Sensing in Ubiquitous Computing

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Overview

1. **Motivation:** why sensing is important for Ubicomp
2. **Examples:** how sensing features in ubicomp projects
3. **Discussion:** main trends? what's new?
4. **Perceptual Computing:**
   lifting sensor observations to 'useful information'
5. **Distribution:** issues in distributed sensing
6. **Energy:** how it dominates design decisions

1 – Motivation

Human-Centred Motivation for Ubicomp

- Toward systems that adapt to people, as opposed to people adapting to systems:
  - Reactive to what people do
  - Proactive, anticipating what people want to do
  - Situated, sharing context with human user

- From explicit (computer-directed) to implicit (activity-driven) interaction between people and systems

- all this requires ability for observation of human activity

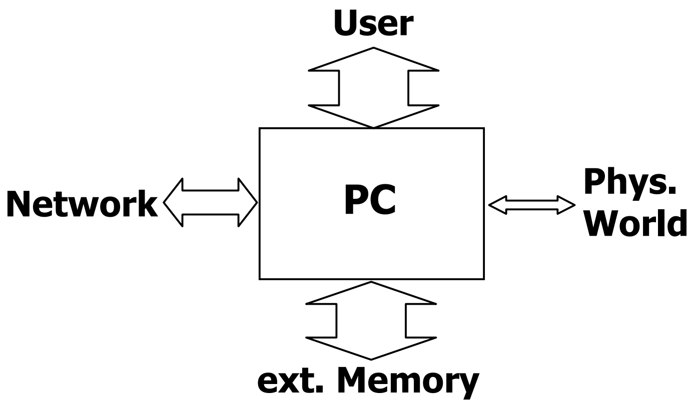
Device Trend

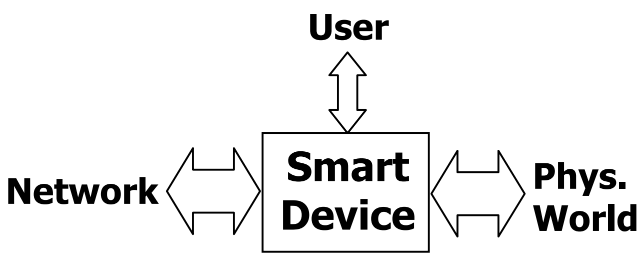
From PC to 'Smart devices'

- more applied than general-purpose ('information appliance')
- less CPU power, memory, UI
- <u>more networking</u>

  "the real power of the concept does not come from any one of these devices; it emerges from the interaction"
- <u>more physical I/O</u>

  "if a computer merely knows what room it is in, it can adapt its behaviour ... without even a hint of AI"



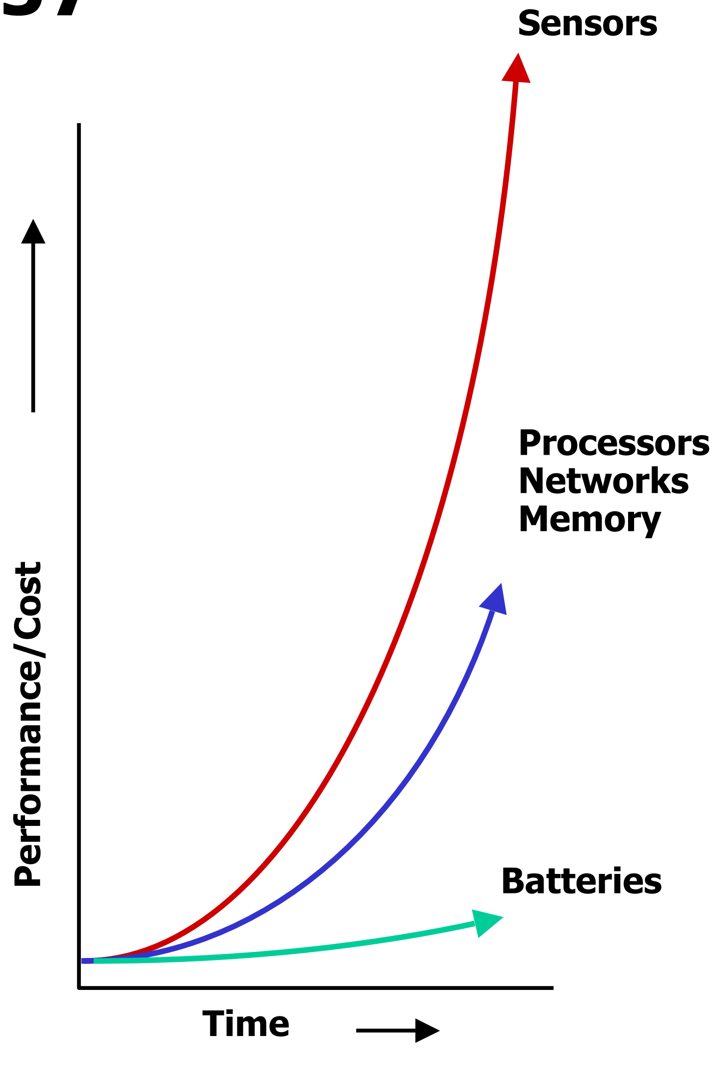


Enabling Technology

Moore's Law again

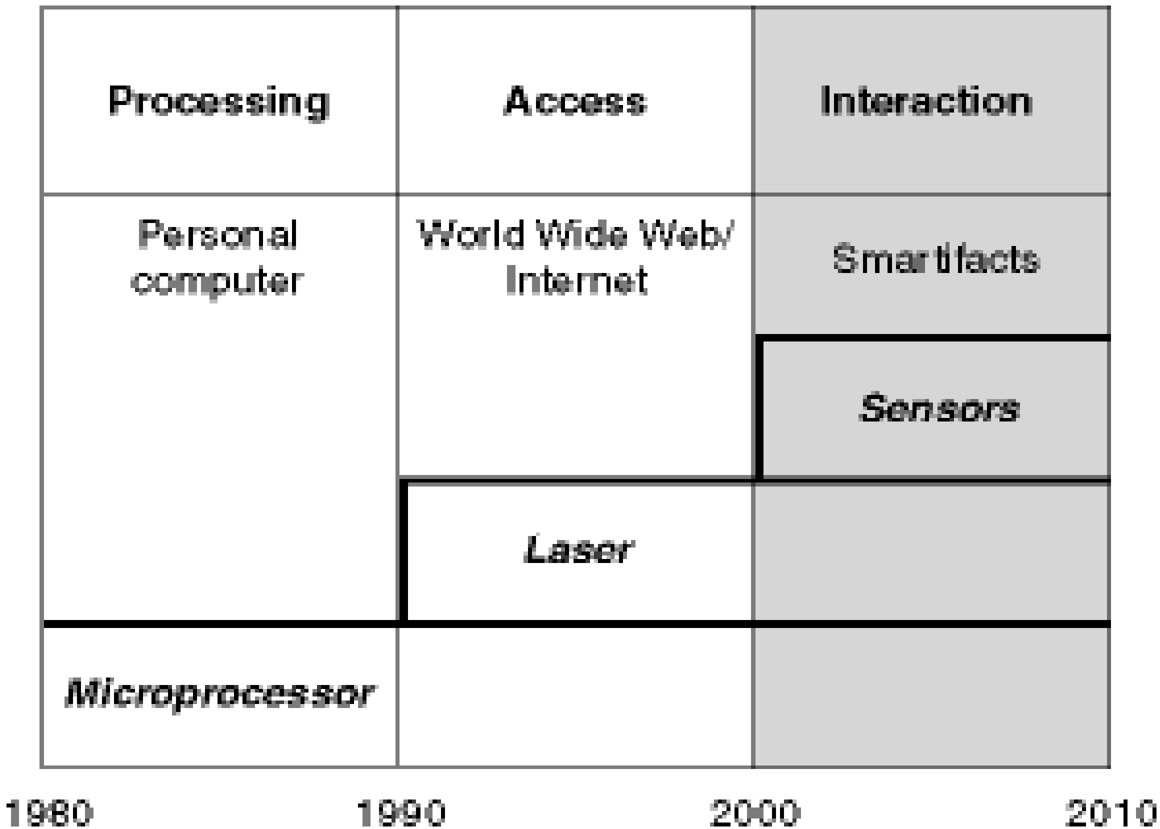
- 'sensors in overdrive'
- dramatic drop in price
- miniaturization
- e.g. MEMS
- e.g. piezo-materials
- e.g. low-cost image sensors

