



THE UNIVERSITY OF
MELBOURNE

v1.0

Context-Aware Computing

Tilman Dingler

Mobile Computing | 27-Aug-2018

COMP90018 - Mobile Computing Systems Programming

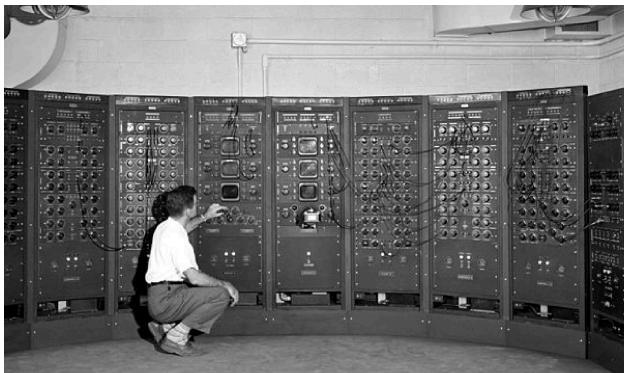
- outdoor / indoor usage
- running
- sitting in lectures
- swimming



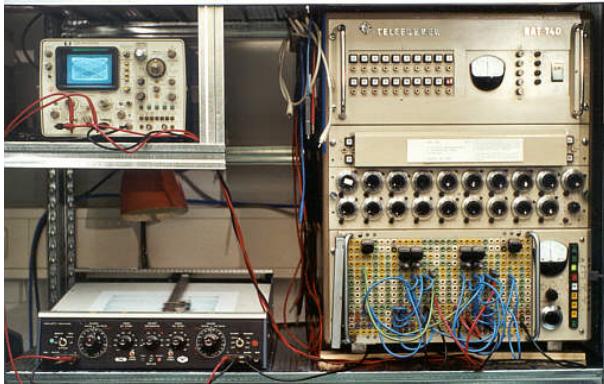
Designing a Watch Interface

1. Context-aware Computing: Definitions and History
2. Using Context in Applications and Interfaces
3. User Activity as Context Variable
4. User's Cognitive State as Context Variable

Learning Outcomes



Lewis Flight Propulsion Laboratory, 1949



Telefunken, 1960



Commodore PET, 1977

Context defined by the computer's location.



How does **context** influence mobile interfaces?

- In nature, having **perception and cognitive functions** are the foundation of **intelligent behaviour**.
- Acting and reacting with respect to the **current situation** is a basic property of most intelligent systems.



light sensor



Gyroscope



GPS

To Make Systems Intelligent they Need Perception

- ...to match the **current situation** requirements.
- **What can be changed?**
 - output, content, appearance, input, ...
- Large number of contexts
 - but selection of context is determined by perception.



brightness



layout



content / display

Context-Awareness Means Changing System Behaviour

Evolution of a Definition

*"Such context-aware software adapts according to the **location** of use, the collection of **nearby people, hosts, and accessible devices**, as well as to **changes to such things over time.**"*



Bill Schilit, 1994

Evolution of a Definition

*"**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**."*



Anind Dey, 2000

Enabling Ubiquitous Computing

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



Mark Weiser, 1991

The Computer for the 21st Century

Specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence

by Mark Weiser

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

is approachable only through complex jargon that has nothing to do with the tasks for which people use computers. The state of the art is perhaps analogous to the period when scribes had to

The idea of integrating computers seamlessly into the world at large runs counter to a number of present-day trends. "Ubiquitous computing" in this context does not mean just computers

The Computer of the 21st Century



|



Google Search

I'm Feeling Lucky

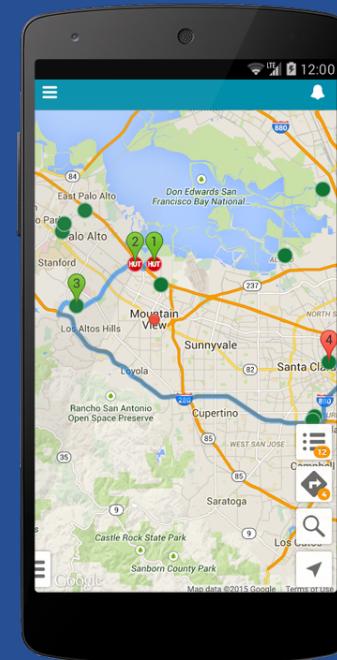
Is this a Context-Aware Interface?



Context in Applications and User Interfaces

Context-Aware User Interfaces

- linking **services and information** to context
 - **low level** functionality: selecting the most appropriate network protocol for communication
 - **high level**: changes of zoom level based on speed



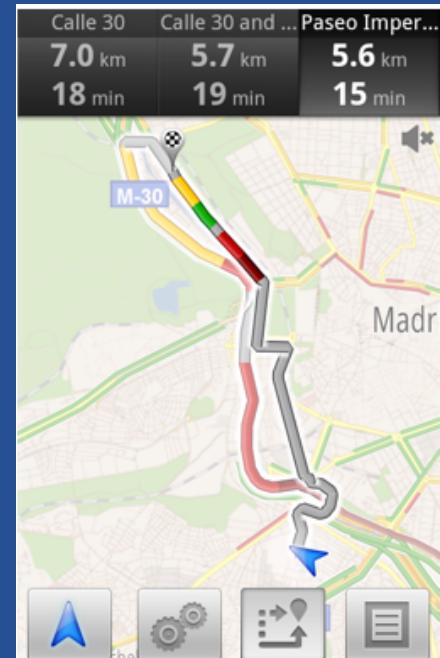
Context-Adaptive Systems

- **Proactive applications** take initiative on behalf of the user, e.g.,
 - a heating system that pro-actively starts heating the house when the context “user on her way home” is detected.
 - a phone that adjusts the ringer profile based on the context “user in a meeting”.



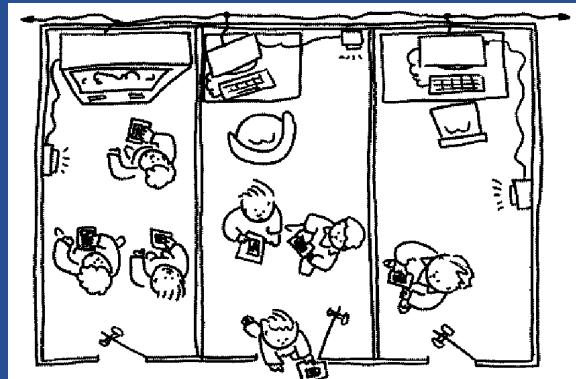
Implicitly Collected Context Data

- can help with later retrieval of information (metadata for **tagging**)
 - e.g., GPS coordinates and timestamps of captured images
- **sharing** implicitly collected data
 - e.g., real-time traffic information based on user data (time, location, speed)



Context-Aware Resource Management

- Using **resources** in the salient environment
 - e.g., list of printers nearby
- Choose available network protocol to save battery life (GSM vs. WIFI)
- Balance between **visibility and transparency**



| Name | Room | Distance |
|-----------|---------|----------|
| caps | 35-2200 | 200ft |
| claudia | 35-2108 | 30ft |
| perfector | 35-2301 | 20ft |
| snoball | 35-2103 | 100ft |

Schilit, 1994

Context-Adaptive Controls

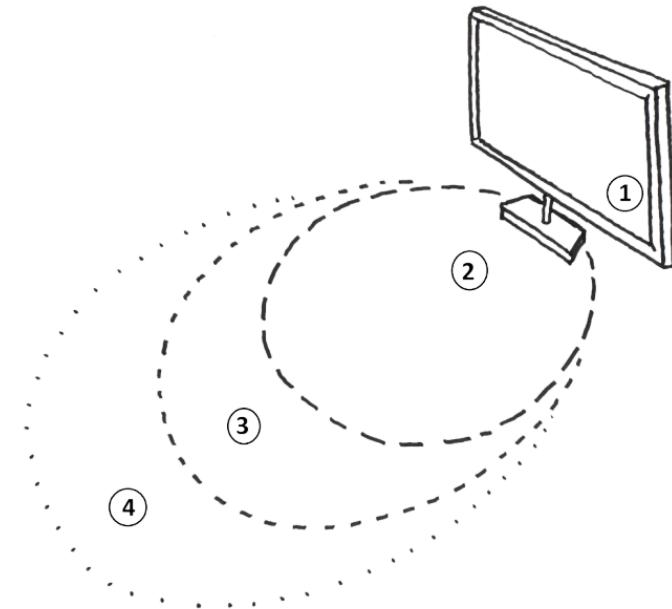


Figure 2: Four spatial zones to provide seamless gesture interaction:
1) Touch area, 2) fine-grained gesture area, 3) general gesture area and
4) coarse gesture area.

Tilman Dingler, Markus Funk, and Florian Alt. **Interaction Proxemics:** Combining Physical Spaces for Seamless Gesture Interaction, PerDis'15.

Managing Interruptions

- based on **sensed context**
 - delay notifications when user is focused
 - “bounded deferral” (*Horvitz, '05*)
- based on **shared context** in communication

| | | |
|---|----------------------------|--|
|  | Thomas Heinze |   Online |
|  | ugur kostak |   Online |
|  | Xavier Anguera |   Impossible is plausile |
|  | Ahmed Fituri (USF) |   Away |
|  | Albrecht Schmidt |   travelling |
|  | Alexander Puschiolov (...) |   Making healthcare acc... |
|  | André Bachofner (Des...) |   Away |
|  | Andrew Crossan |   Away |

Affective Computing

- based on **sensed emotion / affect**
 - e.g., rearrange contact list
 - ground truth collection
- share **affect** in communication
- sensing **stress**
 - **What could we possibly use stress levels for?**



A Tutorial on Human Activity Recognition Using Body-Worn Inertial Sensors

ANDREAS BULLING, Max Planck Institute for Informatics, Germany

ULF BLANKE, Swiss Federal Institute of Technology (ETH) Zurich, Switzerland

BERNT SCHIELE, Max Planck Institute for Informatics, Germany

The last 20 years have seen ever-increasing research activity in the field of human activity recognition. With activity recognition having considerably matured, so has the number of challenges in designing, implementing, and evaluating activity recognition systems. This tutorial aims to provide a comprehensive hands-on introduction for newcomers to the field of human activity recognition. It specifically focuses on activity recognition using on-body inertial sensors. We first discuss the key research challenges that human activity recognition shares with general pattern recognition and identify those challenges that are specific to human activity recognition. We then describe the concept of an Activity Recognition Chain (ARC) as a general-purpose framework for designing and evaluating activity recognition systems. We detail each component of the framework, provide references to related research, and introduce the best practice methods developed by the activity recognition research community. We conclude with the educational example problem of recognizing different hand gestures from inertial sensors attached to the upper and lower arm. We illustrate how each component of this framework can be implemented for this specific activity recognition problem and demonstrate how different implementations compare and how they impact overall recognition performance.

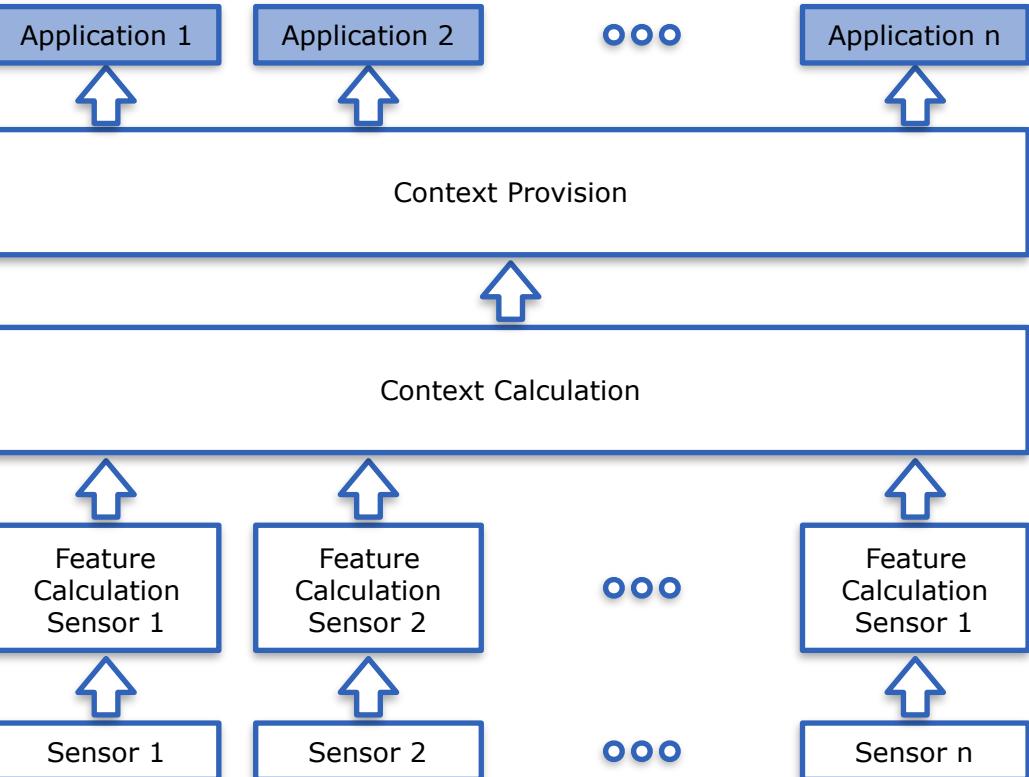
Categories and Subject Descriptors: C.3 [**Special-Purpose and Application-Based Systems**]: Real-Time and Embedded Systems; C.3 [**Special-Purpose and Application-Based Systems**]: Signal Processing Systems; I.5.2 [**Pattern Recognition**]: Design Methodology; I.5.4 [**Pattern Recognition**]: Applications; I.5.5 [**Pattern Recognition**]: Implementation

