Remote patient monitoring for health status assessment

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Outline

- Introduction
  - eHealth /mHealth in a nutshell
  - Statistics and deployment approaches with examples
- Health state models
  - Human health state model
  - Dynamic human health state model
- Remote patient monitoring
- Health state assessment
- Health state visualization
  - Human health state visualization
  - Population health state visualization
- Conclusions

Óbuda University

- 5 faculties
- 13.000 students
- 2nd biggest technical university in Hungary

Monitoring human individuals remotely Motivations

- Problems
  - Large rural areas, non-accessible areas
  - Aging population, longer life expectancy,
  - Healthy long living (prevention)
  - Costly health problems: cardiac problems, neurodegenerative disease issues: Alzheimer, Parkinson’s
  - Sparse/Limited resources: nurses/doctors, beds at hospital, equipments (ECG devices), connectivity

eHealth/mHealth

eHealth (e-health):

stands for healthcare practice supported by electronic processes and communication (´99)

1 term →~50 definitions

- Hot topics
  - EHR/PHR – Electronic Health Record
  - eLearning in Health
  - Computerized physician order entry
  - ePrescribing
  - eHealth analytics and big data in health
  - Clinical decision support systems
  - Consumer health informatics

Hot topics in eHealth (contd.)

- Telemedicine: physical and psychological diagnosis and treatments at a distance, **including telemonitoring of patients functions**;
- mHealth: the use of **mobile technologies** to support health information and medical practices. It holds great potential for facilitating the transformation of health services and data delivery by reaching wide geographical areas and in portable forms.

Main eHealth approaches

- Bottom-up
- Building block approach
- Education focus
- Top down with clear visions
  - eHealth strategy, with concrete plans

eHealth in Europe

- 84% - national universal **health coverage policy or strategy**
- 70% **national eHealth policy or strategy**
- 69% - **financial support** available specifically **for the implementation of their national eHealth strategy**.
- 89% - **universities or technical colleges** teach **students** how to **use information and communication technologies** and **eHealth**,
- 82% - teach **professionals** how to **use information and communication technologies** and **eHealth**

FROM INNOVATION TO IMPLEMENTATION eHealth in the WHO European Region 2016 (stats from 47 of the 53 Member States)

mHealth in Europe

- Capturing and transmitting data to monitor patient conditions via mHealth is
  - a key growth area across Europe.
  - In 2015 70% (32 countries) report using mHealth for patient monitoring.
  - The patient monitoring programmes operate as established (37%), local-level (43%) and pilot programmes (47%).

FROM INNOVATION TO IMPLEMENTATION eHealth in the WHO European Region 2016 (stats from 47 of the 53 Member States)

