v1.1

Context-Aware Computing

Tilman Dingler

Mobile Computing | 27-Aug-2018

COMP90018 - Mobile Computing Systems Programming

X

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

Designing a Watch Interface

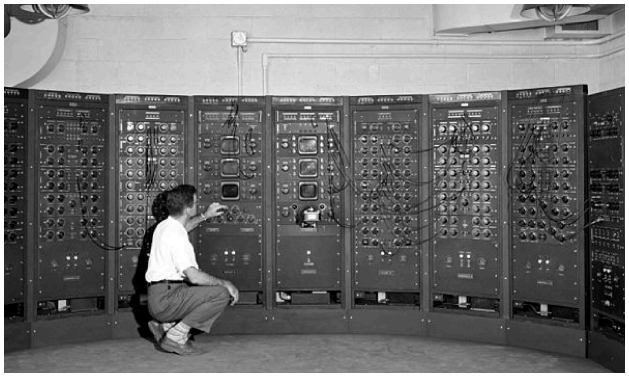
1. Context-aware Computing: Definitions and History

2. Using Context in Applications and Interfaces

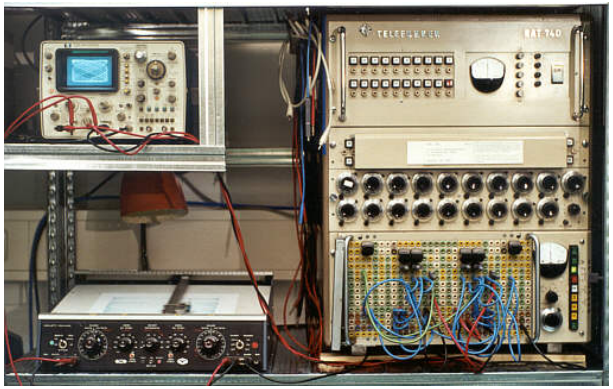
3. User Activity as Context Variable

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.

image src.: wikimedia, Computer Museum of the University of Stuttgart, Wikipedia

How does *context* influence mobile interfaces?

image src.: http://web.uri.edu, Amazon, https://www.interaction-design.org, https://www.tomtom.com

- 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.

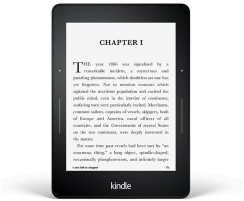
light sensor

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

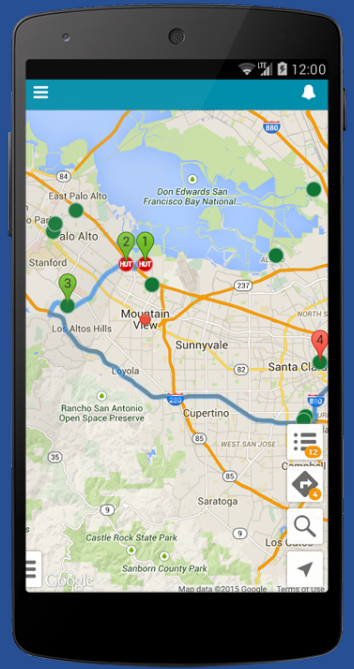
Google Search I'm Feeling Lucky

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

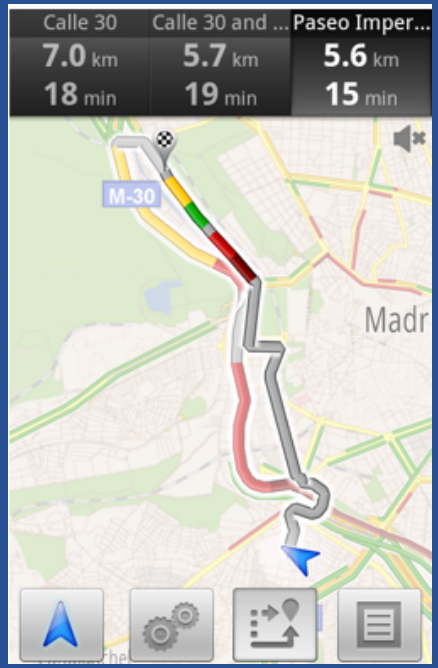


Context-Adaptive Systems

- **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”.

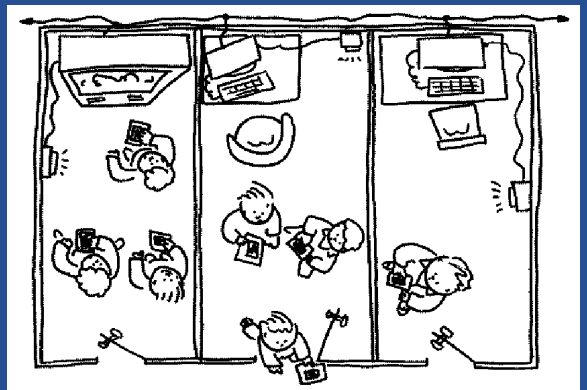
Implicitly Collected Context Data

- 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
- Chose 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

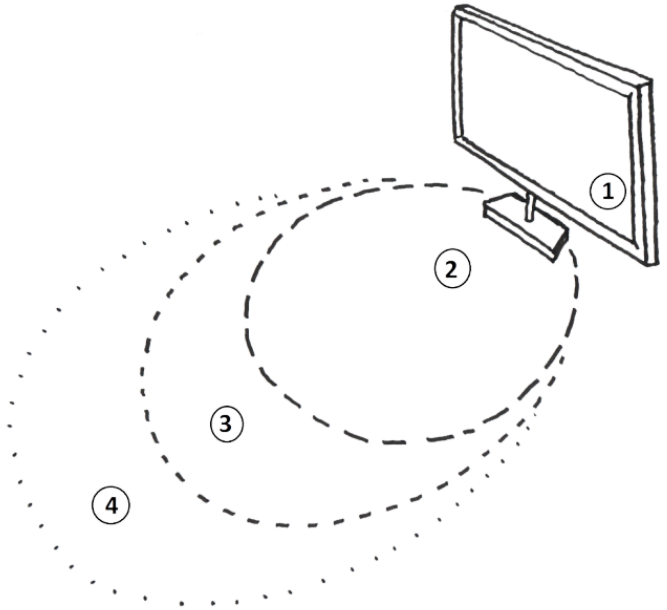
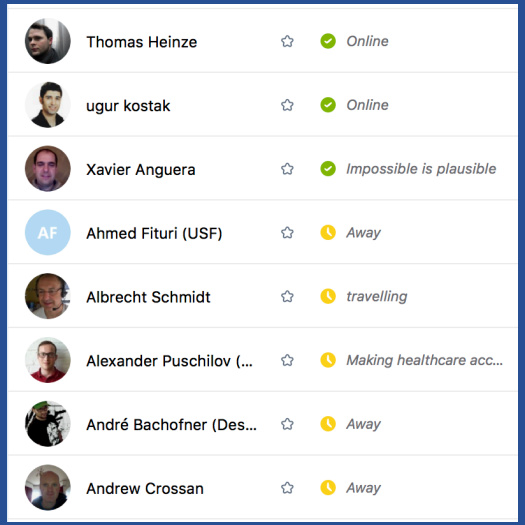


Figure 2: Four spatial zones to provide seamless gesture interaction: 1) Touch area, 2) fine-grained gesture area, 3) general gesture area and 4) coarse gesture area.

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



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.

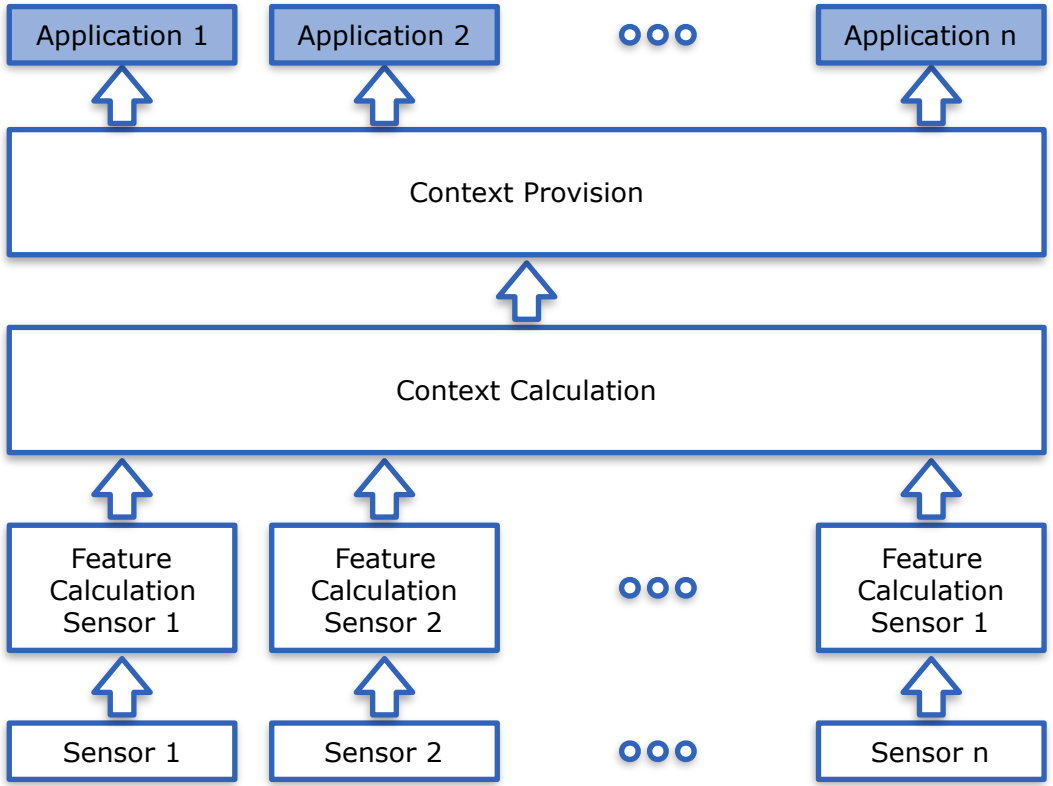
Categories and Subject Descriptors: C.3 [**Special-Purpose and Application-Based Systems**]: Real-Time and Embedded Systems; C.3 [**Special-Purpose and Application-Based Systems**]: Signal Processing Systems; I.5.2 [**Pattern Recognition**]: Design Methodology; I.5.4 [**Pattern Recognition**]: Applications;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