Reading Tip

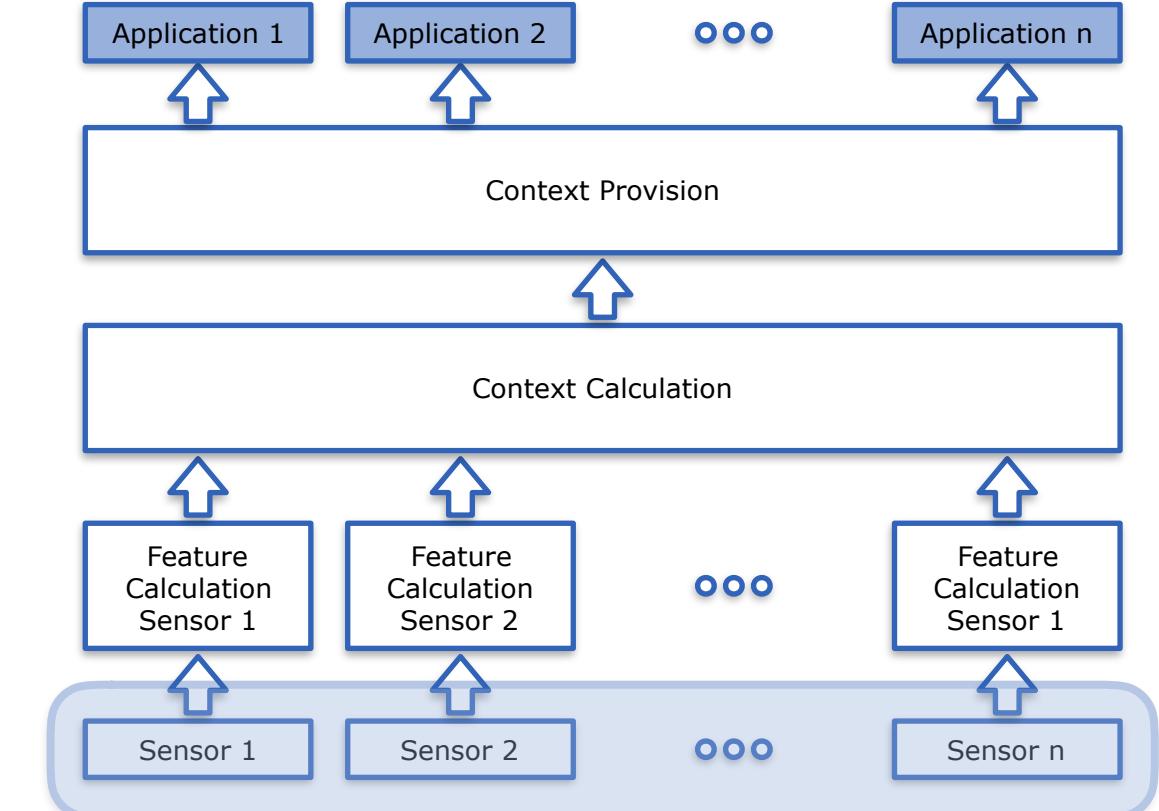
Characteristics of an Human Activity Recognition (HAR) System

- Execution
 - Online vs. offline
- Generalisation
 - User-independent, user-specific, temporal
- Recognition
 - Continuous vs. segmented
- Activities
 - Periodic, sporadic, static
- System model
 - Stateless vs. stateful

Reference Architecture for Context-Aware Computing Systems



Reference Architecture for Context-Aware Computing Systems



From Sensors to Context



- Battery Status
- Screen Events
- Phone Events
- Data Activity
- Ringer Mode
- Notifications
- Proximity
- Location
- SMS
-



Walking
Sitting
Indoors
Outdoors
In company
Alone
Daytime
Nighttime
Busy
Free
...



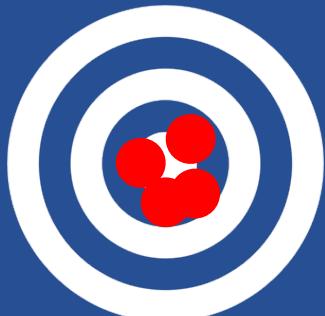
App info

- Your personal information
read contact data, write contact data
- Services that cost you money
send SMS messages
- Your messages
edit SMS or MMS, read SMS or MMS,
receive SMS
- Your location
fine (GPS) location
- Network communication
full Internet access
- Your accounts
act as an account authenticator,
manage the accounts list
- Storage
modify/delete USB storage contents
- Phone calls
read phone state and identity
- System tools
prevent phone from sleeping, write sync
settings

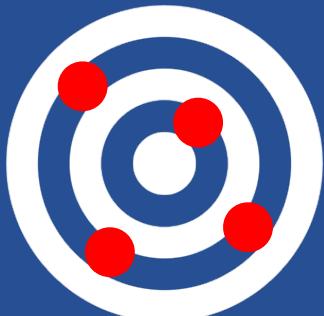
- Access easily granted
- Meaning of permissions often not clear
- Are all applications verified?

Are privacy settings effective?

Choosing a Sensor



*High Accuracy
High Precision*



*High Accuracy
Low Precision*

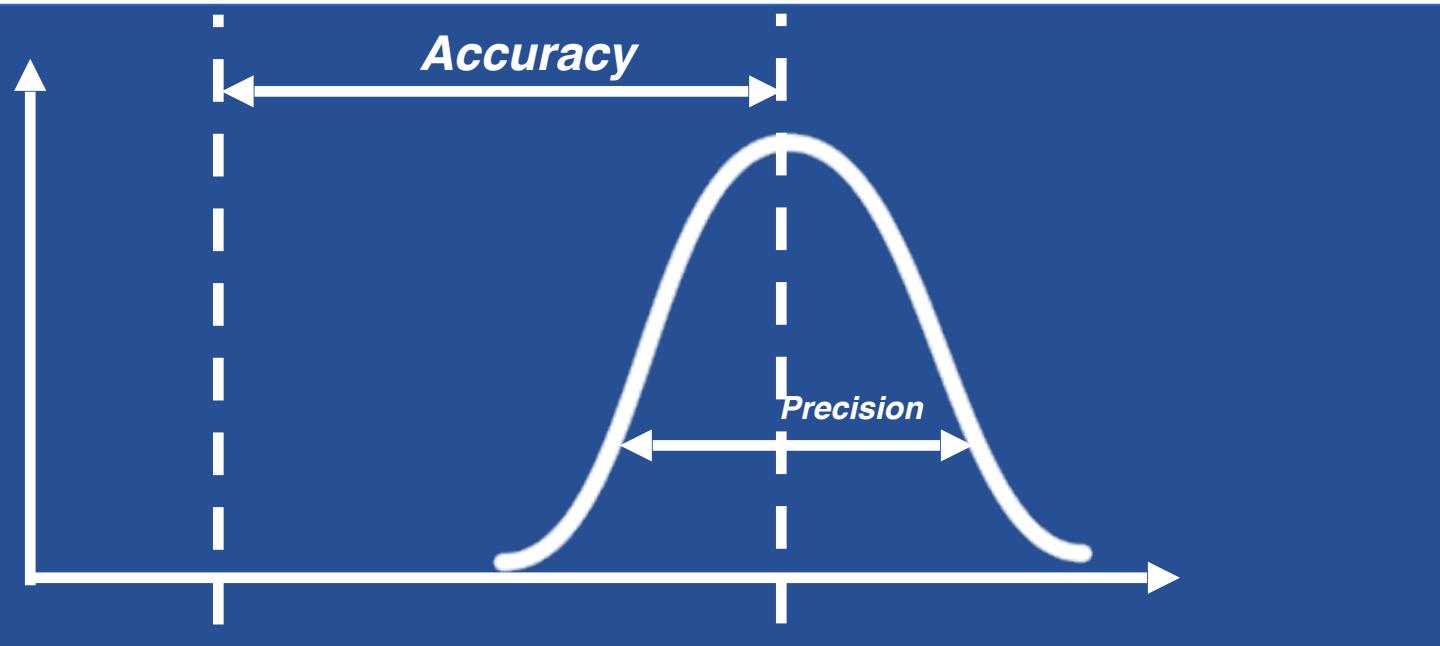


*Low Accuracy
High Precision*



*Low Accuracy
Low Precision*

Choosing a Sensor



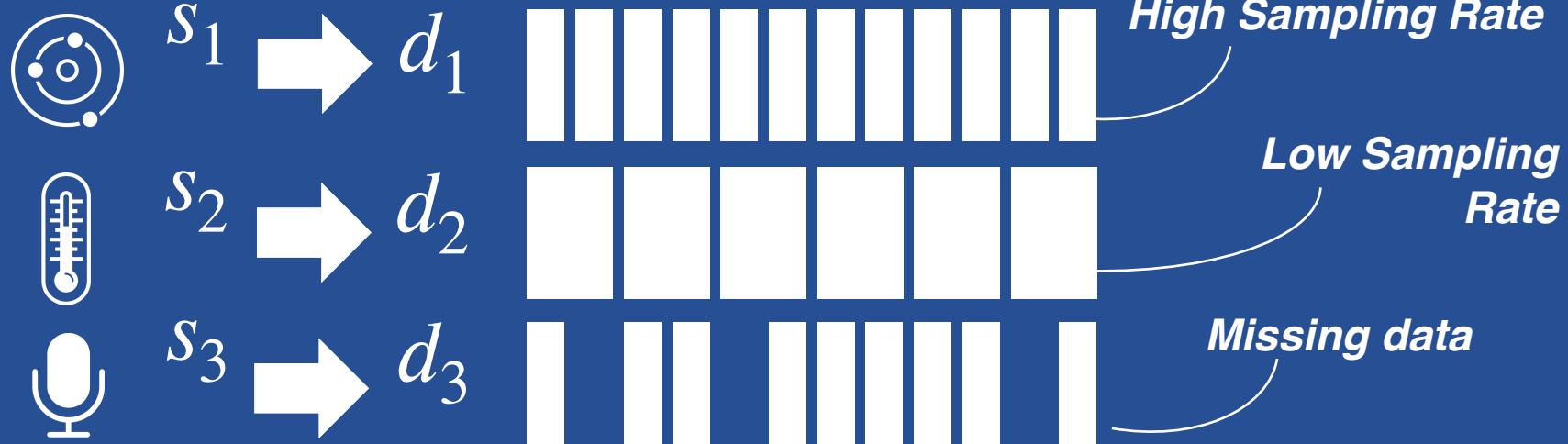
True value

Choosing a sensor

- Accuracy / Precision
- Operating range
 - E.g. pressure sensor of 100g-10kg
- Resolution or sensitivity
 - E.g., thermal sensitivity of 40mK
- Costs
- Energy requirements
- Lifespan

