



Harnessing the power of hybrid AI for designing spatiotemporal behavioral markers for health and their dynamic visualization

Sofie Van Hoecke



**Intermittent, subjective self-reporting**



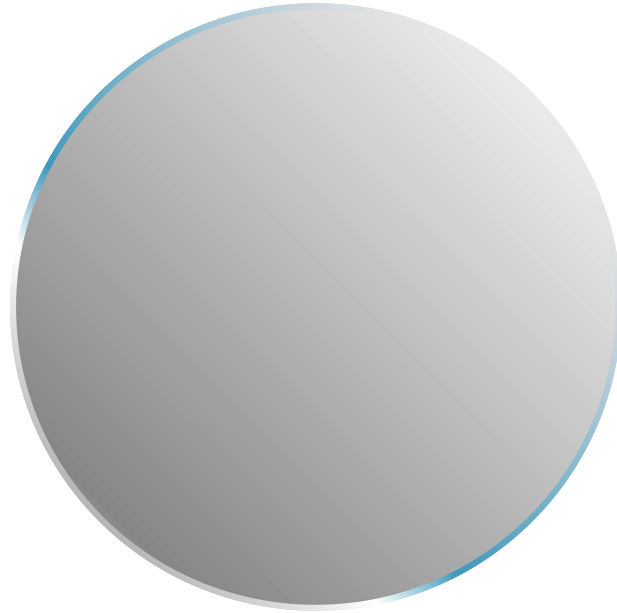
NAAM:

JAAR:

	DAG																														
2017	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
<b>2017</b>																															
<b>MAAND</b>																															
SEPTEMBER																															
HPScore																															
Behandeling																															
OCTOBER																															
HPScore																															
Behandeling																															
NOVEMBER																															
HPScore																															
Behandeling																															
DECEMBER																															
HPScore																															
Behandeling																															
JANUARI																															
HPScore																															
Behandeling																															
FEBRUARI																															
HPScore																															
Behandeling																															



We generate data



WEARABLE AND SMARTPHONE SENSORS

# Wearable sensors

Empatica E4



Heart rate

Skin temperature

Accelerometer

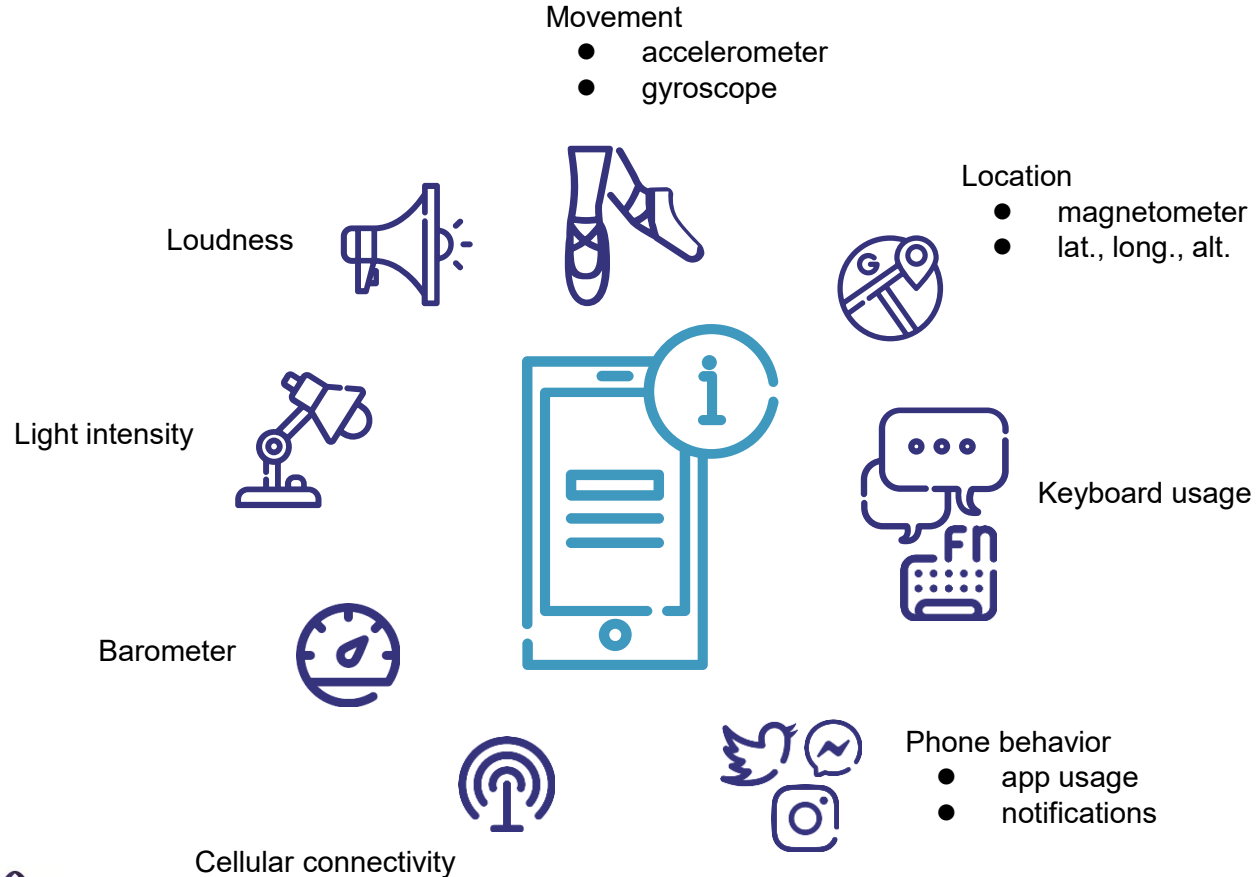
Skin conductance

Screen

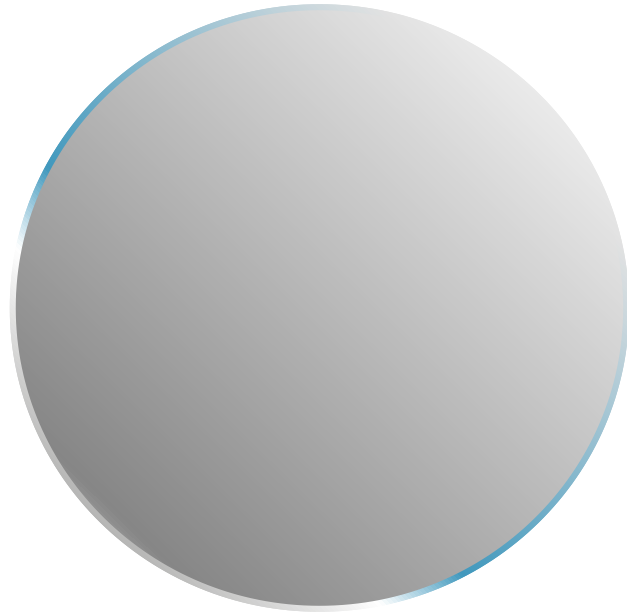
Gyroscope

imec chillband+

# Smartphone (virtual) sensors



We input data



DYNAMIC QUESTIONNAIRES

# Dynamic questionnaires

8:21 52%

× Stress mispredictie

Wat zijn volgens jou de mogelijke oorzaken van deze mispredictie?

- Klamme handen
- Gezweet
- Blozen, warm hebben
- Onaangenaam gevoel in mijn lichaam 1
- Fysieke activiteit - veel beweging
- Fysieke activiteit - weinig beweging 1
- Positieve emoties 1
- Geen van bovenstaande

Anders: (tik tekstveld om te typen)

← →

8:18 53%

× Ochtendvragenlijst

Op dit moment voel ik mij:

- 1 6 7  
moe wakker
- 1 2 7  
vol energie zonder energie
- 1 2 7  
tevreden ontevreden
- 1 6 7  
onrustig rustig
- 1 2 7  
ontspannen gespannen
- 1 7  
onwel/ziek goed/gezond

← →

1:38 30%

× Avondvragenlijst

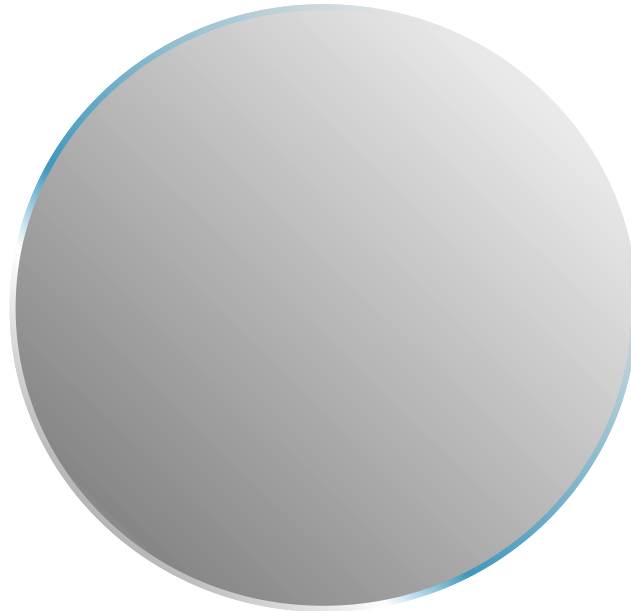
Hoe vaak voelde je vandaag

- ... dat je geen controle had over de belangrijke dingen in jouw leven  
0 3 4  
nooit zeer vaak
- ... dat je jouw persoonlijke problemen aankon?  
0 2 4  
nooit zeer vaak
- ... dat dingen gingen zoals jij dat wilde?  
0 3 4  
nooit zeer vaak
- ... dat moeilijkheden zich zo hoo...

