

## Biomedical Wearable Technologies for Healthcare and Wellbeing

# Introduction

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A.Y. 2023-2024  
Giacomo Cappon



# Agenda

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- Teacher introduction
- What is the course about
- The architecture of wearable IoT systems
- Applications of wearable IoT in healthcare and wellbeing
- Course program
- The exam
- Extra

# Who am I

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## ➤ Giacomo Cappon

- Assistant Professor, Department of Information Engineering, University of Padova
- PhD in Information Engineering, curriculum Bioengineering
- Main research interests: machine learning; Bayesian methods; signal processing; decision support systems; wearable sensors; digital health and therapeutics; telemedicine



## ➤ Contacts

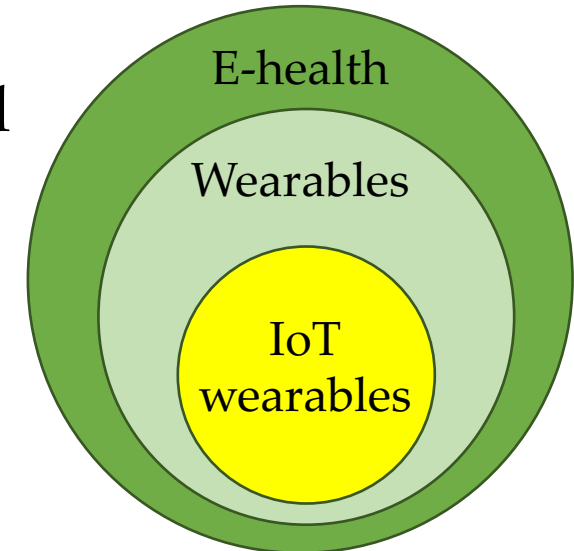
- email: [giacomo.cappon@unipd.it](mailto:giacomo.cappon@unipd.it)
- personal website: <https://gcappon.github.io>
- public repos: <https://github.com/gcappon>

# What is the course about?

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## Biomedical wearable technologies...

- **E-health or digital health:** The use of modern Information and Communication Technologies (ICT) to efficiently deliver all kinds of healthcare services
  - Examples: EHR, telemedicine systems
- **Wearables:** electronic devices worn close to and/or on the surface of the skin, which detect, analyze and transmit biomedical data, such as heart rate, activity, blood pressure, temperature, etc.
- **Internet-of-thing (IoT) wearables:** Wearables that connect and exchange data with other devices (wearable or not) and systems over the Internet or other communication networks



# What is the course about?

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## ... for healthcare and wellbeing

- Our society is facing some important global health challenges
  - **Lifestyle-related illnesses** driven by sedentary life, consumption of processed and fast foods, alcohol drinking and smoking
    - Need to change the paradigm of healthcare, from a mostly reactive system to a **proactive system**
  - **Population ageing** rises the demand of health services and the healthcare expenditure.
    - Need to **decentralizing the healthcare**
    - Covid-19 pandemic called for urgent delivery of healthcare at home

**Biomedical wearable technologies are fundamental to make healthcare scalable and accessible outside the hospital setting and deliver personalized and preventive health services**

# Towards a new model of healthcare

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## ➤ Traditional healthcare system:

- **Reactive:** focused on treating
- **Centralized:** healthcare at hospitals
- **Population-based:** maximizing health outcomes of a certain population
- **Doctor-centric:** only doctor responsible for the patient's care

## ➤ Biomedical wearable technologies play an important role in realizing a **new model of healthcare** which is:

- **Decentralized:** healthcare at home to reduce pressure on hospitals
- **Proactive:** focused on prevention
- **Personalized:** maximising the health outcomes of single individuals
- **Participatory:** engaging individuals in the healthcare process
- **Sustainable:** better management of resources, patient prioritization

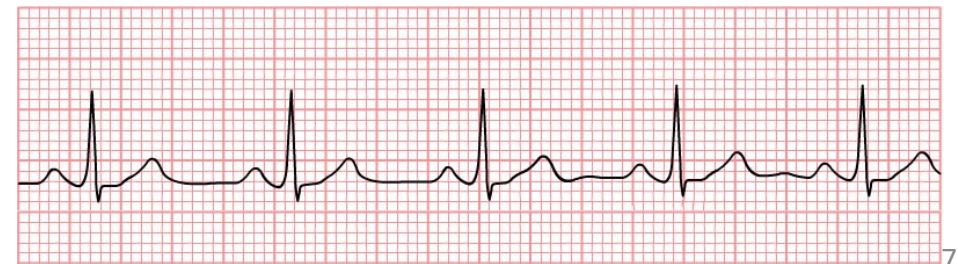
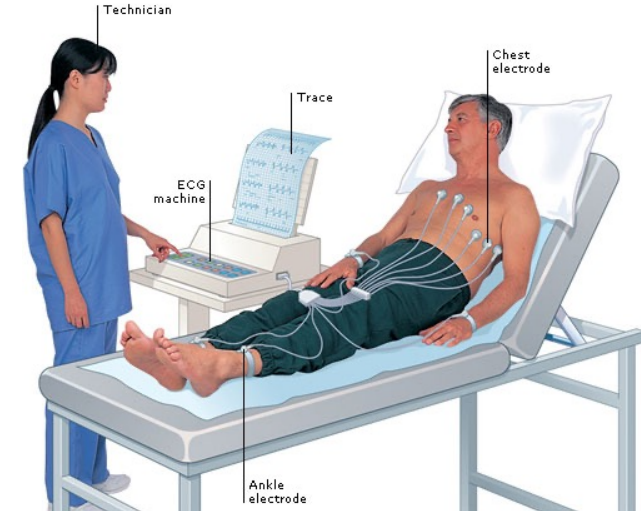
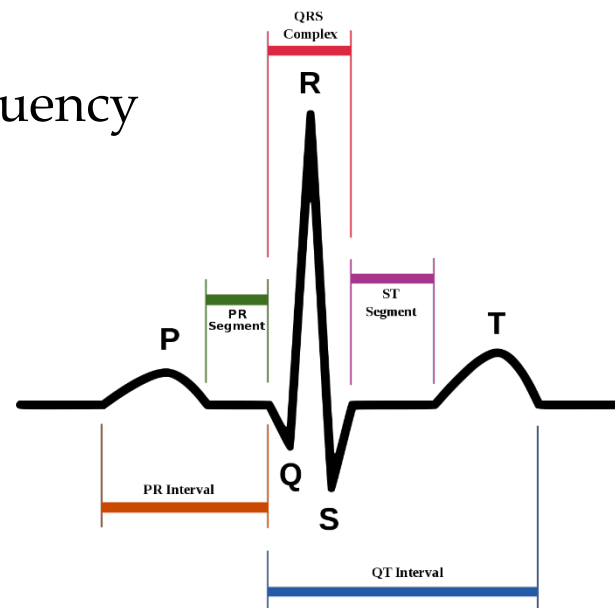
# Examples of biomedical wearable technologies

