Algorithms for context prediction in ubiquitous systems

Lecture in WS08/09

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Overview and structure

Overview and structure

1 **Introduction to context aware computing**

2 **Basics of probability theory**

3 **Algorithms**

- *3.1* Simple prediction approaches: ONISI and IPAM
- *3.2* Markov prediction approaches
- *3.3* The State predictor
- *3.4* Alignment prediction
- *3.5* Prediction with self organising maps
- *3.6* Stochastic prediction approaches: ARMA and Kalman filter
- *3.7* Alternative prediction approahces
  - *3.7.1* Dempster shafer
  - *3.7.2* Evolutionary algorithms
  - *3.7.3* Neural networks
  - *3.7.4* Simulated annealing

Overview and structure

1 Introduction to context aware computing

- *1.1* What is context?
- *1.2* Usage of context in applications
- *1.3* From sensor data to context
- *1.4* What is context prediction?
- *1.5* Usage scenarios for context prediction
- *1.6* Some considerations on context prediction

Overview and structure

1 Introduction to context aware computing

1.1 What is context?

1.2 Usage of context in applications

1.3 From sensor data to context

1.4 What is context prediction?

1.5 Usage scenarios for context prediction

1.6 Some considerations on context prediction

Introduction

What is context?

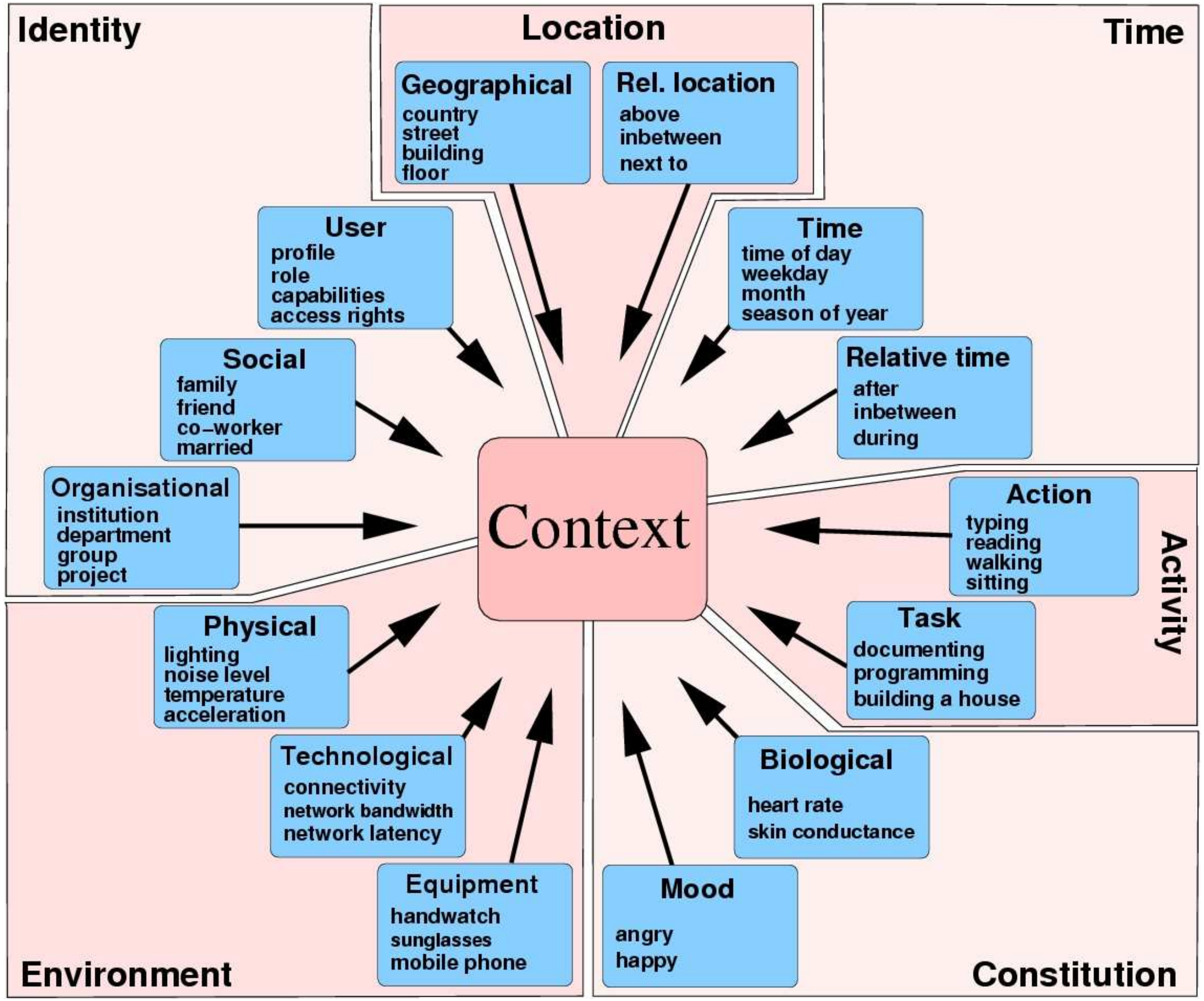
1. „the set of facts or circumstances that surround a situation or event"
2. The parts of a discourse that surround a word or passage and can throw light on its meaning
3. The interrelated conditions in which something exists or occurs (Webster)
4. Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves. [Dey00]

Literature:

[Dour08] **Paul Dourish, What we talk about when we talk about Context, *Personal and Ubiquitous Computing*, 2008.**

[Dey00] **Anind Kumar Dey, Providing architectural support for building context–aware applications, PhD-thesis, 2000.**

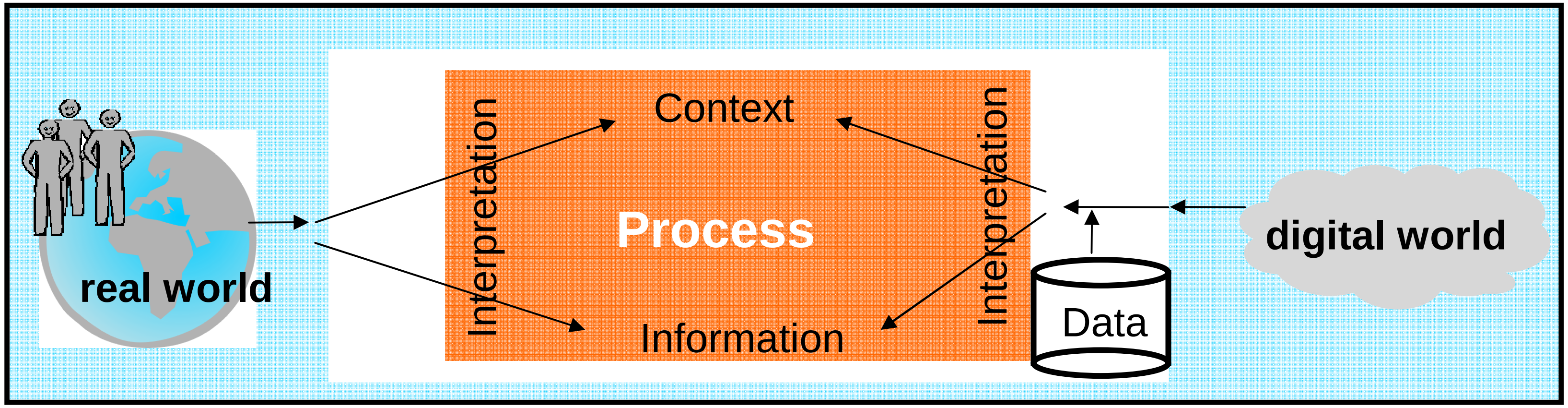
What is context?



What is context?

Context

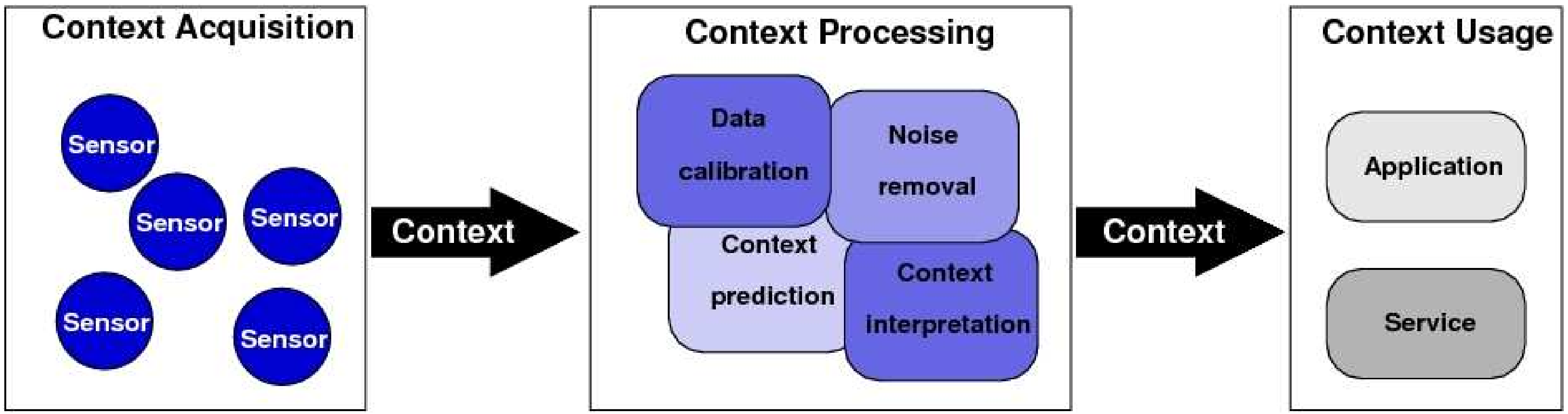
- In addition to acutal information
- The actual view of a process defines what is taken for context and what for information.
- Also „context-only“ or „information-only“ models possible
- Context from the ‚digital world‘ from other computers or from internal data
- Context is obtained by sensory inputs



Overview and structure

Example sensors

Context processing and context utilisation

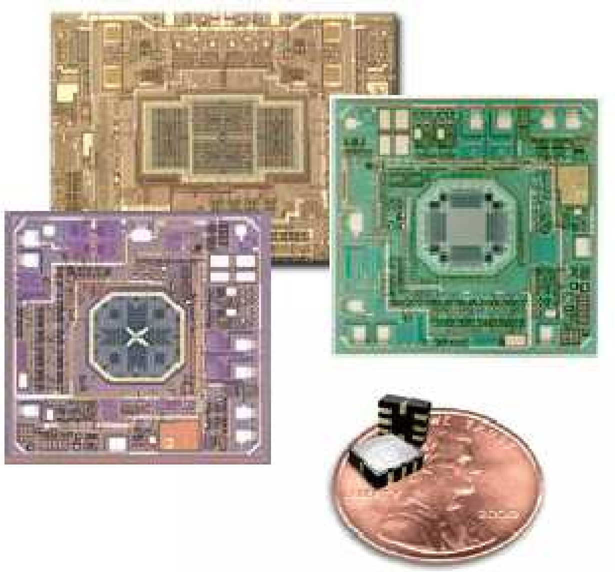


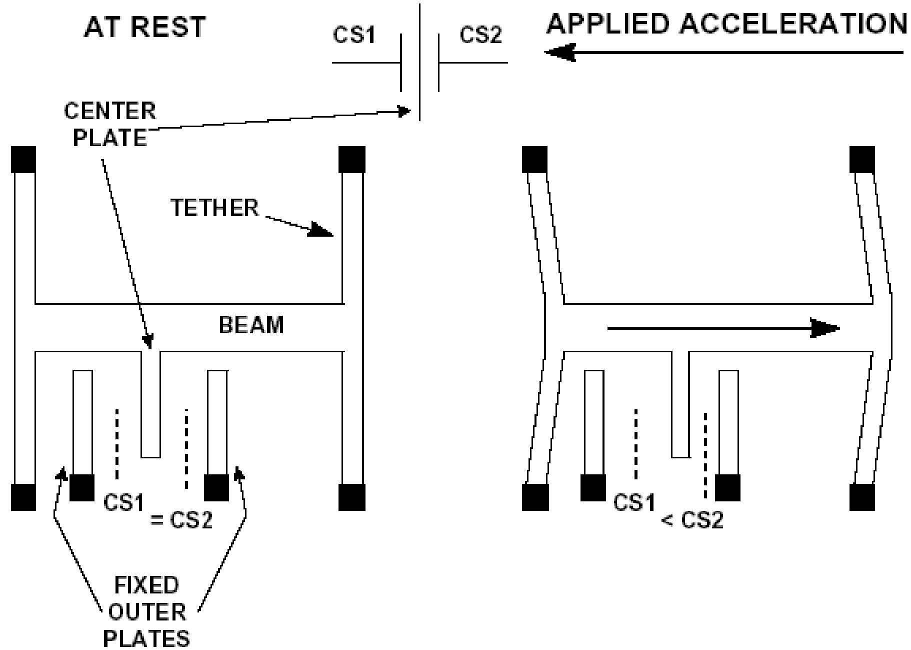
Example sensors

Movement and acceleration

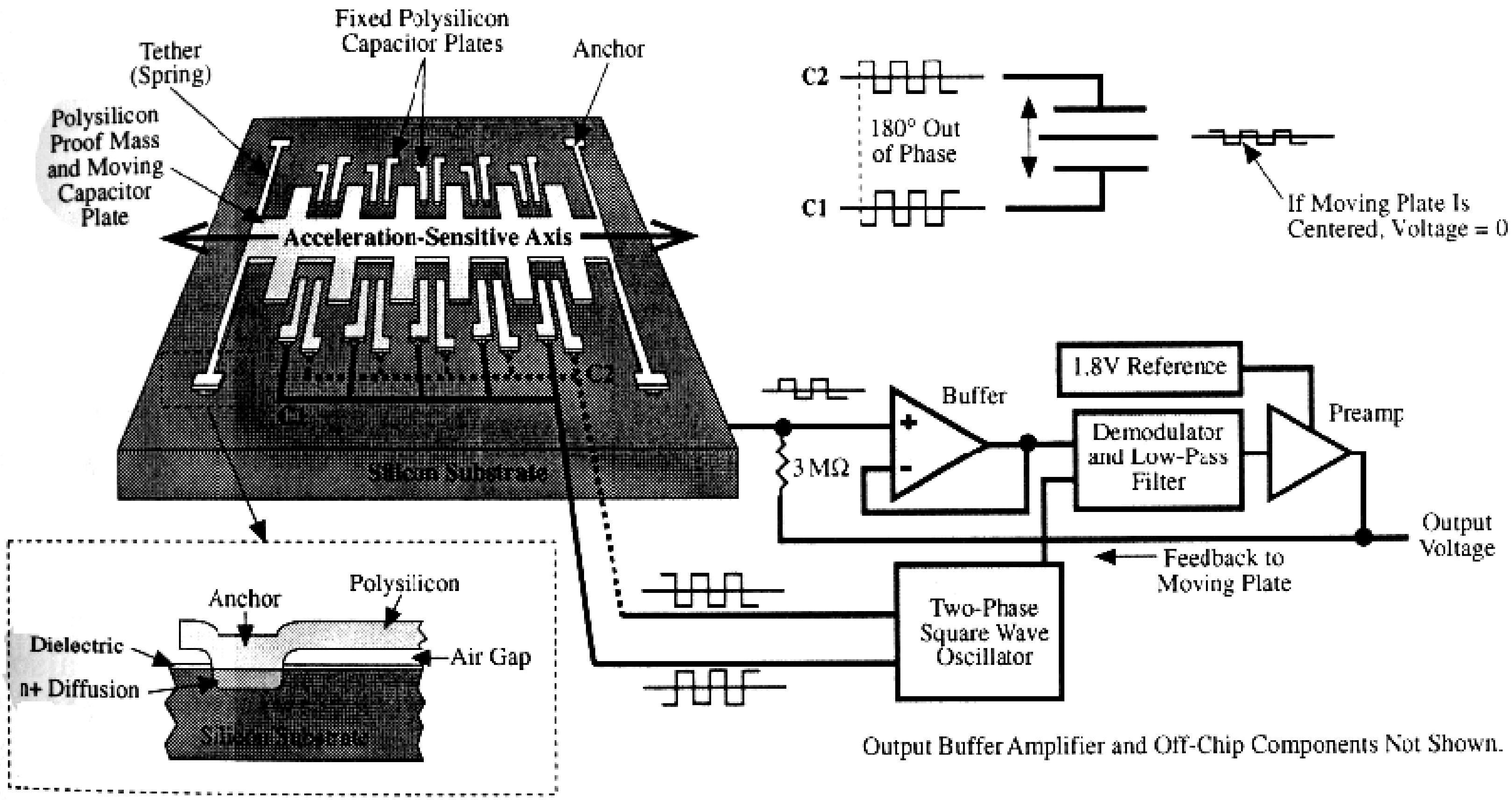
MEMS acceleration sensors

- E.g. Analog Devices ADXL
- Low energy consumption, small, cheap, medium precision
- MEMS = Micromechanical System:Mechanik in Silizium
- Here: Comparison of capacity CS1 and CS2 leads to acceleration





MEMS acceleration



Analog Devices ADCL-50 (famous). Force balanced, capacitive accelerometer.

