CMU Pervasive and Context Aware Computing: Solutions for Aging, Disability, and Independence

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Royal Academy of Engineering,
London, 26-27 June 2003

Overview

- Overview
- CMU Context Aware Wearable Computers: Human-Centric Computing
- Automatic Learning and Monitoring of User's Physiological and Emotional State: ARIUS
- Context Aware Smart Phone: SenSay
- Diabetes Management Assistant: DiMA
- Pervasive Computing in Emergency Medical Applications
- Reflective Systems for Mitigating Disabilities: WearXP
- Smart Room: BARN
- Nursebot
- Conclusions and Future Directions

Introduction

- **Context aware computing is defining the future of mobile computing, making it human-centric**
  - » **Computer is made aware of the user's state, needs and surroundings**
- **Pervasive computing minimizes user distraction**
  - » **User can focus on primary task**
  - » **System can proactively move on the user's behalf**
- **Together, these paradigms augment and enhance human capabilities**

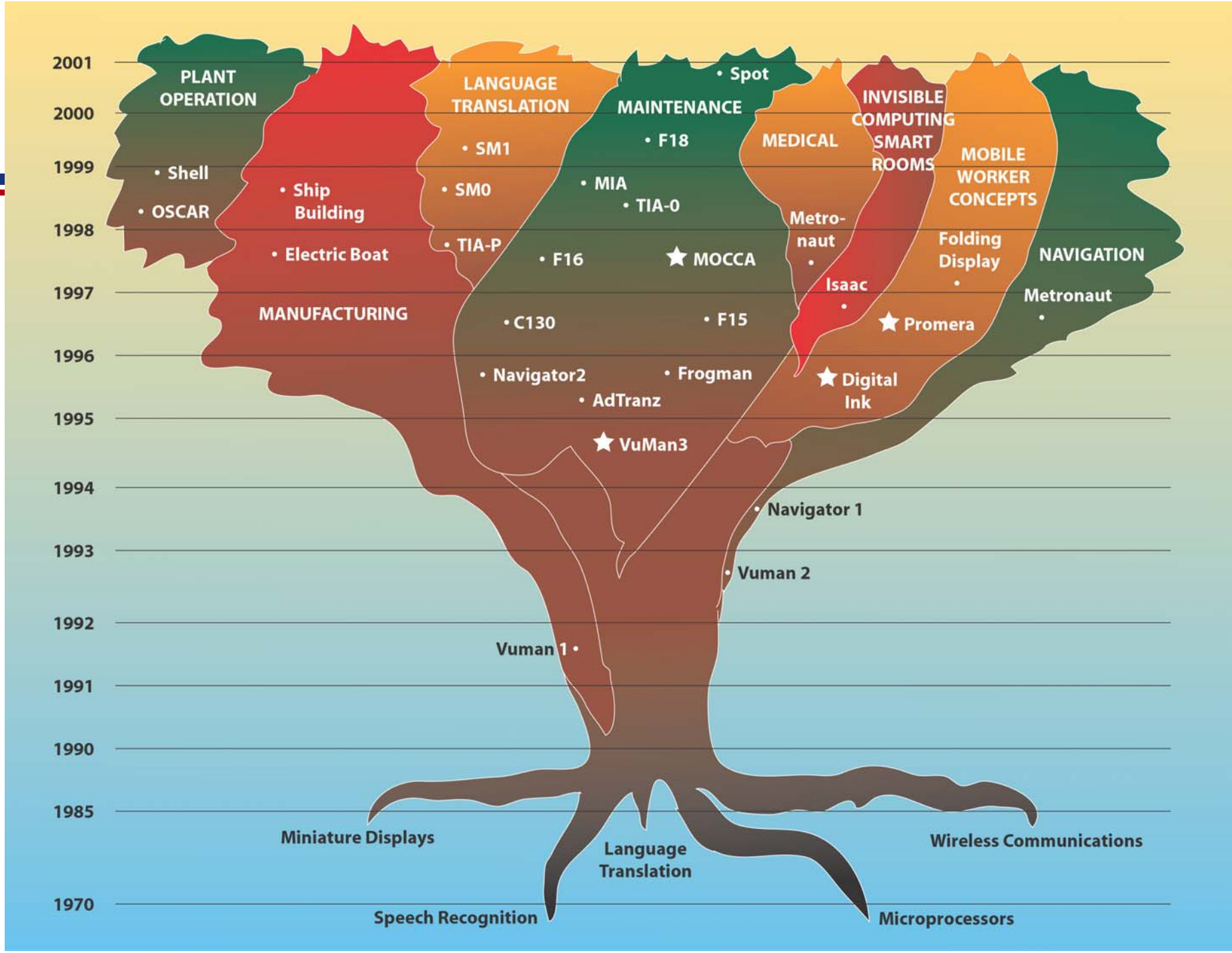
WearableGroup
Carnegie Mellon

1991 - 2001

Ten Years of Wearable Computing at Carnegie Mellon

	Exploratory Systems Design	Customer Driven Systems Design	Visionary Design and Research
2001		**Spot** Research Platform 	**Tactile Display** 
2000		**IBM Wearable** Aircraft Maintenance	**Sprout** Wireless Communicator 
1999	**Itsy/Cue** Wireless Communication and Low Power Innovation	**Smart Modules** Language Translation 	**Streetware** Fashionable Computers 
1998		**Mocca** Mobile Work Assistant	**Design for Wearability** Wearable Shape Research
1997	**Metronaut** Navigation + Information	**TIA-0** Maintenance 	**Folio** Foldable Display 
1996	**ISSAC** Speech Interface Assistant	**OSCAR** Plant Operation Assistant	**Promera** Handheld camera/projector
1995	**Frogman** Underwater Maintenance 	**MIA** Bridge Inspection **TIA-P** Language Translator F-15 Maintenance C-130 Maintenance 	**Digital ink** Digital Pen Computer 
1994		**Navigator 2** Aircraft Maintenance	
1993	**Navigator 1** Navigation Assistant 	**Wu-Man 3** Vehicle Maintenance 	
1992	**Wu-Man 2** Navigation Assistant		
1991	**Wu-Man 1** Manufacturing 		

www.wearablegroup.org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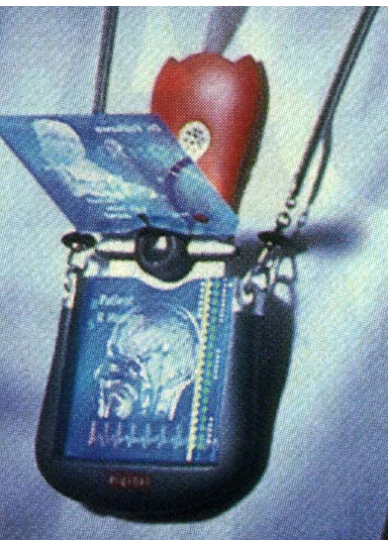
PLANT OPERATION
• Shell
• OSCAR
• Ship Building
• Electric Boat
MANUFACTURING
LANGUAGE TRANSLATION
• SM1
• SM0
• TIA-P
• Spot
MAINTENANCE
• F18
• MIA
• TIA-0
• F16
★ MOCCA
• C130
• F15
• Navigator2
• Frogman
• AdTranz
★ VuMan3
MEDICAL
Metro-naut
Isaac
★ Digital Ink
INVISIBLE COMPUTING SMART ROOMS
MOBILE WORKER CONCEPTS
Folding Display
★ Promera
NAVIGATION
Metronaut
• Navigator 1
• Vuman 2
Vuman 1 •
Miniature Displays
Language Translation
Speech Recognition
Wireless Communications
Microprocessors