eHealth building blocks

- **Infrastructure (connectivity)**
- Software + services
- Devices

are not enough

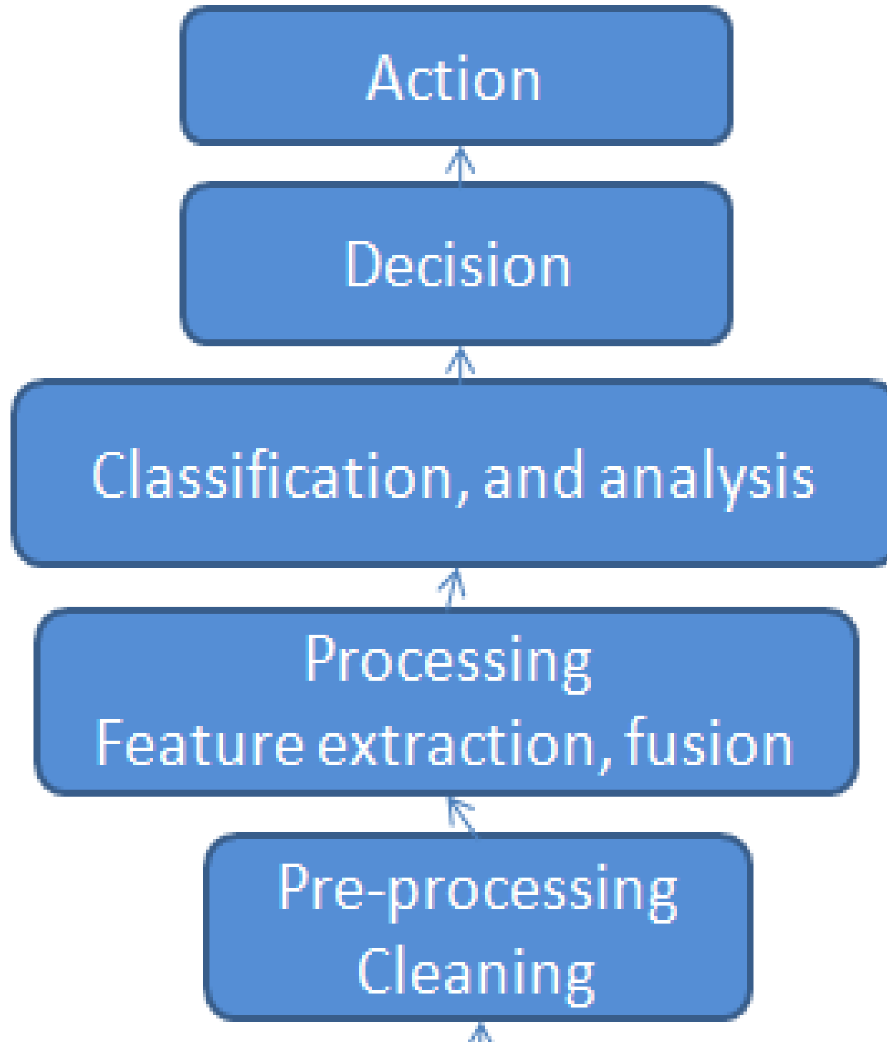
- Human Elements
  - Digital Literacy (basic reading and writing)
  - Education
    - Practitioners
    - Patients
    - Service Providers (new workflows, business models)
- Sustainability is a key factor!