Raw Sensor Data

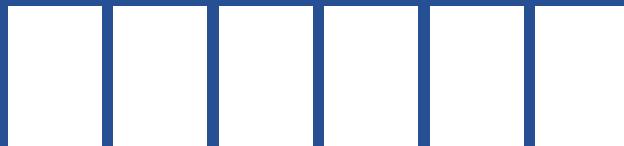
$$D = (d_1 \dots d_n)^T$$



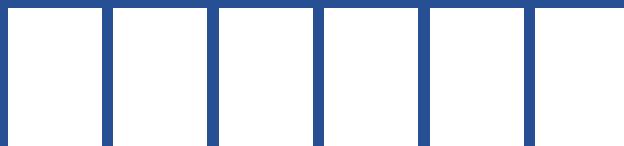
Preprocessing

$$D' = (d'_1 \dots d'_n)^T$$

$s_1 \rightarrow d'_1$



$s_2 \rightarrow d'_2$



$s_3 \rightarrow d'_3$



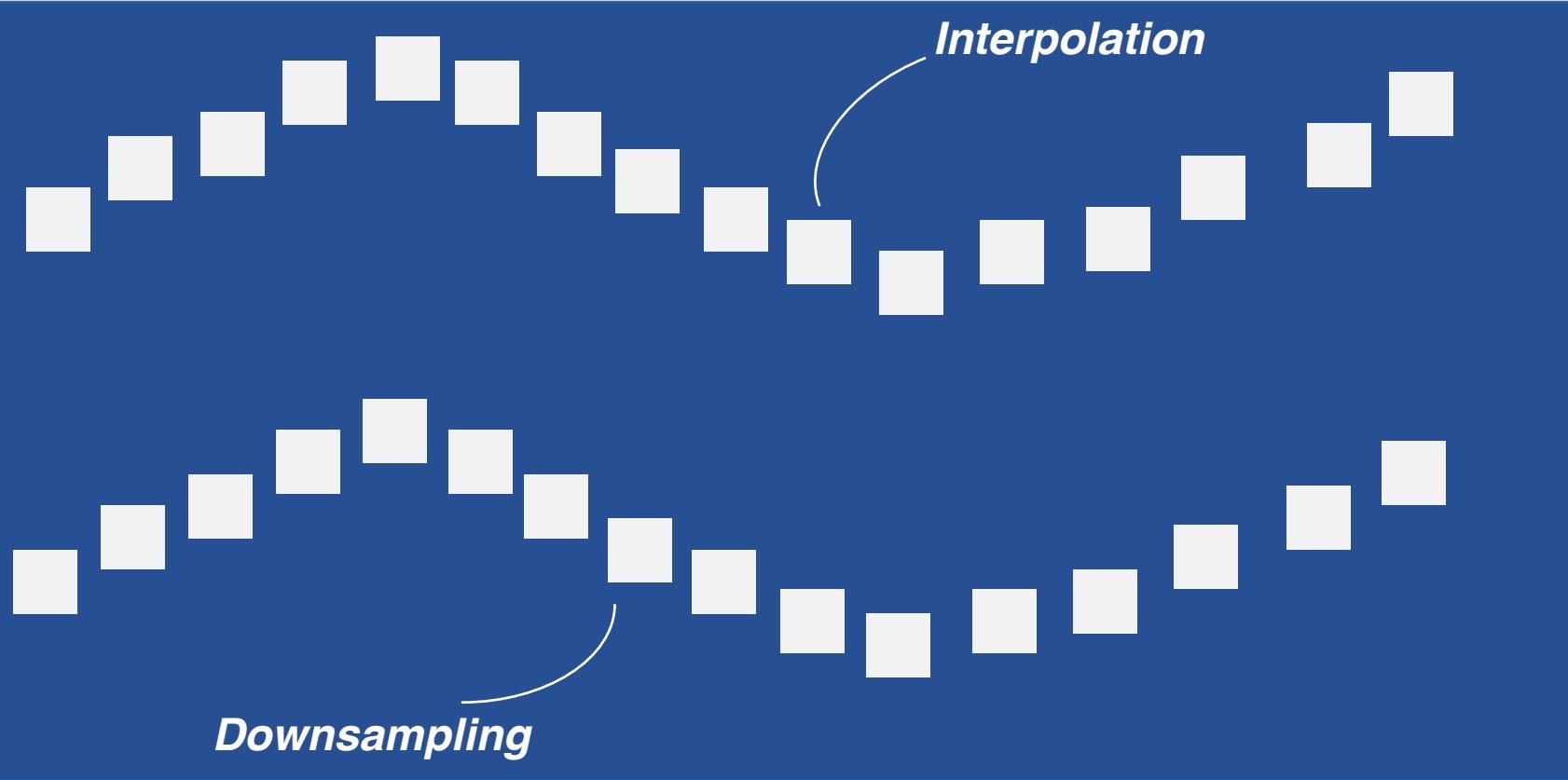
Preprocessing

$$D' = \begin{pmatrix} d'^1_1 & \cdots & d'^t_1 \\ \vdots & \ddots & \vdots \\ d'^1_n & \cdots & d'^t_n \end{pmatrix}$$

Time →

↓ *Data Streams*

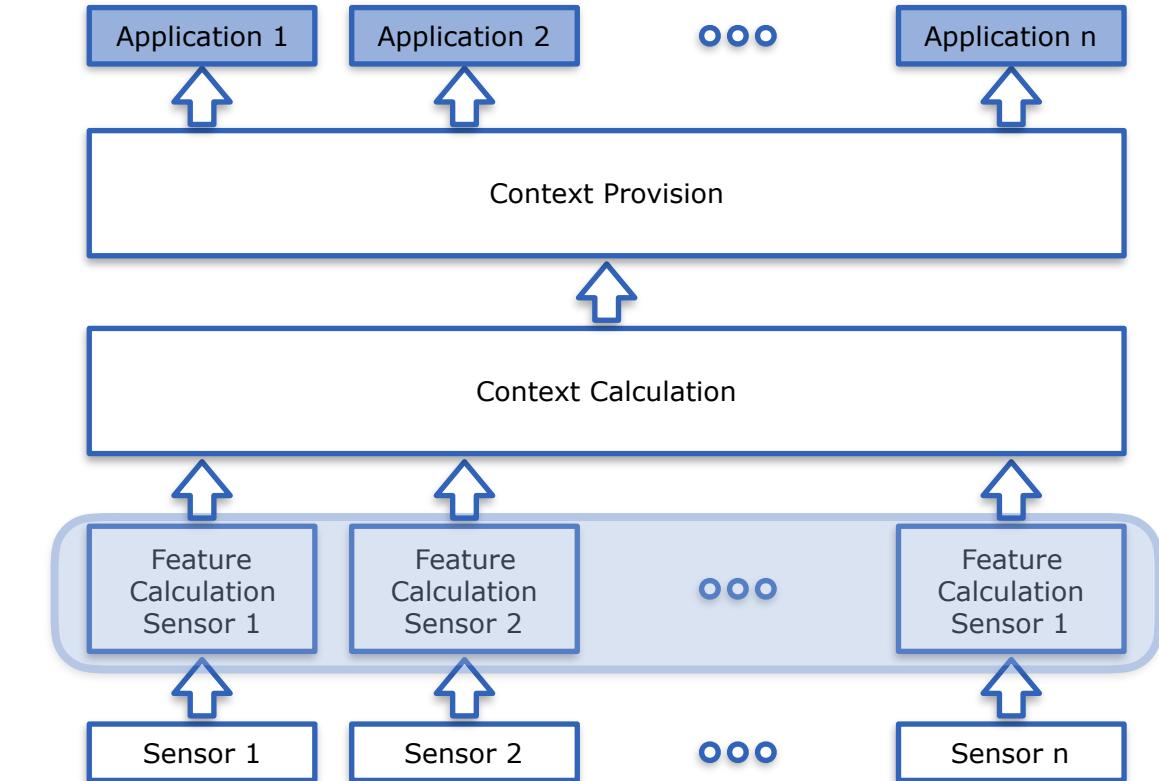
Preprocessing



Segmentation

- Sliding window
 - Non-overlapping vs. overlapping
- Energy based
 - E.g., using thresholds
- Additional context sources
 - Using additional sensors

Reference Architecture for Context-Aware Computing Systems

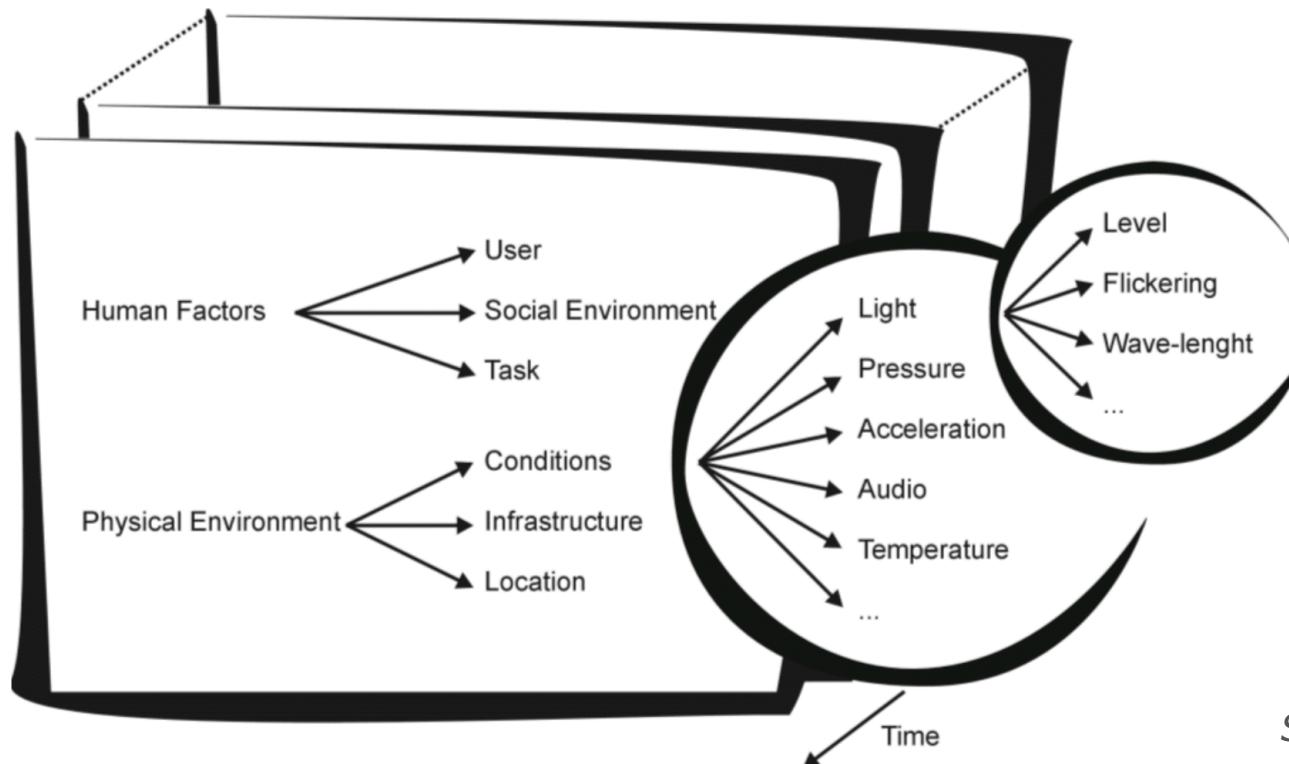


Context Engineering

- A context describes a situation and the environment, a device or user is in.
- A context is identified by a **unique name** / concept.
- For each context a **set of features** is relevant.

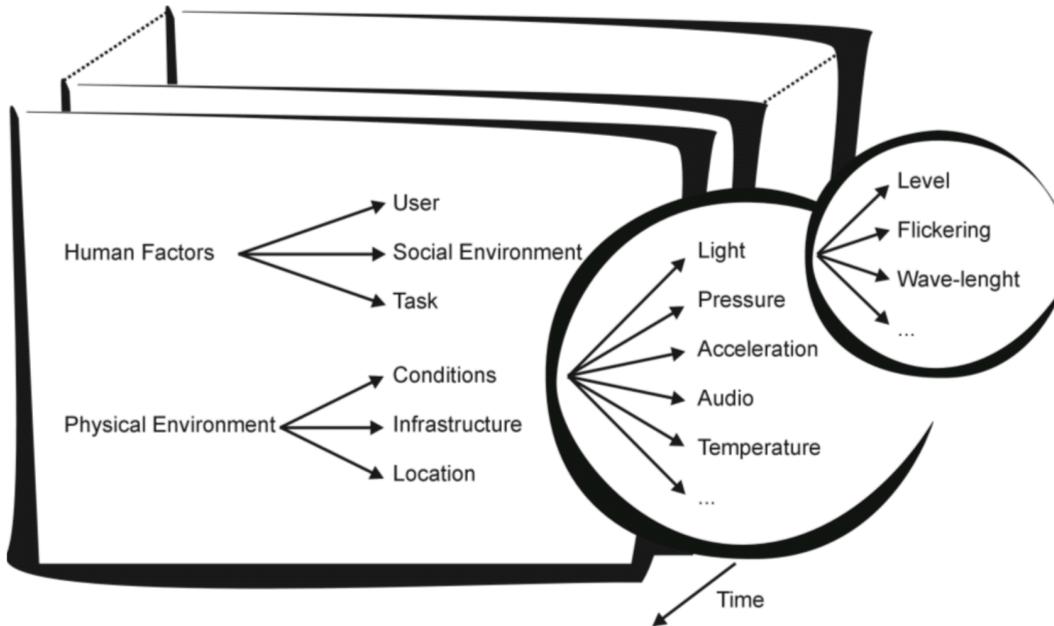
Context: at home?