- but sensors need energy...



The decade of sensors

Sensors driving next wave of IT innovation



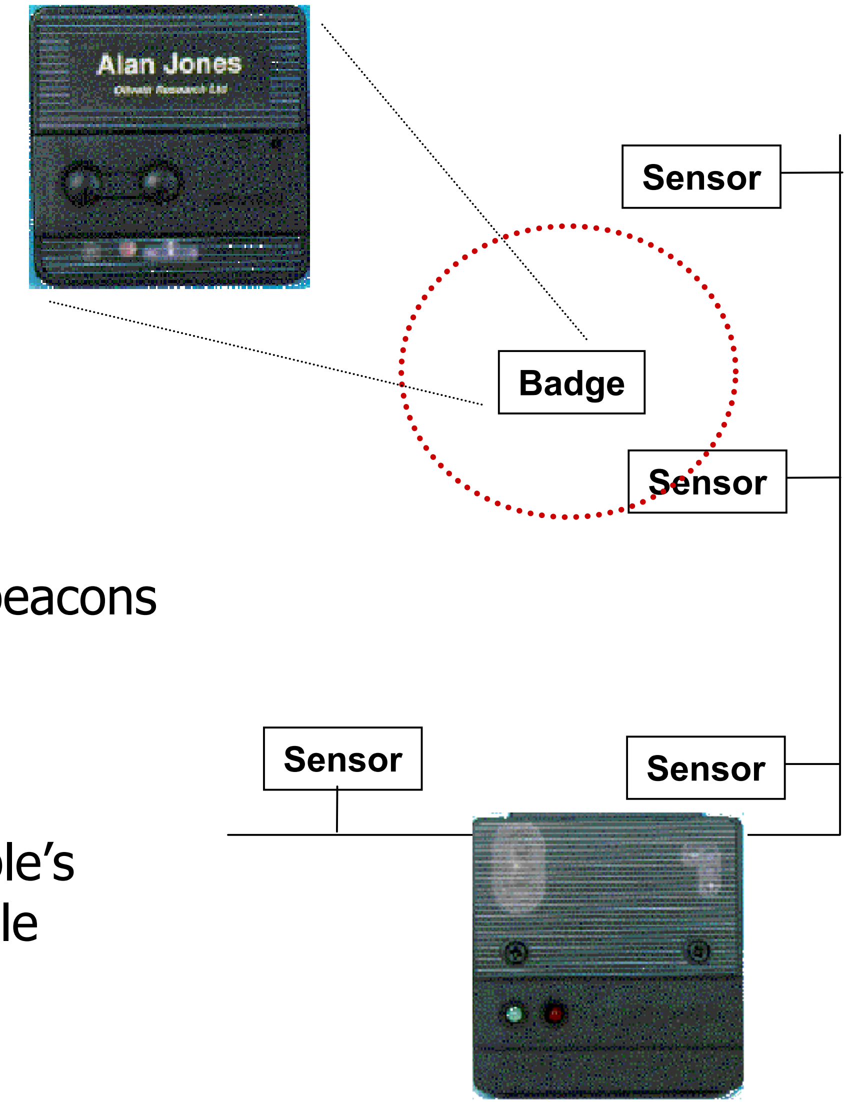
2 - Examples

... of how sensing is used in ubicomp work

not a complete history

... just to get a feel for types of systems/uses

Location sensing

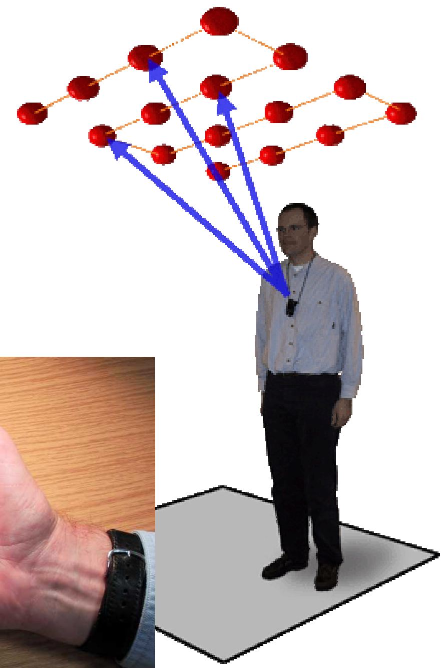


Active Badge System

- ORL, Cambridge/UK, 1989-92
- Locating people (and devices)
- Room-level accuracy
- Badges worn by people emit beacons
- Sensors with known location

- 'artificial sensing': augment phenomenon of interest (people's presence) to make it sense-able

Location sensing



The Bat Ultrasonic Location System

- Highly accurate indoor positioning
  95% of readings within 3cm
- Bat device emits short
  pulse of ultrasound
- Ceiling mounted sensor array
- Trilateration to compute position

