Faculty of Computer Science

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Enabling the Computer for the 21st Century to Cope with Real World Conditions

# Towards Fault-Tolerant Ubiquitous Computing

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## 1991: Mark Weiser[1]

*"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."*

## The vision

- Calm technology, calm computing
  - Never surprising
  - Act without increasing information overload
  - Moves from periphery to center of awareness and back

[1] Mark Weiser. The Computer for the 21st Century. Scientific American, 1991


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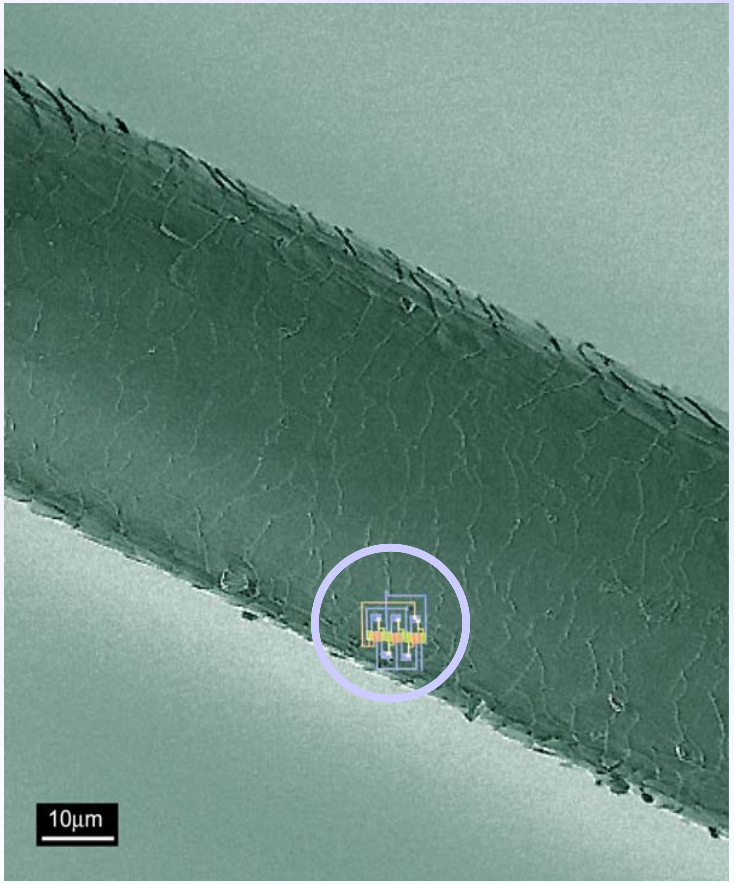
# Enabling Technologies 1/2

## Miniaturization of chips: towards nanotechnology




Source: IBM http://www.ibm.com (March, 24, 2006)

Carbon nano tube ring oscillator circuit compared to a human hair



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# “Resistance is Futile?”

… a possible application area for nanotechnology?

Source: http://www.startrek.com

Seven of Nine (Startrek Voyager series)

# Enabling Technologies 2/2



## Wireless networks and mobile / wearable devices

- Mobility management, ad-hoc communication

## Open / standardized service access

- Semantic Web, ontology frameworks
- Grid infrastructures, service discovery frameworks