← →

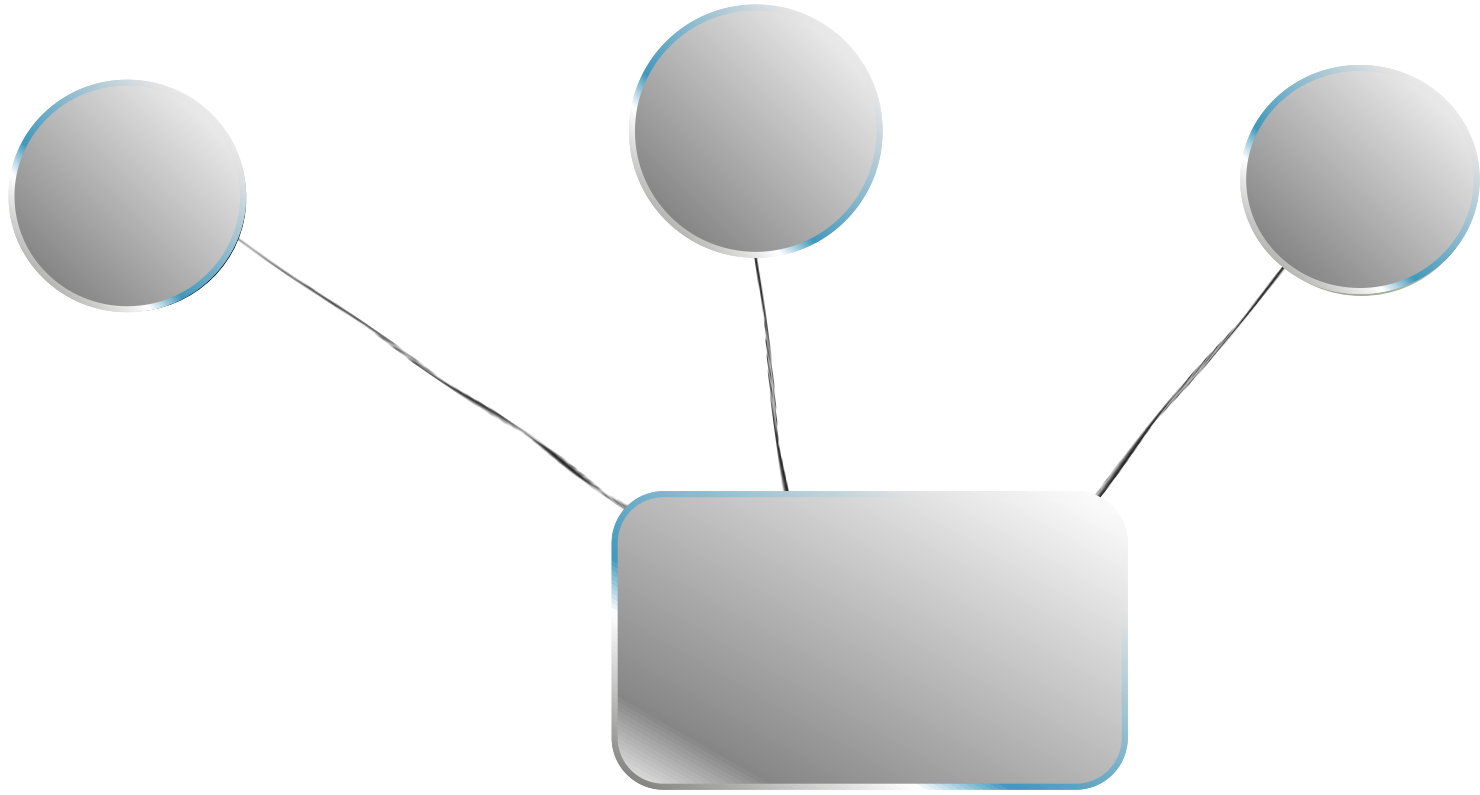


Even if we speak, we generate data



SPEECH

By combining and analysing data, it becomes valuable



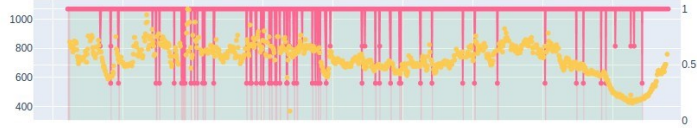
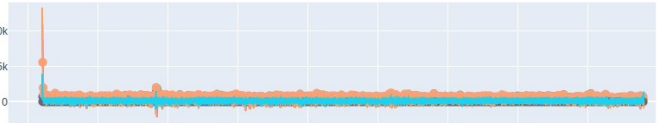
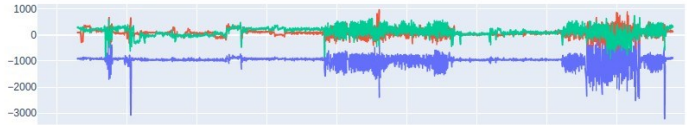
SPATIO-TEMPORAL  
BEHAVIORAL MARKERS

By combining and analysing data, it becomes valuable



SPATIO-TEMPORAL  
BEHAVIORAL MARKERS

# By combining and analysing data, it becomes valuable

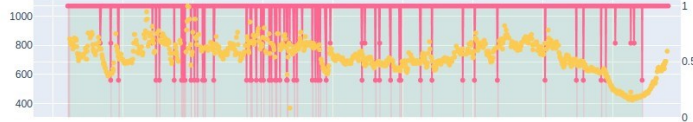
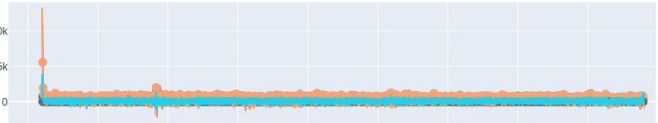
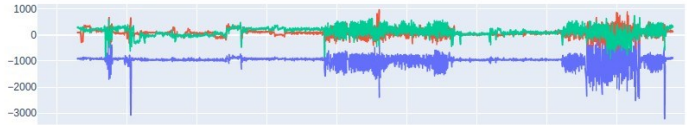


- [R] ACC\_x ~1s
- [R] ACC\_y ~1s
- [R] ACC\_z ~1s
- [R] ecg ~1s
- ECG\_R\_Peaks\_ECG\_neurokit
- ECG\_R\_Peaks\_ECG\_neurokit\_threshold
- ECG\_R\_Peaks\_ECG\_scipy\_100Hz\_cleaned\_biosppy\_neurokit
- [R] ECG\_scipy\_100Hz\_cleaned\_biosppy ~1s
- ECG\_R\_Peaks\_ECG\_scipy\_100Hz\_cleaned\_biosppy\_neurokit\_threshold
- ECG\_R\_Peaks\_ECG\_scipy\_100Hz\_neurokit
- [R] ECG\_scipy\_100Hz ~1s
- ECG\_R\_Peaks\_ECG\_scipy\_100Hz\_neurokit\_threshold
- ECG\_R\_Peaks\_processed
- [R] ECG\_cleaned\_biosppy ~1s
- [R] r\_peak\_agreement ~1s
- [R] GARMIN hr ~1s
- [R] ECG -> HR ~1s
- [R] HRV\_ms ~1s
- [R] polar-algo: HR ~1s



SPATIO-TEMPORAL  
BEHAVIORAL MARKERS

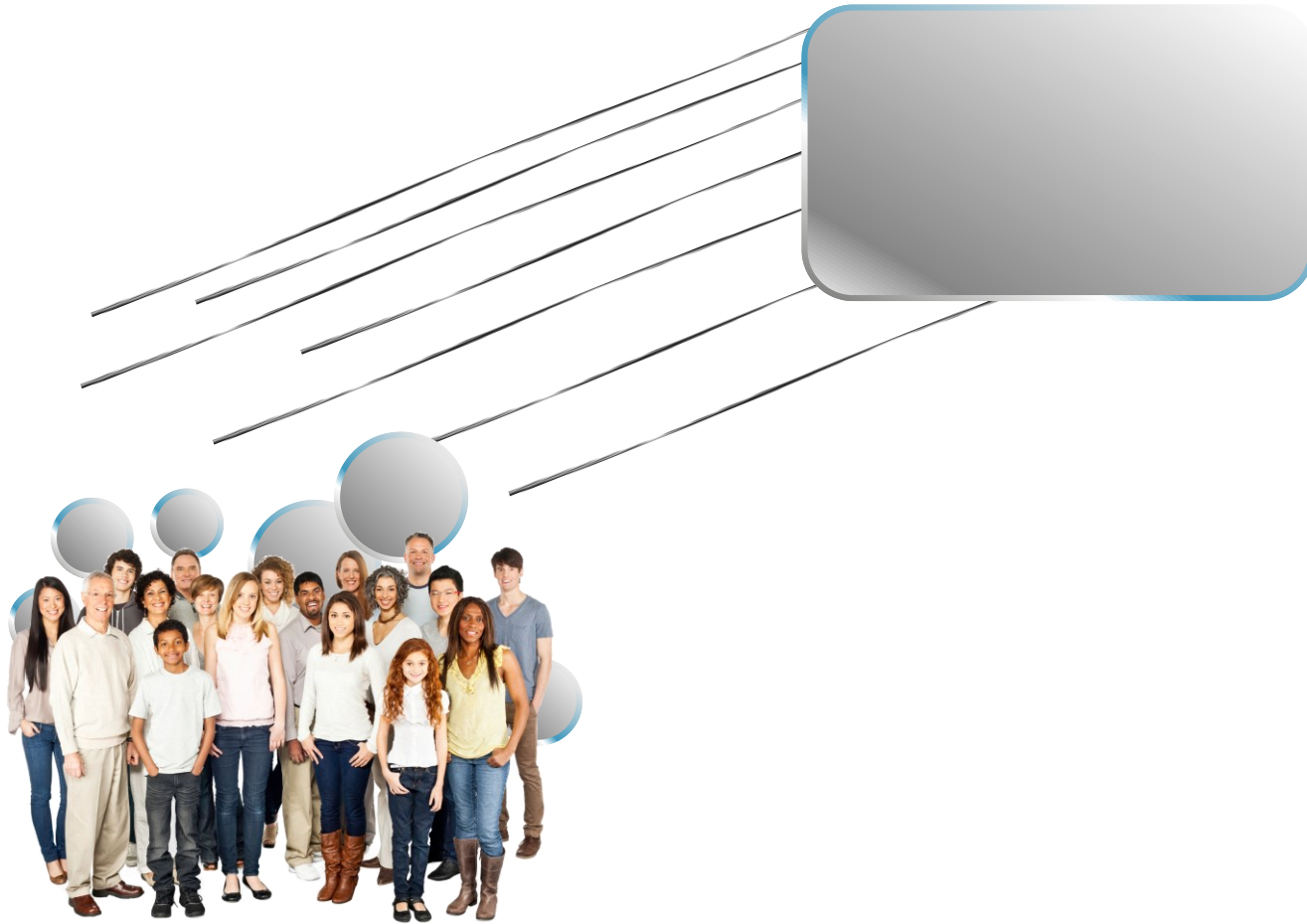
# By combining and analysing data, it becomes valuable

