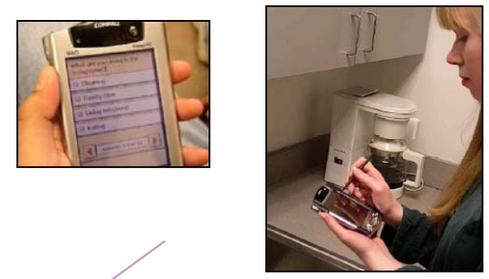
# Goal: allow context awareness

Sensors



Most sensors are simple and binary

Activity Examples (labels)



or
Activity Models

Machine Learning and Pattern recognition (training/inferencing)

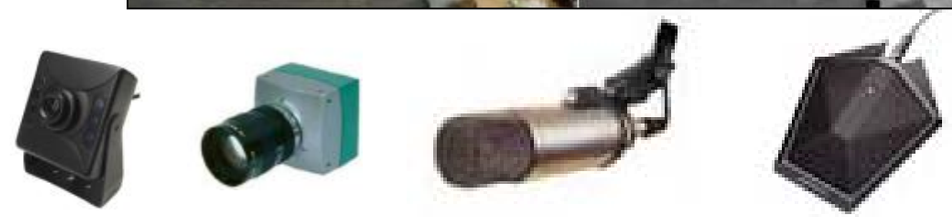
Activity probabilities/detection

**Toileting**

- Toilet Flush
- Faucet
- Soap

# Avoid microphones and cameras

- avoid using audio, visual, electromagnetic or other sensors placed in the environment



- Why?
  - Sensors may be perceived as invasive
  - Succeptible to environmental conditions
  - Signal interpretation extremely difficult
  - Difficulty of signal interpretation depends on sensor placement (increasing installation difficulty)

# MITes (MIT Environmental Sensors)

Goal: collect data from hundreds of multi-modal sensors (environmental and wearable) from single receiver in non-laboratory deployments

- Easy of installation
- Ease of use
- Adequate performance
- Affordable for research
- Well characterized/tested

# MITes sensor kit includes

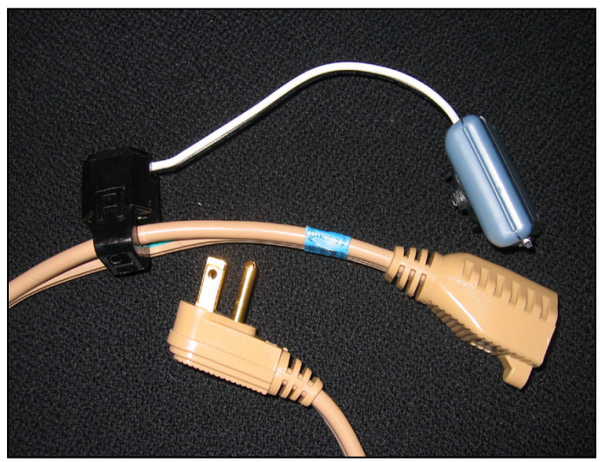
## Six environmental sensors (low bandwidth)

| | | |
|---|---|---|
| movement | light | Proximity |
| **object-usage-detection** | temperature | current sensing |

## Five wearable sensors (high bandwidth)

| | | |
|---|---|---|
| **onbody acceleration** | RFID reader wristband | ultra-violet radiation exposure |
| **heart rate** | location beacons | |

# Proximity MITes (MERL)



# Our Hardware sensing Tool #2
# MITes: Portable toolkit of sensors


Temperature and Light

# MITes receiver

Single receiver
USB or serial
Connector receives
all sensor data