Light sensors

Context recognition

- Light intensity (trivial)
- Indoors / Outdoors: 50 Hz oscillation, distribution of light spectrum, light intensity
- Indirect physical value: Movement

Sensors

- In various wavelengths, multi-wavelength-sensors possible
- Solar cells useful with limitations
- Klassical sensor type

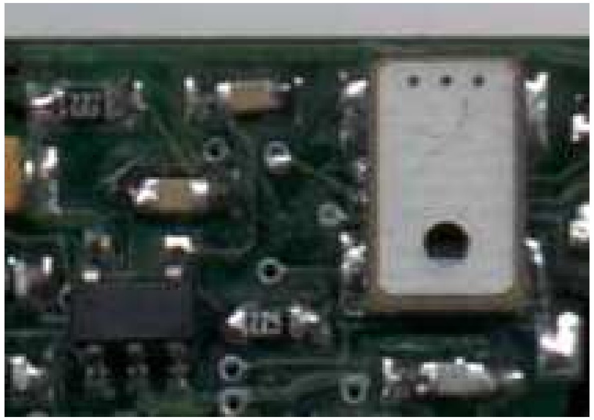
Audio sensors

Context recognition

- Ambient audio (esp. pattern) – indicator of environmental activity changes
- Easy distinction between speech and ambient noise
- Recognised patterns (e.g. driving cars) allow deduction of place
- Recognition of places by pattern analysis feasible

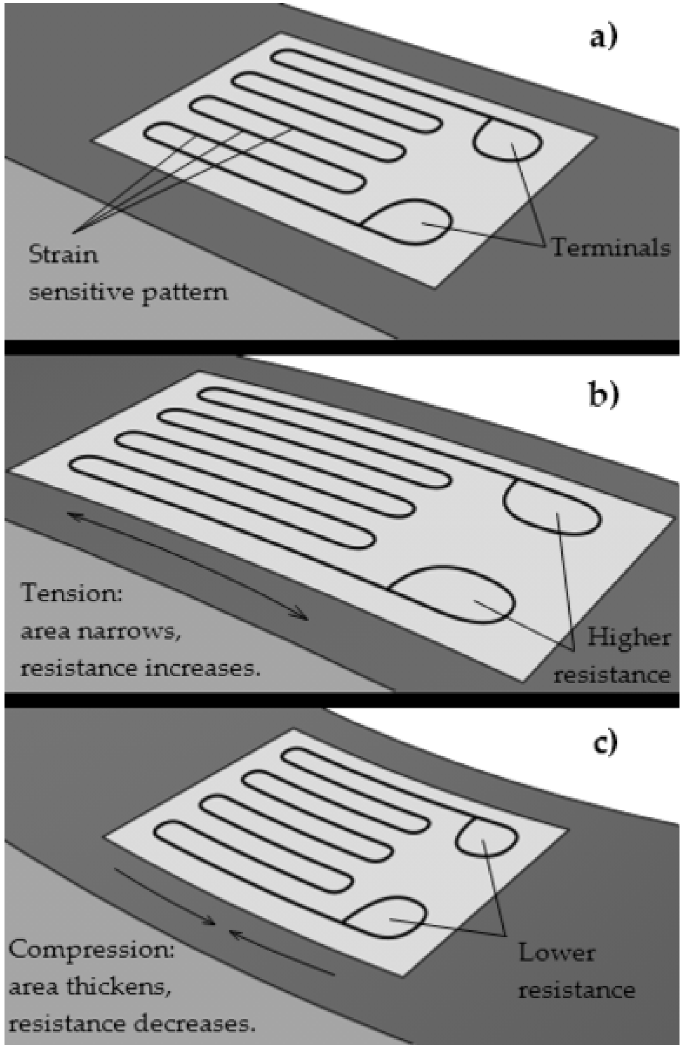
Sensors

- Microphone and Amplifyer
  - Cheap
  - Small frequency spectrum (<10kHz)
  - Low dynamic
  - High noise level
- Audio evaluation therefore difficult

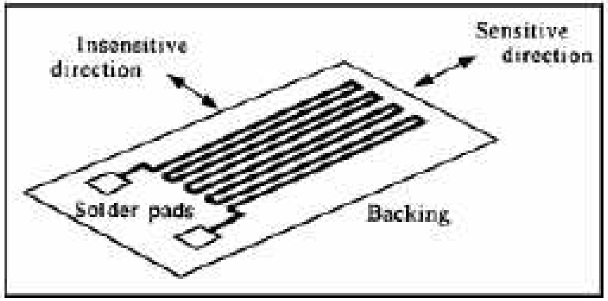


Pressure

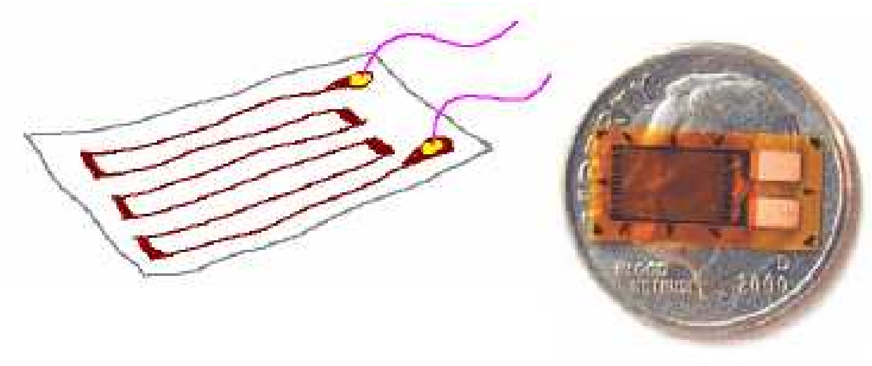
- Z.B. IEE ca 3-10 Euro
- Very imprecise



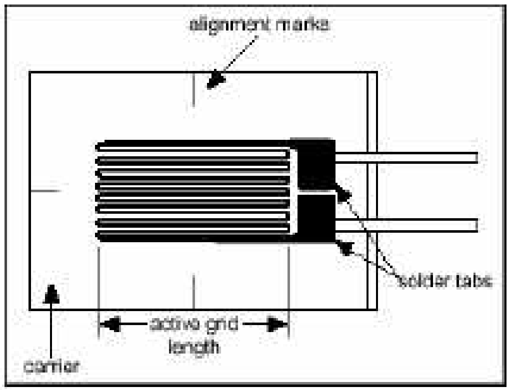
Foil pressure sensors

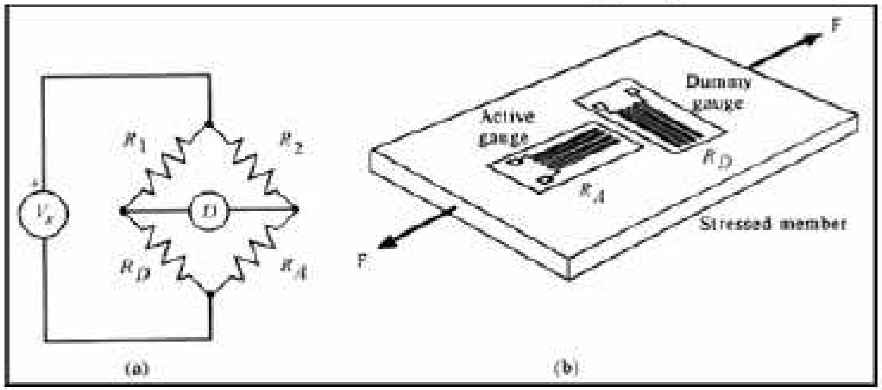


One directional foil strain gauge



Two-directional strain gauge

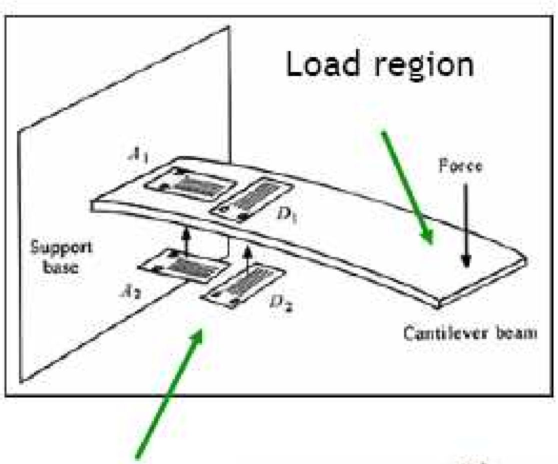


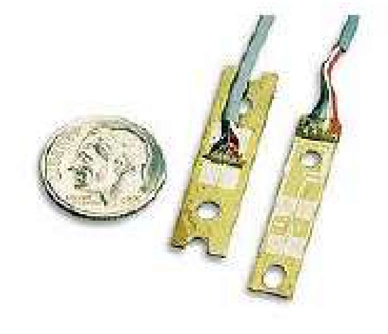


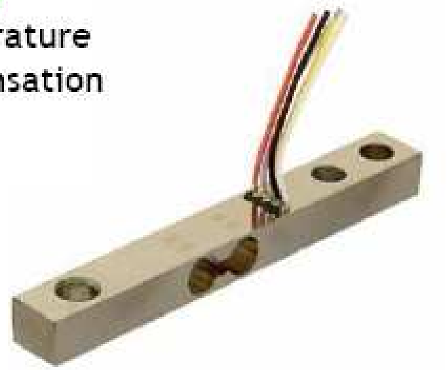
Thin foil (typically 5 µm thick) patterned on thin materials.

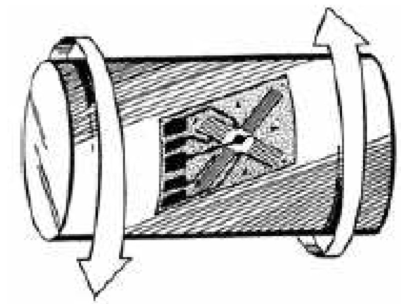
Lastzellen

- **Precise, since calibrated, tight production tolerance**
- **> 100 Euro**





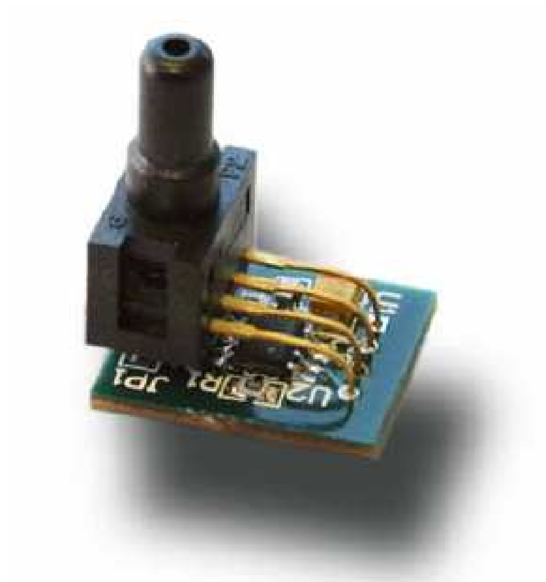


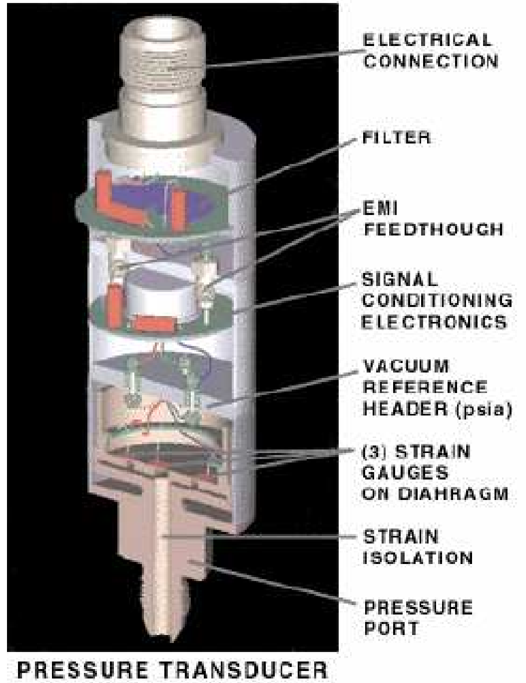


Strain gauge can be used to make a load cell and to measure torque.

Auch Luftdruckzellen sind möglich

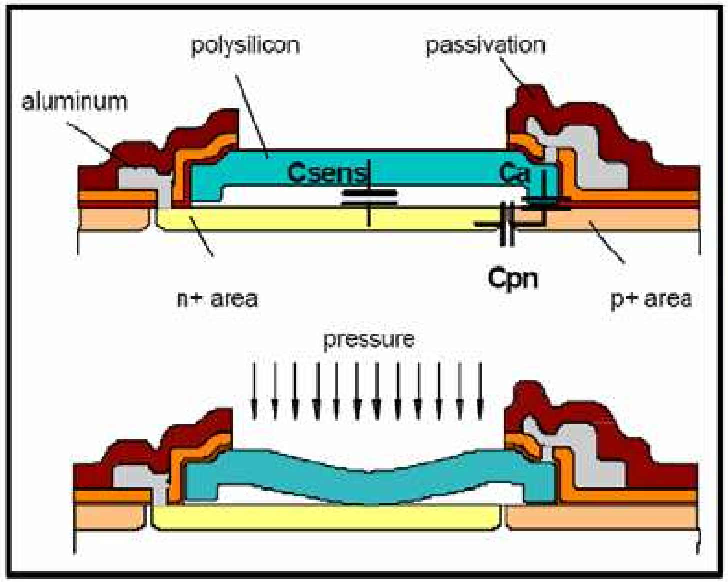
Please read:
http://www.sensorland.com/HowPage059.html
http://www.sensorsmag.com/articles/0700/62/main.shtml

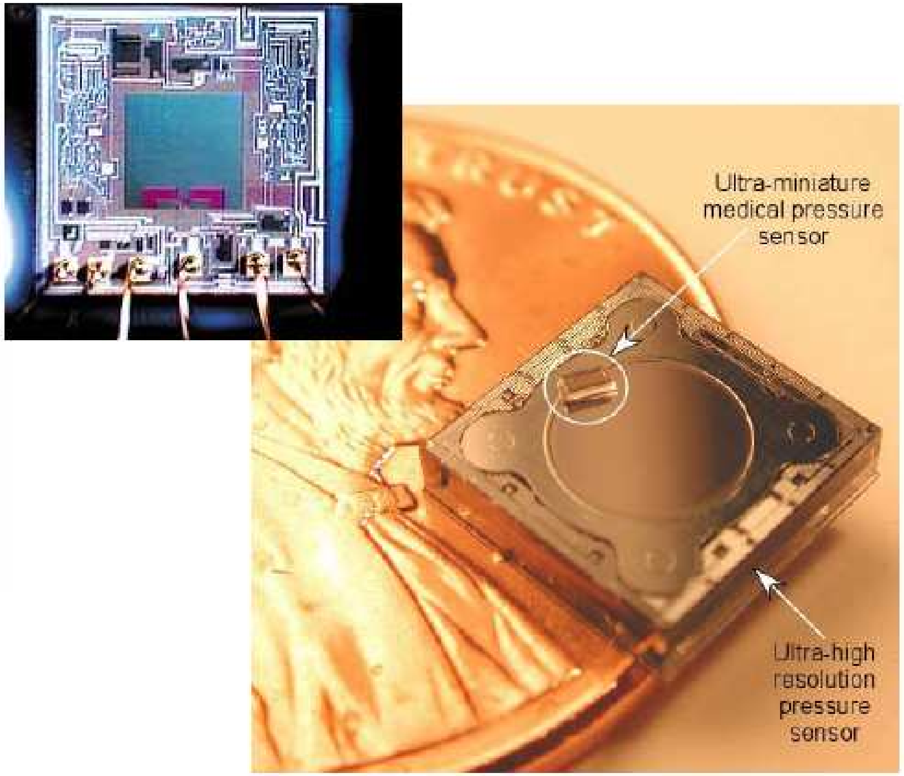




Pressure can be measured using diaphragm based sensors.