Context Feature Space



Schmidt et al., 1999

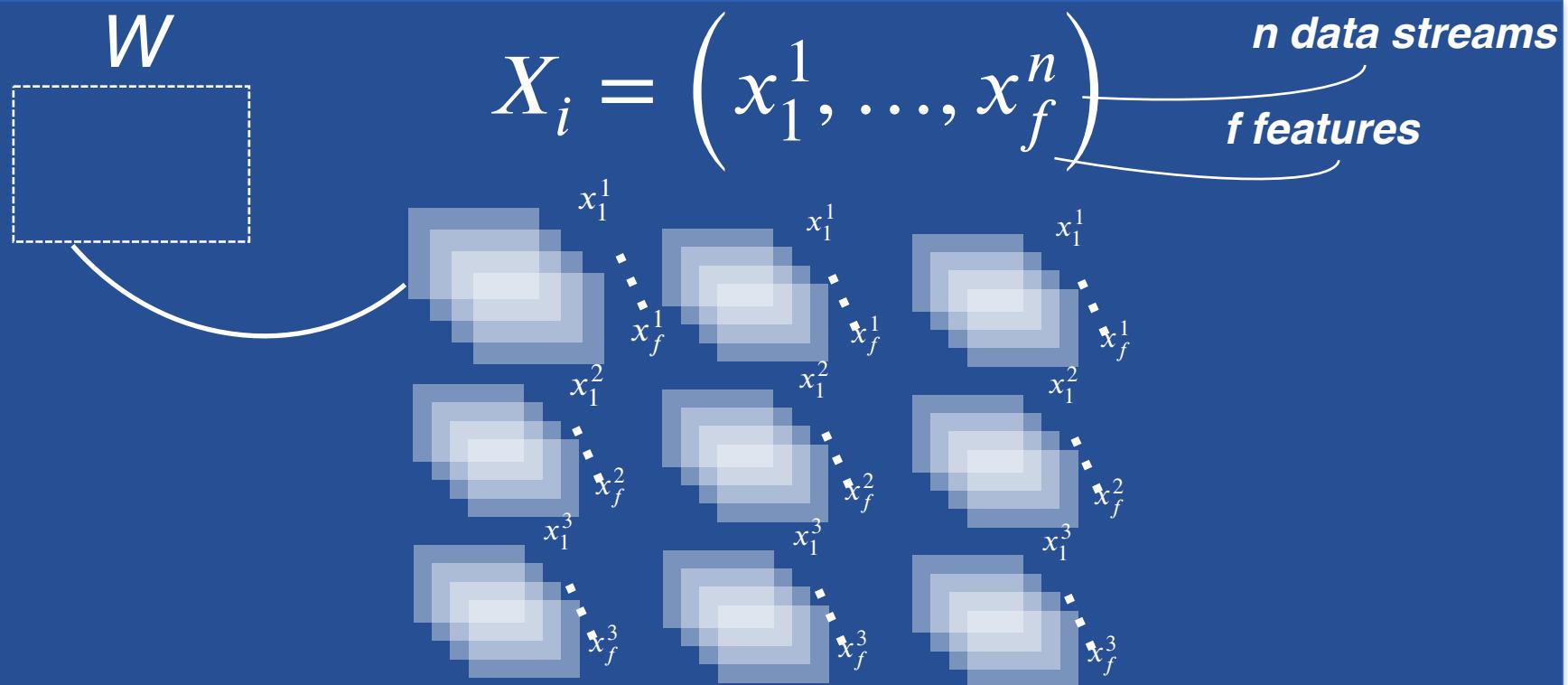
Context Feature Space



src.: <https://www.tomtom.com>

Schmidt et al., 1999

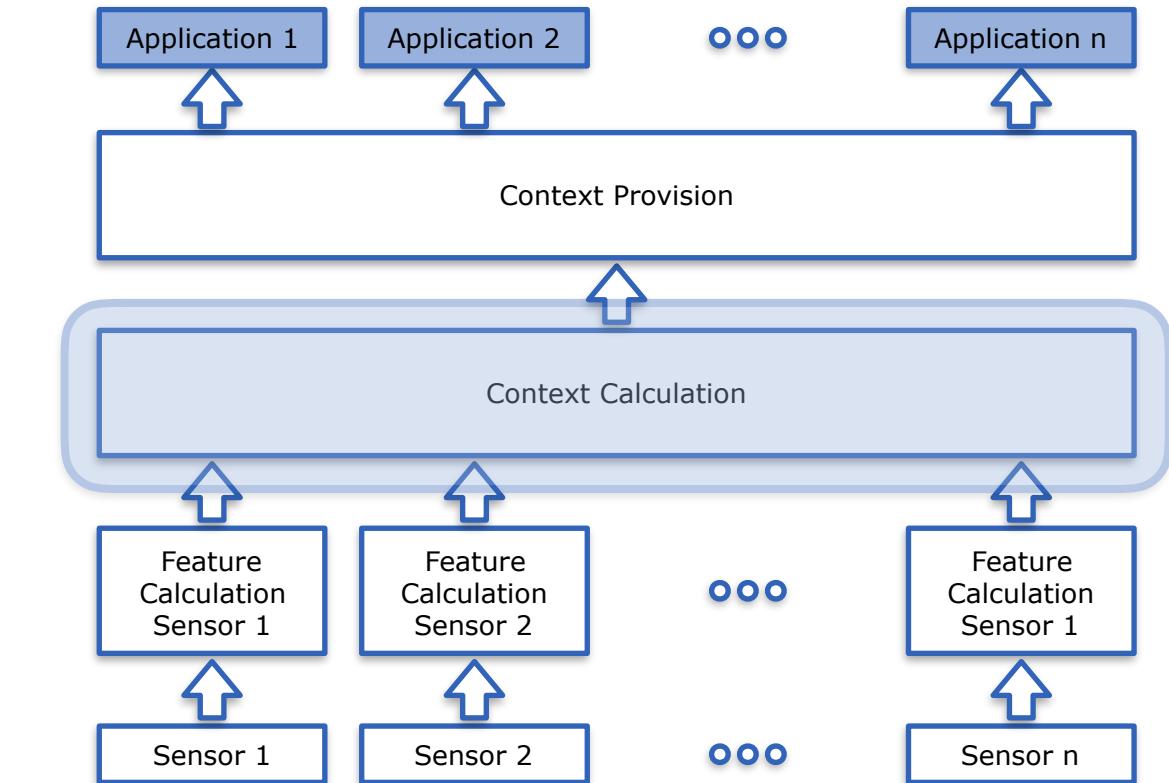
Feature Extraction



Features

- Min / Max
- Skewness
- Mean
- Energy
- Kurtosis
- Variance
- Range
- ...

Reference Architecture for Context-Aware Computing Systems



Classification

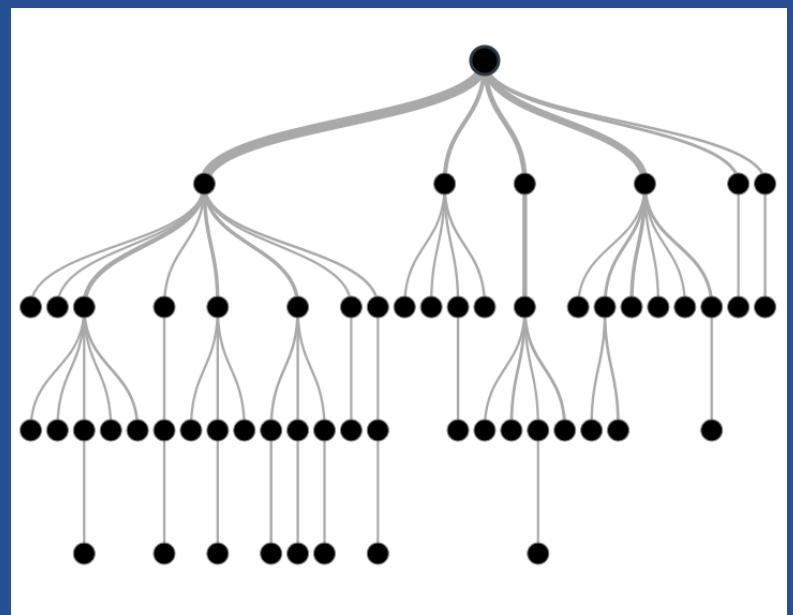
Activity $P_i(y | X_i, \theta)$ *Model parameters*
For each segment *Feature set*

$$P_1(\text{swimming} | X_1, \theta) \quad P_1(\text{sitting} | X_1, \theta) \quad P_1(\text{running} | X_1, \theta)$$



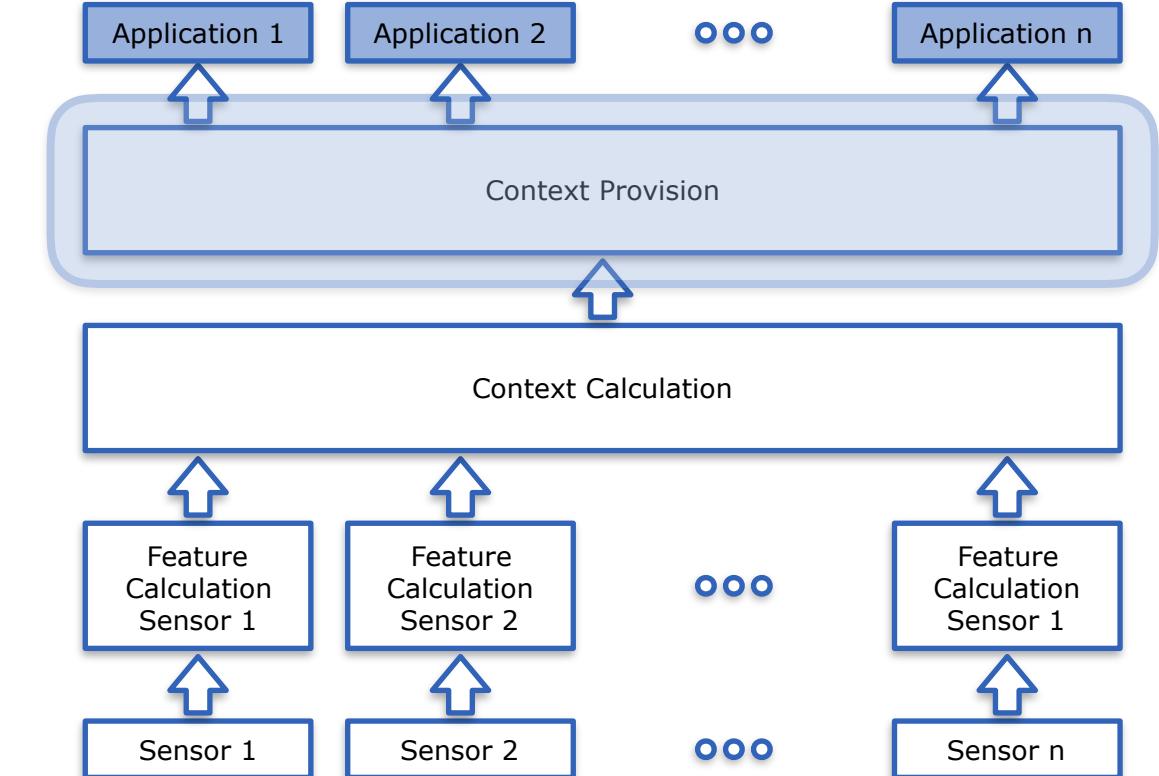
Context Determination

- Rule-based classifiers
- Nearest neighbour matching
- Probabilistic classifiers
- Machine-learning techniques
 - Decision trees, random forests
 - Neural networks



