Mobile Health & Activity Monitoring

spring term 2023 | ETH Zürich

prof. christian holz

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healthcare

digital health

?

healthcare

diagnostics

patients

healthcare

4 billion people in the world have no access

technology has the opportunity to be part of
the solution to create more equitable access

[https://www.unicef.org/press-releases/almost-2-billion-people-depend-health-care-facilities-without-basic-water-services]

healthcare

$7.5 trillion business world-wide

$1 trillion is going to waste in the US/year

physician activities

- spend 2x as much time entering clinical documentation
- for each patient visit

not a normal business

- people don't shop on price
- accidents: look for best possible care

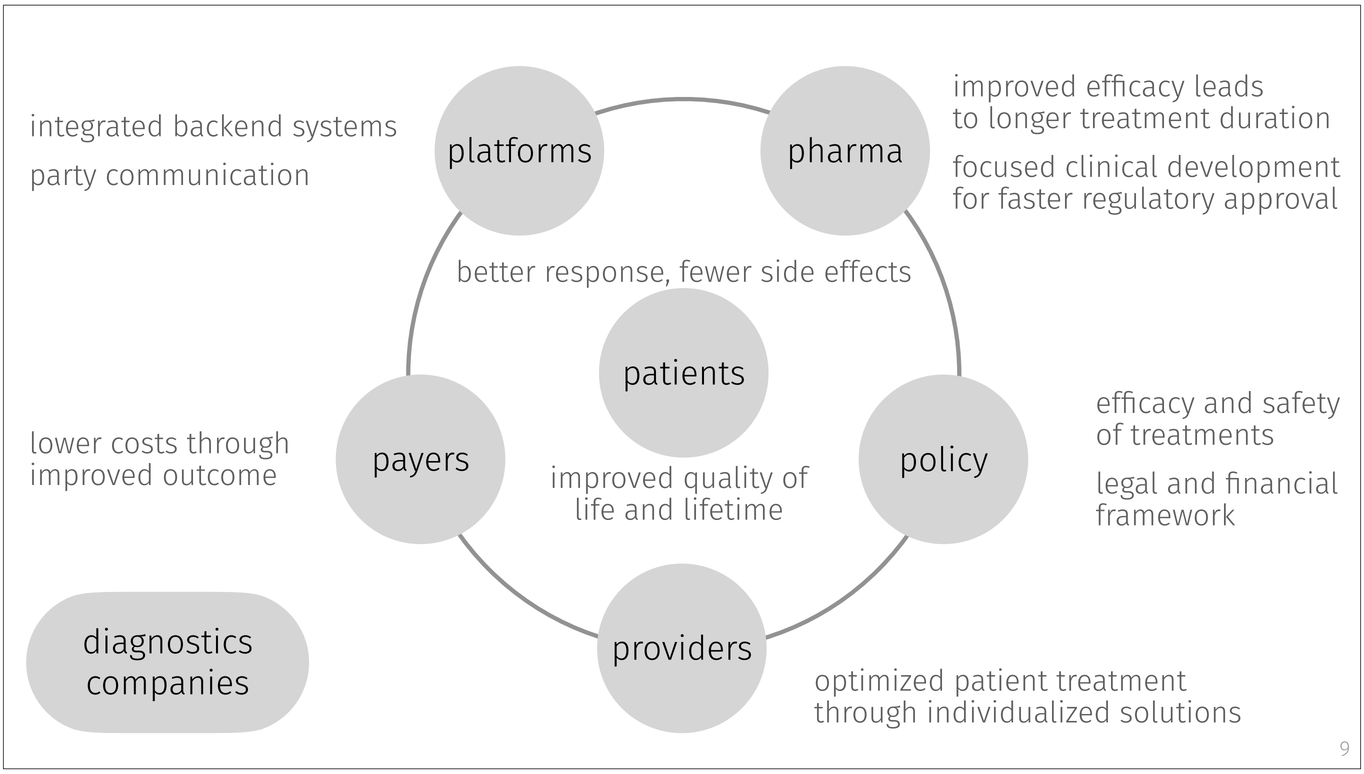
healthcare

digital services as an opportunity

- data and services move to central systems
- data, computation, processing to make use of data

change in *care*

- away from fee-for-service to value-based care
- doctors and clinics are being reimbursed on quality of the outcomes



healthcare digitization

digitization process

- HITECH Act (2009) requires healthcare organizations to digitize healthcare records over the past 20 years
- massive digitization of healthcare and medicine since
- past 10 years: from 15% of health records digital to today: > 98% records digital

medical devices and processes

- from analog to digital+connected
- analyses of biomarkers, records, genome, proteome

now: what can or should we do with all that data? and is it good enough?

mobile health

?

data-driven insights require representative data capture

it's the key requirement to advance personalized healthcare

capturing real-world settings is crucial, yet non-trivial

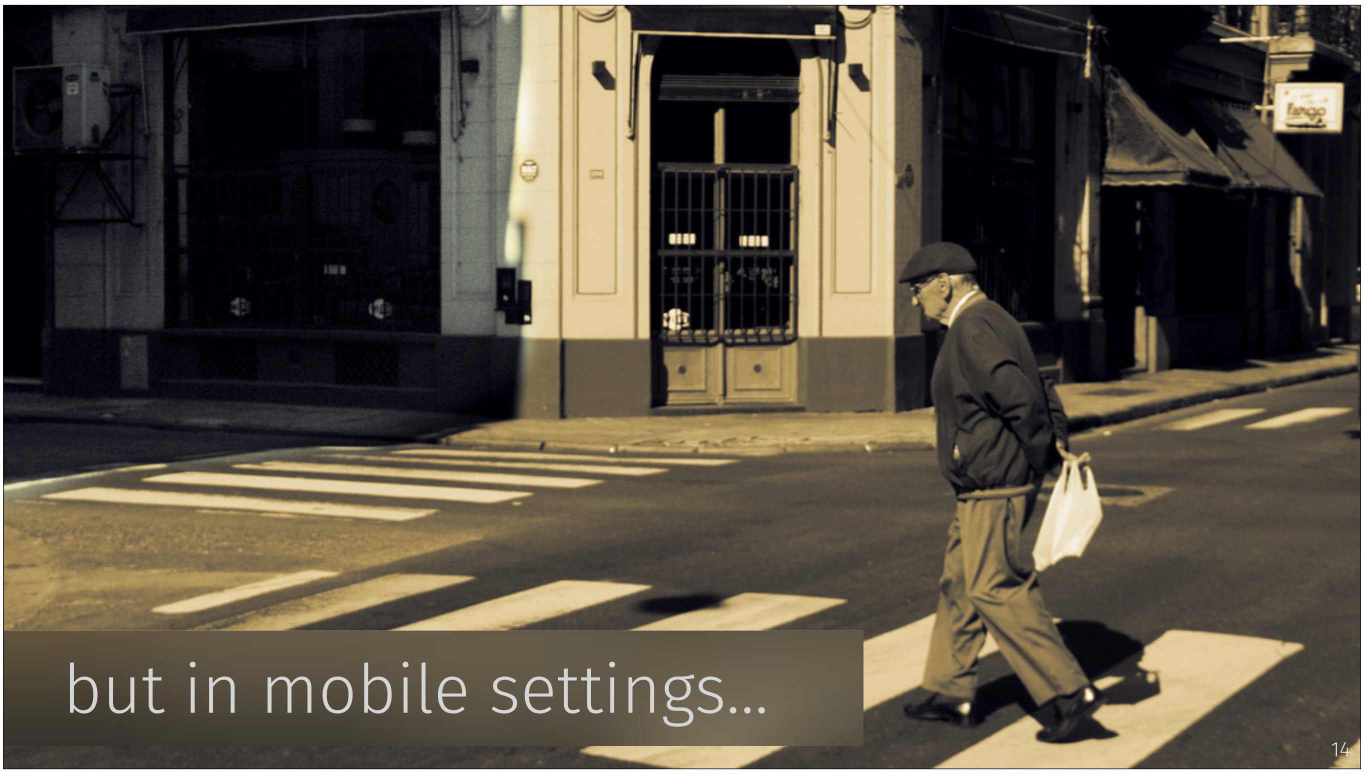
intervention needs to happen in the moment

clinical environments

continuously measures
physiological signals

representative of
direct and indirect needs

treatment and outcomes



before designing interventions, we need data that is

representative, continuous and high-resolution

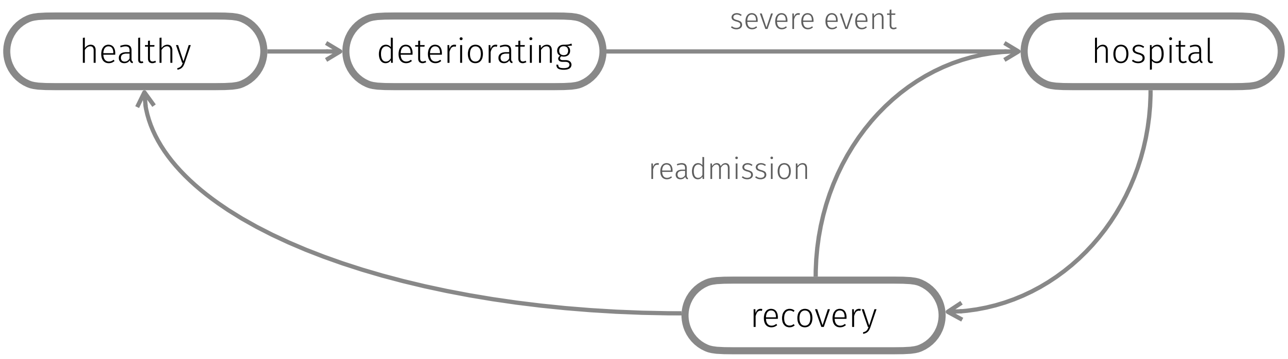
'easy' to measure, at each and every moment in time

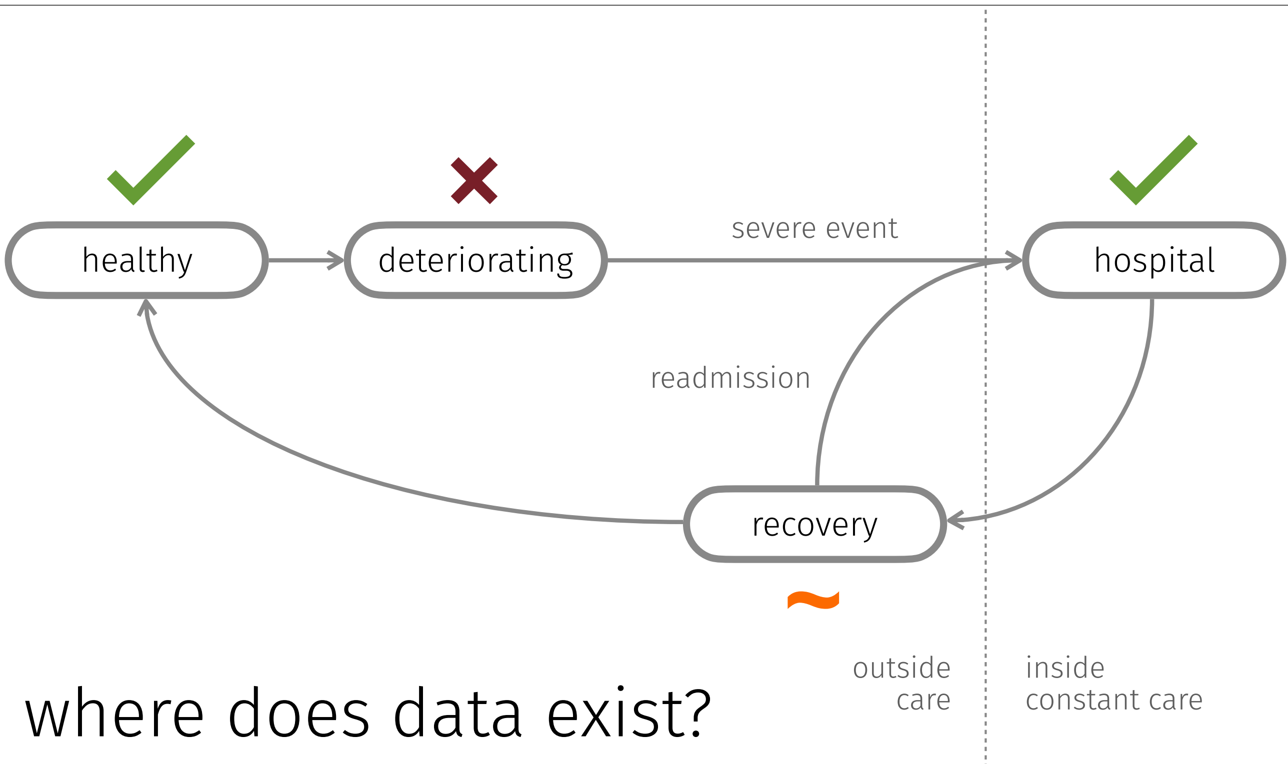
➪ unobtrusive, a key challenge

we have a lot of data…

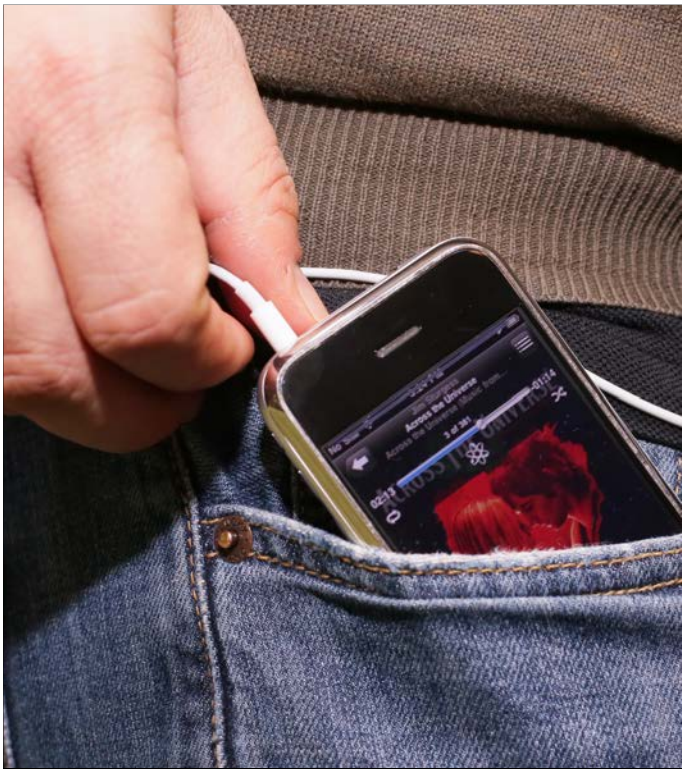
I argue: we need more data.

➪ but not of the same kind!
there's an unmet need for data that matters!





where does data exist?



what we need

continuous physiologically accurate signals

on convenient and mobile form factors that are socially acceptable

➪ carryable or wearable

categories of mobile health

1. education, reminders, and data management
2. population health
3. physiological signals
4. momentary state assessment
5. continuous health monitoring
   through data-driven insights

why are you
taking this course?

what are your
intended outcomes?

categories of mobile health

1. education, reminders, and data management
2. population health
3. physiological signals
4. momentary state assessment
5. continuous health monitoring
   through data-driven insights

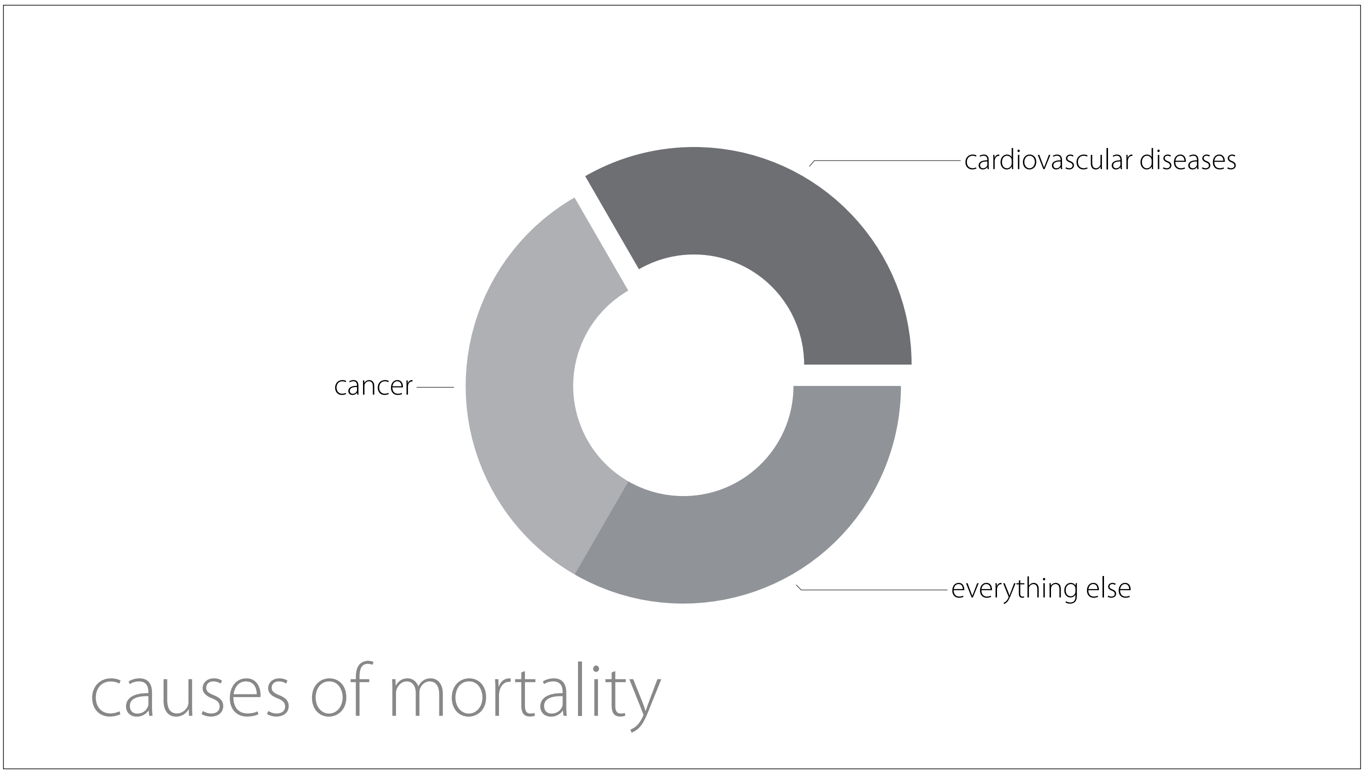
focus
of this
course

activity monitoring

?

what's actually the 'health' part?