MEMS, Piezobasierte Sensoren für Druck



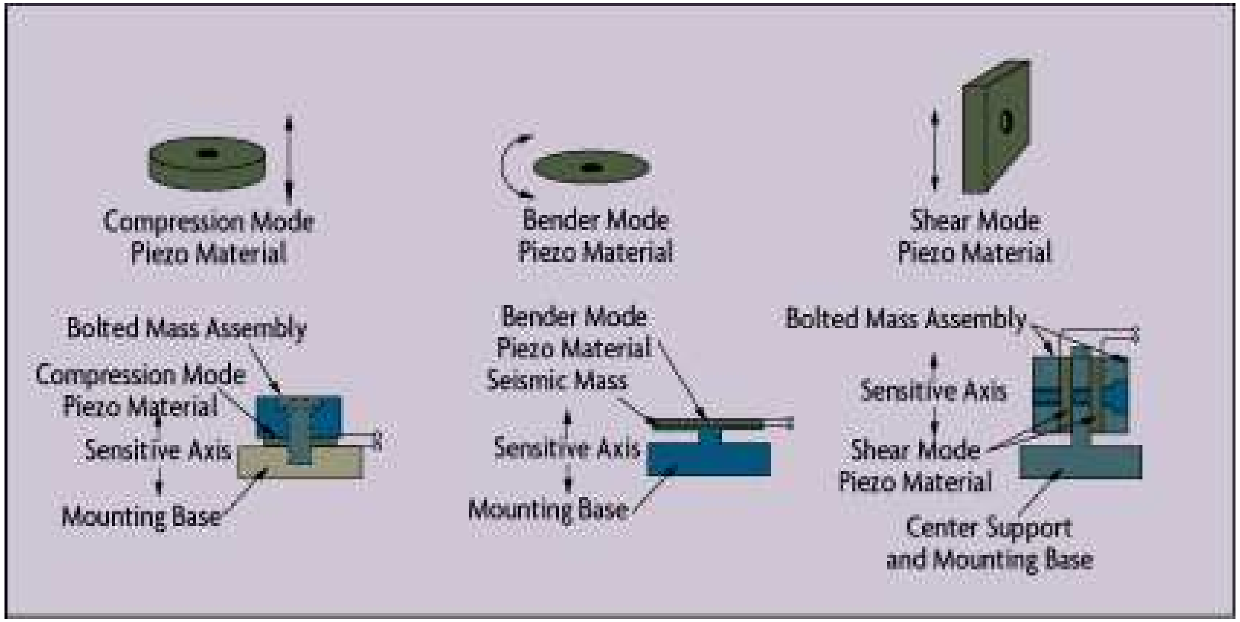


Capacitance changes with deflecting membrane. Measured using AC circuitry.

Kraftsensoren (Force Sensors)

Basierend auf Piezo-Materialien

- Piezo is highly stable
- Piezo emits electric voltage when deformed
- Not suited for static settings



Movement and acceleration

Context recognition

- Activity: Trigger sleep mode (save energy)
- Level of activity
- Own context: Object movement, person is nervous, specific handling of objects
- Environmental context: Vibration, earthquake

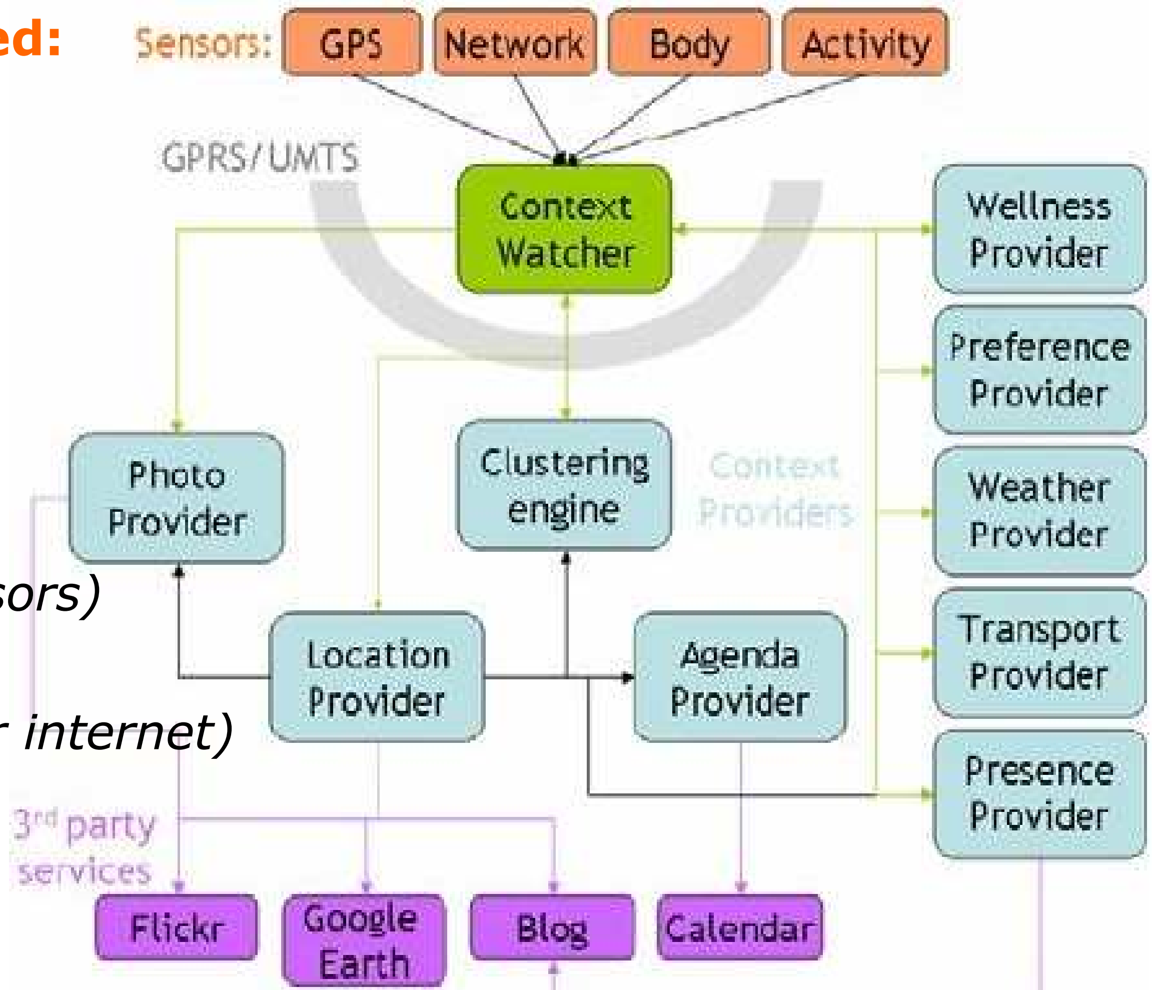
Sensors

- Ballswitch
  - (nearly) no quiescent current
  - Various types, filled with gas/liquid
  - e.g. Acceleration with fixed value (liquid)
  - Vibration (filled with gas)

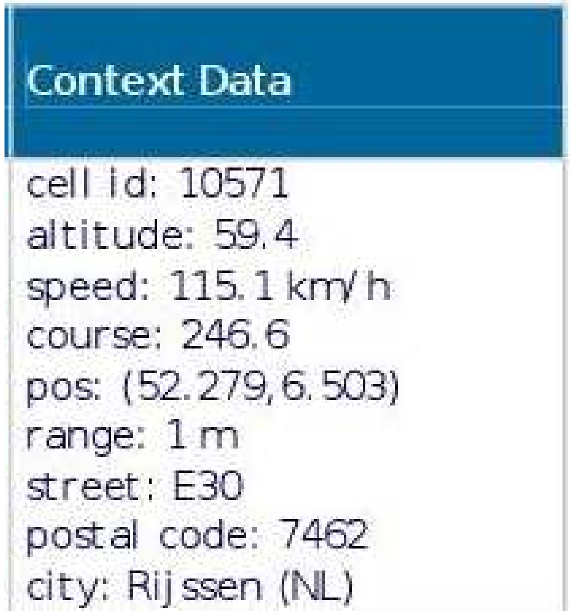
Example: Context Watcher

Context sources utilised:

- Location
  - *(GSM cell-ID; GPS)*
- Mood
  - *(user input)*
- activity
  - *(calender based)*
- Bio-data
  - *(heart and foot sensors)*
- Weather
  - *(location based over internet)*
- Photo/picture
  - *(camera)*



Example: Context Watcher



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- *1.1* What is context?
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Sensor data

Information obtained

- Patterns

Classification of sensor information

- Based on pattern
- Based on source
- Based on accuracy
- Based on parameters the sensor provides

Sensor data

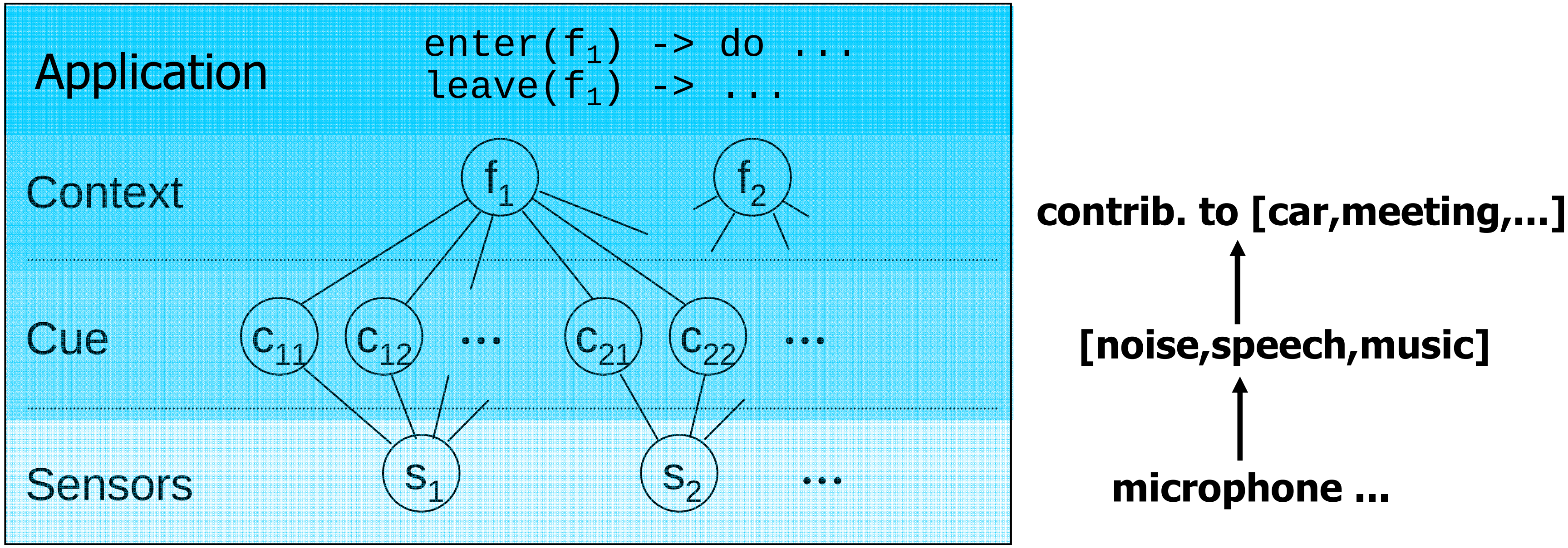
Parameter to classify sensor information

- Location
  - Angle, length, distance, position, ...
- Mechanic
  - Weight, bending, pressure, vibration, acceleration, ...
- Time
  - Relative/absolute, duration
- Clima
  - Temperature, humidity, wind, air pressure
- Optical
  - Light intensity, wavelength, spectrum, pattern
- Acoustic
  - Loudnes, frequency, pattern
- Electrical
  - Current, voltage
- Chemical / Environmental
  - Ozone, gas, pH, radioactivity
- Bio
  - Blood pressure, pulse rate, skin conductance

Context recognition

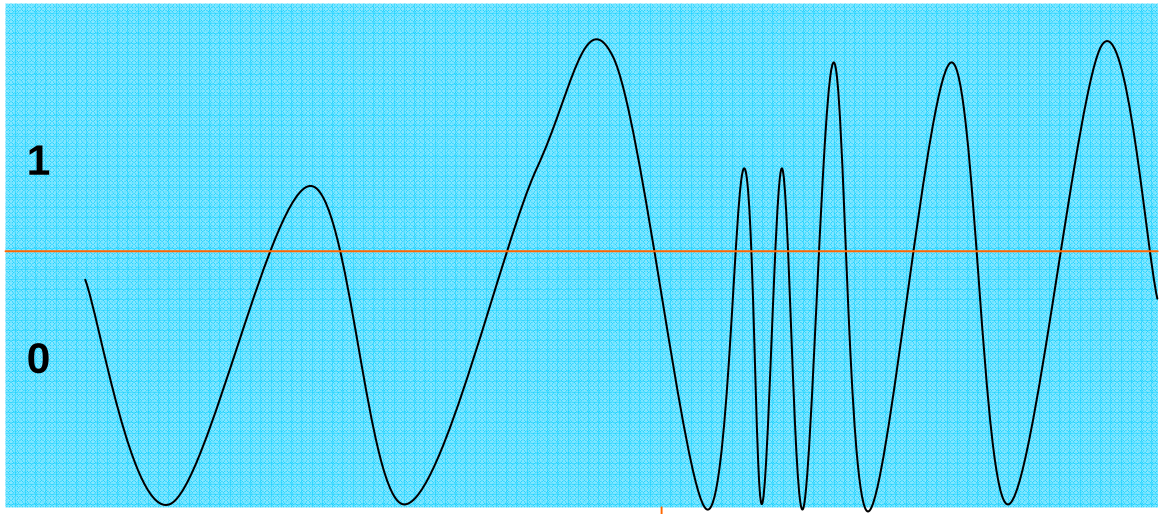
Context processing stages

- Raw electrical signals
- Interpretation of signals as electic values
- Aggregation, first abstraction of signals
- Further abstraction based on semantics
- Interpretation of abstracted data to contexts



Raw electrical signals

Interpretation of the alteration of electric parameters (resistance, voltage, frequency, ...) and mapping onto electric value as, for example, voltage



Voltage over time

000000001110000000111111000101010011110001111

Mapping onto state

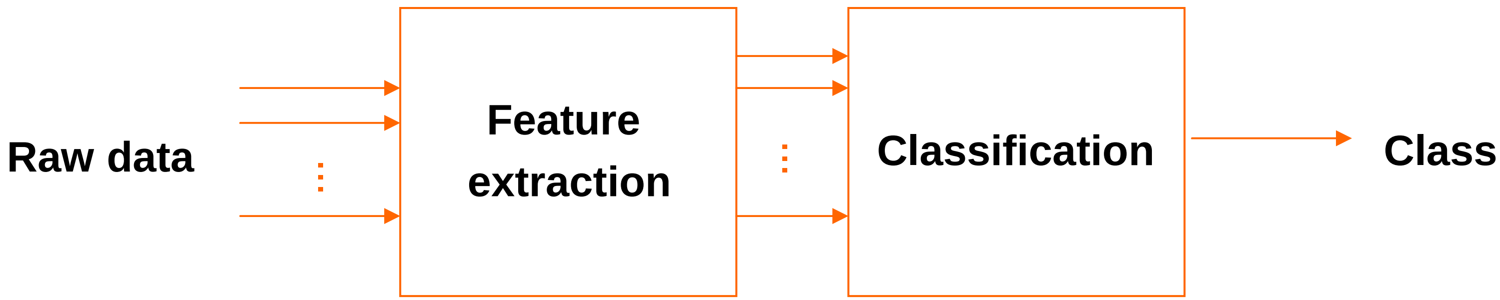
Quiet...........................Loud.......medium loud................

Aggregation of the electric value of one or many sensors and mapping onto a feature

Pattern recognition

Classical pattern recognition

- Obtain features from raw data by utilisation of prior knowledge
- Mapping of features onto classes by utilisation of prior knowledge
- What are characteristic features?
- Which approaches are suitable to obtain these features?