src: <https://www.analyticsvidhya.com>

Reference Architecture for Context-Aware Computing Systems

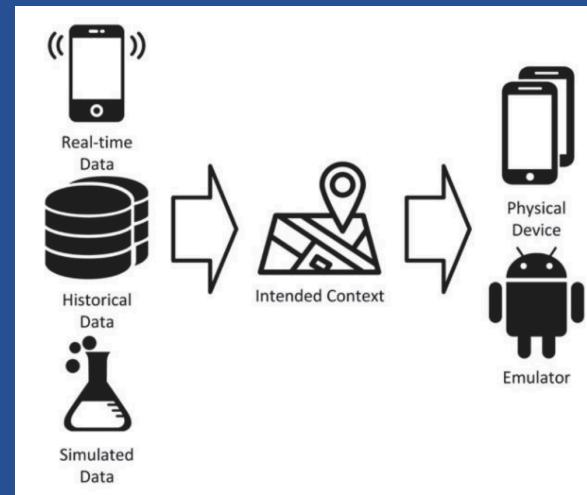


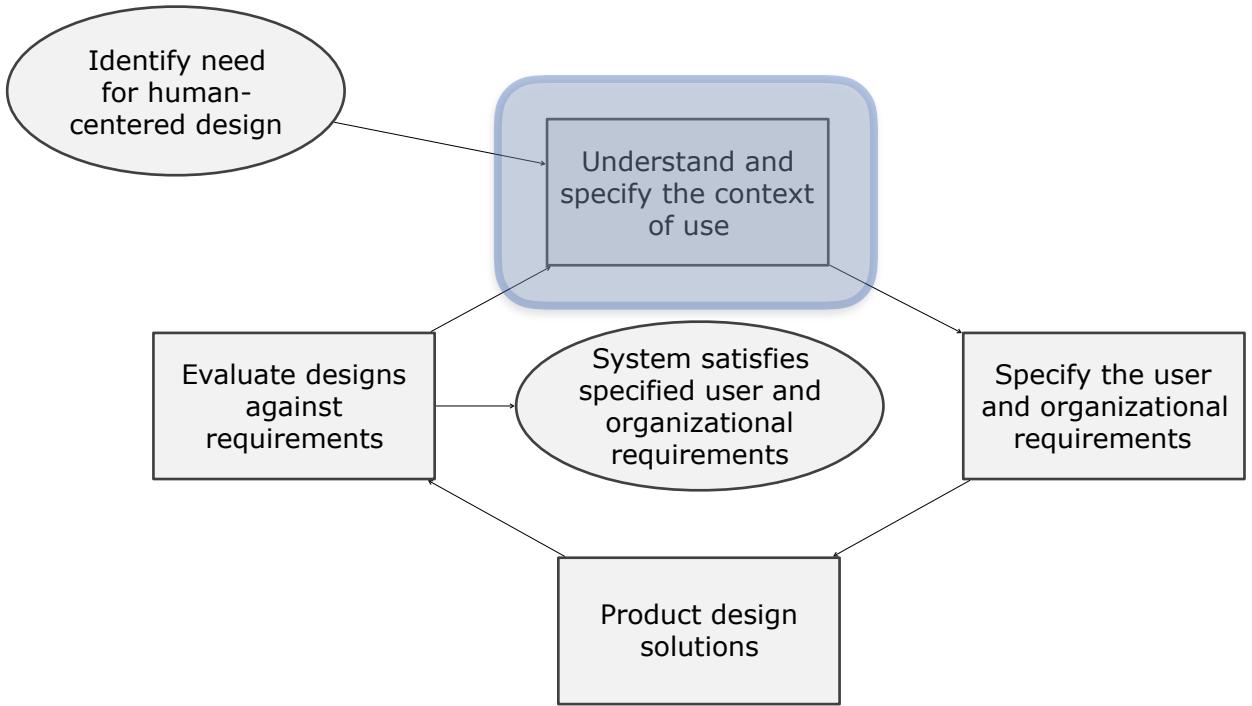


Tools for Building Context-Aware Systems

Building Context-Aware Systems

- The (conceptual) Context Toolkit by Dey, 2001
<http://www.cs.cmu.edu/~anind/context.html>
- The AWARE Framework by Ferreira et al., 2015
<http://www.awareframework.com/>
- The TestAWARE framework by Luo et al, 2017

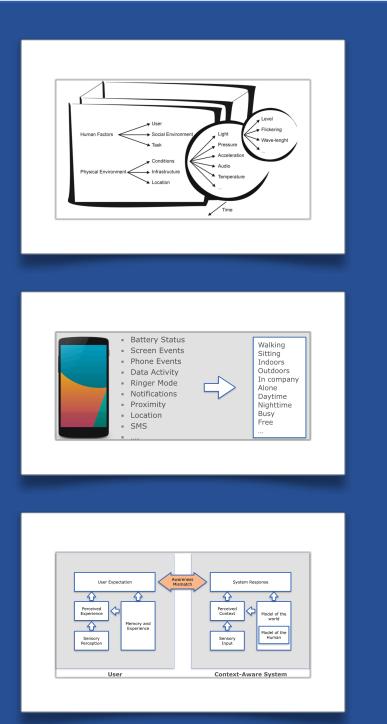




ISO 9241-210: Human-Centered Design Lifecycle

Guidelines for Application Designers

1. First, create a (hierarchical) **feature space** listing factors that will influence the system behavior.
2. Find **parameters** that are **characteristic** for the context to be detected and find means of measurement.
3. Determine **degree of proactiveness**.
4. **Provide information** about the sensor information used for deriving context to minimize the *awareness mismatch*.



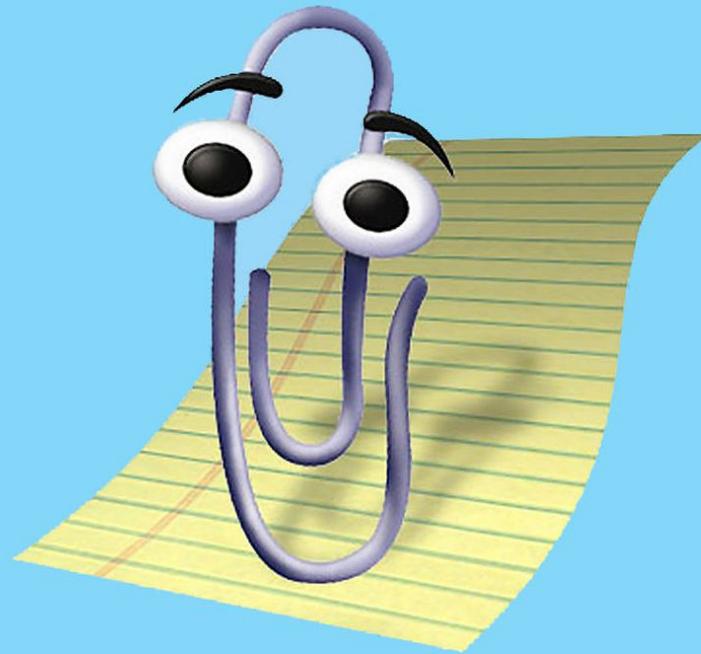
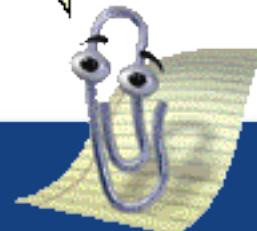


Challenges

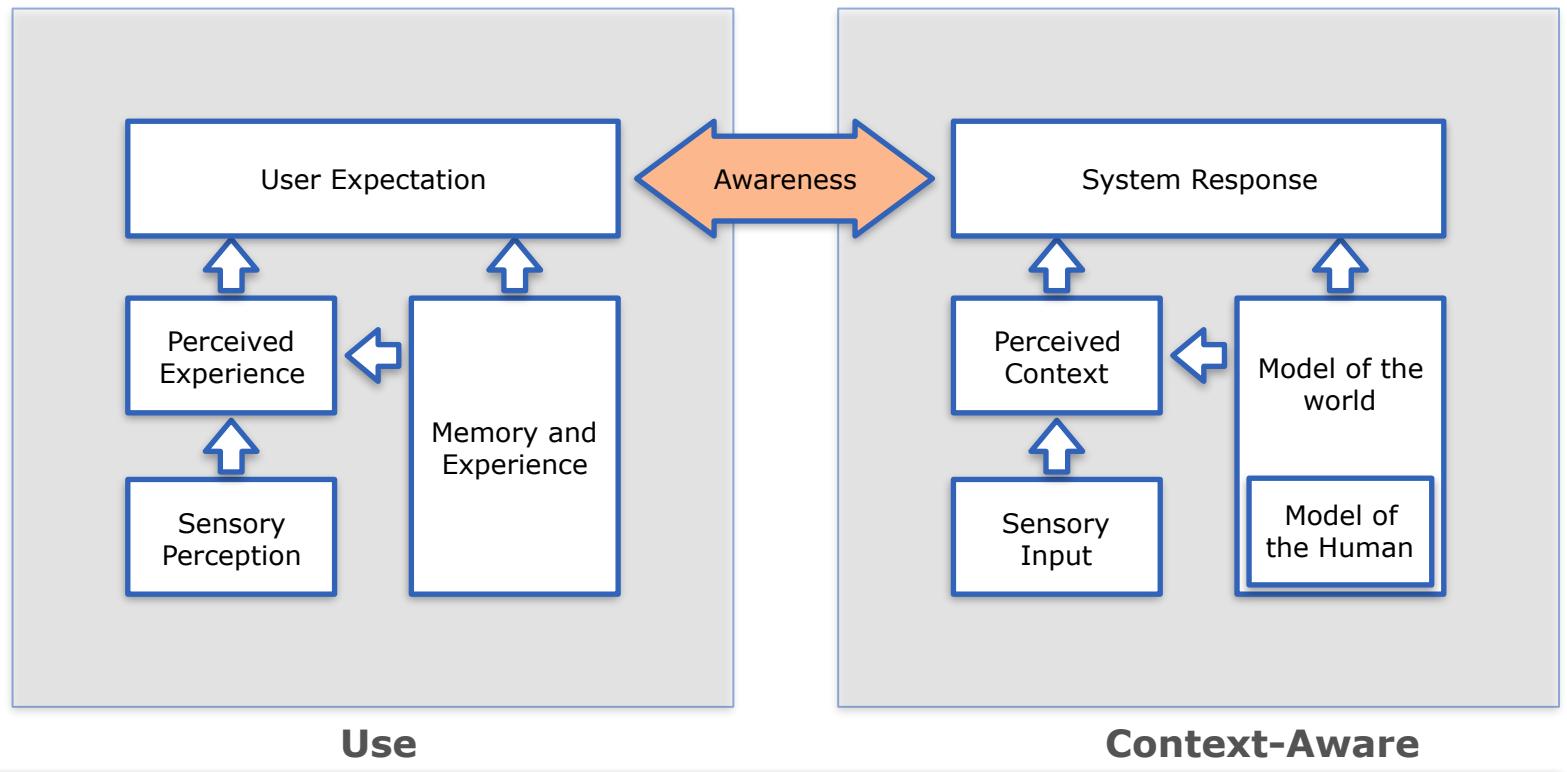
It looks like you're writing a letter.

Would you like help?

- Get help with writing the letter
- Just type the letter without help
- Don't show me this tip again



Context-Aware?



User-Context Perception Model (UCPM)

- Works well in new environments
 - lack of reference points and experience
 - goal: guidance
- Less so for familiar routes
 - expectations
 - other knowledge (lights)
 - goal: efficient guidance

src.: <https://www.tomtom.com>

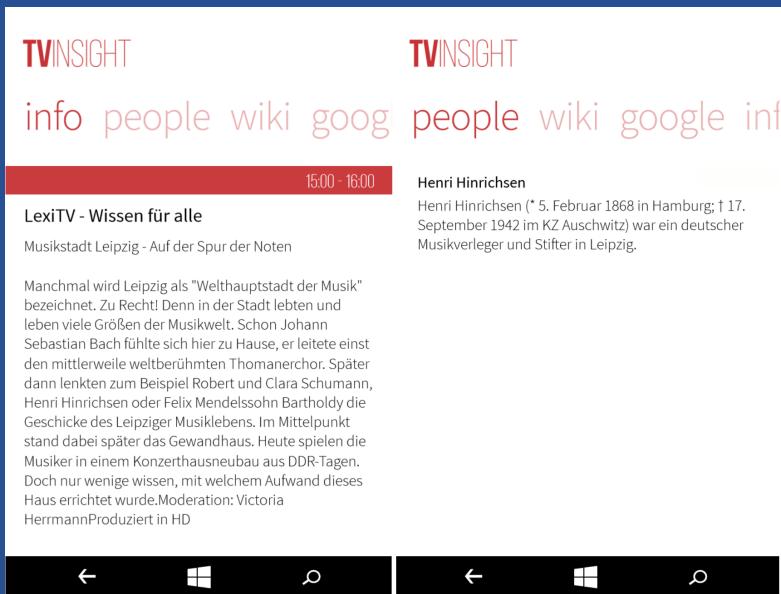


Awareness Missmatch

Challenges of Context-Aware Systems

- Understand the “**Awareness Mismatch**”
- Adaptive UIs can hinder learnability
 - > make underlying causality behind adaption clear
 - > trade-off between **visibility vs. transparency**
- What if it does not work 100%?
 - > use indicators to **communicate state**
 - > allow users to form a valid mental model
 - > failure cannot be “expensive” or “fatal”
- **Privacy and security** implications of implicit data collection

Case Study: Content-Awareness



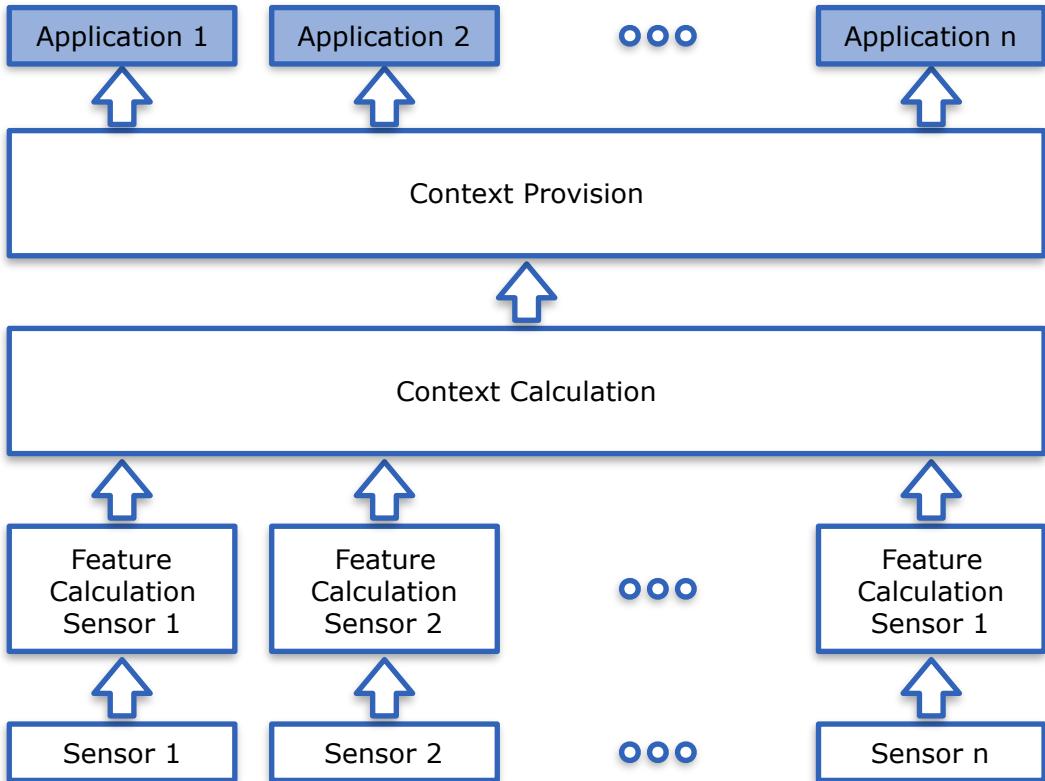
- Content-aware second-screen app



Incorporated 2016

Knittel, Johannes, and Tilman Dingler. "Mining Subtitles for Real-Time Content Generation for Second-Screen Applications." Proceedings of ACM TVX, 2016.

