

Context-Aware Mobile Computing: Learning Context-Dependent Personal Preferences from a Wearable Sensor Array

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- Context-Aware Mobile Phone
- Four states: Meeting, High-Energy, Idle, Normal
- Thresholds from accelerometers and microphones trigger state transitions

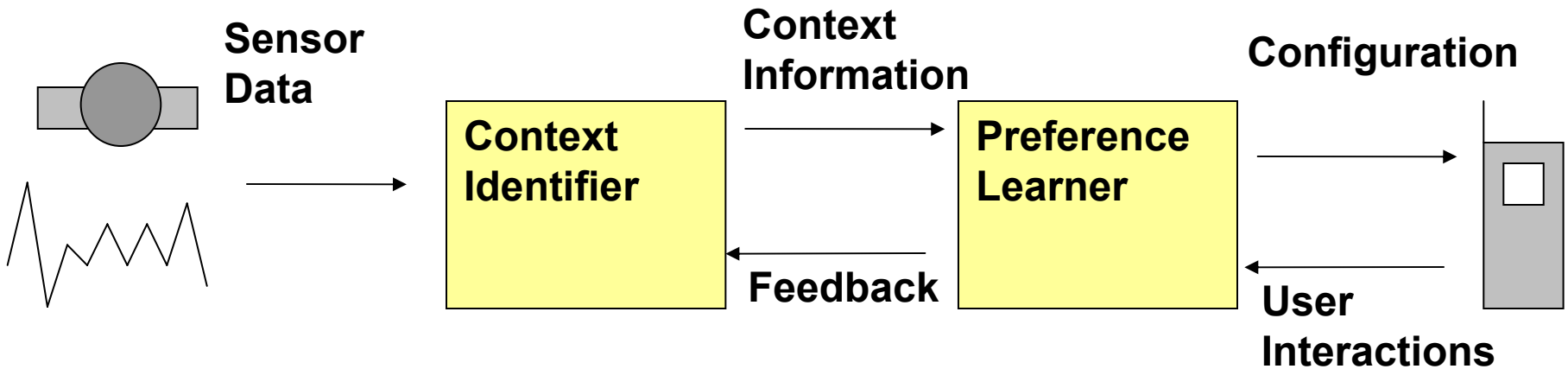
- Problems
 - Threshold values do not generalize well
 - Preferences vary widely among people

Goals

- Enable a wearable computer to *learn* about *individual* user states using sensors
- This process should not require supervision by the user
- Let the computer learn to *associate* user states with user preferences

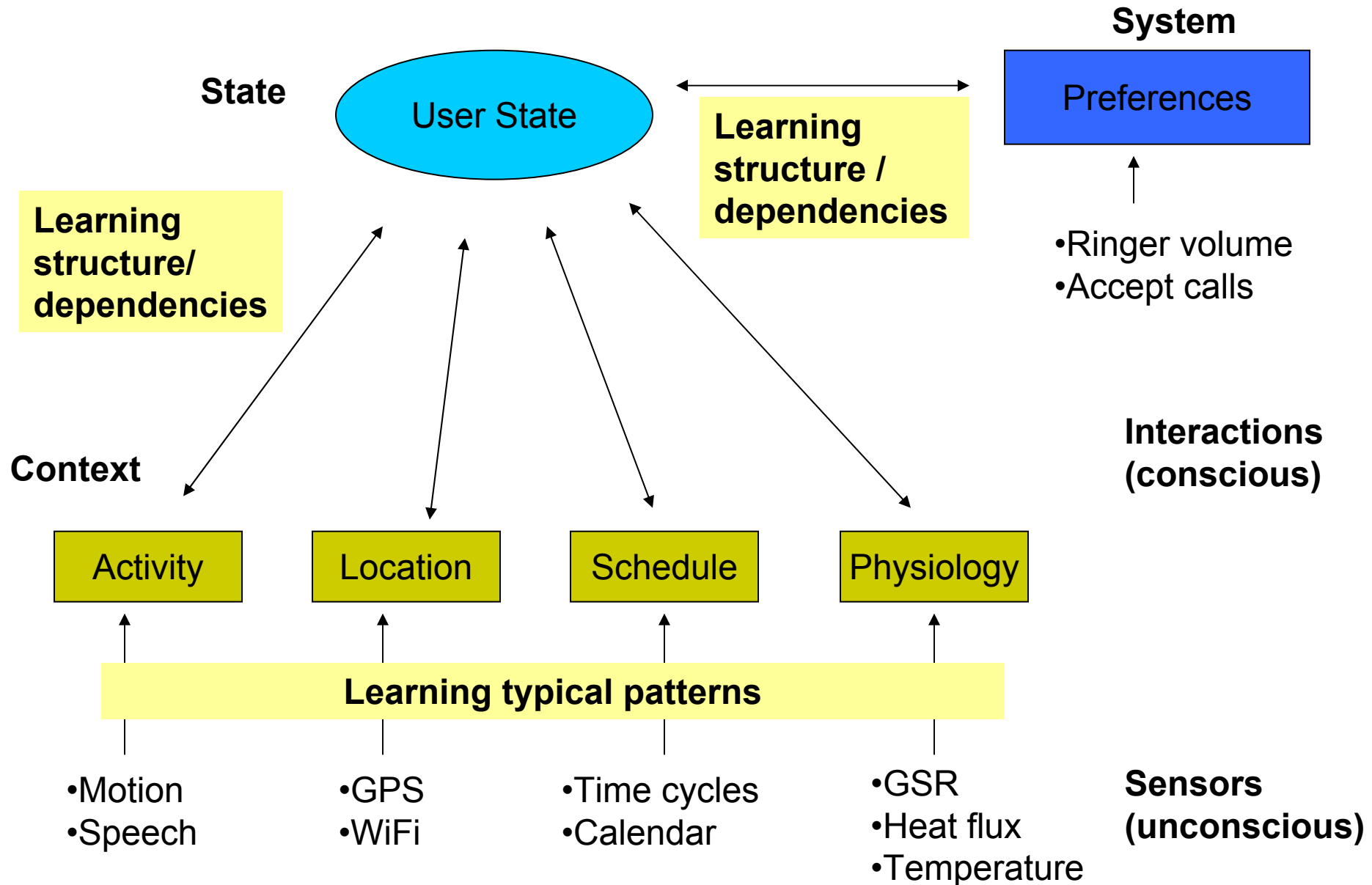
→ **ARIUS**
Adaptive Reflection of Individual User States