Wearable and Context Aware Computers

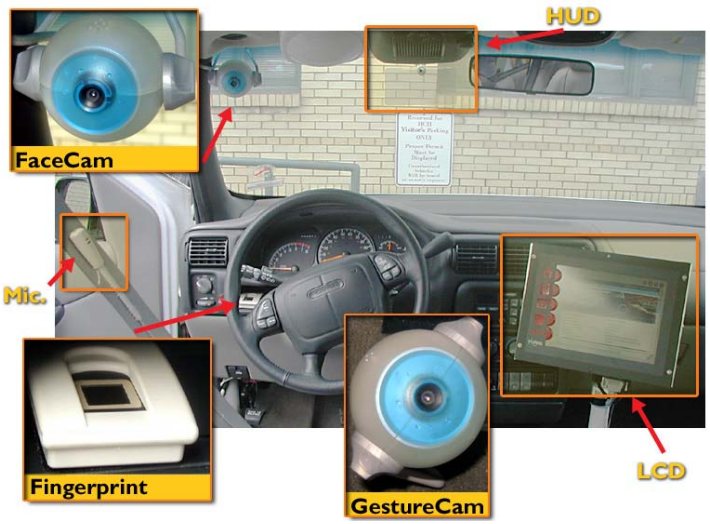
VuMan 3

Navigator 2

TIA-P



MoCCA

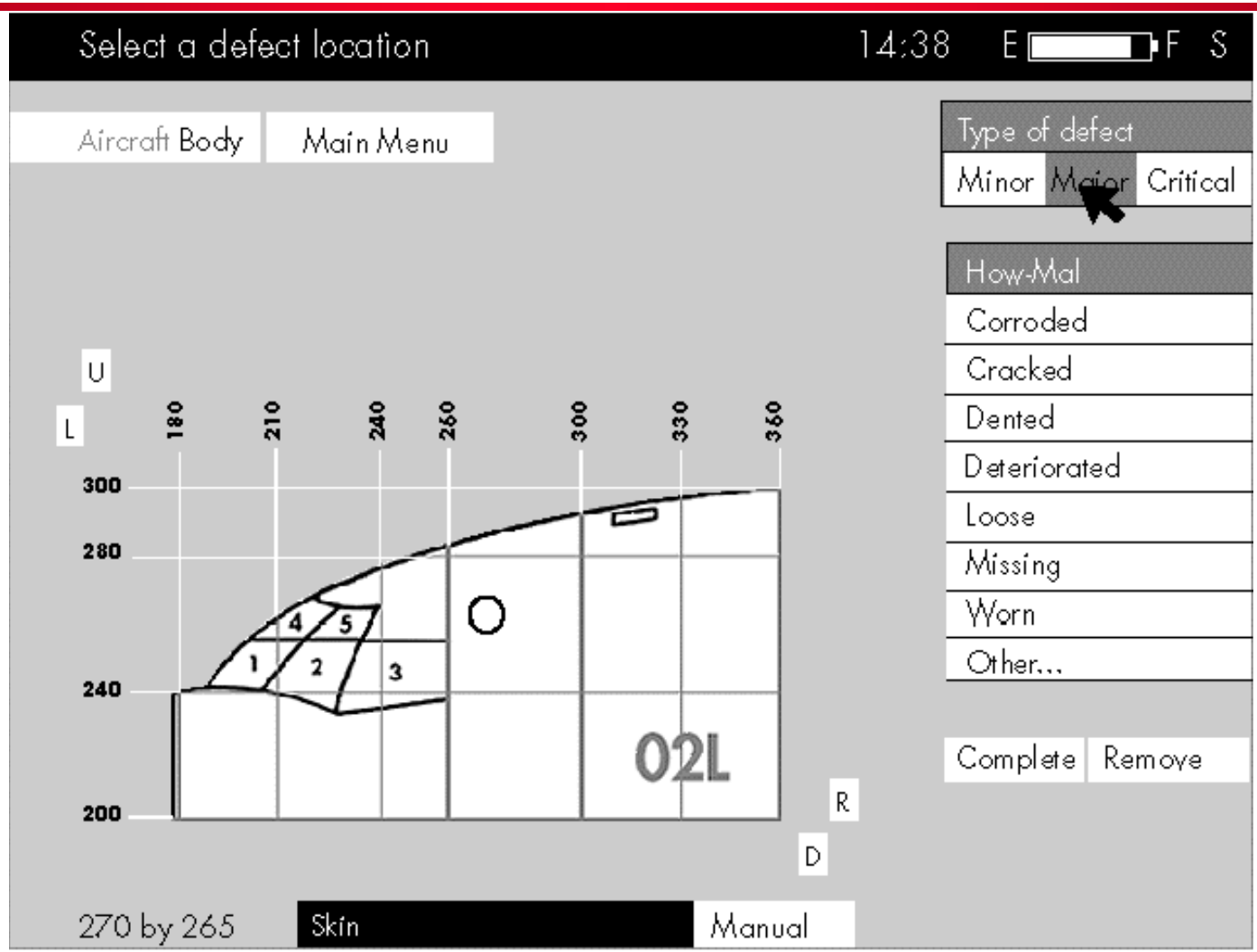


GM/CMU Companion

Spot

MoCCA Prototype

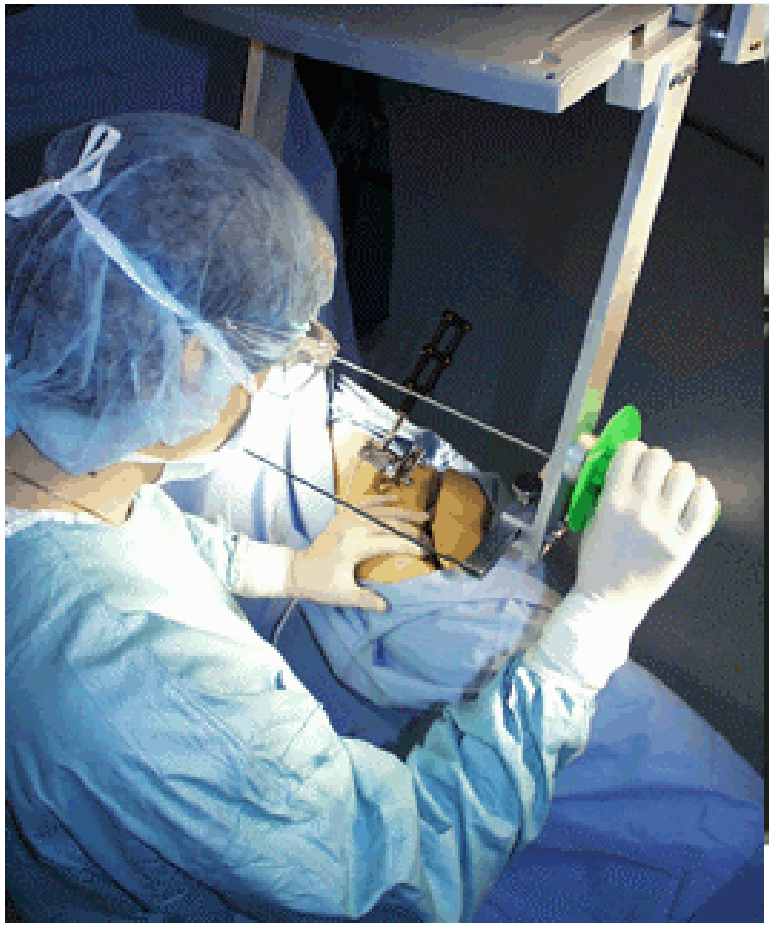
User Interface Screen



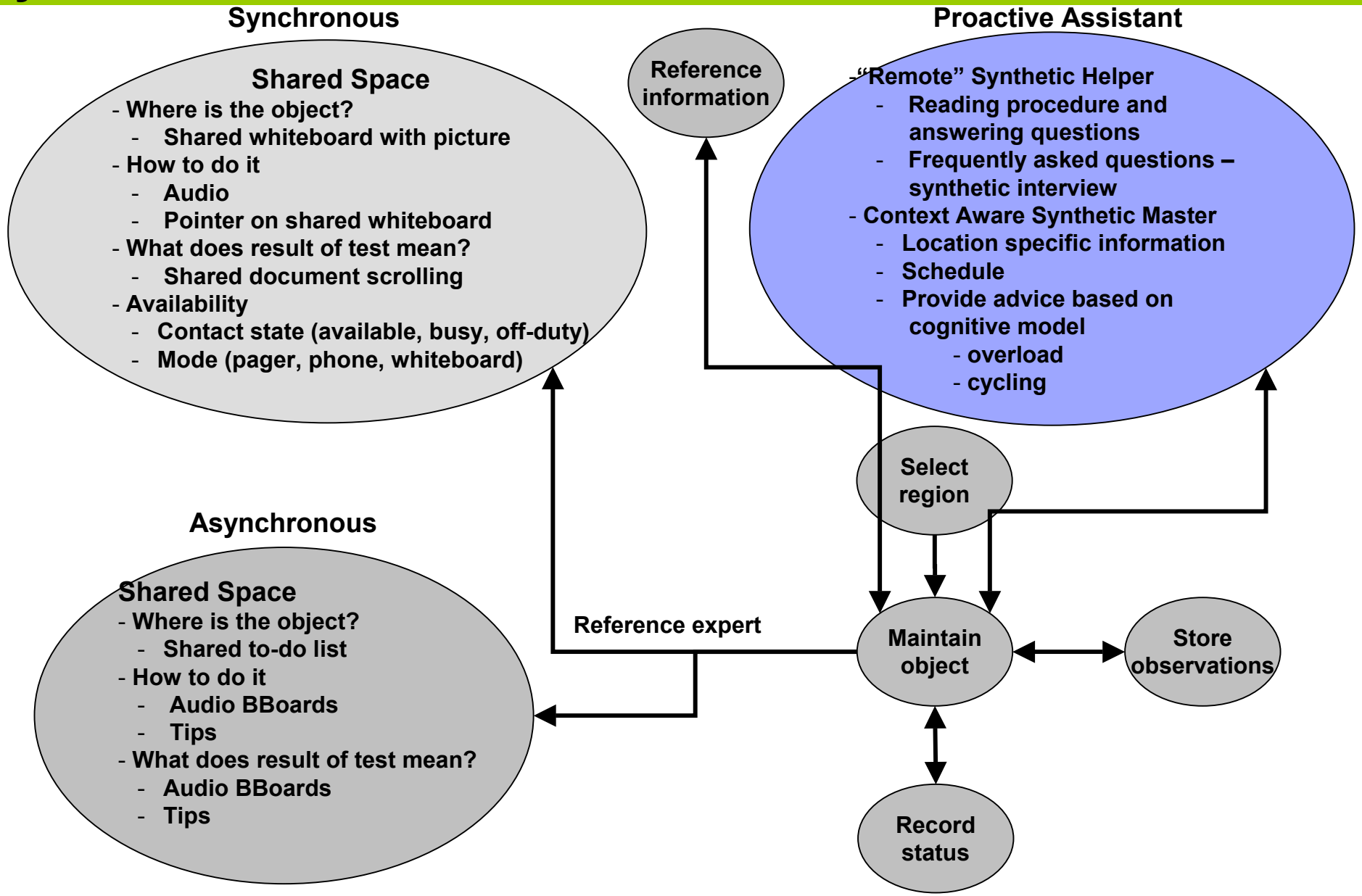
Spot With Head Mounted Display

F-18 Inspection Application: Production vest fits under "Float Coat"

Assisted Surgery



Synthetic Collaboration



Collaboration in Wearable Computing

- **Collaboration. An individual often requires assistance. In a "Help Desk" an experienced person is contacted for audio and visual assistance. The Help Desk can service many people simultaneously.**
- **Information can change on a minute-by-minute and sometimes even a second-by-second basis.**

Chronology

VuMan 3

Navigator 2

TIA-P

MoCCA

GM/CMU Companion

Application

Context-Aware

Team Maintenance

Master / Apprentice
Language Translation

Inspection-Graphics

Inspection-Text

VuMan 3

Navigator 2

TIA-P

MoCCA

GM/CMU Companion

Year

1993

1995

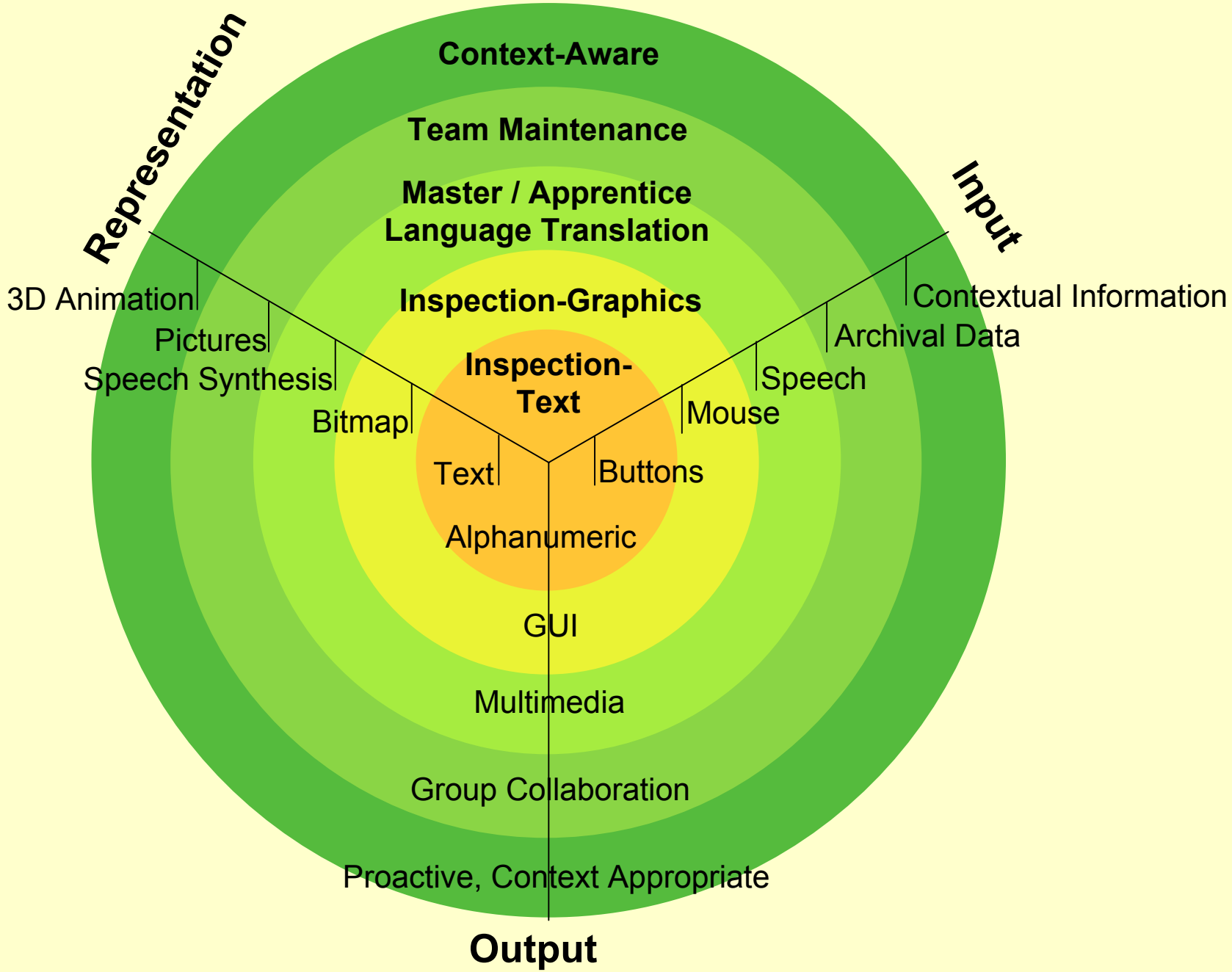
1996

1997

2001

Platform

User Interface - Control and Rendering

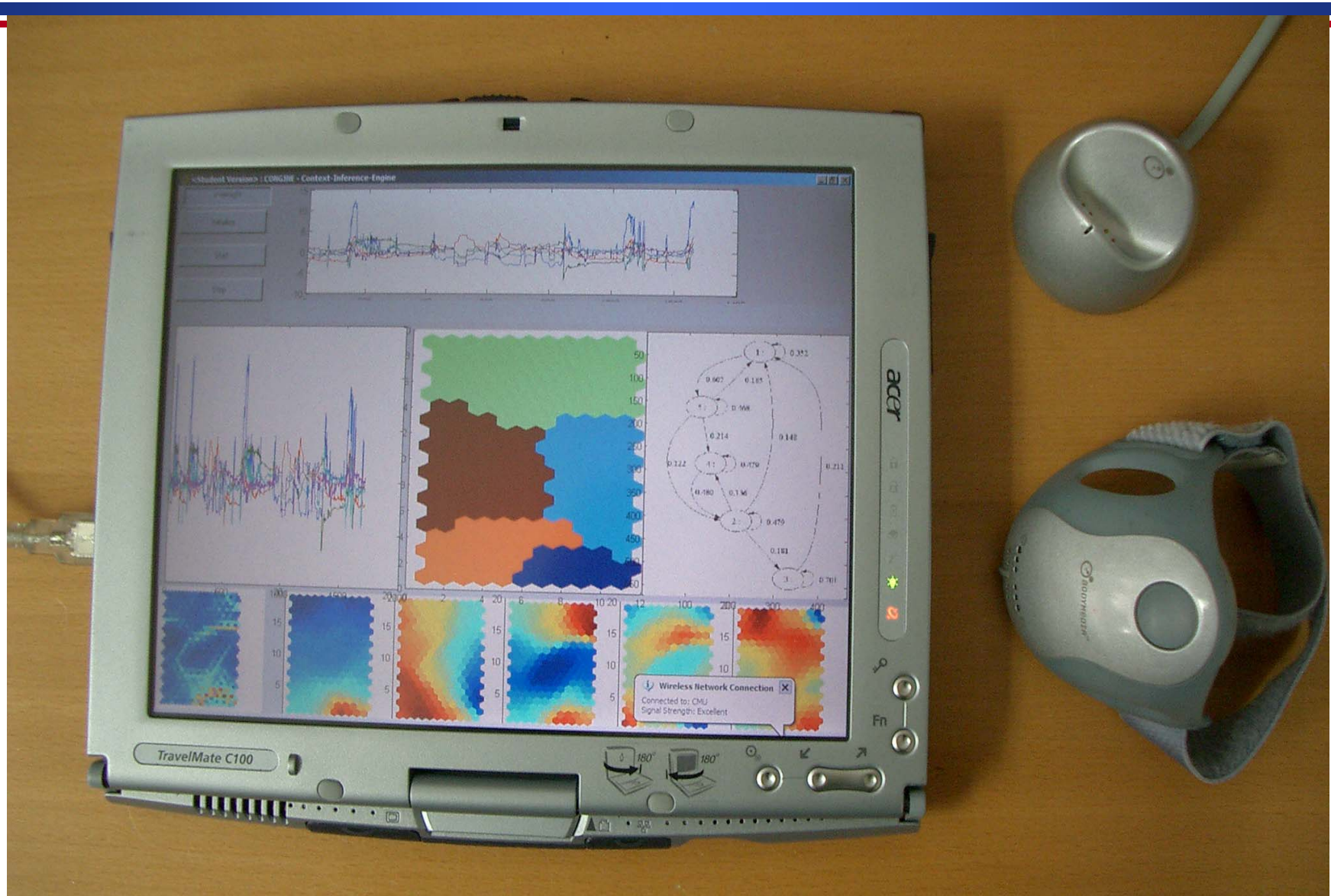


ARIUS: Automatic Learning and Monitoring of User's Physiological and Emotional State