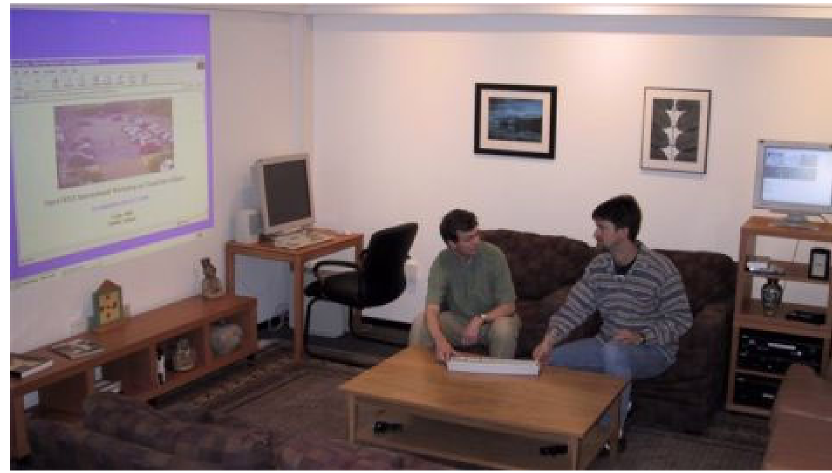
Sentient Computing

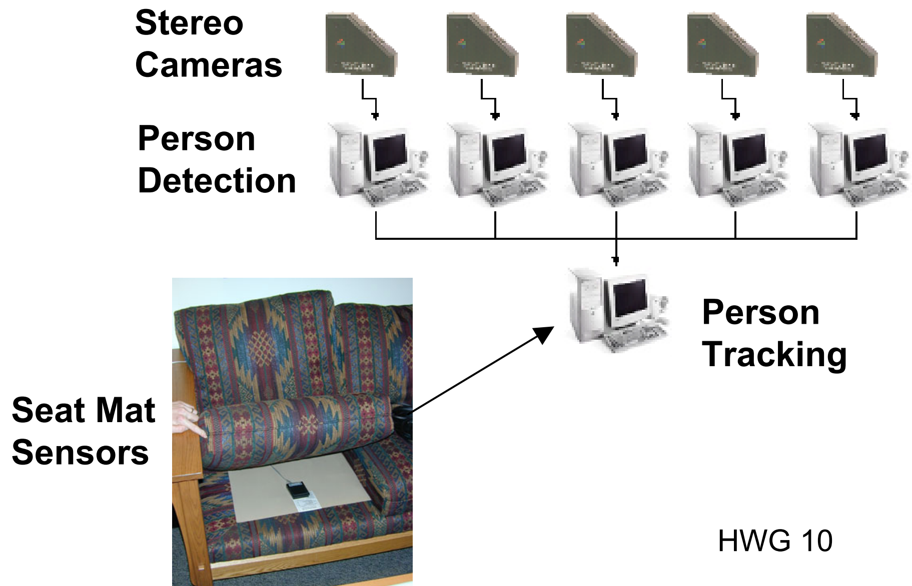
- Use sensors to construct
  model of the environment
- Shared view of the world
  between system and user

Smart environments

EasyLiving

- Microsoft Research
- 'Intelligent Living Room'
- Using computer vision for person tracking
  - predict user intention for task automation
  - support gesture UI
- Use seat mat sensors as additional information for person tracking

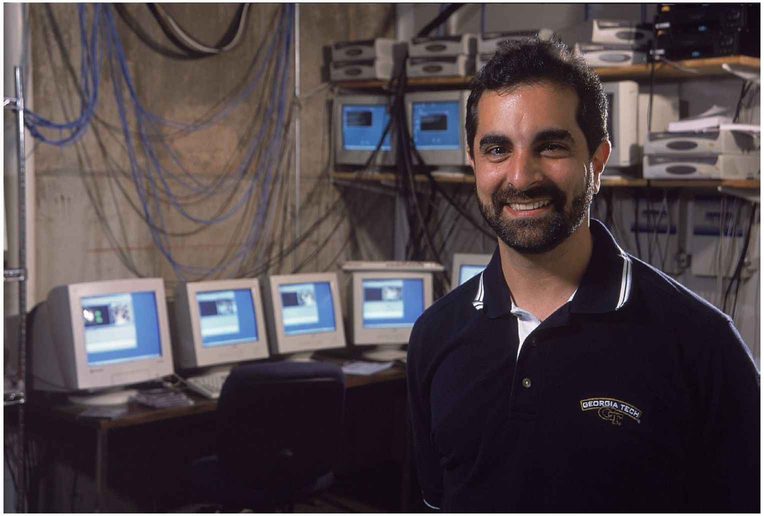




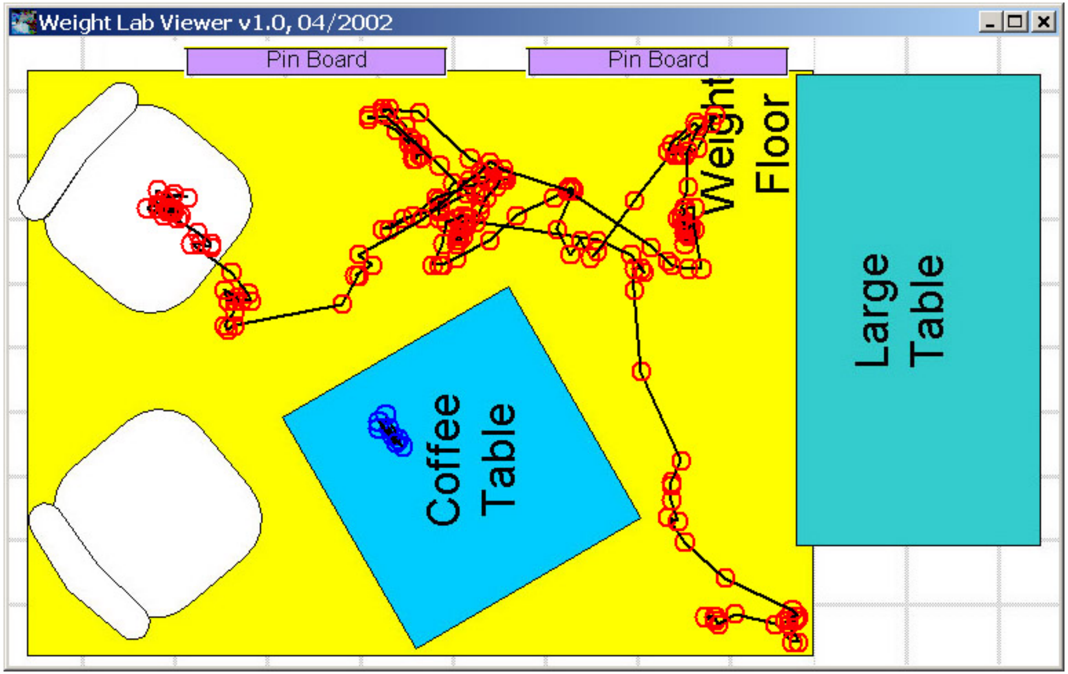
Smart Environments

The Aware Home

- Research initiative at GaTech
- 'A Living Lab for Ubicomp Research'
- Large-scale deployment of sensors for perception of everyday activities