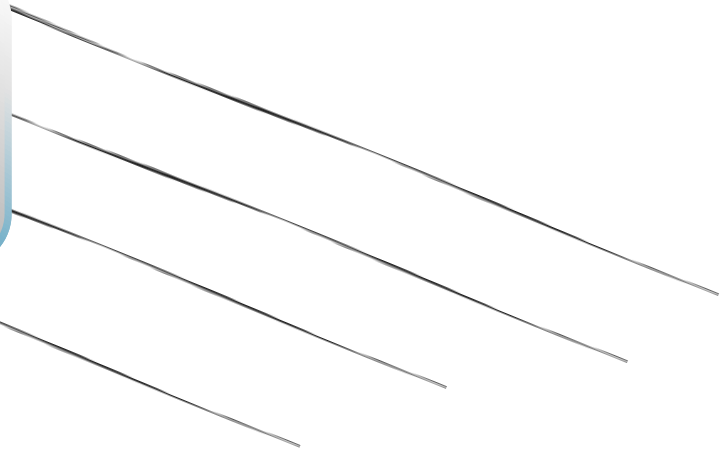


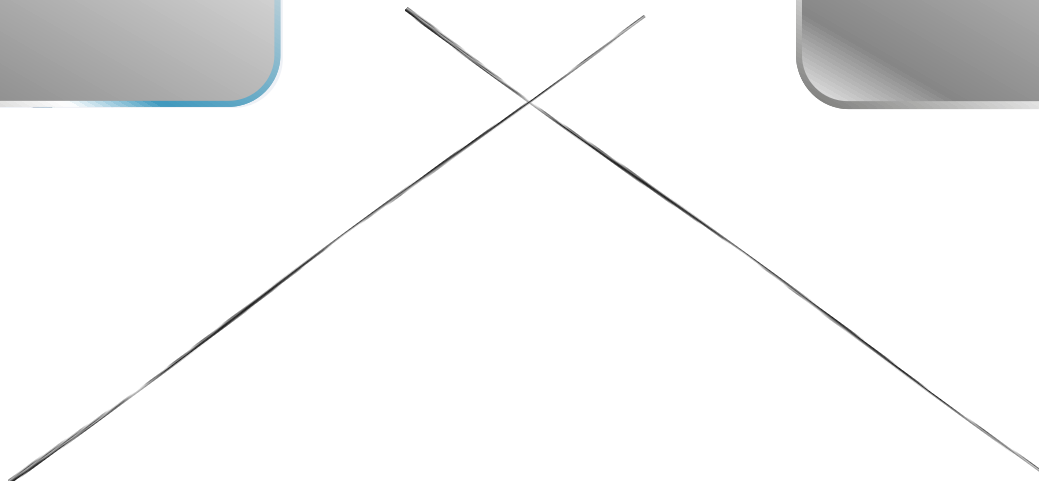
- [R] ACC\_x ~1s
- [R] ACC\_y ~1s
- [R] ACC\_z ~1s
- [R] ecg ~1s
- ECG\_R\_Peaks\_ECG\_neurokit
- ECG\_R\_Peaks\_ECG\_neurokit\_threshold
- ECG\_R\_Peaks\_ECG\_scipy\_100Hz\_cleaned\_biosppy\_neurokit
- [R] ECG\_scipy\_100Hz\_cleaned\_biosppy ~1s
- ECG\_R\_Peaks\_ECG\_scipy\_100Hz\_cleaned\_biosppy\_neurokit\_threshold
- ECG\_R\_Peaks\_ECG\_scipy\_100Hz\_neurokit
- [R] ECG\_scipy\_100Hz ~1s
- ECG\_R\_Peaks\_ECG\_scipy\_100Hz\_neurokit\_threshold
- ECG\_R\_Peaks\_processed
- [R] ECG\_cleaned\_biosppy ~1s
- [R] r\_peak\_agreement ~1s
- [R] GARMIN hr ~1s
- [R] ECG -> HR ~1s
- [R] HRV\_ms ~1s
- [R] polar-algo: HR ~1s



SPATIO-TEMPORAL  
BEHAVIORAL MARKERS



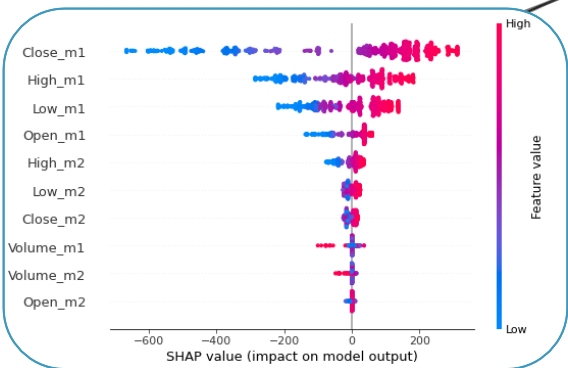






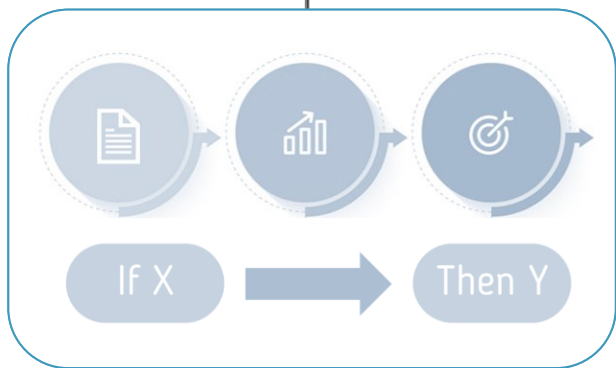
# EXPLAINABLE HYBRID AI

## MODEL EXPLAINABILITY



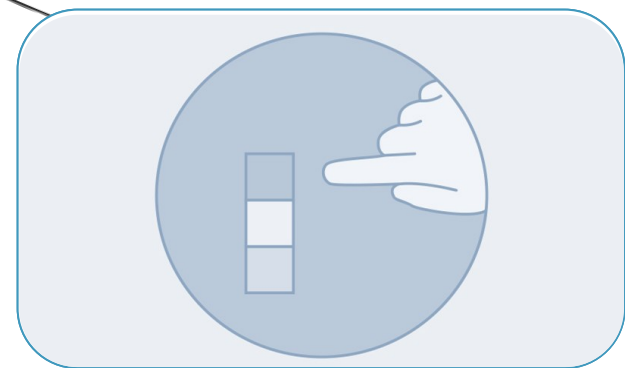
E.g., feature importance

## CORRELATION DERIVATION



E.g., migraine triggers

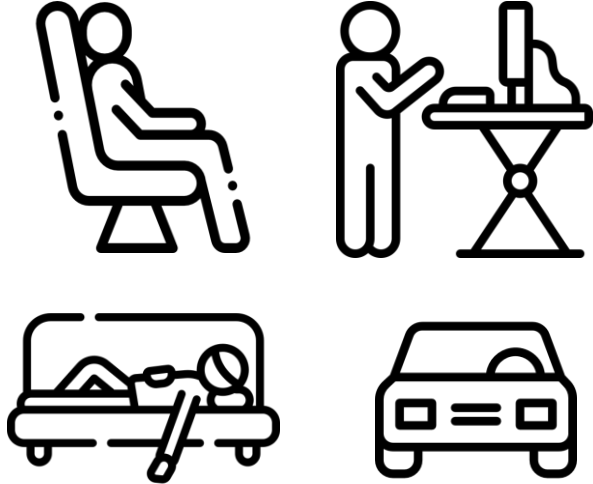
## CAUSAL AI



E.g., treatment effect

# Activity recognition

## Sedentary



## Dynamic



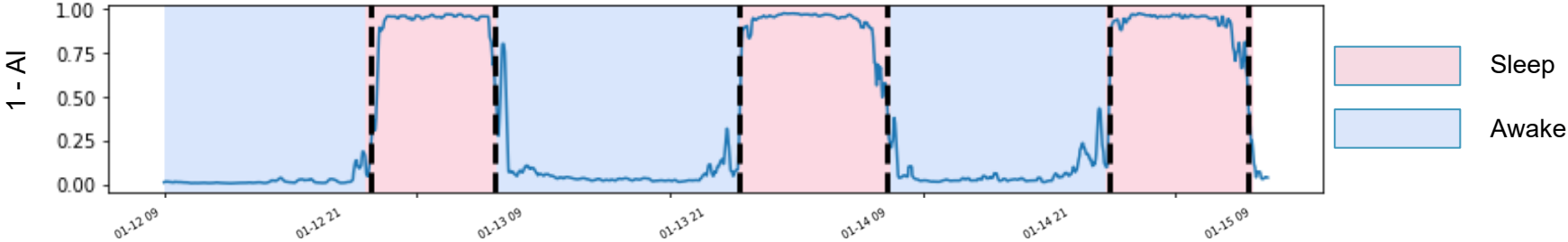
- Extra context info:
- location & route
  - speed & cadence

# Sleep detection

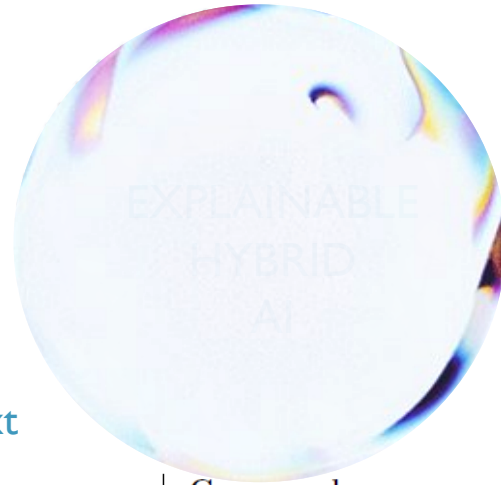


Google sleep API

Activity index (AI) + segmentation



# Stress detection



## Added value of context

Model	Accuracy (std)	Cohen Kappa (std)	Weighted F1 (std)	Compared to Dummy (std)
Baseline (Physio)	40.57 (3.48)	7.80 (1.98)	42.11 (3.08)	6.31 (2.53)
Baseline + Activity	43.09 (0.67)	9.75 (0.09)	44.47 (0.44)	8.68 (0.11)
Baseline + Sleep	42.47 (0.72)	9.51 (0.12)	43.88 (0.59)	8.09 (0.03)
Baseline + Activity + Sleep	45.52 (2.58)	11.19 (1.58)	46.03 (2.12)	10.23 (2.68)

Incorporating activity, sleep or both into baseline model improves stress level classification (accuracy increase, but also std dev decrease)