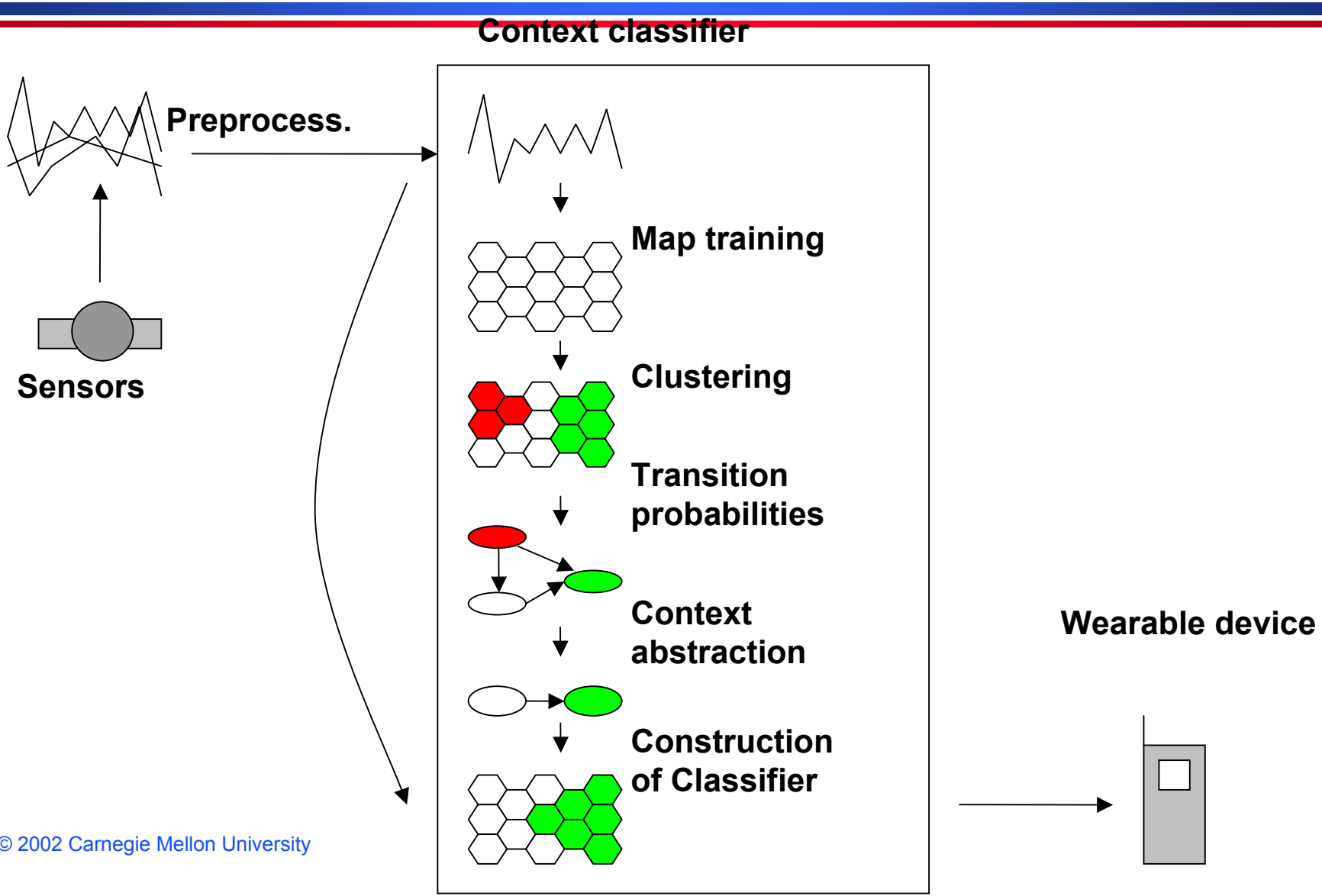
- **Medical support applications require the computer to know user's physiological and emotional state**
- **Use sensors to infer the user's current context**
- **Improve on wearability and usability problems of existing approaches**
  - » **Wearability: Use non-intrusive sensor hardware**
  - » **Usability: Minimize necessary active training**
- **Make a wearable computer *learn* to become *aware* of user states, without supervision**
- **Use of Unsupervised Machine Learning and Statistical Analysis techniques to design and construct an online sensor data classifier**

Wearable Sensor

Data Analysis Platform



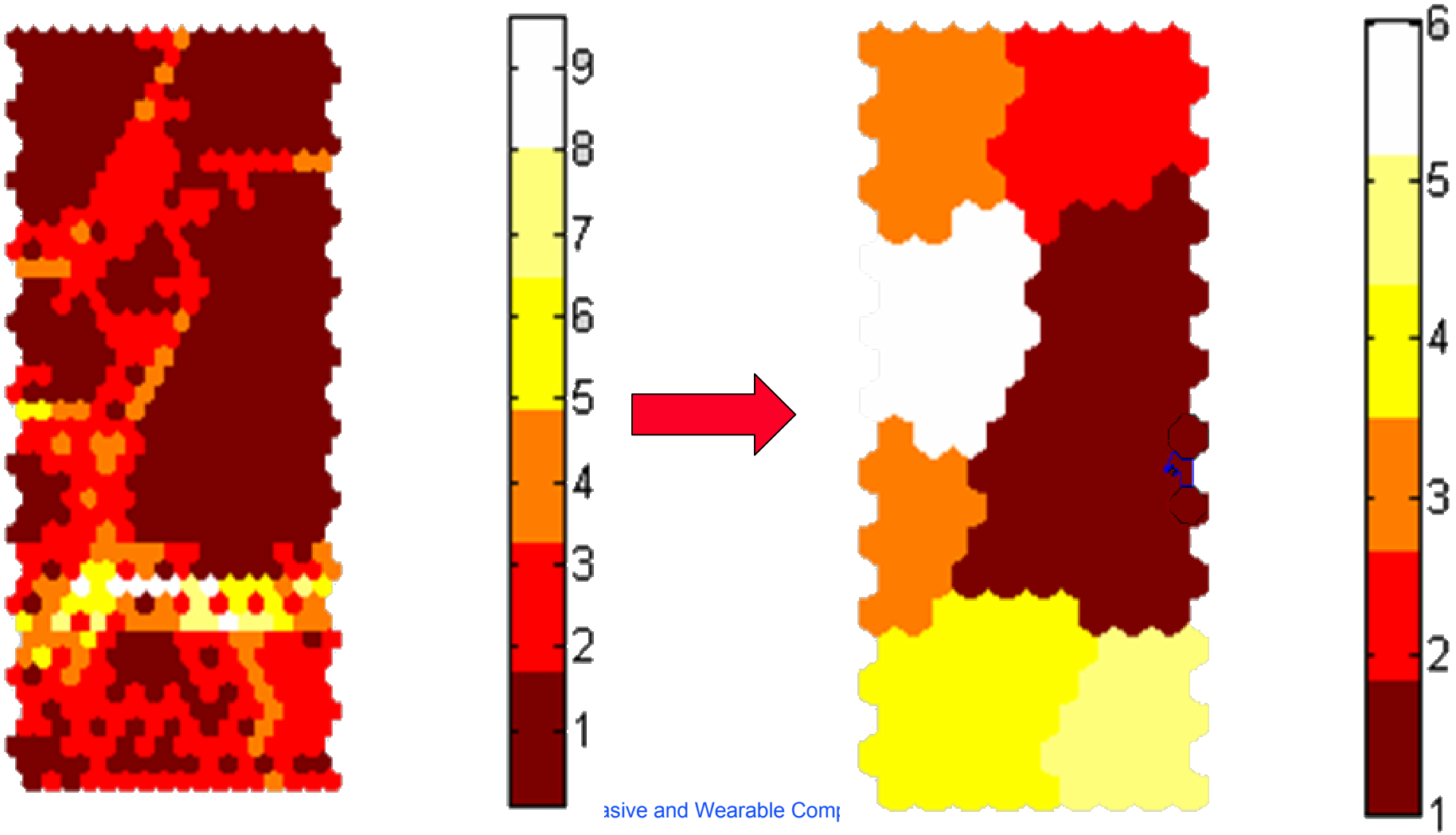
Offline Data Classifier



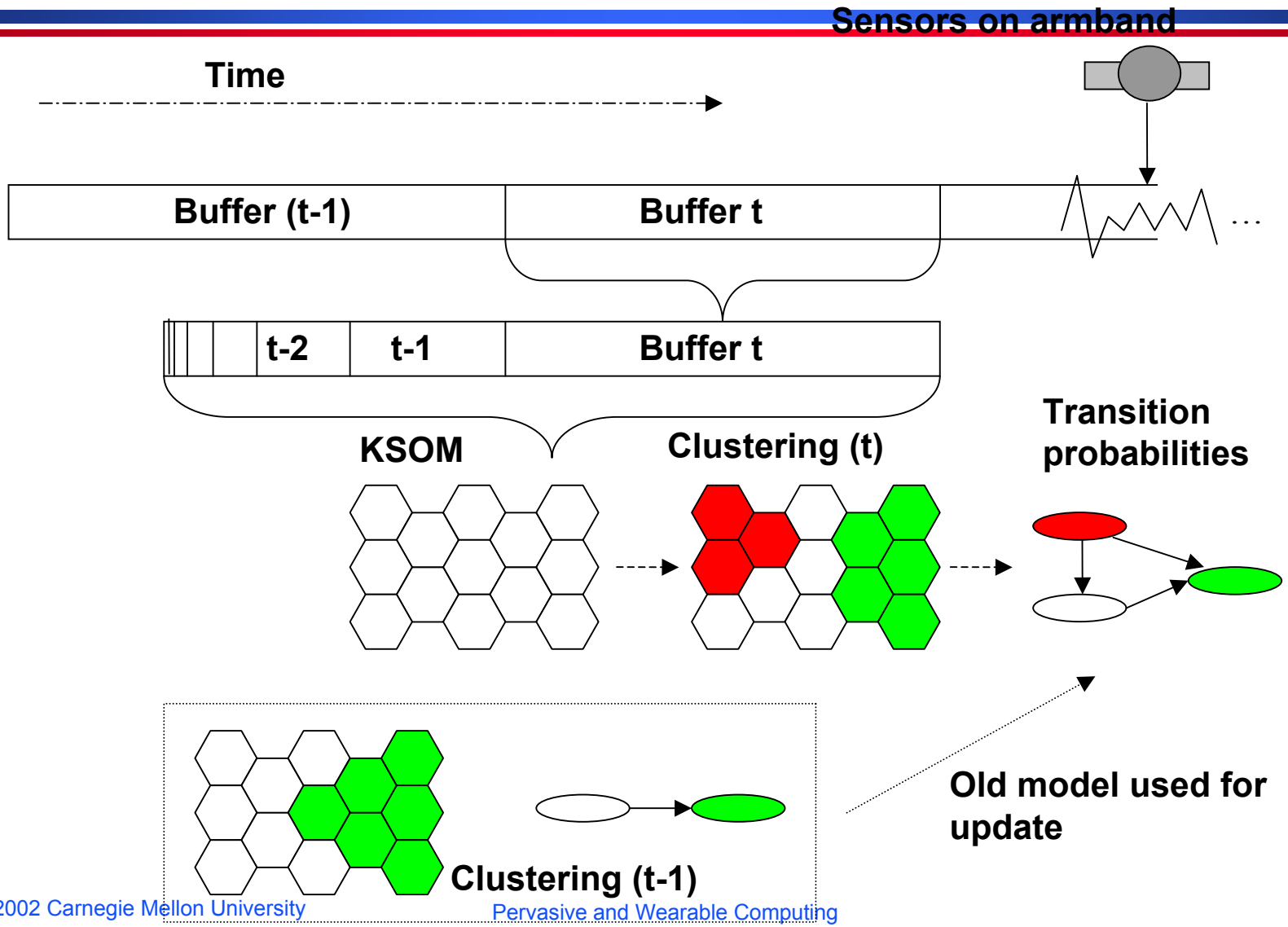
Recurrent SOM

- **Kohonen Self-Organizing Map (KSOM)**
  - **Vector Quantization method**
  - **Based on Competitive Learning with Neighborhood Kernel**
  - **Topology preservation**
  - **Dimension reduction**
- **Recurrent SOM**
  - **Modification of KSOM for time-series data**