## Heart rate monitor

- Heart rate (HR): frequency of heart beats [beats/min]
- Monitoring HR allows to detect bradycardia (slow HR), tachycardia (fast HR) or arrhythmia (irregular HR)

In hospital:

- **Electrocardiogram (ECG):** electrical activity of the heart measured by on skin electrodes (usually 12)
- HR determined as the frequency of peaks of the R wave

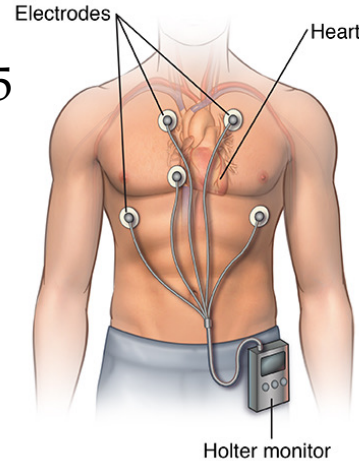


# Examples of biomedical wearable technologies

## Heart rate monitor

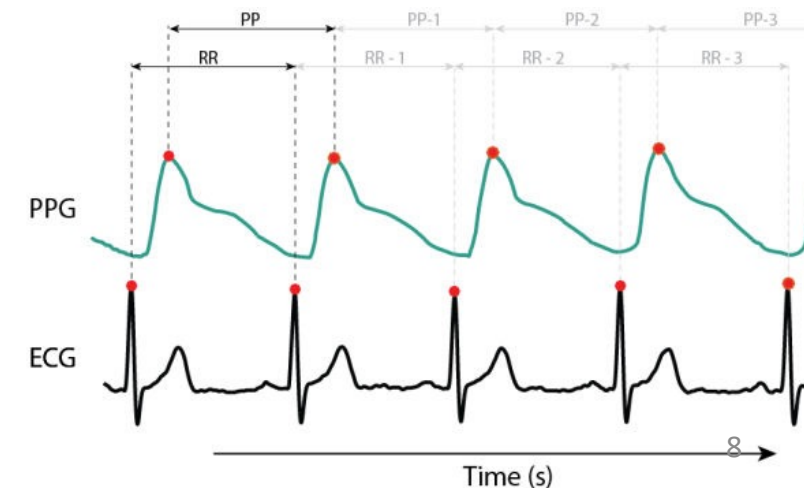
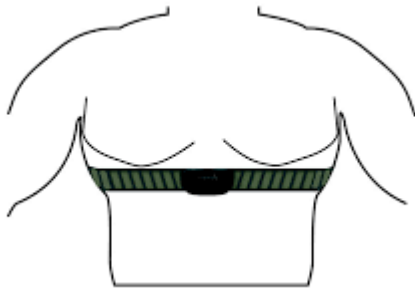
- Wearable HR monitors for home use:

- **Holter monitor:** portable ECG monitor, 5 electrodes placed on the chest
- Used for medical purpose
- Low portability, used for 24-72 hours



- **Smartwatches** use an optical sensor that shines light and measures changes in light absorption to estimate changes in capillary blood volume
- Resulting signal: photoplethysmogram (PPG)
- HR estimated as the frequency of P waves

- **Chest straps:** electrical activity of the heart measured with electrodes integrated in a chest band/strap





# Examples of biomedical wearable technologies

## Glucose monitoring sensors

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- Blood glucose (BG) concentration: concentration of glucose in the blood [mg/dL or mmol/L]
- Abnormal BG levels, e.g., hyperglycemia (too high BG) and hypoglycemia (too low BG), may occur in people with metabolism disorders (e.g., diabetes).

In hospital/laboratory:

- **Biochemistry analyzers**
  - Exploit a chemical reaction driven by specific enzymes (e.g., glucose-oxidase)
  - Invasive (blood sample required), only sparse measurements possible

At home:

- **Self-monitoring of blood glucose (SMBG) or glucometer:**
  - drop of capillary blood collected by fingerprick and put in a test strip
  - a portable glucose analyzer, through an electrochemical sensor, detects the BG concentration in the capillary blood
  - Minimally-invasive but not wearable: only sparse measurements possible (e.g., 3-4 per day)



# Examples of biomedical wearable technologies

## Glucose monitoring sensors

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### ➤ Continuous glucose monitoring (CGM) sensors