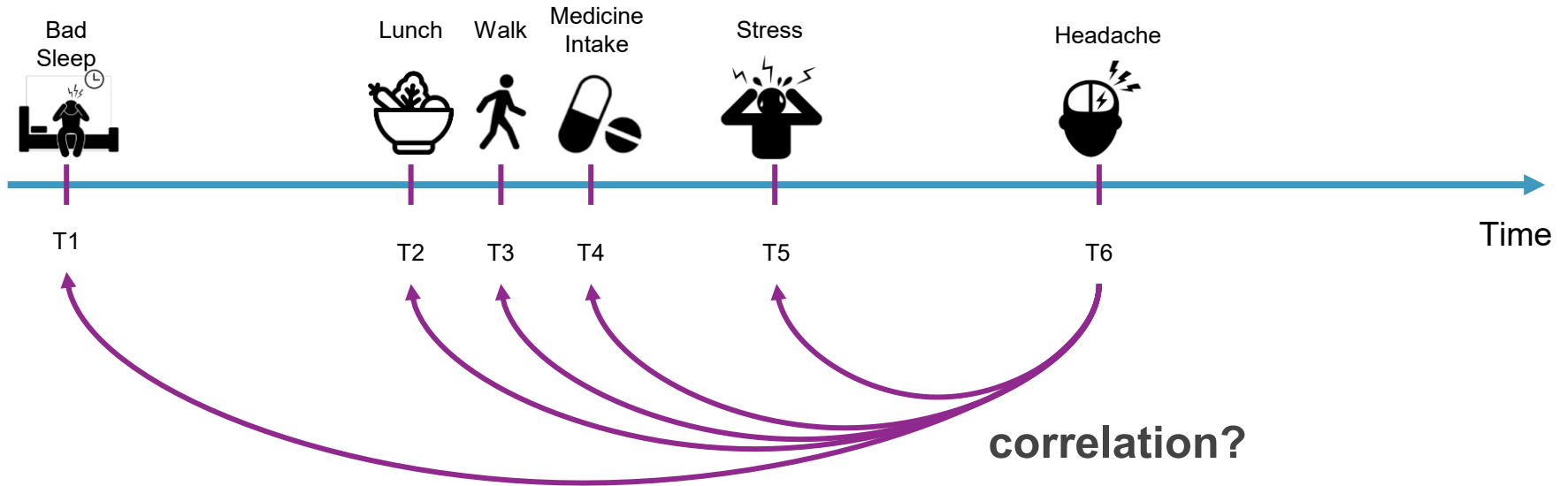
Incorporating both = best model

→ **context matters**

→ **currently further extending towards spatiotemporal context**

# Trigger detection

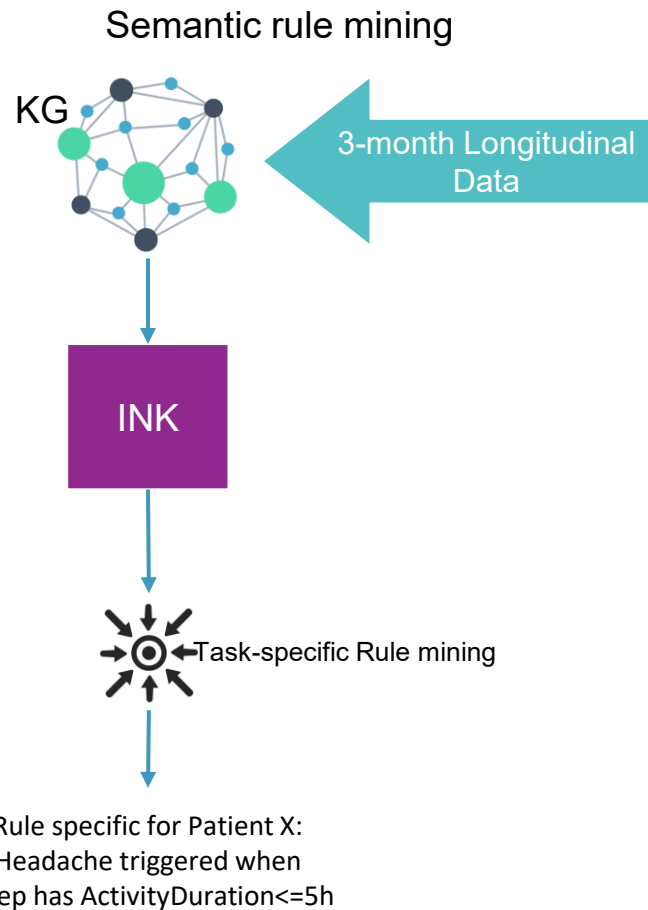
Finding correlations between a headache and previous events



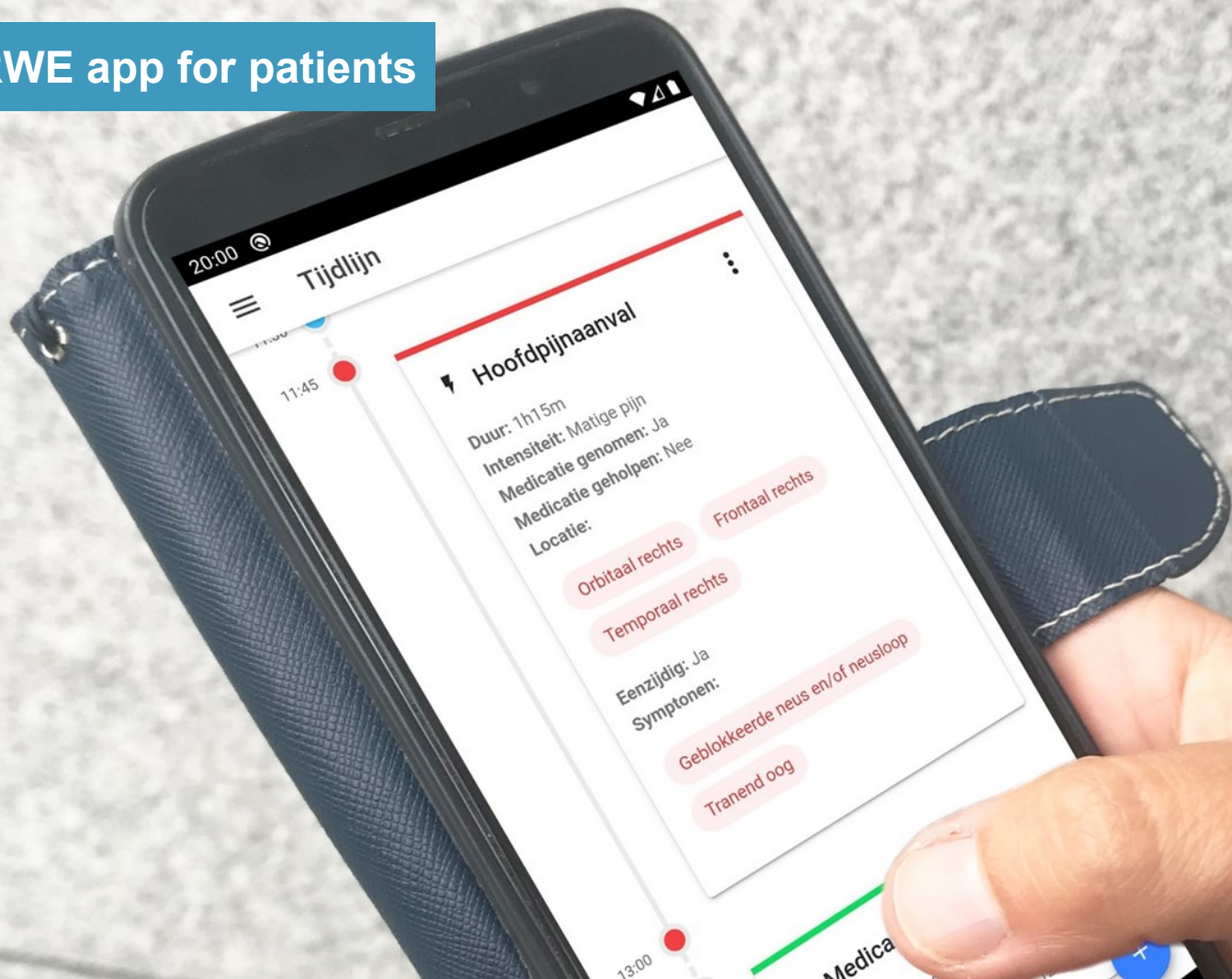
# Trigger detection

## Time-based Apriori via ML rule mining

Trigger	Proportion
Bad sleep	0.61
Medication	0.61
Current menstruation	0.50
Abnormal sleeping	0.39
Abnormal low stress	0.28
Commuting	0.28
Abnormal high stress	0.22