Remote patient monitoring
Sensor data handling

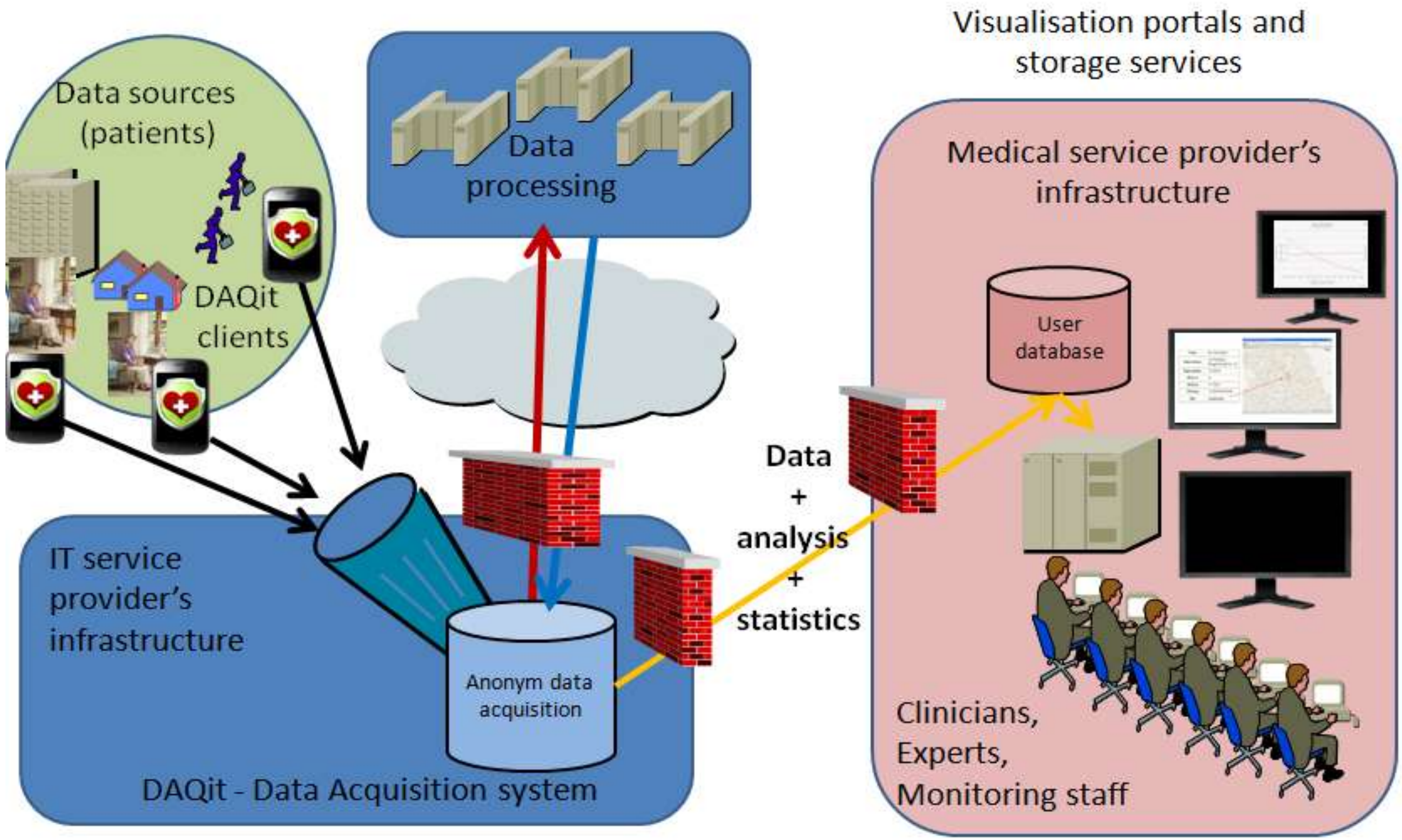
- Data Acquisition (DAQ)
  - Single/multiple sensors
- Data management
  - Processing/filtering
- Store and retrieve
- Vizualisation
- Data sharing

What if setup is unknown?

Generic workflow



Remote patient monitoring architecture



Measured biosignals/sensor data

- Acquired data:
  - Actual temperature of the human individual is 40^{o} C.
  - Blood oxygenisation level is 98%.
  - Blood glucose level is 6.6 .
  - Accelerometer has reported a 1 g movement to A_z.
  - Patient does not moved since 6 hours.
  - Patient’s hand moved 1 cm.
  - Patient’s hand oscillate 1 cm with an average amplitude.
  - ECG diagrams show heart fibrillation

Are these values bad or good? How accurate?

Animal and vegetation health state models

- Objective health state assessment is difficult
  - Data collection→Data fusion (convert information in a common format/space)→Data evaluation
- Examples
  - BC (Body Condition) scoring methods for animal experiments (mouse, rat, etc.)
    - based on easy-to-measureable parameters (body weight, external marks, physical appearance, responses to external stimuli) using 1-4 /1-10 grading levels
  - Vegetation Health Indices (VHI) combine estimation of moisture and thermal conditions. VH (VHI, VCI, TCI)
    - using high resolution radiometer satellite images

Human patient health state models

- Disease specific scoring schemes
  - COPD Assessment Test (CAT)
  - Medical Research Council dyspnoea scale (mMRC)
    - Data:SpO2 (pulse oximeter), blood glucose level (blood glucose meter), FEV1 (spirometer)
- Scoring schemes derived from statistical data analysis
  - Diabetes risk scores
  - Data: height, weight, age, gender, life style, …

STATIC!

- State-transition modeling (STM)
  - Health states & transitions

Health Metric (HM)-space

Health Metric (HM)-space: dimension-less information space.