Example context processing TEA - Audio

Requirements

- Restricted memory space
- Computing power restricted

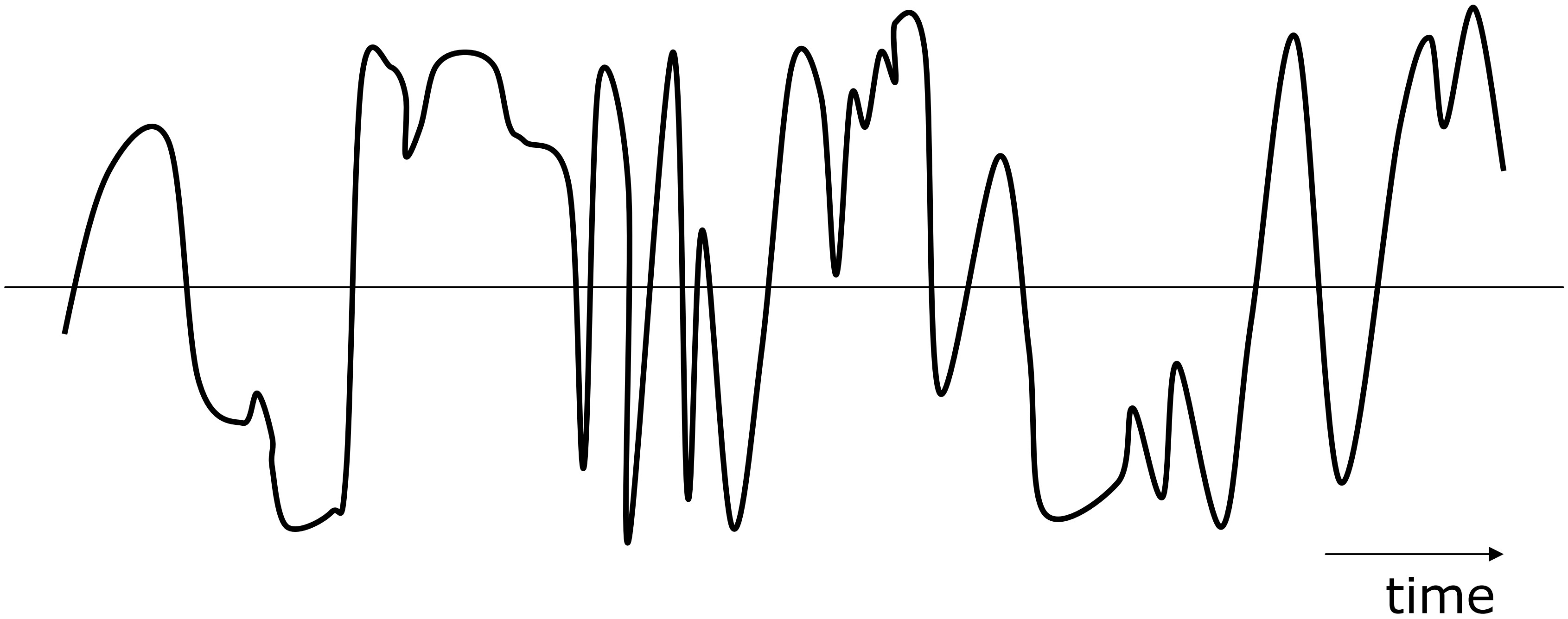
Benefit

- Many sensors → Many features

Example approach

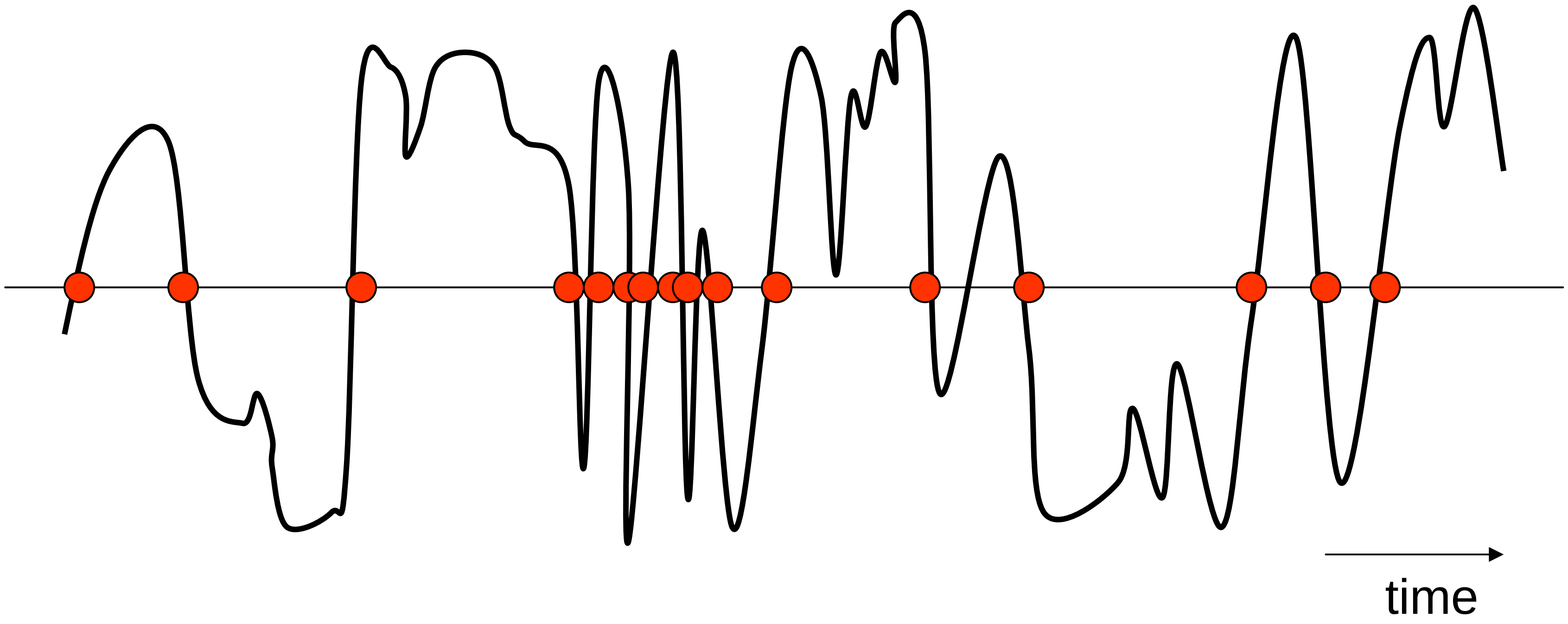
- Utilise time domain (no transformation)
- Utilise statistic measures
- Feature extraction based on small amount of data

Audio signal processing



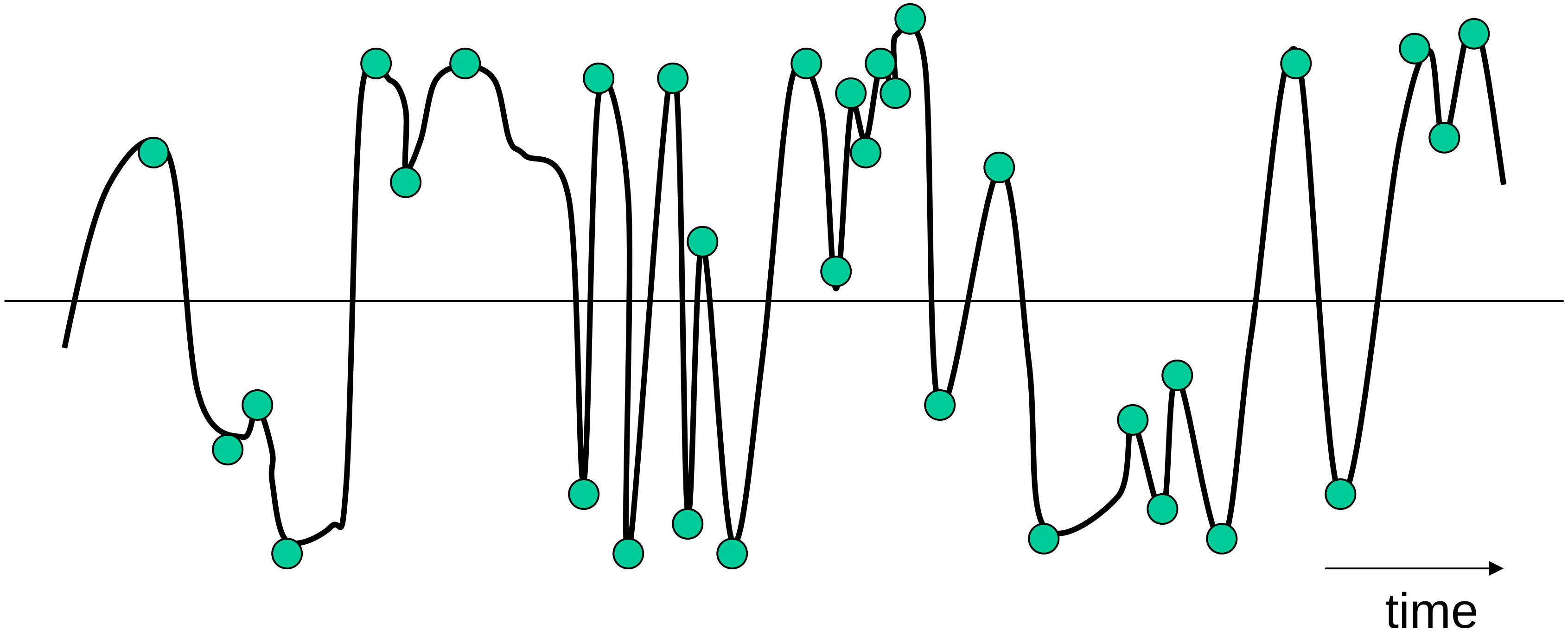
- Data in time domain

Processing of zero crossings



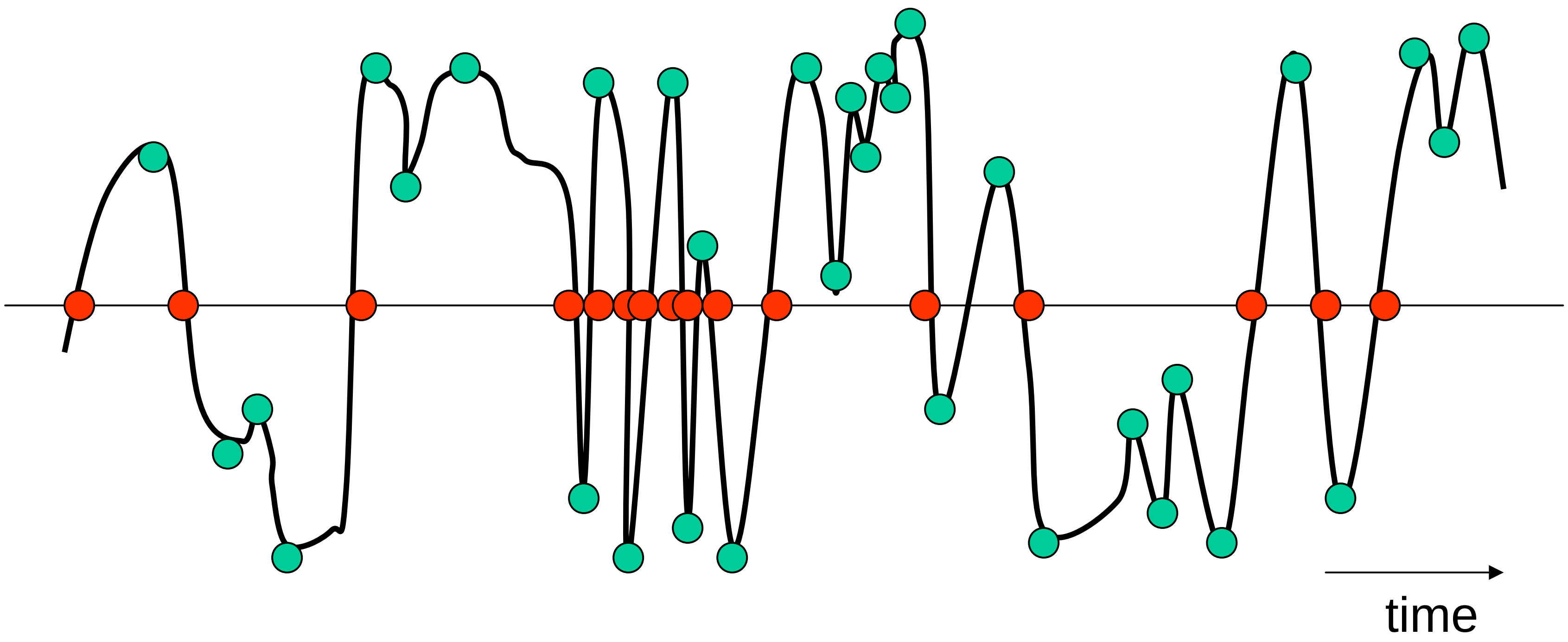
- Count zero crossings
- Distance between zero crossings