Project Glabella


cardiovascular diseases
cancer
everything else
causes of mortality

~108 million American adults have **high blood pressure** (45%)

high blood pressure was a primary cause of death
for more than 500,000 Americans in 2018

1 in 5 American adults is **unaware** of having high blood pressure

only 1 in 4 hypertensive people have their values under control

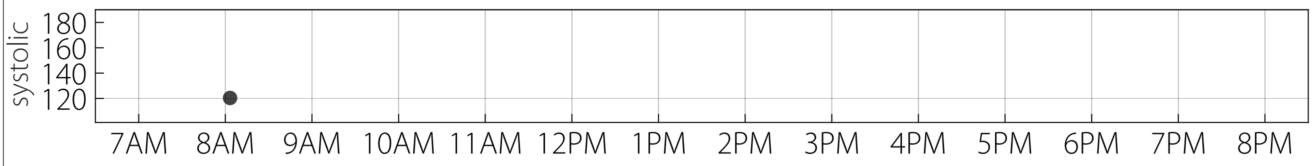
high blood pressure

https://www.cdc.gov/bloodpressure/facts.htm

monitors are good for
long-term tracking

blood pressure measurements

monitors are good for
long-term tracking

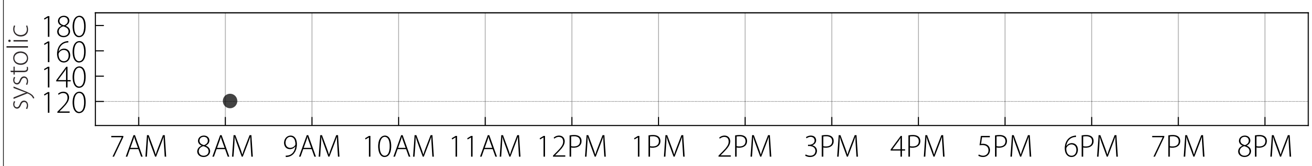


blood pressure measurements

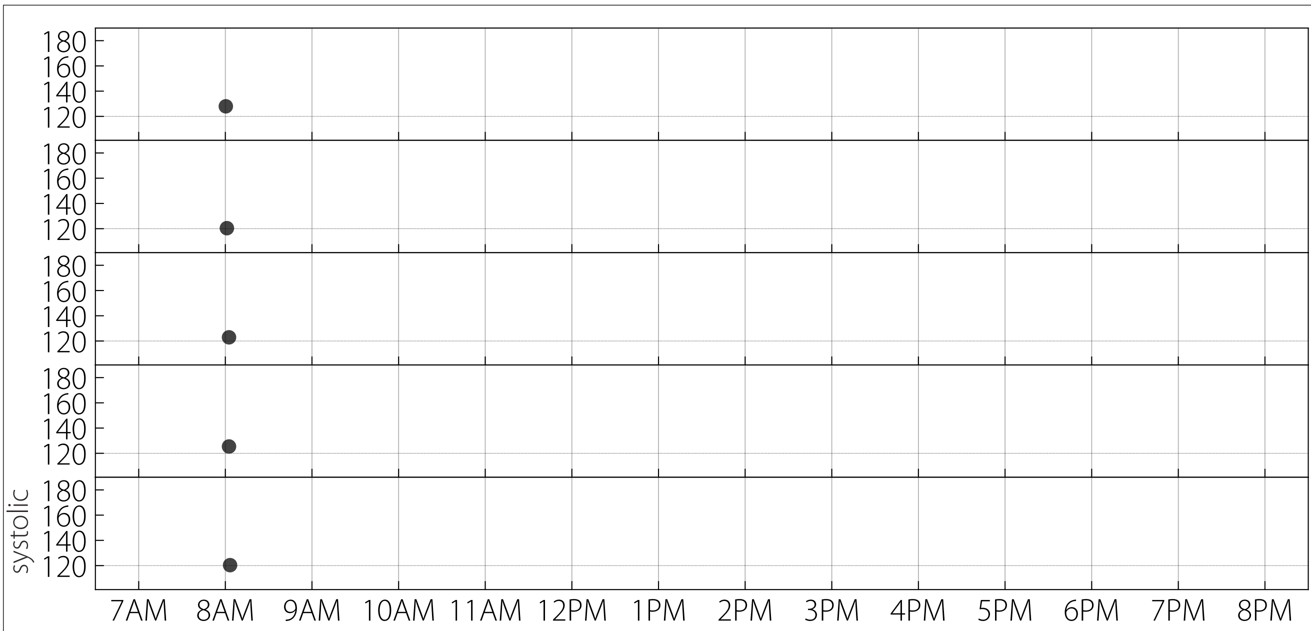
monitors are good for
long-term tracking

not so good in
mobile settings

needs correct attachment
takes time



blood pressure measurements

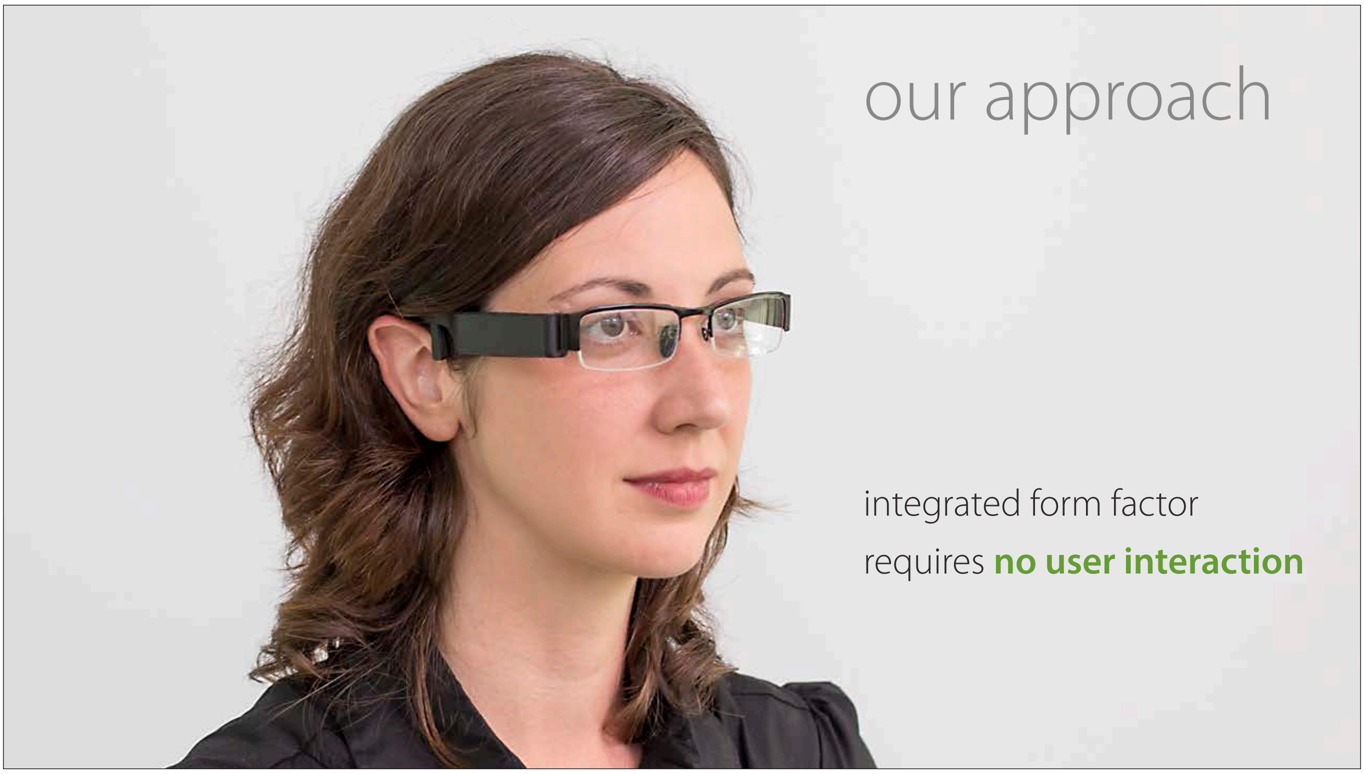


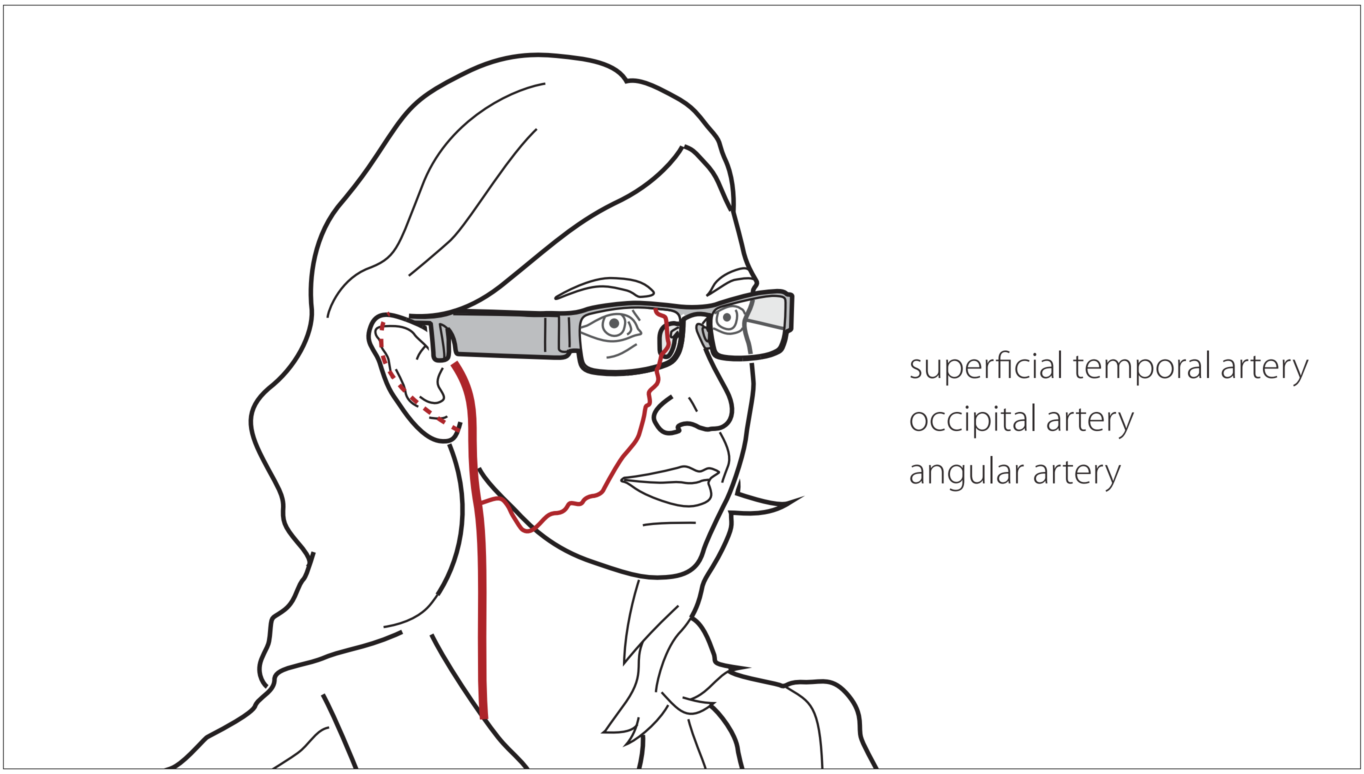
blood pressure measurements

blood pressure during the day

additionally influenced by **short-term events**

- eating and drinking — Smith et al., *Physiology & Behavior 1997*
- events at work — Lindquist et al., *Hypertension 1997*
- exercise or postural changes — Imholz et al., *Cardiovascular Research 1990*
- medication intake


our approach
integrated form factor
requires no user interaction

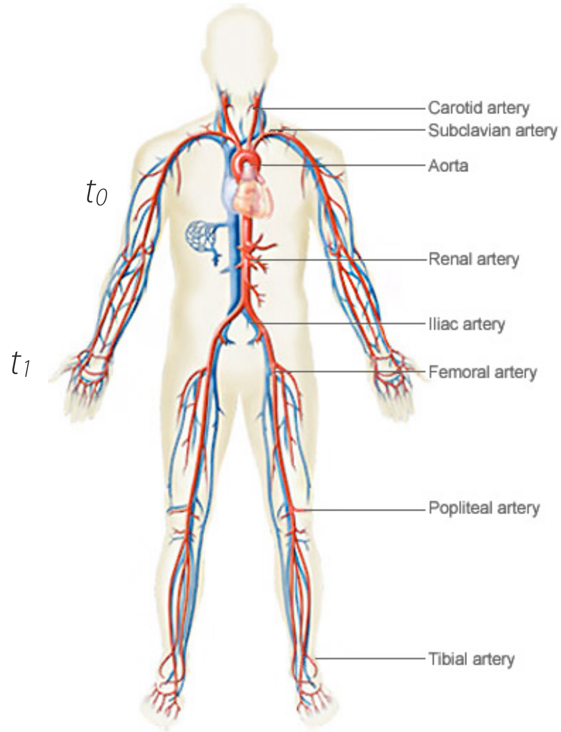

superficial temporal artery
occipital artery
angular artery

pulse transit time

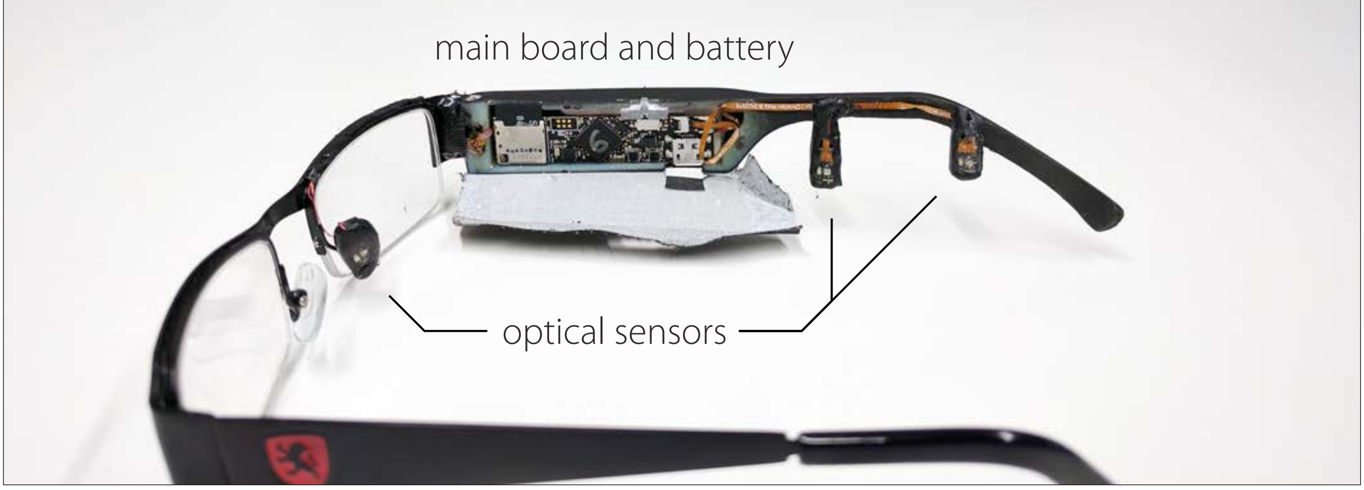
the time it takes a pulse wave to travel between two sites of the body