Reading Tip

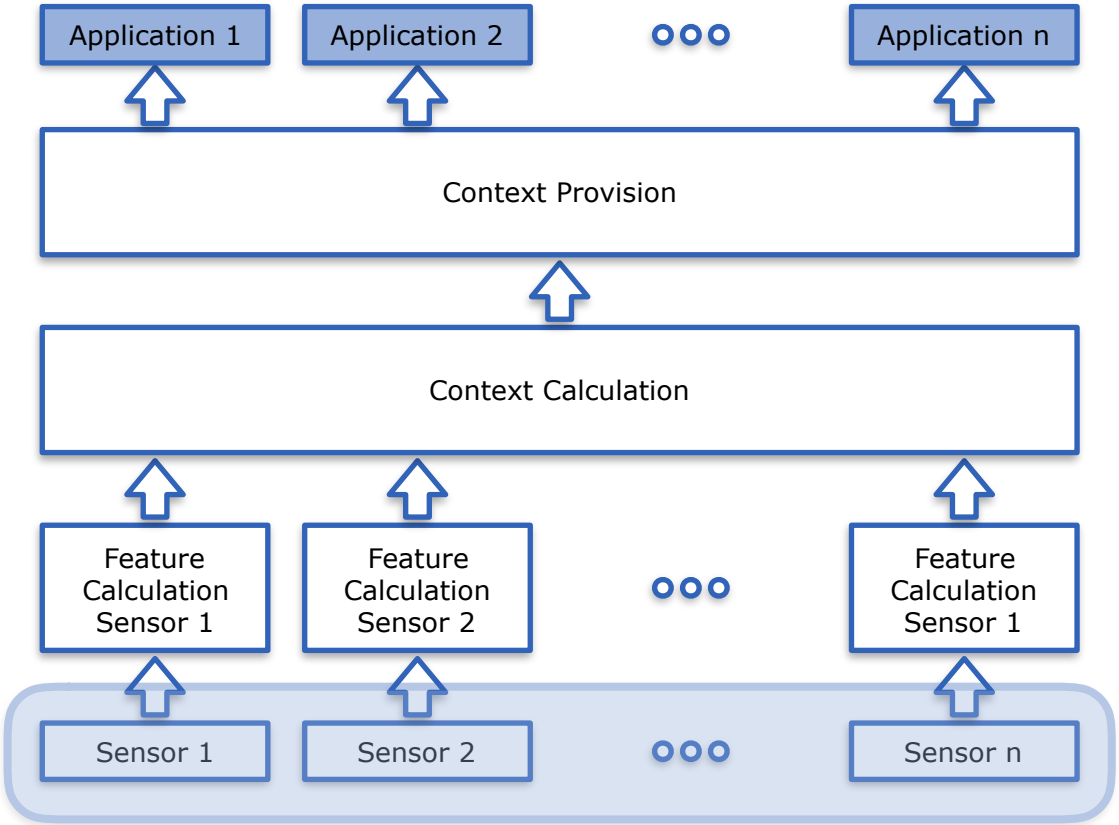
Characteristics of an Human Activity Recognition (HAR) System

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

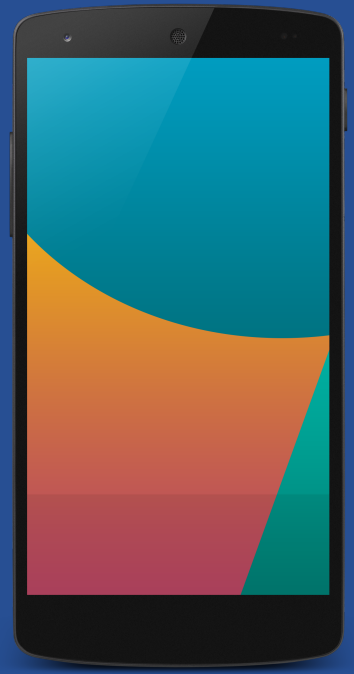
Reference Architecture for Context-Aware Computing Systems



Reference Architecture for Context-Aware Computing Systems



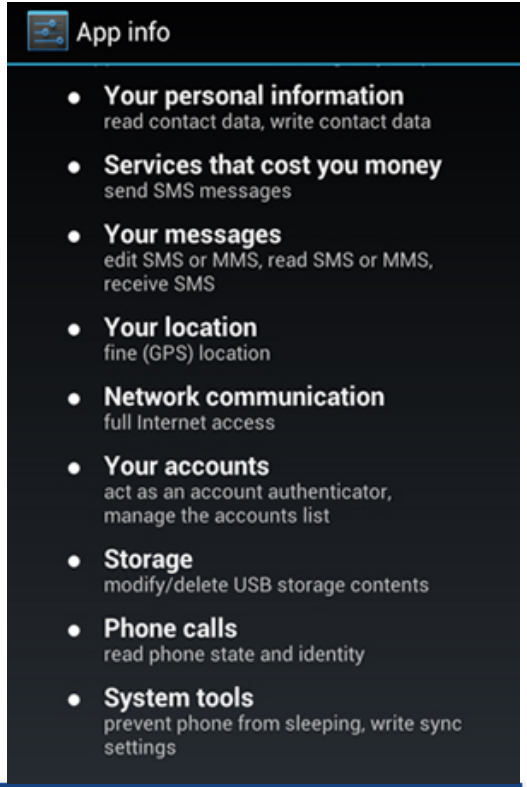
From Sensors to Context



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

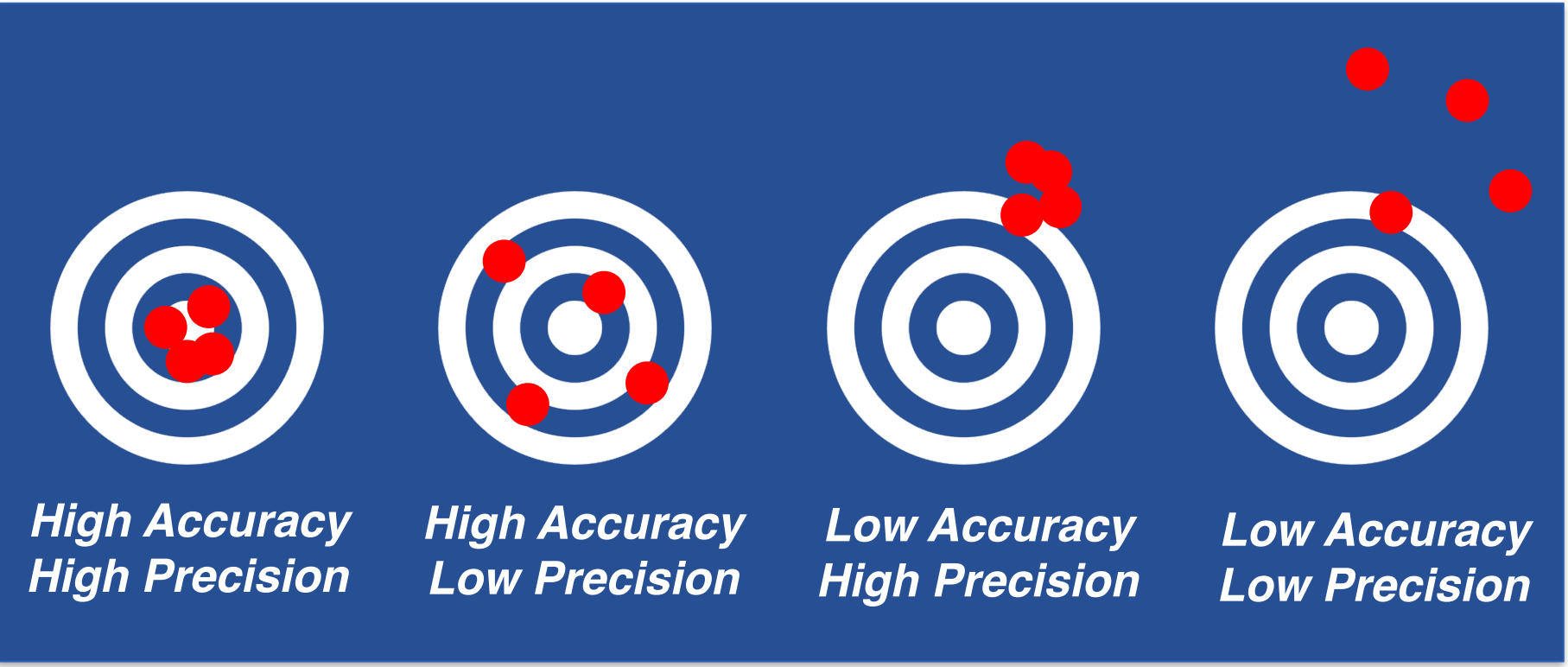
Walking
Sitting
Indoors
Outdoors
In company
Alone
Daytime
Nighttime
Busy
Free
…