Summary



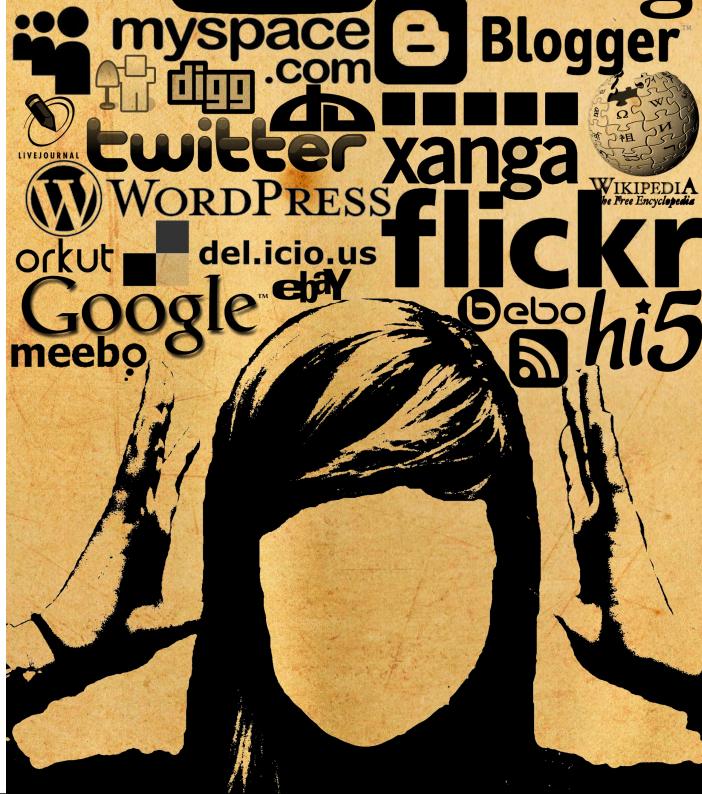
Why Context-Awareness?

- Simple, **enjoyable devices**
 - fluent interactions
- **Implicit interaction**
 - allows for quicker / more effective interactions
 - reduces cognitive load
- For designers who don't have to anticipate ONE context at design time
 - UIs can be **optimized at runtime**
- Context-aware systems make us more **efficient**



Cognitive States as Context Variable

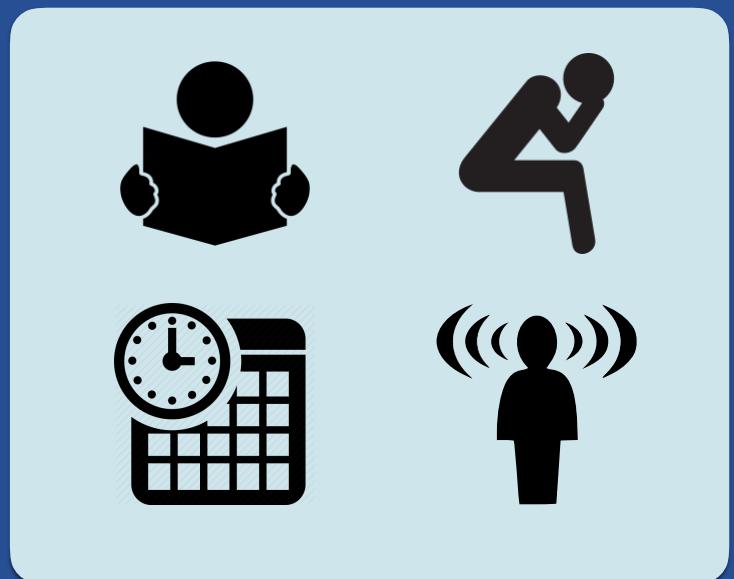
- Iqbal and Horvitz, 2007
- Mark et al., 2015



Overload, Distraction, and Frustration

Cognition-Aware Systems

- Opportune moments for **information intake and learning**
- Context-aware **UI adaption**
- **Schedule alignment** according to internal body clock
- **Stress prevention** through sleep/wake regulation
- **Self-awareness**



Cognitive Performance Varies Throughout the Day

- 1. How can technologies gain awareness of performance variations?**
- 2. How can applications use awareness of the user's cognitive context?**

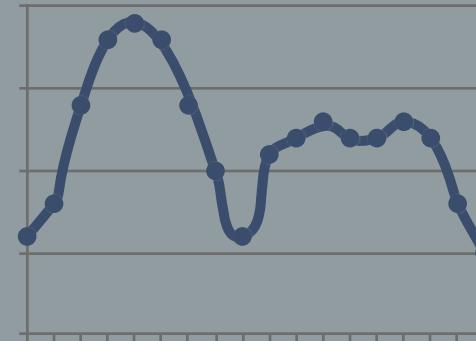
Cognition-Aware Systems

1



**Momentary
Receptiveness**

2



**General Attention
Patterns**

Scarcity of Attention?

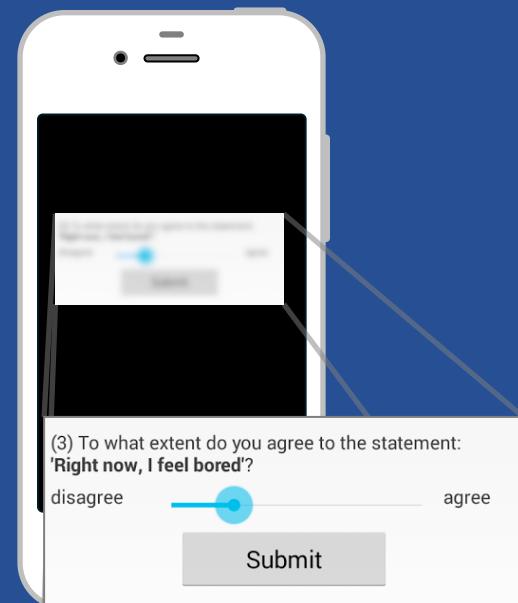
- People are highly attentive throughout the day
- Turn to their phones “to kill time” (Brown et al., 2014)

“a bored person is not just someone who does not have anything to do; it’s someone who is **actively looking for stimulation**”
(Eastwood, 2002)

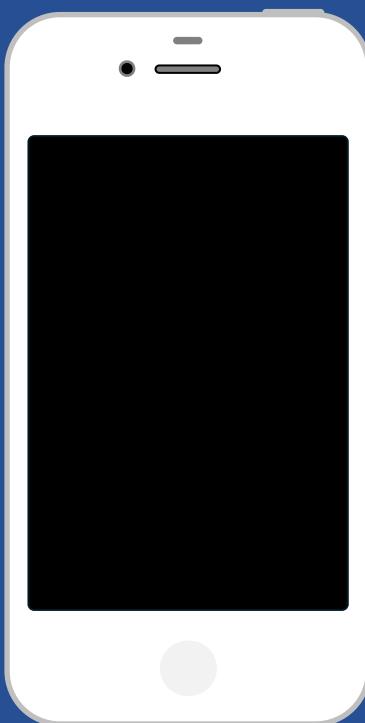


Field-Study: Detecting Boredom Throughout the Day

- **54** Participants
 - 21–46 ($M=30.6$) years
- 11 female, 23 male, 19 not disclosed
- Two weeks, 2014
- Over 40M sensor log entries
- 4398 valid self-reports of boredom



Field-Study: Boredom Throughout the Day



| Sensor | Description |
|----------------|---|
| Battery Status | Battery level ranging from 0-100% |
| Notifications | Time and type (app) of notification |
| Screen Events | Screen turned on, off, and unlocked |
| Phone Events | Time of incoming and outgoing calls |
| Proximity | Screen covered or not |
| Ringer Mode | Silent, Vibration, Normal |
| SMS | Time of receiving, reading, and sending SMS |

| Sensor | Description |
|----------------|--|
| Airplane Mode | Whether phone in airplane mode |
| Ambient Noise | Noise in dB as sensed by the microphone |
| Audio Jack | Phone connected to headphones or speakers |
| Cell Tower | The cell tower the phone is connected to |
| Data Activity | Number of bytes up/downloaded |
| Foreground app | Package name of the app in foreground |
| Light | Ambient light level in SI lux units |
| Screen Orient | Portrait or Landscape mode |
| Wifi Infos | The WiFi network the phone is connected to |

Always
collected

Only
collected if
phone in use

Extracting Context: 35 Features, 7 Categories

| Category | Example Feature | Explanation |
|------------------------------|-------------------------|--|
| Context | Semantic Location | Home, work, other, unknown |
| Demographics | Age, gender | 38, female |
| Last Communication Activity | Time last incoming call | Time passed since somebody called the participants |
| Usage (intensity) | Bytes received | Number of bytes downloaded in the last 5 minutes |
| Usage (externally triggered) | Number of notifications | Number of notifications received in the last 5 minutes |
| Usage (idling) | Number of apps | Number of apps launched in the last 5 minutes |
| Usage (type) | Most used app | App used for the most time in the last 5 minutes. |

Boredom Prediction Take-Aways

Boredom can be detected from phone-usage patterns with an accuracy of approx. 75% to 83% AUCROC

We found boredom to be related to regency of communication, phase of the day demographics, intensity and type of phone usage, and type of used apps

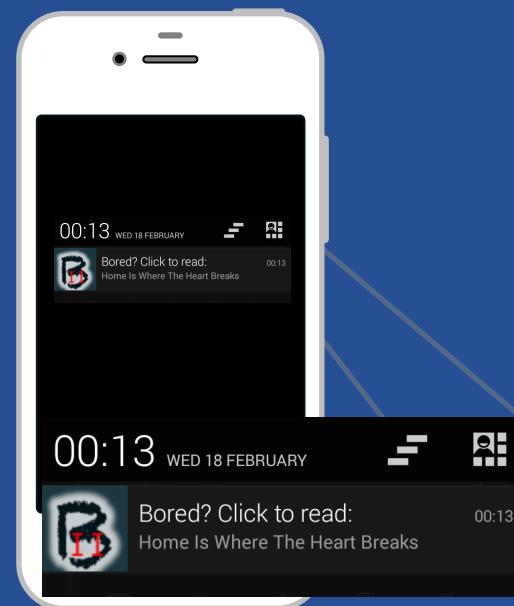
Feature Analysis: Boredom Usage Patterns

| Feature | Import | Correlation | The more bored, the .. |
|--------------------------|--------|-------------|------------------------|
| time_last_outgoing_call | 0.0607 | -0.143 | less time passed |
| time_last_incoming_call | 0.0580 | 0.088 | more time passed |
| time_last_notif | 0.0564 | 0.091 | more time passed |
| time_last_SMS_received | 0.0483 | 0.053 | more time passed |
| time_last_SMS_sent | 0.0405 | -0.090 | less time passed |
| time_last_SMS_read | 0.0388 | -0.013 | more time passed |
| light | 0.0537 | -0.010 | darker |
| hour_of_day | 0.0411 | 0.038 | later |
| proximity | 0.0153 | -0.186 | less covered |
| gender (0=f, 1=m) | 0.0128 | 0.099 | more male (1) |
| age | 0.0093 | n.a. | +20s/40s, -30s |
| | | | |
| num_notifs | 0.0123 | 0.061 | more notifs |
| time_last_notif_cntr_acc | 0.0486 | -0.015 | less time passed |
| time_last_unlock | 0.0400 | -0.007 | less time passed |
| apps_per_min | 0.0199 | 0.024 | more apps per minute |
| num_apps | 0.0124 | 0.049 | more apps |
| bytes_received | 0.0546 | -0.012 | less bytes |
| bytes_transmitted | 0.0500 | 0.039 | more bytes |
| battery_level | 0.0268 | 0.012 | the higher |
| battery_drain | 0.0249 | -0.014 | the lower |