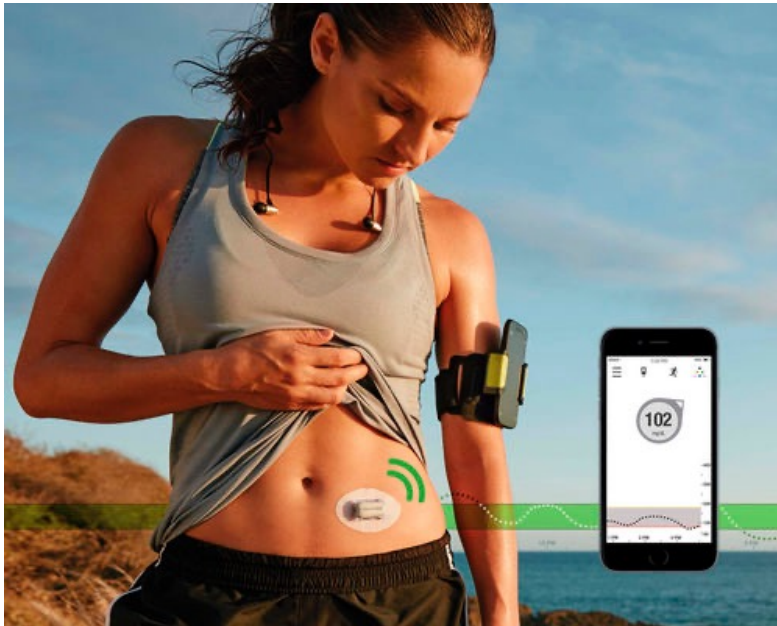
- Minimally-invasive sensors measuring glucose concentration in the interstitial fluid at almost continuous time (e.g., every 5 min) for several consecutive days (e.g., 10 days)
- Needle electrode placed under the skin, exploiting glucose oxidation reaction
- The transmitter, placed over the electrode, wirelessly transfers the measured data to a portable display device
- Mainly used in people with type 1 diabetes



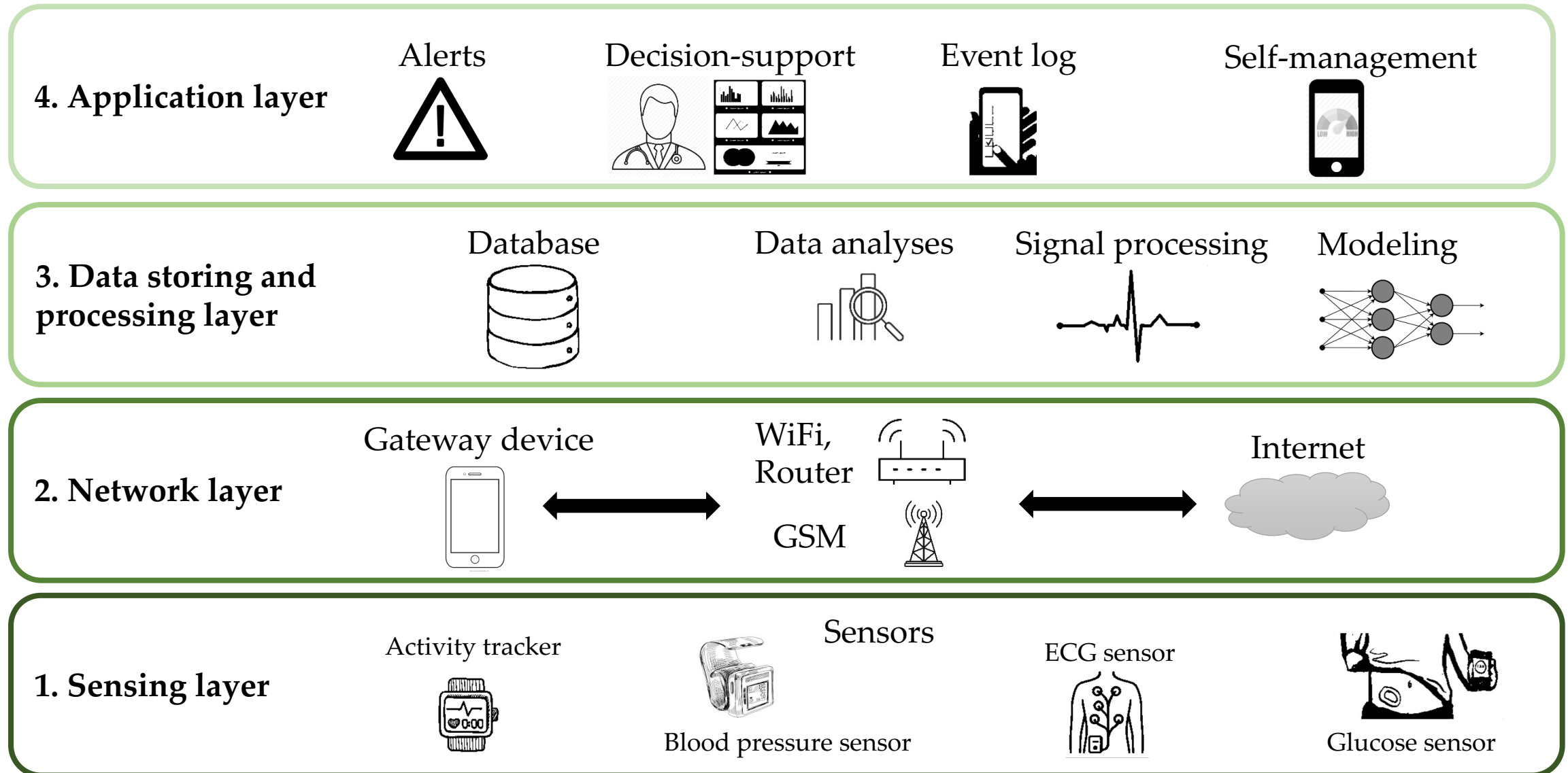
# Modern wearable technologies become IoT

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- Modern wearable sensors can wirelessly connect to internet-connected devices, such as smartphones, by which the user can share their data with other people (e.g., doctor or family/friends) and upload them in the cloud



# The architecture of wearable IoT systems



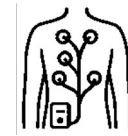
# 1. Sensing layer

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- This layer includes sensors, which are responsible for:
  - **Collecting the data** either directly from the body through contact sensors or from peripheral sensors providing indirect information of body and behaviours
  - **Preparing the data** for on-board analysis, closed-loop feedback or remote transmission for more comprehensive analysis and storing
- Key components of IoT wearable sensors:
  - Miniaturized **sensor hardware**
  - **Embedded processor** with storage capabilities, power management and communication circuits
- Typically limited computing power and storage capabilities.