ARIUS Two Step Approach



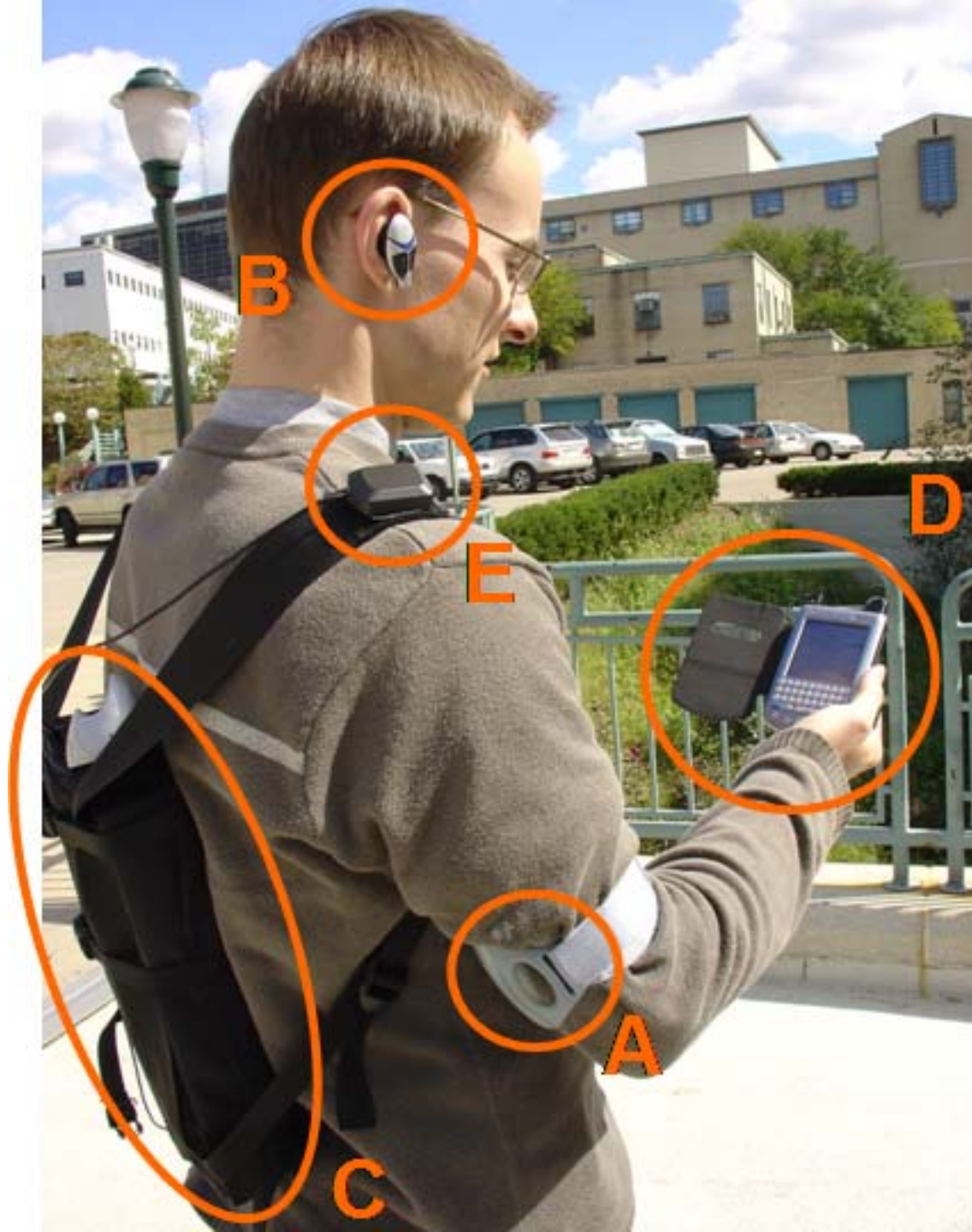
	Sensors	Interactions
<i>User's attention</i>	Not required	Required
<i>Availability</i>	Abundant	Scarce
<i>Values</i>	Continuous	Discrete
<i>Dynamics</i>	Time series	Protocol based

Learning User's Preferences



Accomplishments

- Development of methods for
 - Context Identification
 - Preference Learning
- Design and implementation of a wearable study platform realizing these methods
- Evaluation in several experiments