Processing of direction changes



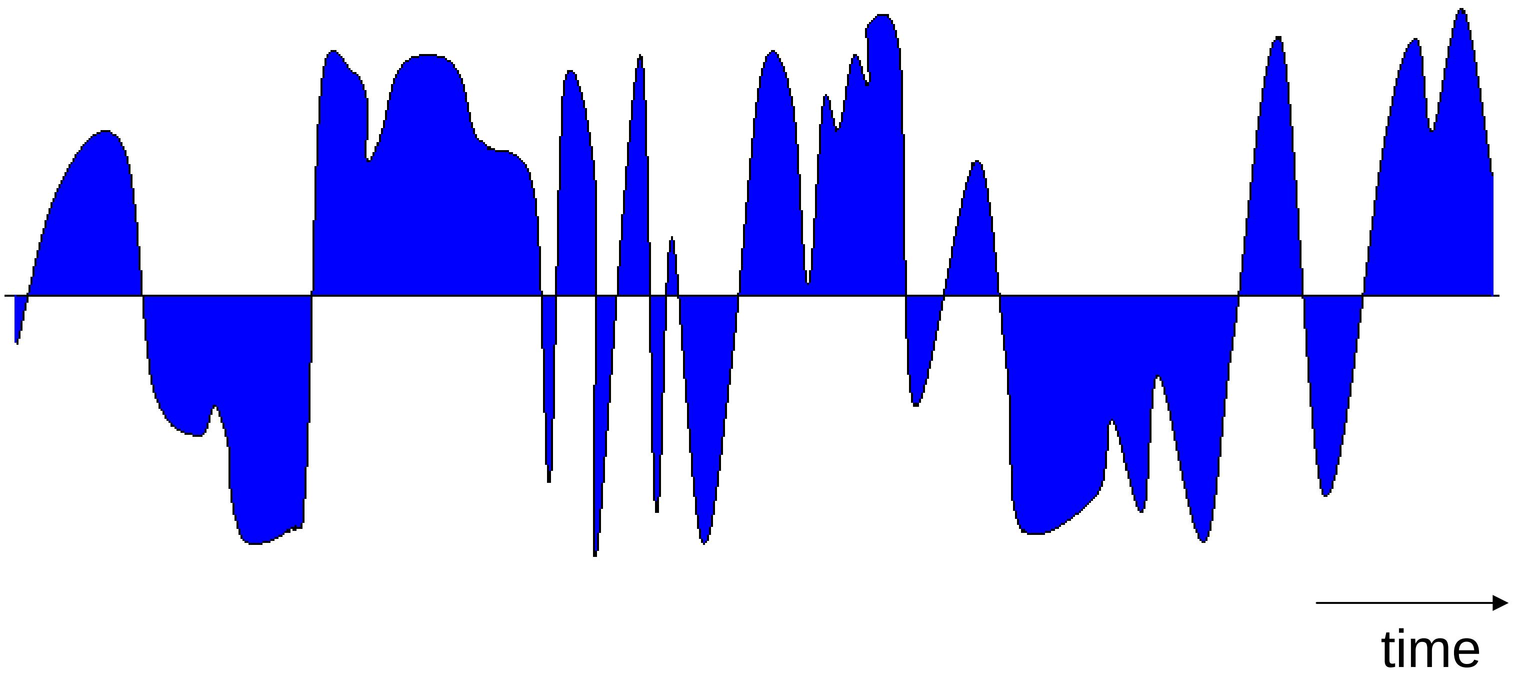
- Count direction changes

Processing ratio



- ratio = Direction changes / Zero crossings

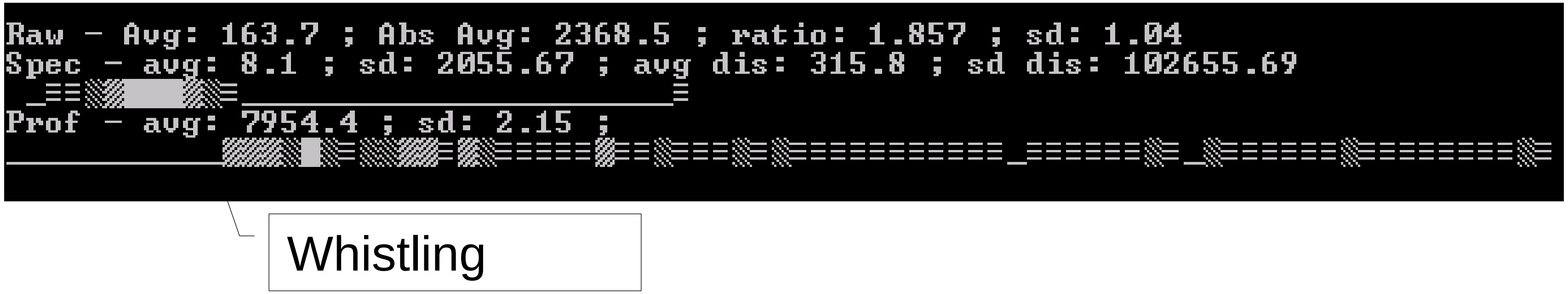
Processing integral



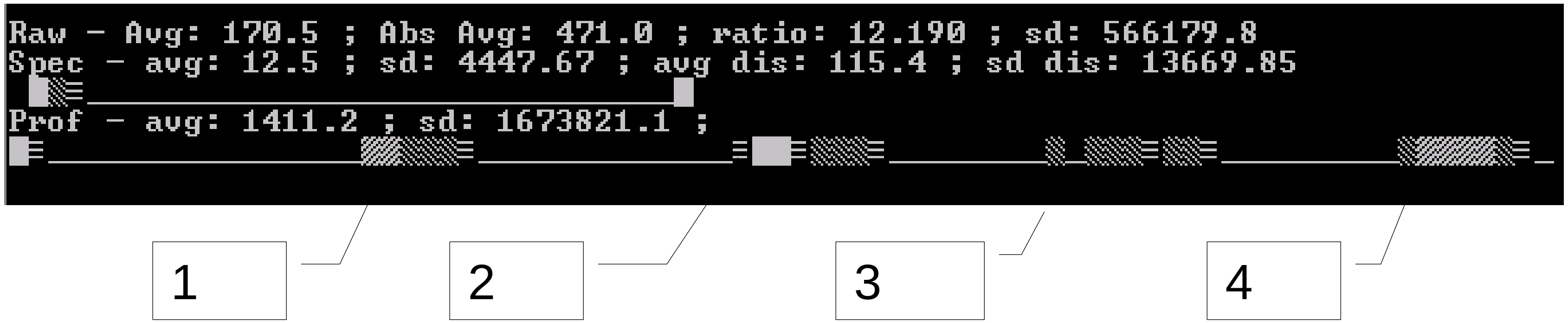
- Area between curve and x-axis

Processing

whistling



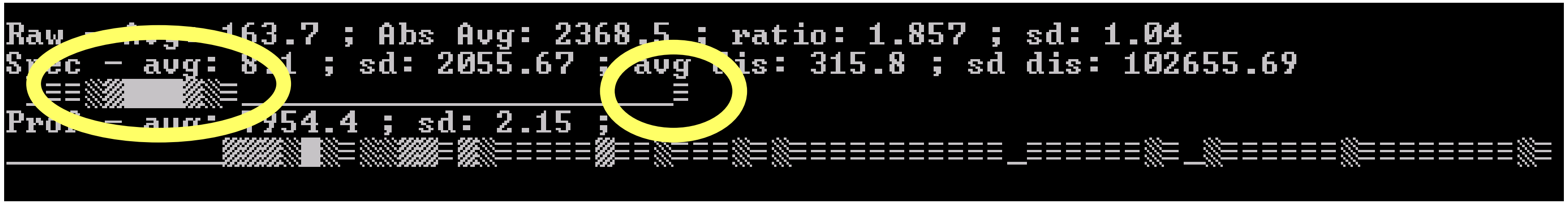
speech



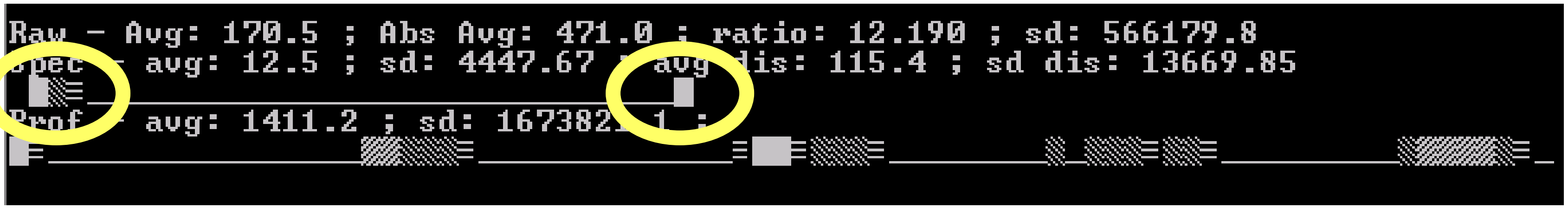
- Several chunks for speech

Processing

whistling



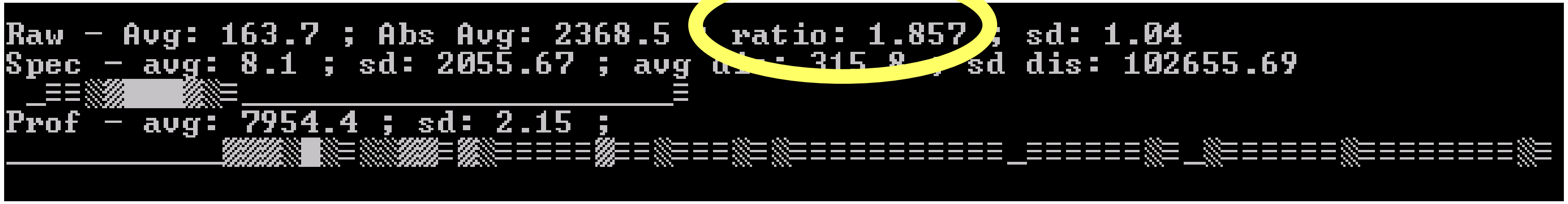
speech



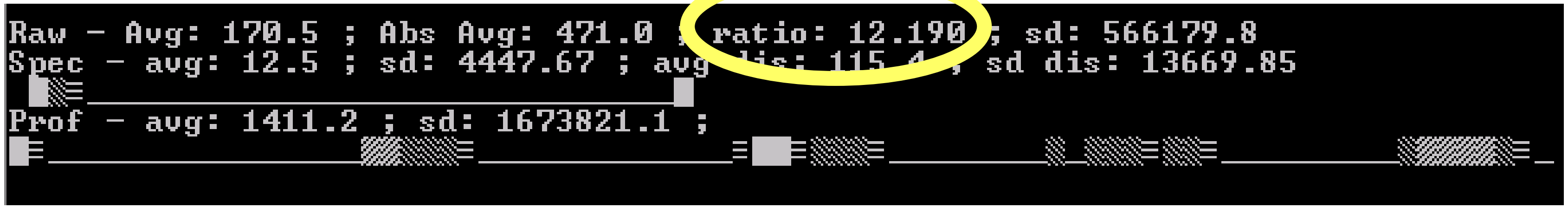
- Distance between zero crossings: distinct behaviour of oscillation at start and end

Processing

whistling



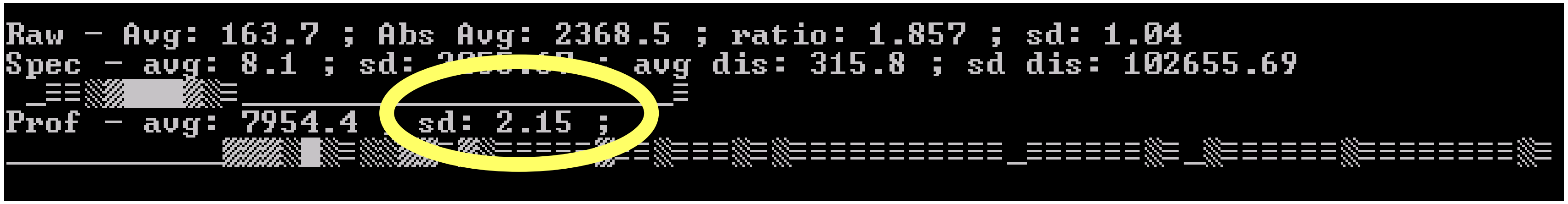
speech



- Distinct ratio zero crossings / direction changes

Processing

whistling



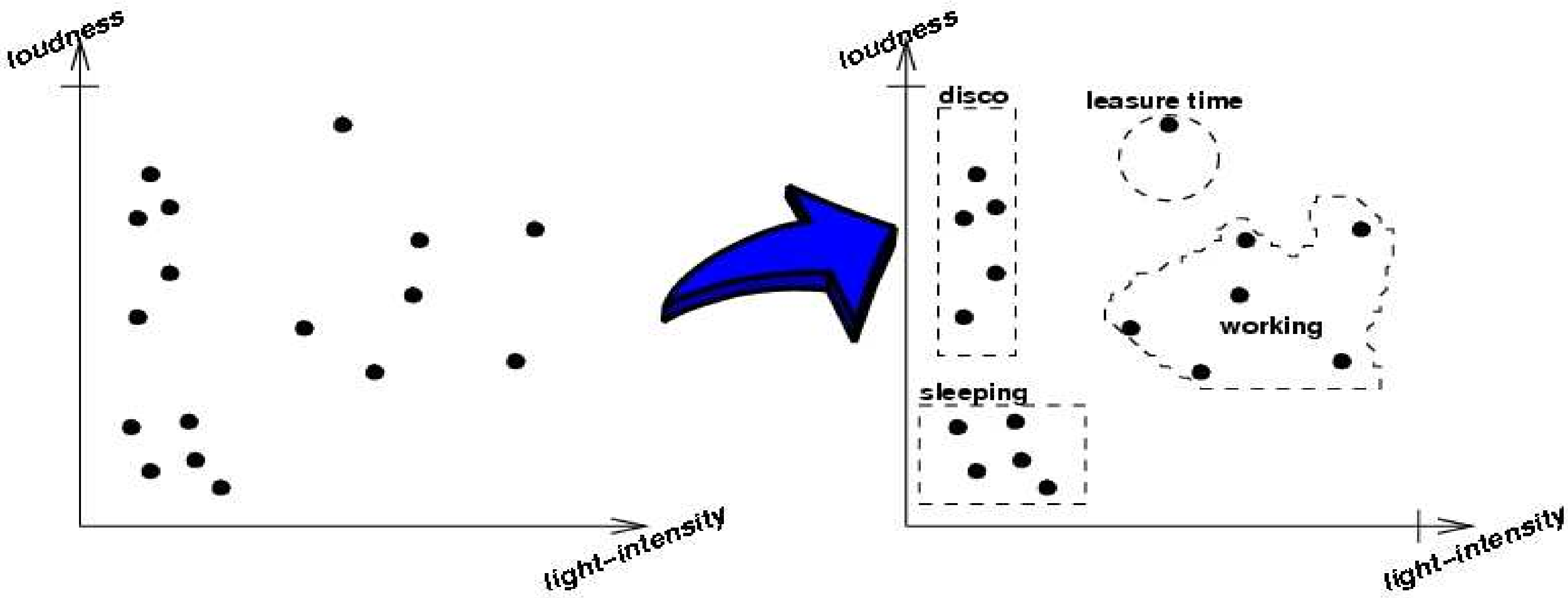
speech

- Significant change in standard deviation of chunks

Context recognition

From features to contexts

- Measure available data on features
- Probably with regard to probability distribution
  - Measured value always approximation of actual value
- Context reasoning by appropriate method
  - Syntactical (rule based ; e.g. RuleML);
  - Statistical: HMM, NN, SOM, SVM, Bayes Nets …



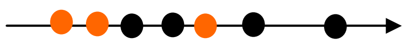
Context recognition

Allocation of sensor value by defined function

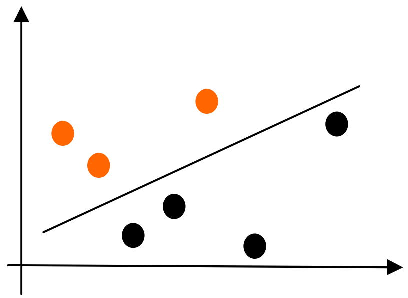
- Corellation of various data sources
- Several methods possible – simple approaches
  - Template matching
  - Minimum distance methods
- „Integrated" feature extraction e.g.
  - Nearest Neighbour
  - Neural Networks

Problem

- Measured raw data might not allow to derive all features required
- Therefore often combination of sensors



Zu wenig Features



Genug Features

Context recognition

Methods – Syntactical (Rule based)

- Idea: Description of Situation by formal gramma (Symbols and Rules)
- Description of a (agreed on?) world view
- Example: RuleML

Comment

- Pro: Combination of rules and identification of loops and inpossible conditions feasible
- Contra:
  - Very complex with more elaborate situations
  - Extension or merge of rule sets typically not possible without contradictions

Context recognition

Methods – Statistical

- Idea: Modelling of situation by probability theoretic measures
- Examples
  - HMM, NN, SOM, SVM, Bayes Nets …
- Probabilistic world model
  - Adaptation to changing environment possible

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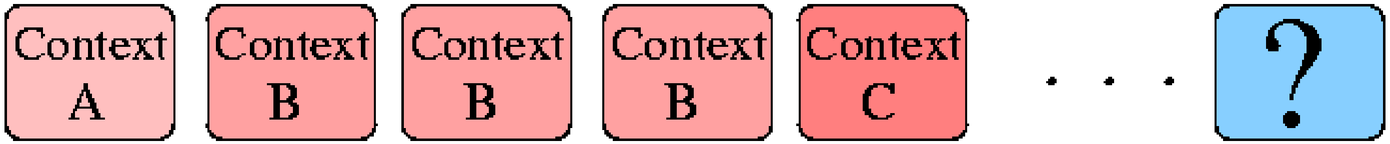
What is context prediction?

Informal descriptions:

- *„Context Prediction [...] aims at inferring future contexts form past (observed contexts).*" [Mayr04]
- *„In Kombination mit verschiedensten bekannten Informationen soll aus dem augenblicklichen Kontext heraus der nächste Kontext vorhergesagt werden.*"[Petz05]



Literature:

[Mayr04] **Mayrhofer, R.M, An Architecture for Context Prediction, PhD-Thesis, 2004.**

[Petz05] **Petzold, J, Zustandsprädiktoren zur Kontextvorhersage in ubiquitären Systemen, PhD-Thesis, 2005.**

What is context prediction?

Formal definition of context prediction:

- Let k, n, i ∈ N and t_i describe any interval in time. Furthermore, let T be a context time series. Given a probabilistic process $\pi(t)$ that describes the context evolution at time t_i , context prediction is the task of learning and applying a prediction function $f_{t_i} : T_{t_{i-k+1},t_i} \rightarrow T_{t_{i+1},t_{i+n}}$ that approximates $\pi(t)$.

What is context prediction?

Context prediction is a search problem:

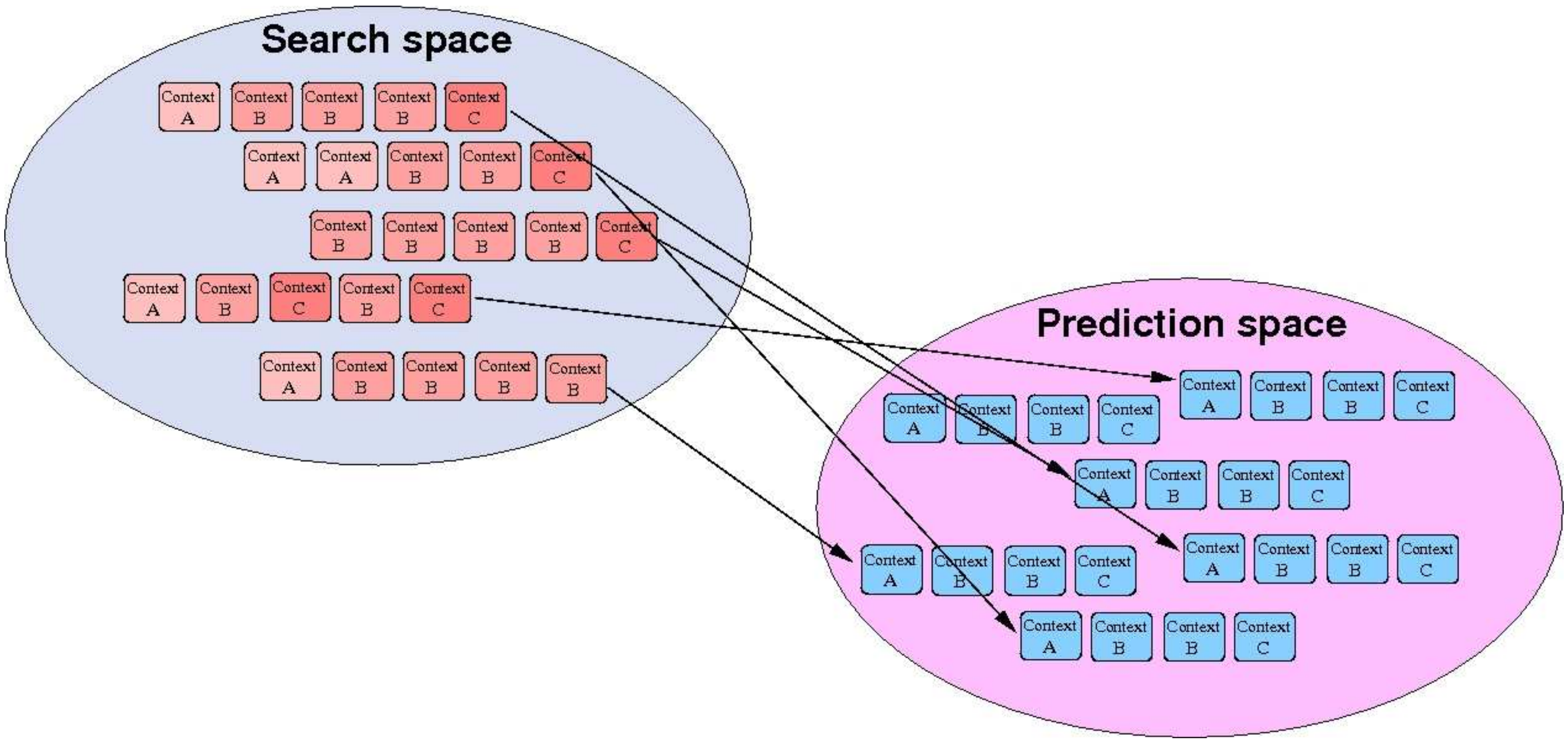
- A search problem Π is described by
  1. the set of valid inputs Λ_Π
  2. for I $\in \Lambda_\Pi$ the set $\Omega_\Pi(I)$ of solutions

  An algorithm solves the search problem Π if it calculates for I $\in \Lambda_\Pi$ an element $\Omega_\Pi(I)$ if $\Omega_\Pi(I) \neq \varnothing$ and rejects otherwise.

What is context prediction?

Context prediction is a search problem:

- Context prediction is mainly to find the correct mapping between search space and prediction space



What is context prediction?

Accuracy of context prediction approaches:

- For any context prediction algorithm A, the prediction accuracy is given by the approximation quality d if the algorithm produces predictions whose prediction quality is bounded from above by d.

- Let T denote a time series and $d : T \times T \to R$ be a distance metric. We measure the quality of a prediction by the distance of the predicted context time series to the context time series that is actually observed in the predicted time interval.

What is context prediction?