requires no cuff and can be measured during **each beat**

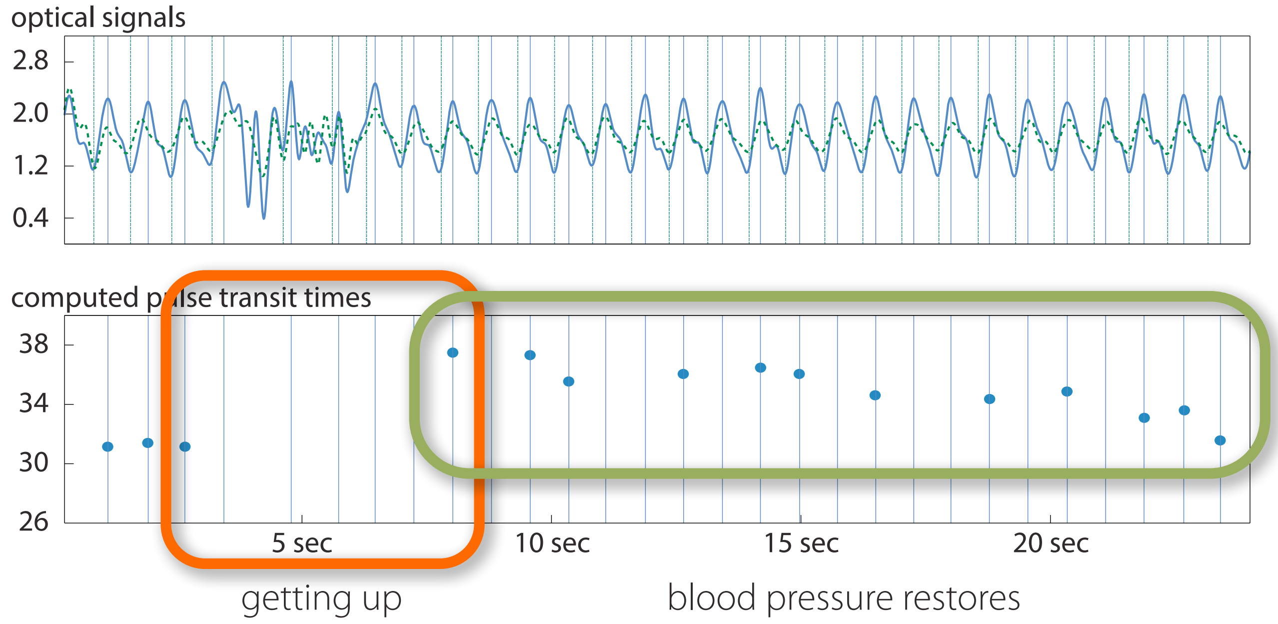
hypothesis



Glabella prototype



example: getting up after leaning back



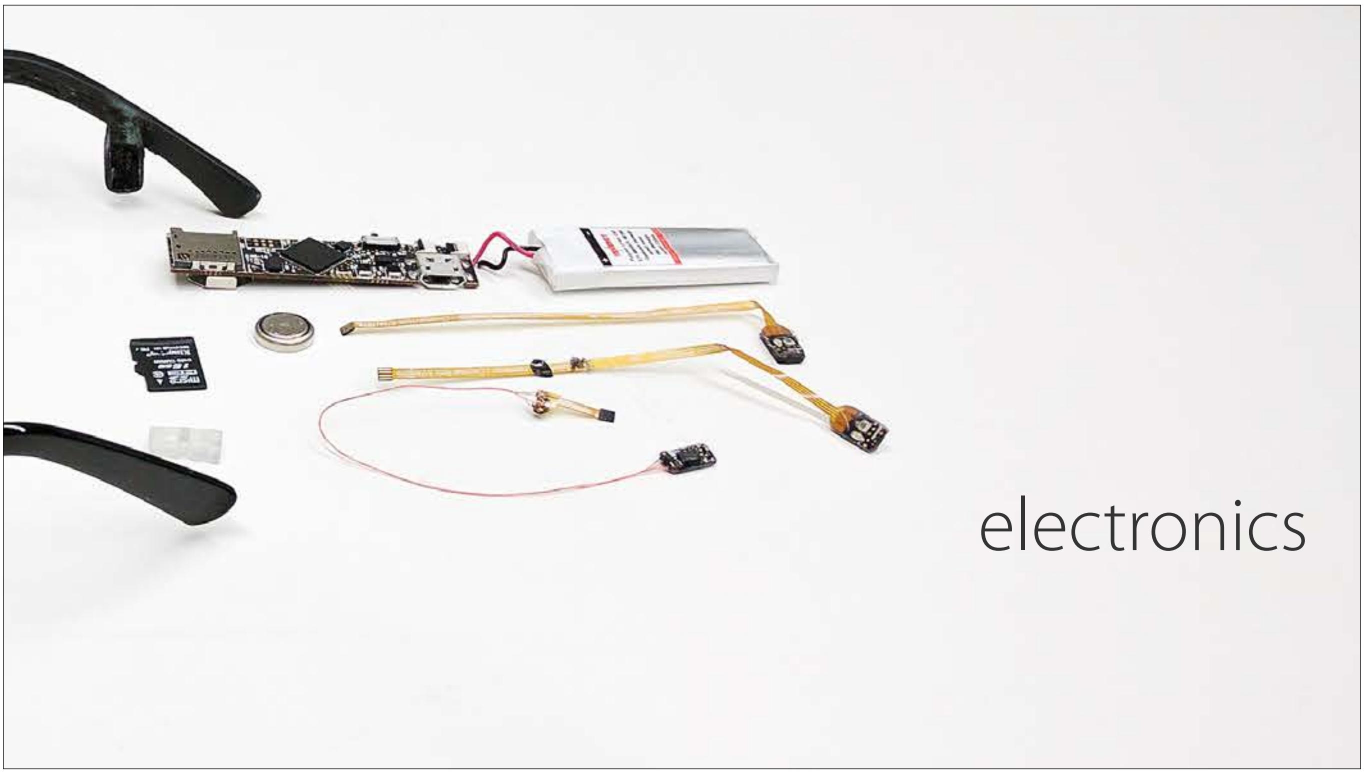
Glabella prototype

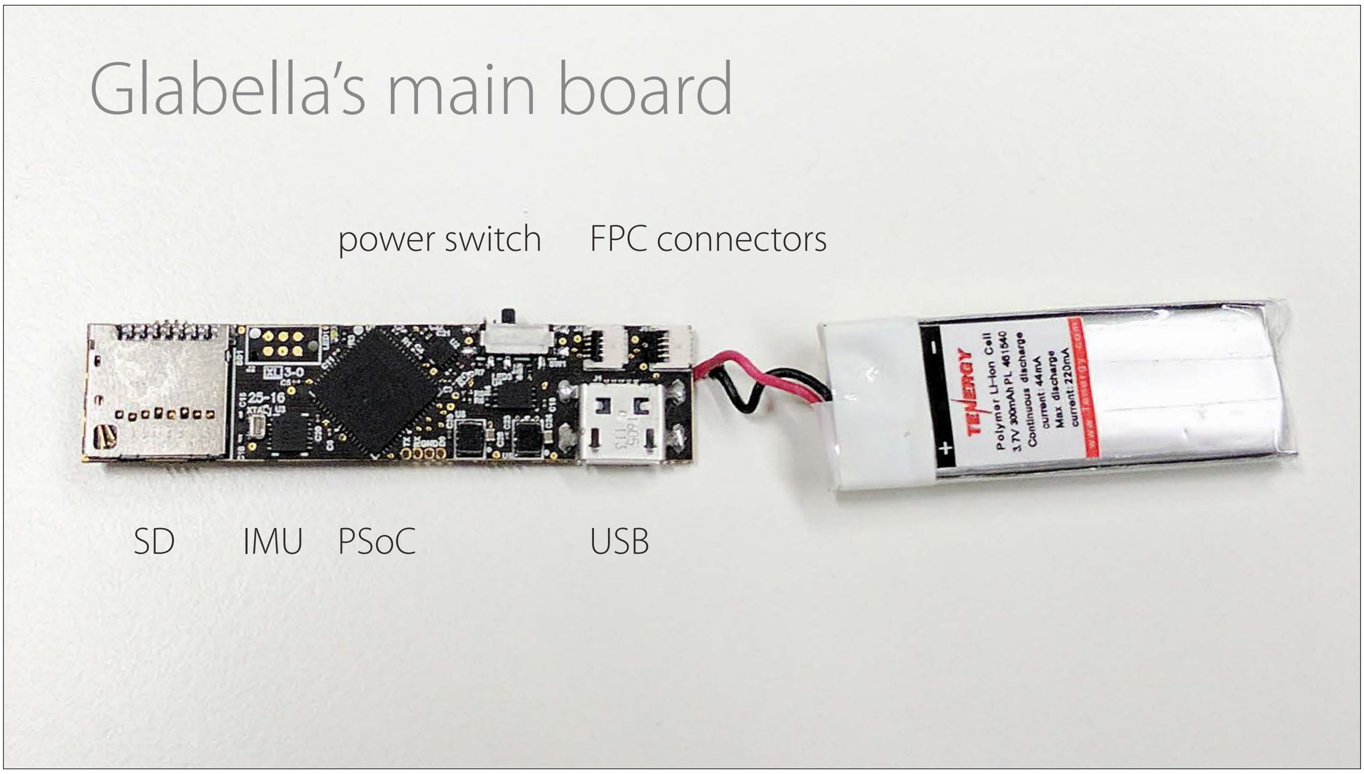
continuously collects

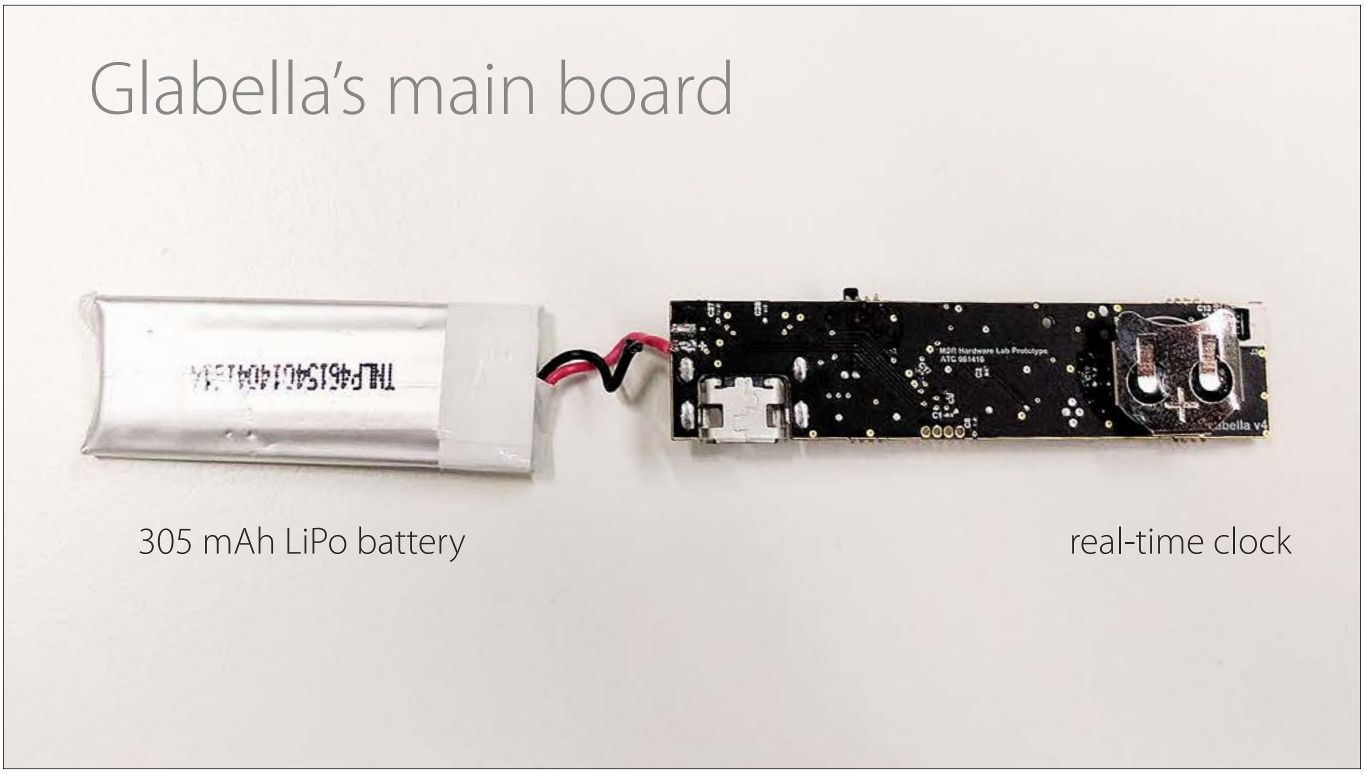
- 3 optical reflections (at up to 5 kHz)
  for heart rate, oxymetry, blood pressure
- 3-DOF inertial motions (at 200 Hz)
  for activity detection, step count, …

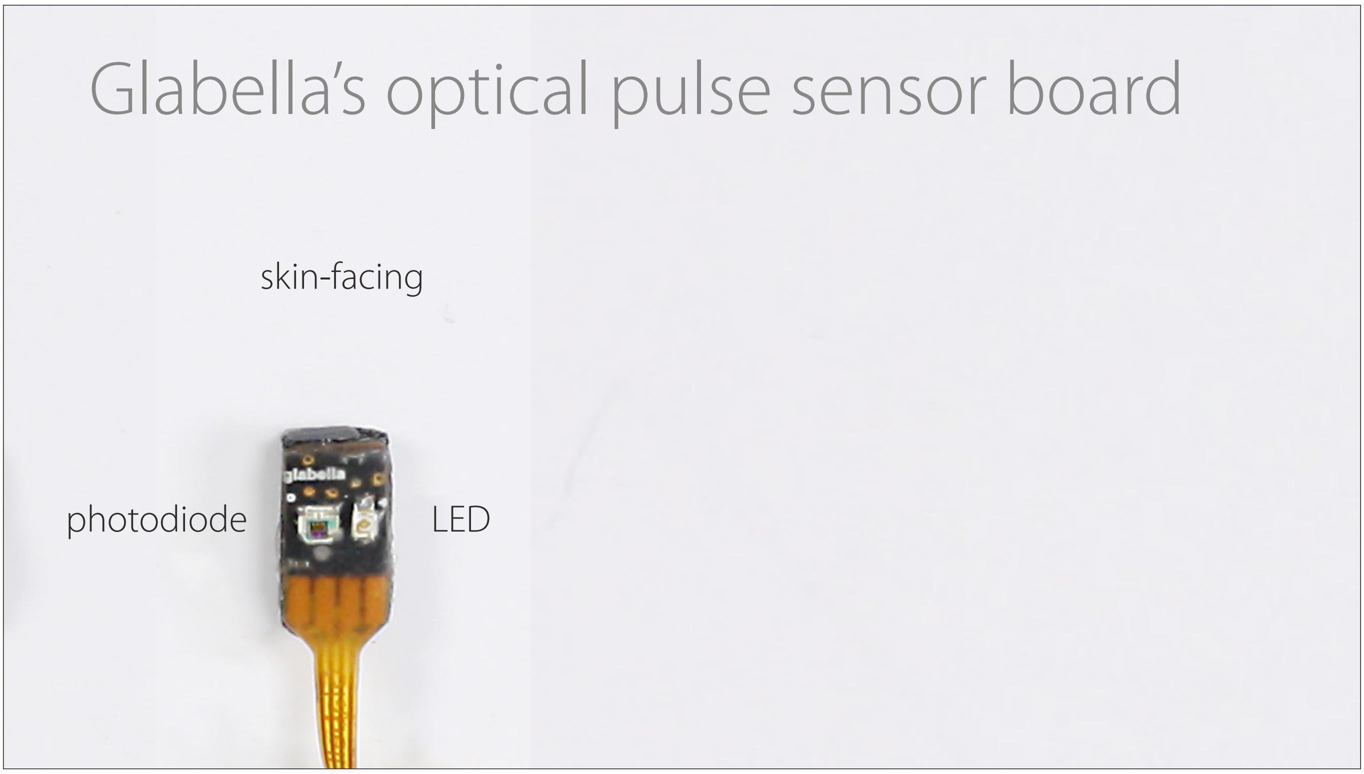
24 hours runtime

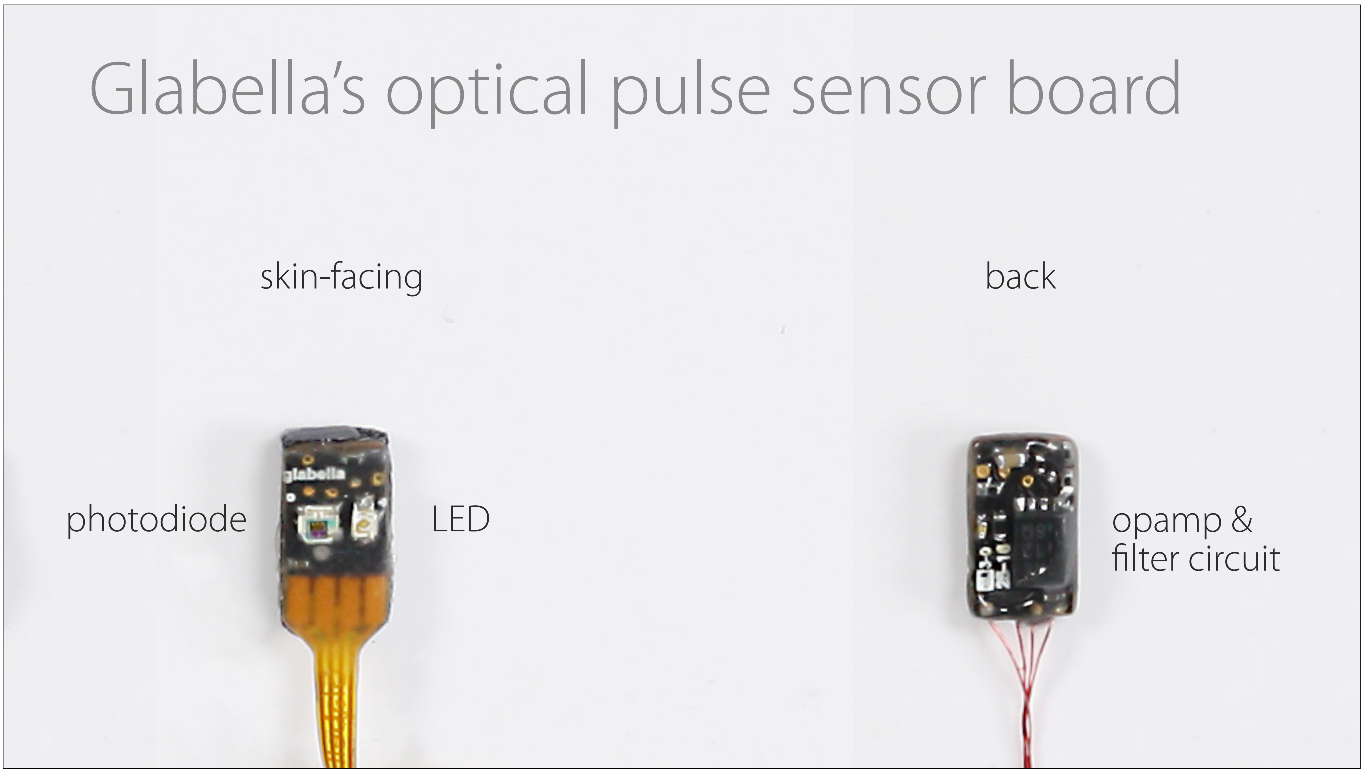
45 grams in weight

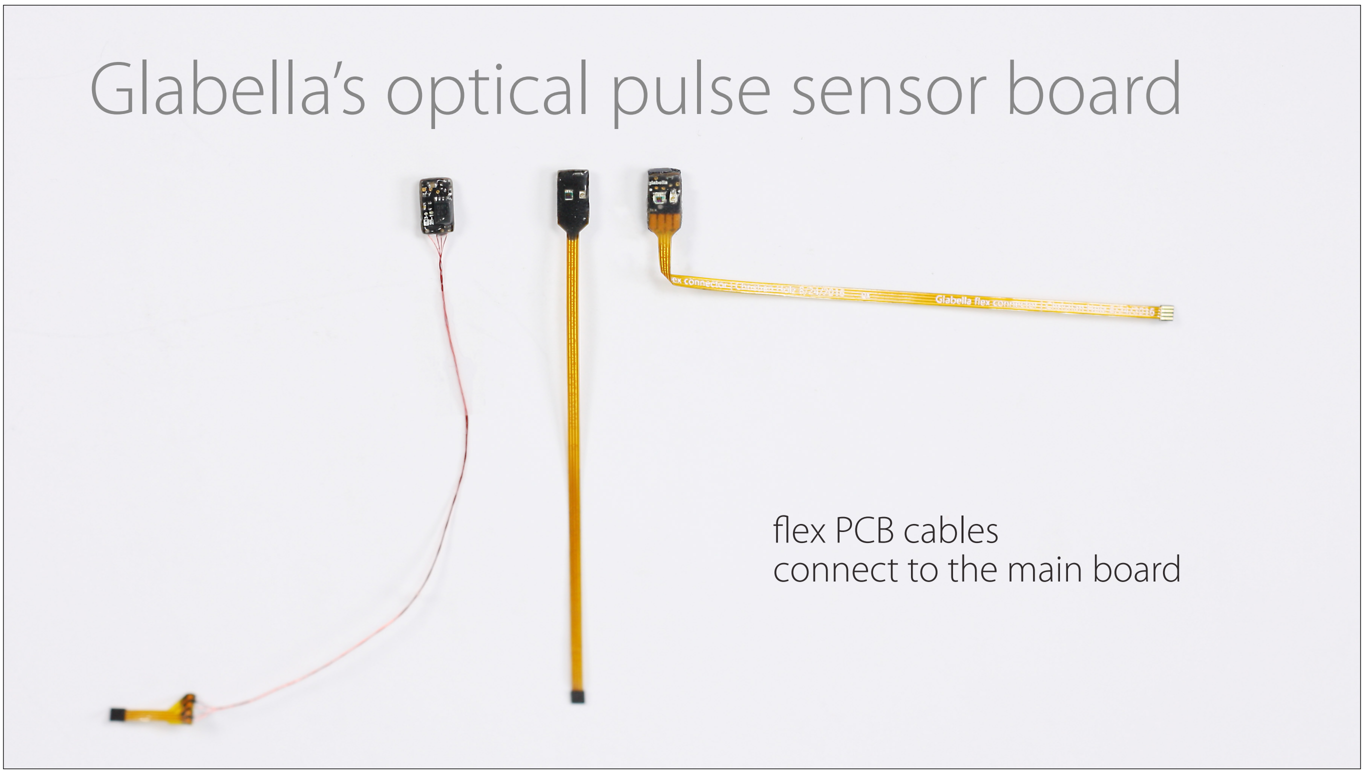

electronics


Glabella's main board
power switch
FPC connectors
SD
IMU
PSoC
USB


Glabella's main board
305 mAh LiPo battery
real-time clock


Glabella's optical pulse sensor board
skin-facing
photodiode
LED

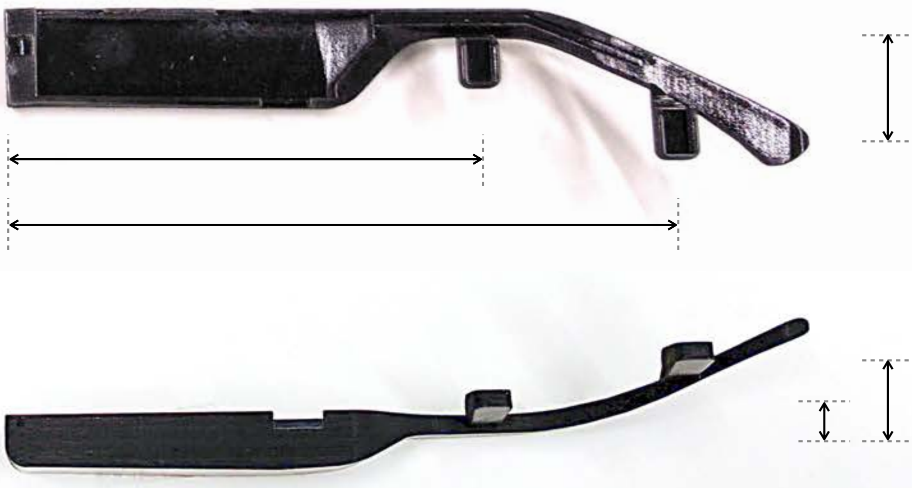

Glabella's optical pulse sensor board
skin-facing
back
photodiode
LED
opamp &
filter circuit