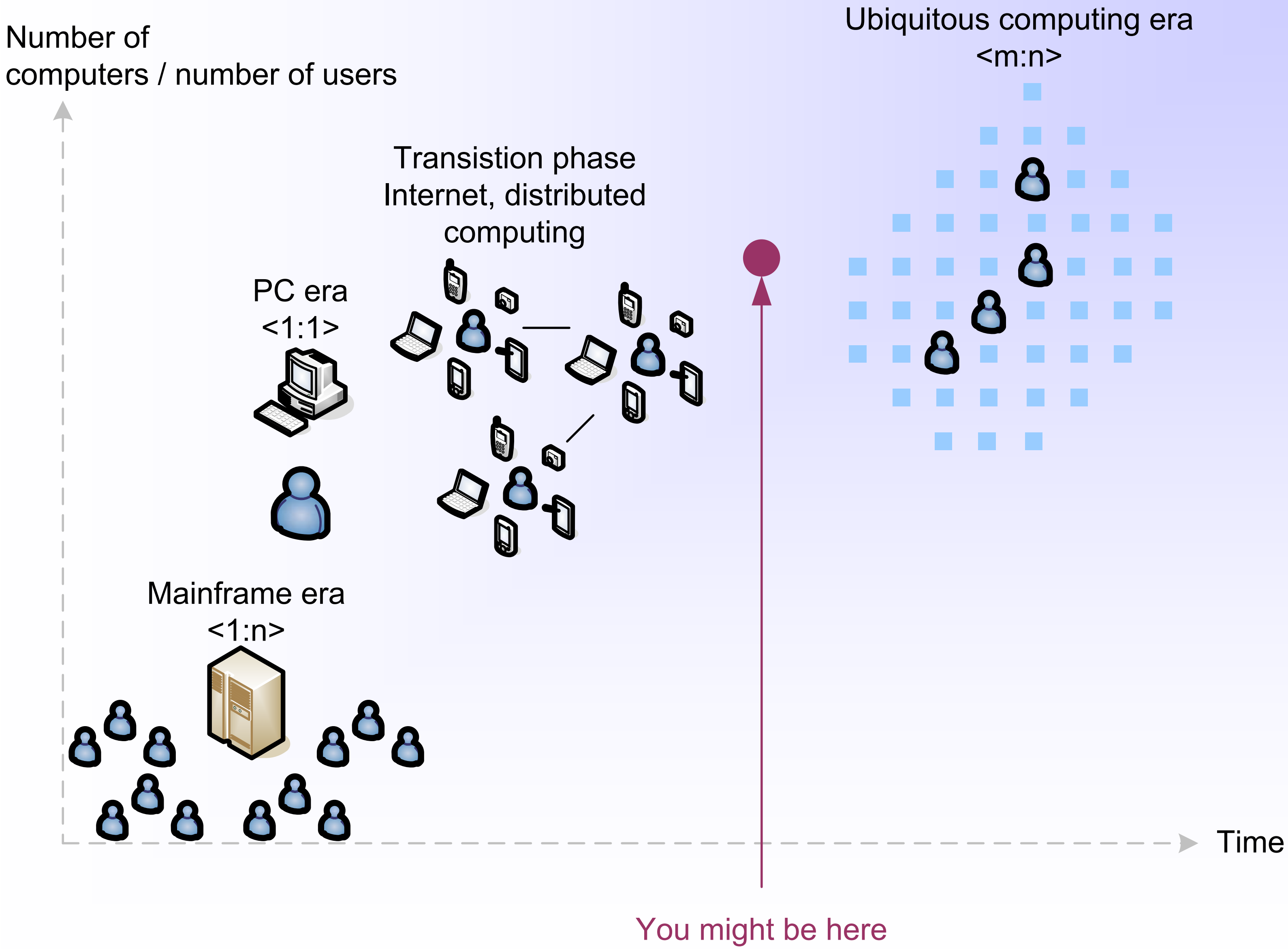
## Sensing infrastructures

- D-GPS, ГЛОНАСС, (Galileo), RFID, video cameras
- Sensor manufacturers: environmental conditions, bio-signals