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

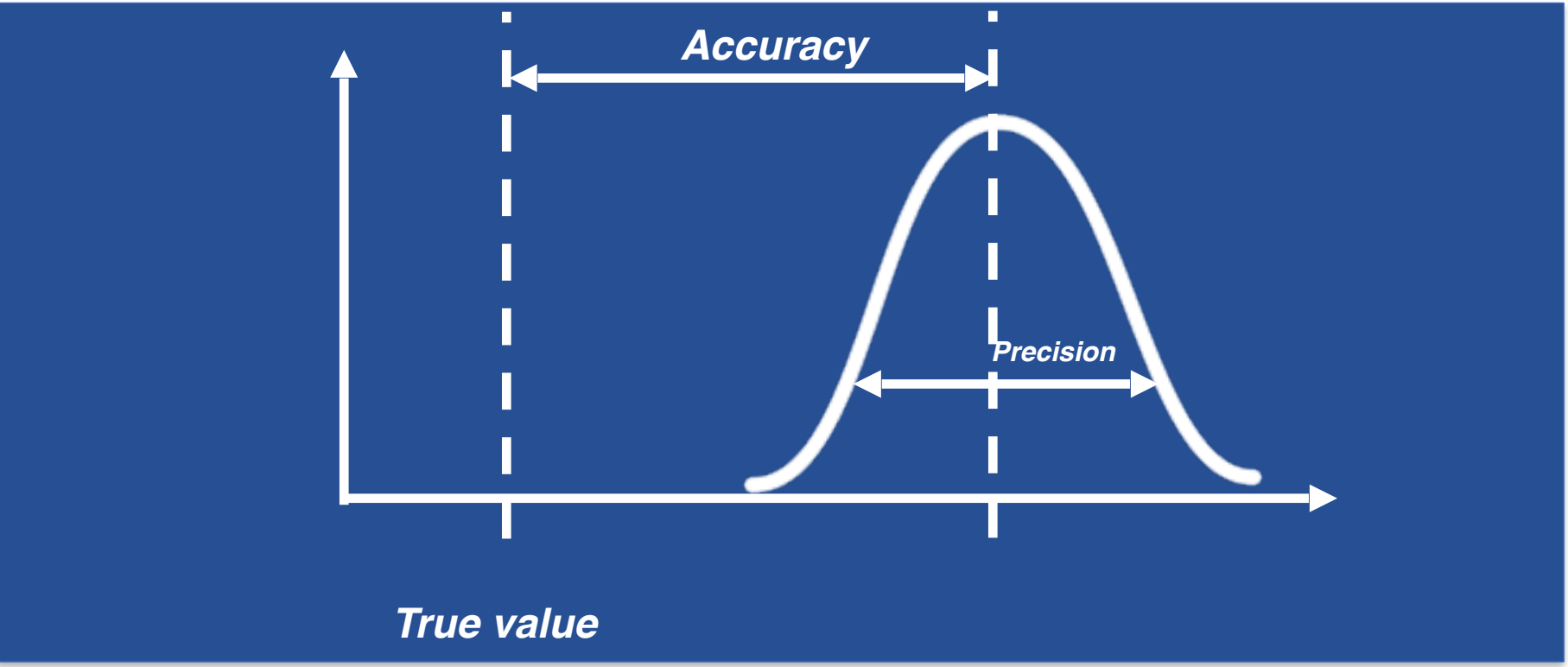


Are privacy settings effective?

Choosing a Sensor



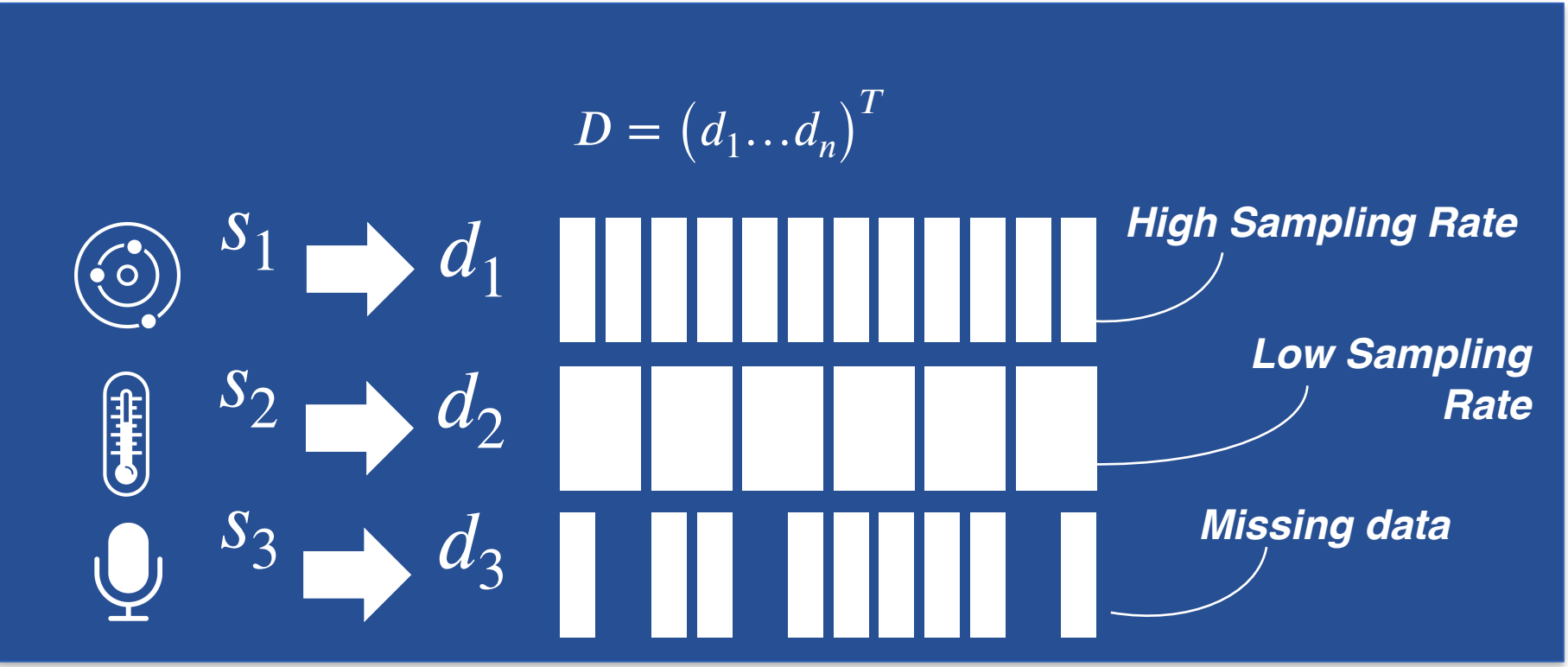
Choosing a Sensor



Choosing a sensor

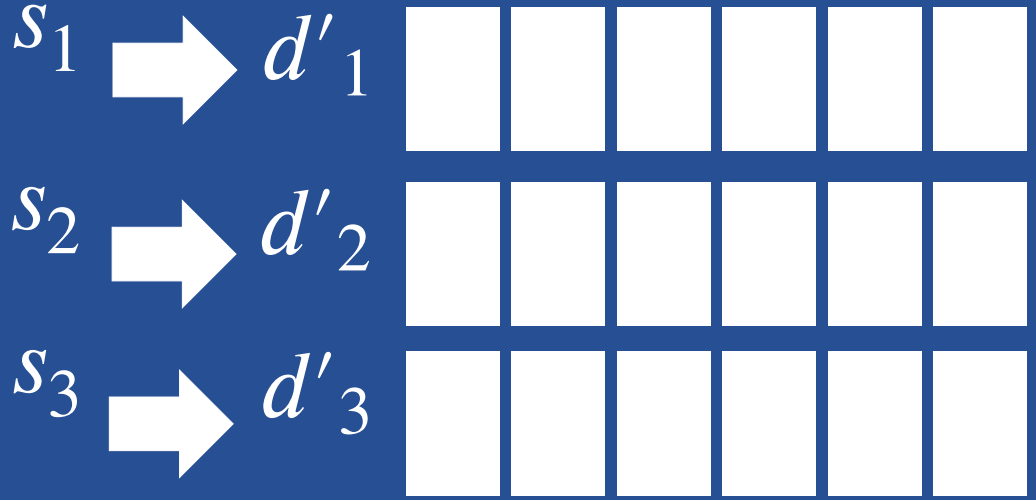
- Accuracy / Precision
- Operating range
  - E.g. pressure sensor of 100g-10kg
- Resolution or sensitivity
  - E.g., thermal sensitivity of 40mK
- Costs
- Energy requirements
- Lifespan