Smart Environments



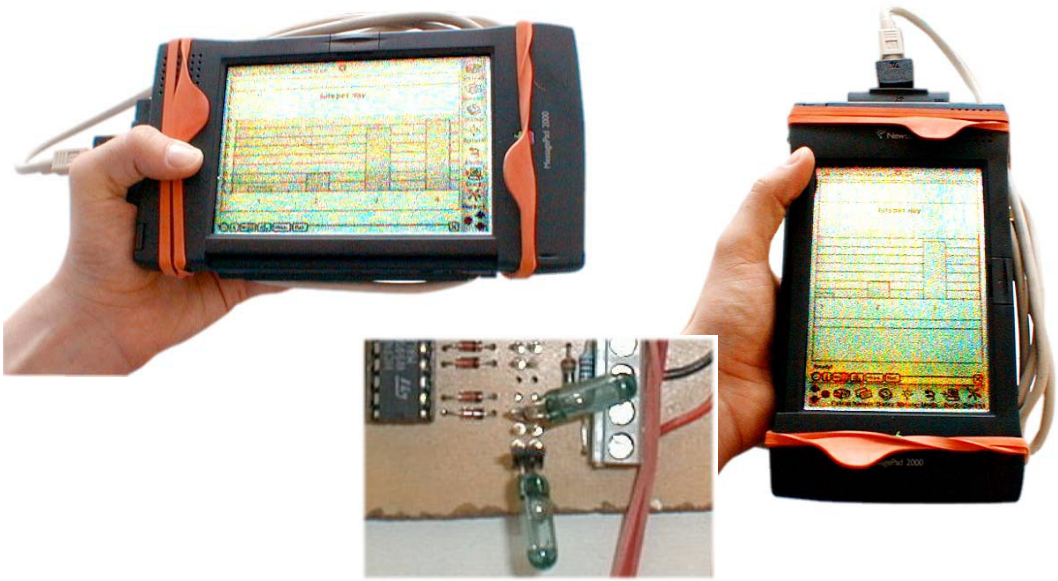
"Weight Lab"

- An environment in which all surfaces are load-sensitive
- Floor, tables, chairs, shelves, trays …
- Activity tracking with unobtrusive infrastructure

Smart Devices

My first smart device ...

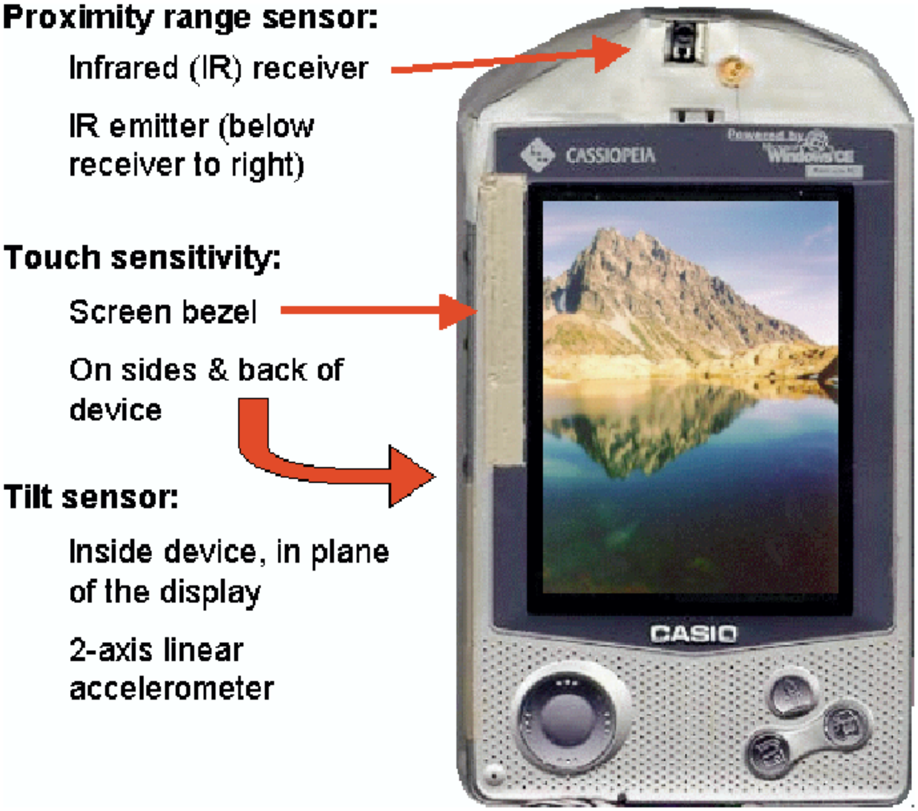
- Orientation-aware Newton MessagePad
- Sensors as UI element



Smart Devices

Smart Palm PC

- Microsoft Research Hinckley et al
- Sensors to improve user interaction
- Detecting simple percepts
  - holding & duration
  - tilt, orientation
  - etc
- Detecting gestures
  - “dictaphone” gesture
  - scrolling



Smart Devices

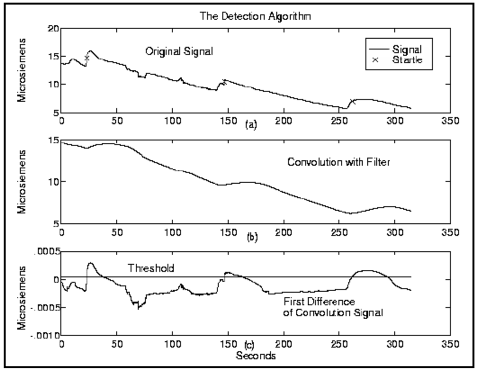
TEA Mobile Phone

- Integration of diverse simple sensors (light, audio, accel., temp., touch)
- Sensor fusion for perception of device context (car, meeting, home, ...)
- Shared context among phone users
  - context call
  - context phonebook

Wearable Sensing

StartleCam

- MIT MediaLab
- Example for sensing the user
- Sensing generally important in wearables (intimate technology -> shared context)



Wireless sensing

The Mediacup

- TecO Karlsruhe, 1999-2000
- Wireless sensor device embedded in ordinary coffee cup
- Movement, weight, temp. sensing
- On-board computation of user-level context: „filled up“, „gone cold“, etc.
- Augment passive artefact with continuous digital presence
- >95% reliable context prediction in everyday use

Wireless Sensing

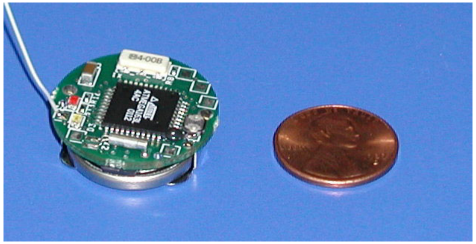
Smart-Its

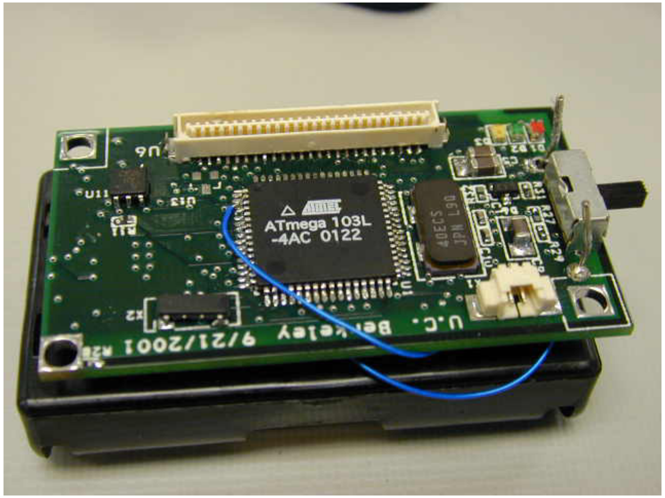
- PIC Microcontroller, RFM 868 MHz, Light, Audio, Accel., Temp. Sensors
- Designed for augmentation of passive objects
- Small scale (4x4x1 cm) and low-powered
- ~150 Devices in use
- various device versions
  - Bluetooth Smart-It, ETHZ
  - "DIY" Smart-It, Lancaster