## Artificial Intelligence (AI)

- Planning and learning, bio-inspired - smart behavior

# Evolution of Human-Computer Relationship



# Application Prototypes

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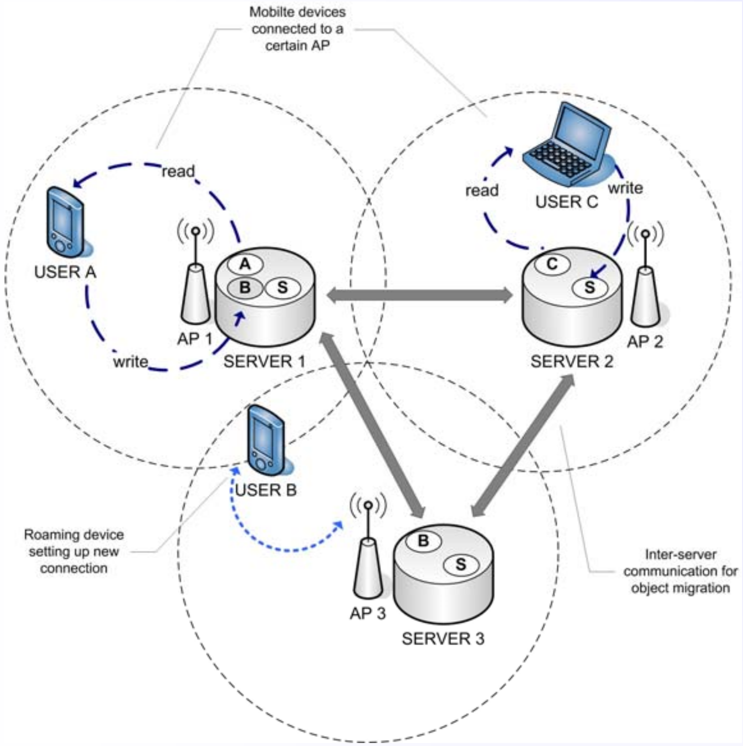
## Follow-me data objects




## Smart museum artifacts

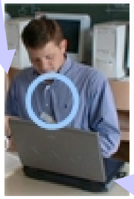
Artist information
Painting details
Historical details
Personal notes
etc.

RFID

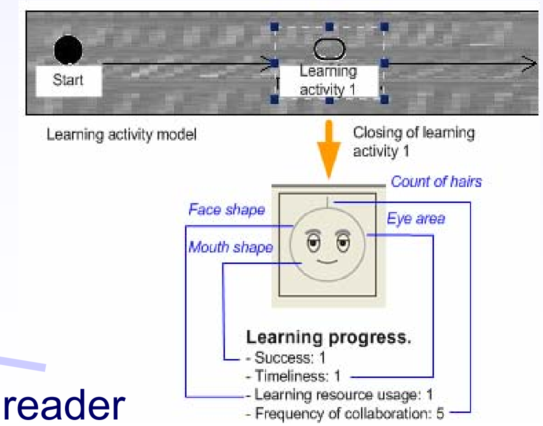
Gustav Klimt. The Kiss

## Pervasive e-teaching

RFID tags



RFID reader





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# Selection of “New Computers and Services”


## Every day objects[1]

- Media Cup
- Smart door plate
- Coffee pump
- Hot clock

## Hello.Wall[2]

- Visual patterns
- Symbols for distributed collaborations

[1] M. Beigl et al. MediaCups: Experience with Design and Use of Computer-Augmented Everyday Objects. International Journal on Computer Networks and Communication, 2001
[2] N. Streitz et al. Designing Smart Artifacts for Smart Environments. IEEE Computer, 2005

# So - Why Reasoning About Faults in UbiComp?

Recall Mark Weiser's vision of calm computing

- People are always surrounded by technology
- People are (nearly) not aware of pervasive technologies

People will depend on these technologies

- Assure, that they are dependable
- In addition, people should "never be surprised"


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# Dependability

*Dependability of a computing system is the ability to deliver services that can justifiably be trusted.[1]*

## Threats

- Faults, Errors, Failures

## Attributes

- Availability, Reliability, Safety, Confidentiality, Integrity, Maintainability

## Means

- Fault prevention, removal, forecasting, tolerance

[1] Laprie et al. Fundamental Concepts of Dependability. LAAS report no. 01-145, 2001