Raw Sensor Data



Preprocessing

$$D' = \left(d'_1 \ldots d'_n\right)^T$$



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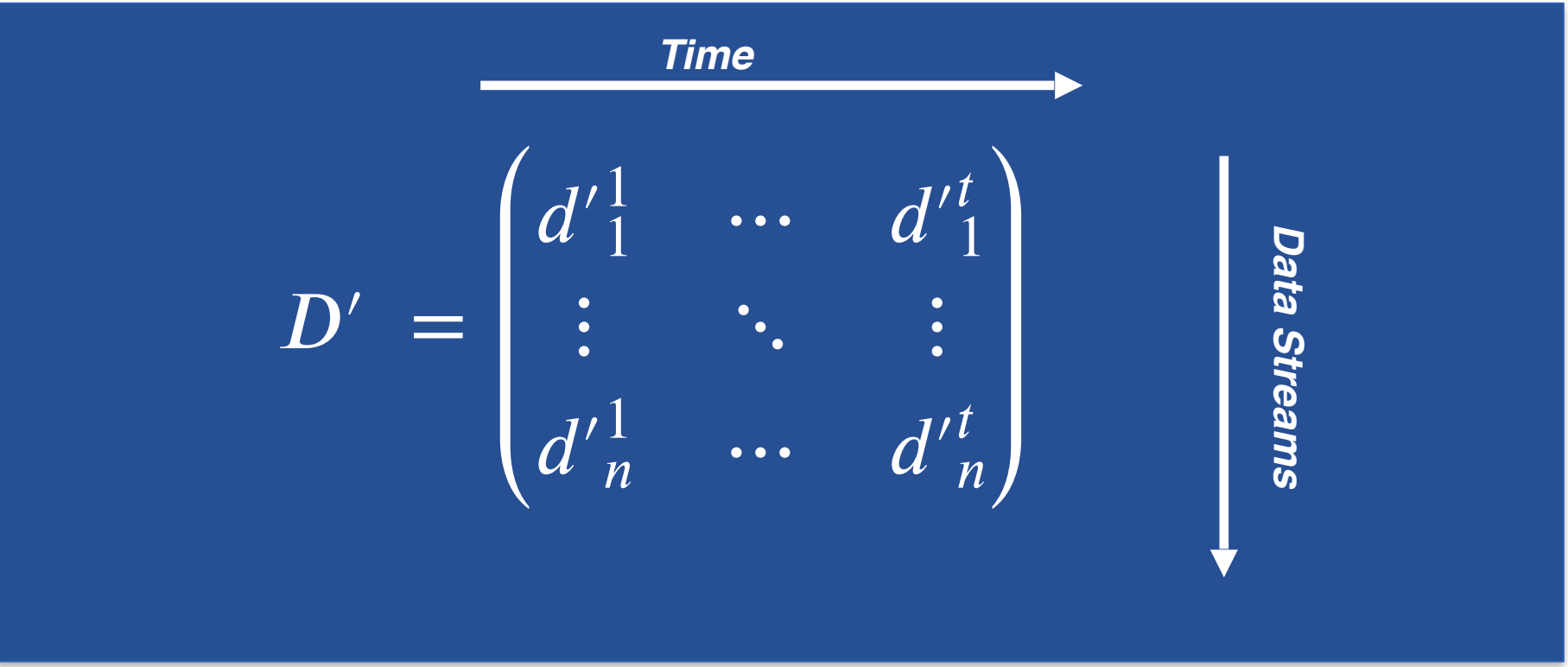
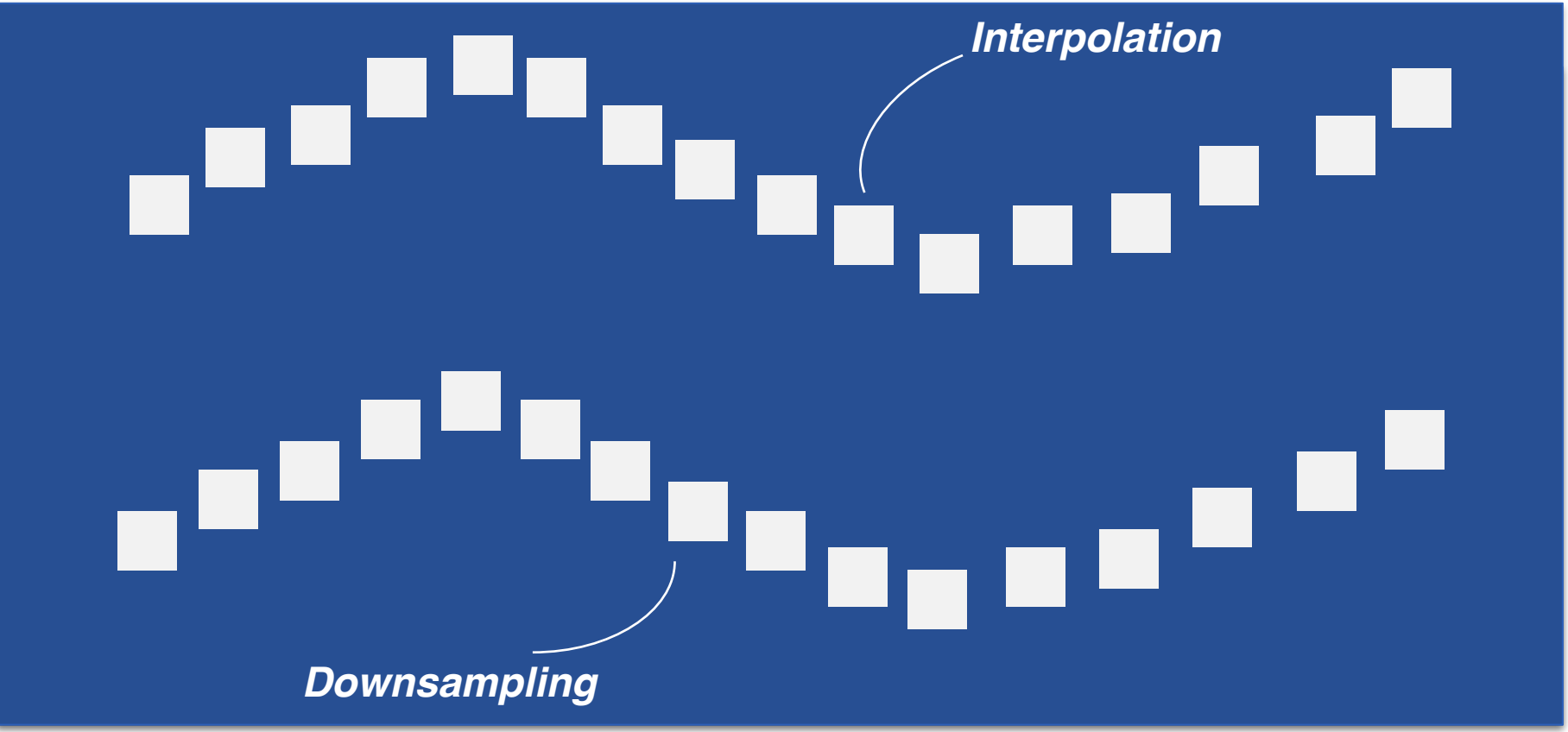


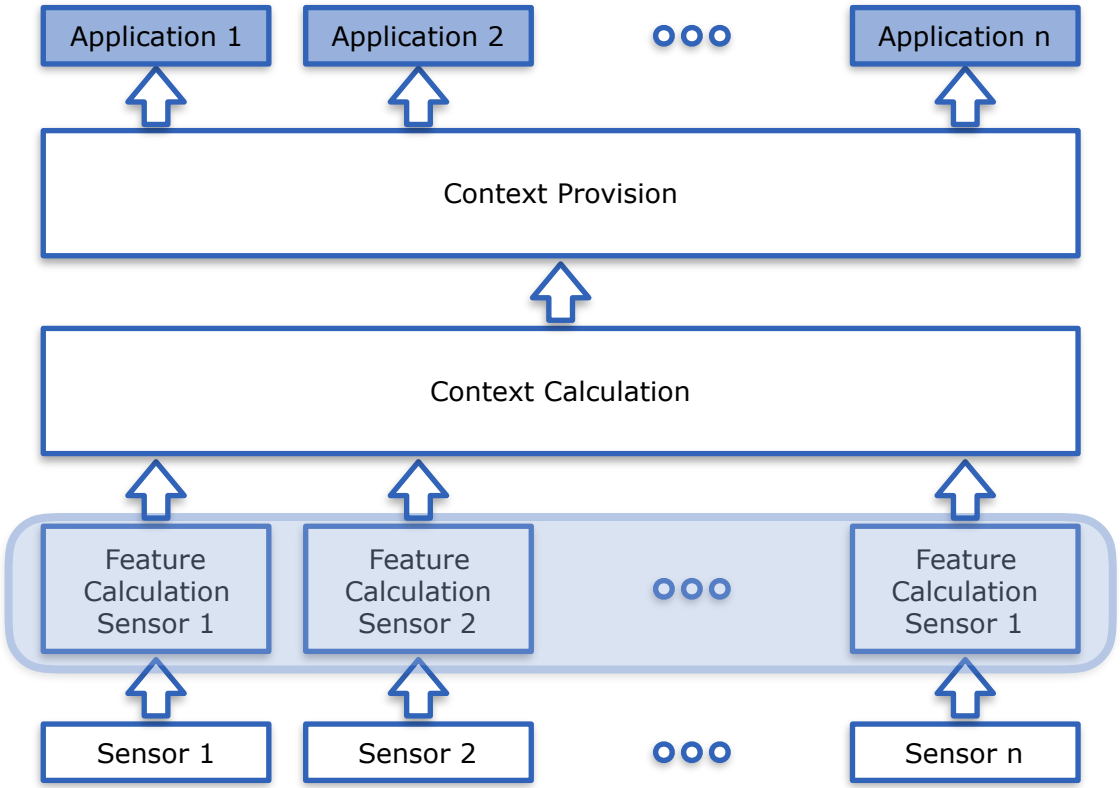
Preprocessing



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

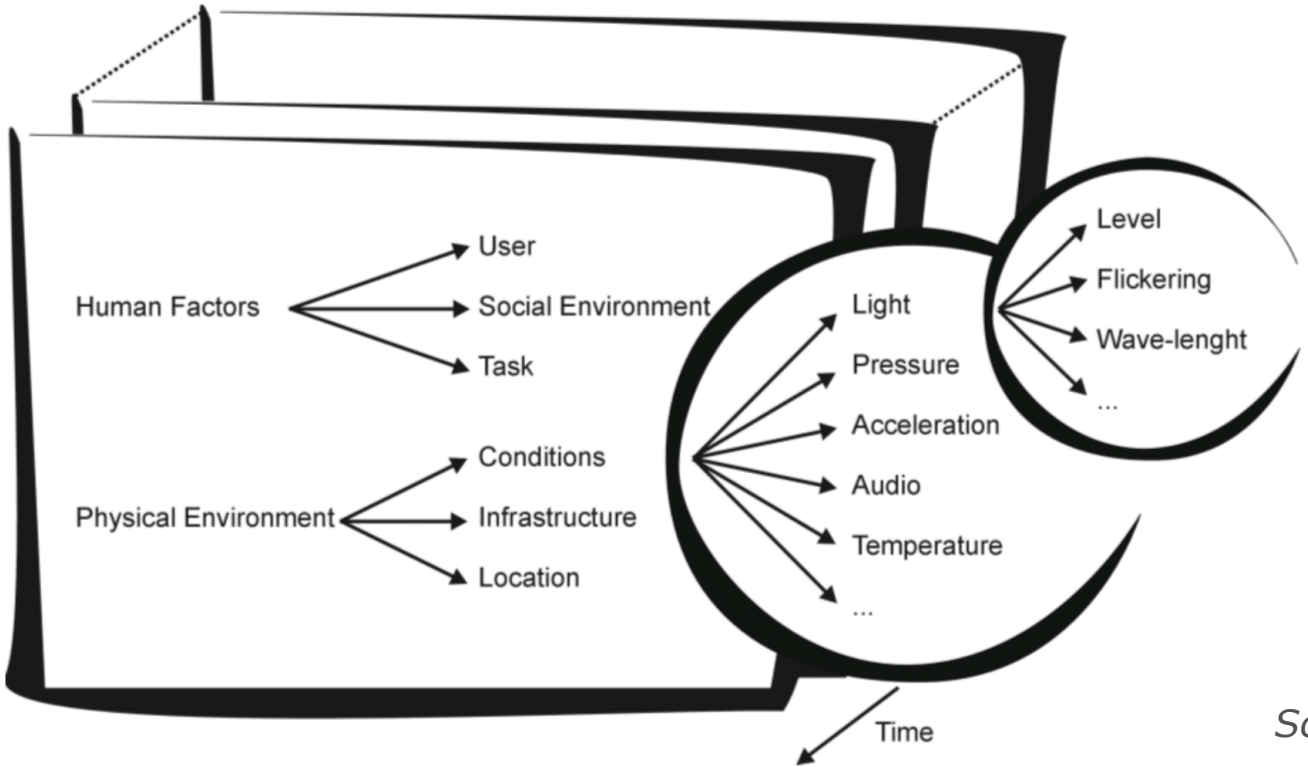


Context Engineering

- 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.