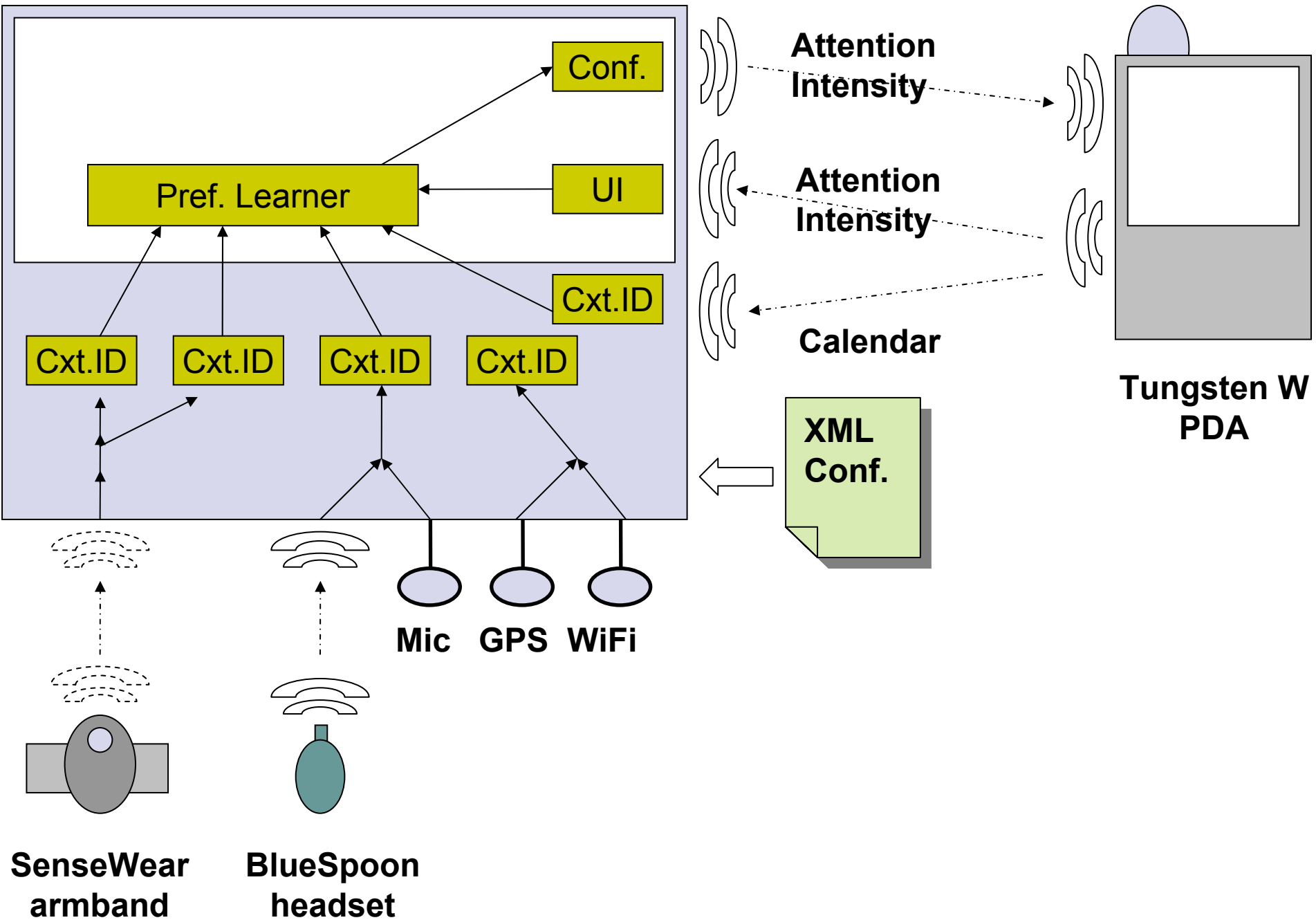


Wearable Sensors





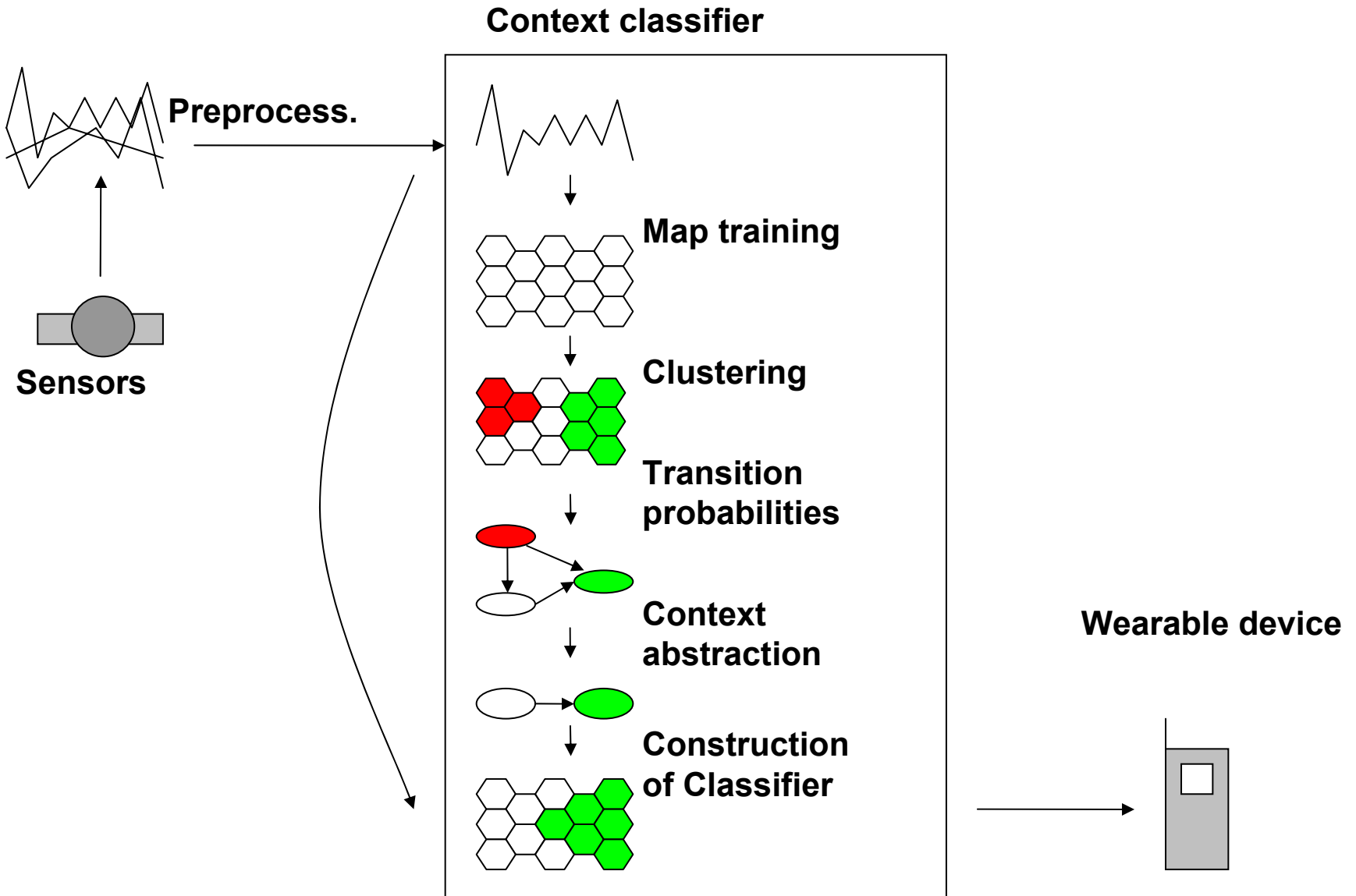
Fujitsu P1120 LifeBook



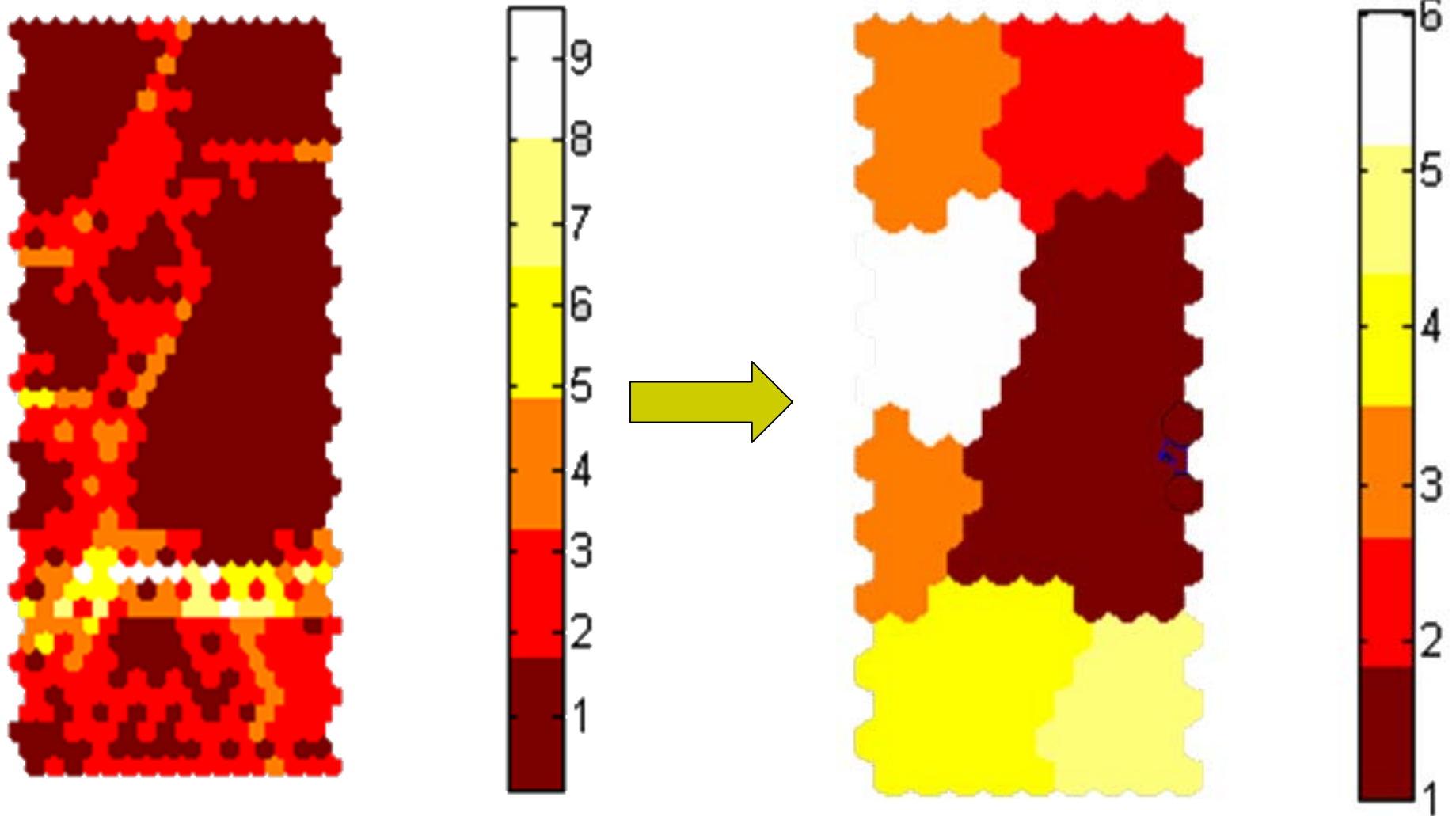
Context Identification

- Unsupervised, dynamic identification of locally-constant contexts
- Issues:
 - Preprocessing / Feature Extraction (RA, SAD, FFT, PCA, Normalization, ...)
 - Clustering (KSOM, k -Means)
 - Identifying the number of classes (context abstraction)