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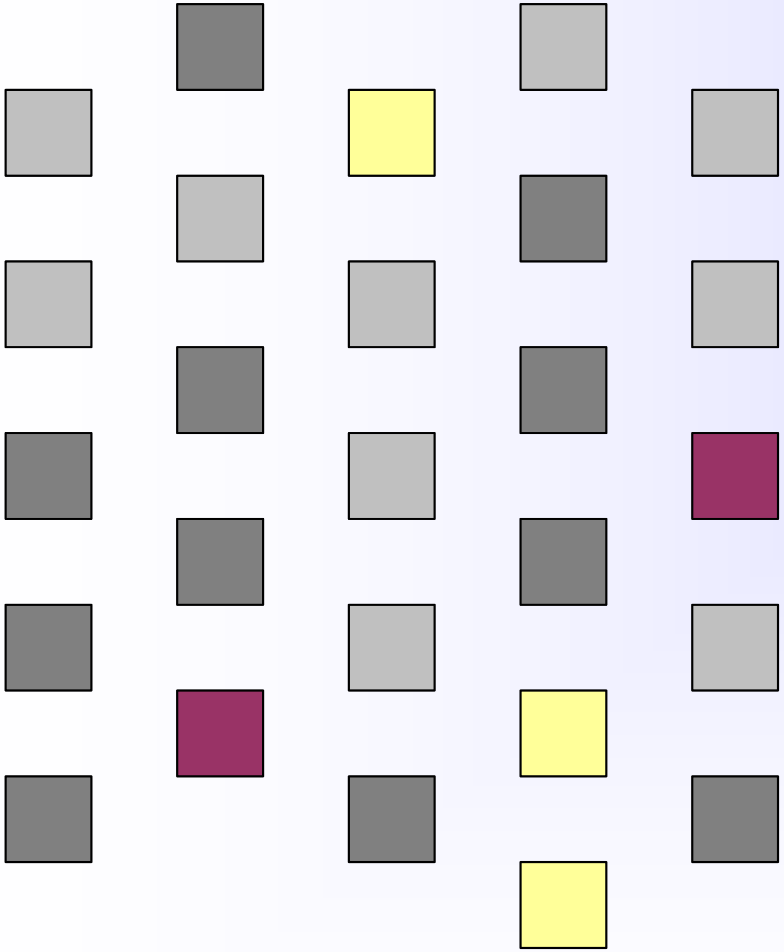
# UbiComp From a System's Perspective

- Distributed system
- Embedded system
- Interactive system



Sensor

Actuator

Computing unit

User interface



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# The Distributed System's Perspective

General issue: scale

Network and mobile devices

- Wireless networks
- Ad-hoc, mesh nets – e.g. MANETs and VANETs
- Threats to dependability
  - Connectivity failures
  - Unreliable wireless medium

Service interaction

- Asynchronous (and synchronous) operations
- Decentralized (and centralized) operations
- Threats to dependability
  - Protocol and service failures (timeouts)
  - Consensus-based coordination



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# The Embedded System's Perspective

## Context-awareness

- Sensor integration – sensor networks
- Sensor fusion, interpretation, prediction
- Threats to dependability
  - Sensor malfunctioning in value or time domain
  - Disconnection of nodes in sensor networks
  - Interpretation not sufficient, prediction limited

## Controlling and activating

- Controlling actuators – mechanical parts
  - e.g. controlling car windows, dimming the light
- Real-time requirements
- Threats to dependability
  - Timing requirements are not met
  - Result is not "as expected" (e.g. half open)



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# Environmental Sensors

## Sensor types

- Acceleration
- Temperature
- Humidity
- Luminance
- Sound
- Pressure
- etc.

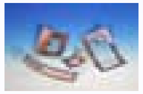
Rain sensor. Source: http://www.trw.com

GPS trainer. Source: http://www.garmin.de

GPS CF Card + PDA

## Dedicated object augmentation

- Location of objects
- Identification of objects



RFID inlays and keyring.
Source: http://www.tiris.com/rfid

# Bio-signal Sensors and Systems

## Sensor types

- Breath
- Galvanic skin response
- Heart rate (ECG)
- Brain activity (EEG)
- Eye, muscle activity (EOG, EMG)
- etc.