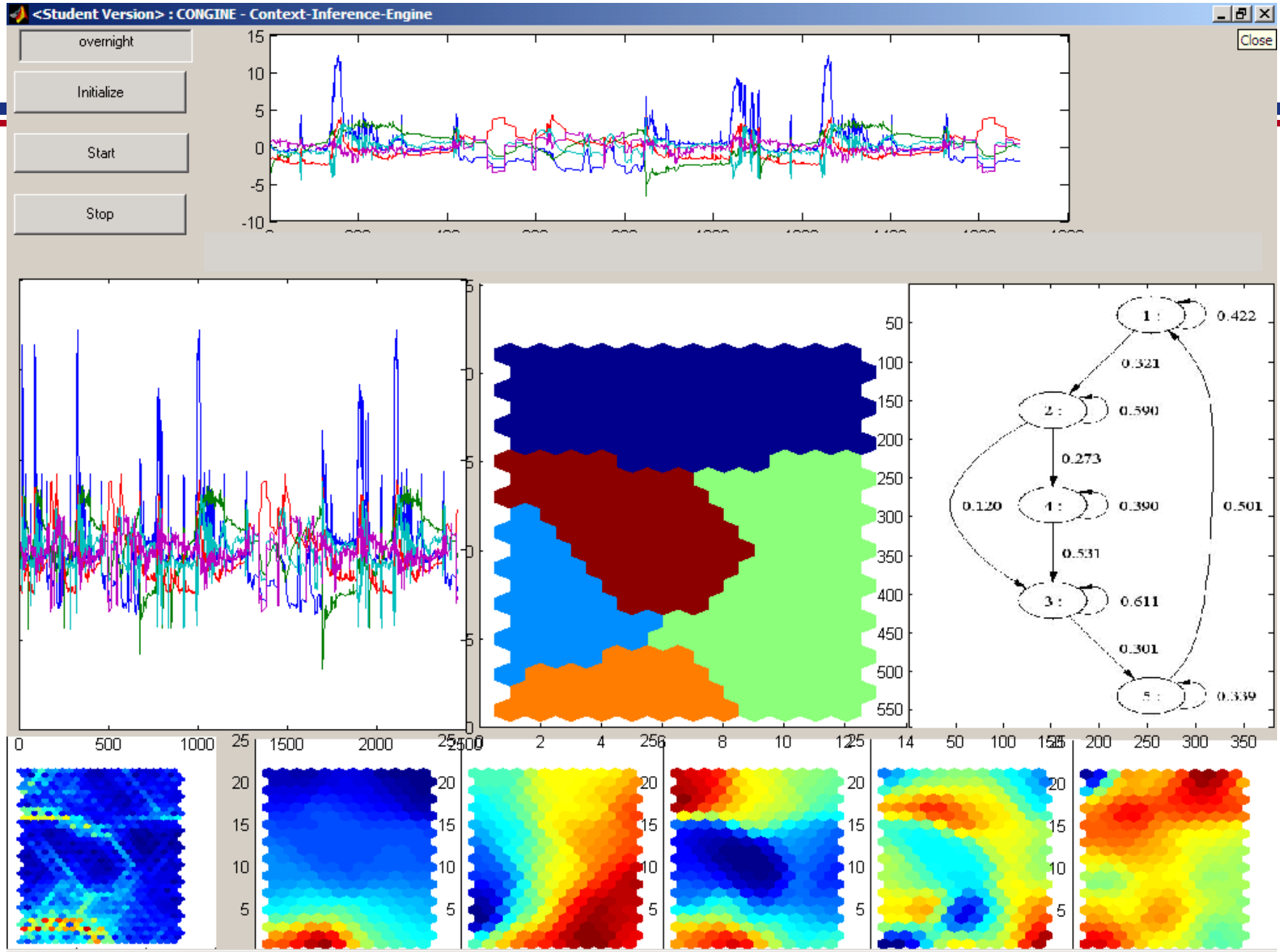
Example Clustering Results



Online Data Classifier



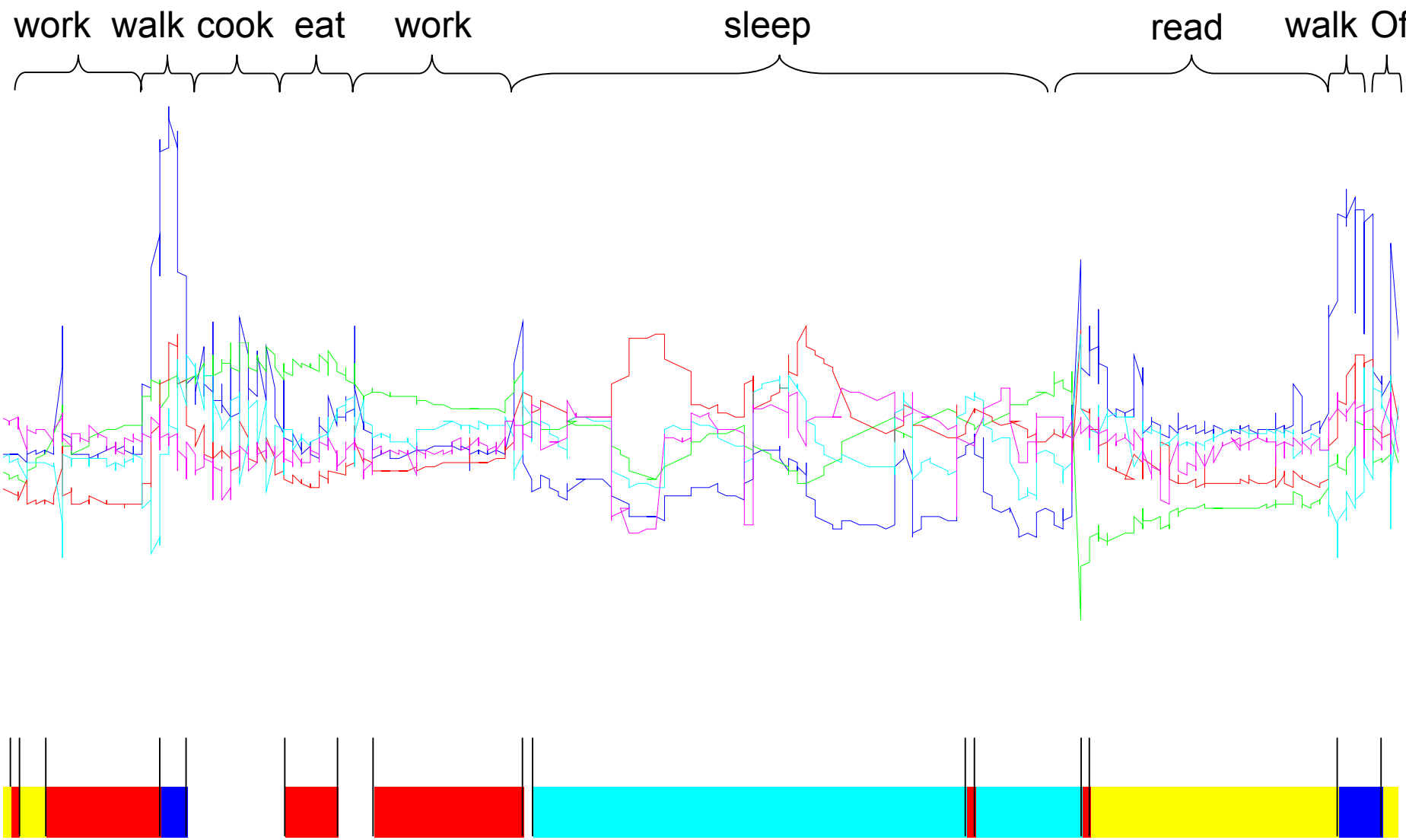
Data Classifier GUI



Results of the First Study

Sample	*Size*	*Annotated Contexts*	*Clusters*	*Time-stamps*	*Transitions*	*Quant. Error*
A-1	20h / 2d	C,E,H,O,S	6	9	11	0.5
A-2	25h / 2d	C,E,F,H,O,R,S	6	9	14	0.3
A-3	29h / 2d	C,E,H,O,S	5	8	17	0.4
B-1	57h / 6d	B,C,H,M,O,S	4	26	35	0.6
B-2	17h / 3d	M,O	2	20	25	0.5
B-3	26h / 4d	C,M,N,O,S	4	18	24	0.6
B-4	22h / 3d	C,D,E,L,O,M	4	25	27	0.8
B-5	46h / 5d	C,E,L,M,O	3	37	35	0.9

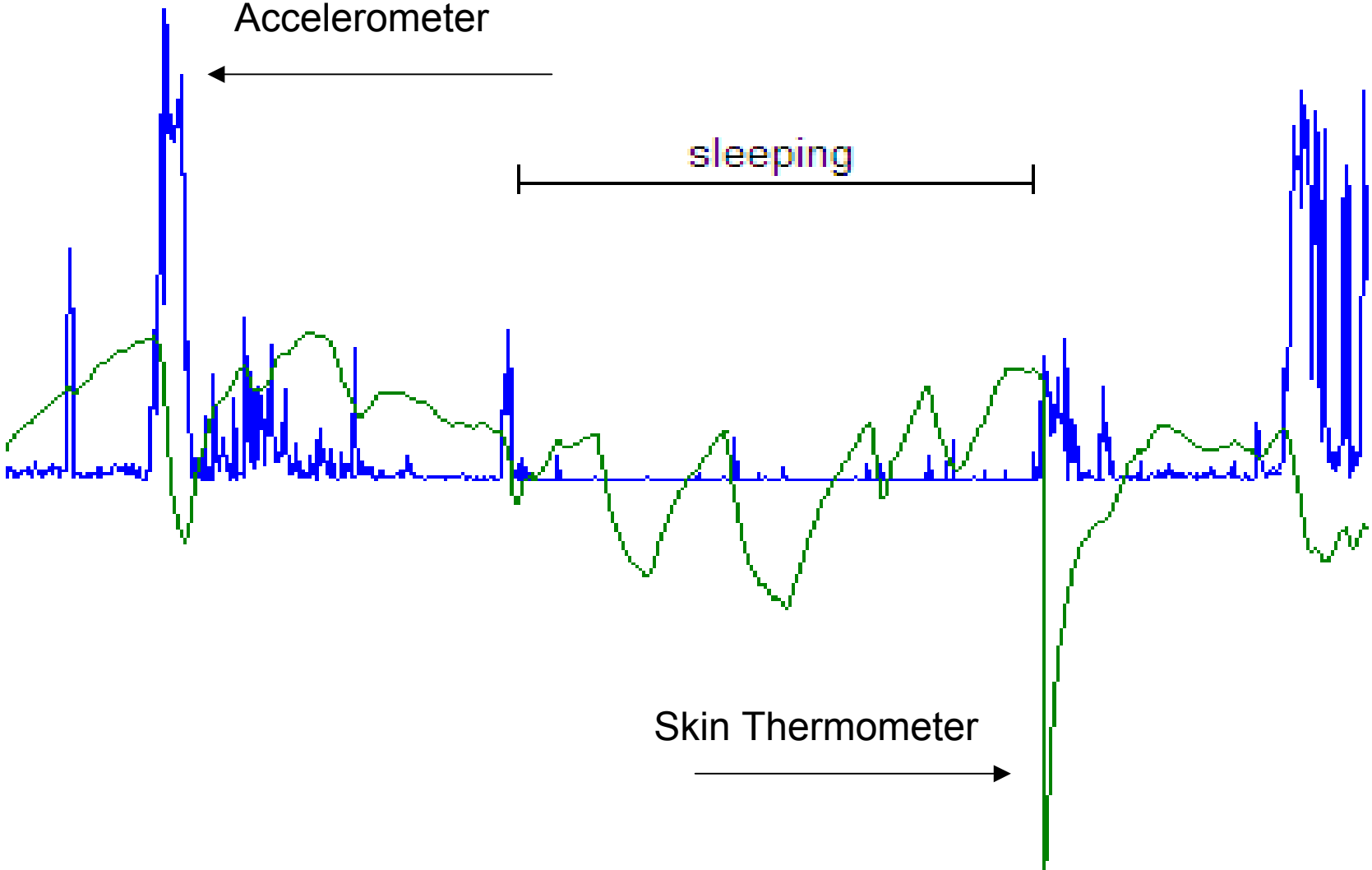
Analysis of the Clustering



Results of the Second Study

- Real-time movement classification possible
- Online classifier is stable even with small memory buffer size
- Small memory and computation time requirements

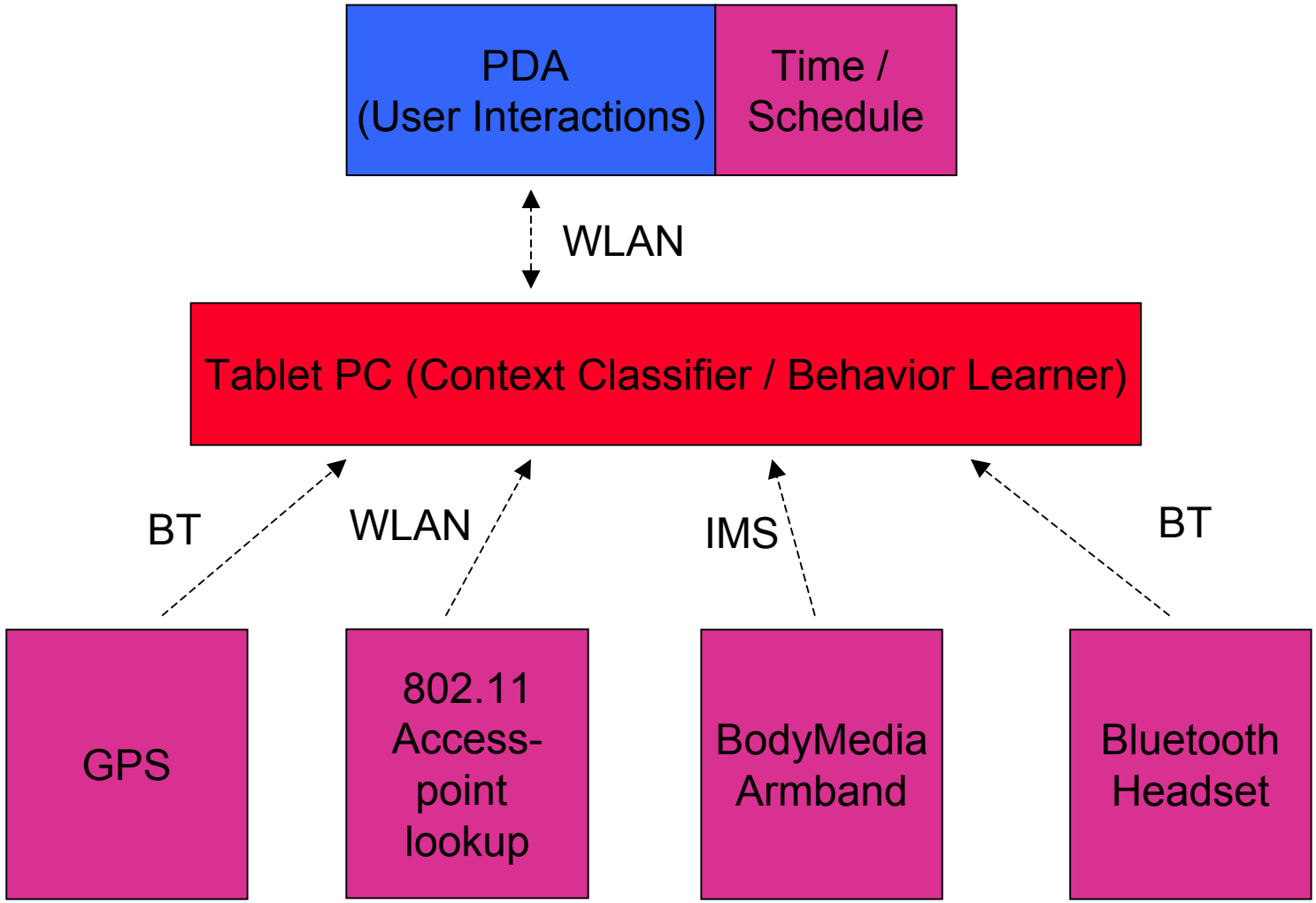
Sleeping State Characterization



ARIUS: Results

- **Self-organizing context identification possible**
  - **The number of automatically identified and manually annotated clusters differ in average by one**
  - **Movements can be characterized with 1 sec. lag**
  - **Dynamic identification is possible**
- **Low hardware requirements**
  - **2 MB memory buffer, weak processor feasible.**
  - **Low-level sensors**