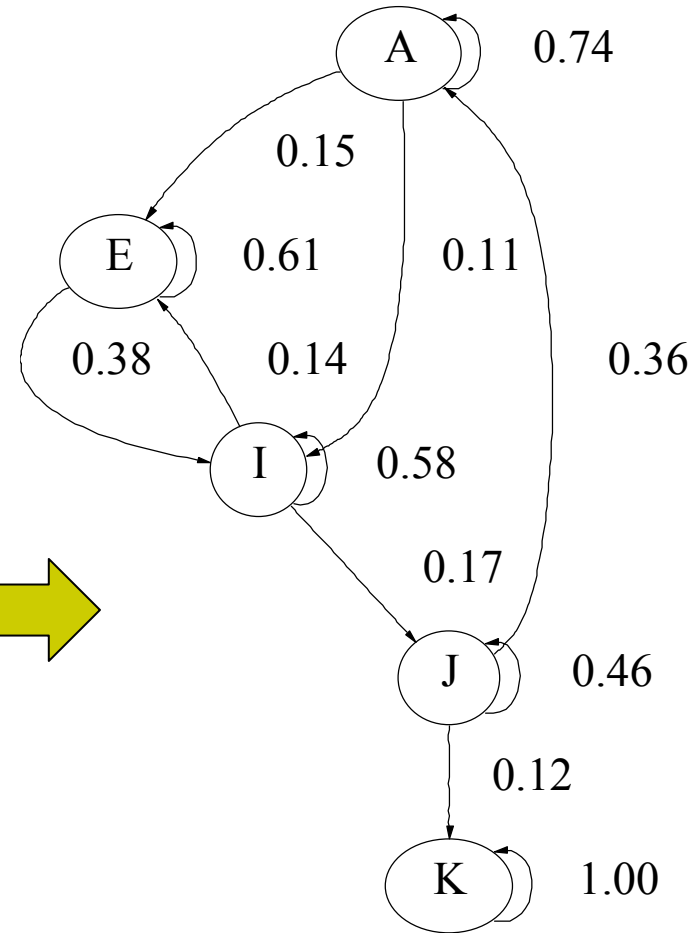
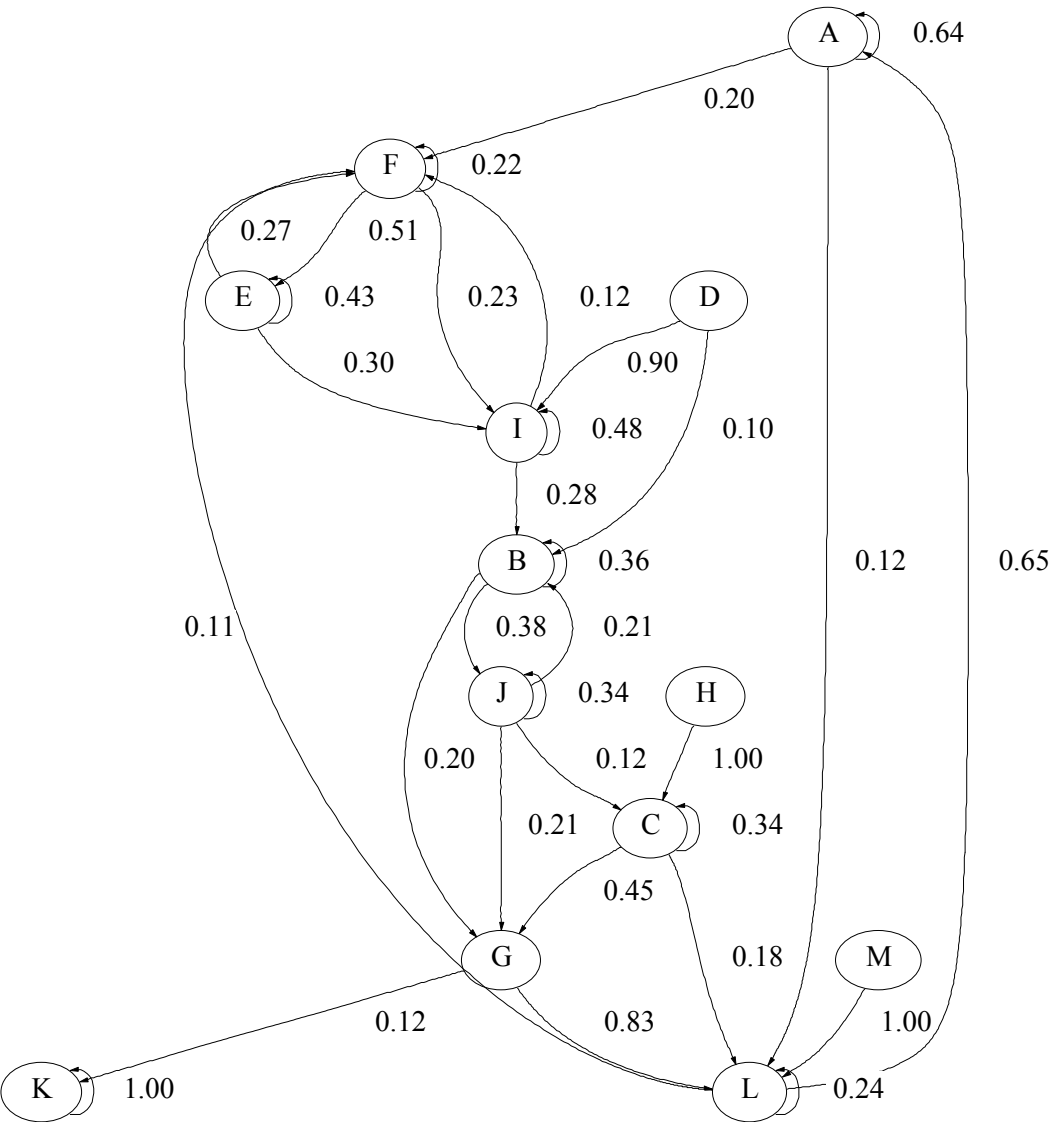
Offline Data Classifier