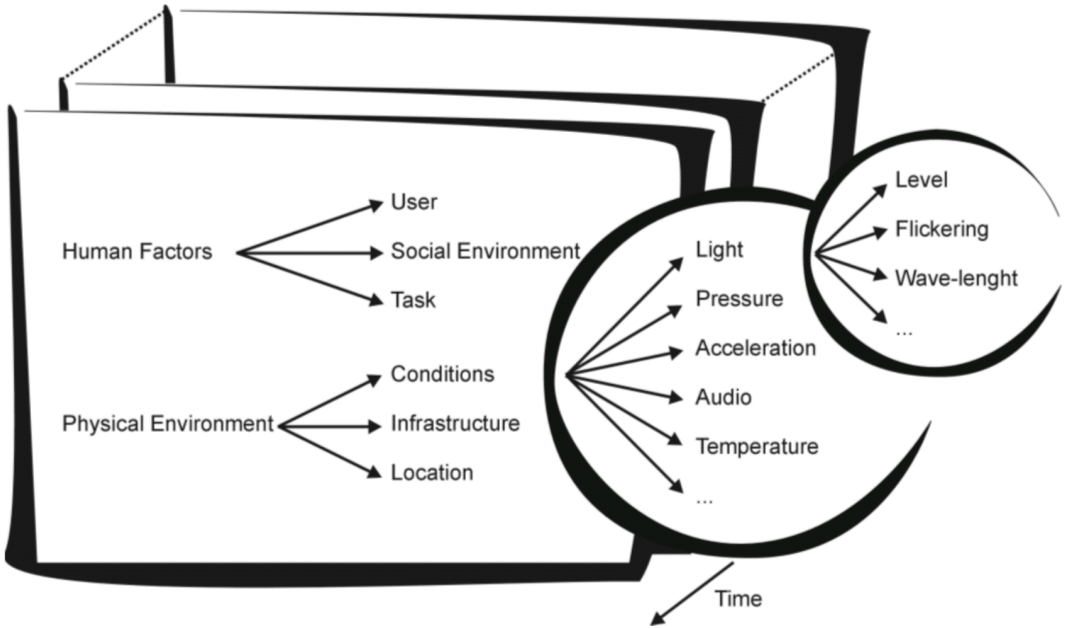
Context: at home?

Context Feature Space



Schmidt et al., 1999

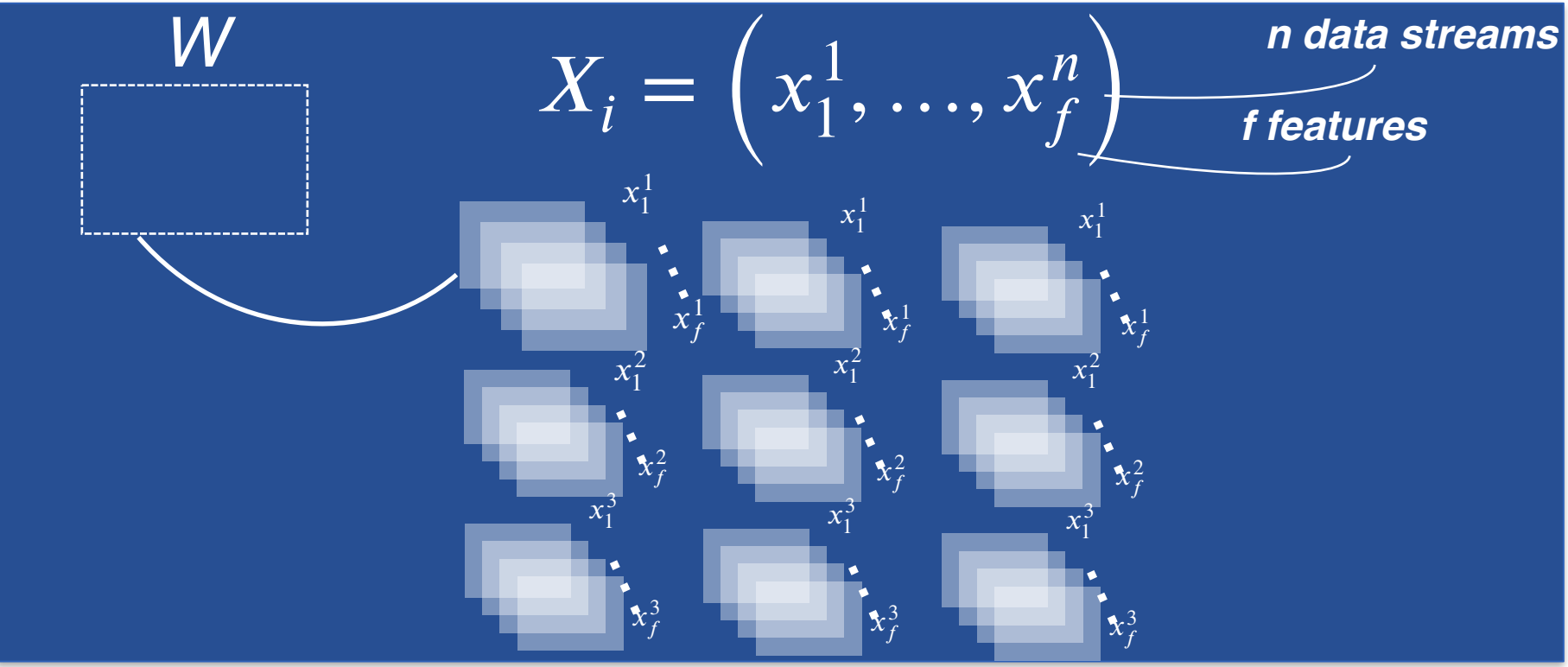
Context Feature Space



Schmidt et al., 1999

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

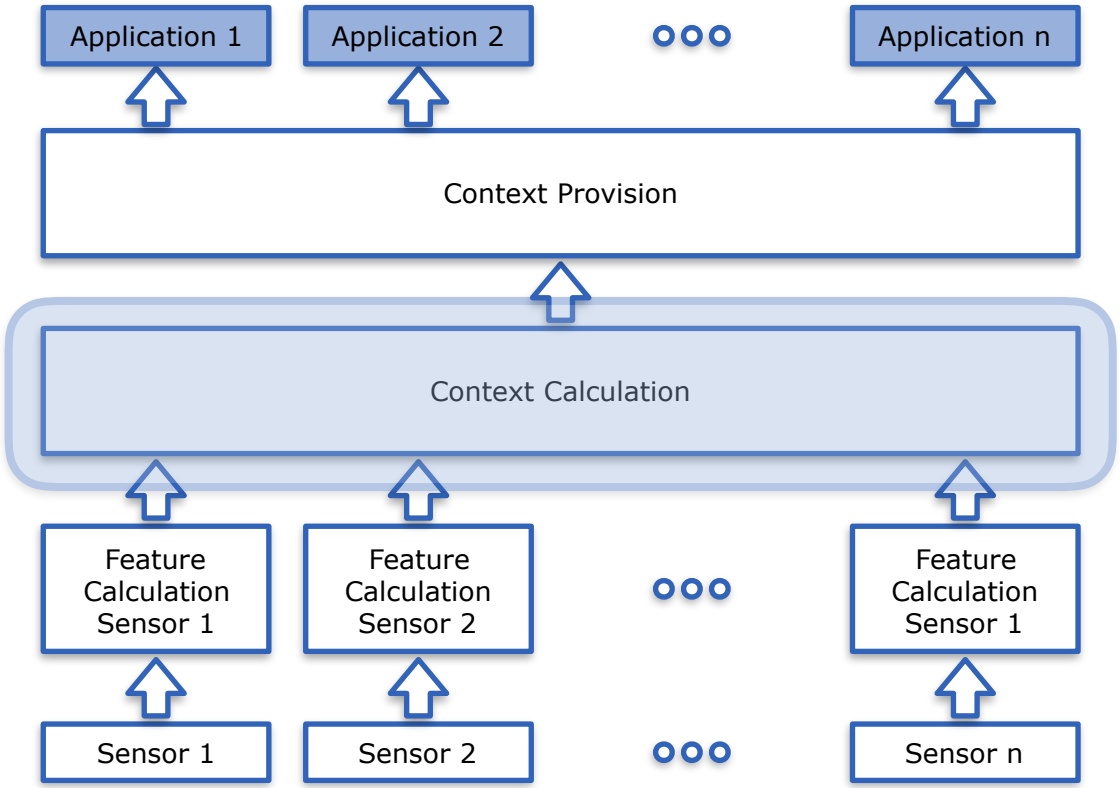
Feature Extraction



Features

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

Reference Architecture for Context-Aware Computing Systems



Classification

Activity

Model parameters

$$P_i(y \mid X_i, \theta)$$

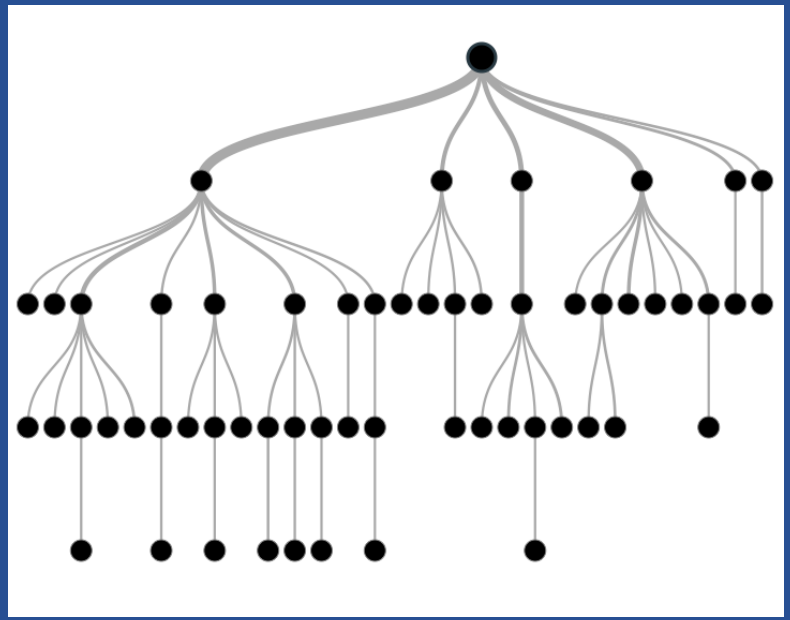
Feature set

For each segment

$P_1(swimming \mid X_1, \theta)$ $P_1(sitting \mid X_1, \theta)$ $P_1(running \mid X_1, \theta)$