Measured sensor data → conversion into this HM-space

The HM space provides information how big the difference between the measured parameter value and a pre-defined reference scale.

The conversion builds up from two parts: a normalization, and make it dimension-less and do a distance calculation.

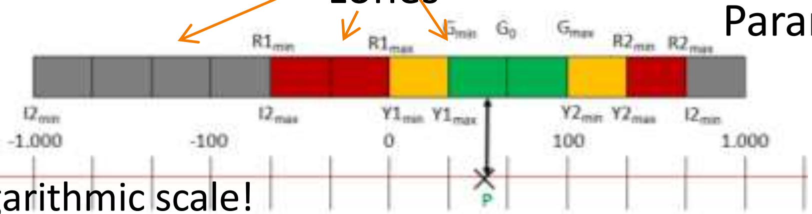
Health state model in information space

- Can change constantly, as remote monitoring data arrives
- Supports non-stop DAQ and processing
  - Measured data conversion into HM - space
- Can built up from arbitrary type and amount of sensor data
- Can incorporate historical data
- Can incorporate individual and population level parameter impact values

Human health state model

- *S* dimension-less value (in HM-space) can be calculated from the measured sensor parameter value.

zones



Logarithmic scale!

Parameter distance vaue in zone Z

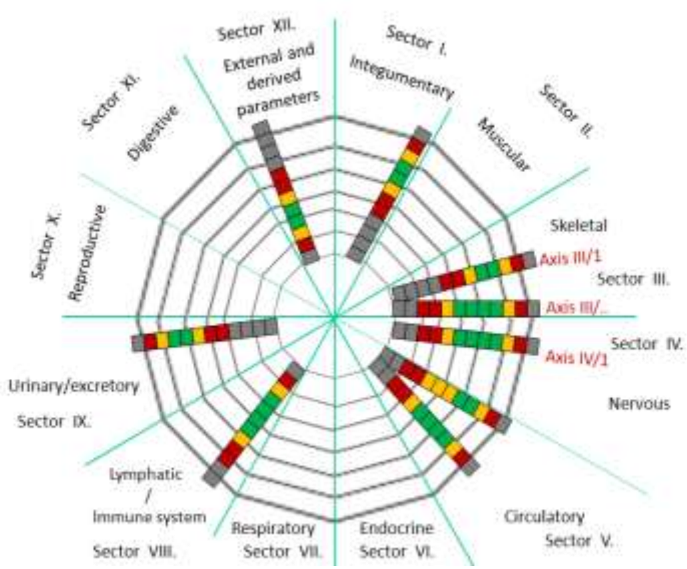
Conversion function of the zone Z

$$S = \sum_{k=1}^{R} \Delta Z_k * F_k$$

$$HM_j = \sum_{i=1}^{N_K} Si * w_i \le C$$

$$\sum_{i=1}^{N_K} w_i = 1$$

$$HM_{TOTAL} = \sum_{j=1}^{T} HM_j$$



Dynamic human health state model

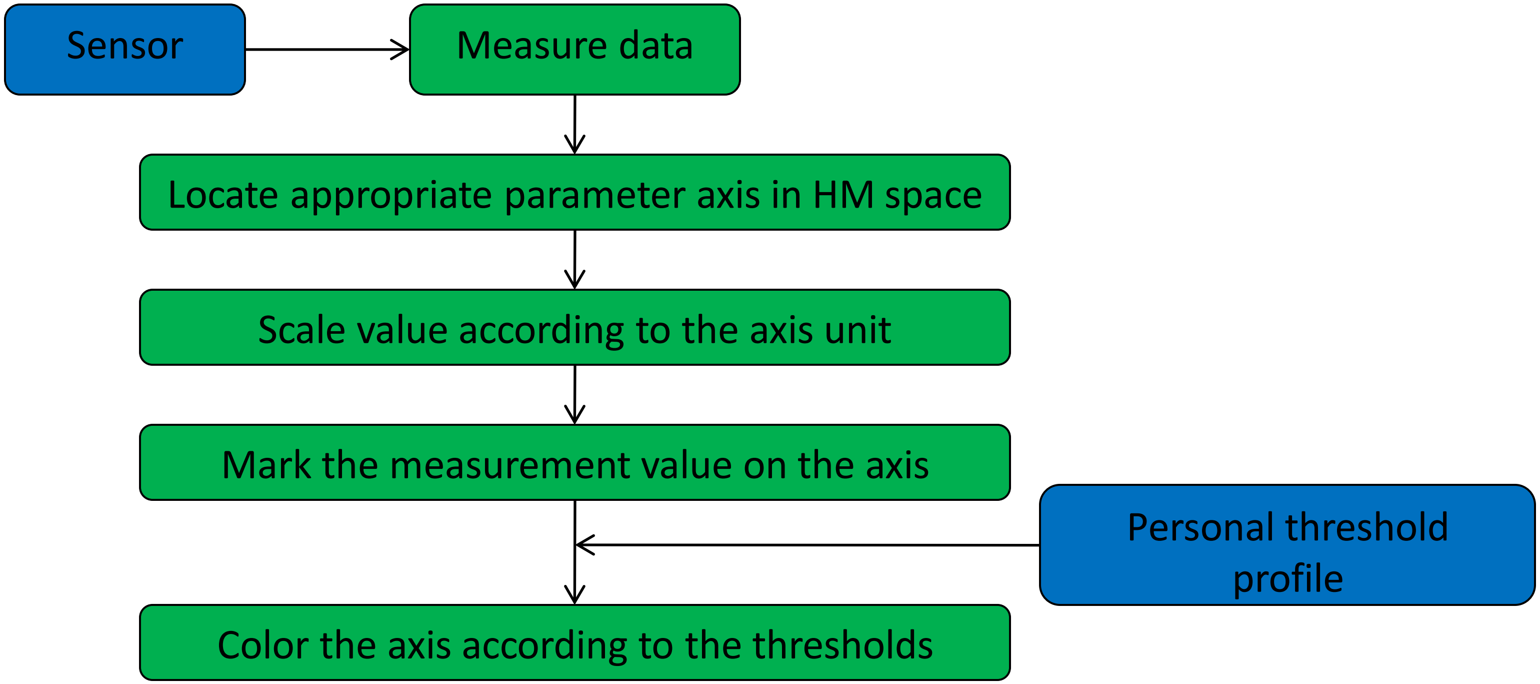
- Let $V_{1..M,t}$ be values of P parameter at t € $[t_0,t_a]$, until t_a actual time instance.
- Let P_i parameter defined in time t by $V_{j,t}$ using the following equation:

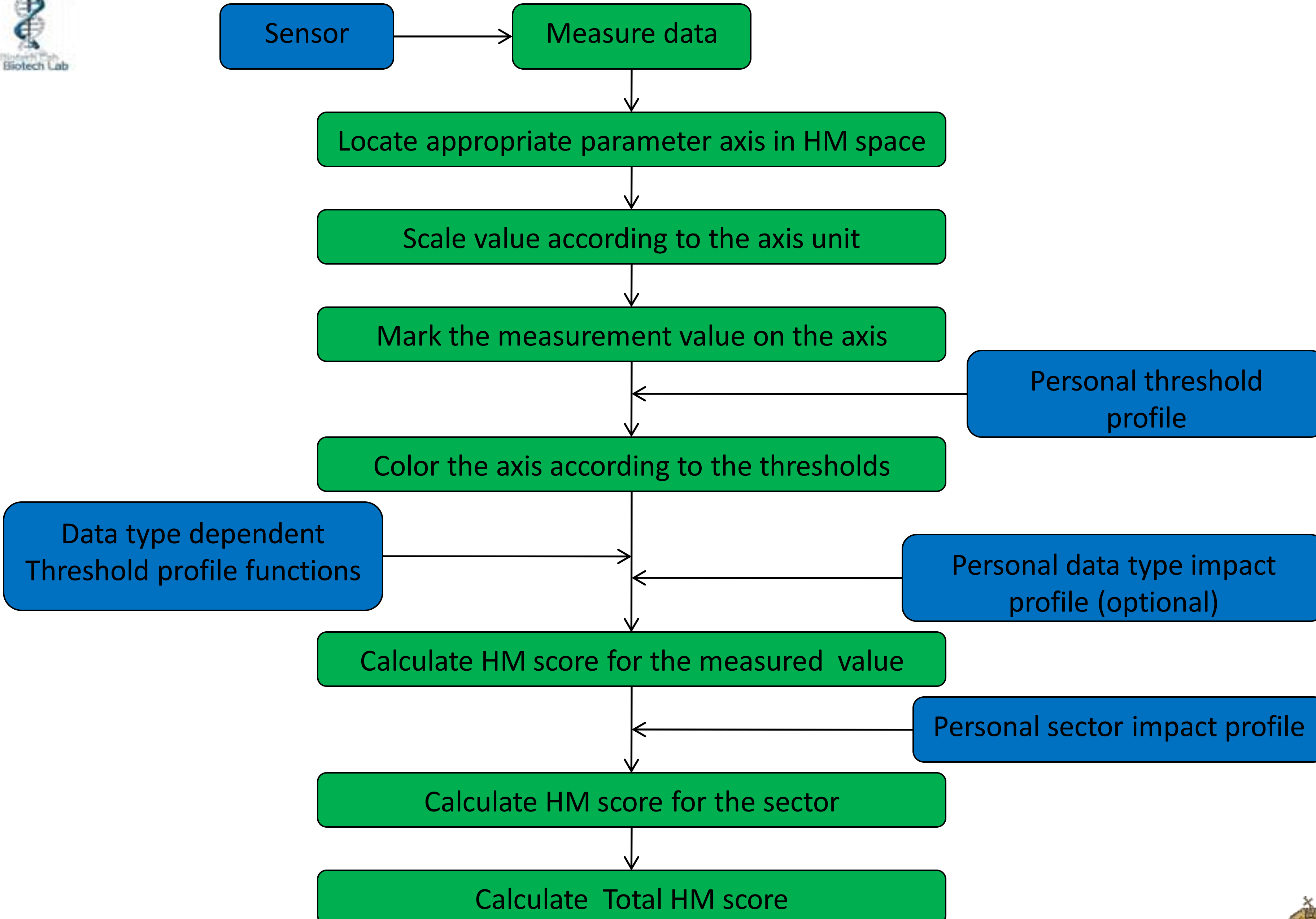
$$P_i = \sum_{j=1}^{M} \left[F_P\left(V_{j,t}\right) * \frac{D_P}{(t_a - t_m) + 1} \right]$$

- ,where D_P is the decay function of parameter P, t_m the time instance when the measurement was done, t_a is the actual time instance, let F_P be the quality function of the $V_{j,t}$ value.

$$P_{i\_AVG} = \frac{\sum_{j=1}^{M} \left[F_P\left(V_{j,t}\right) * \frac{D_P}{(t_a - t_m) + 1} \right]}{M}$$

Health state calculation workflow




Sensor
Measure data
Locate appropriate parameter axis in HM space
Scale value according to the axis unit
Mark the measurement value on the axis
Personal threshold profile
Color the axis according to the thresholds
Data type dependent Threshold profile functions
Personal data type impact profile (optional)
Calculate HM score for the measured value
Personal sector impact profile
Calculate HM score for the sector
Calculate Total HM score

Remote patient monitoring

Requirements

- Multimodal sensor monitoring
- Many different
  - Data type
  - Value unit
  - Scale
- Adaptable
- Personalizable
- Generic visualization