# RWE app for patients





# Activities

17 May 2022



16 Oct 2021



NORMAAL

DETAILED

15:22

**Sedentary** ✓

Activity Index: low



17:39

16:54

**Headache**

20:55

17:14

**Medicine**

17:14

11:27



16 Oct 2021



NORMAAL

GEDETAILLEERD

23:13<sup>1</sup>

**Sedentair** ✓

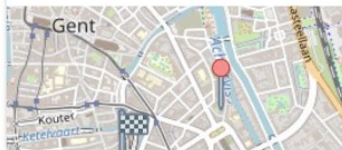
dichtbij Appartement  
Louise

08:52

08:53

**Wandelen**

Snelheid: 5.13 km/u  
Cadans: 114 stappen per minuut  
Activiteitsindex: medium



09:02

09:11

**Sedentair** ✓

11:10

11:28



16 Oct 2021



NORMAAL

GEDETAILLEERD

23:38<sup>1</sup>

**Liggen** ✓

dichtbij Appartement  
Louise

07:22

07:23

**Sedentair** ✓

dichtbij Appartement  
Louise

07:27

07:28

**Liggen** ✓

dichtbij Appartement  
Louise

08:05

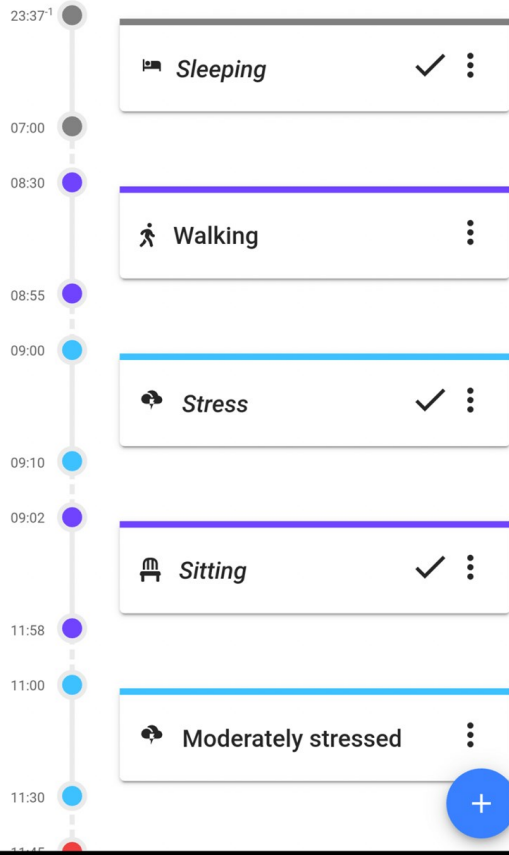
08:06

**Zitten** ✓

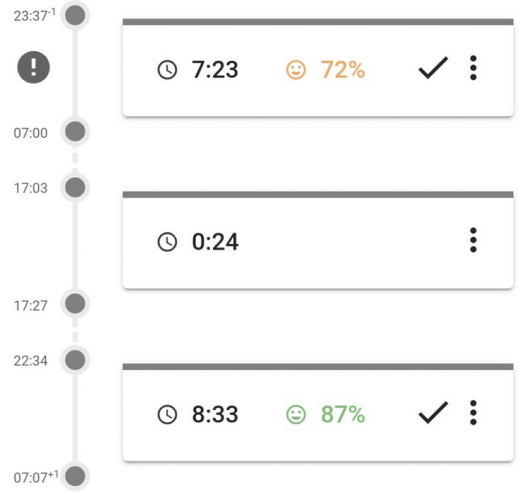
dichtbij Appartement  
Louise



← 4 Jun 2020 →



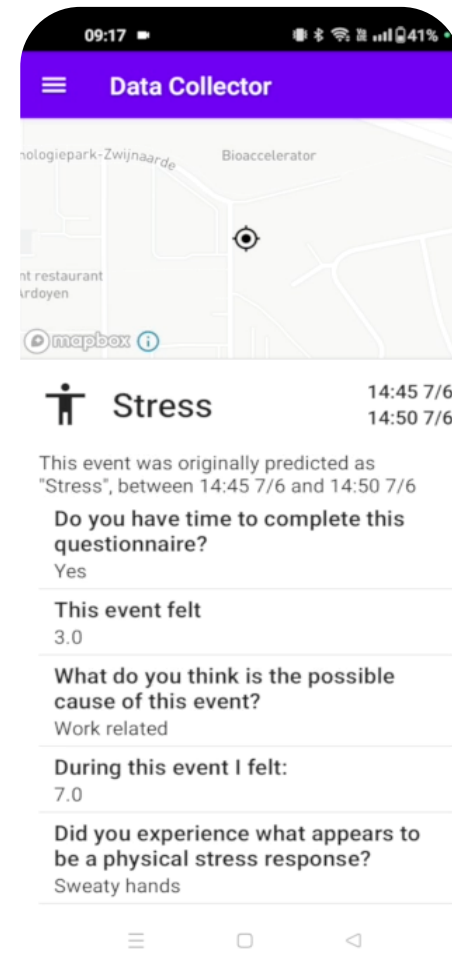
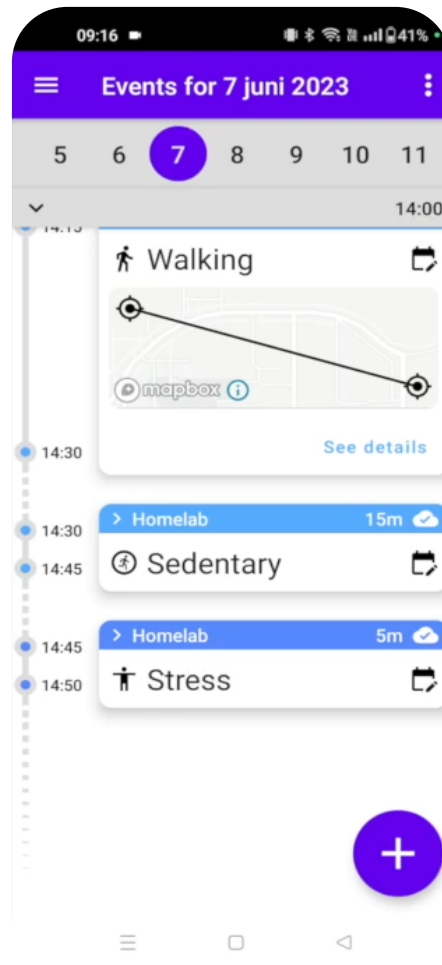
← 4 Jun 2020 →



Sleep



Stress



# User can add (and label) events

1:57 28%

← Add Medicine SUBMIT

**Time**  
Choose the time of a medicine intake

Time 14 Apr 2022 13:57

**Medicine**  
Choose the medicine taken

CHOOSE MEDICINE

Medicine chosen: Paracetamol 500mg (oral)

15:07

← Add Headache SUBMIT

**Intensity**  
Choose the intensity of a headache

CHOOSE INTENSITY

Chosen intensities: Severe

**Time**  
Select the time of the headache-

Start time 20 Oct 2020 10:30

End time 20 Jun 2020 12:00

**Location**  
Choose the location of the headache

CHOOSE LOCATION

Location chosen:

Temporal Right Parietal Right

My headache is unilateral

Yes

No

14:03

☰ Timeline

← 4 Jun 2020 →

23:37<sup>1</sup> 🛌 Sleeping ✓ ⋮

07:00

08:30 🚶 Walking ⋮

08:55

09:00 🌀 Stress ✓ ⋮

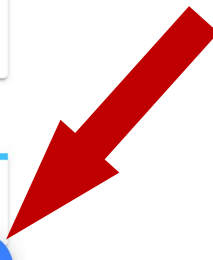
09:10

09:02 🪑 Sitting ✓ ⋮

11:58

11:00 🌀 Moderately stressed ⋮

11:30 +



patient\_id MBRAIN21-025

t\_start 2022\_10\_28

t\_end 2022\_11\_26

label snooze

# In-house designed labeling dashboard

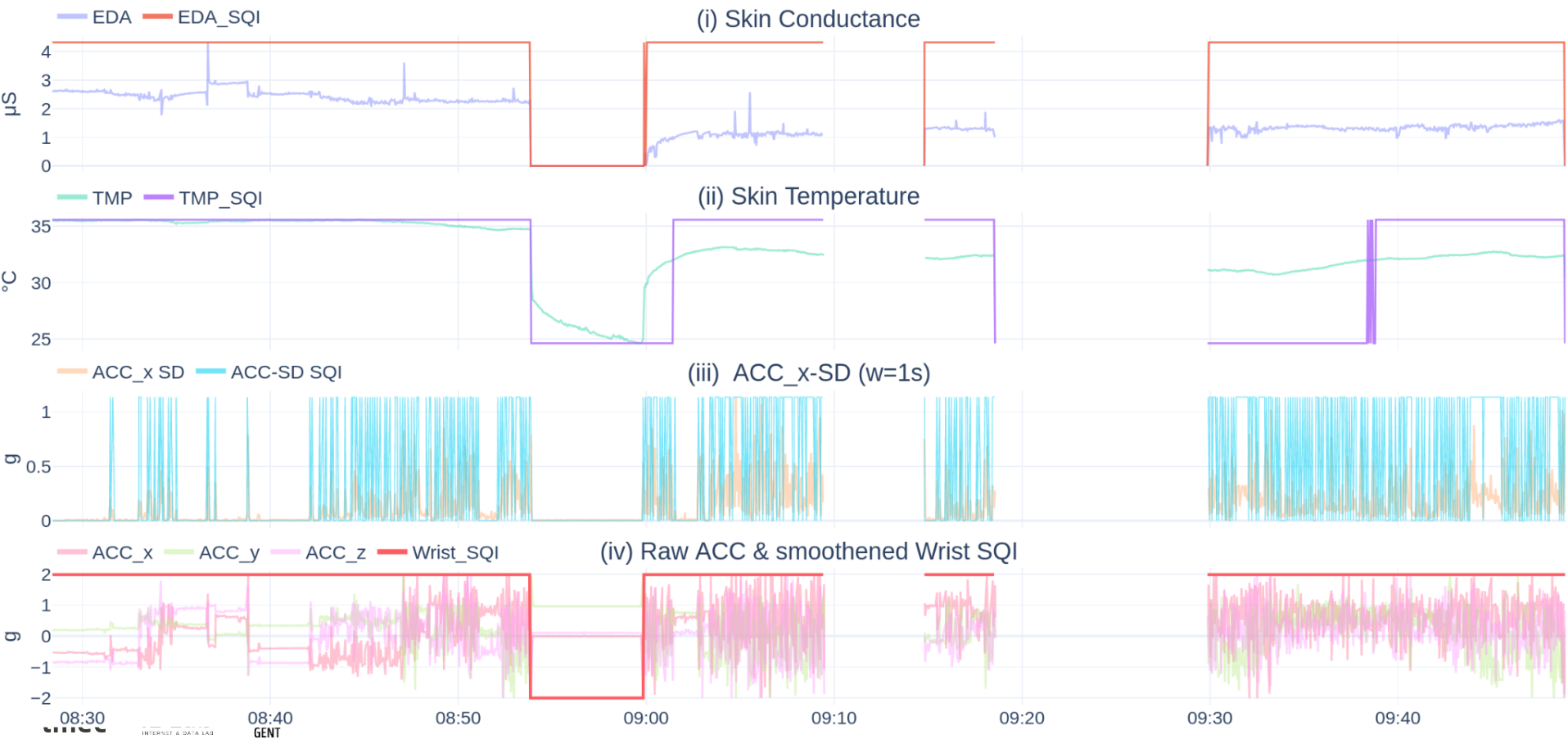
Run Interact



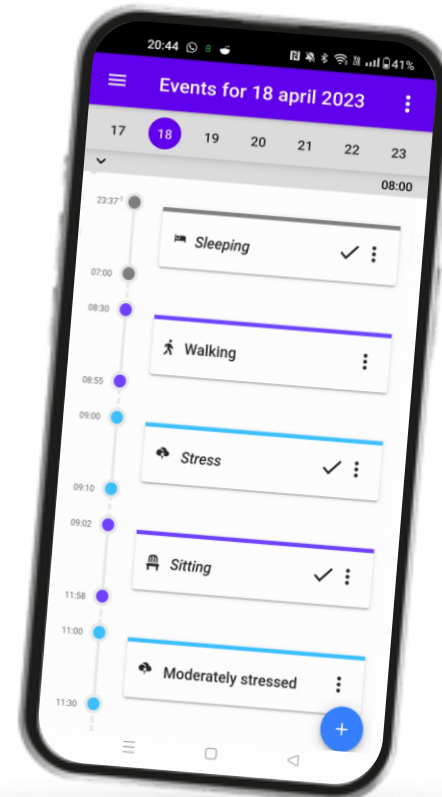
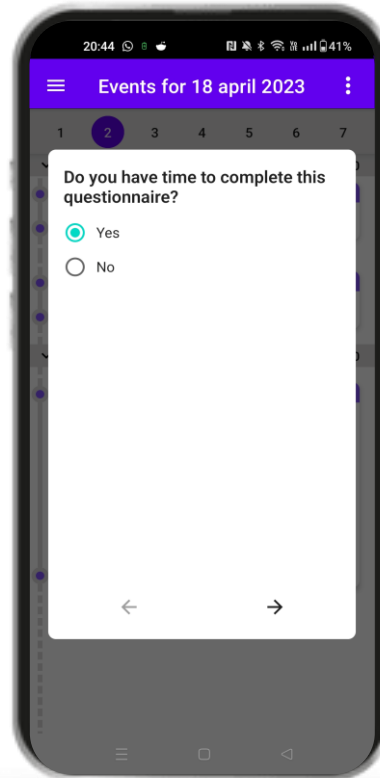
- [R] e4\_EDA ~5m
- [R] e4\_TMP ~5m
- [R] e4\_IBI ~5m
- [R] e4\_BVP ~5m
- [R] e4\_ACC\_y ~5m
- [R] e4\_ACC\_z ~5m
- [R] e4\_ACC\_x ~5m
- [R] app\_name ~5m
- screen\_state
- [R] keyboard ~5m
- [R] lux ~5m
- [R] x ~6m

be.telenet.tv  
 com.adobe.reader  
 com.google.android.projection.gearhead  
 com.kbc.mobile.android.oob  
 com.google.android.apps.photos  
 NULL package name  
 com.samsung.android.biometrics.app.setting