## Contact sensors

ECG sensor



Glucose sensor



## Peripheral sensors

Step counter



Microphone and camera

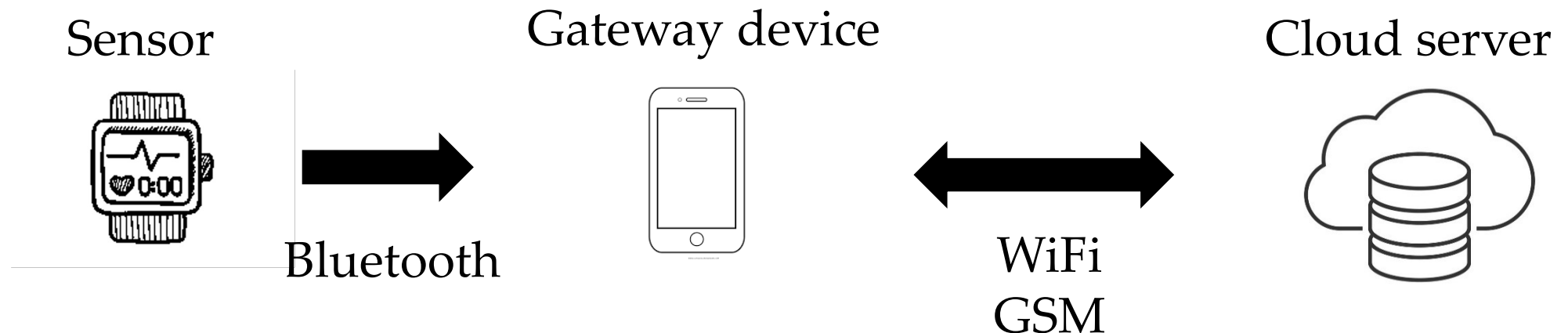




## 2. Network layer

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- For more comprehensive data analysis and storage, the sensor layer needs to transmit the data to **cloud computing servers** (remotely-located computing machines).
- This transmission can be mediated by a companion device that serves as a **gateway**, i.e., it enables the information to flow from sensors to the cloud server.
  - Example of gateway devices: smartphones, tablets and PCs.
- The communication must be **secured** through:
  - Authentication protocols for writing, modifying and accessing the data
  - Security and privacy protocols for preserving the data



# 3. Data storing and processing layer

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- Layer responsible for data storing and complex processing
  
- Key components:
  - **Database** for structured data storing
    - Data organized based on a specific data model (relational, hierarchical, object-oriented,...)
  
  - **Algorithms** for data processing
    - Statistical analysis
    - Feature extraction (e.g., heart rate, calories expenditure, ...)
    - Signal processing (e.g., filtering, artifact removal, ...)
    - Data mining (e.g., cluster analysis, anomaly detection, sequential pattern extraction, ...)
    - Data modeling (knowledge-based, data-driven or hybrid approaches)
    - Artificial intelligence (knowledge representation, machine learning, natural language processing, machine perception, automated planning, ...)

# 3. Data storing and processing layer

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➤ Layer responsible for data storing and complex processing

➤ Key components:

Topic not covered

■ ~~Database for structured data storing~~

- ~~• Data organized based on a specific data model (relational, hierarchical, object-oriented,...)~~

■ Algorithms for data processing

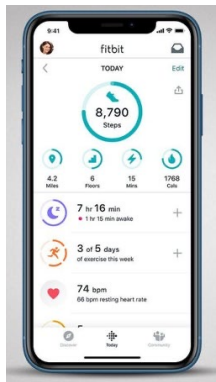
- Statistical analysis
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# 4. Application layer

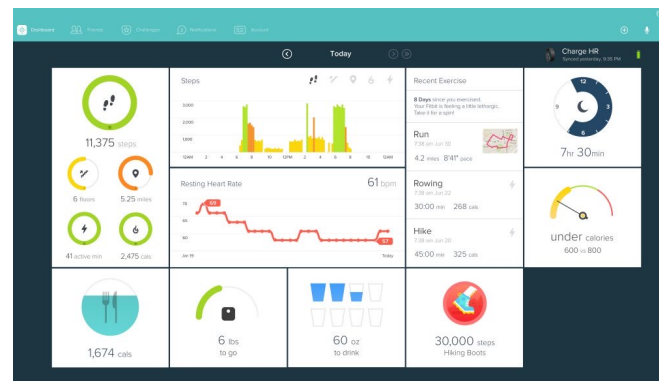
- Layer responsible for visualizing raw or processed data to end-users and for providing decision support to them through a software application
- Possible end-users: patients, physicians, caregivers, analysts, data managers, administrators, etc.
- Possible types of applications:

Mobile app



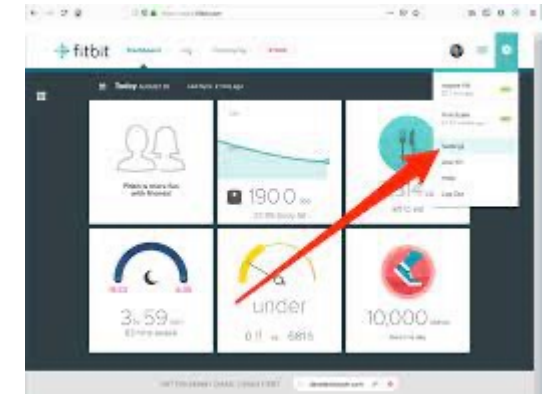
App installed in a mobile device (e.g. smartphone, smartwatch, tablet, etc.)

Desktop app



App installed in a computer. It can work offline.

Web app



App that runs on the browser. Installation not required. Internet access required.