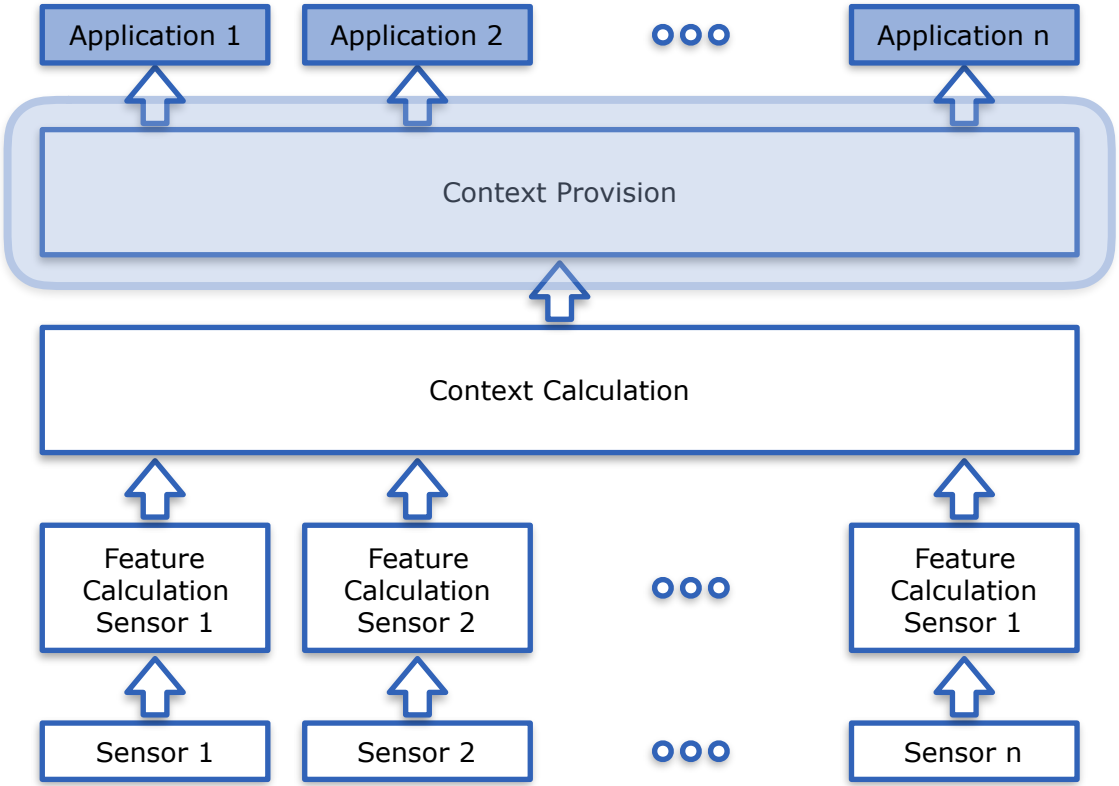
Context Determination

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



src: https://www.analyticsvidhya.com

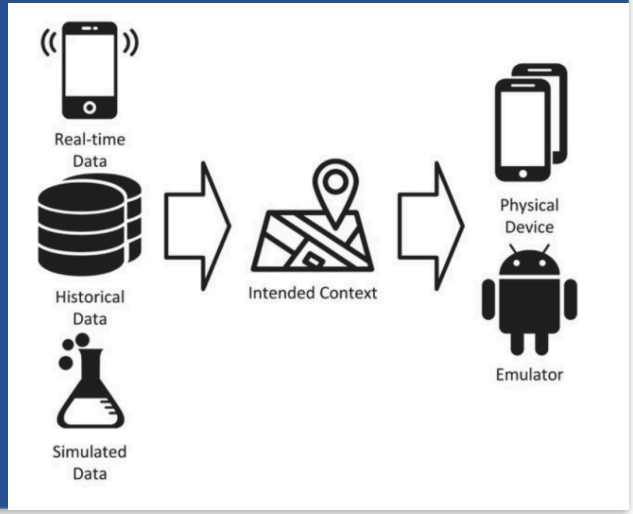
Reference Architecture for Context-Aware Computing Systems

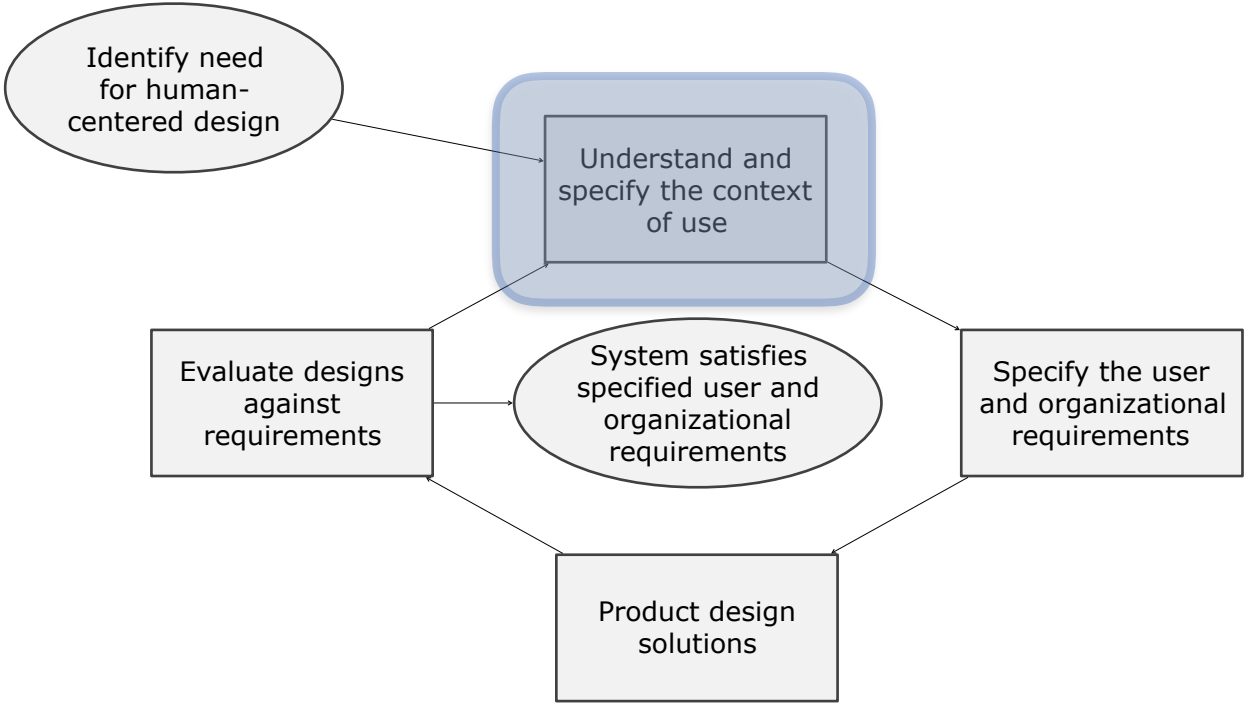


Tools for Building Context-Aware Systems

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

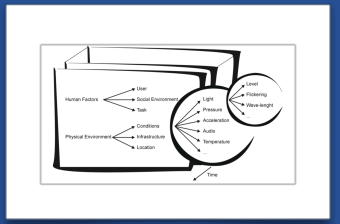


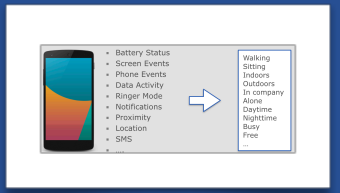


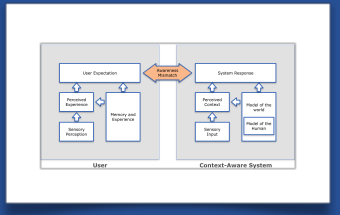
ISO 9241-210: Human-Centered Design Lifecycle

Guidelines for Application Designers

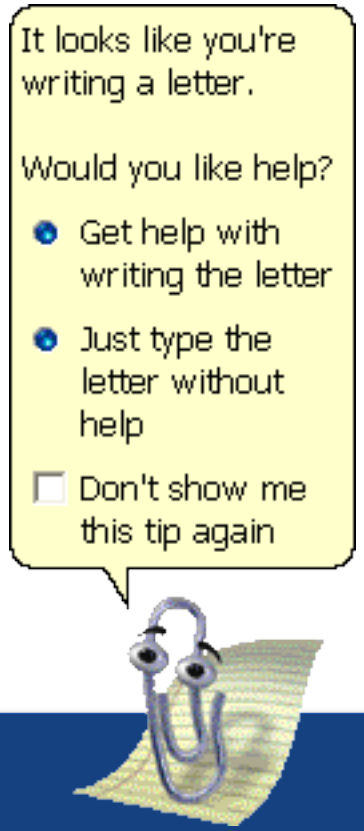
1. First, create a (hierarchical) **feature space** listing factors that will influence the system behavior.
2. Find **parameters** that are **characteristic** for the context to be detected and find means of measurement.
3. Determine **degree of proactiveness**.
4. **Provide information** about the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