Wireless Sensing

Berkeley Motes / Smart Dust

- Platform for wireless sensor networks
- Designed for large-scale networks
- Tiny OS
- Messaging Model
- Multihop routing
- Data filtering / aggregation





3 – Discussion

Summary of sensing uses in Ubicomp

- Device-based sensing (Portable, Wearable)
  - Sense the user, the location, the immediate environment
  - Enable proactive/reactive behaviours, novel UI techniques
- Environment-based sensing
  - Homogeneous sensing infrastructure to supply devices
  - Smart environment control, responsive rooms etc
- Wireless sensor devices and networks
  - Heterogeneous sensors, ad hoc organized
  - Large-scale observation of the physical world
  - Deep embedding in physical artefacts

What's new

Traditional sensing applications

- Highly engineered for specific applications
- Sensors to obtain particular inputs to a process
  - interest in very specific physical phenomena
- Tight coupling of sensing and effect

Sensing in Ubicomp

- Flexible platform to support many types of application
  - Including unanticipated applications
- Phenomena of interest are unstructured
  - Generic interest in observing human activity
- Strong interest in separation of concerns
  - Decoupling sensing and effect

This trend may well be reversed when actuators become as pervasively deployable as sensors now!

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6. **Energy:** how it dominates design decisions

4 – Perceptual computing

Closing the gap between sensors and applications

- sensors observe physical phenomena
- applications operate on 'higher-level' models of the world
- perceptual computing: to extract meaning from observations
- two drivers
  - AI tradition: modelling human capabilities
  - task-driven: interest in specific aspect of the world

Perceptual Computing

"The physical world is a partially observable dynamic system ..."

"... sensors are physical devices with inherent accuracy and precision limitations"

(Estrin et al, Berkeley)

How a system sees the world

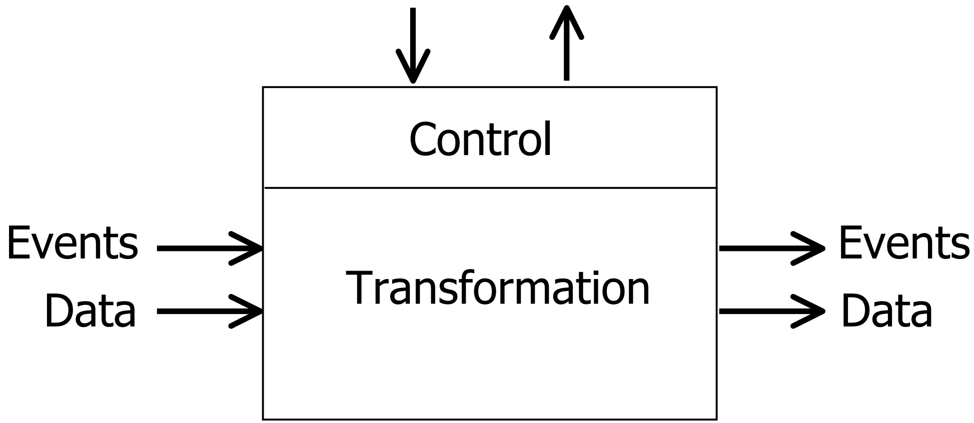
System's view of physical world

- at the lowest level:
  - world seen as collection of sensors
- sensors generate values for observable variables
  - can be symbolic or numeric
  - can be synchronous data streams or asynchronous events
- sensor data is associated with meta-data, e.g.
  - time
  - location
  - confidence
  - etc.

Perceptual components

Basic perceptual component

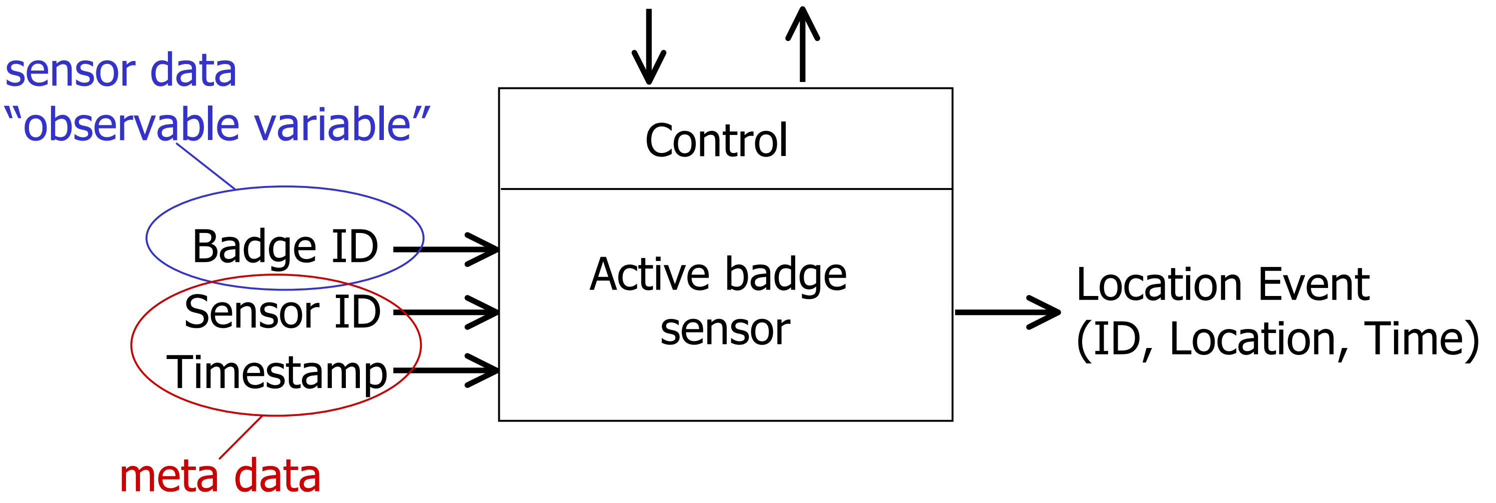
- transforming observed events/data to “higher level” events/data