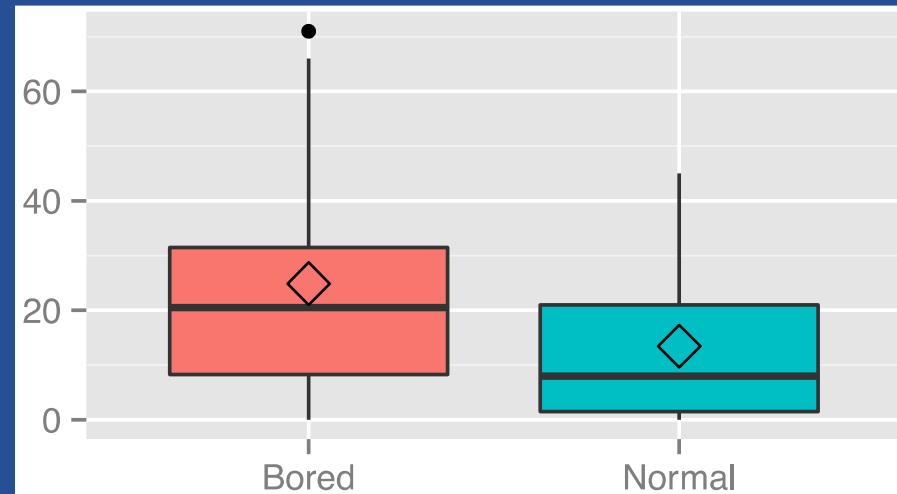
- **Recency of communication activity**
time since last incoming or outgoing communication
- **Phase of the day**
hour of the day, ambient light
- **Demographics**
gender and age
- **General usage intensity**
phone out of pocket or time since last phone use
- **Intensity of recent usage**
of unlocks, or # of apps launched in last 5mins

Using Boredom to Predict Opportune Moments for Content Delivery

- **16** Participants
 - 18 – 51 (M=39) years
 - 13 male, 2 female, rest did not disclose
- Two weeks, 2015
- 941 Buzzfeed recommendations
- 48% when predicted bored



Results: Content Acceptance (clicks)



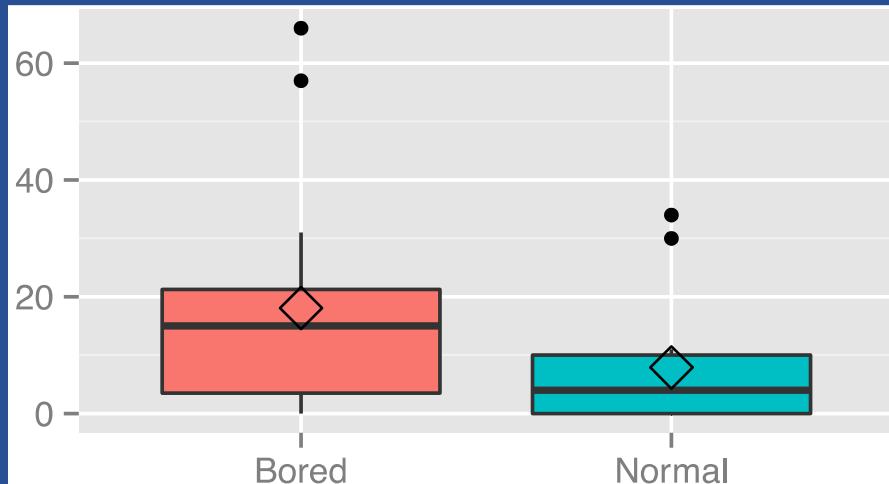
% of clicked notifications (Mdn)

8% when **not bored**
20.5% when **bored**
(as inferred by the model)

Difference significant
 $z = -2.102, p = .018$

Large effect
 $r = -.543$

Results: Engagement



% of clicks where people spent more than 30 sec reading (Mdn)

4% when **not bored**

15% when **bored**

(as inferred by the model)

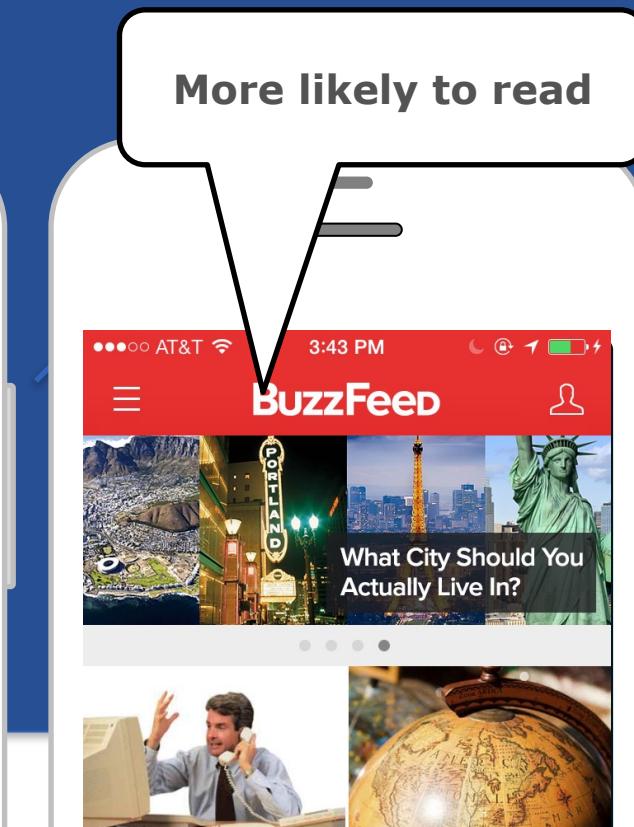
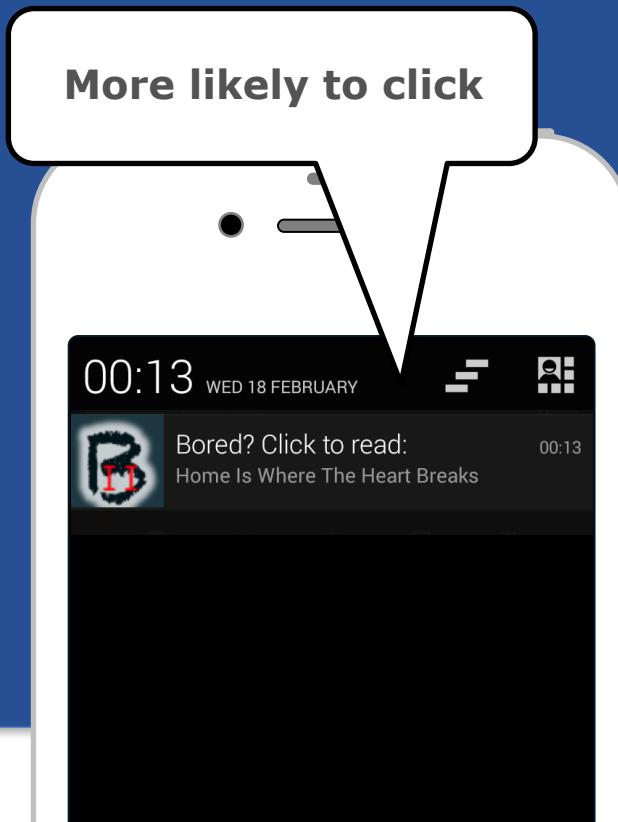
Difference significant

$z = -2.102$, $p = .018$

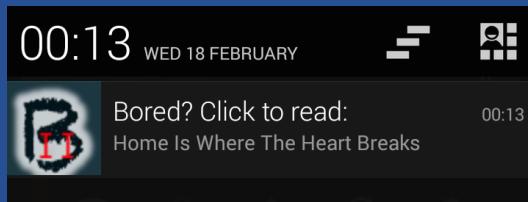
Large effect

$r = -.511$

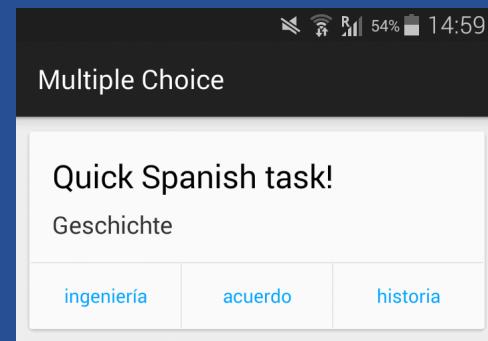
When predicted bored, participants were ...



Detecting opportune Moments for...



Content
recommendations

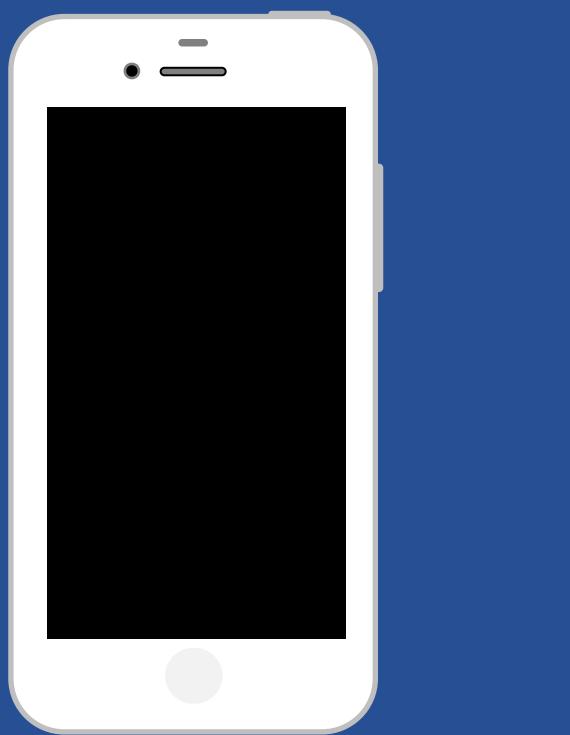


Microlearning

Field-Study: Opportune Moments for Learning

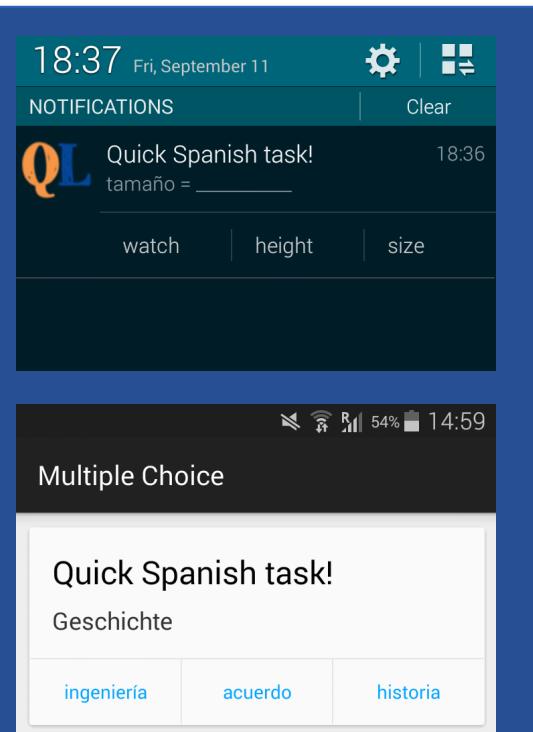
- Mixed Method
- **84** phone users
 - mean age 31 ($SD=11.7$) years
- 28 female, 56 male

- Over 5M sensor log entries
- 14,632 learning reminders triggered
 - based on predicted boredom



Using Opportune Moments for Language Learning

- 18.9% interacted notifications
- 37.6% completed while on-the-go
- Usage patterns different from boredom prediction
- Re-training model:
 - 71.2% recall



Tilman Dingler, Dominik Weber, Martin Pielot, Jennifer Cooper, Chung-Cheng Chang, and Niels Henze. Language Learning On-The-Go: Opportune Moments and Design of Mobile Microlearning Sessions, MobileHCI '17. ACM, Vienna, Austria.