# Applications of wearable IoT in healthcare and wellbeing

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Some health applications:

- Telemonitoring and telemedicine in chronic diseases
- Investigative monitoring for diagnostic purposes
- Sensor-based biomechanical telerehabilitation

Some wellbeing applications:

- Sport and fitness sensing
- Activity and sleep monitoring
- Falls detection

# Telemonitoring and telemedicine in chronic diseases

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## ➤ **Chronic diseases:**

- Conditions that last 1 year or more and require ongoing medical attention or limit daily activities
- About 70-80% of the entire healthcare expenditure

## ➤ **Telemonitoring:** patient's data collected by sensors are transmitted to the doctor that review the data

## ➤ **Telemedicine:** if necessary, the doctor makes decisions regarding the patient's health state and provides feedback to the patient

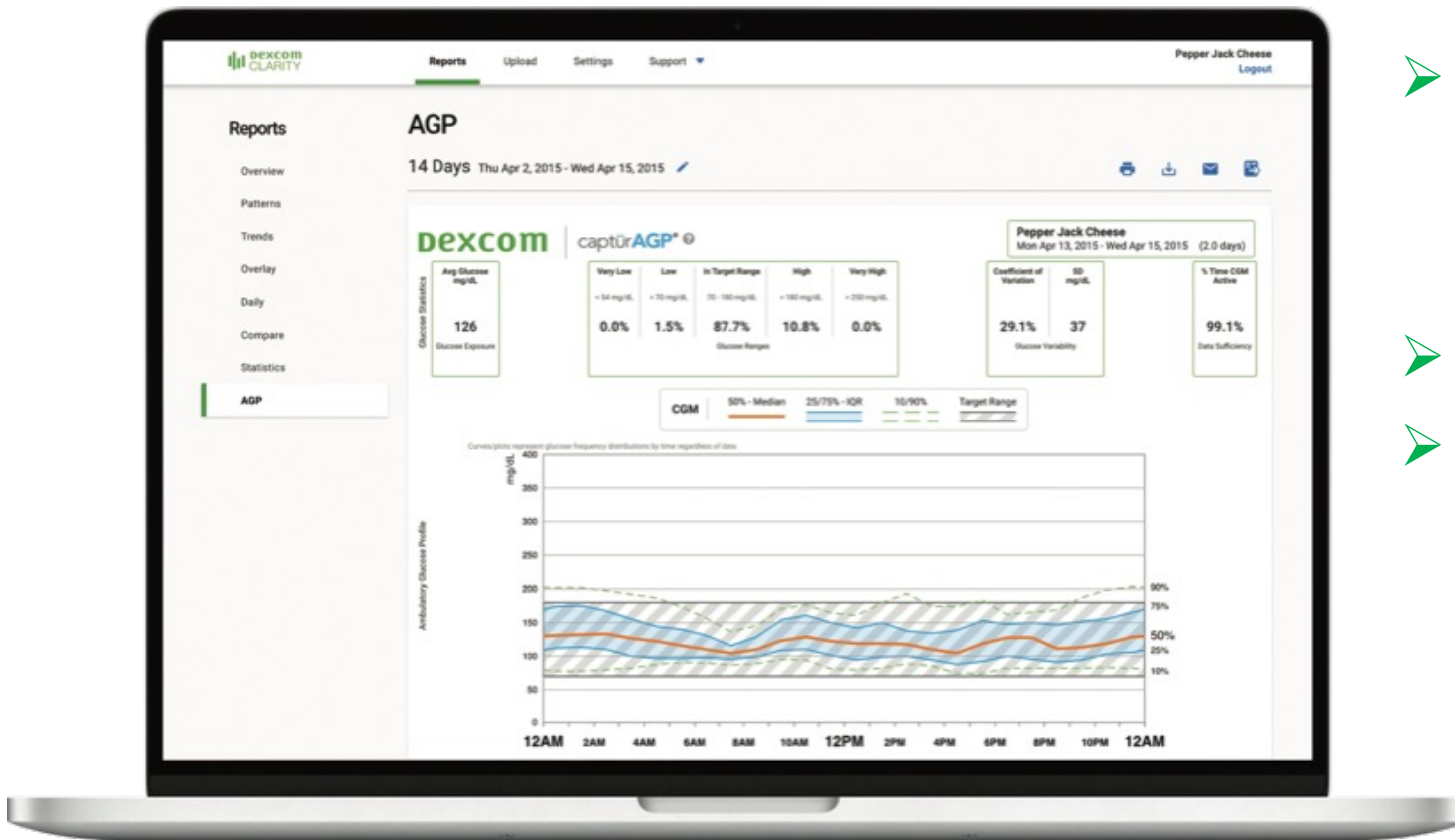
## ➤ Affordable, clinical-grade sensing for home use are required

## ➤ Telemonitoring and telemedicine can greatly improve chronic disease management

- Reduce visits and their duration
- Early detection and reaction to adverse health events
- Notify caregivers about health changes that may go unreported or unnoticed by the patient but that may represent early warning signs of an impending health event

# Telemonitoring and telemedicine in chronic diseases

- Example: Telemonitoring of glucose concentration in people with diabetes



- Through a dedicated telemonitoring application, the doctor can remotely review patients data at any time
- Continuous data synchronization
- Remote monitoring also possible for parents and caregivers

# Investigative monitoring for diagnostic purpose

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- Monitoring of health parameters in **outclinic context**, for a limited period of time (e.g., few days) to **detect** a particular health condition that cannot be observed in clinic, to track the progress of a disease, or to **monitor** recovery from a specific health event.
- Examples:
  - **Professional CGM sensor:** CGM provided to the patient for a short period (e.g., 7 days). Based on the collected data the doctor can adjust/optimize the patient's therapy.
  - **Holter and extended-holter systems:** monitor HR for limited periods (e.g., 1-7 days) for detection of heart issues, e.g., cardiac arrhythmias
  - **At-home sleep test** for the diagnosis of obstructive sleep apnea (stops in breathing during sleep): monitoring of sleep at home for at least 1 night using wearable sensors provided by the doctor (breathing sensor, effort belt, pulse oximeter, and microphone)

# Sensor-based biomechanical telerehabilitation

- Key components:
  - Wearable **inertial sensors** tracking patient's movement
  - **Interactive software**
    - displays personalized rehabilitation exercises
    - receives the sensors' data
    - provides the real-time representations of the patient
    - provides visual feedback to the patient, e.g. using an avatar
  - A **platform for clinicians** to remotely follow the therapy sessions in real-time or review the data offline
- Main application: remote monitoring of patient performance and progress in a rehabilitation programs (e.g., post-stroke, post-fall, or post-surgical operation)



# Sport and fitness sensing

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- Most common sensors: chest straps, wristbands, footpods and insoles, sensor patches, sensors in sportwear clothing (smart clothing), sensors in sportwear equipment
- **Real-time monitoring of performance and coaching** through portable display devices
- **Off-line review of sport statistics**, on web-based portals
- **Data sharing and social networking**
- **Gamification of fitness data**: gaming features (e.g. fitness challenges) encourage the adoption of fitness technologies.