Glabella's optical pulse sensor board
flex PCB cables
connect to the main board


mechanical design


off-the-shelf metal-frame glasses
parametrized frame
3D printed with digital ABS
mechanical design

to fit a wearer's
head dimensions



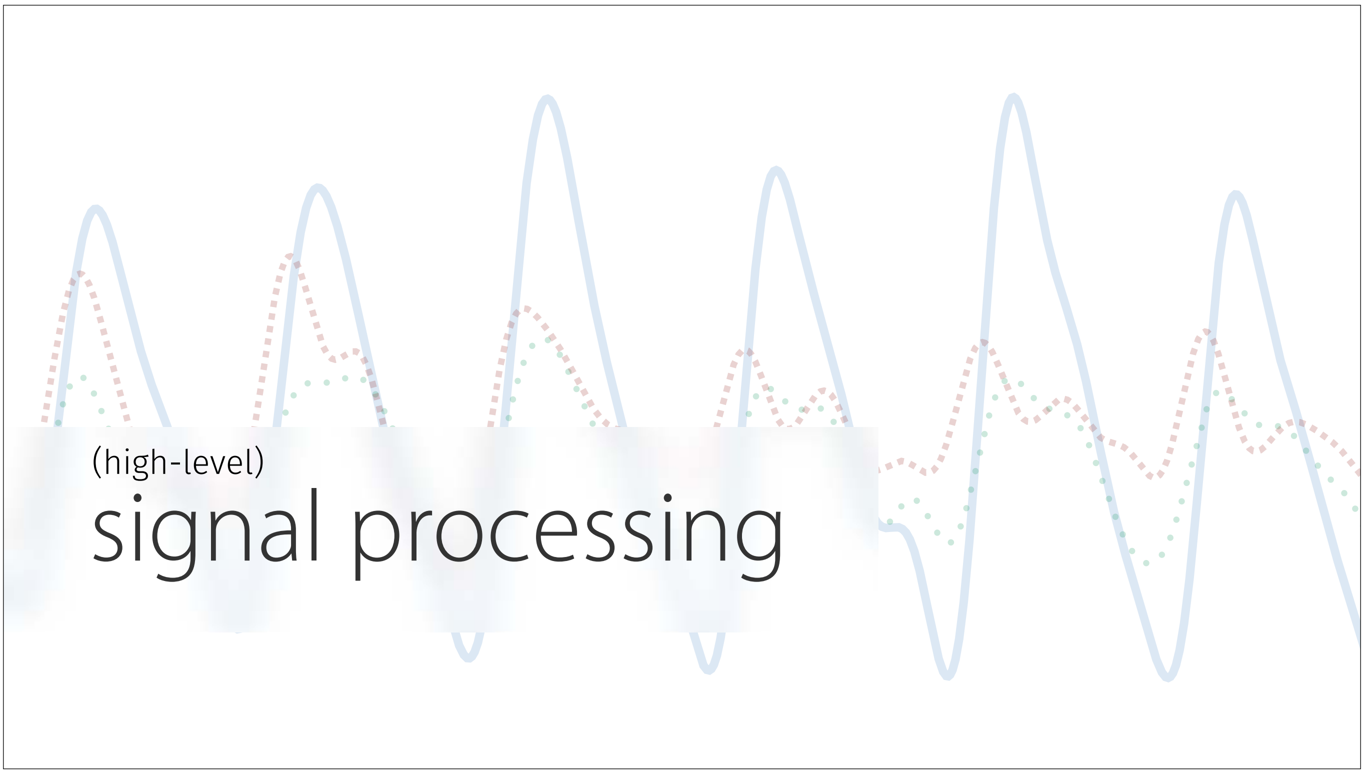
to ensure
sensor contact

mechanical design parameters

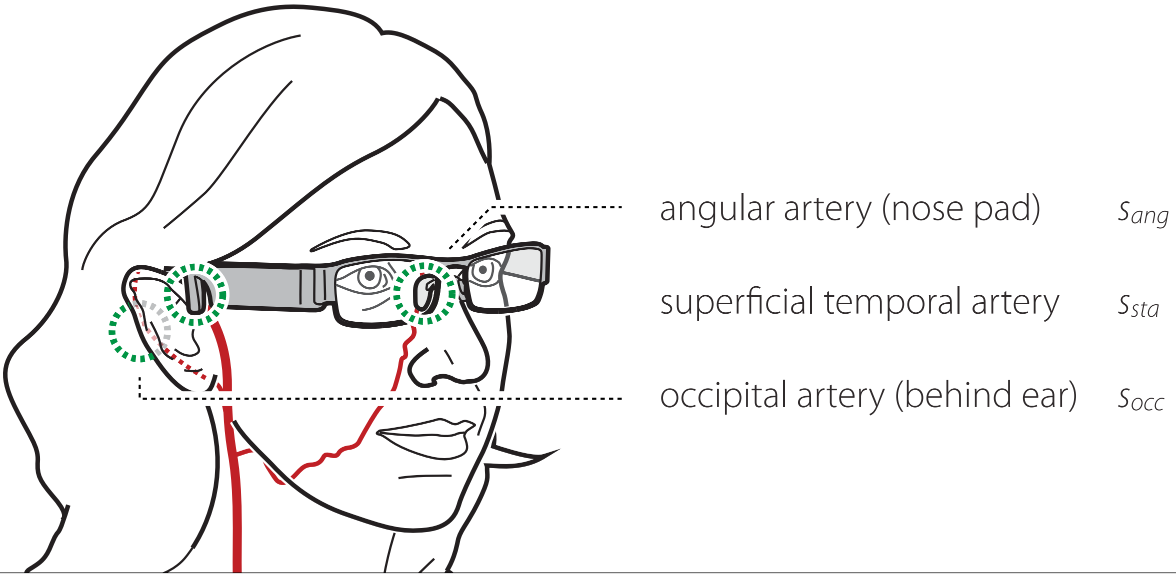
underfilled hot glue
to sustain constant skin contact

underfilled sensor


3D printed nose pad
with embedded, underfilled optical sensor

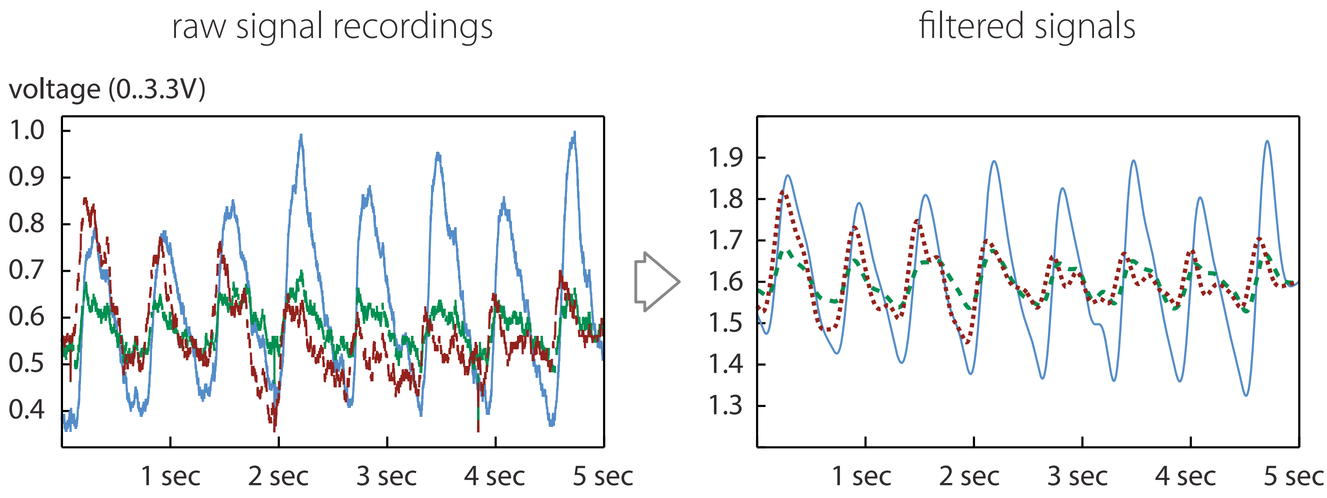

(high-level)
signal processing

3 optical signals



1. filter optical signals
2. analyze the dominant frequency of each optical signal
3. detect pulses and extract temporal features
4. validate candidate features
5. compute pulse transit times

signal processing



1 filter optical signals

bandpass filter (0.4 Hz, 8 Hz)

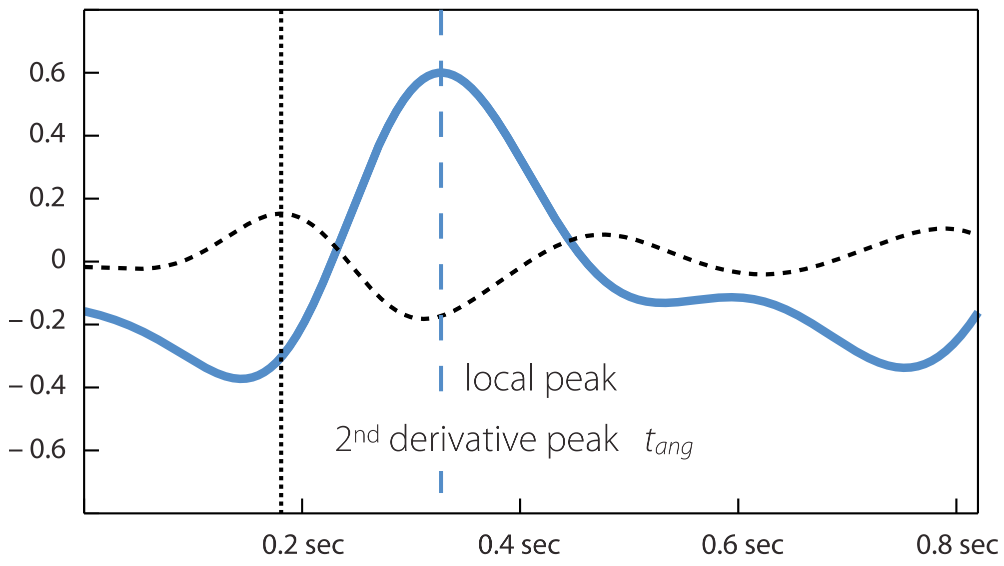
apply Fast Fourier transform to each 15-second window

to extract dominant frequencies f_{ang}, f_{sta}, f_{occ}

derive heart rate if $|\, f_{ang} - f_{sta} \,| < \varepsilon$ and $|\, f_{ang} - f_{occ} \,| < \varepsilon$

otherwise discard this window for feature extraction

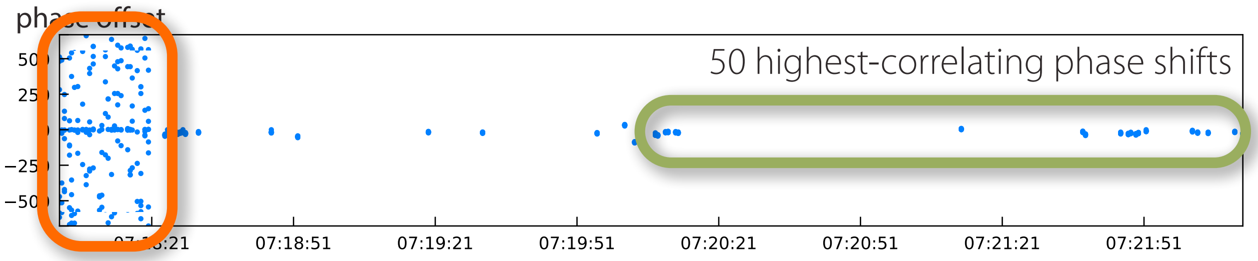
2 derive the dominant frequencies



3 detect pulses, extract temporal features

discard if IMU variance exceeds a threshold

4 validate candidate features



4 validate candidate features

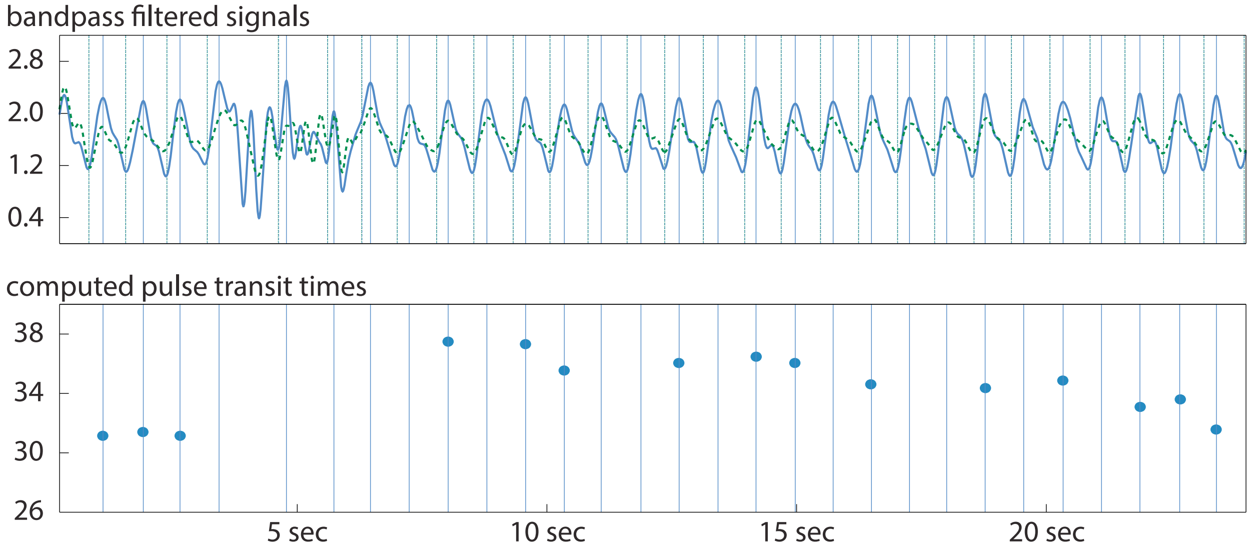
pulse transit time between the sensors on

superficial temporal artery & angular artery $PTT_{ang-sta} := t_{ang} - t_{sta}$

occipital artery & angular artery $PTT_{ang-occ} := t_{ang} - t_{occ}$

5 compute pulse transit times

example: getting up after leaning back



sustain operation and capture useful data
during everyday wear and **regular activities**

determine the correlation between the
pulse transit times recorded by our prototype and
systolic blood pressure values measured by a cuff-based monitor

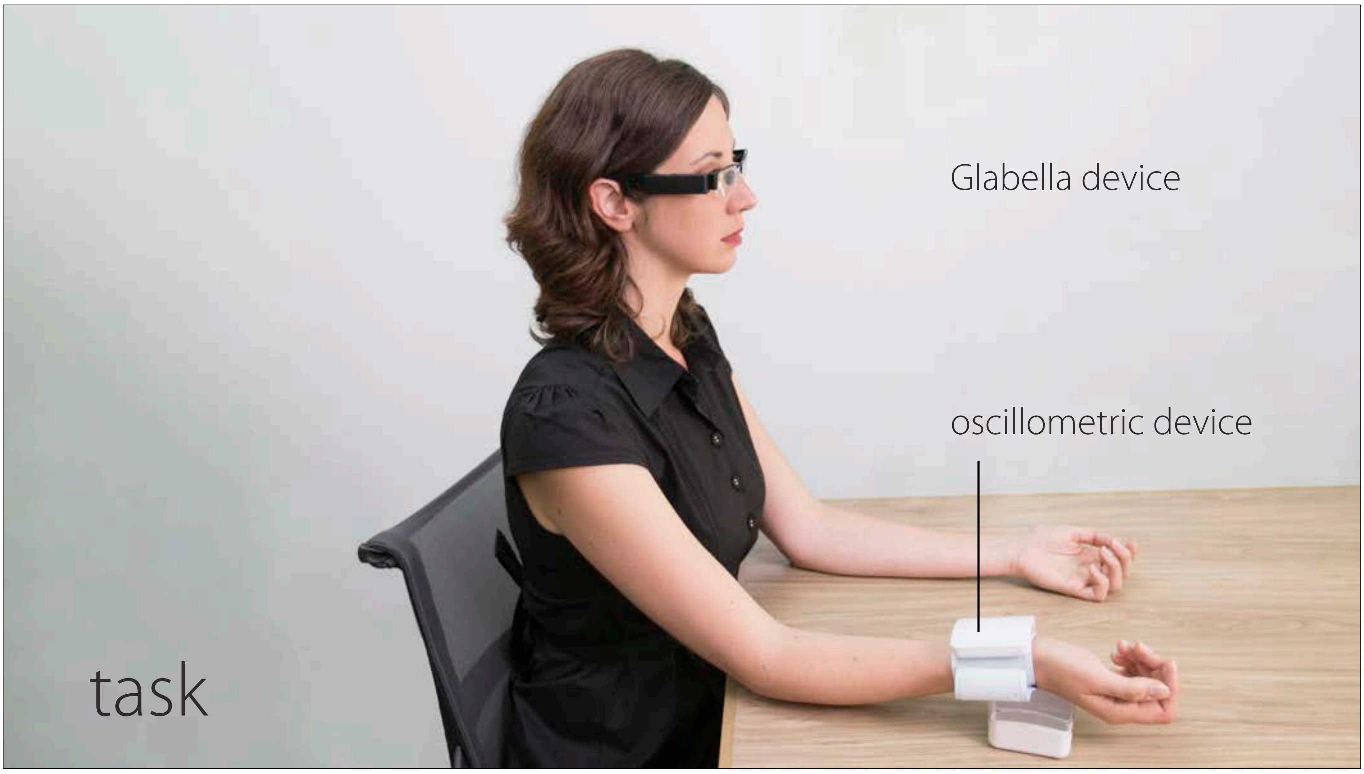
goals

wear the custom-fit prototype glasses
at least **12 hours** per day

record blood pressure values three times an hour
at least **30 measurements** per day

5 days of participation

task


Glabella device
oscillometric device
task


screening session
for **custom fitting**
and instructions
procedure

pick up the box

wear the custom-fit prototype
and record measurements from **Monday through Friday**

procedure

all participants had Fitzpatrick Skin Type II

no known related medical conditions (e.g., hypertension)