Perceptual Components

Example: Active Badge Sensor

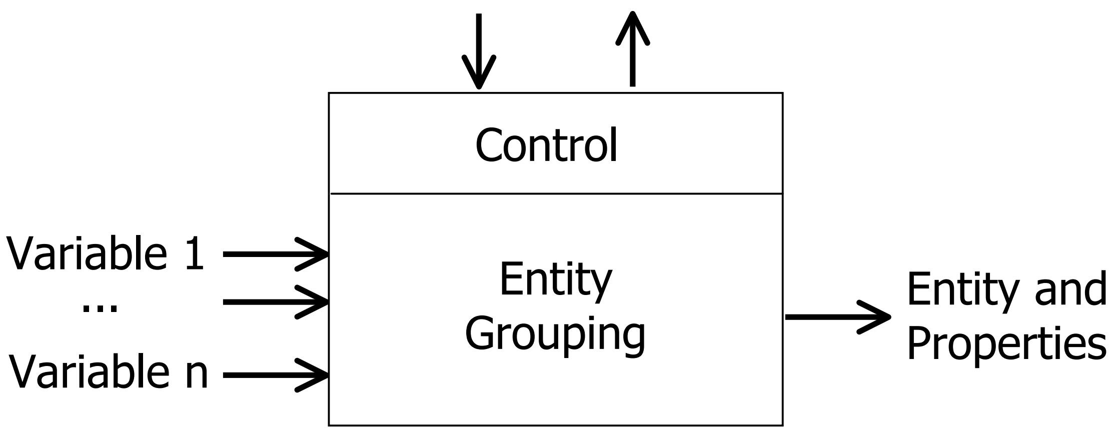
- transforming badge sightings to location events



Perceptual Components

Detecting entities

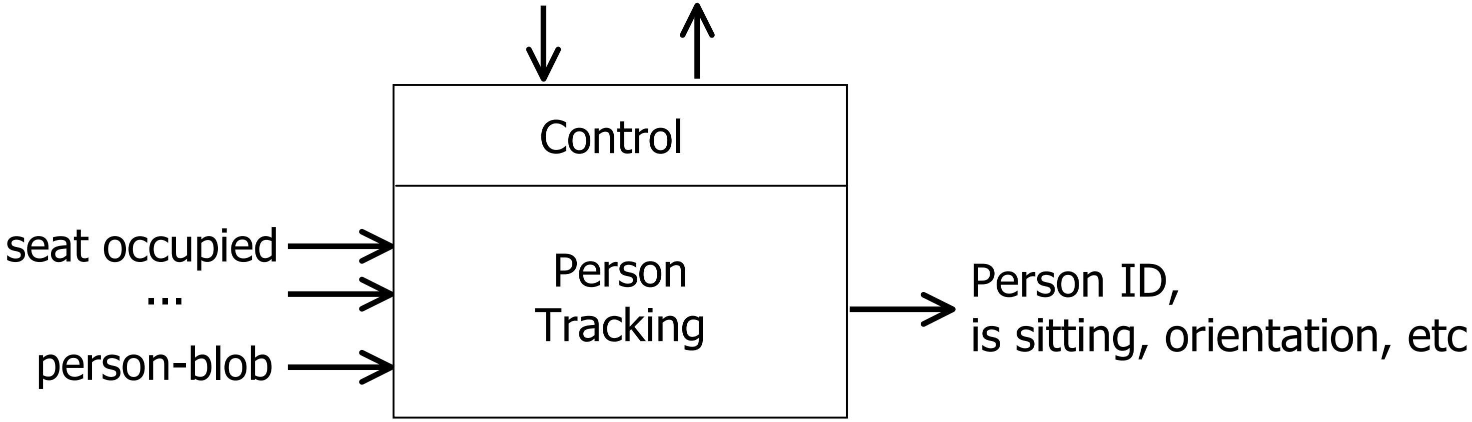
- grouping of observations
- entity corresponds to a physical object
- from system perspective:
  association of correlated observable variables



Perceptual Components

Detecting entities

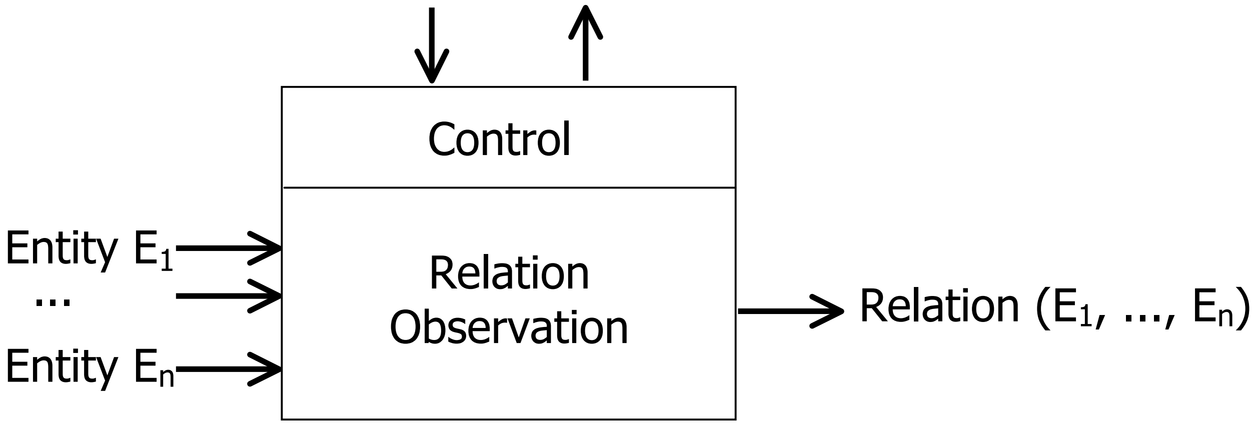
- e.g. Easy Living
- associating mat sensor observation and camera observation with the same entity



Perceptual Components

Detecting relations

- determining relations between entities
- e.g. spatial proximity



Sensors/Perception in Ubicomp

The popular choices

- Location sensing and computer vision
- Homogeneous infrastructure: (usually) single type of sensor
- Fairly well understood, e.g. location models
- Generic source of information
  - Location: usually an index to much more information
  - Vision: high information content in visual scenes

Some alternatives

- Multi-sensor perception
  - Combination of specific sensors to obtain generic percepts
- Pervasive deployment of specific sensors
  - Dense networking to obtain more generic observations

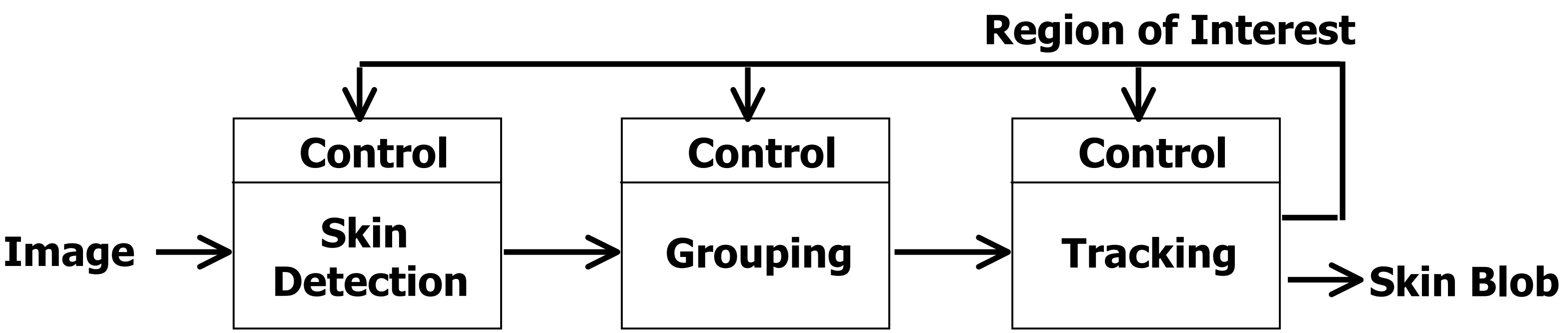
Location vs. Vision Systems

Location system

- comparatively simple perceptual process
- geometry- or model-based transformations
- location powerful as <u>index</u> to further information