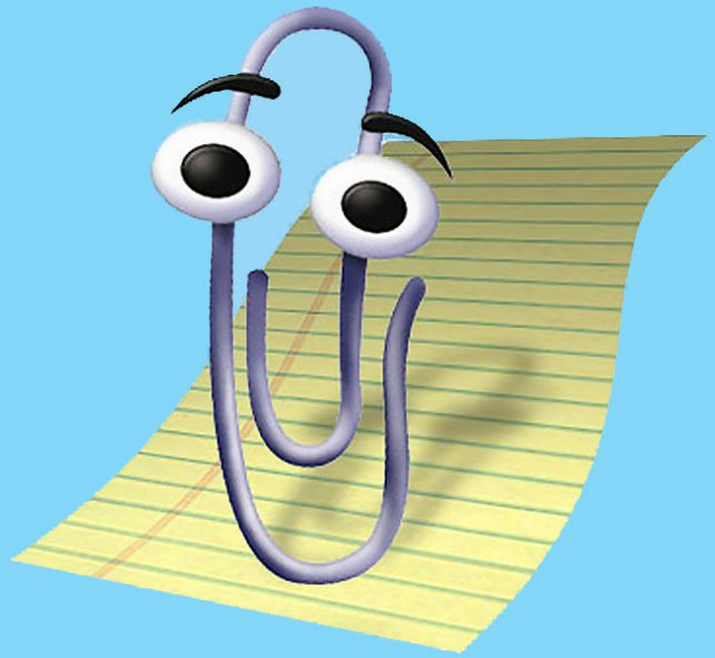




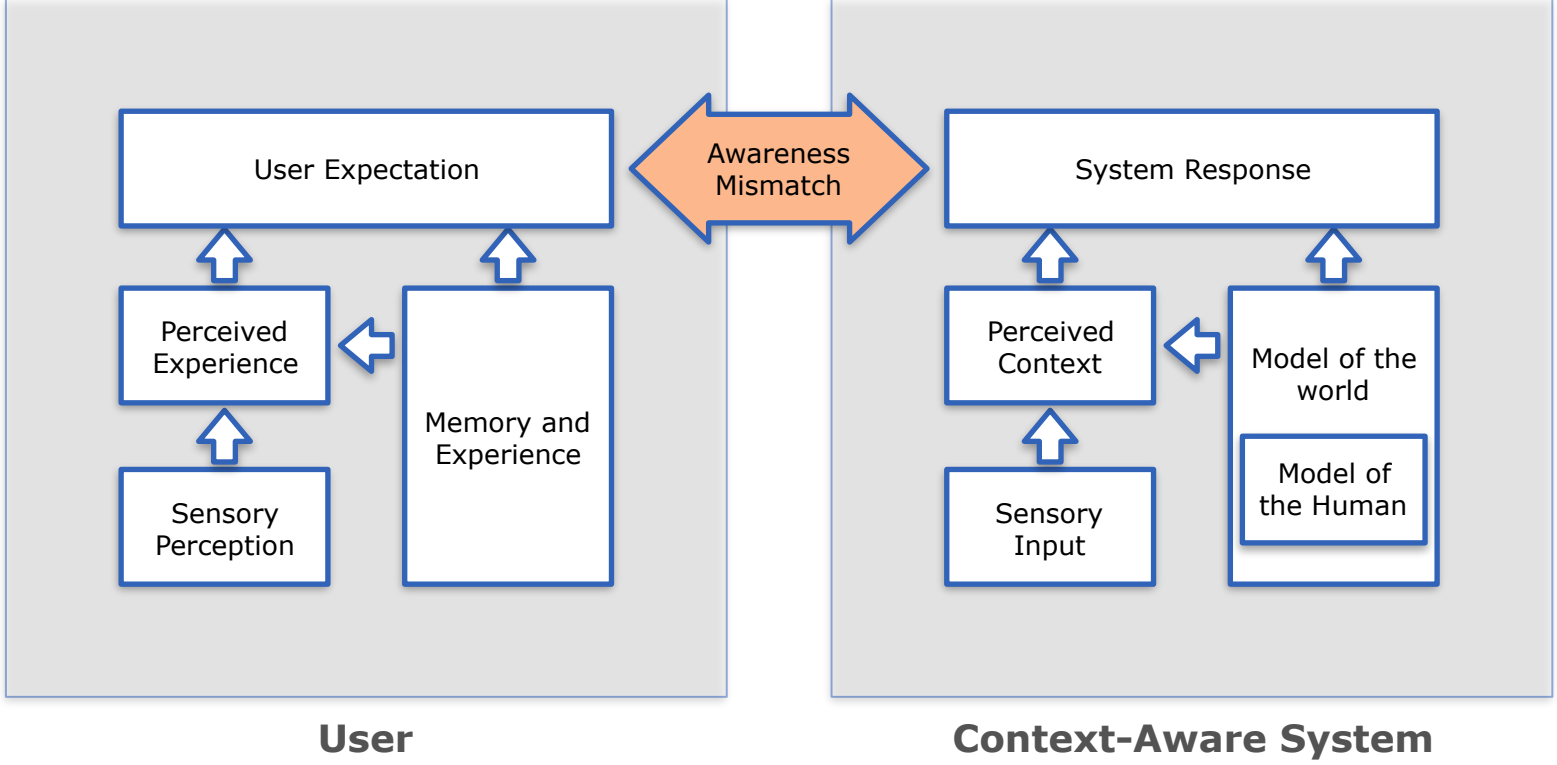


Challenges





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 Missmatch**"
- 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

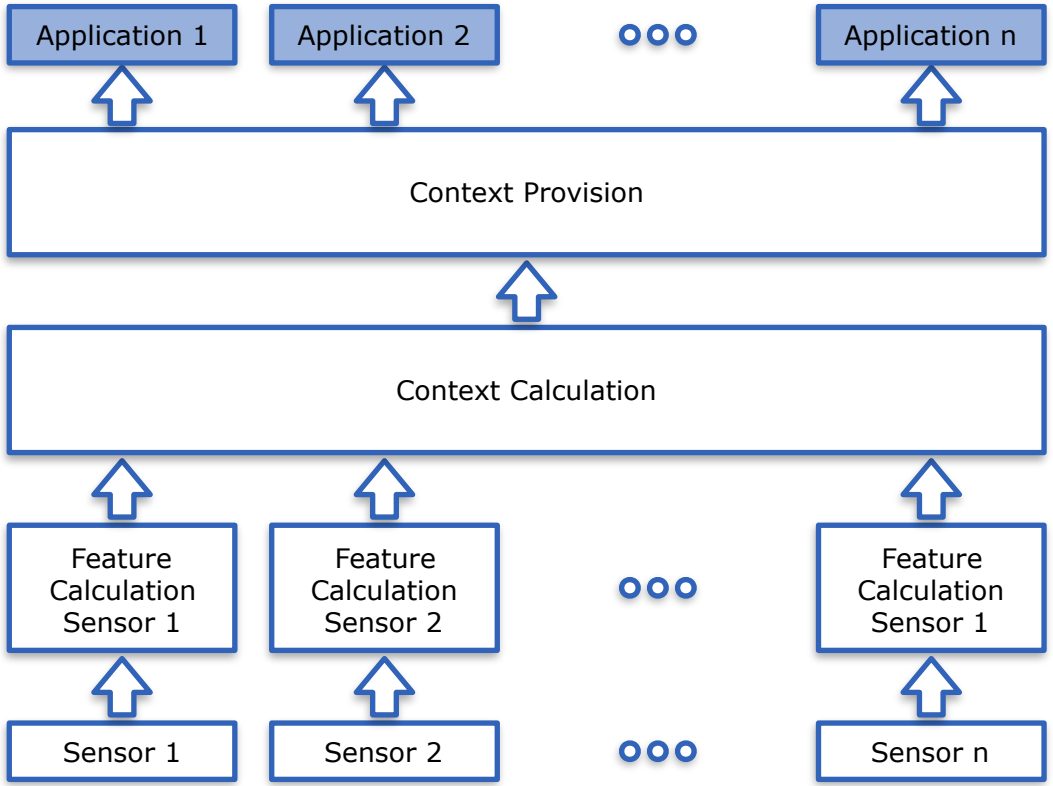
- Content-aware second-screen app

FLICKSTUFF

Incorporated 2016

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

Summary


Application 1
Application 2
Application n
Context Provision
Context Calculation
Feature Calculation Sensor 1
Feature Calculation Sensor 2
Feature Calculation Sensor 1
Sensor 1
Sensor 2
Sensor n

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**

Scarcity of Attention?

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

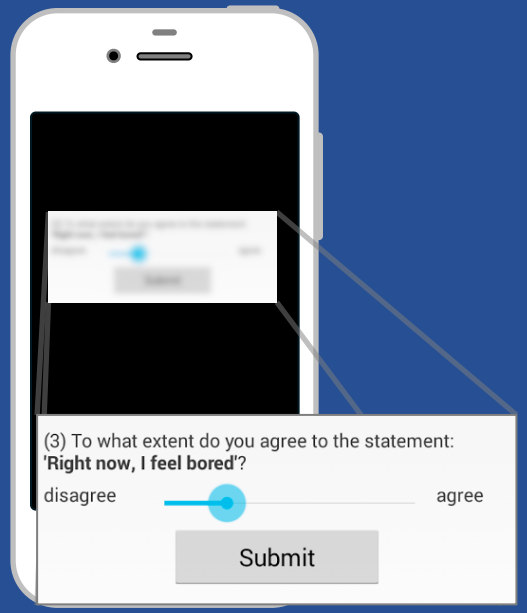
"a bored person is not just someone who does not have anything to do; it's someone who is **actively looking for stimulation**" *(Eastwood, 2002)*

Context: ‘Boredom’

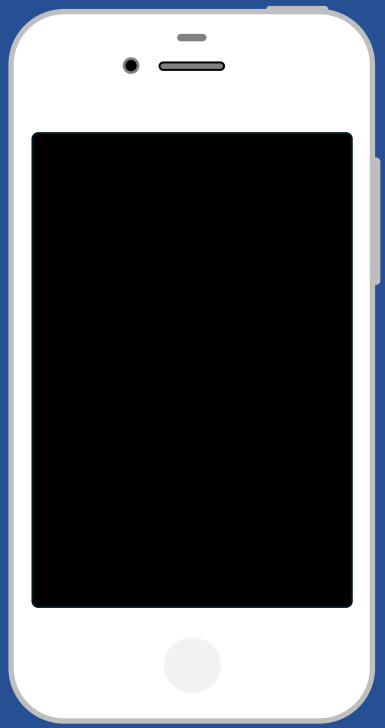
Field-Study: Detecting Boredom Throughout the Day

- **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

Always collected

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

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

M. Pielot, T. Dingler, J. S. Pedro, and N. Oliver. When attention is not scarce - detecting boredom from mobile phone usage. UbiComp '15, pages 825–836, New York, NY, USA, 2015. ACM

Feature Analysis: Boredom Usage Patterns

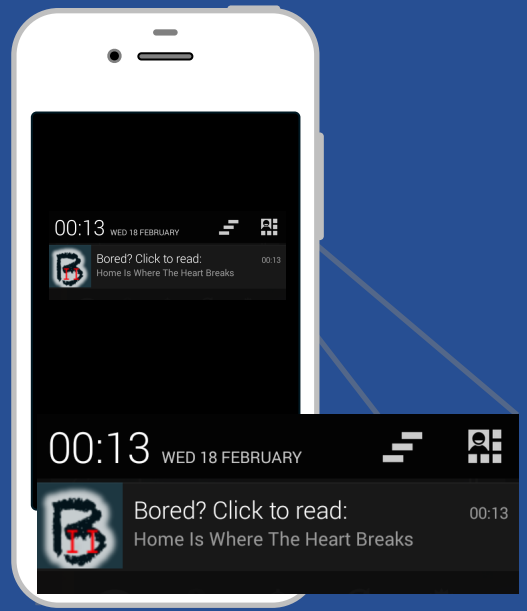
Feature	Import	Correlation	The more bored, the..
time_last_outgoing_call	0.0607	-0.143	less time passed
time_last_incoming_call	0.0580	0.088	more time passed
time_last_notif	0.0564	0.091	more time passed
time_last_SMS_received	0.0483	0.053	more time passed
time_last_SMS_sent	0.0405	-0.090	less time passed
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