DAQ software
-DAQit software suit-

DroidHub

Panic Button

- Targets
  - Diabetes, Hypertension, Cardiac diseases
  - Obesity/bulemy monitoring
  - Domestic assistance: Panic/Emergency situations
  - Real-time sport activity monitoring
- Features
  - Full scale patient monitoring ecosystem
  - Client & Servers:data acquisition & visualization & processing
  - Multimodal : ~30+ different sensors

Sensor set

- COTS (Commercial off-the-shelf) sensors
- Sensor drivers at client side is written carefully
  - Huge work: incompatible, proprietary solutions
  - Sensors are protected by law (no reverse engineering ☹)

Sensor sets

- ***Diabetes monitoring***

Model type	Manufacturer	Connection type
Accu-check Active	Roch e Ltd.	Wired, via Smartpix ™/USB Wireless infrared (via ir2voice™)
Mygluecohealth	Mygluecohealth Ltd.	Wireless, BTv2
Dcont Personal Optimum	77 Elektronika Ltd.	Wireless, infrared (via ir2voice™)
Dcont Partner	77Elektronika Ltd	Wireless, infrared (via ir2voice™)
Breeze II.	Bayer AG.	Wired, via USB

Sensor sets (contd.)

- ***Hypertension monitoring***

Model type	Manufacturer	Sensor type	Connection type
UA-767 PBT	AND Ltd.	Blood pressure monitor	Wireless (BTv2)
BlueBP	Meditech Inc.	ABPM	Wireless (BTv2)

- ***Cardiac monitoring***

Model type	Manufacturer	Sensor type	Connection type
Cardioblue	Meditech Inc.	Mobile ECG 5 ch	Wireless (BTv2)
Savvy	Savvy Inc.	Mobile Ecg 1 ch	Wireless (BTv2/v4)

- ***Blood oxigenisation***

Model type	Manufacturer	Sensor type	Connection type
Onyx II 9560	Nonin Medical Inc.	Pulse oxymeter	Wireless (BTv2)

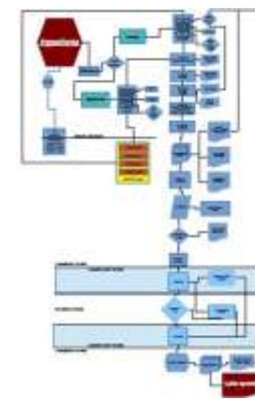
Sensor sets (contd.)

- ***Activity/movement monitoring***

Model type	Manufacturer	Sensor type	Connection type
HxM	ZephyrTechnology Ltd.	Pulse monitor	Wireless (BTv2)
Bioharness	Zephyr Technology Ltd.	DAQ harness: pulse,posture,R-R,Heart rate	Wireless (BTv2)
H6/H7	Polar Inc.	Heart rate sensor	Wireless (BTv4)
Quardio (Consumer electronic grade)	Quardio Inc.	Mobile ECG , GSR, temperature, pulse, breathing activity, 1 day	Wireless (BTv4)

When, how and what to measure
(Medical measurement protocols)

- Consensus protocols from healthcare professionals
  - Examples:
    - Hypertonia measurement protocol (72 hours, holter like)
  - Also described by computer readable format
    - Measurement sensor should be pre-programmed in advance



- In many cases new protocol needed:
  - Basic protocol + additional measurement points, longer monitoring time, finer resolution
  - Long time to develop/acknowledged one

Visualization requirements

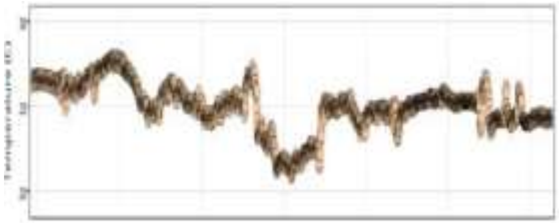
- Compare individual sensor data
  - To older parameter values
    - Visualize in a user-friendly way
  - To other individuals or to average population values
- Dynamic / real-time
- Multi-modal (many sensor type)
- Visualize sensor data at population scale