Computer vision

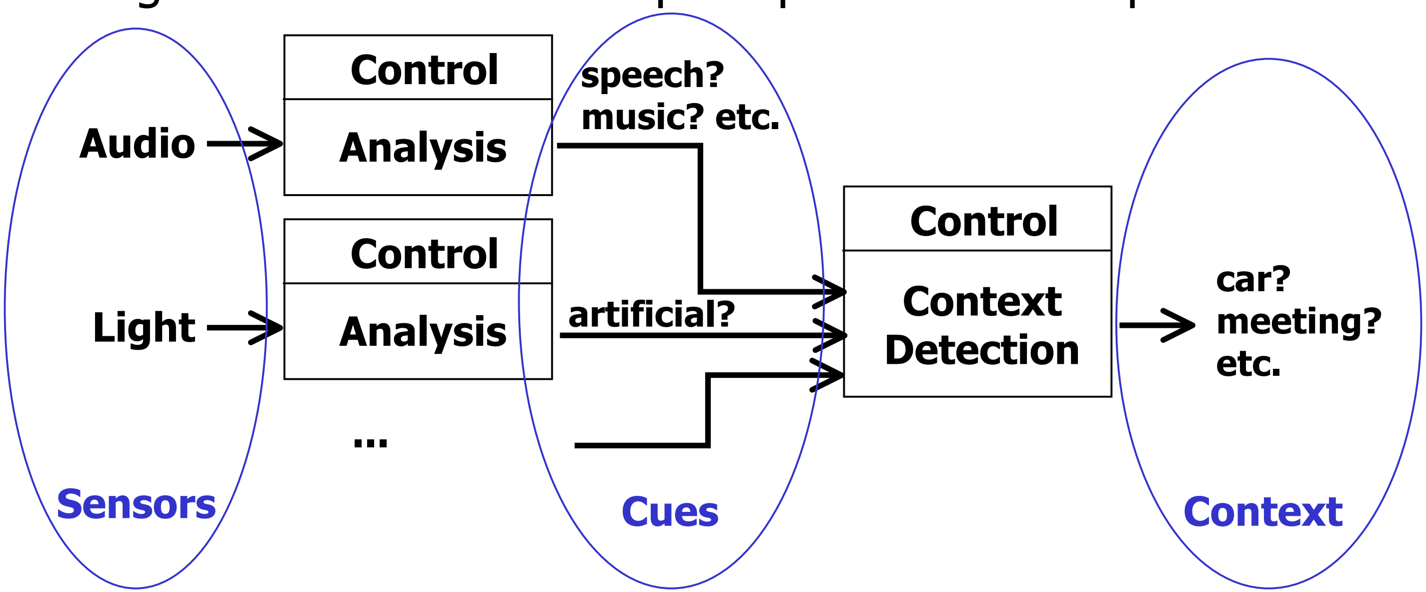
- complex perception architectures
- chains of transformations, e.g.



Multi-sensor perception

Sensor fusion

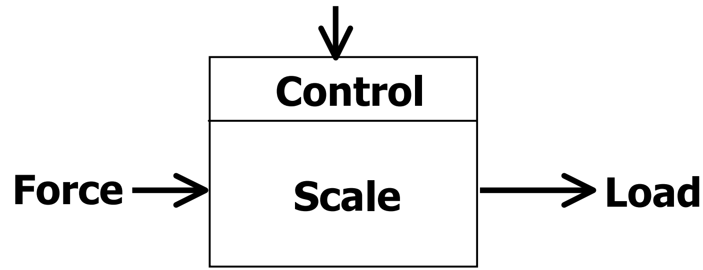
- typically two transformation steps
  - first ‘cooking the sensors’ (low-cost sensor analysis)
  - then combining extracted features
- well suited for embedded devices
- e.g. TEA architecture for perception of mobile phone context:



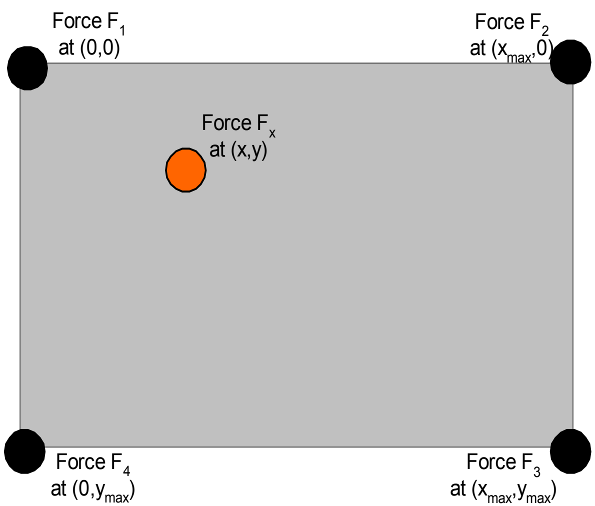
Load Sensing

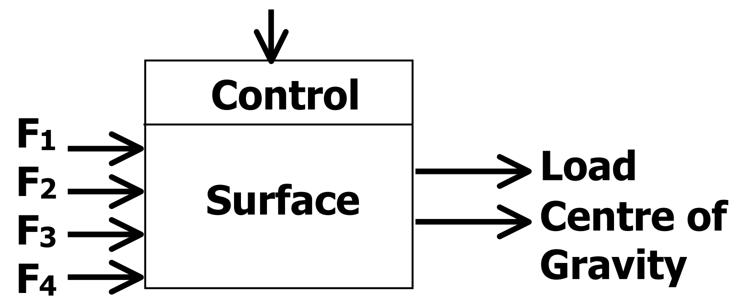
Basic load sensor

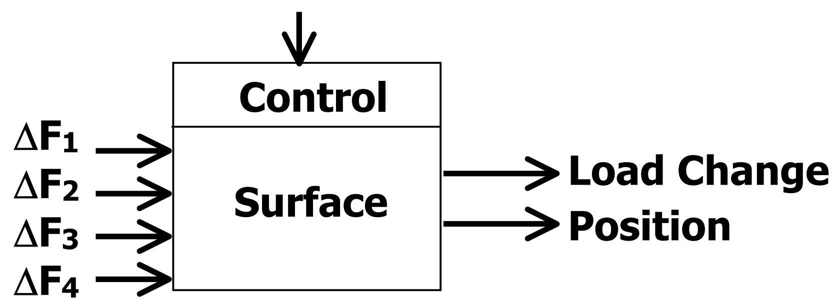
- e.g. your kitchen scale



Load-sensing surface



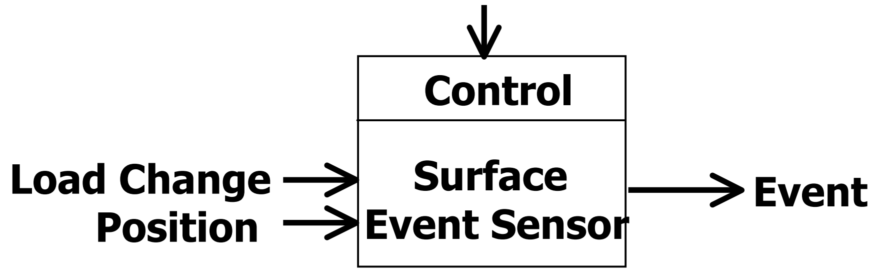




Load Sensing

Basic event detection

- Object placement
- Object removal

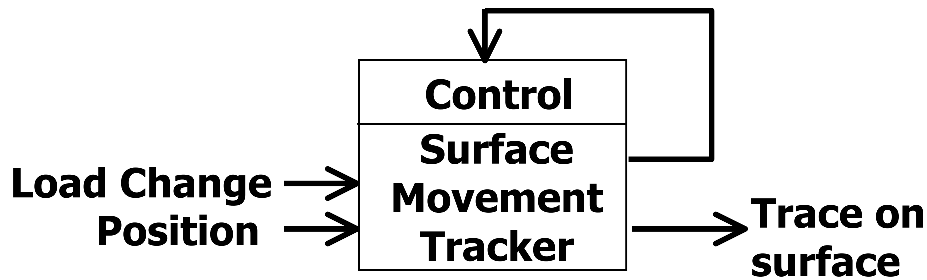


Further event processing

- Detect movement
- Detect specific events
- Detect Object ID/Class

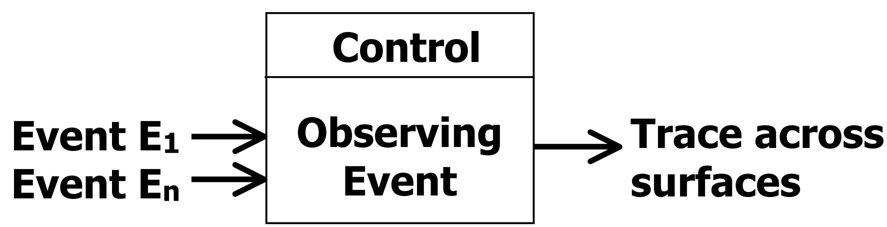
Tracking movement

- Detecting traces on surfaces



Tracking objects

- Tracking across surfaces
- Correlation of events
- Grouping events associated with the same object



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5 - Distribution

Why distributed sensing

- Facilitate combination of distributed observations
- Factoring out sensing from devices into infrastructure
- Separation of sensing and application into distributed entities

Some implications

- Location and time need to be considered
- Data delivery from sensor to application
- Where to sense: device vs. infrastructure

Location and Time

Application Perspective

- Location and Time considered as context of particular interest
- Though rarely location/time as such, but location of people/objects and time of events/activities

Sensor System Perspective

- Physical phenomena are location- and time-dependent
- Every sensor observation is made a specific location and at a specific time
- Every observed variable is associated with location and time as meta-data
- There are real-time and "real-place" issues

Location and Time

Real-time issues

- Value of observation time-dependent
  - e.g. can become irrelevant after some time
- Latency can contribute to inaccuracy
  - e.g. location reading of moving objects
- Synchronization of distributed observations (sensor fusion)

"Real-place" issues

- Arising with mobile/flexible sensor nodes
- Value of observation location-dependent
  - e.g. less relevant the greater the distance between sensor node and observed entity
- Location also relevant for sensor fusion
- Localization hot issues for wireless sensor networks!

Sensor Data Delivery

Application-level Delivery Models

- Continuous: sensors communicate their data at prespecified rate
- Event-driven: report data only if event of interest occurs
- Request-reply: report only response to an application request

Network-level Routing Models

- Flooding: broadcasting observations to neighbours, who rebroadcast until application is reached
- Directed Diffusion: data-centric protocol
  - Data is named by attribute-value pairs
  - Applications submit queries, diffused through the network
  - Nodes satisfying the query start transmitting data

Where to Sense

Smart Device vs Smart Environment

- e.g. location sensing
  - 'GPS model': infrastructure sends it's coordinates, device computes it's position
  - 'Active Badge model': device/client sends beacon, infrastructure computes position
- Wearable computing vs ubiquitous computing debate
- Privacy issues: who's in control over location information
- Distributed systems issues
  - System-wide location management
  - Client reliance on infrastructure
  - Protocols to talk about location
  - etc

6 - Energy

Why energy is such an issue

- Wireless embedded devices rely on stored energy
  - some ideas around for harvesting energy
- Energy storage is advancing but at a slow rate

- Energy will continue to be the most limiting resource in design of wireless sensor devices

Energy cost

Where the energy goes

- Relative energy consumption in wireless sensor devices
  - Most expensive: wireless communication (sending, receiving, and also just listening)
  - less expensive (by a magnitude): sampling sensors
  - least expensive (again by a magnitude): computation

"3000 instructions could be executed for the same energy cost as sending a bit 100m by radio"

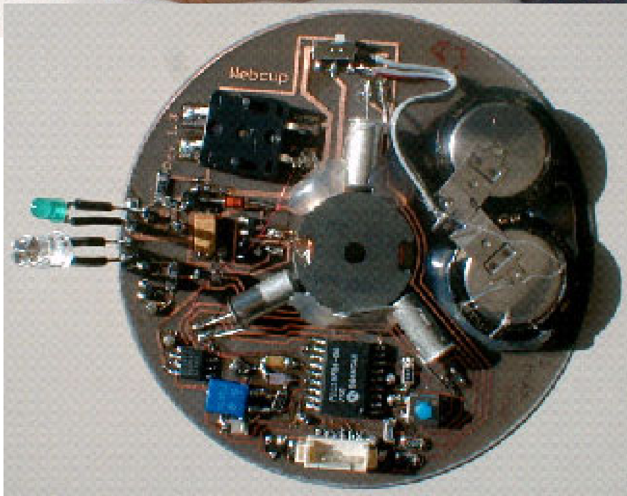
Implications

- Reduce communication in favour of computation
- Event-driven instead of continuous sensing and communication

Example: Mediacup Design

Design dominated by energy issues

- Sensor choice
  - Ball switches for motion detection instead of acceleromter
  - Enables interrupt-based rather than continuous sampling
- Communication:
  - Coded percepts instead of raw sensor data
  - Broadcast only every 2s
- Wireless charging
  - instead of batteries
- Processing
  - low-powered processor (PIC)
  - Maximize sleep time



Wrap-Up

Sensing in Ubicomp

- Important enabling role: proactive systems, context-awareness
- Some key differences to traditional sensing
- Perception, Distribution, Energy
- There would be a lot more to say
  - Human-computer interaction issues
  - Human in the loop vs task automation
  - Transparency and control
  - Design of perceptual user interfaces, e.g. how to deal with inherent ambiguity
  - …