$400 gratuity depending on compliance

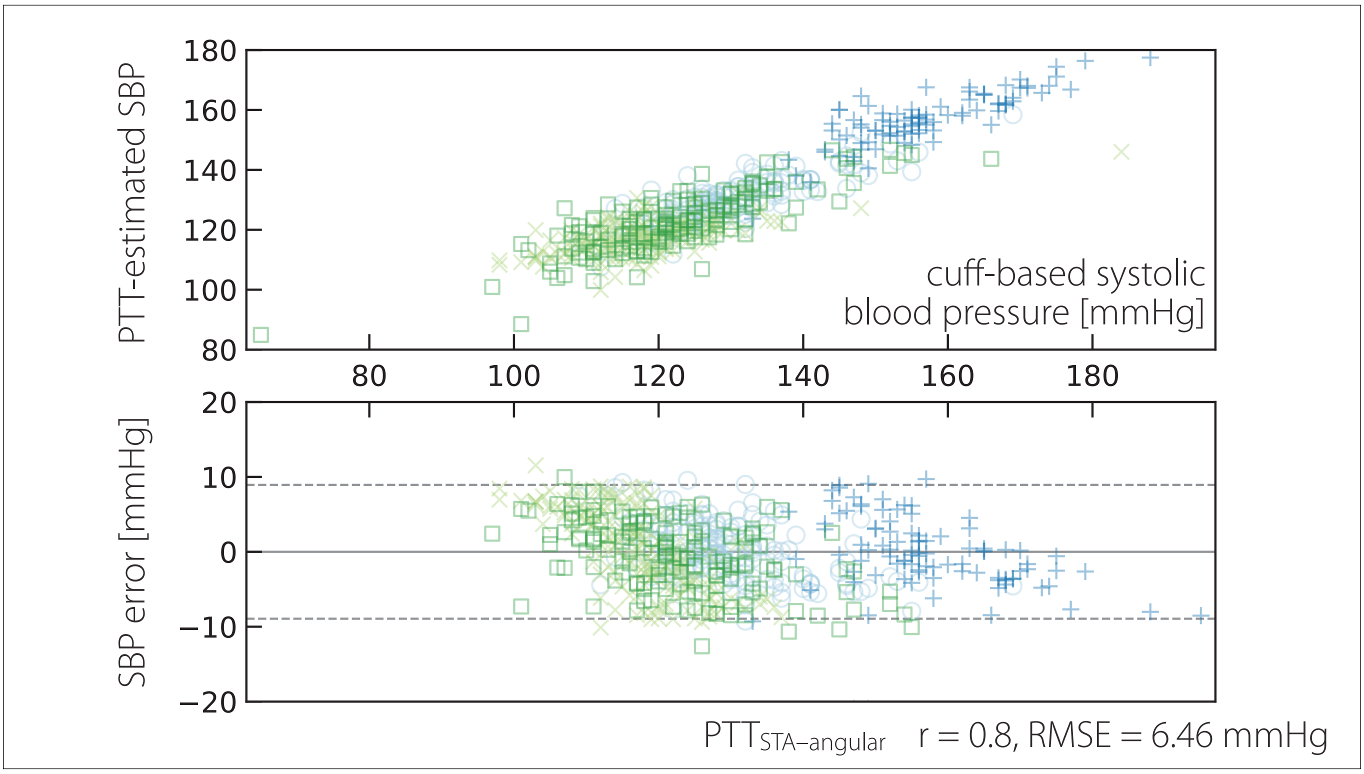
participants

analyzed surrounding ±2 minutes
of each blood pressure measurement

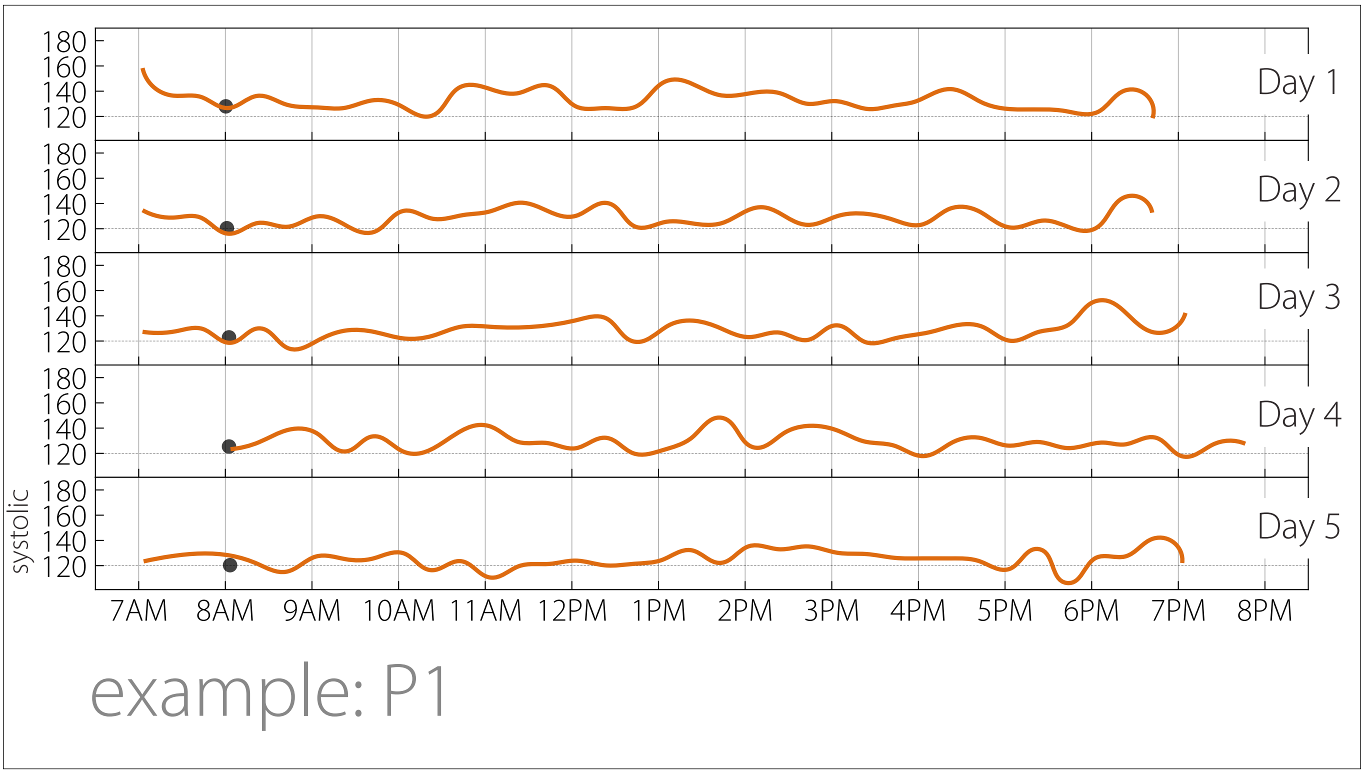
to predict the wearer's

- heart rate
- systolic blood pressure

results



PTT-estimated SBP
SBP error [mmHg]
cuff-based systolic blood pressure [mmHg]
$PTT_{STA\text{–}angular}$ r = 0.8, RMSE = 6.46 mmHg



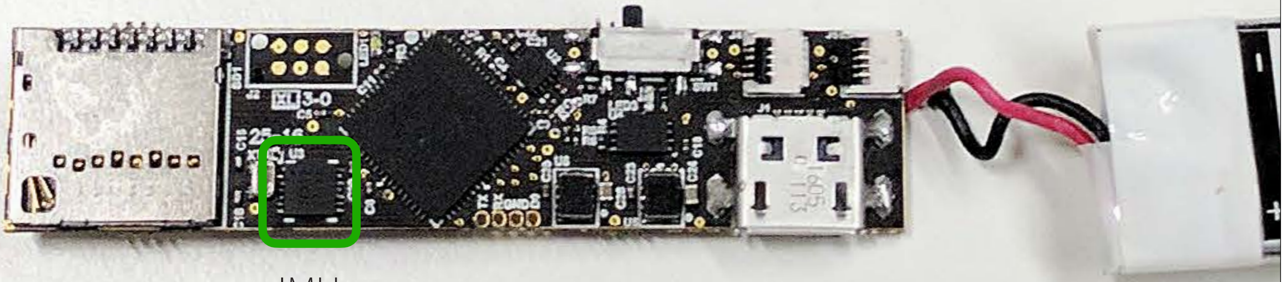
systolic
Day 1
Day 2
Day 3
Day 4
Day 5
7AM 8AM 9AM 10AM 11AM 12PM 1PM 2PM 3PM 4PM 5PM 6PM 7PM 8PM
example: P1


continuously tracks heart rates and blood pressure
lightweight, convenient, and integrated
without requiring any input from the user
all throughout the day and regular activities

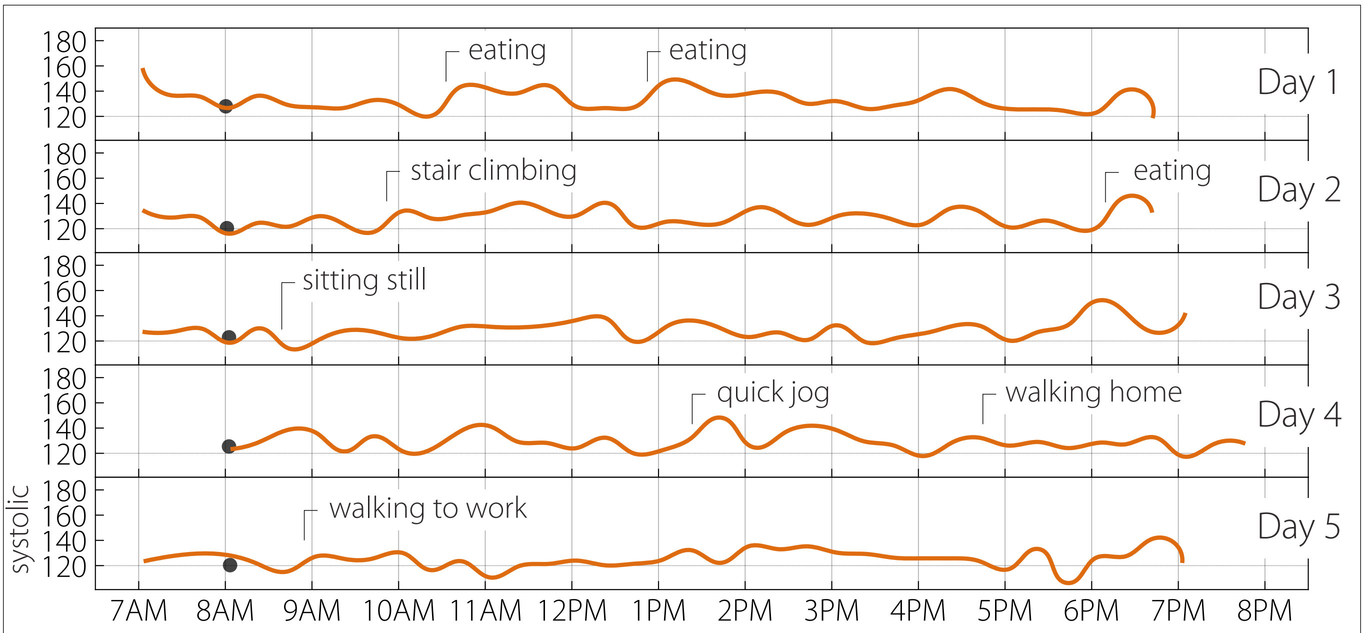

GET LOUD
ZARA

where's the activity part?

Glabella's main board



IMU

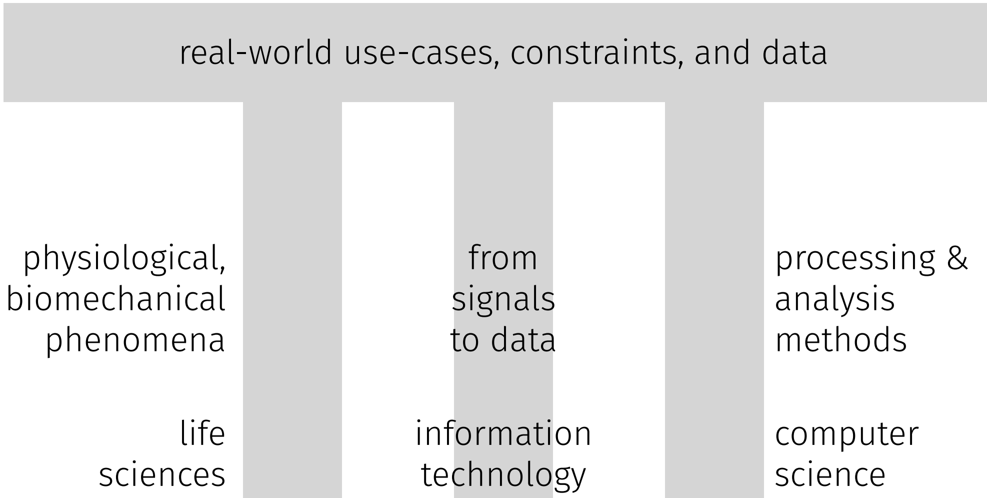


example P1: activity

Course goals

Mobile Health & Activity Monitoring

the three pillars of this course



questions we will aim to answer

for mobile health,

- What is the data that you have?
- What's the type of data you need?
- How do you get the type of data you need but don't have?

more methodologically,

- How do you devise methods to get it?
- And how do you evaluate them in representative (ecologically valid) ways?

finally, what's the human component in this process?

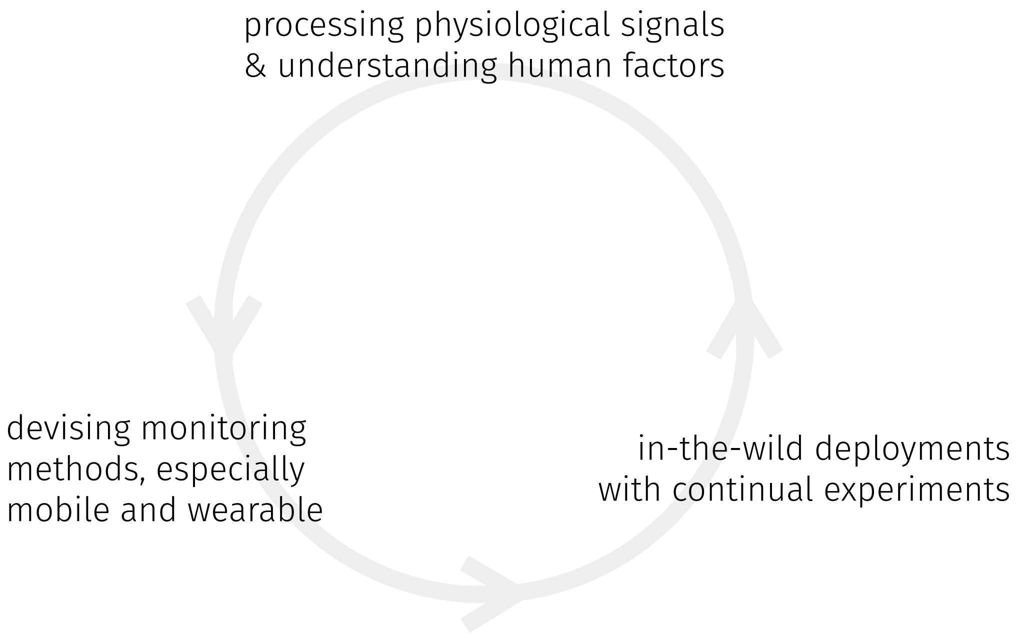
- Where, when, and how to measure to get to the what?
- Relevance and acceptance, human factors such as compliance

outcomes

by the end of the term, you will
- understand the wider ecosystem of mobile health
- get an overview of human physiology (focus on vital signs)
- understand how health diagnostics devices work,
  including concept, sensing method, device implementation, and application
- be able to dissect them
- learn physiological signal characteristics and processing methods
- learn how to evaluate interfaces in *representative environments ("in the wild")*

through the exercise, you will
- get first-hand experience with cross-modal data processing (time series!)
- develop processing methods for real-world (vs. applying ML to benchmarks)

➪ mobile health falls into the empirical sciences



this course is necessarily applied

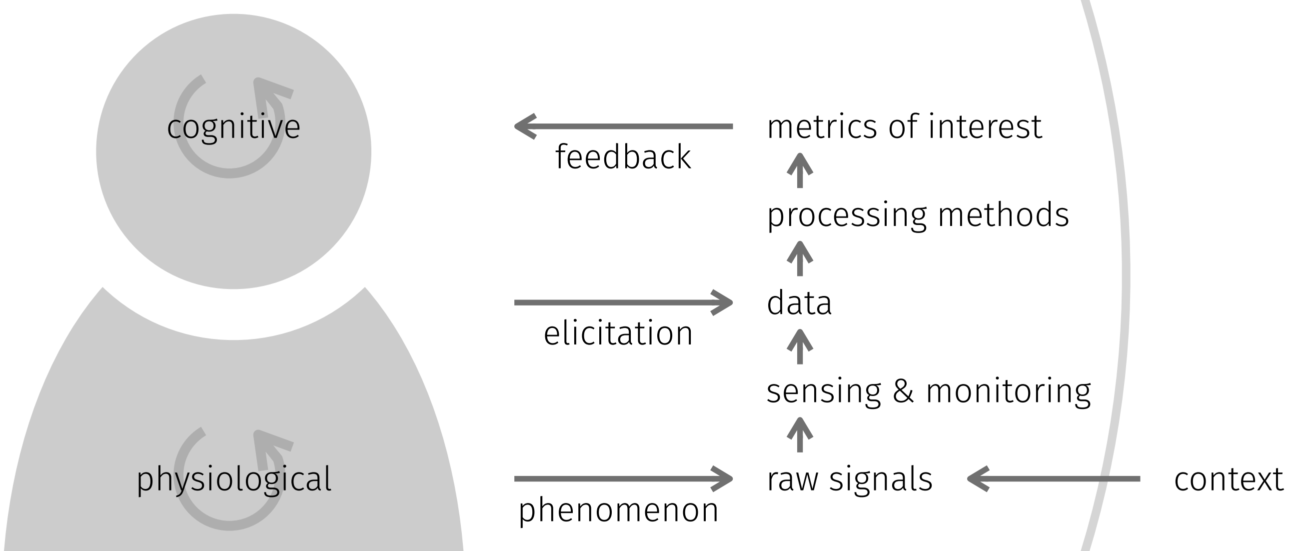
real-world problems and constraints

cross-disciplinary

- health sciences
- engineering
- human factors/social sciences

➪ think of this as a refresher of concepts from each domain,
allowing you to dive into the domain of mobile health,
where the total is more than the sum of the parts

this course



what this course is not

theoretical
- no proofs, no elaborate method design (if interested ➪ thesis)
- instead: overview over existing methods

hardware engineering
- won’t build, assemble, or innovate in hardware (if interested ➪ thesis)
- won’t dive into materials too much or expect detailed understanding

comprehensive medical curriculum
- instead: focus on vital signs and high-level cardiovascular processes
- application domain

#	DATE	WHO	TOPIC
1	Feb 20	Christian Holz	Introduction and course overview
2	Feb 27	Christian Holz	
3	Mar 6	Christian Holz	
4	Mar 13	Christian Holz	
5	Mar 20	Christian Holz	
6	Mar 27	Christian Holz	
7	Apr 3	Björn Braun	
–	Apr 10	—	*week after Easter*
–	Apr 17	—	*Sechseläuten*
8	Apr 24	Manuel Meier	
–	May 1	—	*first of May*
9	May 8	Christian Holz	
10	May 15	Shkurta Gashi	
11	May 22	Christian Holz	
–	May 29	—	*Whitsun*