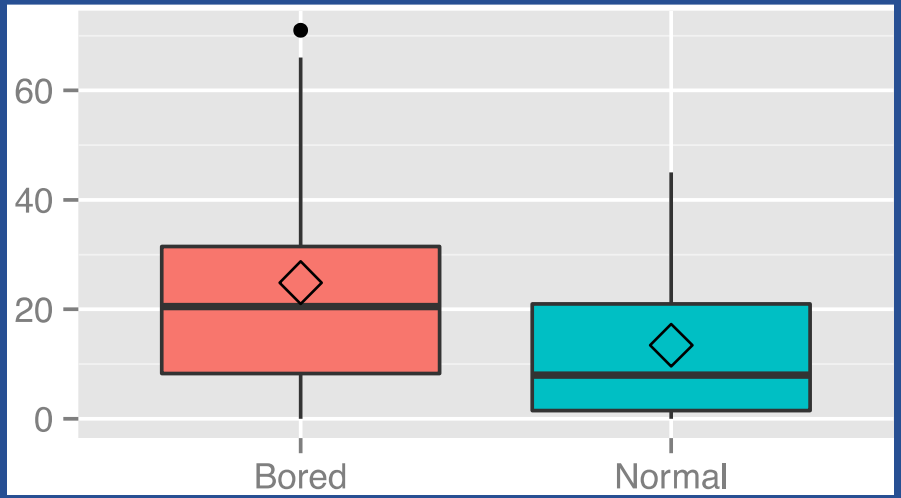
Using Boredom to Predict Opportune Moments for Content Delivery

- **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

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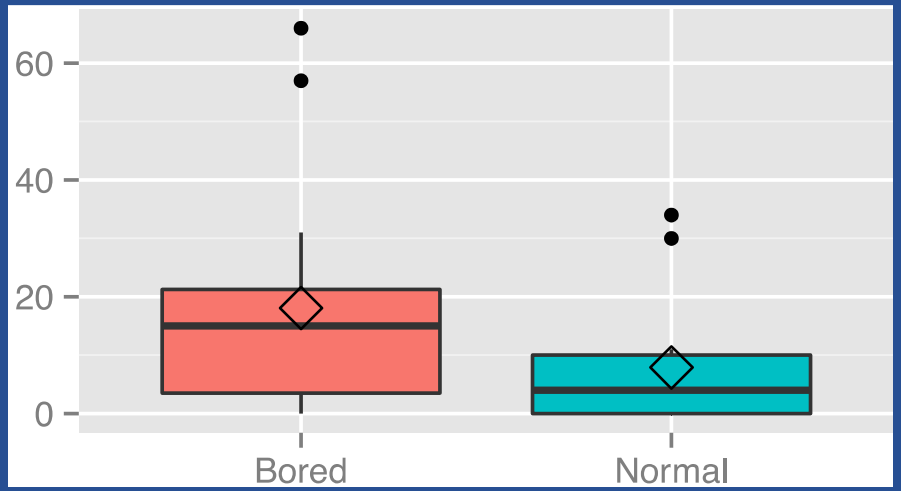
Results: Engagement



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

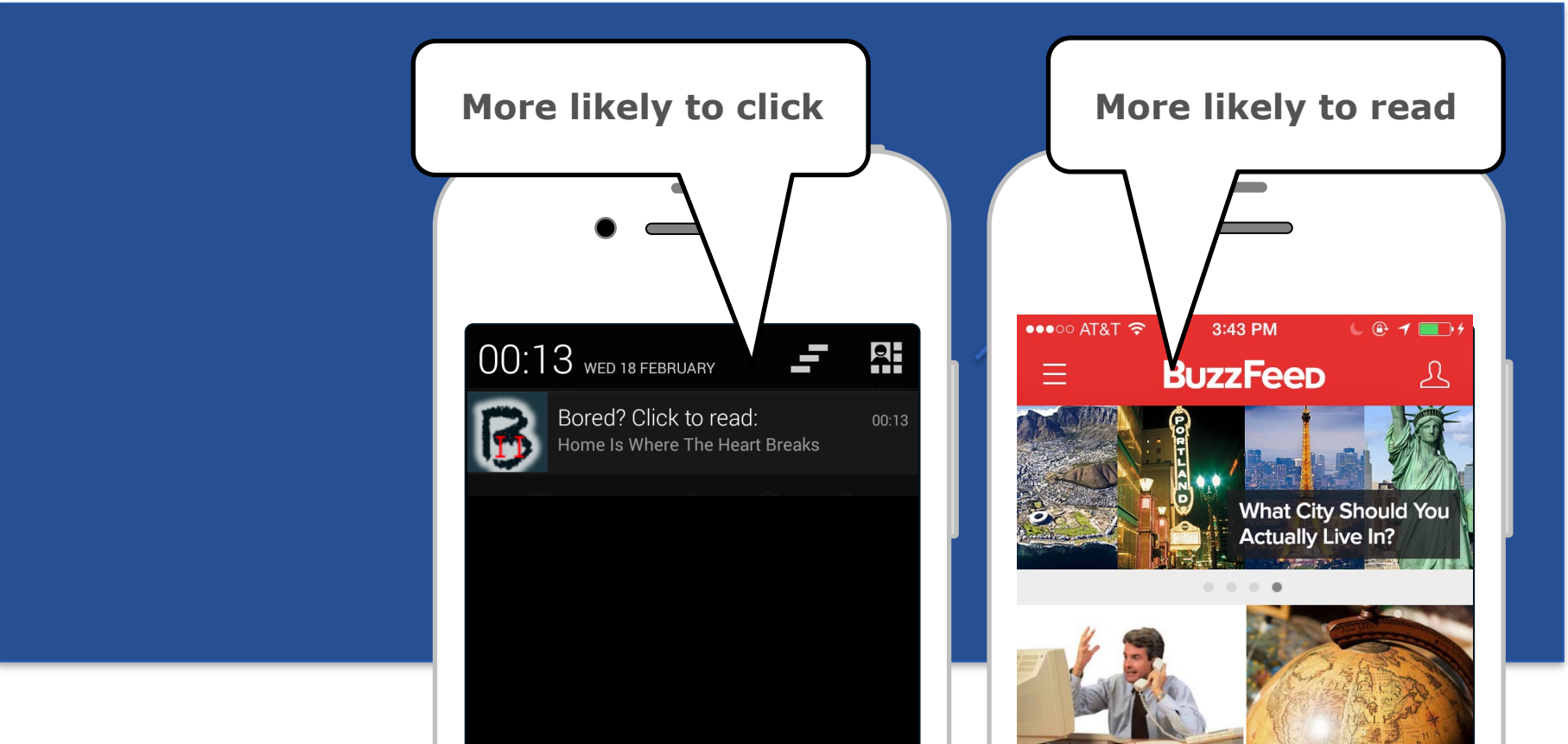
4% when **not bored**
15% when **bored**
(as inferred by the model)

Difference significant
z = -2.102, p = .018

Large effect
r = -.511

M. Pielot, T. Dingler, J. S. Pedro, and N. Oliver. When attention is not scarce - detecting boredom from mobile phone usage. UbiComp '15, pages 825–836, New York, NY, USA, 2015. ACM

When predicted bored, participants were …



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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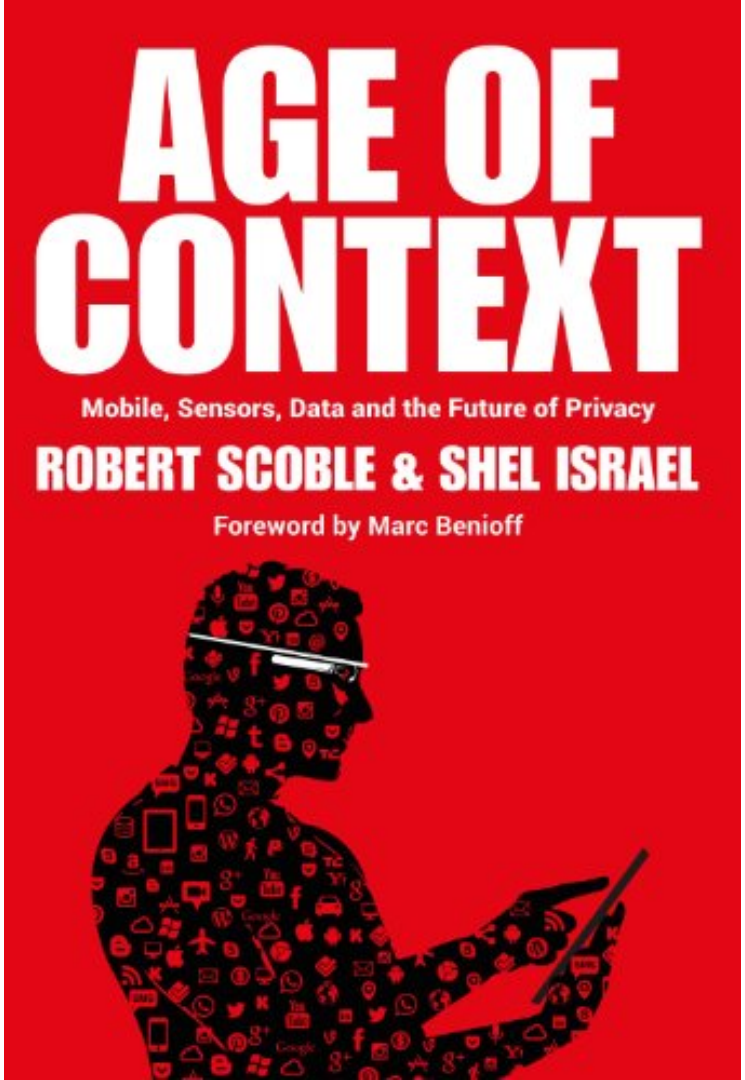
References and Further Readings



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