# Activity and sleep monitoring

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- Measurements of activity (steps, distance traveled, etc.), calorie balance, sleep quality.
- Objectives:
  - **Encourage movement** in sedentary individuals
  - **Obesity management:** monitor an individual's participation in a weight management program and maintain engagement
  - **Sleep monitoring** by contact sensors (e.g. wristbands) or non-contact sensors (e.g. under-mattress sleep trackers)



## Baby sleep monitoring sensors:

- Inertial sensors monitor movement of the chest or stomach area
- Built-in tactile stimulator triggered if no movement is detected for 15–20 seconds
- If no movement detected after use of tactile stimulation, an alert is generated





# Fall detection

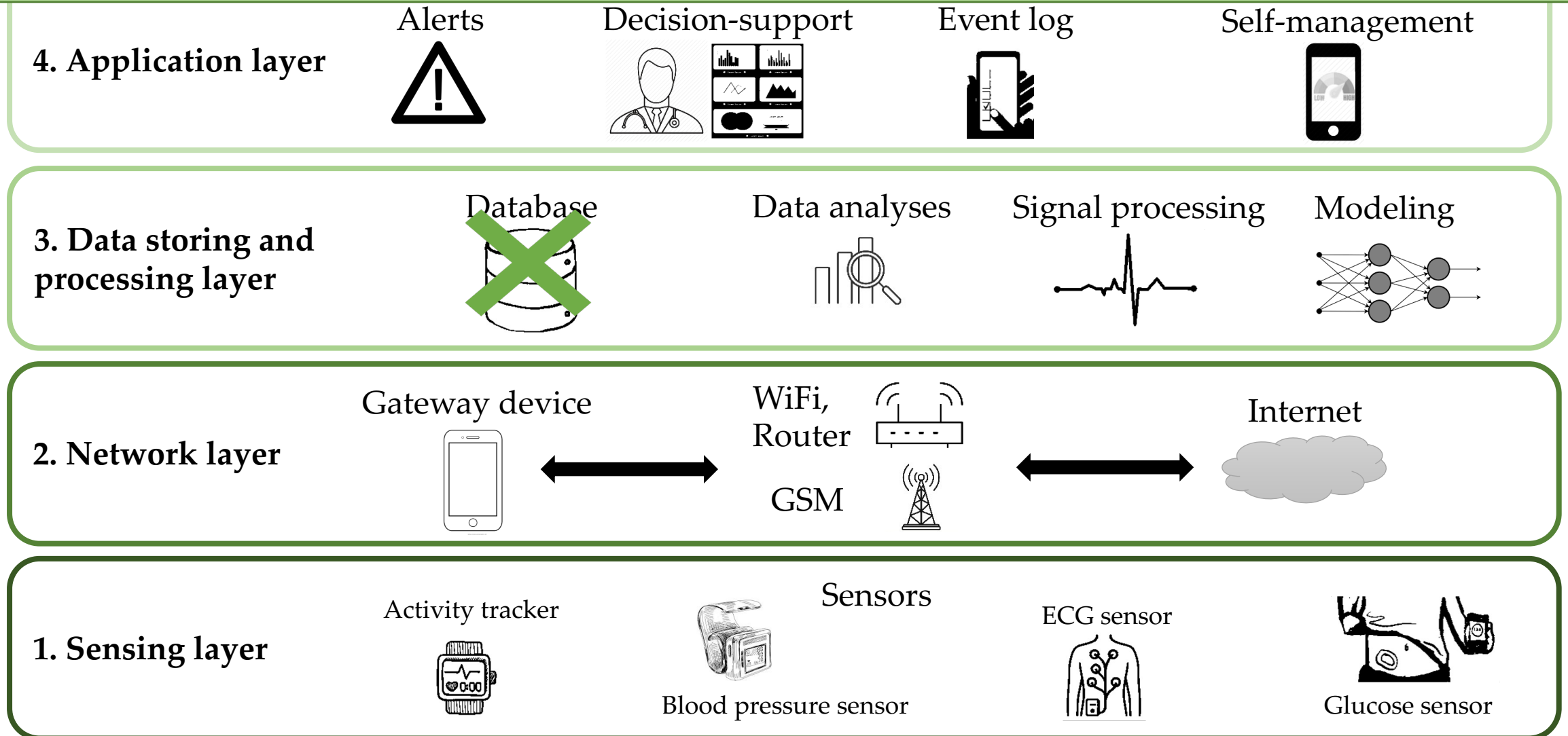
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- Falls-related injuries are the biggest cause of injury-related death in older adults
- **Fall detection devices:**
  - Detection device based on **inertial sensors** worn on the wrist or waist or as a pendant.
  - An algorithm analyses movement measurements in real-time and sends an **alert** to an in-home base station if a fall is detected.
  - The in-home base station notifies a call center, which contacts the wearer.
  - If an emergency is determined or there is no response, the call center notifies the **emergency services** and alerts designated caregivers and family.
- Also available in smartwatches used for sport sensing



# The architecture of wearable IoT systems

In this course we will go through the four layers of wearable IoT systems starting from the lowest layer.