ARIUS Architecture



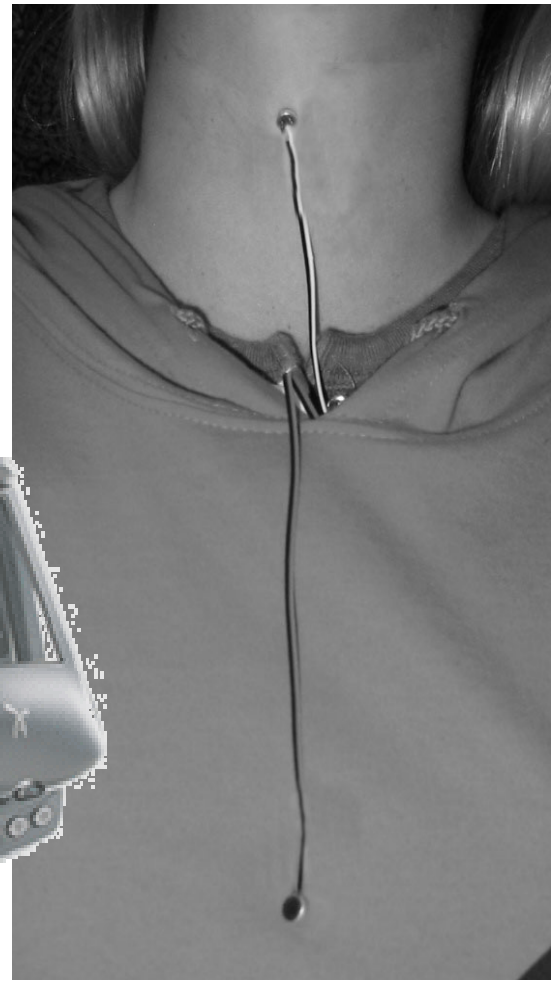
SenSay: Context Aware Cell Phone

- Adapts to dynamically changing environmental and physiological states.
- Sets ringer volume, vibration, and phone alerts
- Provide remote callers with the ability to communicate the urgency of their calls, make call suggestions to users when they are idle, and provide the caller with feedback on the current status of the SenSay user.
- Sensors including accelerometers, light, and microphones are mounted at various points on the body to provide data about the user's context.

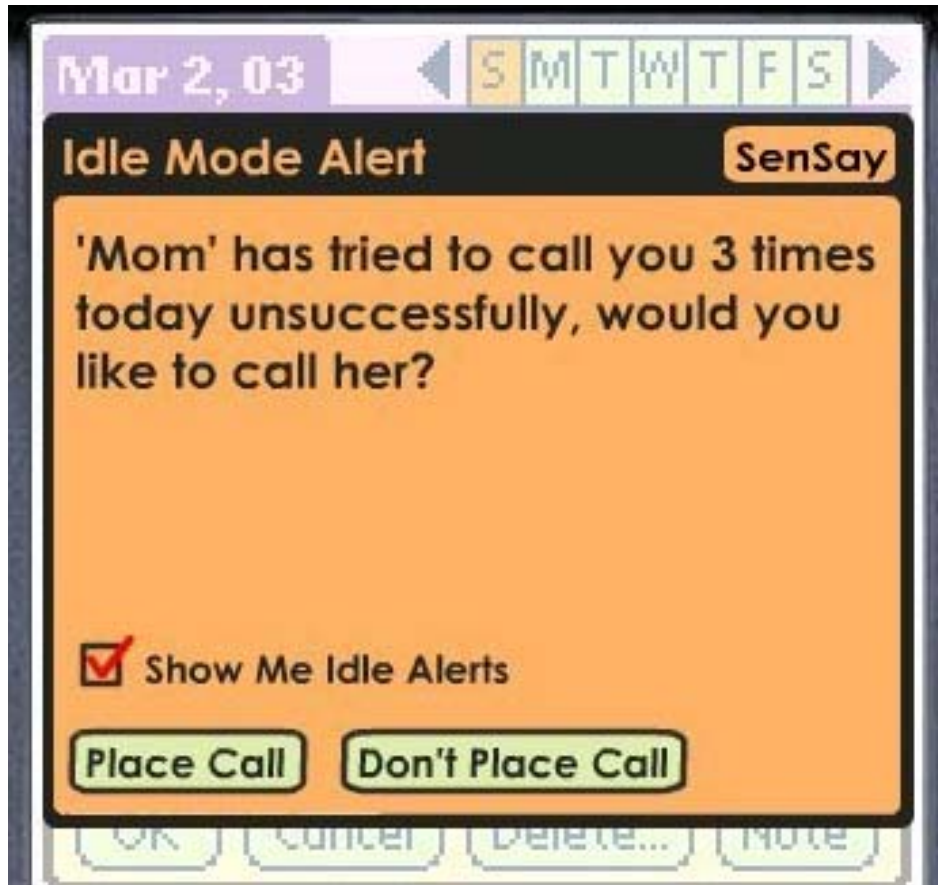
SenSay: Context Aware Cell Phone

- Decision module uses a set of rules to analyze the sensor data and manage a state machine composed of uninterruptible, idle, active and normal states.
- Results show a clear delineation can be made among several user states by examining sensor data trends.
- Augments contextual knowledge by accessing applications such as electronic calendars, address books, and task lists.
- Alleviates cognitive load on elderly users by various methods including detecting when the user is uninterruptible and automatically turning the ringer off.