…only 11 lectures

who we are

lecturers and TAs

lecturer

Prof. Christian Holz
Assistant Professor in Computer Science

"Human-Computer Interaction"
⊂ (computational interaction
∪ mixed reality
∪ mobile health)
lots of research outside the lab

collaborations across D-HEST, D-ITET, D-MAVT

about me

background in software engineering/geography

PhD in human-computer interaction

2013 – 2015	research scientist at Yahoo Research, San Francisco, CA
2015 – 2019	research scientist at Microsoft Research, Seattle, WA
2019 –	assistant professor at ETH Zürich, D-INFK Sensing, Interaction & Perception Lab https://siplab.org

teaching assistants

Max Moebus
M.Sc. Stats/Oxford
head TA

Kate Gadola
ongoing M.Sc.
ETH CS

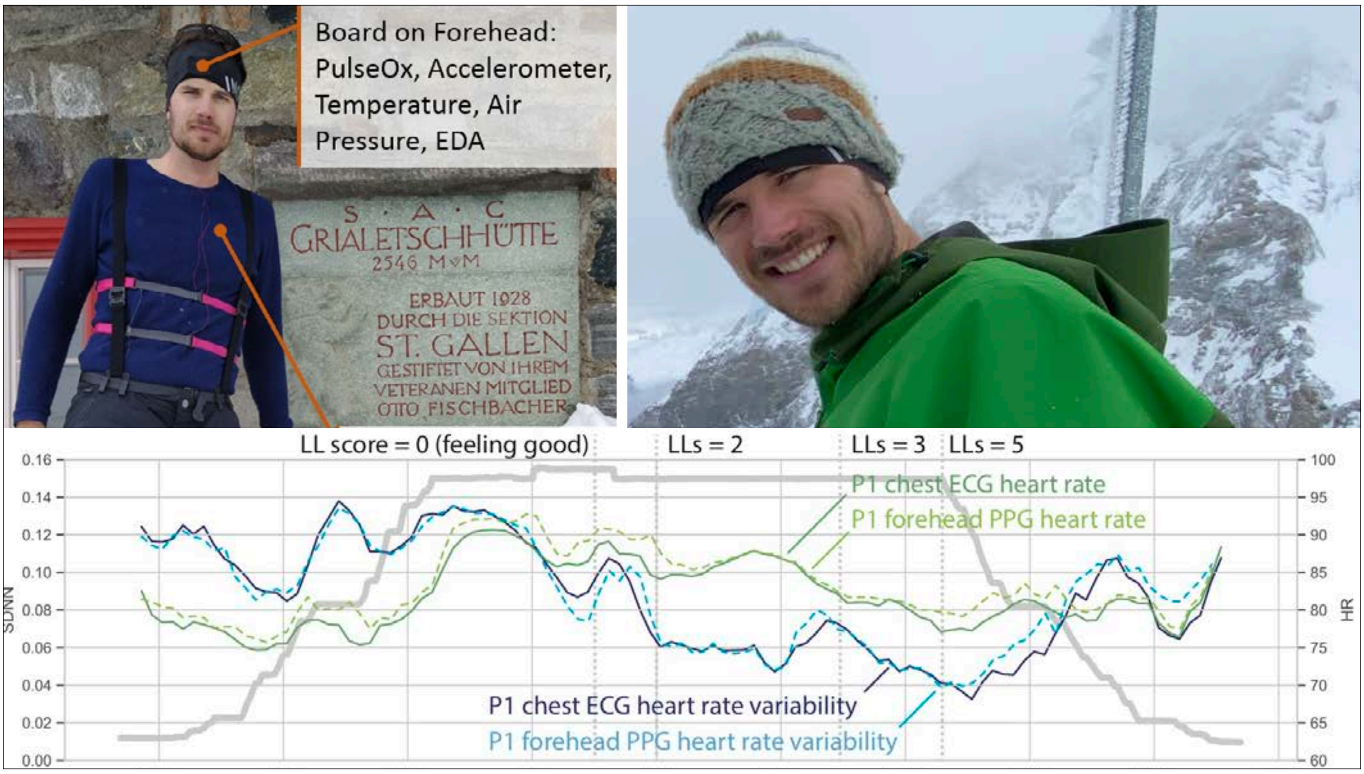
Björn Braun
M.Sc. RSC
ETH

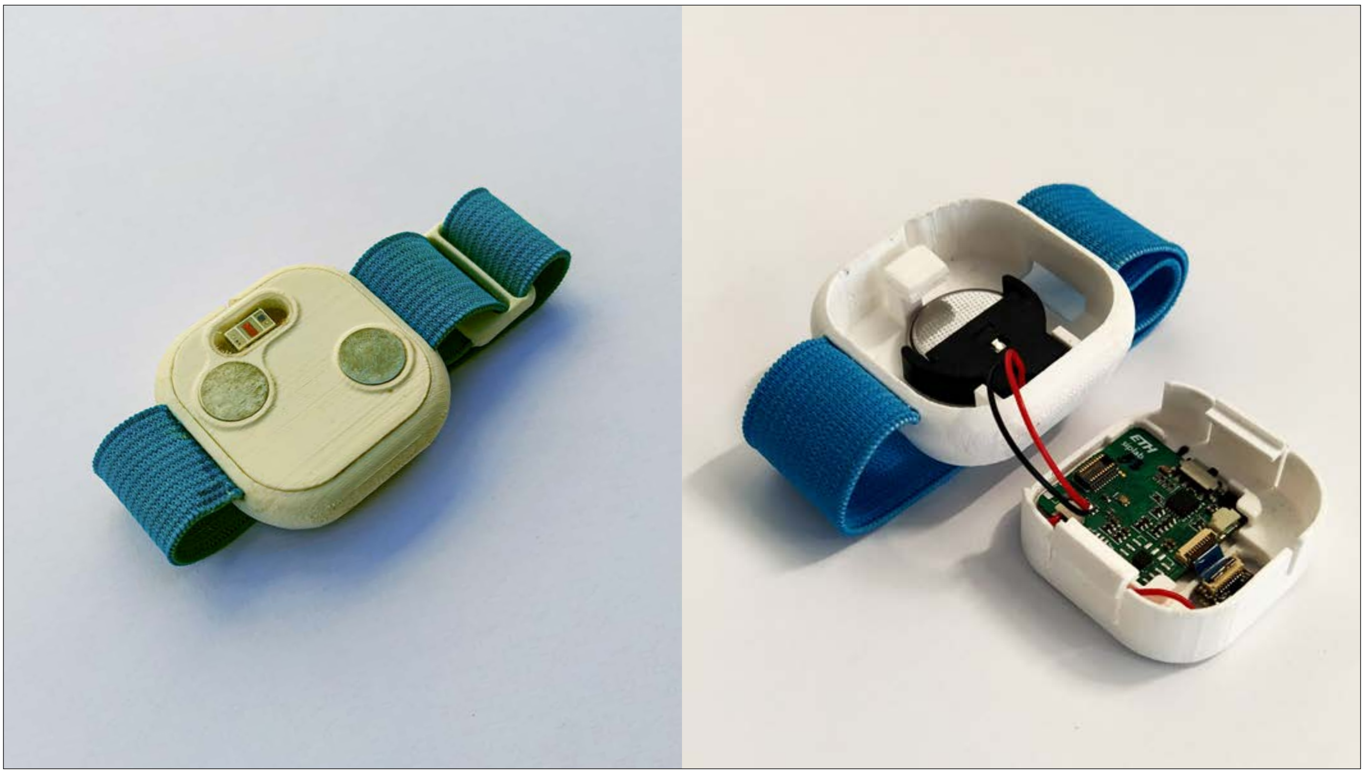
Paul Streli
M.Sc. EECS
Imperial

Manuel Meier
M.Sc. ITET
ETH

➪ contact the TAs through Moodle

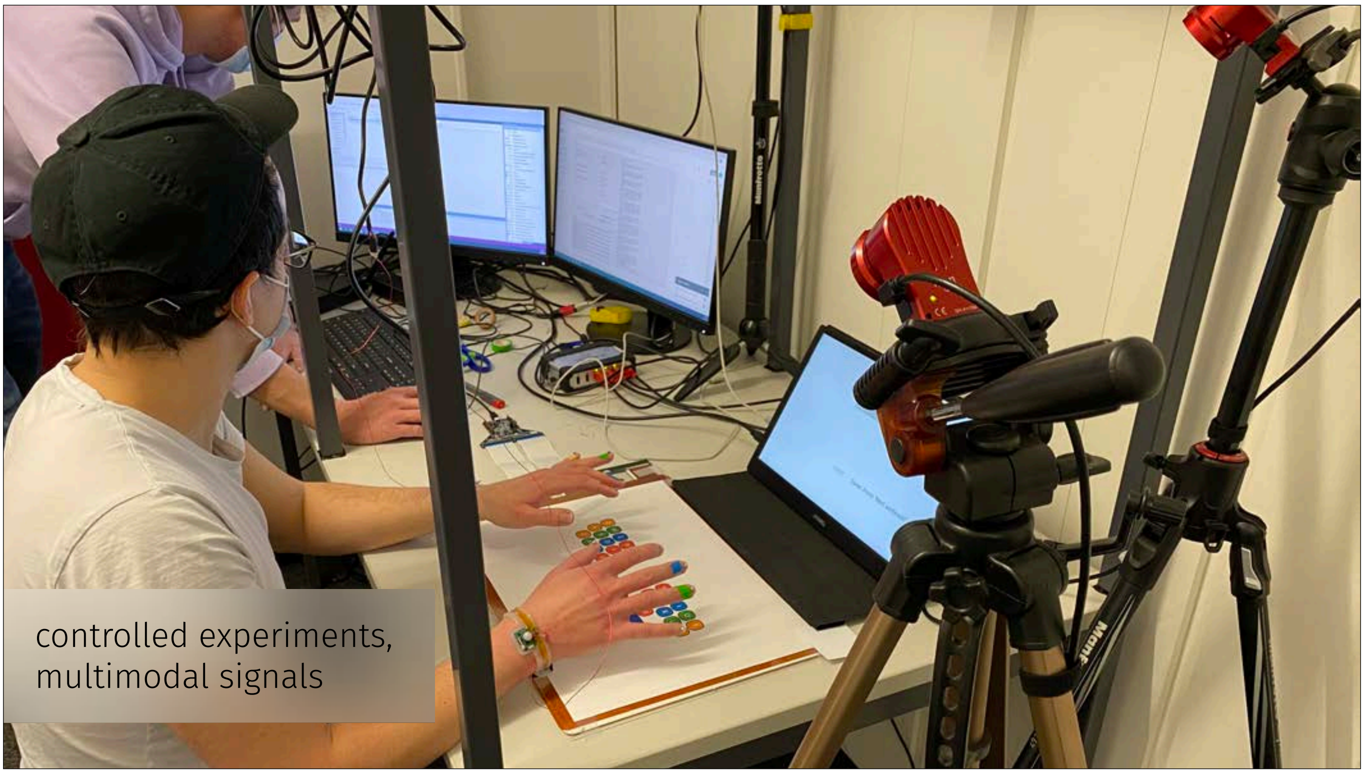

Board on Forehead:
PulseOx, Accelerometer, Temperature, Air Pressure, EDA
S · A · C
GRIALETSCHHÜTTE
2546 M ü M
ERBAUT 1928
DURCH DIE SEKTION
ST. GALLEN
GESTIFTET VON IHREM
VETERANEN MITGLIED
OTTO FISCHBACHER
Board on Chest:
ECG, PulseOx, Accelerometer, Temperature, Air Pressure, Breathing Rate
ETH
siplab

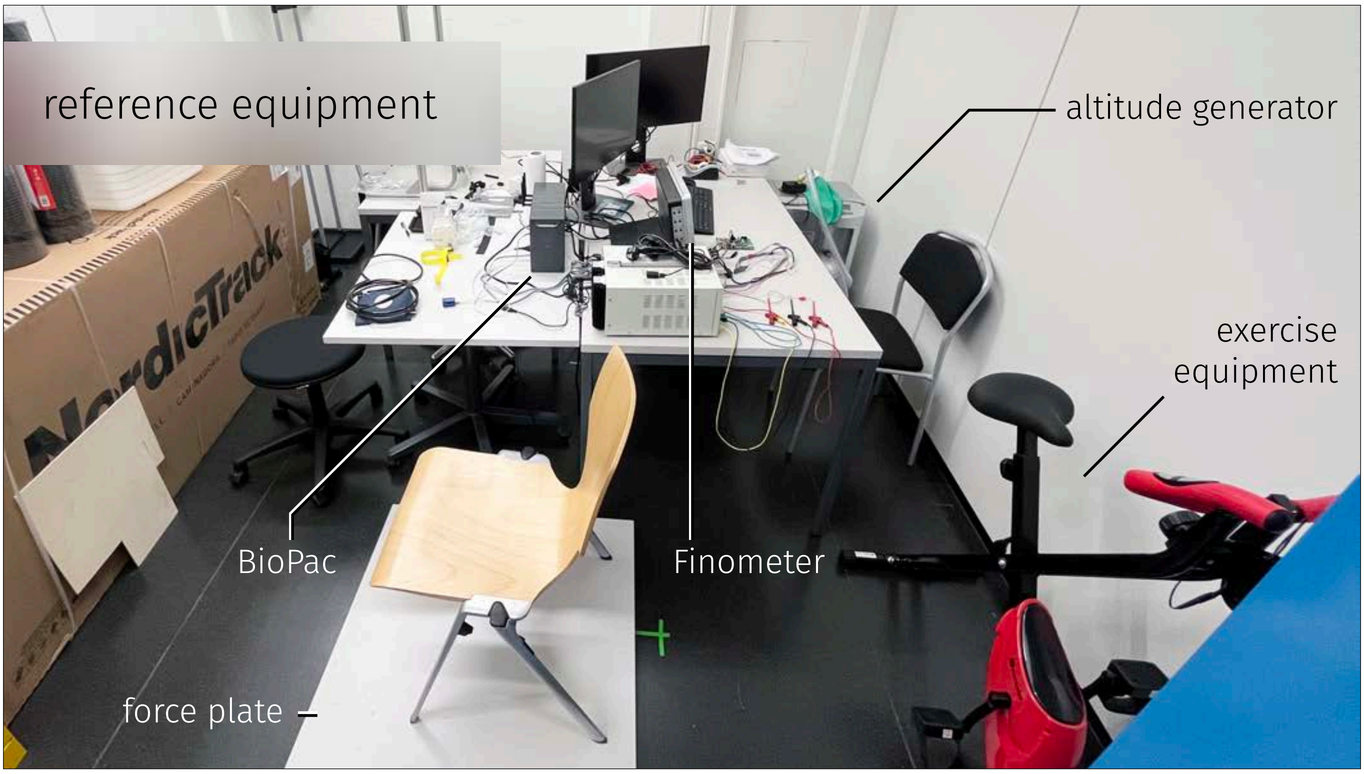

Board on Forehead:
PulseOx, Accelerometer, Temperature, Air Pressure, EDA
S · A · C
GRIALETSCHHÜTTE
2546 M ü M
ERBAUT 1928
DURCH DIE SEKTION
ST. GALLEN
GESTIFTET VON IHREM
VETERANEN MITGLIED
OTTO FISCHBACHER
LL score = 0 (feeling good)
LLs = 2
LLs = 3
LLs = 5
P1 chest ECG heart rate
P1 forehead PPG heart rate
P1 chest ECG heart rate variability
P1 forehead PPG heart rate variability
SDNN
HR
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
100
95
90
85
80
75
70
65
60



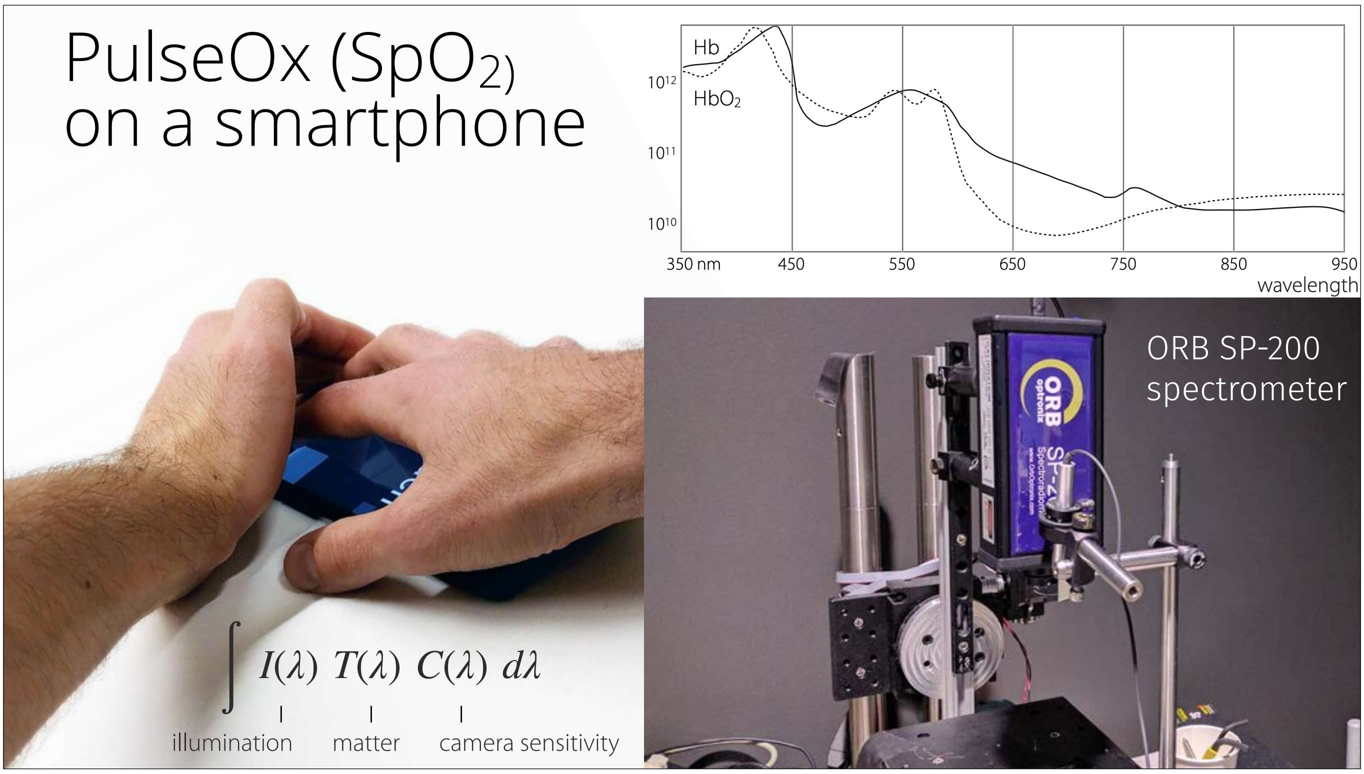

…but everything starts in the lab:
physiological phenomena, hypotheses, sensor design


…but everything starts in the lab:
physiological phenomena, hypotheses, sensor design


controlled experiments,
multimodal signals


reference equipment
altitude generator
exercise
equipment
BioPac
Finometer
force plate
NordicTrack


6 min
jungfrau.ch


PulseOx (SpO_2)
on a smartphone
Hb
HbO_2
10^{12}
10^{11}
10^{10}
350 nm
450
550
650
750
850
950
wavelength
ORB SP-200
spectrometer
$\int I(\lambda)\ T(\lambda)\ C(\lambda)\ d\lambda$
illumination
matter
camera sensitivity