Possible distance metrics between contexts:

- Table-Look-up for non-numeric context types
  - Alternatively, non-numeric contexts might be mapped onto numeric context types

- Various approaches for numeric context types:
  - One-dimensional: simple difference between values
  - Multi-dimensional:
    - Euclidic distance between input vectors
    - RMSE

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (p_i - d_i)^2}{n}}$$

    - BIAS

$$BIAS = \frac{\sum_{i=1}^{n} |p_i - d_i|}{n}$$

- Further approaches feasible

What is context prediction?

Requirements:

- In order for context prediction to be feasible, the input sequence has to be predictable in any sense:
  - Periodic patterns
  - Trends
  - Repetitions of typical patterns
  - …
- Problem:
  - Mood is part of definition of context but hardly accessible by sensors

What is context prediction?

Input sequence typically predictable in UbiComp:

- Human behaviour patters are reproducible [Ande01]
  - Cognitive psychology: ‘script’ describes actions and circumstances that characterise specific context or context pattern.
  - Scripts similar for groups of individuals; small alterations between different cultures or societies
- ”Behaviour consists of patterns in time” [Magn04]
- Typical behaviours in team–sport games like soccer [JBGB03]
- It is possible to recognise the software programmer of a piece of programming
- code based on her programming style [Krsu94].

Literature:

[Ande01] Anderson, J.R., Cognitive psychology and its implications, Spectrum, 2001.

[Magn04] Magnusson, M.S., Repeated patterns in behaviour and other biological phenomena, In: Oller, K., Gabriel, U.: Evolution of Communication systems: A comprehensive approach, MIT Press, 2004.

[JBGB03] Jonsson, G.K., Bjarkadottir, S.H., Gislason, B., Borrie, A., Magnusson, M.S., Detection of real time patterns in sports: Interactions in football, L`ethologie applique aujourd`hui, 2003.

[Krsu94] Krsul, I., Authorship analysis: Identifying the author of a program, 1994

What is context prediction?

Difficulties / Adversary environment:

- Fluctuation of context sources
- Adaptive operation (learning) required
- Input sequence erroneous due to
  - Measurement errors
  - Errors that occur during context processing

Overview and structure

1 Introduction to context aware computing

1.1 What is context?

1.2 Usage of context in applications

1.3 From sensor data to contexts

1.4 What is context prediction?

1.5 Usage scenarios for context prediction

1.6 Some considerations on context prediction

Usage Szenarios

Possible applications for context prediction:

- From [Petz05] and [Mayr05]:
  - Smart Office Building: next location prediction
  - System reconfiguration
  - Accident prevention
  - Alerting
  - Planning aid

Literature:

[Mayr05] **Mayrhofer, R.M., Context Prediction based on Context Histories: Expected Benefits, Issues and Current State-of-the-Art, Proceedings of the 1st international Workshop on exploiting context histories in smart environments (ECHISE) at the 3rd Int. Conference on Pervasive Computing, 2005.**

[Petz05] **Petzold, J, Zustandsprädiktoren zur Kontextvorhersage in ubiquitären Systemen, PhD-Thesis, 2005**

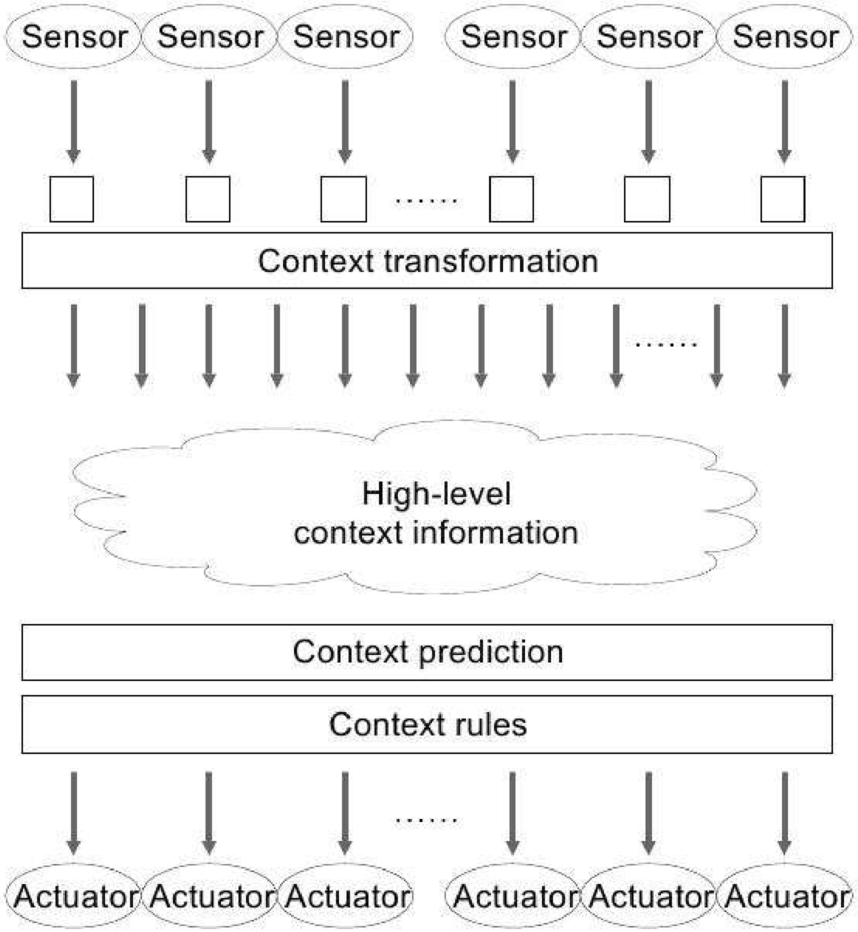
Overview and structure

1 Introduction to context aware computing

- *1.1* What is context?
- *1.2* Usage of context in applications
- *1.3* From sensor data to contexts
- *1.4* What is context prediction?
- *1.5* Usage scenarios for context prediction
- *1.6* Some considerations on context prediction

Context prediction architectures

Context prediction architectures:

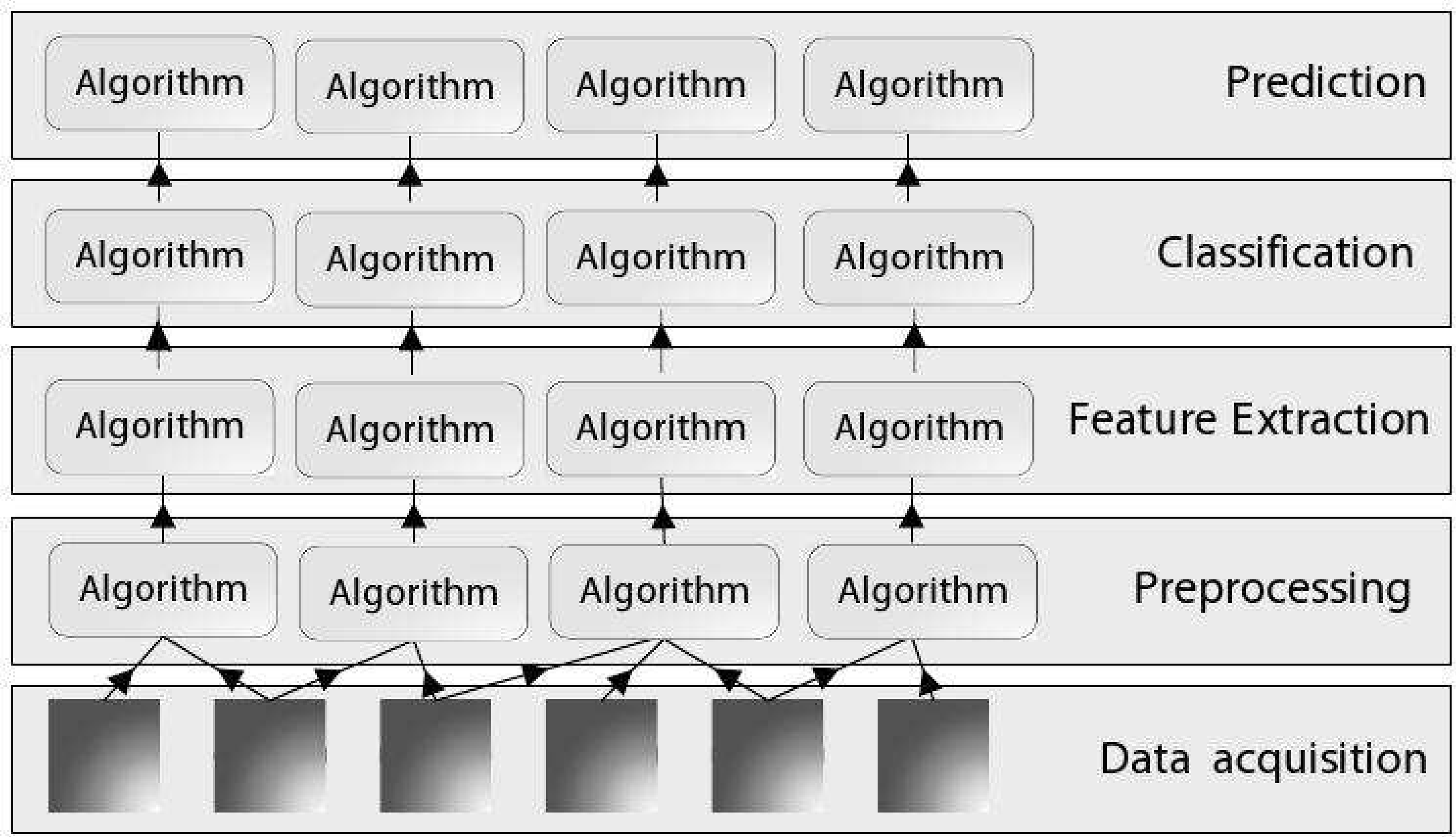


Literature:

[Fers03] Ferscha, A., Pervasive Computing, Datenbank-Spektrum, 2003.

Context prediction architectures

Context prediction architectures:

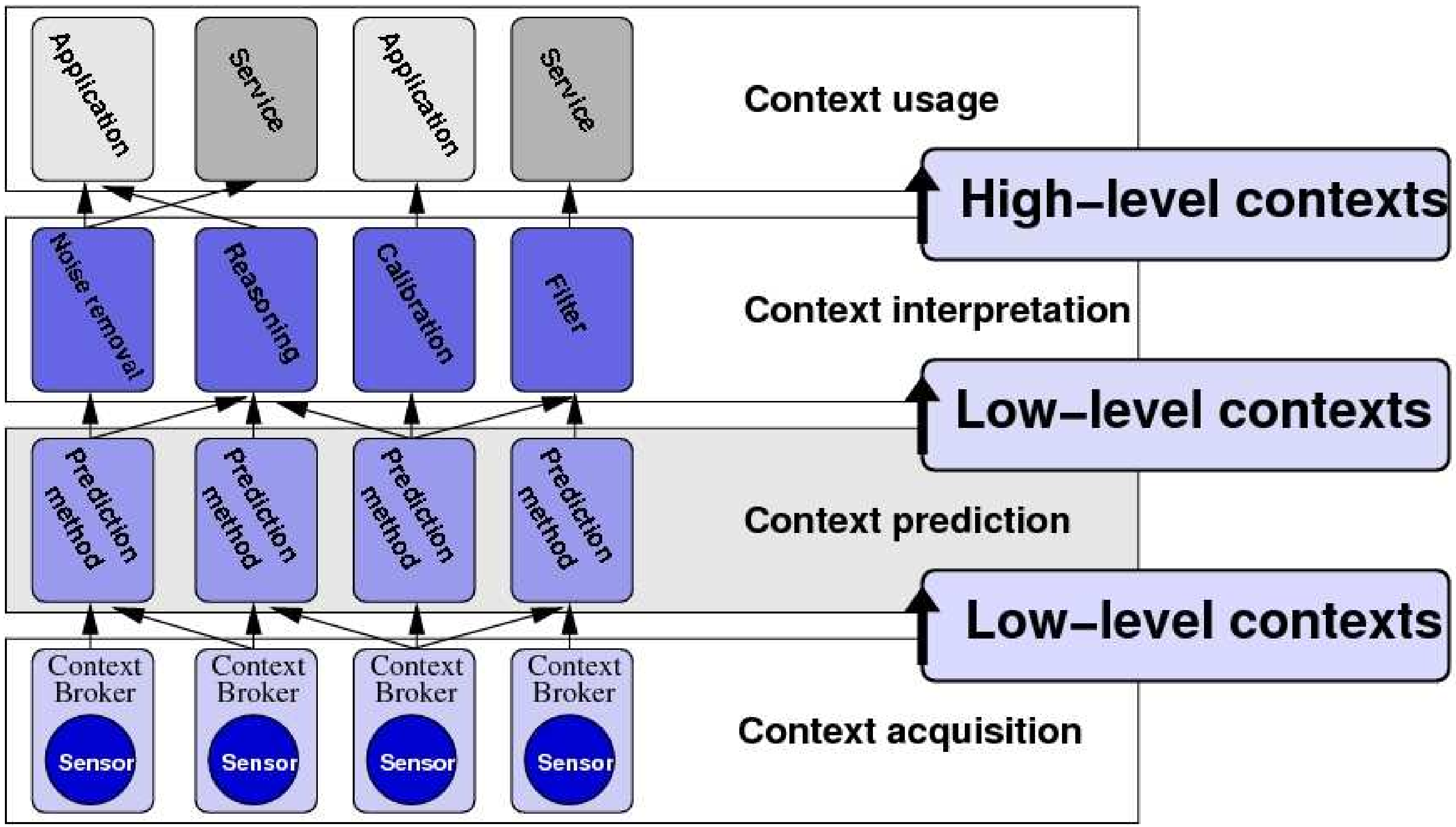


Literature:

[NMF05] Nurmi, P., Martin, M., Flanagan, J.A.,Enabling Proactiveness through context prediction,Workshop on Context Awareness for Proactive Systems, 2005.

Context prediction architectures

Context prediction architectures:



Context abstraction levels

Various context abstraction levels of context:

[ShTh94,Dey00]: Low level contexts and higher level contexts

- Low level: Data directly output from sensors
- Higher level: Further processed data

[Maen]: raw data, low level and high level

- Raw data: 24°C, 70% humidity
- Low level: conditions like ‚warm', ‚high humidity'
- High level: Activities like ‚having lunch'

Hard to evaluate for computers

- We distinguish between raw data, low level context, high level context based on amount of preprocessing applied.

At which abstraction level is context prediction to be applied?

Literature:

[ShTh94]	Shilit, B.N., Theimer, M.M., Disseminating active map information to mobile hosts, IEEE Network, 1994.
[Dey00]	Anind Kumar Dey, Providing architectural support for building context–aware applications, PhD-thesis, 2000.
[Maen03]	Mäntyjärvi, J., Sensor-based context recognition for mobile applications, PhD-thesis, 2003.