Co-Design Study (ICT4D): Deployment in Cape Town, South Africa

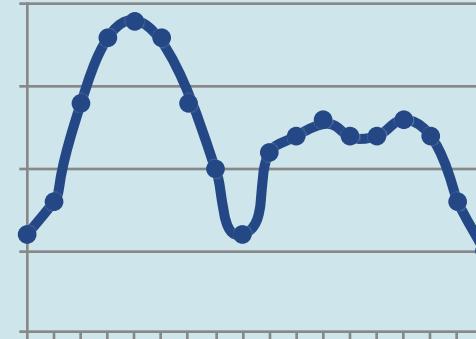
Cognition-Aware Systems

1



**Momentary
Receptiveness**

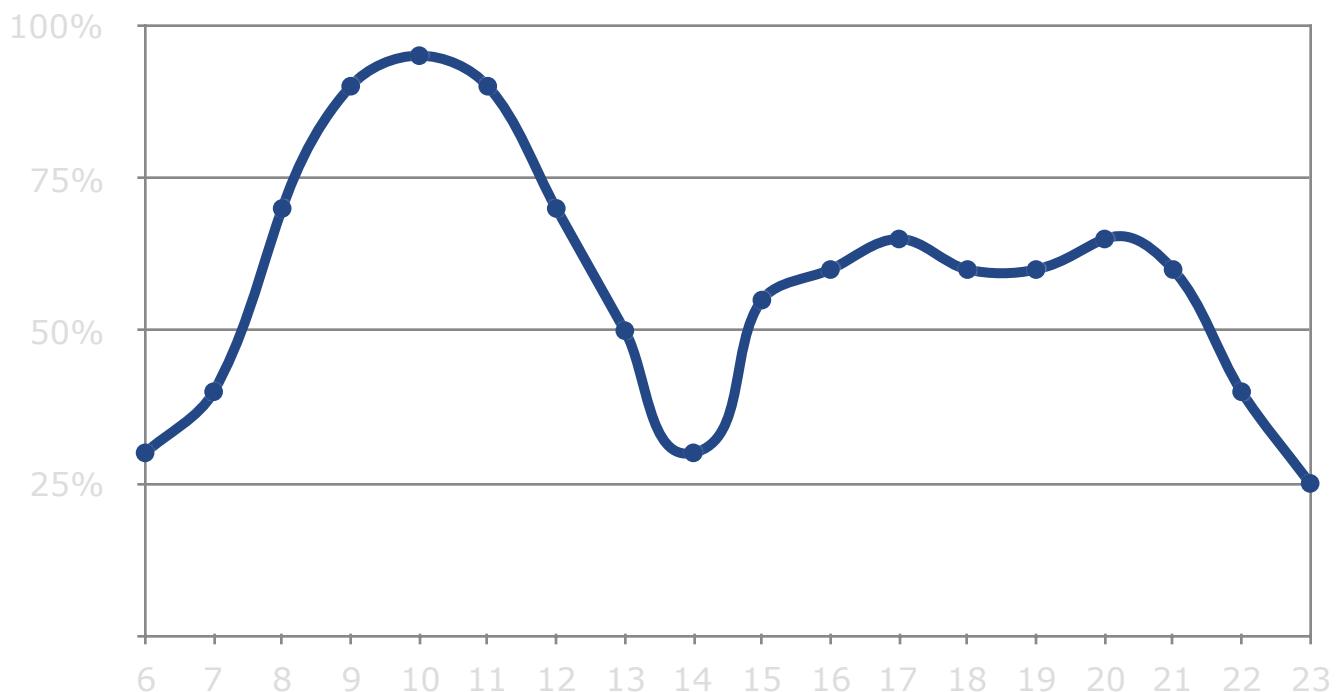
2



**General Attention
Patterns**

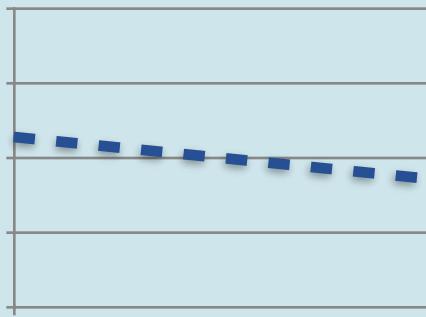


© Fotograf: Julia Pietsch, Blende-Fotowettbewerb

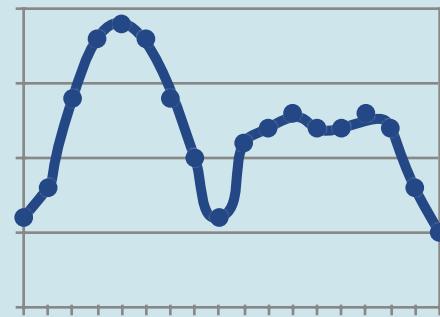


Circadian Rhythm of Cognitive Performance

Performance Measures Largely Influenced by 2 Processes:



**Sleep / Wake
Homeostasis**

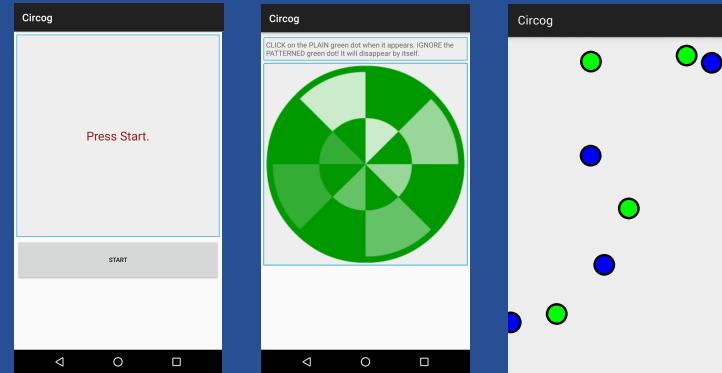


**Circadian
Process**

Borbély, 1982

Toolkit for Eliciting Circadian Rhythms

- Eliciting
 - **Alertness and Cognitive Performance**
- **Open Source** Task battery
 - 1-2min tasks
 - PVT economical, but dull
 - GNG and MOT adaptable
 - integration in application and games
 - allow researchers and designers to build more implicit cognition-aware systems

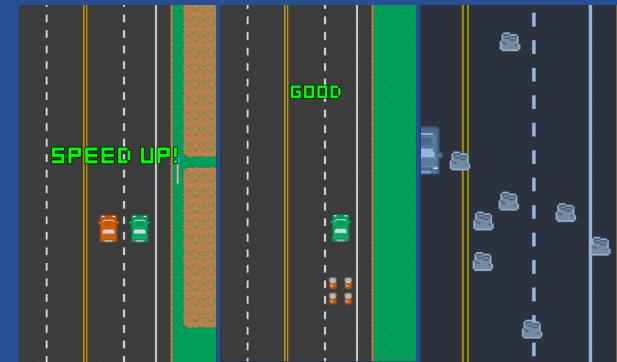
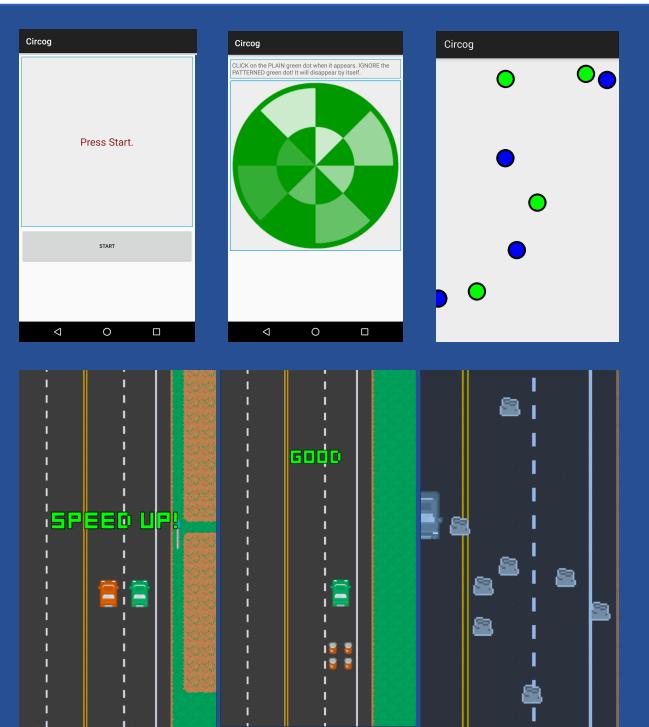
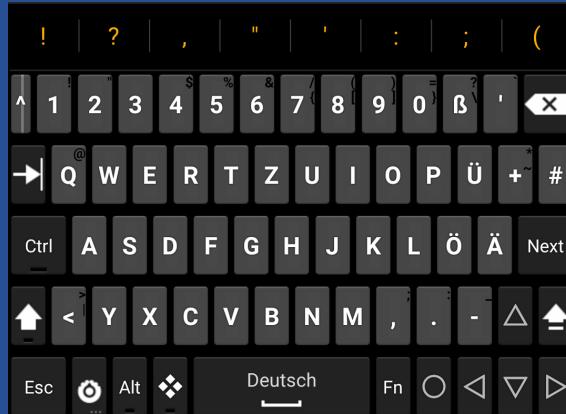


<https://github.com/Til-D/circog>

Tilman Dingler, Albrecht Schmidt, and Tonja Machulla. Building Cognition-Aware Systems: A Mobile Toolkit for Extracting Time-of-Day Fluctuations of Cognitive Performance. IMWUT '17. ACM, Maui, 2017, USA

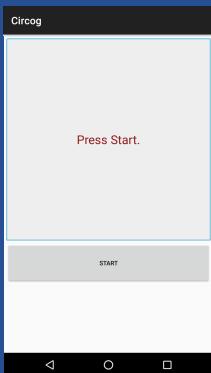
Using Game Data and Typing Behaviour to Track Fluctuations

- Time-dependent fluctuations in
 - Gameplay metrics
 - Typing metrics (speed, errors,..)

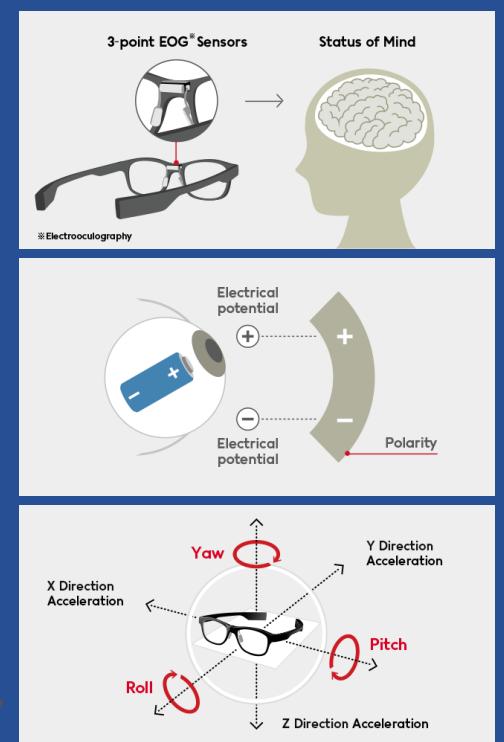


Using Eye-Movement Data to Track Fluctuations

- 2 weeks user study
- Collecting
 - Eye movement and blink data
 - Ground truth
 - Self-Assessments (Karolinska Sleepiness Scale)
 - Reaction times (PVT task)

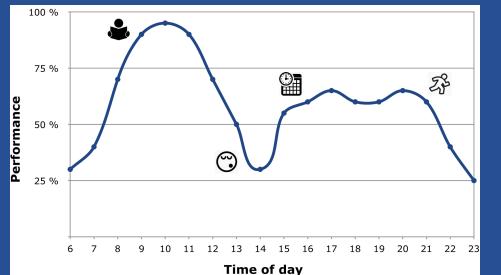


<https://jins-meme.com/>



Scheduling Interventions

- Exposure to blue light
 - take a walk
 - blue light emitting lamps
- Caffeine intake
- Activating activities
- Naps



Engagement *when* and *how*

- Cognitive states
 - attention
 - alertness
 - cognitive performance



Identify **opportune moments** for content delivery



Adapt UIs in real-time to match user's cognitive state

Adaptive Reading Interfaces



Rapid Serial Visual Presentation
(RSVP)

Alice was beginning to get very tired of sitting by her sister on the bank, and of having nothing to do: once or twice she had peeped into the book her sister was reading, but it had no pictures or conversations in it,...

Kinetic Stimuli

T. Dingler, A. S. Shirazi, K. Kunze, and A. Schmidt. Assessment of stimuli for supporting speed reading on electronic devices. AH '15, pages 117–124, New York, NY, USA, 2015. ACM

1. Context-aware Computing: Definitions and History
2. Using Context in Applications and Interfaces
3. User Activity as Context Variable
4. User's Cognitive State as Context Variable

Summary

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- Dey, Anind K. "Understanding and using context." Personal and ubiquitous computing 5.1 (2001): 4-7.
- Knittel, Johannes, and Tilman Dingler. "Mining Subtitles for Real-Time Content Generation for Second-Screen Applications." Proceedings of the ACM International Conference on Interactive Experiences for TV and Online Video. ACM, 2016.
- **Schilit, Bill, Norman Adams, and Roy Want. "Context-aware computing applications." Mobile Computing Systems and Applications, 1994. WMCSA 1994. First Workshop on. IEEE, 1994.**
- Schmidt, Albrecht, Beigl, Michael and Gellersen, Hans-Werner (1999): There is more to context than location. In Computers & Graphics, 23 (6) pp. 893-901
- **Weiser, Mark. 1999. The computer for the 21st century. SIGMOBILE Mob. Comput. Commun. Rev.3, 3 (July 1999), 3-11.**

References and Further Readings

AGE OF CONTEXT

Mobile, Sensors, Data and the Future of Privacy

ROBERT SCOBLE & SHEL ISRAEL

Foreword by Marc Benioff



Patrick Brewster Press,
2014