## Brain Computer Interface (BCI)

- Electrical brain signal patterns
- Used to control simple functions
  - e.g.: using a virtual keyboard
- But: intrusive technologies outperform non-intrusive technologies!

EEG Electrode Cap.
Source: http://www.gtec.at

# The HCI Perspective

## Input and interaction

- Natural interfaces (e.g. gestures)
- Principle of delegation
- Activity recognition
- Threats to dependability
  - Recognition (e.g. unknown persons)
  - Indirection causes uncertainties

## Everywhere displays

- Using non-traditional displays
  - Walls, cups, tables
- Threats to dependability
  - Display selection
  - Privacy

# Principles of Fault-Tolerant Behavior

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## Error detection

- Observation
- Comparison (to expected service)

Fault occurs

↳ Error is detected

↳ FT mechanism is invoked

## Fault tolerance (FT) – basic mechanisms

- Redundancy
  - Additional resources, error correcting codes
- Recovery and restart
  - Stateless vs. stateful components


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# Selected Research Issues

… for fault tolerance in ubiquitous computing

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## Distributed computing

- Reacting to dynamic changes in time
- Disconnecting components, varying link quality
- Redundant components cause additional costs

## Context awareness (and environmental control)

- Various sensors with different accuracy
- Redundant similar sensors might be rare
- Timing “guarantees” conflict dynamicity

## HCI

- Traditional error notification is not desired
- Uncertainty is a serious cause for misinterpretation
- Integration of human feedback?


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# Promising Direction: Autonomic Computing

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Analogy to the human autonomic nervous system

- IBM initiative from 2001[1]

Self-x properties – for fault tolerance mechanisms

- Self-configuring
- Self-protecting
- Self-healing, self-testing (e.g. fault-injection)
- Self-optimizing, self-evaluation
- etc.

Including AI research

- Autonomous software agents, robots
- Planning, reasoning, and learning

[1] Richard Murch. Autonomic Computing. IBM Press. 2005


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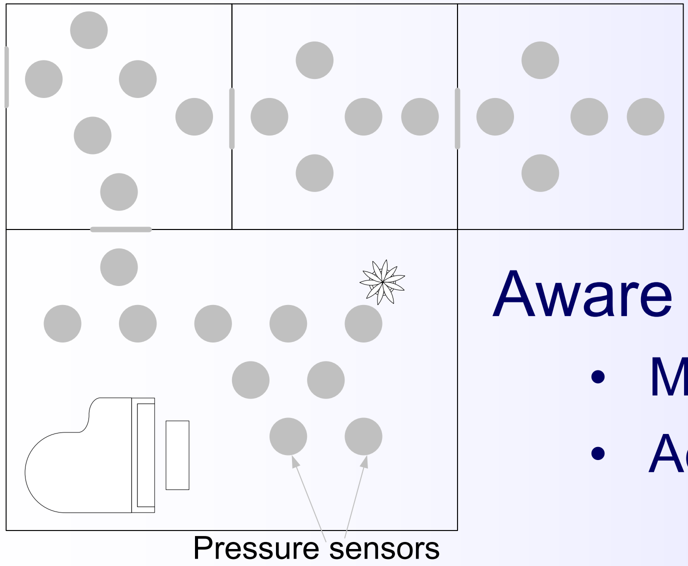
# Ex.: Smart Home Environment Projects




## Aware Home Initiative[1] projects

- Monitoring elderly relatives, 2001
- Activity recognition

## House_n PlaceLab[2]

- Research facility, 2003/04
- Sensors: $CO_2$, barometric pressure, microphones, door switches, etc.