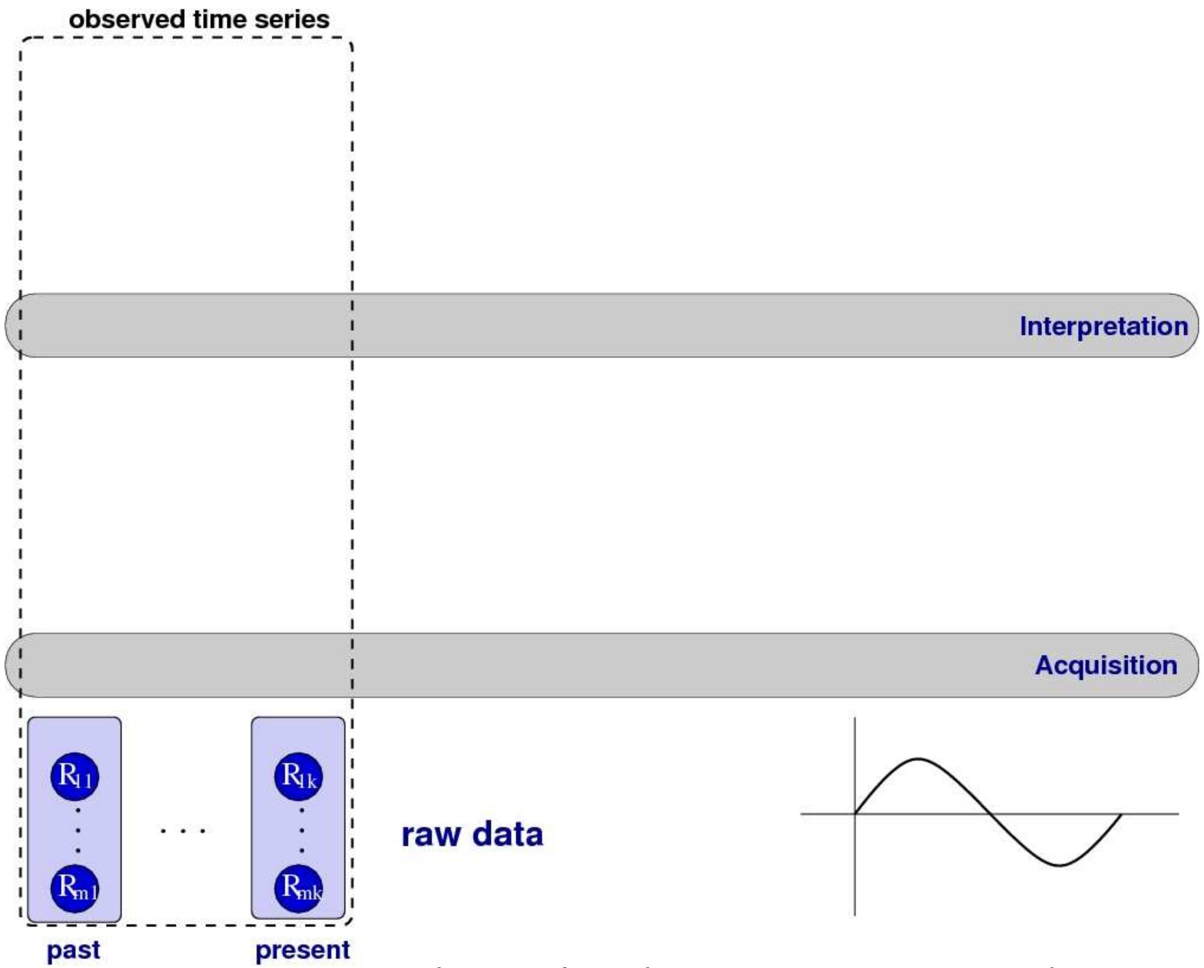
Context abstraction levels

Various context abstraction levels of context:

High-level context	Low-level context	Raw data	Context source
walking	14°C	001001111	thermometer
walking	57.2°F	001001111	thermometer
watching movie	64dB	109	microphone
listening music	64dB	109	microphone
at the beach	47° 25.5634'N; 007° 39.3538'E	GPRMC[8]	GPS sensor
swimming	47° 25.5634'N; 007° 39.3538'E	GPGGA[9]	GPS sensor
writing	z	0x79	keyboard [en]
writing	ы	0x79	keyboard [ru]
writing	z	0x7a	keyboard [de]
office occupied	z	0x7a	keyboard [de]

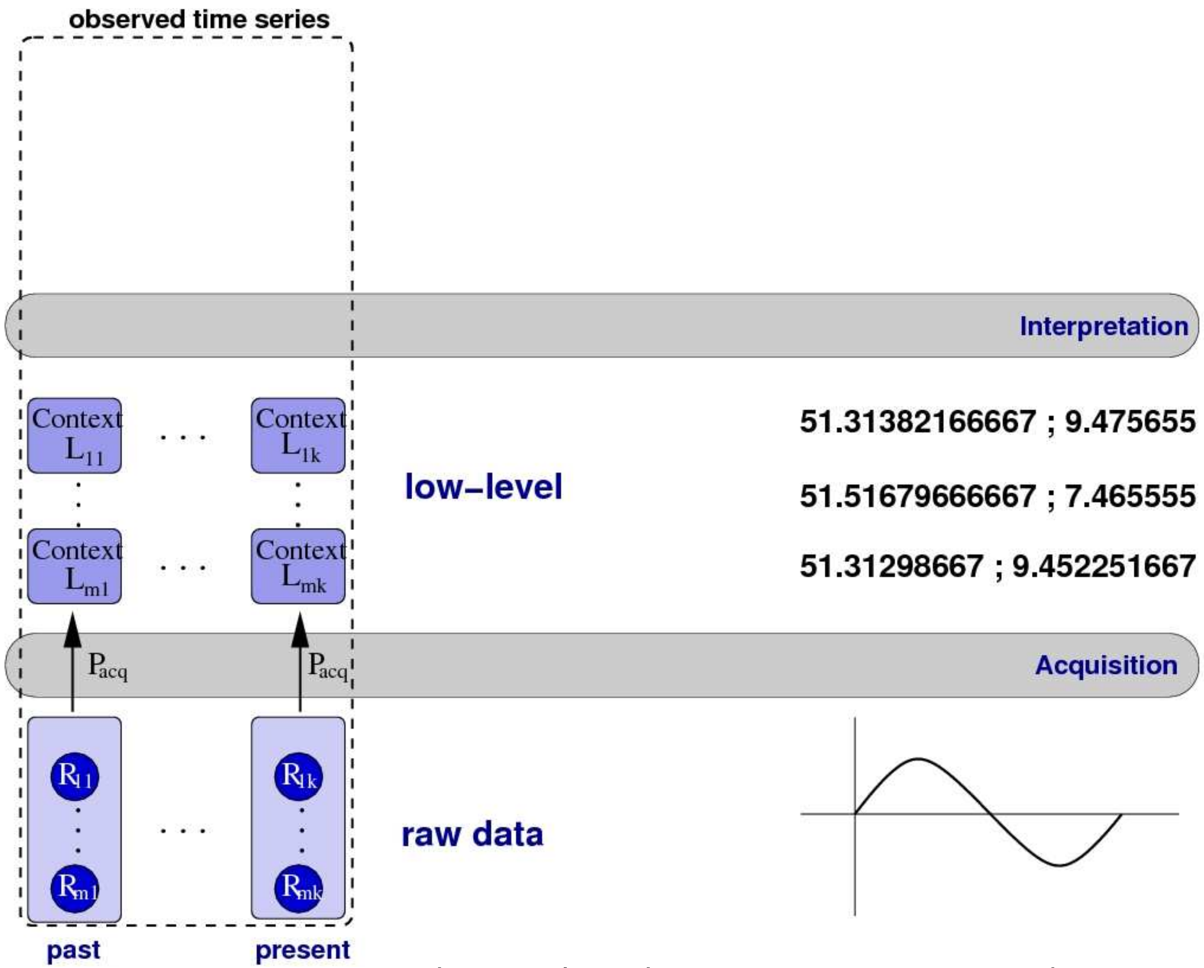
Context abstraction levels

High-level and low-level context prediction:



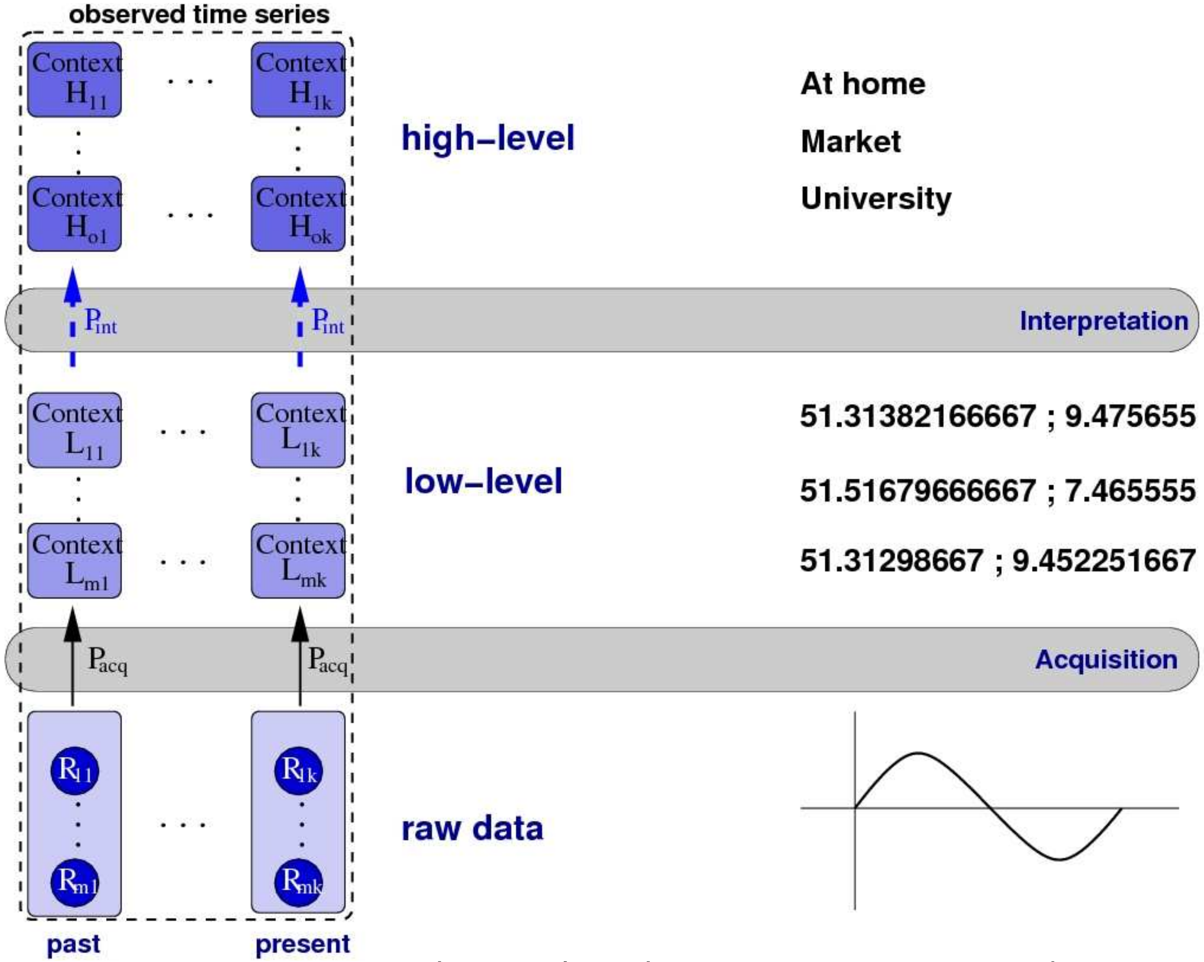
Context abstraction levels

High-level and low-level context prediction:



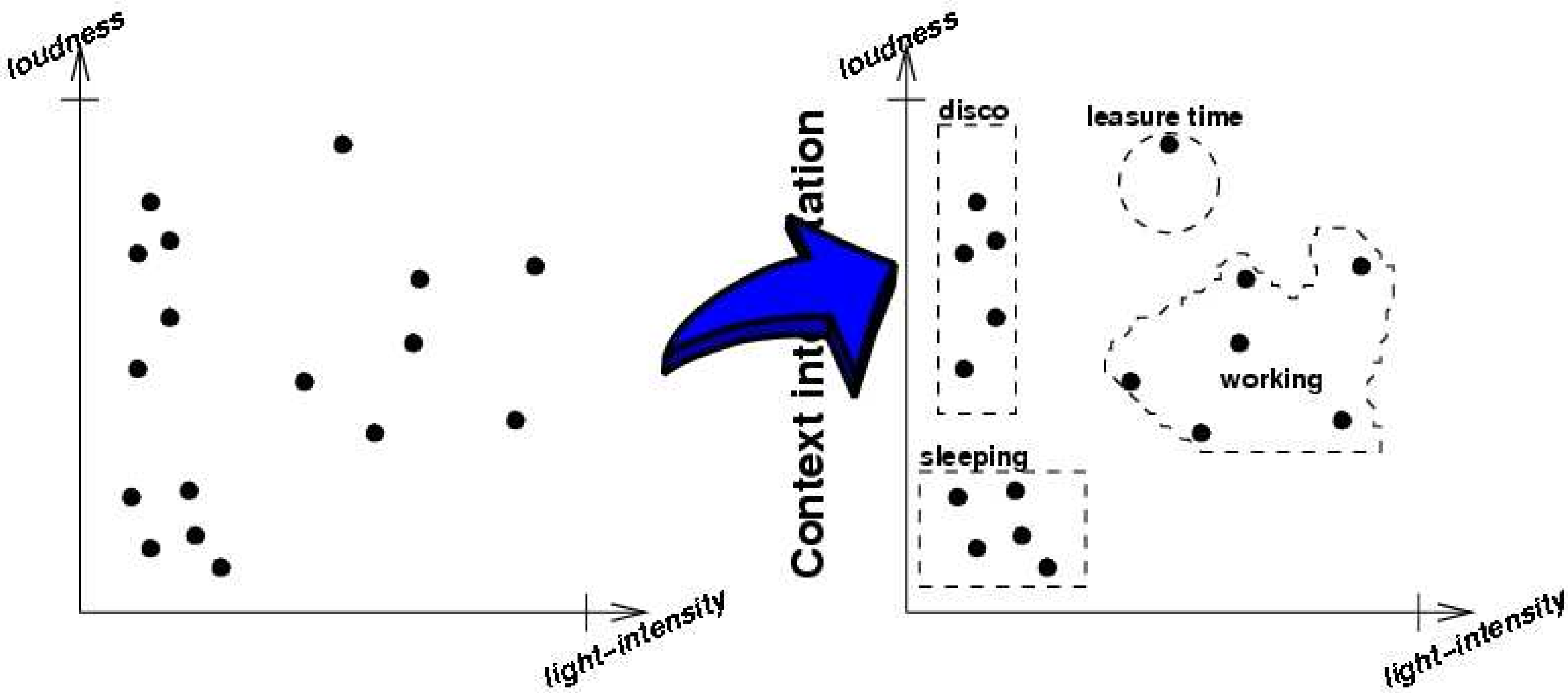
Context abstraction levels

High-level and low-level context prediction:



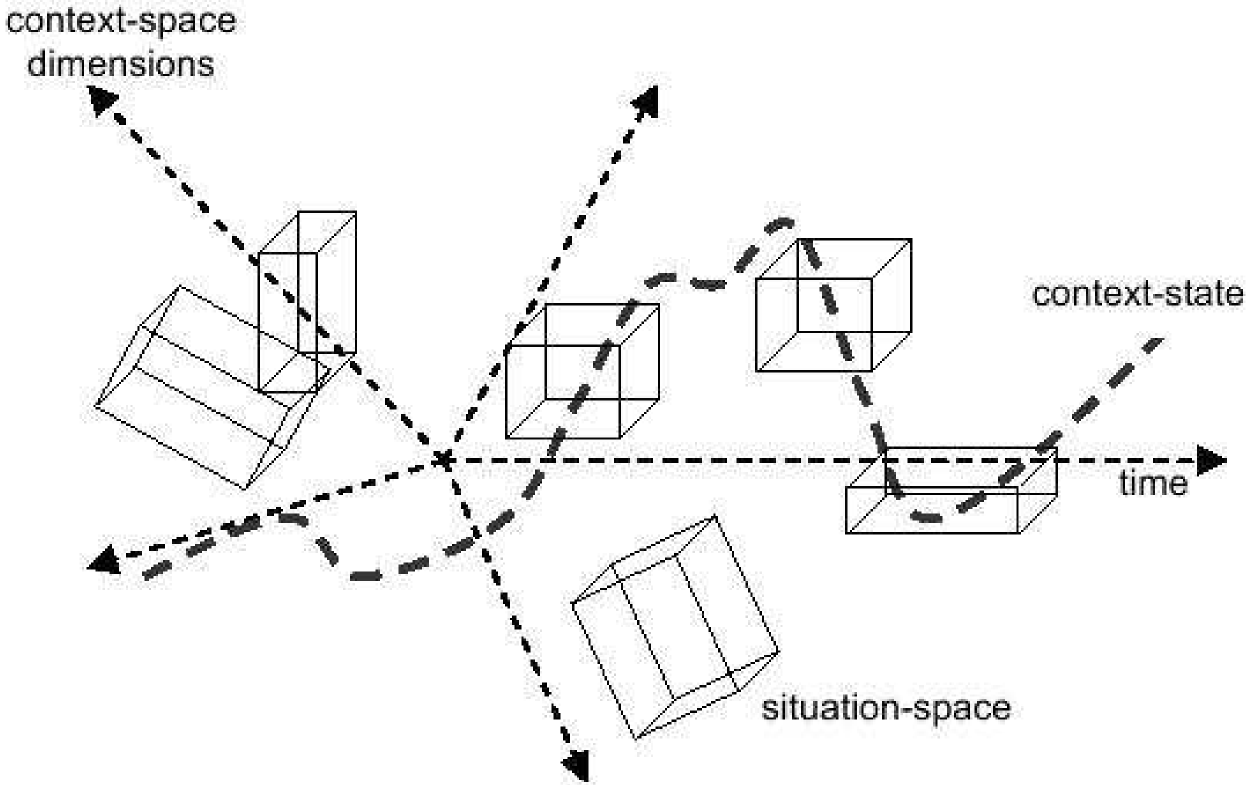
Context abstraction levels

Illustration of high-level and low-level contexts



Context abstraction levels

Illustration of high-level and low-level contexts

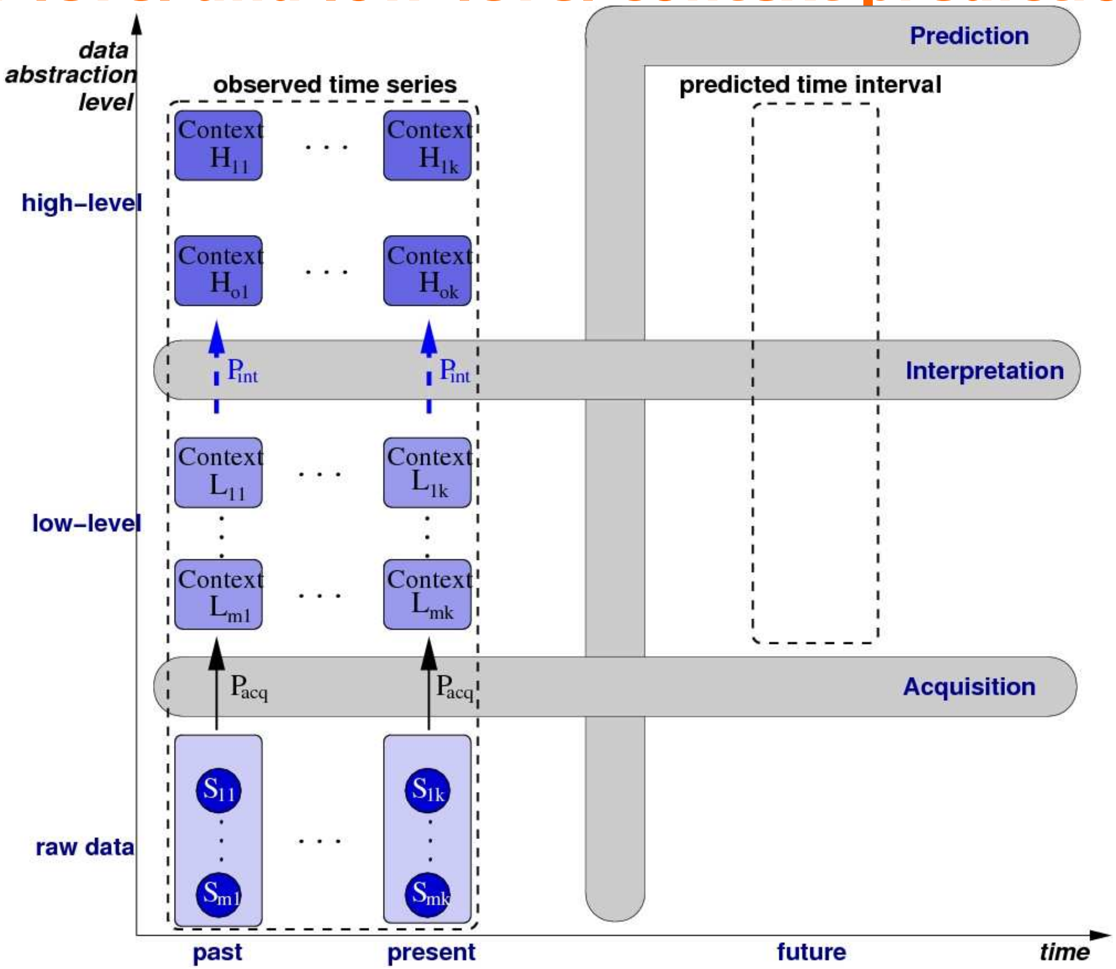


Literature:

[PBZL05] **Padovitz, A., Bartolini, C, Zaslavsky, Loke, S.W., Extending the Context Space Approach to Management by Business Objectives, 12th Workshop on HP OpenView University Association (HP-OVUA), 2005.**

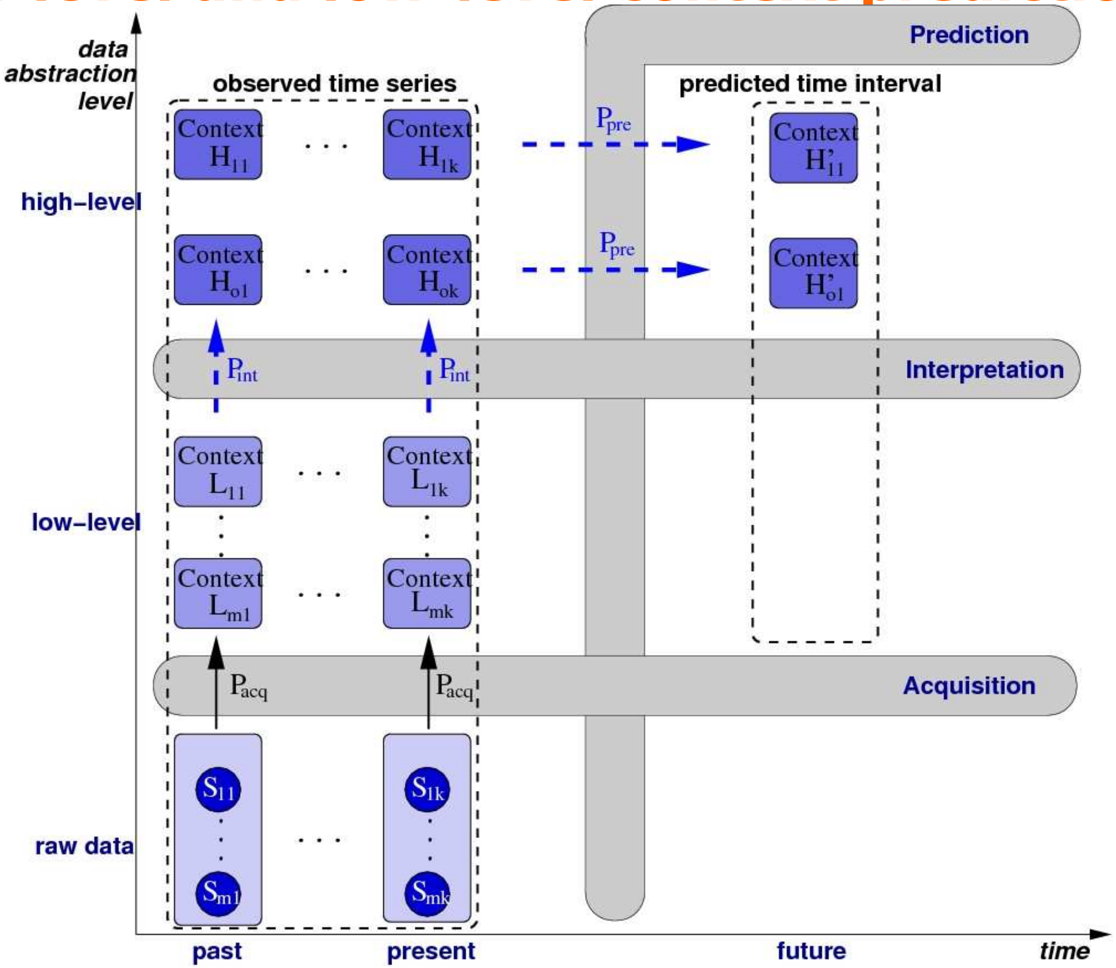
Implication of abstraction levels

High-level and low-level context prediction:



Implication of abstraction levels

High-level and low-level context prediction:



Implication of abstraction levels

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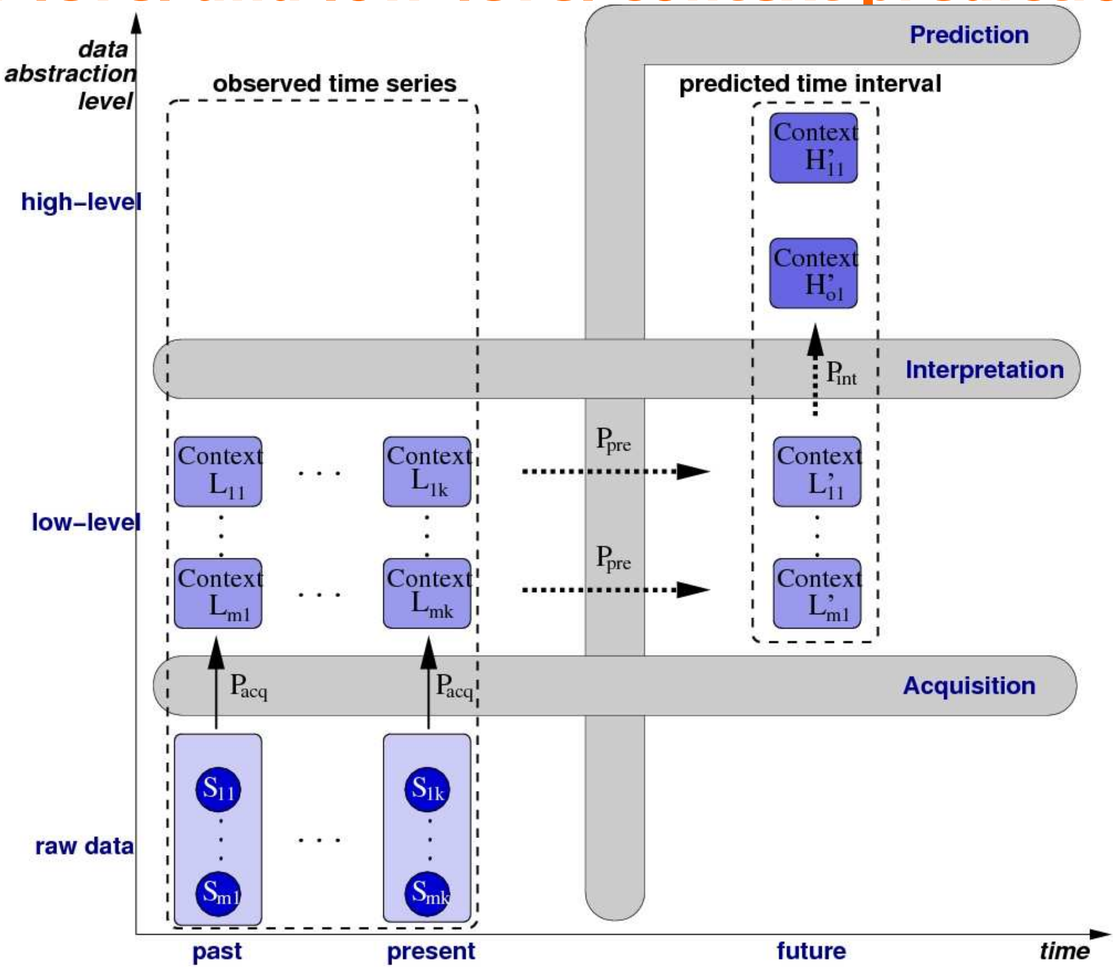
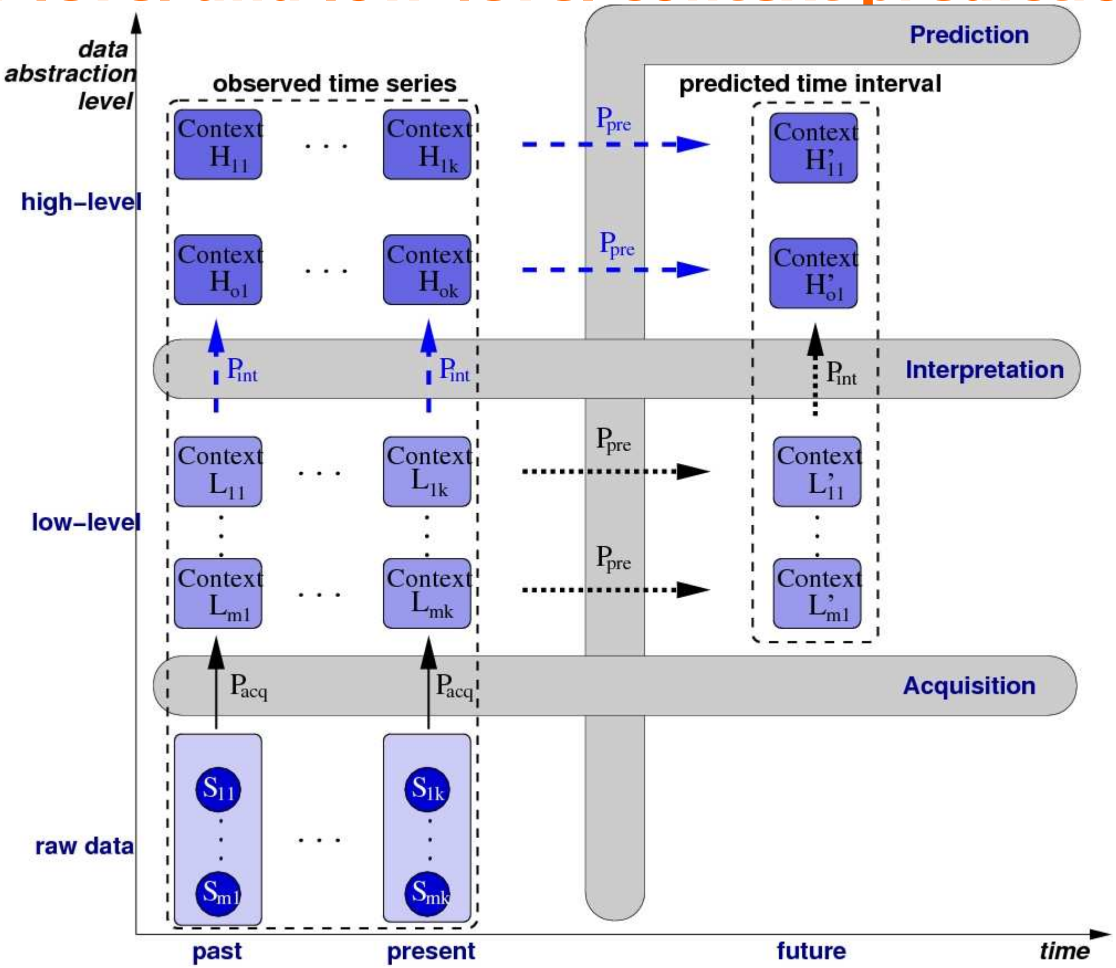


Implication of abstraction levels

High-level and low-level context prediction:

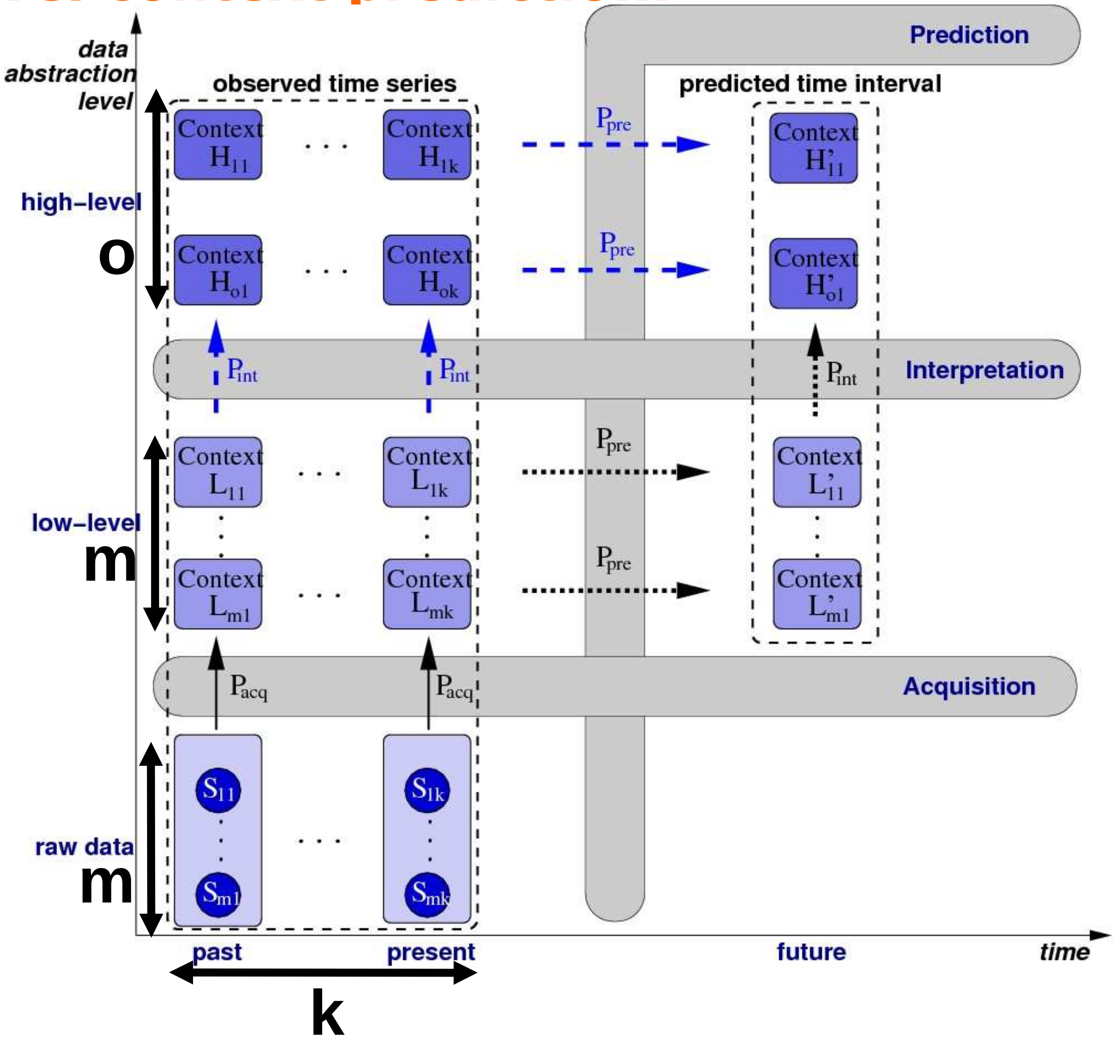


Implication of abstraction levels

High-level and low-level context prediction:

$$P_{acq}^{km} \cdot P_{int}^{ko} \cdot P_{pre}^{o}$$

$$P_{acq}^{km} \cdot P_{pre}^{m} \cdot P_{int}^{o}$$



k: # of input time intervals
m: context sources per interval
o: high-level contexts per interval
P_{acq}: Probability: No acquisition error
P_{pre}: Probability: No prediction error
P_{int}: Probability: No interpretation er