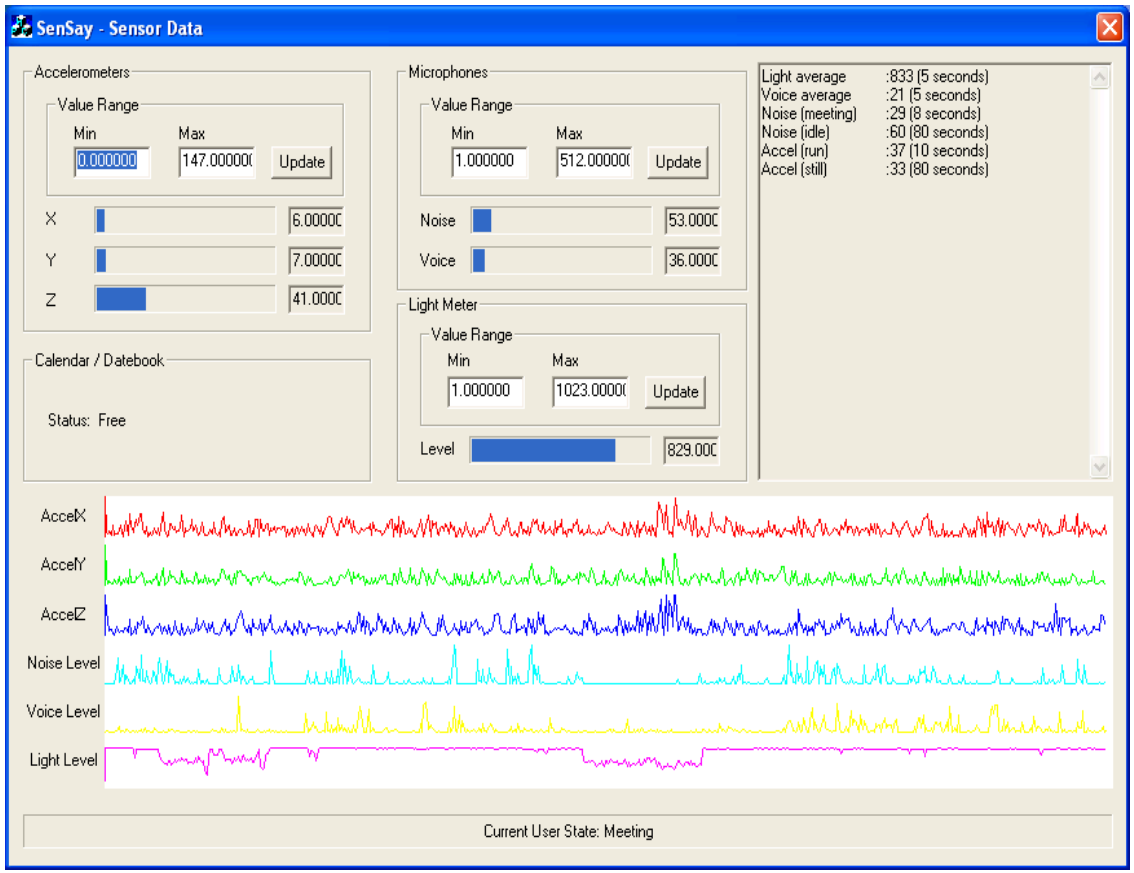
Sensay



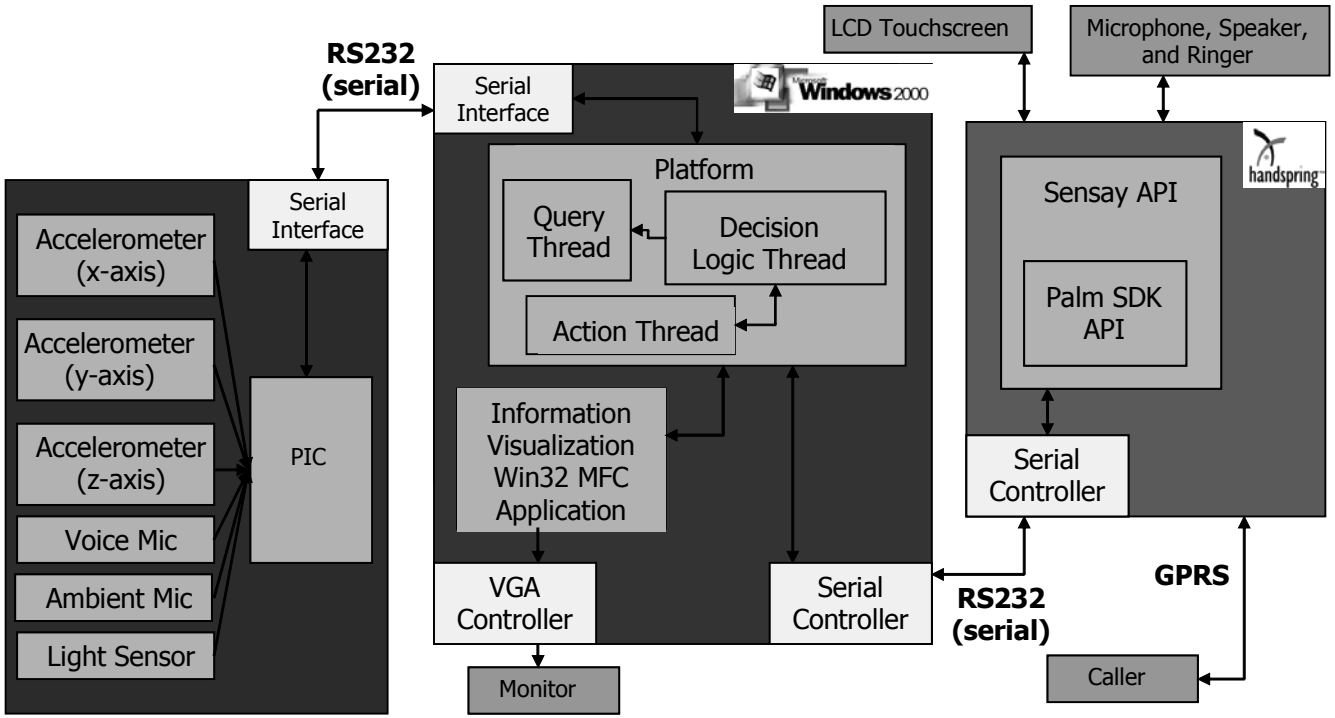
Sensay



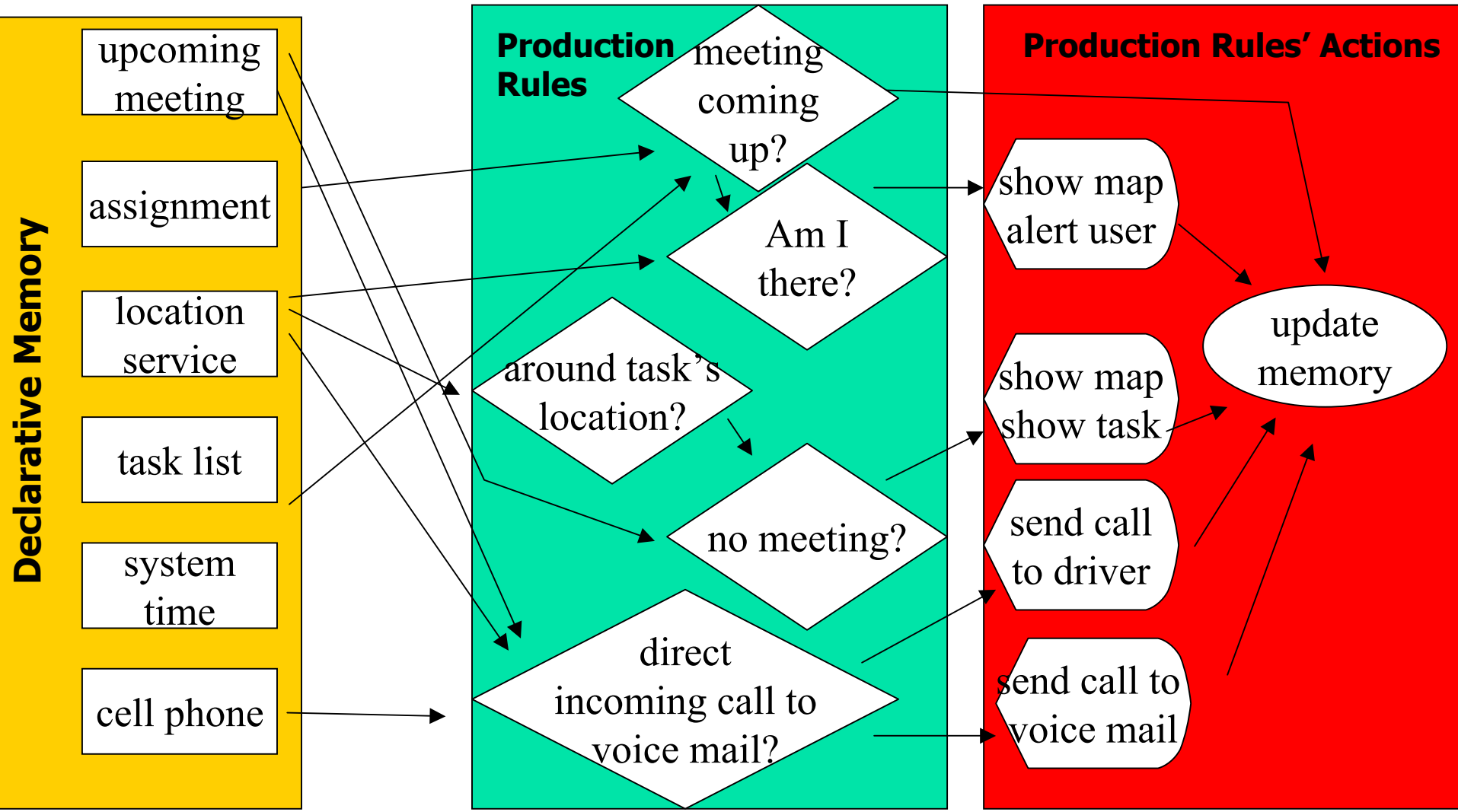
GUI in Action



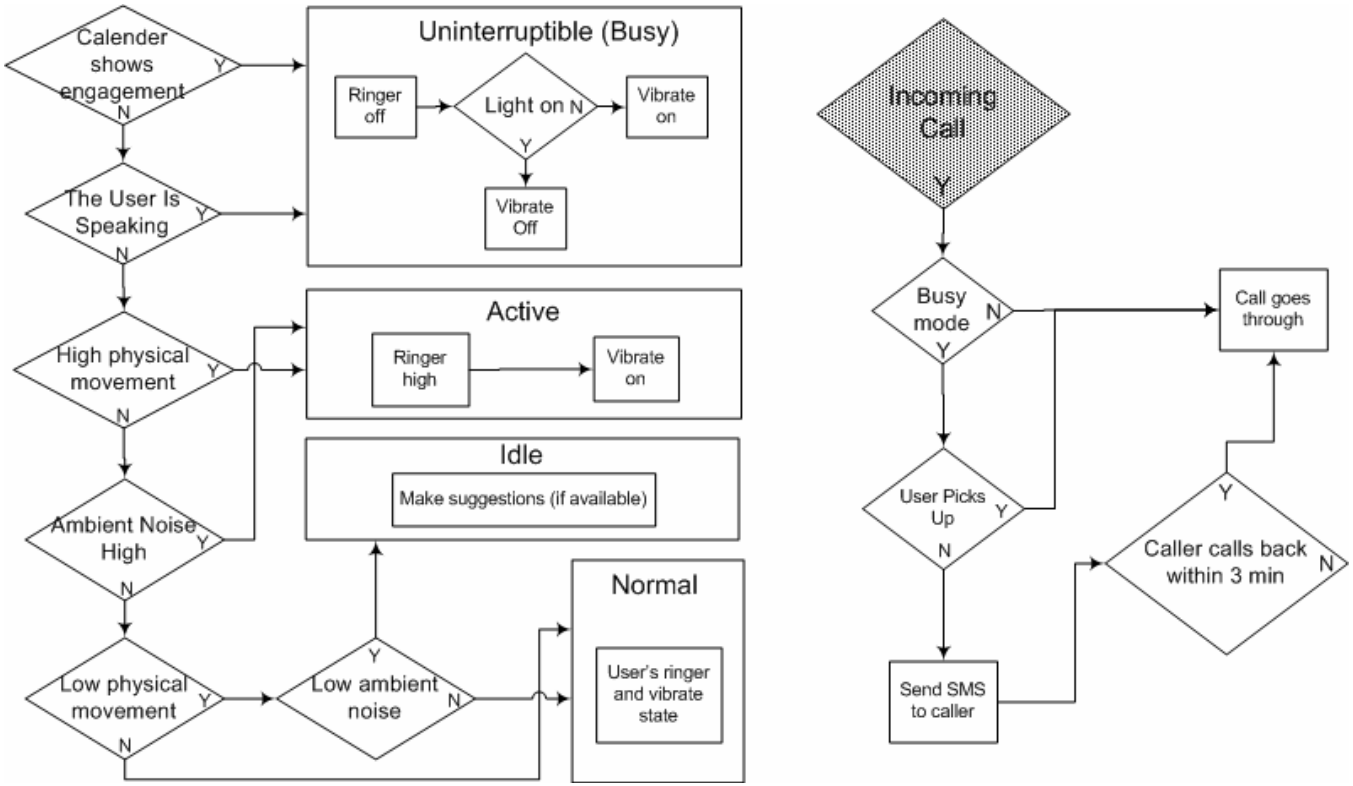
System Architecture



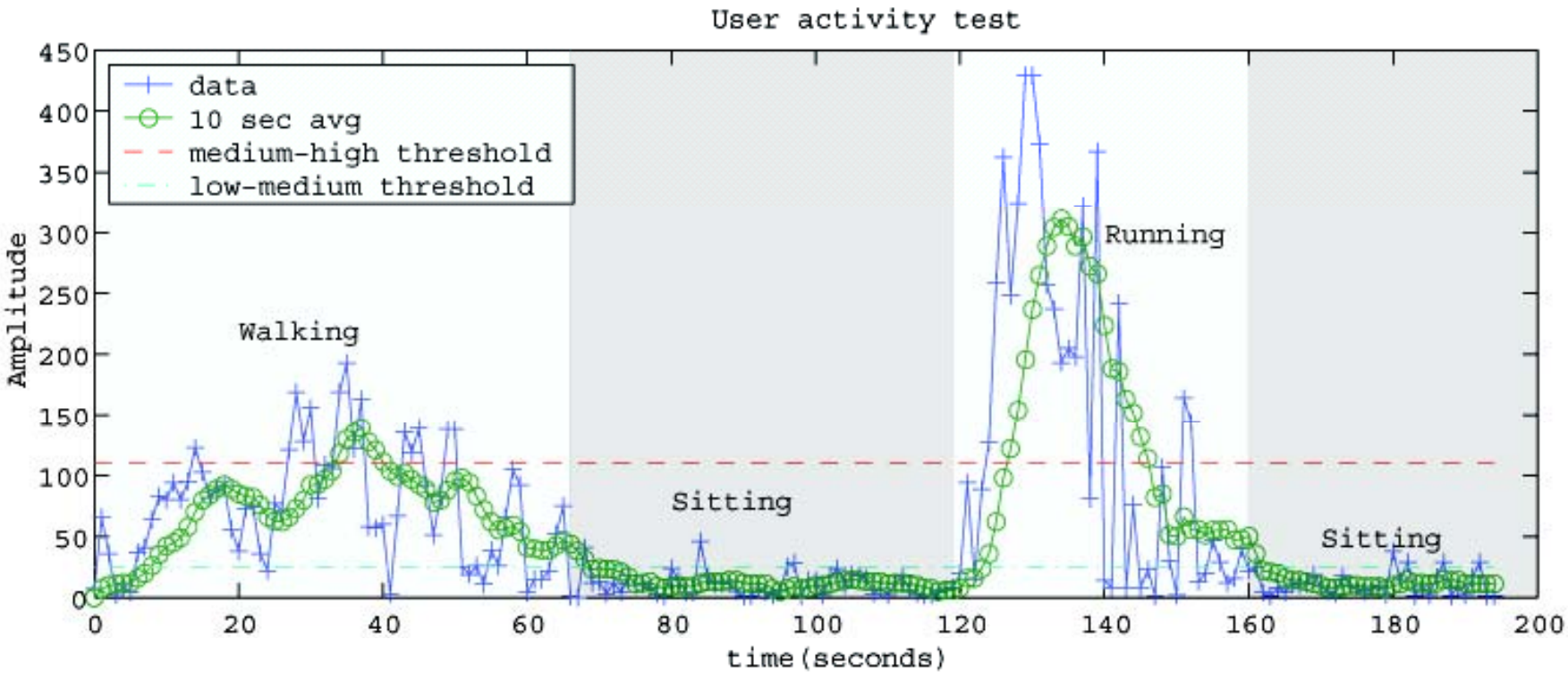
Context Aware Cell Phone



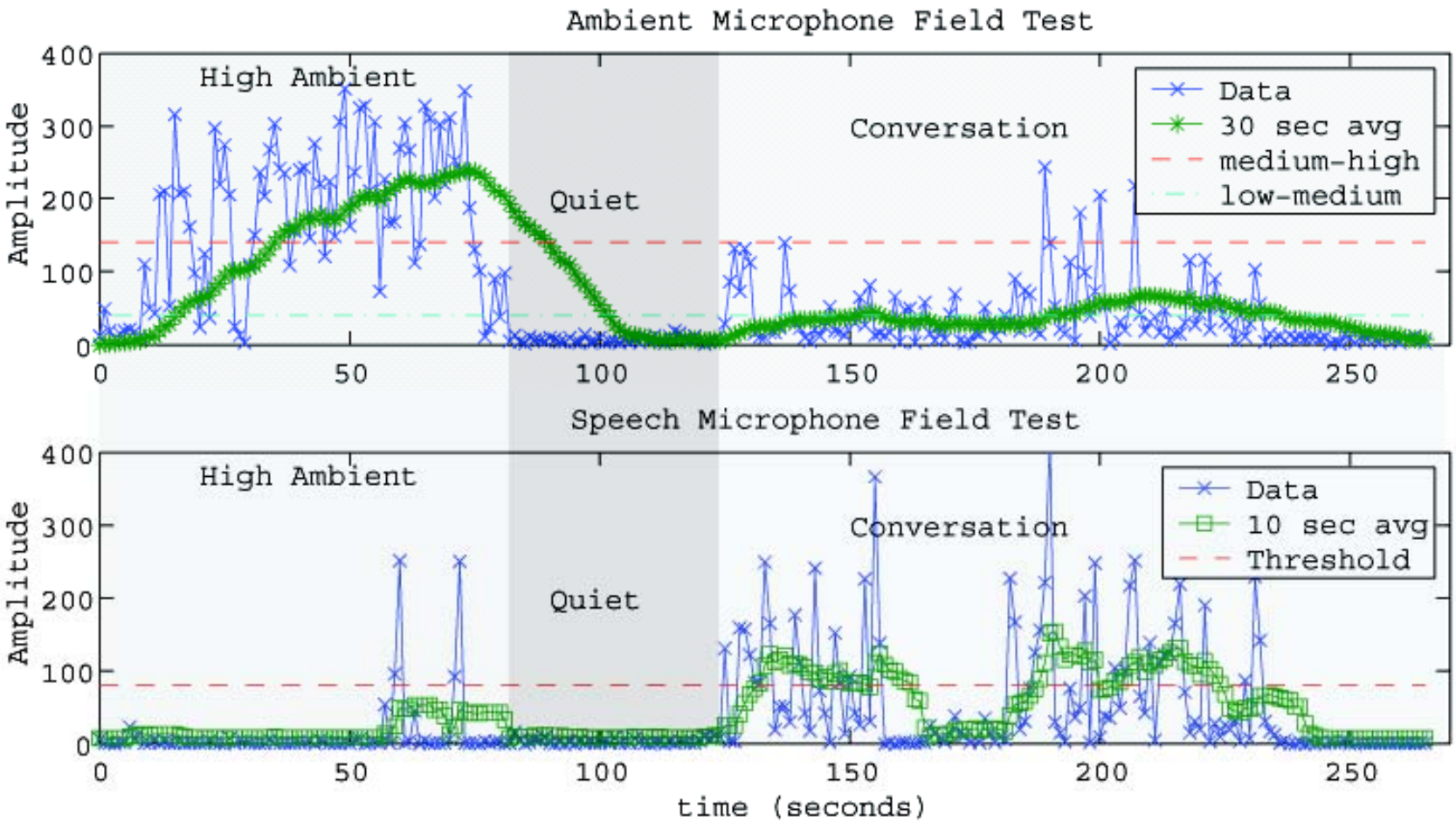
State Diagram



User Activity



Microphone Field Test

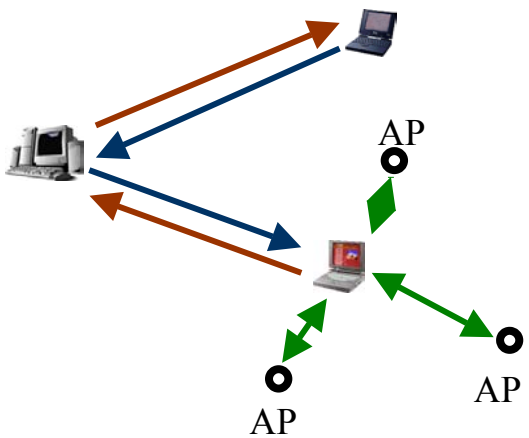


Location Service for Hospitals

- We have been designing and building navigational aids to help patients with brain damage and mentally challenged persons since 1995.
- The first system includes a RF-based location sensing system with transponders placed at fixed locations in a room.
- User wears transceiver which communicates with the transponders
- Distance is determined based on the time a RF beacon needed to travel both directions
- Triangulation is performed to determine a person's position.