# Automatically detecting wearable non-wear



# RWE app for patients



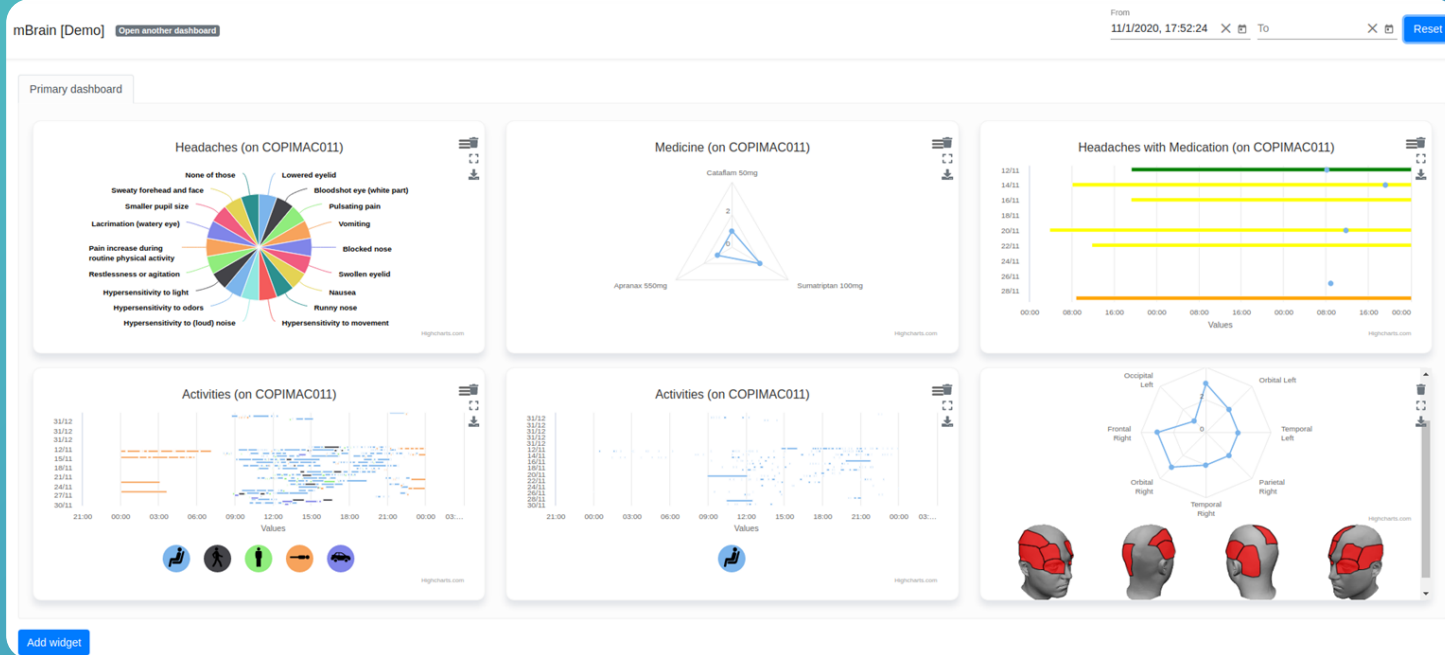
# RWE dashboard for clinicians

## DYNAMIC CLINICIAN DASHBOARDS



# RWE dashboard for clinicians

## DYNAMIC CLINICIAN DASHBOARDS





# Semantic description of sensors and services



# Semantically describing all (virtual) sensors

## Body Sensors

- ✦ Smartwatch
  - ✦ GPS
  - ✦ Heart Rate
  - ✦ ...
- ✦ Body Temperature
- ✦ GlucoMeter
- ✦ ...

## Environment Sensors

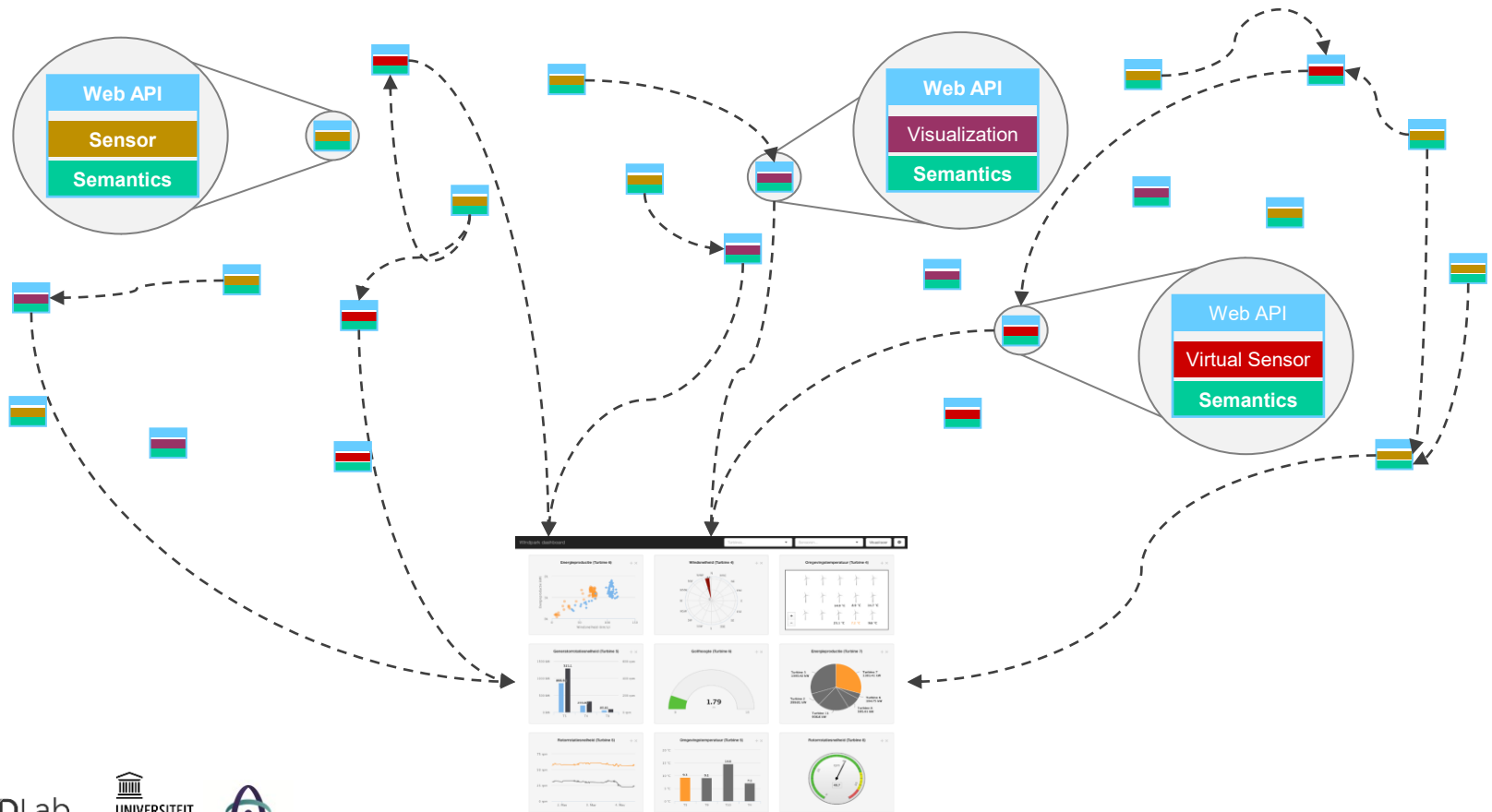
- ✦ Presence Detection
- ✦ Temperature Sensors
- ✦ CO2 Sensors
- ✦ ...

## Virtual Sensors

- ✦ Human Labeling
  - ✦ Migraine Attacks
- ✦ Stress Detection
- ✦ Activity Recognition
- ✦ Sleep Detection
- ✦ ...

And similar for all visualization widgets...