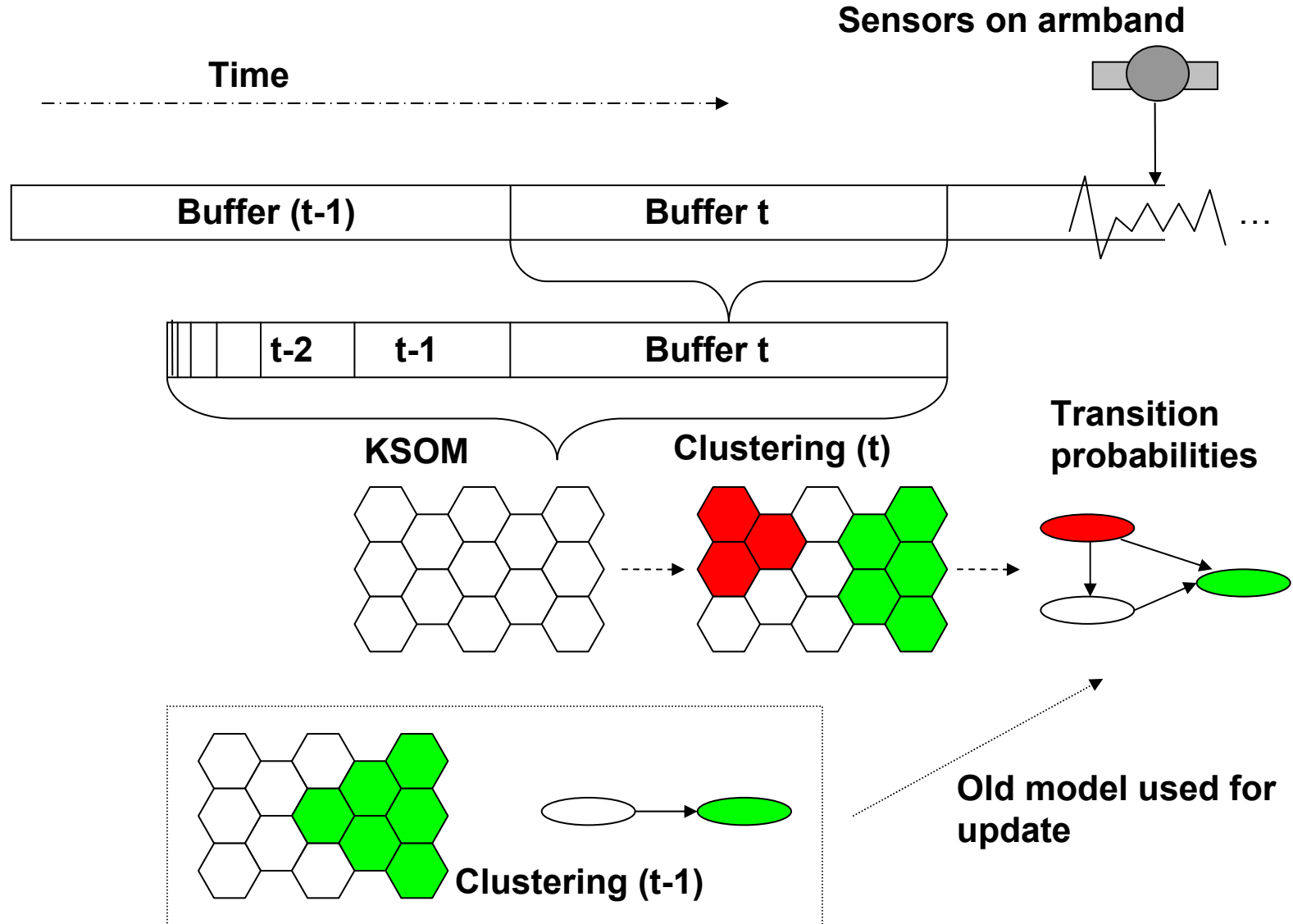
Example Clustering Results



Context Abstraction



Online Data Classifier



Location-Awareness

- Combination of two complementary sensors
 - Outdoors: Global Positioning System
 - Indoors: 802.11b signal strength triangulation
- Clustering Approach to identify
 - indoor locations
 - outdoor locations
 - entrances
- Scaling problems!

Preference Learning

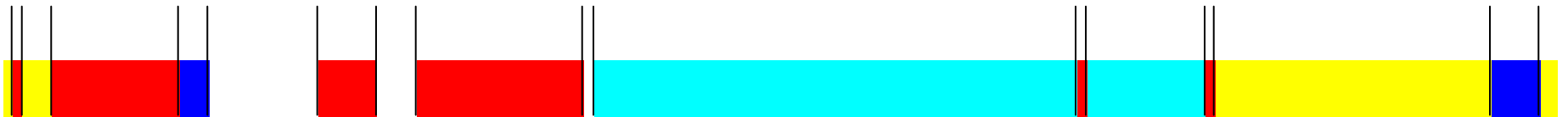
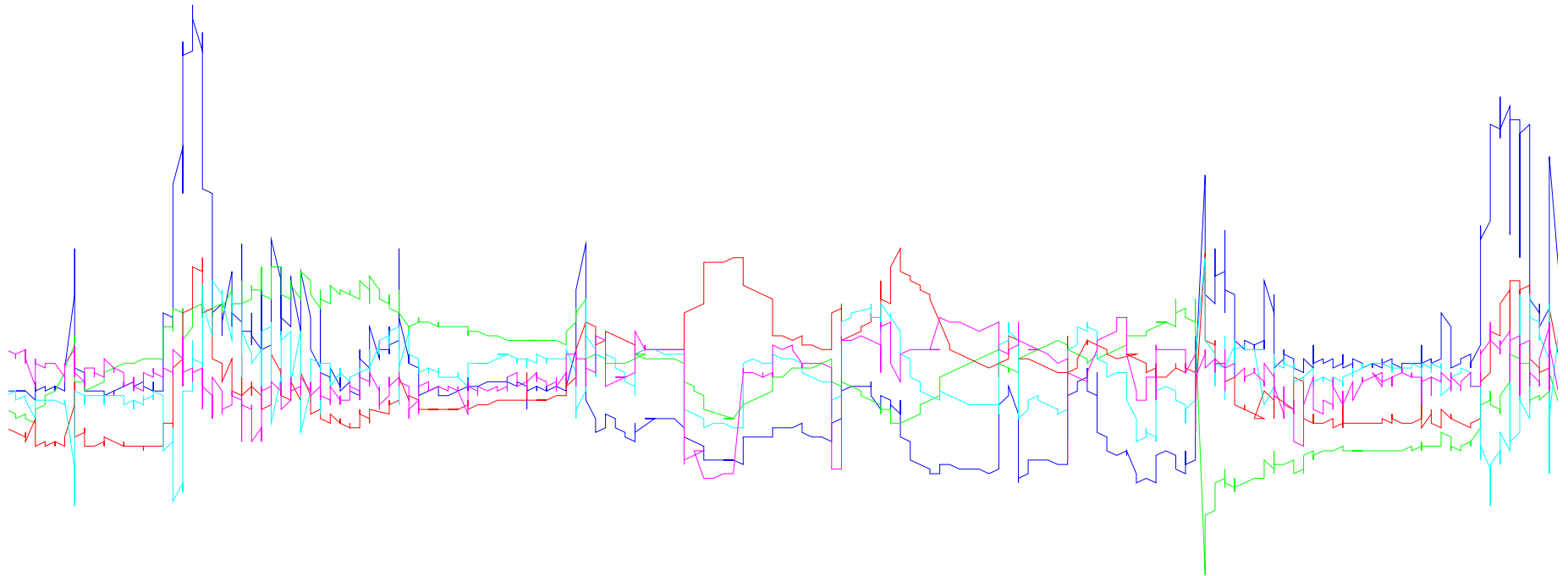
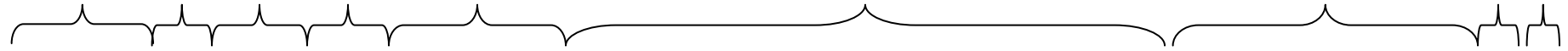
- Creating a generative model relating the context- and system variables
- Technique: Bayesian Networks
 - Efficient method to compute joint PDF
 - Can handle incomplete data
 - Can incorporate dynamics
- Issues
 - Algorithms for parameter- / structure learning
 - Hidden variables
 - Priors

Experimental Design

- Motivation of machine learning approach
 - Survey among college phone users (preliminary)
 - Threshold analysis
- Evaluation of Context Identification method
 - Self-report study
 - Real-time movement identification / classification
- Evaluation of Preference Learning method
 - SenSay training
 - Self-report study

Clustering ↔ Self-reports

work walk cook eat work sleep read walk Off.