[1] http://www.awarehome.gatech.edu

[2] http://architecture.mit.edu/house_n/placelab.html

# Ex.: Fault Tolerance in Smart Home Environments



## Follow me music

- Fault: speakers are malfunctioning
- Error detection
  - Self-detection, micro and volume analyzer
  - Human gestures (additional video camera)
- Fault tolerance mechanisms
  - Turn off speakers in that room and use speakers in neighboring room (graceful degradation)

## Movement tracking of elderly persons

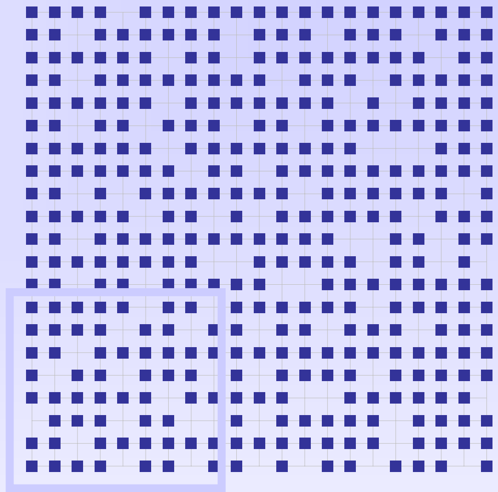
- Fault: pressure sensor is malfunctioning
- Error detection
  - No values, sporadic values, inconsistent values
- Fault tolerance mechanisms
  - Use “regular pathway” history information to mask the missing sensor information

# Ex.: Wireless Sensor Networks (WSNs)

Usage: environmental monitoring, military

Large scale WSNs

- Usually single event to detect
- Multi-hop ad-hoc communication
- Usually cheap sensors
- Group n in event range



Small scale WSNs

- Sensor boards with various sensors
- Different and sophisticated applications
- Continuous value range

# Ex.: Fault Tolerance in WSNs

## Distributed fault-tolerant binary event detection[1]

- Fault: sensor node failure (due to manufacturing, etc.)
- Error: no messages received, wrong values received
  - event / non-event
- Fault tolerance mechanism: k out of n "voting"

## Simple weather sensor application: "sunny" / "overcast"

- WSN consisting of luminance (and temperature) sensors
- sensor interpretation: luminance → "sunny", "overcast"

- Fault: sensor failure of luminance sensor (fail silent)
- Error: missing sensor value for luminance
- Fault tolerance mechanism: sensor interpretation uses temperature instead and degraded confidence in result

[1] Luo et al. On Distributed Fault-Tolerant Detection in Wireless Sensor Networks, IEEE Transactions on Computers, 2006

# Fault-Tolerant Pervasive Computing Infrastructure

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… focusing on distributed computing aspects

## Main threats

- Disconnection
- Weak connection

## Fault-tolerant middleware approaches

- Asynchronous communication – Tuple Space[1] approaches
- Surrogate node for task execution – e.g. Gaia[2]
- Recovery / restart
- Degraded service provisioning (self-adaptation)
  - Working on copies / consistent reintegration

[1] Gelernter et al. Coordination Languages and their Significance. Communications of the ACM, 1992
[2] http://gaia.cs.uiuc.edu


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# Important Cause for Faults: Movement

Due to

- Widespread use of mobile devices
- Wearable computers
- Body-area networks connecting to infrastructure

Movement or motion

- Velocity, retention
- Direction
- Time series: <location, point in time>
- "location-awareness" turns into "mobility-awareness"


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# Mobility-Aware Pervasive Services

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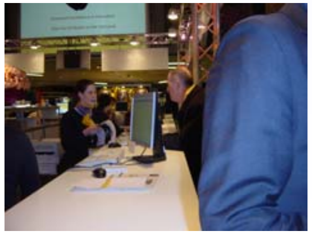
Office
- Information just in time
- Copy of shared data (system)

Street
- Accidents
- Underground tickets

Cafe
- Reservation
- News selection

By train, by car
- Traffic jams
- Route planner



Hospital, Conference venue
- Path finder
- Parking reservation

Pro-active service

Service provisioning

Service adaptation

t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# Introducing Mobility Predictors

- Notion for location and retention
- Assumption: regularities exist in pathways
  - Temporal and spatial
  - Mobility predictor examples: LeZi Update, k-order Markov, Random Waypoint, etc.