# Semantic description of sensors and services



# DYNAMIC CLINICIAN DASHBOARDS

Dynamic dashboard Dashboards Help Admin

mbrain

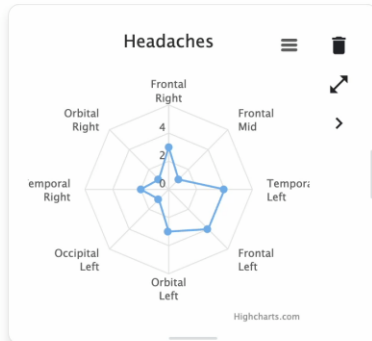
Migraine Make public

From 2/28/2022, 10:00:25

To 5/15/2022, 10:00:38

Reset

MBRAIN21-027 MBRAIN21-029 Interaction rate DEMO

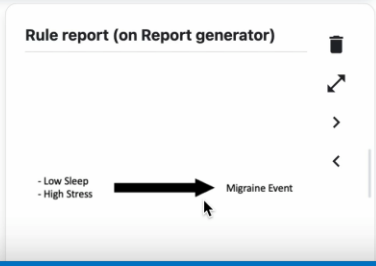
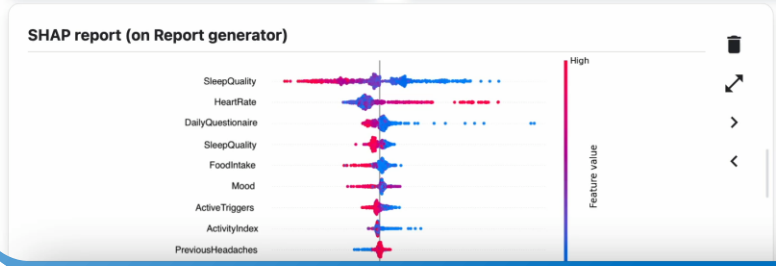


Hide events

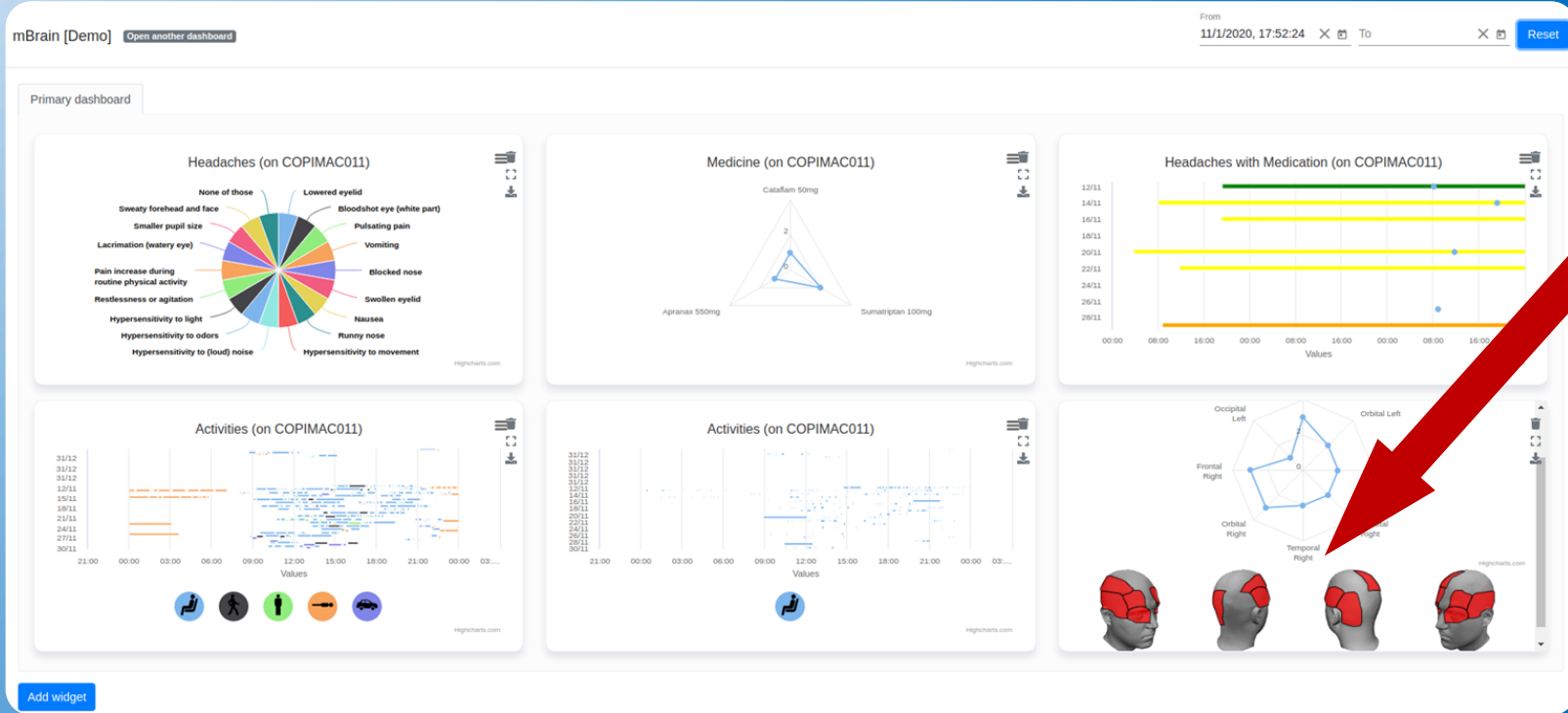
No events detected.

Fetch historical event alerts since:

Choose 'from'-date...



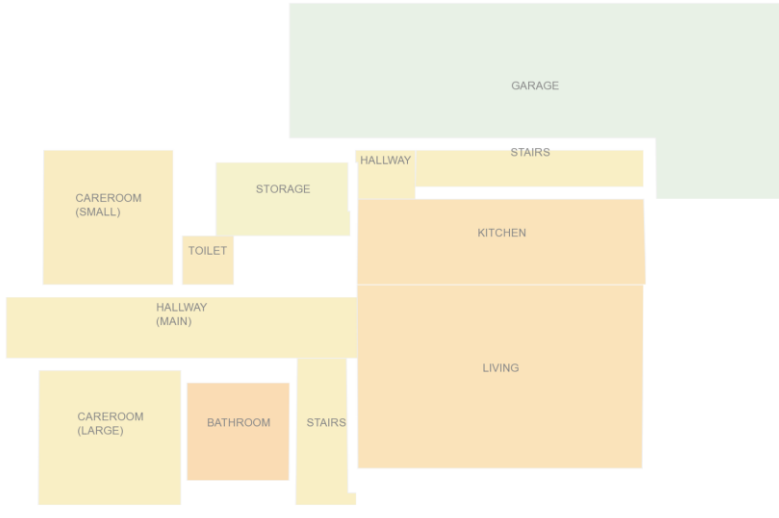
# DYNAMIC CLINICIAN DASHBOARDS



# Dynamic spatial visualisation of sensor data

<--> SOTA geospatial only

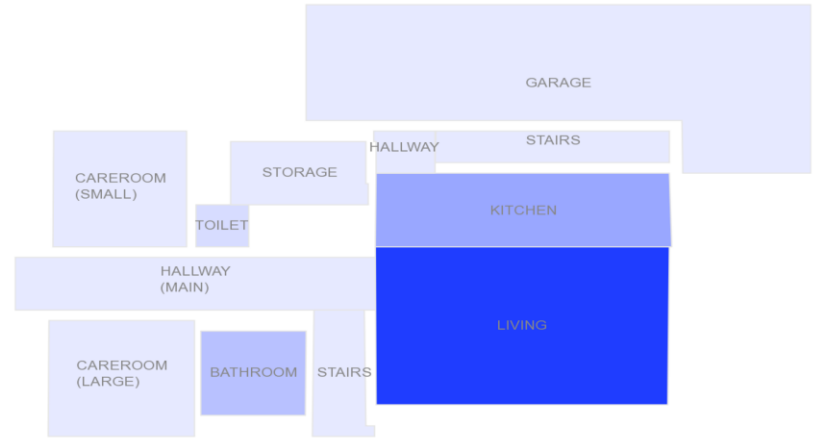
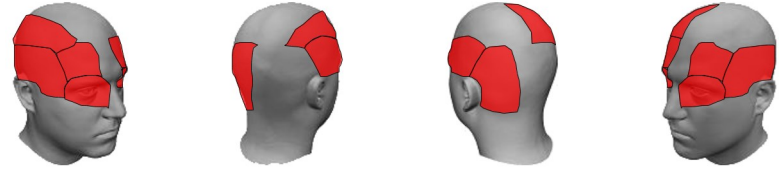
Headache pain



Temperature



Highcharts.com



Detected stress



Highcharts.com

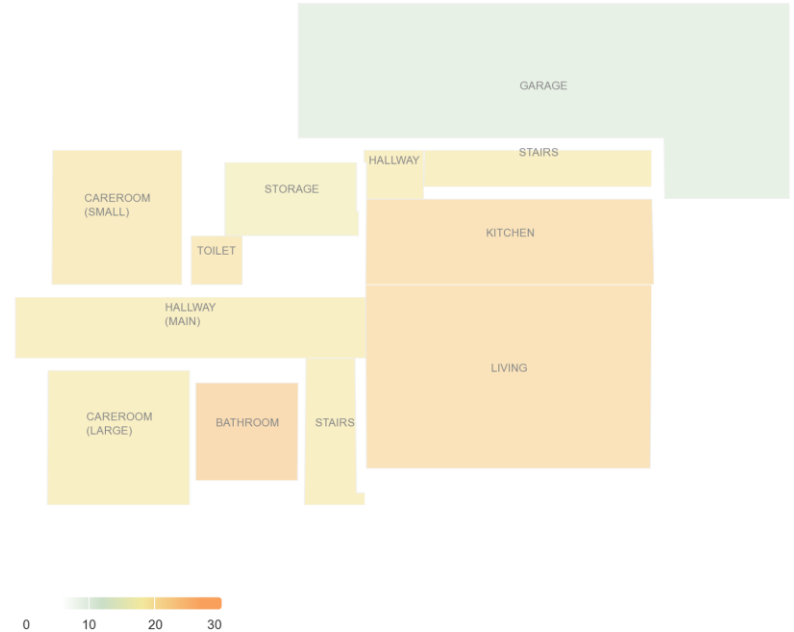
# Towards Dynamic Visualization using Semantic Web Technologies

## Capturing Domain Knowledge

`<homelab>` a `ssn:System`, ex:**Building** ;  
    `ssn:hasSubSystem` `<groundfloor>` .

`<groundfloor>` a `ssn:System`, ex:**Floor** ;  
    `ssn:hasSubSystem` `<kitchen>` .

`<kitchen>` a `ssn:System`, ex:**Room** .



# Towards Dynamic Visualization using Semantic Web Technologies

## Capturing Domain Knowledge

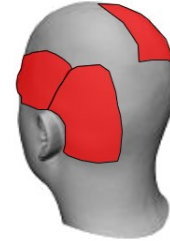
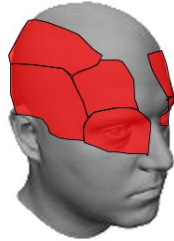
ex:**Head** rdfs:subClassOf ssn:System ;  
    ssn:hasSubSystem

ex:**RightFrontalLobe**,

ex:**LeftFrontalLobe**,

ex:**RightOrbitalLobe**,

...