# Course program

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## ➤ 12 theory lectures

- Monday 12:30-14:30, Room 14E (Padiglione 14 – Fiera di Padova)

## ➤ Contents:

- Wearable sensor technologies
- World wide web, HTTP communication protocol
- The representational state transfer (REST) paradigm
- Application programming interfaces (APIs)
- Elements of cryptography
- Authentication protocols
- Regulation for health data management

# Course program

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- 12 laboratory lectures
  - Tuesday 14:30-16:30, Rooms Te+Ue (Polo Didattico di Via Gradenigo)
  
- Contents:
  - The Git version control system
  - Dart programming language and the Flutter framework
  - Building mobile/web applications in Flutter
  - User Interface design
  - Navigation
  - State management
  - Basic data persistence
  - Networking

# The exam

## ➤ **Written test:** Theory exam

- 15 closed questions
- 3 open questions
- Duration: ~90 min
- Max vote: 20/30

### Dates of the written test

- First round: 20 Jun 2024, 14:00 (Room Be+Ve)
- Second round: 08 Jul 2024, 14:00 (Room Ae+Be)
- Third round: 03 Sep 2024, 14:00 (Room De)
- Fourth round: 31 Jan 2025, 14:00 (Room De)

## ➤ **Project:** Development of an application that integrates and elaborates data from a smartwatch. To be done in groups of 3 students.

- Deadline for completion: The project code must be delivered by July 14<sup>th</sup> 2024, and no later than the day before the project discussion.
- Discussion of the project (in group): day and time to be defined in dedicated
  - Window 1: from 01/07/2024 to 19/07/2024
  - Window 2: from 19/08/2024 to 20/09/2024
- Duration of the discussion: 45 min (25 min presentation + 20 min Q&A)
- Max vote: 12/30

## ➤ **Final mark:** sum of the votes of the written test and the project.

# Project: What's the spirit here

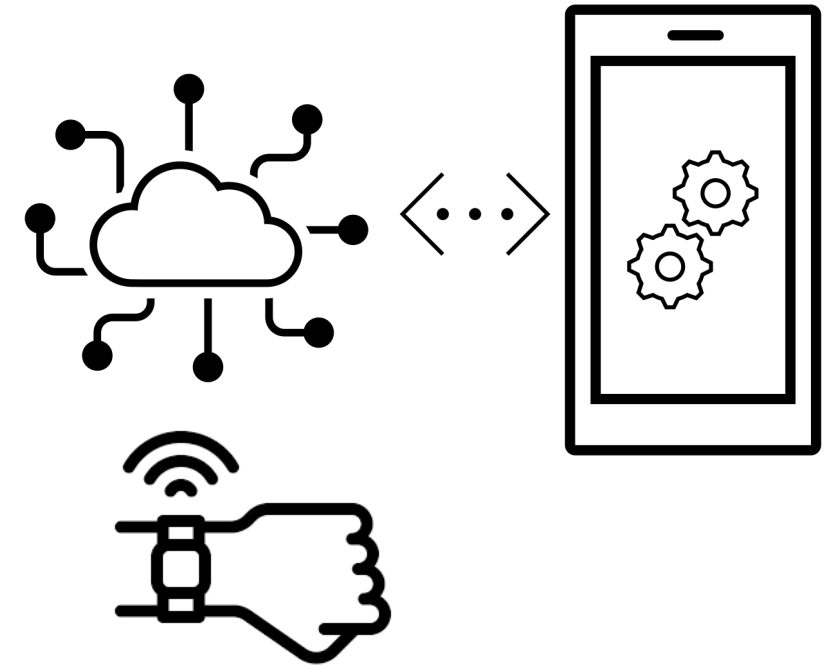
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- The goal is learning “**How to do SOMETHING using wearable devices**”
- What **I DO** expect from you
  - To use your imagination to create that SOMETHING
  - To learn to build something from scratch
  - To use code built by others
  - To work together
  - To use Google and StackOverflow
- What **I DO NOT** expect from you
  - To create the new Google
  - To reinvent the wheel (copying others code is fine)
  - To create extra complicated UI with animations and stuff
  - To implement sophisticated design pattern (even if it would be a nice thing to do)

# Project structure

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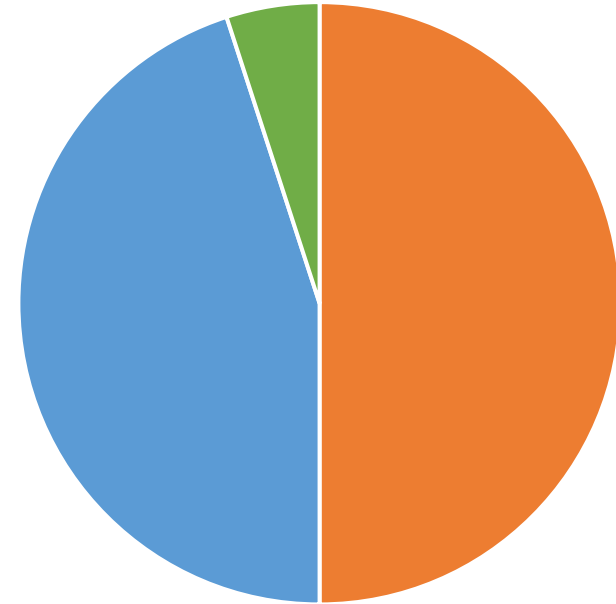
- The project consists of building an app for iOS or Android that collects user data from a wearable device through Web APIs, visualizes them, and does some tricks with them.
- Core functionalities:
  - Correct app flow
  - User authentication and management
  - Data collection
  - Data visualization and presentation
- Additional functionalities → It's up to you!  
Some examples:
  - Run some analysis on data and provide suggestions to the user
  - Implement some literature algorithm
  - ...