User mobility history ↓ Mobility pattern ↓

Comparison

↓

Prediction of
Next k locations, next l retention periods
(incl. confidence values)

↓

Pro-active service invocation


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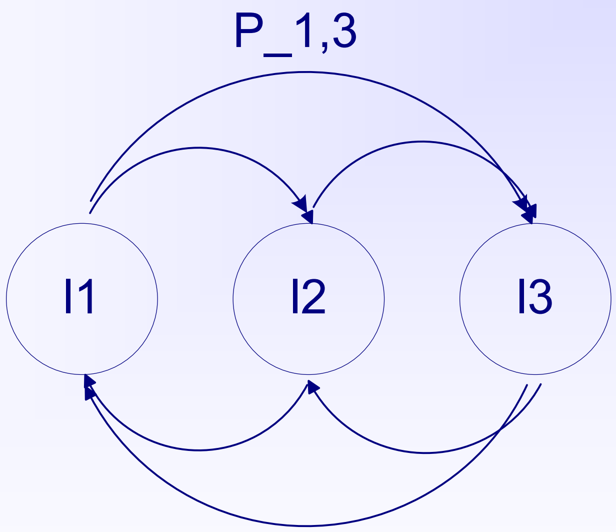
# Example k-order Markov Mobility Predictors

## Principle

- Prediction depends on the last k history states
- Transition probabilities determine movement estimation




Example: 1-order Markov predictor for 3 locations

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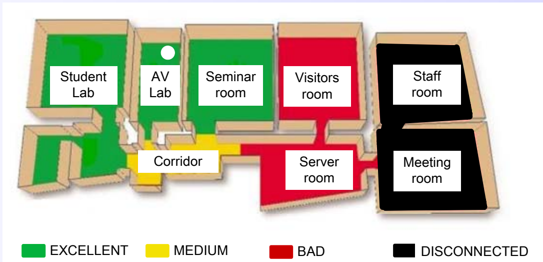
# Using Mobility Prediction for Fault Tolerance

Introducing a new Mobility-Aware Coordination Layer to space-based middleware

- Tolerating weak links, disconnection by “working on copies”




Depending on

- Mobility prediction: next link state, next retention period
- Current link state, current remaining retention period

Pro-active (and reactive) activation of

- Copy, release locked data, synchronize

One promising result

- Asynchronous coordination throughput can be increased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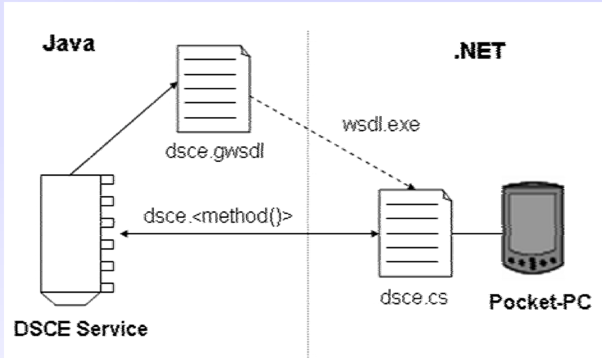
# Ongoing Prototypes: Austrian Grid Project[1]

## Mobile GridMiner

- Extension for ubiquitous data mining grid access
- Fault-tolerant job status notification service
  - PDA GUI, email, SMS, sound




## Environmental monitoring

- Location-aware
- GPS accuracy not sufficient
- Movement-history based corrections

[1] http://www.austriangrid.at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# Sustainability of FT in Pervasive Computing

… will fail tolerance be important?

Beyond-the-horizon TG1: Pervasive Computing and Communications – one of three research lines[1]

- Evolve-able systems …”enabling autonomic adaptation to unforeseen situations, interpreting context …”

Thus:

- Autonomous and bio-inspired, emerging fault tolerance
- Acting in-time

Embedded and ubiquitous computing

- Emerging workshops including fault tolerance issues

Middleware conferences and workshops

[1] http://www.ercim.org/publication/Ercim_News/enw64/bth1.html