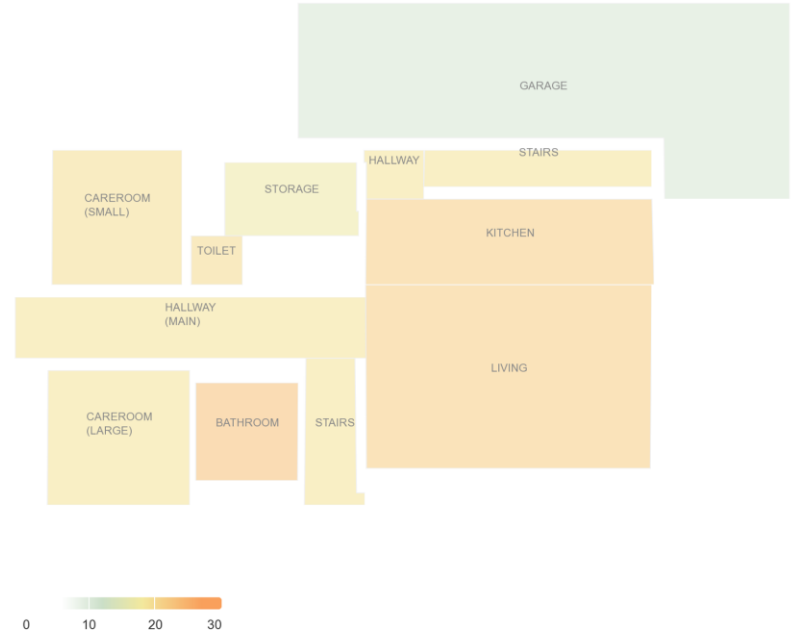
# Towards Dynamic Visualization using Semantic Web Technologies

## Sensor Mapping

```
<kitchen> a ssn:System, ex:Room ;  
    ssn:hasSubSystem <dht/1.19243> .
```

```
<dht/1.19243> a ssn:Sensor ;  
    sosa:observes <dht/1.19243.humidity> ;  
    sosa:observes <dht/1.19243.temp> .
```

```
<dht/1.19243.temp> a sosa:ObservableProperty .
```



# Towards Dynamic Visualization using Semantic Web Technologies

## Visualization Mapping

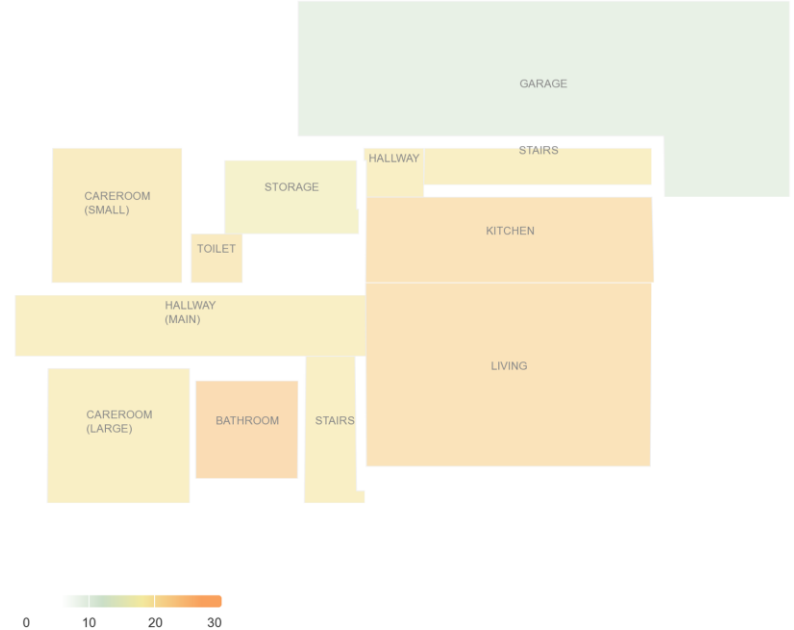
### Ontology

```
<groundfloor.floorplan> a dashb:Visualization ;  
  dashb:hasComponent [  
    dashb:visualizedSystem <kitchen>  
  ]
```



### GeoJSON

```
{  
  "type": "FeatureCollection",  
  "name": "groundfloor.floorplan",  
  "features": [  
    {  
      "type": "Feature",  
      "properties": { "id": 6, "name": "kitchen", "floor": 0 },  
      "geometry": { "type": "MultiPolygon", "coordinates": [] }  
    }  
  ]  
}
```

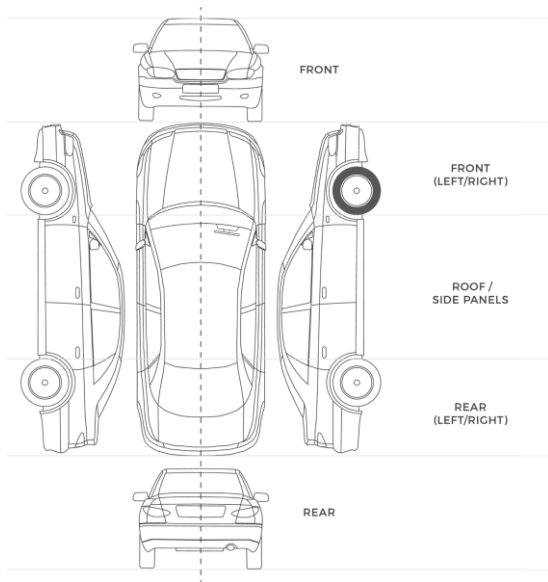


Highcharts.com

# Spatio-Temporal Visualizations beyond Healthcare

## Examples

### Manufacturing and Industrial IoT



### Air quality / Building Management





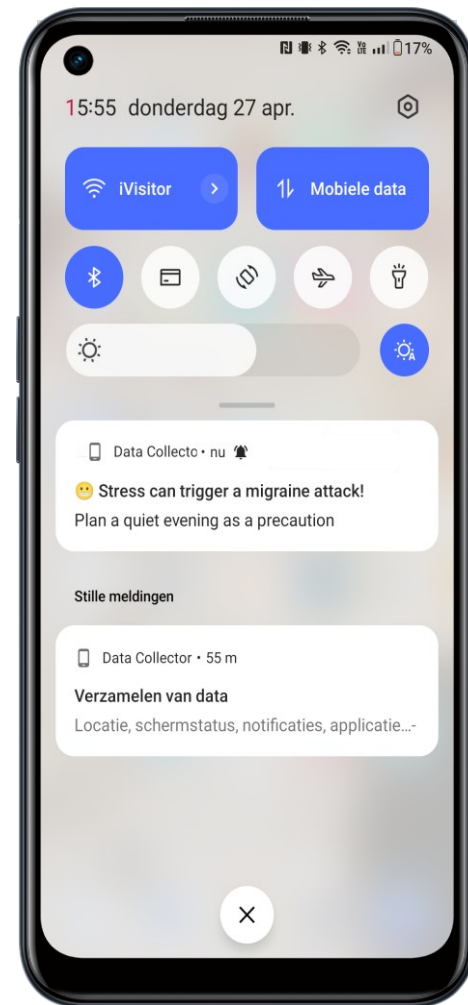
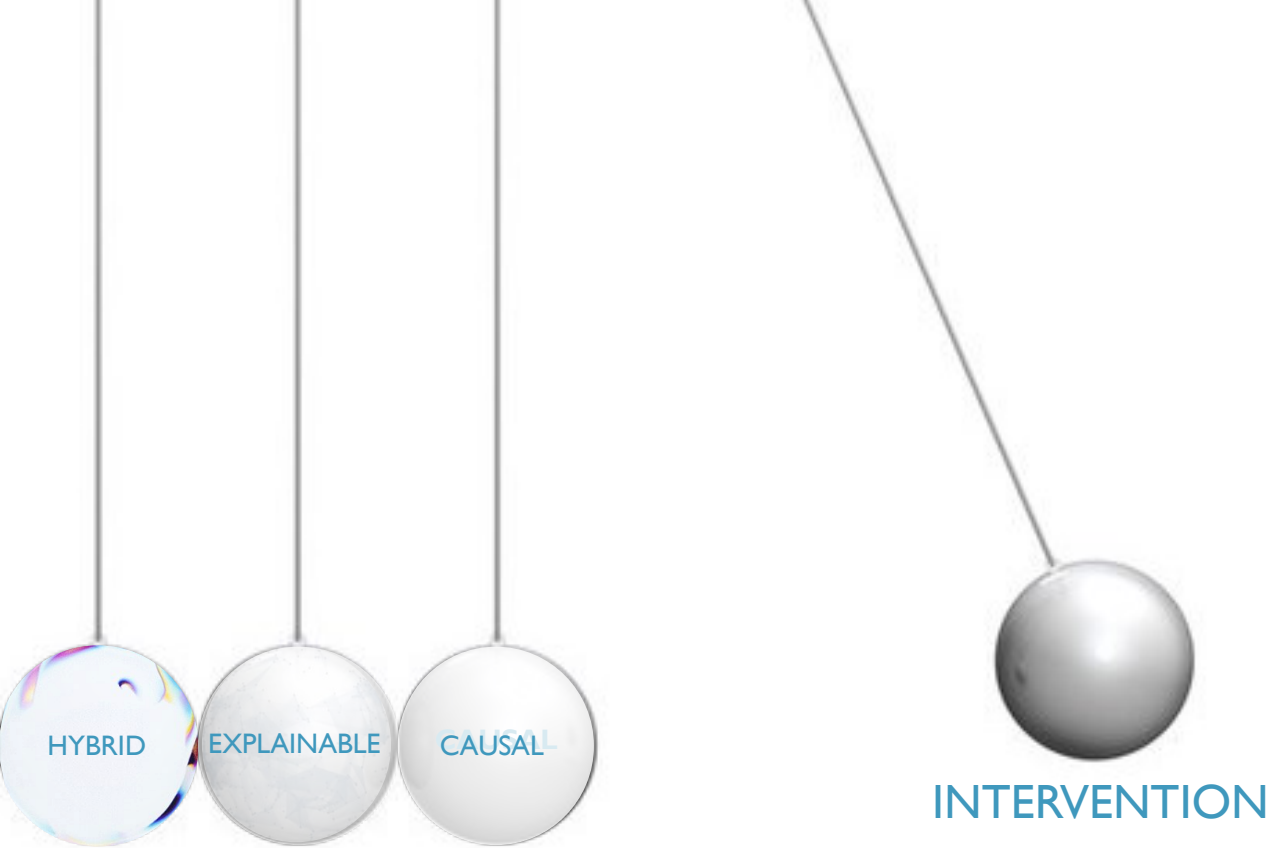
Framework with monitoring app, behavioral markers and dashboards for continuous, objective health monitoring

# Make clinicians sharper and visualize what they couldn't see before





**Empowering  
clinicians, pharma,  
coaches, ...**





**Empowering  
clinicians, pharma,  
coaches, ...**

**Also  
empowering  
patients, care  
providers, ...**





# Designing AI-driven spatiotemporal behavioral markers and collecting RWE to improve our health and quality of life



# Questions?

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