# Grading

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- What are the grading criteria
  - Compliance to core functionalities
  - Originality of the additional feature
  - Quality of teamwork
- How much these criteria matter?
  - Core functionalities: 50%
  - Additional app functionalities: 45%
  - Quality of teamwork: 5%

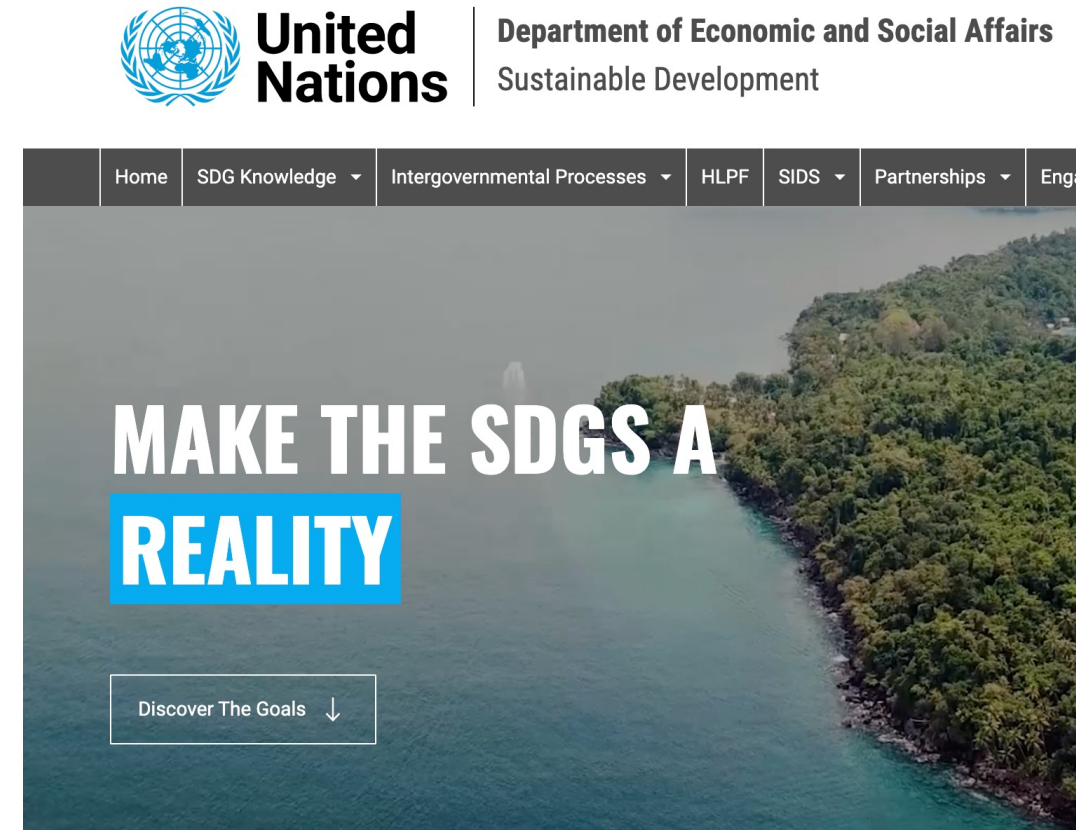


- Core functionalities
- Additional functionalities
- Quality of teamwork



# Choose your target

- Your app must represent a solution for the current SDGs (Sustainable Development Goals) targets
- SDG are 17 topics representing the current big challenges humanity must face and solve



# Choose your target

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- These are the target you can choose from (see the moodle page for more details):
- **SDG 2: Target 2.2** (By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons)
  - **SDG 2: Target 2.3** (By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment).
  - **SDG 3: Target 3.4** (By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being).
  - **SDG 3: Target 3.5** (Strengthen the prevention and treatment of substance abuse, including narcotic drug abuse and harmful use of alcohol).
  - **SDG 4: Target 4.7** (By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development).
  - **SDG 8: Target 8.9** (By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products).

# Tutoring activities

- Need help? They are here to cover your back with answers and extra tutoring activities



- Luca Cossu

[luca.cossu@phd.unipd.it](mailto:luca.cossu@phd.unipd.it)



- Michele Atzeni

[michele.atzeni@phd.unipd.it](mailto:michele.atzeni@phd.unipd.it)

Calendar of the tutoring activities

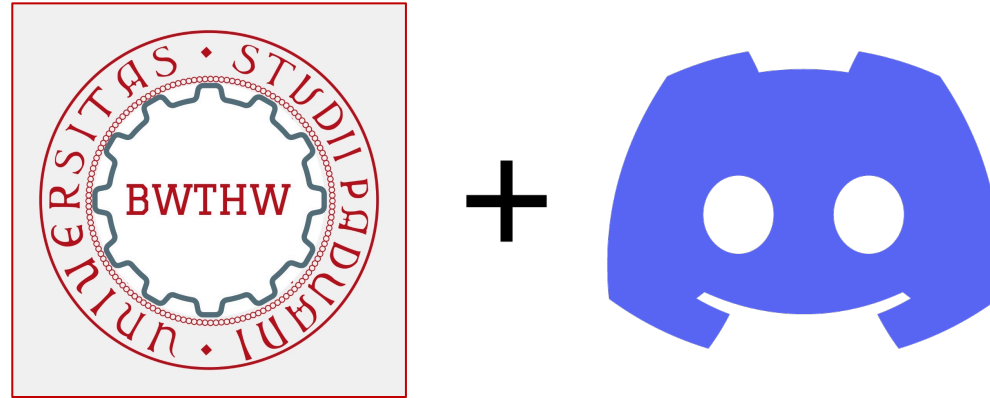
Day	Time	Room	Topic
3/8/24	10:30 - 12:30	Ae	Tutoring 1: Extra
3/15/24	10:30 - 12:30	Ae	Tutoring 2: Dart
3/22/24	10:30 - 12:30	Ae	Tutoring 3: App Presentation + Setup
4/12/24	10:30 - 12:30	Ae	Tutoring 4: Navigation
4/19/24	10:30 - 12:30	Ae	Tutoring 5: State Management
5/3/24	10:30 - 12:30	Ae	Tutoring 6: SharedPreferences + Authentication
5/10/24	10:30 - 12:30	Ae	Tutoring 7: HTTP Data request
5/17/24	10:30 - 12:30	Ae	Tutoring 8: Algorithm
5/23/24	10:30 - 12:30	Ae	Tutoring 9: Wrapping up
5/28/24	10:30 - 12:30	Ae	Tutoring 10: Bonus

To be confirmed

# Discord server

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New



- Join the Discord server to get in touch and ask questions
- Link: <https://discord.gg/9HyPTfM>