MiBot

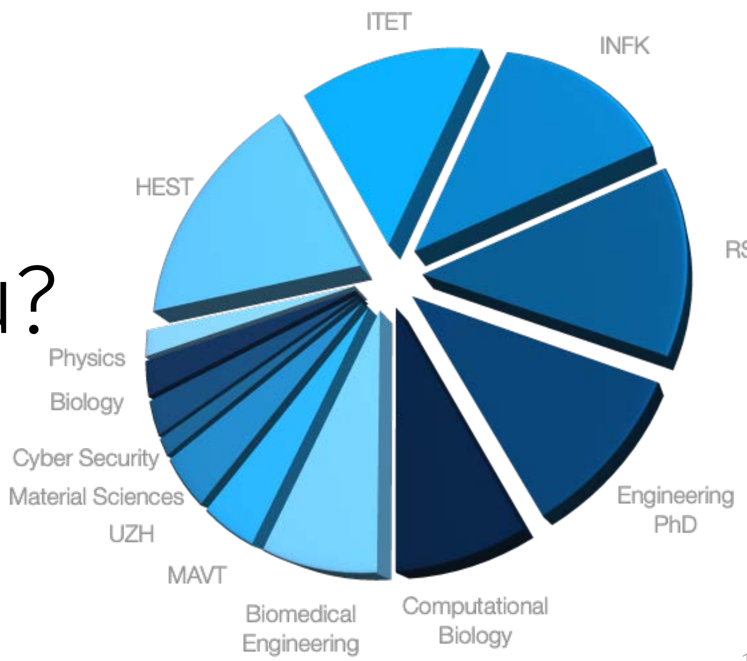
migraine mitigation

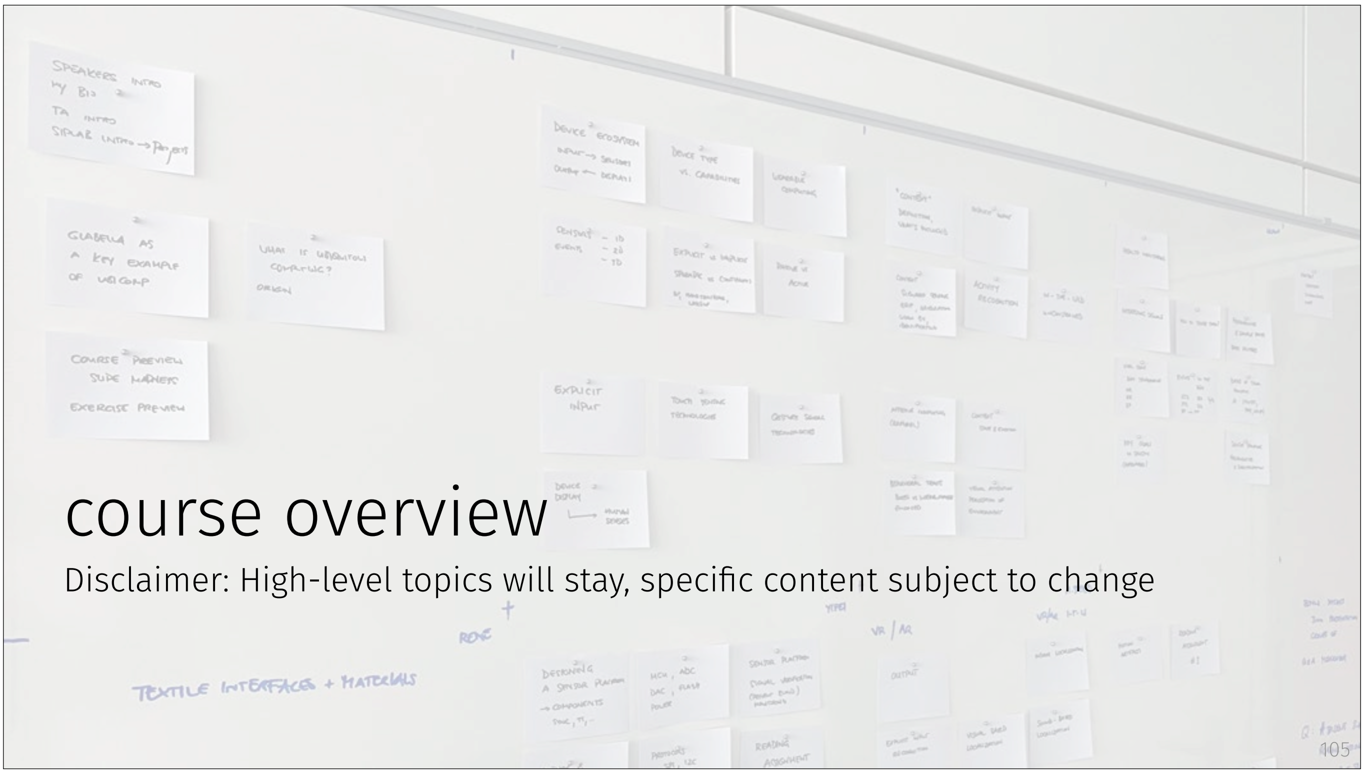
massage-based
prevention and
treatment

who are you?

program and aspirations

expectations of the course, hopes, and wishes?

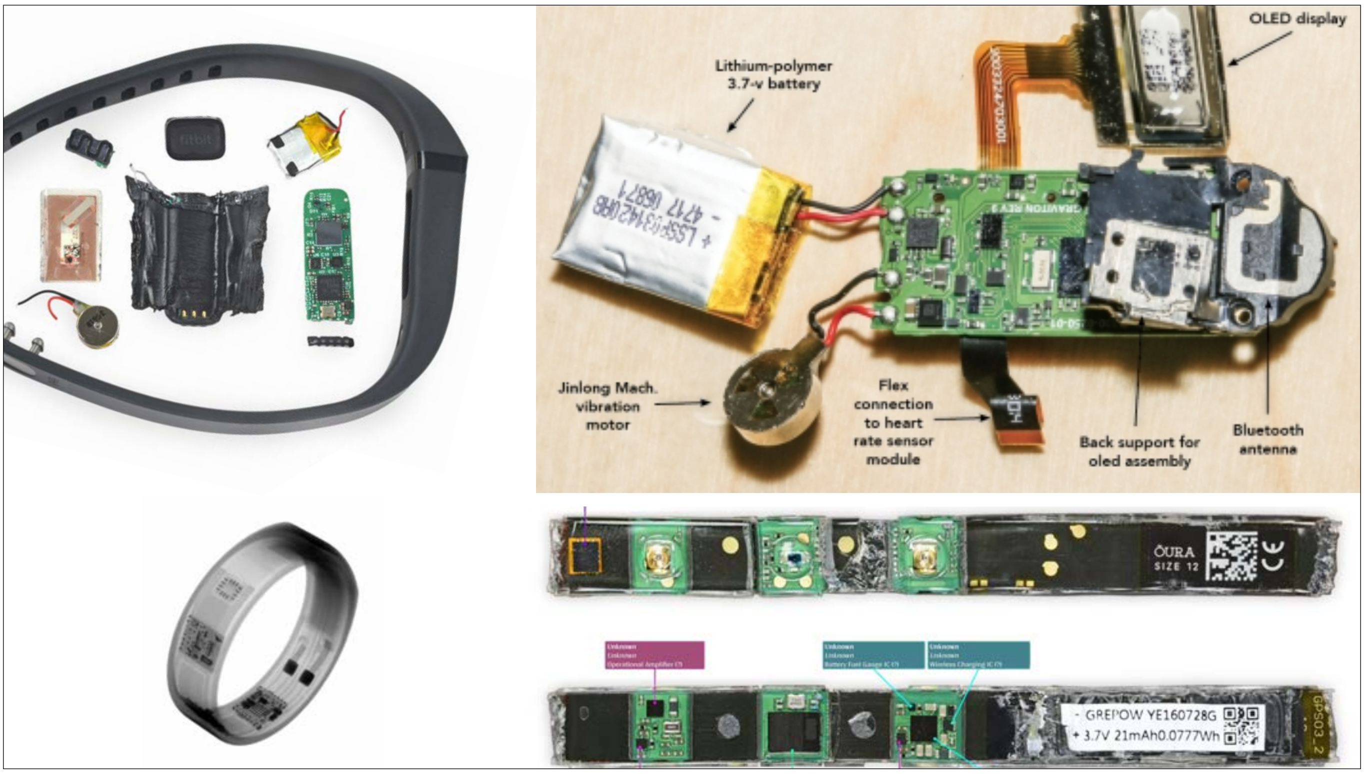




course overview

Disclaimer: High-level topics will stay, specific content subject to change

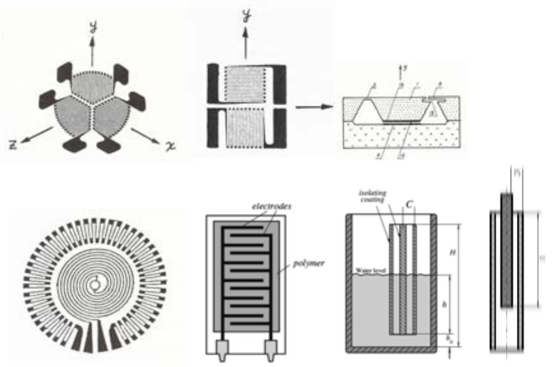
what makes a wearable health tracker (work)?



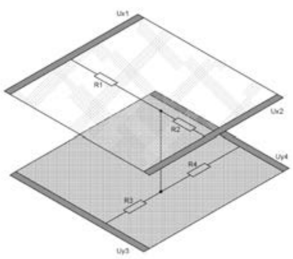
types of sensors

physical phenomena & measurable modalities

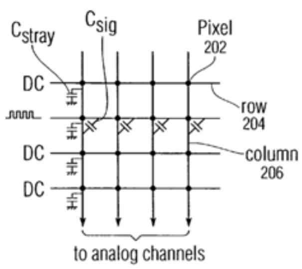
implicit vs. explicit sensing



resistive



capacitive



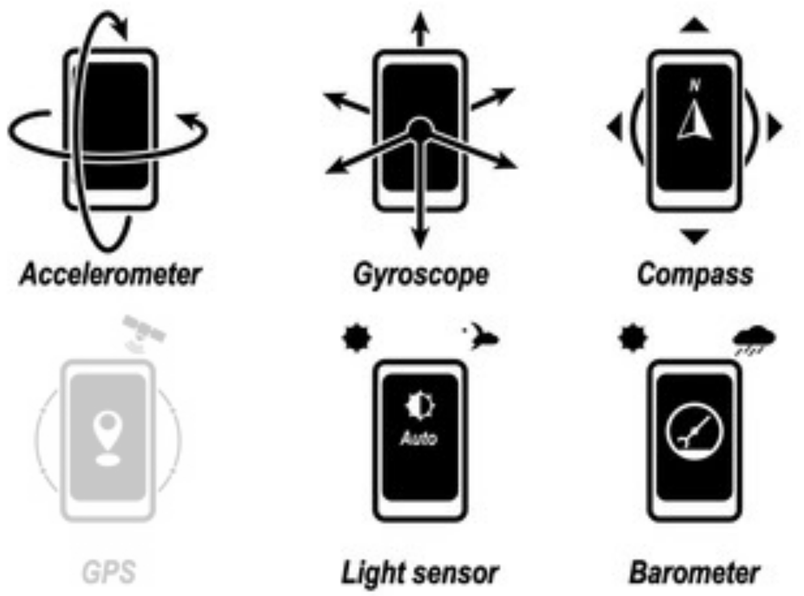
devices, sensors, sensing principles

detecting
activity

detecting
hand-object interaction

detecting
context of use

activity & context sensing



what are the signals,

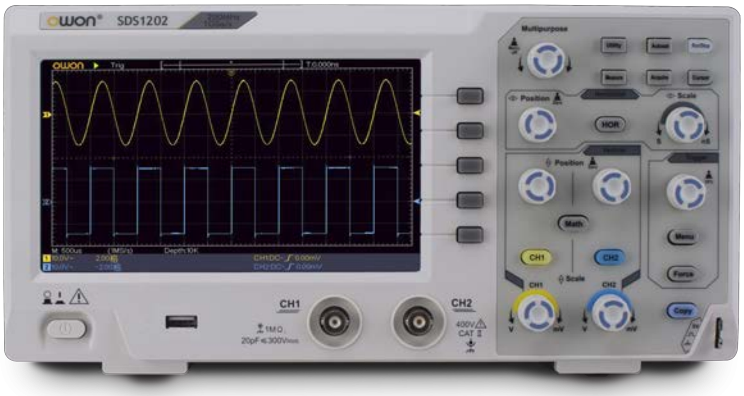
where do they come from,

how to process them
to turn them into data

simple methods to
detect events

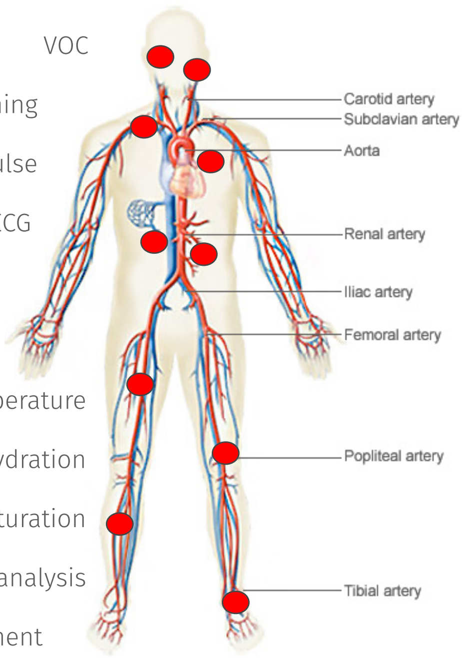
motion detection

signals (time & frequency domain)
analog vs. digital
sampling



“sensing”

VOC
breathing
pulse
ECG
blood pressure
core temperature
skin temperature
hydration
oxygen saturation
sweat analysis
movement

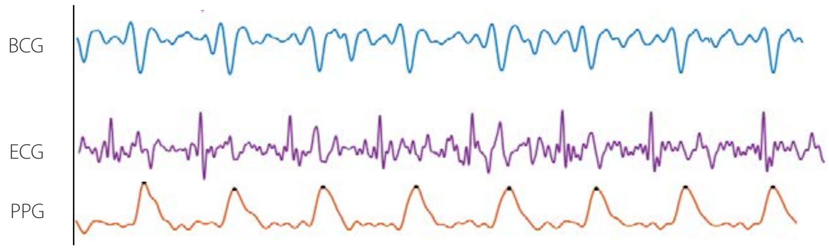


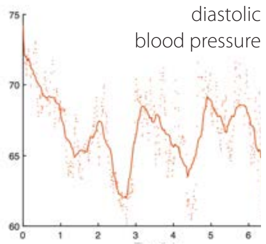
vital signs and
their meaning

health monitoring: physiological processes resulting signals

means to measure them

non-invasive vs. invasive monitoring





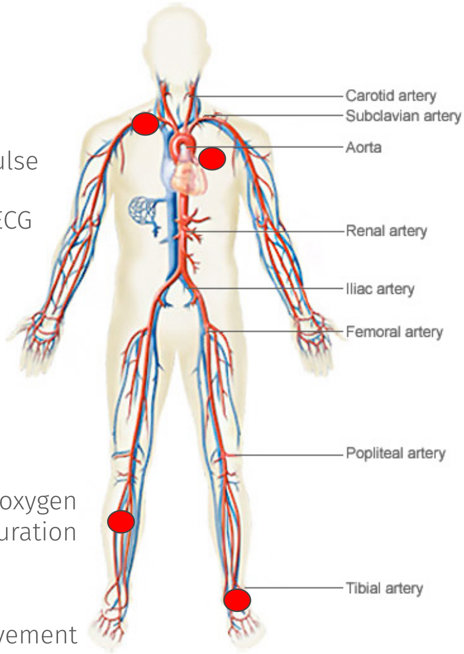
processing

pulse

ECG

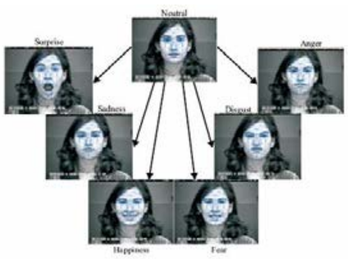
oxygen saturation

movement

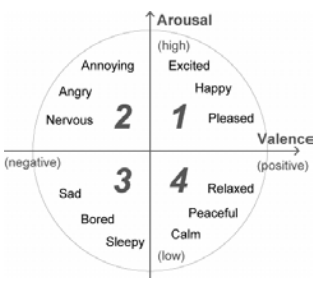


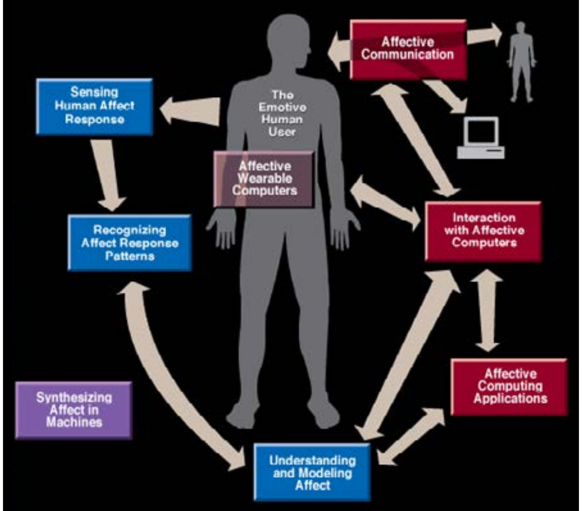
health monitoring: physiological signals & processing

emotion



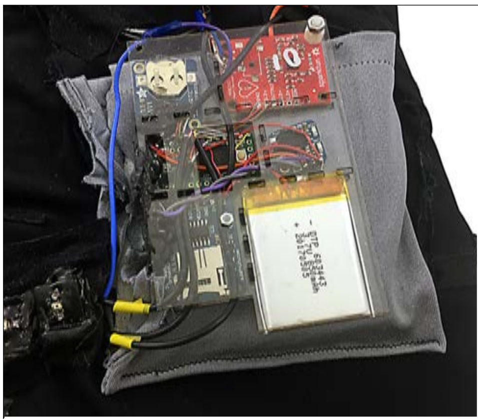
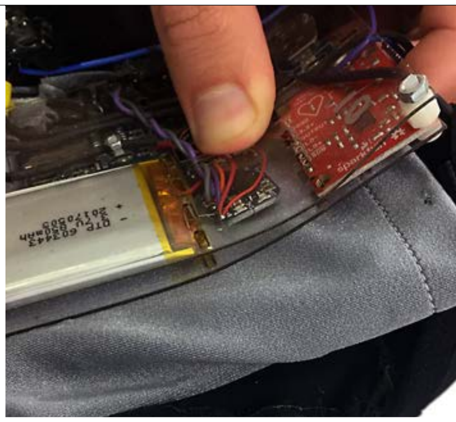
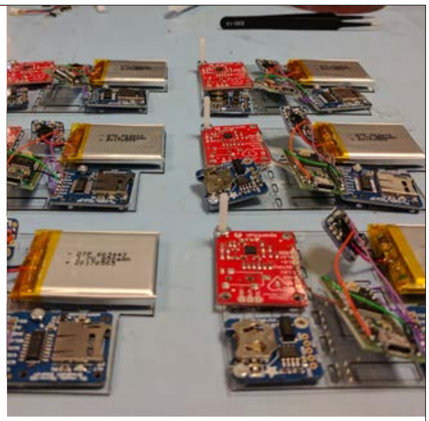
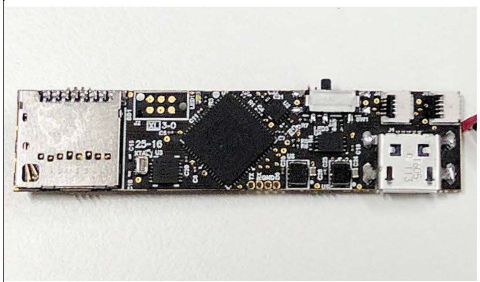
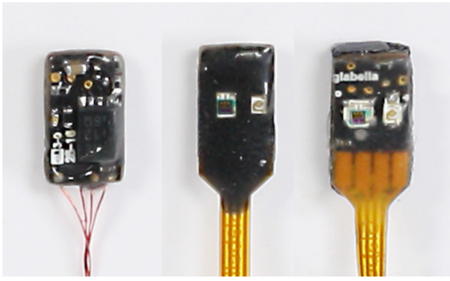
affect





methods to estimate affect

affective computing

synchronization, power

data storage, read out

MPUs, ADC, DAC

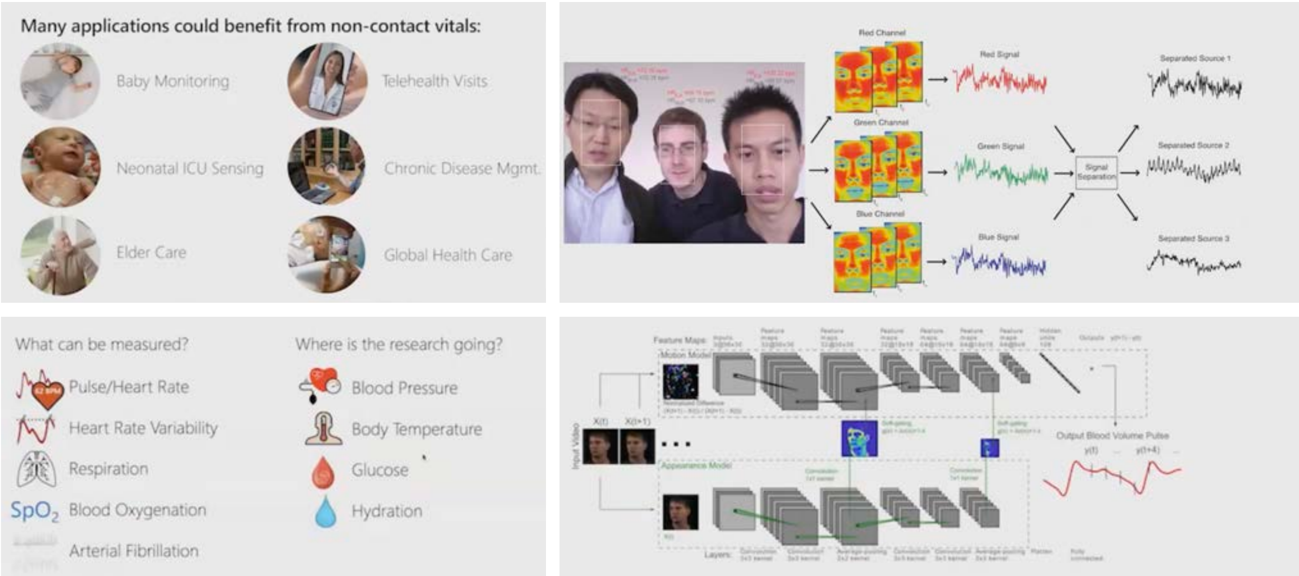
+ where to process?