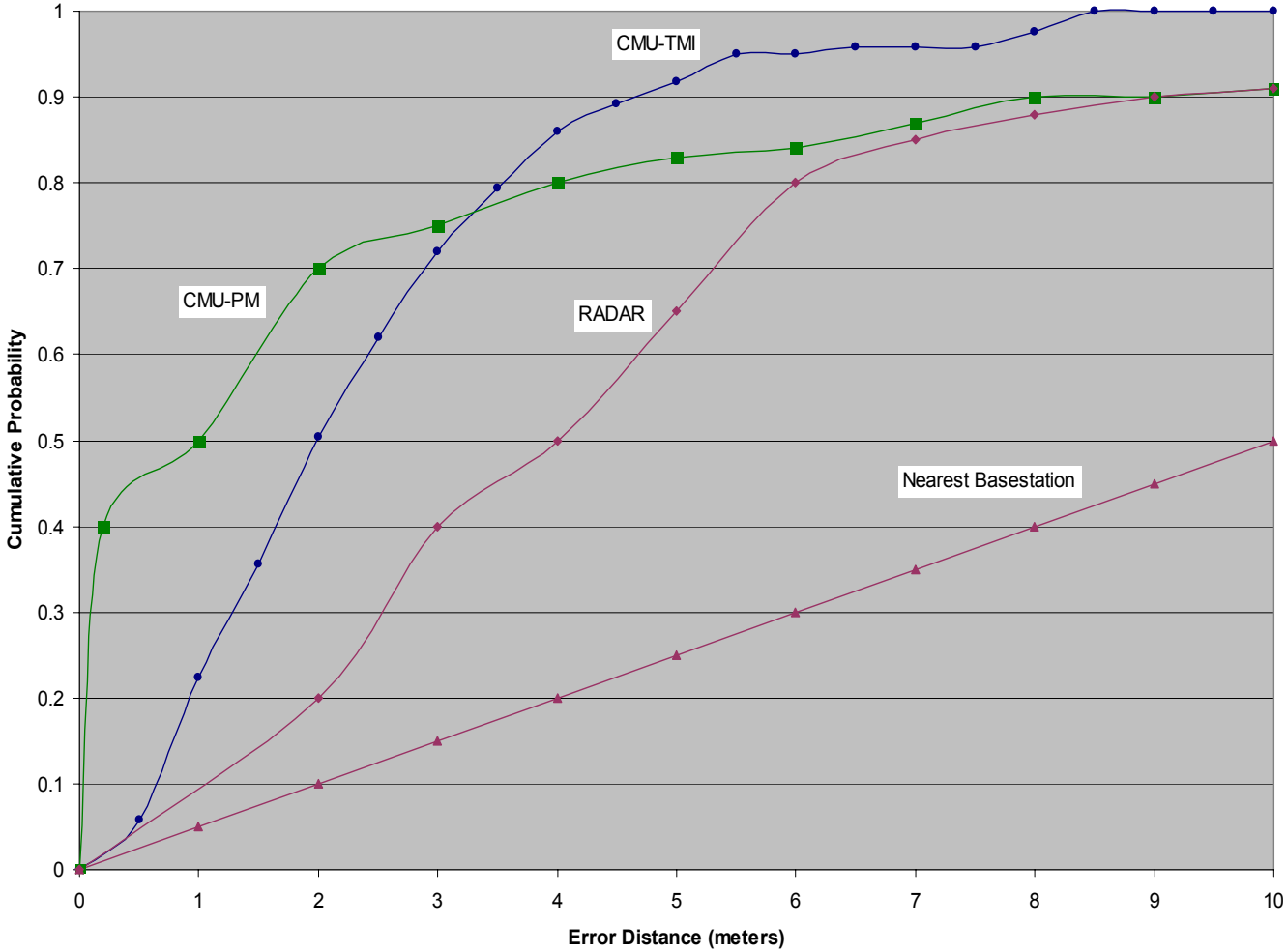
CMU People Locator

- Requests for location information are forwarded to the target computer.
- The target computer triangulates its position from the strength of the signals of several nearby nodes.
- It then returns the information back to the server, which sends it back to the original client



- **Precise** - Can determine location with accuracy of up to five feet.
- Requires gathering information by the target computer from multiple access points (AP).
- Support for privacy control.

Location Service



Diabetes Management Assistant: DiMA

- Help patients adjust to “diabetic lifestyle”
- Improved patient-doctor communication
  - » Provide accurate, up-to-date information
  - » Additional method of communication
- Small, portable, all-in-one system
  - » Handheld computer, with attachable modules
  - » Integrated hardware/software monitoring system
- Make health monitoring more routine
  - » Ability to set alarms/reminder messages
- Make logbook entry more automatic
  - » Glucose readings automatically logged into logbook

Improved Communication

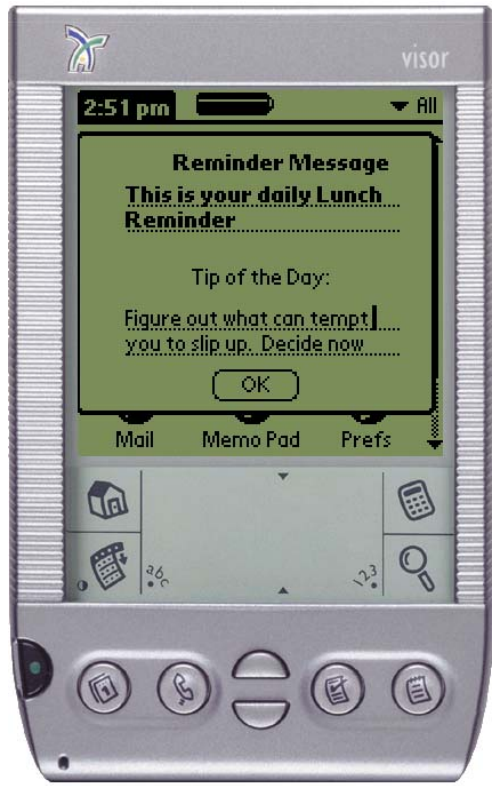
- **Provide accurate, up-to-date information**
  - » **Meal pictures using integrated digital camera provide nurse with more accurate idea of portion sizes**
  - » **Logbook can display statistical averages and graphs of the patient's progress**
  - » **Website contains online version of the logbook**
- **Additional method of communication**
  - » **Website lets patients and doctors post questions to each other**

Logbook Software

- **Logbook**
  - » Blood sugar
  - » Insulin
  - » Medicine
  - » Meals
  - » Exercise
- **Graphing**
  - » Pie chart, line and modal graphs
- **Blood Sugar Meter**
  - » Calculates blood sugar level from test strip
- **Statistics**
  - » Period averages

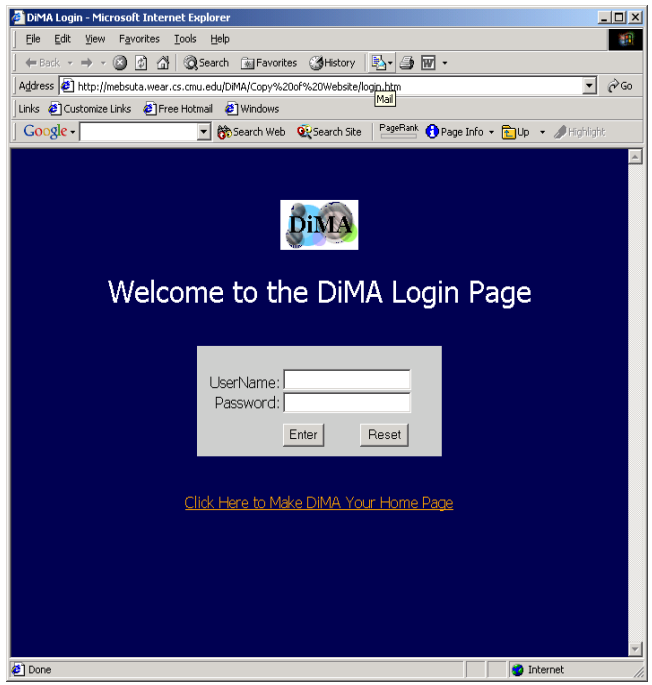
DiMA Alarm Application

- Allows patient to set alarms for different events
- Ability to edit/delete existing alarms
- Ability to repeat alarms daily only
- Ability to select reminder type without having to insert message

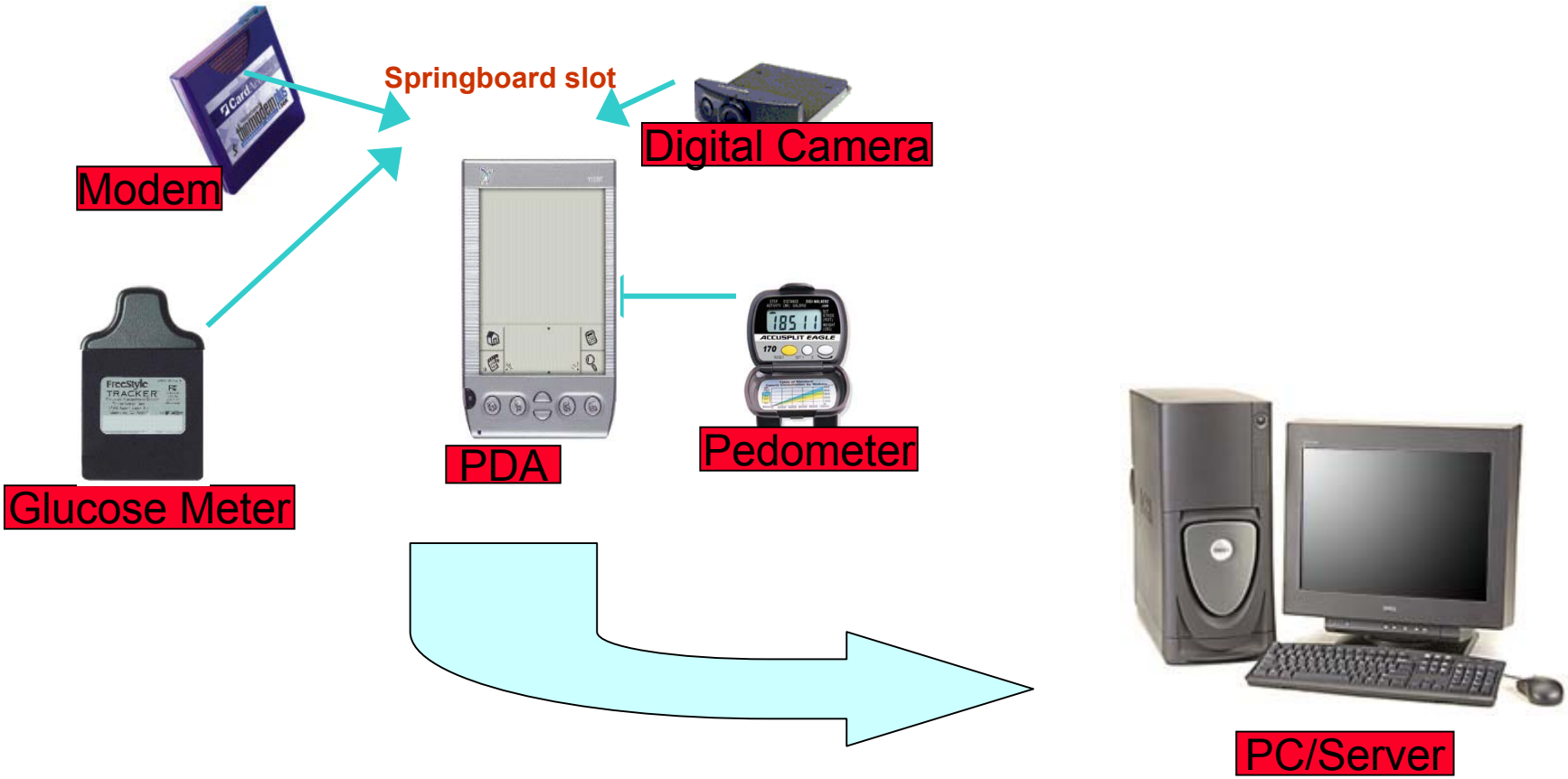


Website

- **Patient Interface**
  - » Monitor progress
  - » Communicate with doctor
  - » Link to doctor recommended websites
- **Doctor/Nurse Interface**
  - » View up-to-date patient information
  - » Communicate with patient
  - » Recommend sites to patients
  - » Data mining can be performed and doctors can predict illness development