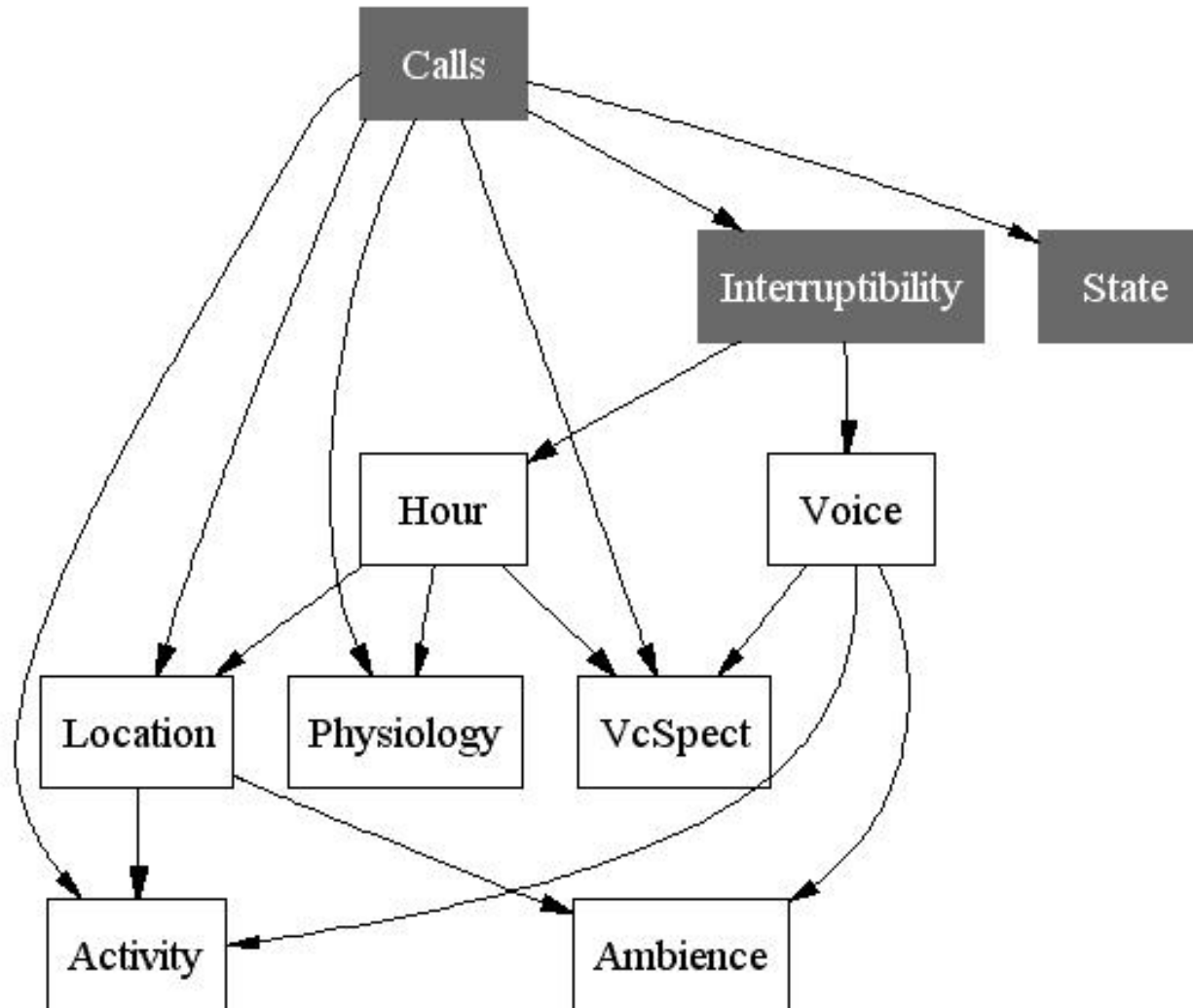
Self-report Study Results

<i>Sample</i>	<i>Size</i>	<i>Annotated Contexts</i>	<i>Clusters</i>	<i>Time-stamps</i>	<i>Transitions</i>
A-1	20h / 2d	C,E,H,O,S	6	9	11
A-2	25h / 2d	C,E,F,H,O,R,S	6	9	14
A-3	29h / 2d	C,E,H,O,S	5	8	17
B-1	57h / 6d	B,C,H,M,O,S	4	26	35
B-2	17h / 3d	M,O	2	20	25
B-3	26h / 4d	C,M,N,O,S	4	18	24
B-4	22h / 3d	C,D,E,L,O,M	4	25	27
B-5	46h / 5d	C,E,L,M,O	3	37	35