(conceptually) designing a wearable for health & activity sensing

from special-purpose sensing devices to mobile phone apps

- complement or even take over data acquisition
- aid diagnostics through context

complementary mobile phones

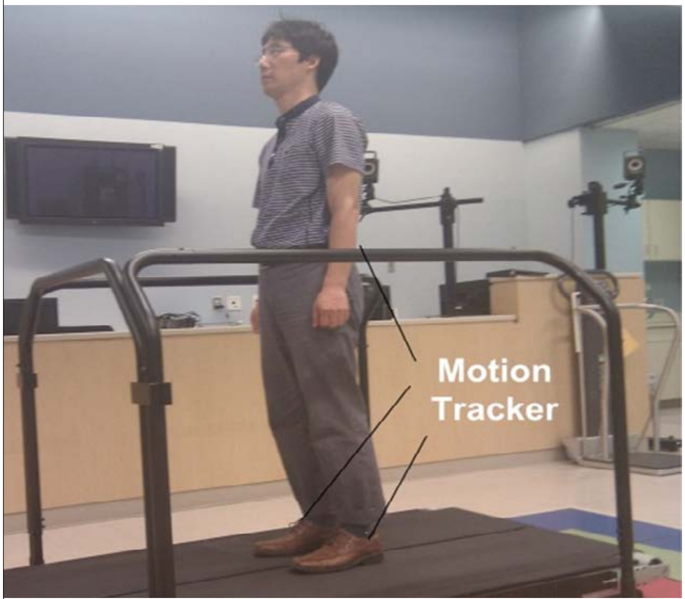


camera-based non-contact health sensing

controlled lab experiments

how to record data

controlled lab experiments vs. in the wild



logging & power
online vs. offline
processing
device reliability
state recovery

how to record data ...more than adding a battery

questionnaires

During the past week, I found that:	Strongly disagree						Strongly agree
My motivation is lower when I am fatigued.	1	2	3	4	5	6	7
Exercises brings on my fatigue.	1	2	3	4	5	6	7
I am easily fatigued.	1	2	3	4	5	6	7
Fatigue interferes with my physical functioning.	1	2	3	4	5	6	7
Fatigue causes frequent problems for me.	1	2	3	4	5	6	7
My fatigue prevents sustained physical functioning.	1	2	3	4	5	6	7
Fatigue interferes with carrying out certain duties and responsibilities.	1	2	3	4	5	6	7
Fatigue is among my three most disabling symptoms.	1	2	3	4	5	6	7
Fatigue interferes with my work, family, or social life.	1	2	3	4	5	6	7

clinical equipment+supervision

clinical assessment
vs.
continual monitoring everywhere

a mobile health use-case: monitoring neurological conditions

lecture format

fully hybrid

- in person teaching
- recorded and posted online

interactive

- raise your hand anytime
- time management = my job

reading assignments

4 reading assignments

full papers or articles, published at Mobile Systems/Digital Health venues

mandatory reading assigned each ~3 weeks

two papers

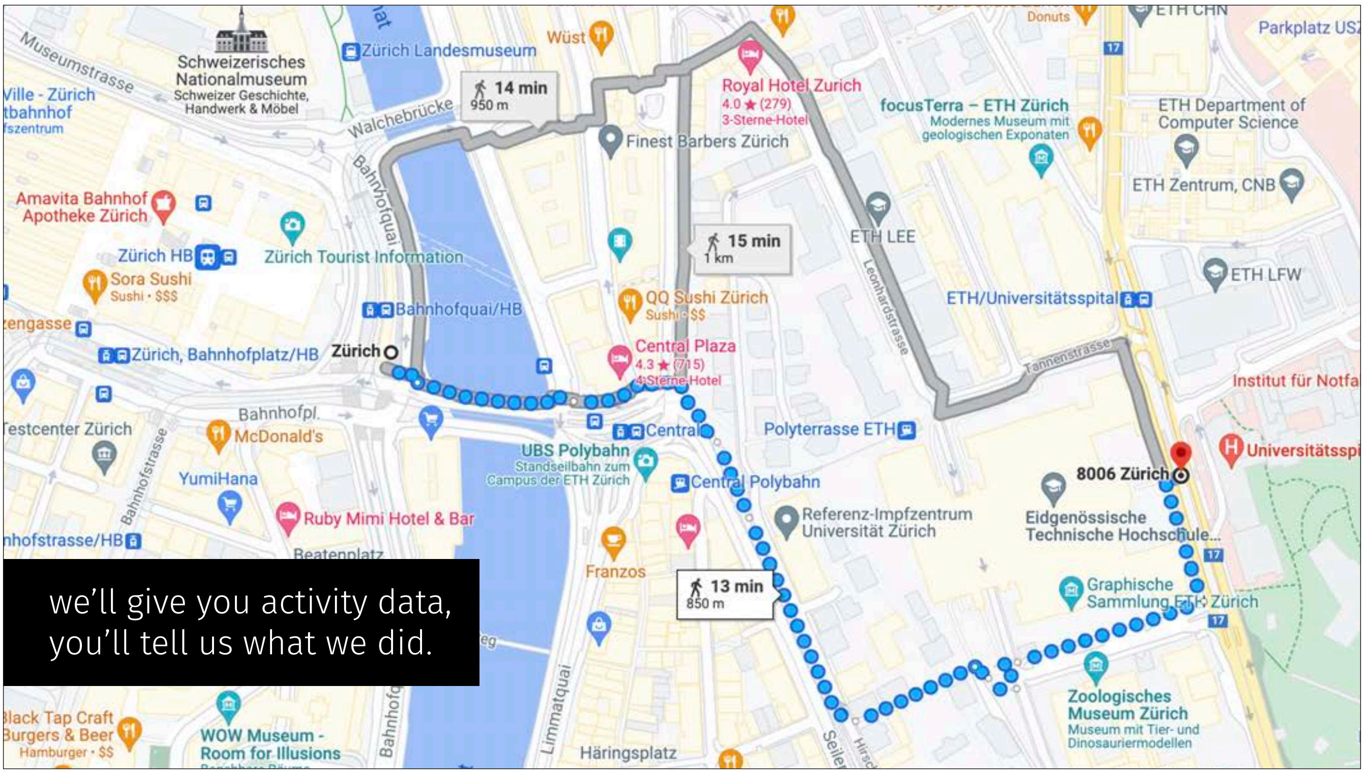
- discussed in class
- relevant for exam

two papers

- useful for the exercise
- great overview and good start to solve tasks

exercise

(very applied)



LilyGo smart band

each group gets one

battery-operated wearable band

includes sensors

- 3-axis accelerometer
- 3-axis gyroscope
- 3-axis magnetometer
- (sensor) temperature

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LilyGo smart band

each group gets one

battery-operated wearable band

includes sensors

- 3-axis accelerometer
- 3-axis gyroscope
- 3-axis magnetometer
- (sensor) temperature

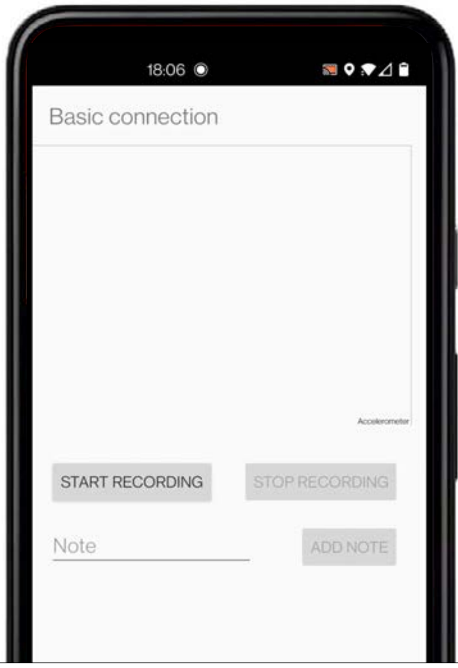
pairs with your phone

additional sensors
- GPS
- barometer
- ...

smartphone app

connects to smartwatch through BLE,

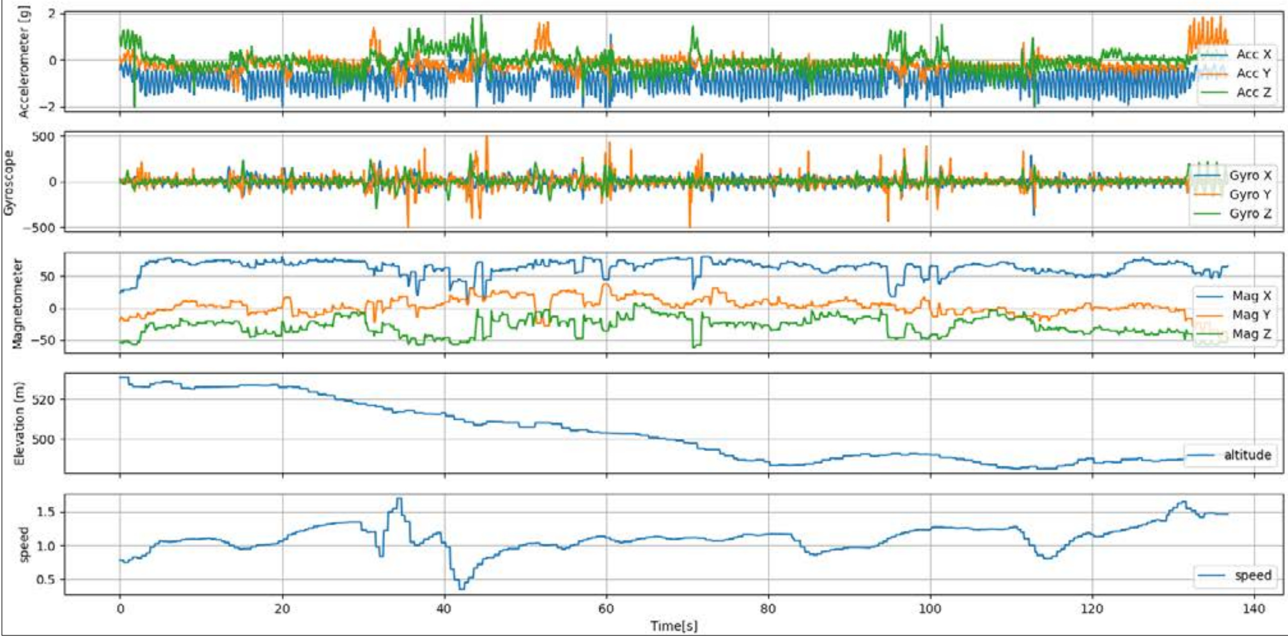
logs additional data, including:
- GPS
- 3-axis phone accelerometer
- 3-axis phone gyro
- 3-axis phone magnetometer
- barometric altitude



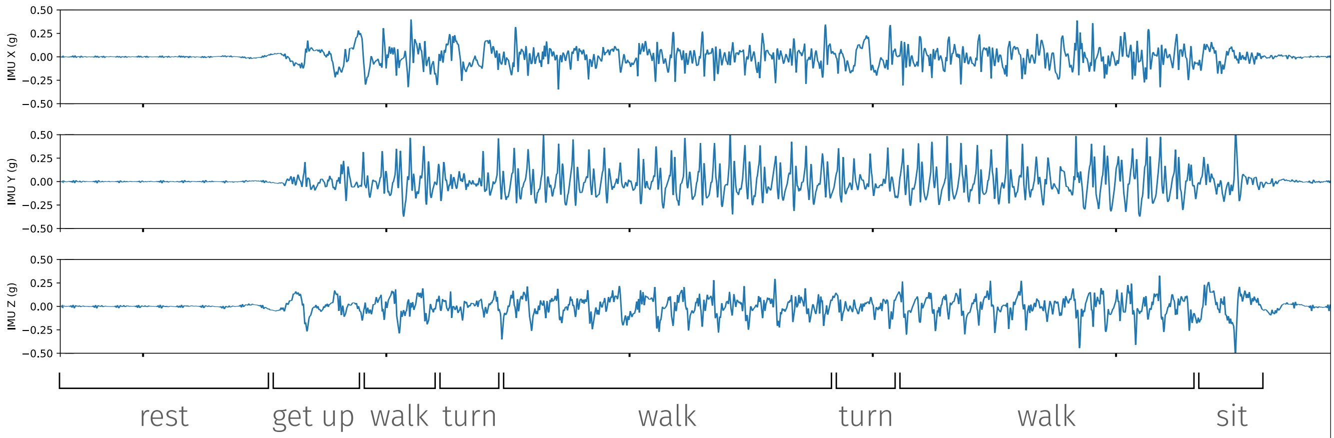
Python environment for loading+viz

```
coords = list(zip(trace.data['latitude'].values[100:-40], trace.data['longitude'].values[100:-40]))
m = Map(center=coords[int(len(coords)/2)], max_zoom=22, zoom=18, basemap=basemaps.OpenStreetMap.Mapnik)
m.layout.width='900px'
m.layout.height='600px'
ant_path = AntPath(locations=coords, delay=2000)
m.add_layer(ant_path)

# display directional speed if data available
if 'speed' in trace.data:
    for i in range(len(coords)):
        if i % 20 == 0:
            size = trace.data['speed'].values[i] * 20
            middle = int(size/2)
            icon = Icon(icon_url='img/arrow.png', icon_size=[size, size])
            #marker = Marker(location=coords[i], draggable=False, rotation_angle=example.data['bearing'].values[i]-90, rotation_origin='middle center', icon=icon)
            #m.add_layer(marker)

m
```

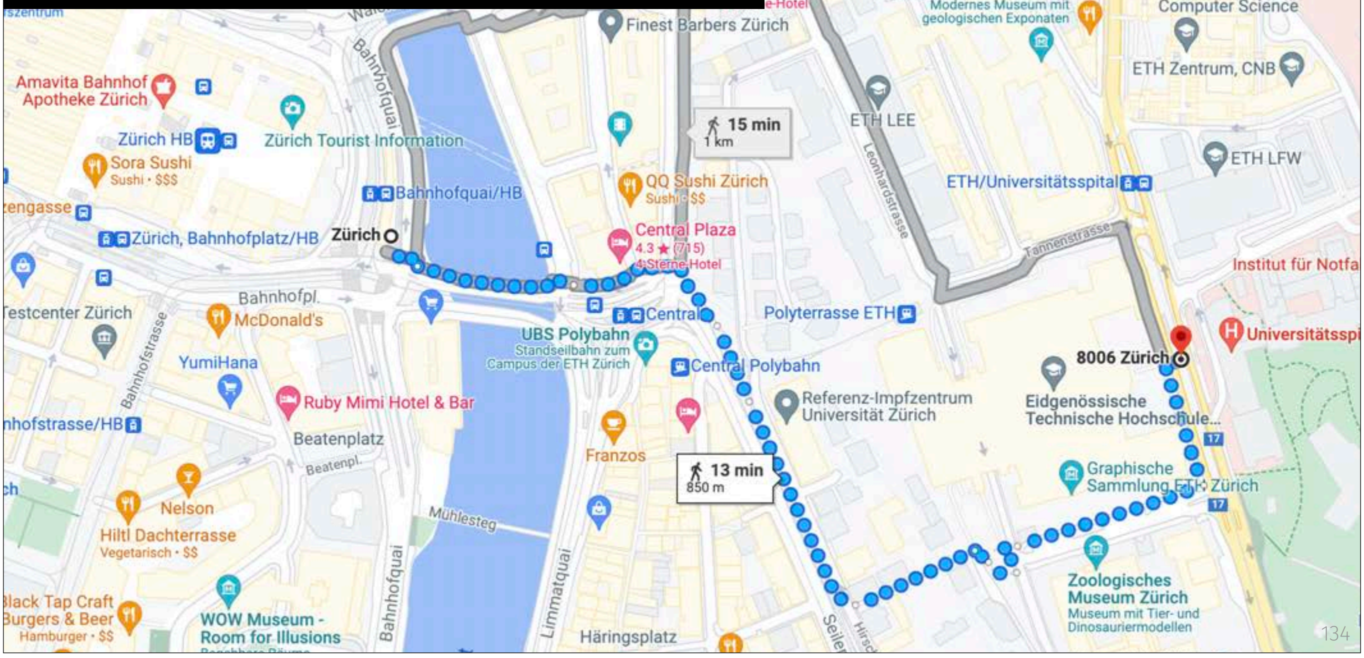
Python environment for loading+viz



your job: classify activities…



and resolve the paths



sub tasks

step counting

detecting

- mode of transport (e.g., walk, cycle, tram, ...)
- path taken across city
- location of device on the body

detailed task description will be released by next week

formalities

exercise in groups

three deadlines for sub tasks (enough time for exam)

exercise accounts for 50% of total grade

formalities

weekly exercise Q&A sessions

- slot to be announced
- tutorials, intros, overview as needed (input appreciated)
- attendance optional
- starting Week 3

announcements and communication

- TAs will announce important bits on Moodle
- Q&A also through Moodle

exam

exam

end-of-term exam (Semesterendprüfung)

- presence exam, computer based
- 90 minutes

➪ counts 50% of the grade

in early June

office hours

Wednesdays 9–10am

in person:

- book 15 min slot through link
- STD G 29.2
- https://siplab.org/contact

Zoom:

- https://ethz.zoom.us/my/christianholz
- has waiting room

summary

summary

11	lectures	(not always 90 minutes)
2	weeks break	(1 week for Easter, Sechseläuten)
1	exercise	(accompanying the semester)
4	reading assignments	
1	end-of-term exam	(Semesterendprüfung)

course repository

- https://go.siplab.org/mhealth2023
- user: mhealth2023, password: PuntaNizuc

contact

- everything through Moodle
- https://moodle-app2.let.ethz.ch/course/view.php?id=19753

end

prof. christian holz
mobile health & activity monitoring, spring 2023

sensing,
interaction &
perception lab

optional reading

Christian Holz and Edward J. Wang. 2017. **Glabella: Continuously Sensing Blood Pressure Behavior using an Unobtrusive Wearable Device.** *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 3, Article 58 (September 2017), 23 pages. DOI:https://doi.org/10.1145/3132024