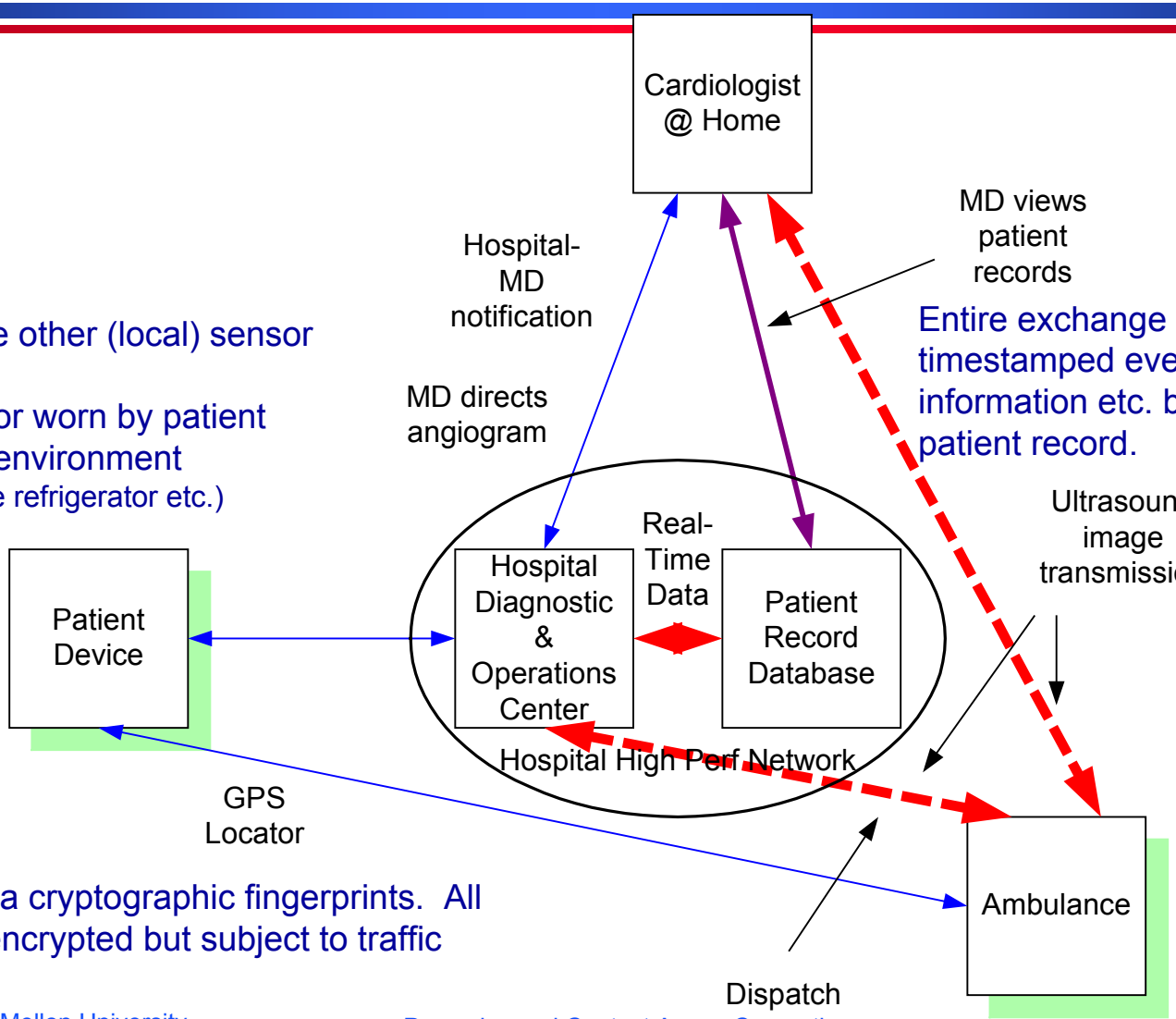
System Architecture



Pervasive Computing in Emergency Medical Applications

- A smart agent on a cardiac patient's pacemaker recognizes an abnormality in the EKG
- It warns the patient's electronic personal assistant which calls an ambulance and alerts the patient.
- The ambulance's agent uploads current information about the patient's condition to the hospital's systems
- The hospital systems
  - » acquire the patient's medical history from remote systems,
  - » contact the patient's personal physician (perhaps engages a video conference)
  - » present a complete record to the medical personnel.
- The medical personnel in consultation decide it may be too late to save the patient if they wait until arrival at the hospital.
- The doctors with the help of the ambulance technicians perform a remote surgery on the patient while still in the ambulance

Medical Scenario Overview



May incorporate other (local) sensor data such as
- embedded in or worn by patient
- embedded in environment

(prescription bottle refrigerator etc.)

Entire exchange including timestamped events images device information etc. becomes part of patient record.

Data integrity via cryptographic fingerprints. All transmissions encrypted but subject to traffic analysis…

Additional Interesting Scenarios

- **Should assume a more powerful instrument**
  - » **Integrates communication e.g. audio**
  - » **Reads historical information from patient embedded and wearable sensors (e.g. vital signs over time)**
  - » **Tracks information about drug use (from sensors on prescription bottles) food intake (from sensors on refrigerator)**
- **Other more Sophisticated Capabilities**
  - » **Patient carries smart-card with medical record cache**
    - – **automatically synchronizes with actual medical record whenever it is near a network**
    - – **incorporates recent history (e.g. from sensors above)**
    - – **assures availability of medical data without network connectivity**
  - » **Drug delivery devices that require a physician to remotely "arm" them when delivery is urgently needed (e.g. in case of heart attack)**
- **Pre-planning for surgery including treatment simulation using models**

Cognitive Disabilities

Condition	Incidence	Source
Traumatic Brain Injury	800/100,000	Naugle, 1990
Strokes in persons aged 65-74	74.3 per 1,000	National Center for Health Statistics, 1994
Strokes in persons over 75	103.7 per 1,000	National Center for Health Statistics, 1994
Incidence of moderate to severe dementia	15 per 1,000	Lauter, 1985
Projected incidence of Alzheimer's disease by 2020	7 million Americans	Progress Report on Alzheimer's Disease, 1995

Reflective Systems for Mitigating Disabilities: WearXP

- **Wearable Platform for eXtraordinary People (WearXP)**
- **The *reflective middleware platform* that can *reason about both it's own internal behavior and the user's behavior as it relates to the user's interaction with the system*.**
- **The goal of the middleware is to assess the effectiveness of the human-computer system in real-time and to detect breakdowns in its function.**
- **Alzheimer's patients need to relearn certain skills, navigation, communication**

Reflective Systems for Mitigating Disabilities: WearXP

- **Reflection refers to a system that can reason about and act upon itself. It provides a representation of its own behavior that is amenable to *inspection* and *adaptation*, and is *causally connected* to the underlying behavior it describes.**
  - » **"Causally-connected:" changes made to the self-representation are immediately mirrored in the underlying system's actual state and behavior, and vice-versa.**
- **A reflective system is one that supports an associated *causally connected self-representation*. Reflection enables both *inspection* and *adaptation* of systems at run time. Inspection allows the current state of the system to be observed while adaptation allows the system's behavior to be altered at run time.**

Reflective Systems for Mitigating Disabilities: WearXP

- **The middleware combines a unique set of attributes:**
  - **Reflective: able to reason about its own and the user's behavior**
  - **Composable: provides building blocks that can be assembled and integrated**
  - **Context-aware: able to determine and react to outside parameters**
  - **Mobile: targeted at mobile computing applications**

Smart Room: BARN

Smart Room: BARN

- Location sensing based on video marker tracking
- RFID tags used for logging in and configuring environment
- Cameras, microphones, projectors
- Possible applications
  - » Tracking patients and their activities
  - » Monitoring items removed and added to medicine cabinet (such as medications)
  - » Remotely instructing patients on how to perform tasks
  - » Automatically operating devices on patient's behalf when necessary (turning appliances, lights on and off)

Robotic Assistants for the Elderly: Nursebot

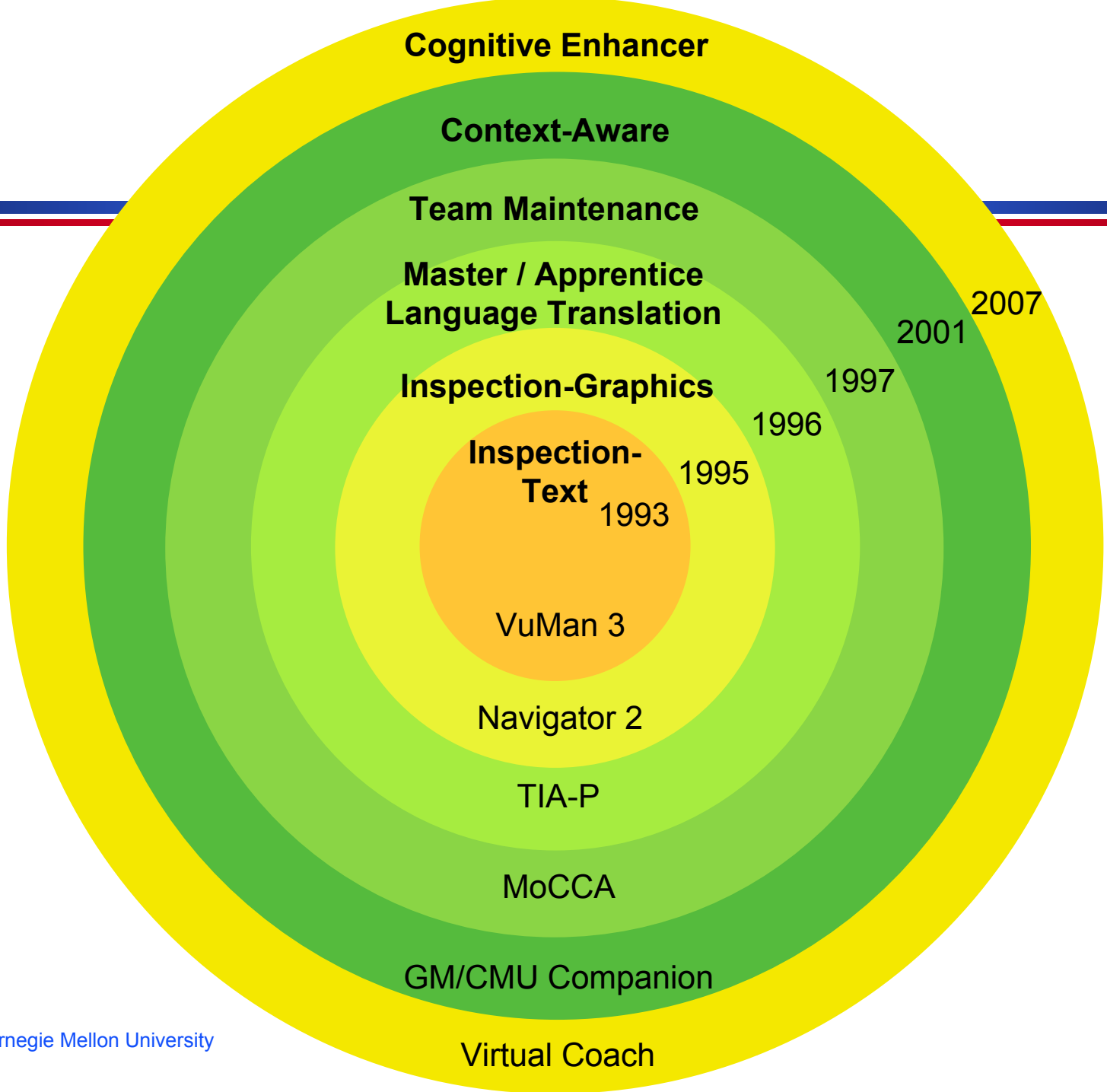
- Assists elderly people suffering from chronic disorders in their everyday life
- An autonomous mobile robot that “lives” in a private home of a chronically ill elderly person.
- Research platform for testing ideas to assist elderly:
  - » Intelligent reminding: enables elderly who forget to live at home
  - » Tele-presence: care-givers interact with remote patients
  - » Data collection and surveillance: detect emergencies
  - » Mobile manipulation: aids arthritis and similar ailments sufferers
  - » Social interaction: robots can provide social contact

Nursebot

Nursebot

Nursebot

Nursebot



Conclusions and Future Directions

- Over two dozen novel generations of wearable computers and several pioneering pervasive computing systems have been built as human-centric computing systems
- This led to the paradigm of context aware computing
- Wearable computers can now detect user's physiological and emotional state
- This information is used to proactively assist a user
- This is particularly critical in applications for the elderly and disabled
- We have developed numerous technologies and prototypes which aid the elderly and disabled in gaining independence
- The fundamental nature of this research, and its importance will increase as technology and computer-assisted living becomes more pervasive
- Minimize user distraction; increase user capabilities

Conclusions and Future Directions

- For the first time, create a wearable augmented cognition platform and software application to support independent living
- Assess cognitive performance on-line
- Provide immediate suggestions to user for cognitive augmentation and independent living