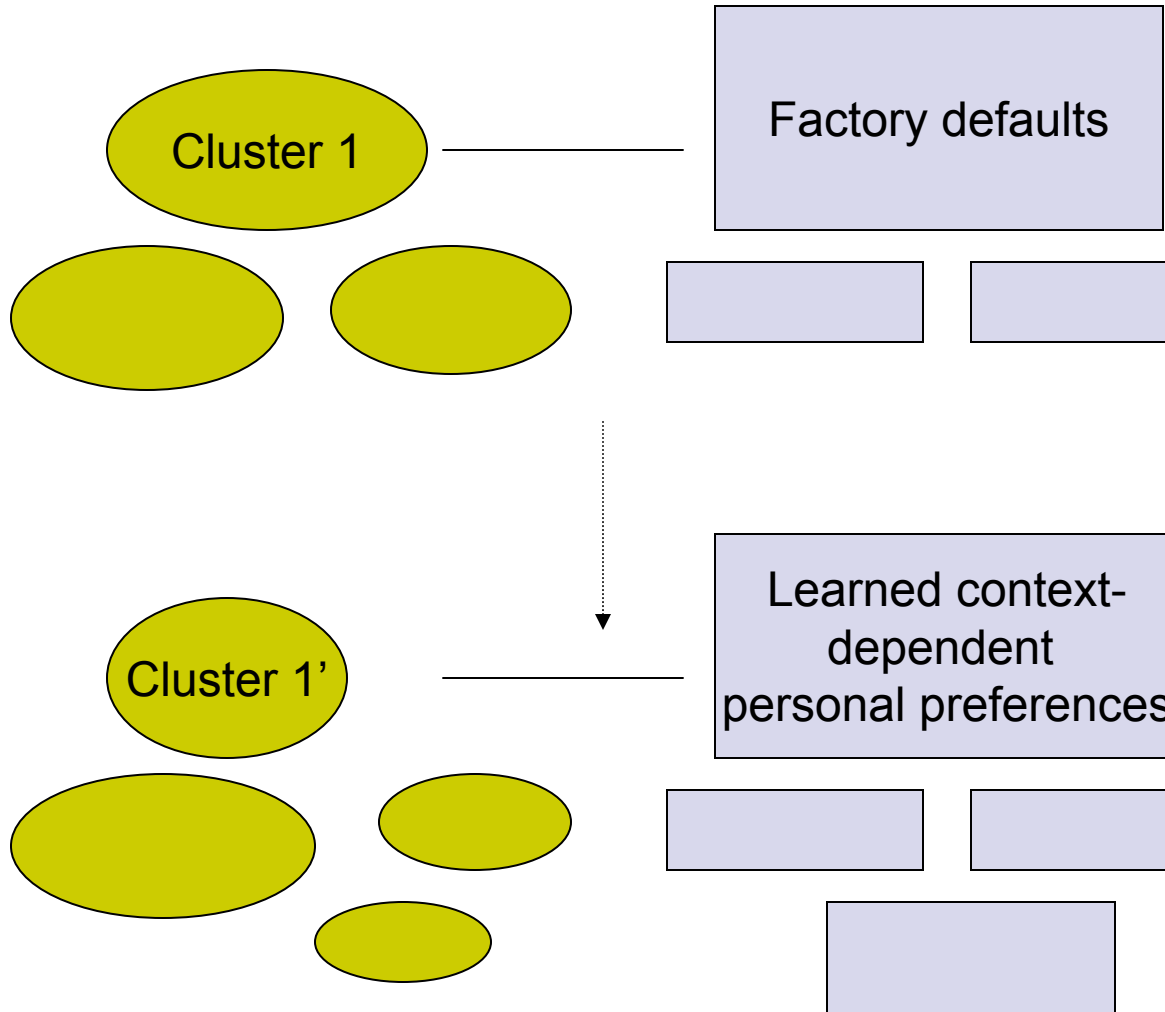
SenSay Training

<i>Activity</i>	<i>Audio</i>	<i>Phone action</i>	<i>Time (s)</i>
Working	Talking	Silent	9.2
Working	Whistling	High	9.0
Working	Silence	Medium	14.0
No motion	Talking	Silent	6.5
No motion	Not talking	Medium	8.5
Walking	Talking	Low	10.2
Walking	Not talking	Maximum	11.0
Driving	Talking	Vibrate	8.2
Driving	Not talking	Low	9.0

Self-Report Network Structure



System Initialization



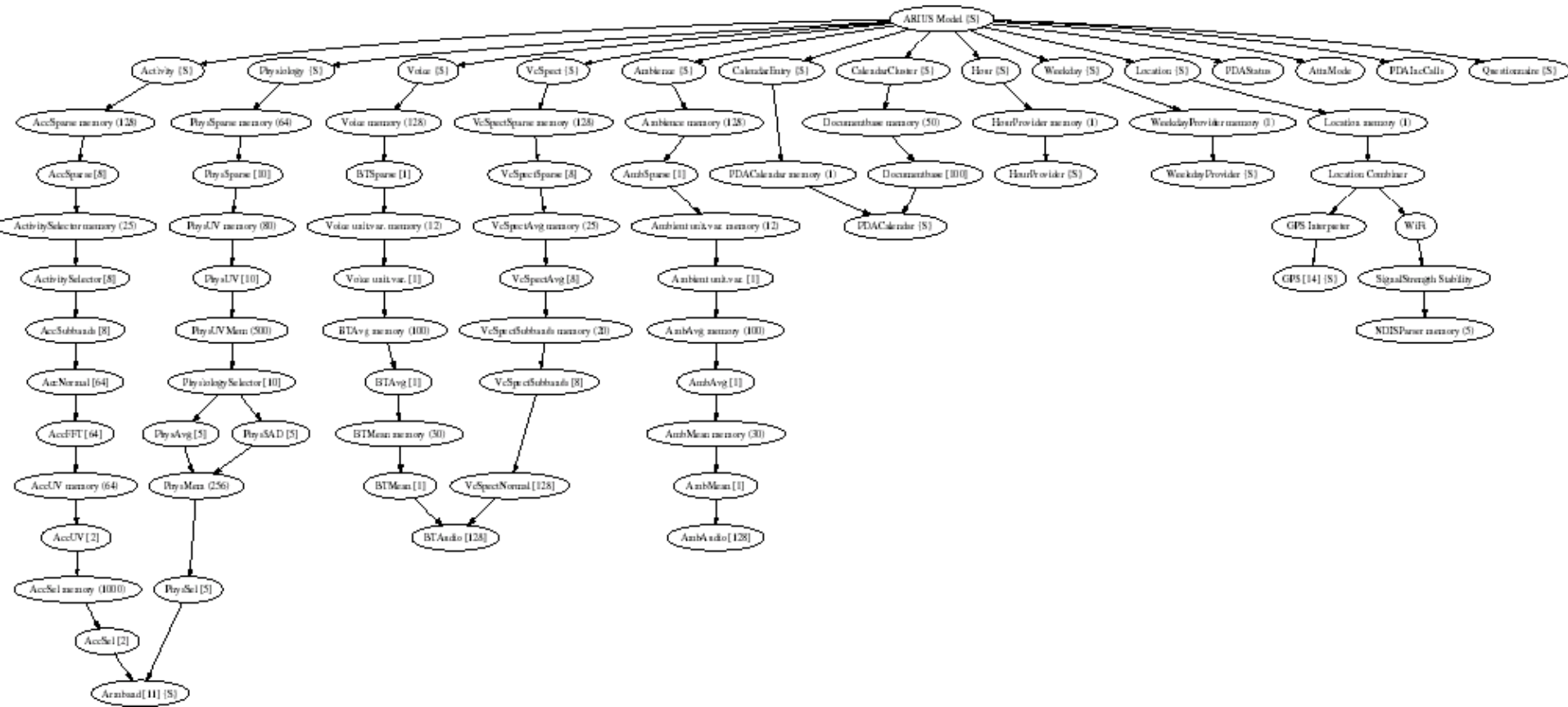
ARIUS Software Architecture I

- Sensor fusion process modeled as a directed acyclic graph
 - Sensors and User Interactions are sources
 - Preprocessing steps are internal nodes
 - Clustering / Learning algorithms are sinks
 - Configurable using XML
 - Object oriented implementation (Java)
 - Extendable with new sensors / preprocessing steps

ARIUS Software Architecture II

- Event based communication
 - Distribution of events over the network or streaming into a database (different speeds)
 - Infrastructural sensors can connect upon availability
 - High level of concurrency
- Maintenance / Reliability
 - Acoustic feedback in case of error
 - Tap into sensor fusion graph
 - Runs 10+ hours without recharging

ARIUS running...



Results & Future Work

- Learning context-dependent personal preferences possible, at least for
 - Limited number of study participants
 - Locally-constant contexts from low-level sensors
 - Mobile phone application
- Method can be realized on wearable hardware

- Other applications of the presented method
- Extended studies
- Further hardware integration