Biosignal visualization

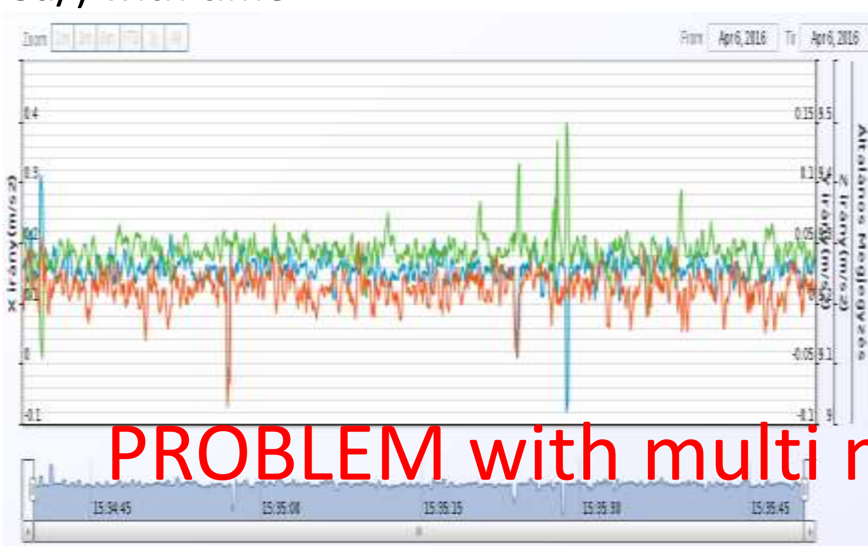
Numerical data visualization example in tabled format

Sensor name	ID	Temperature	Humidity	Last update	Status
SHT	001	50 °C	30	2015-10-20-20:53:10:16544	OK
SHT	101	30.89 °C	44.1	2015-8-15-11:55:23.87084	OK
SHT	102	34.65 °C	37.9	2015-8-15-11:42:59.14927	OK

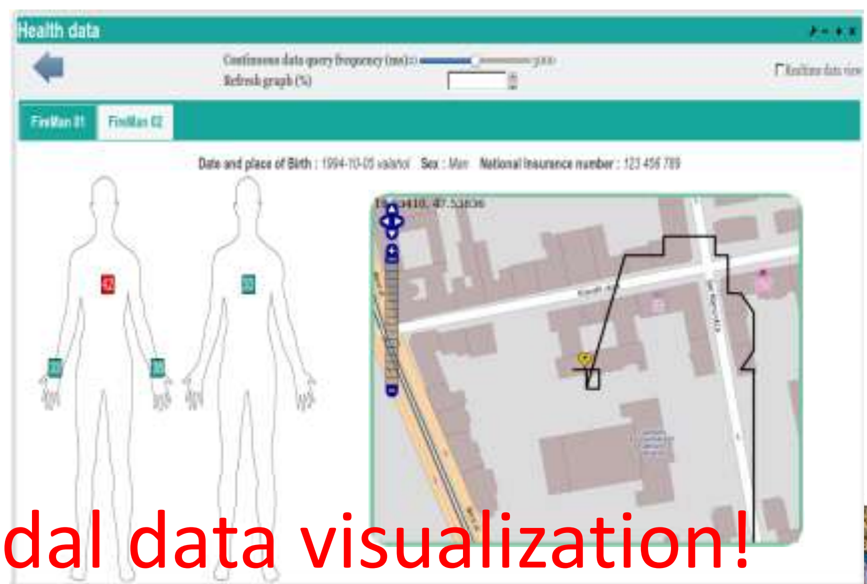
Example single modality diagram



Continuous multimodal sensor data visualization on overlapping coordinate systems(3 axis acceleration /x-blue, y-green, z-red/) with time



Complex data visualization (location activity and temperature)



PROBLEM with multi modal data visualization!

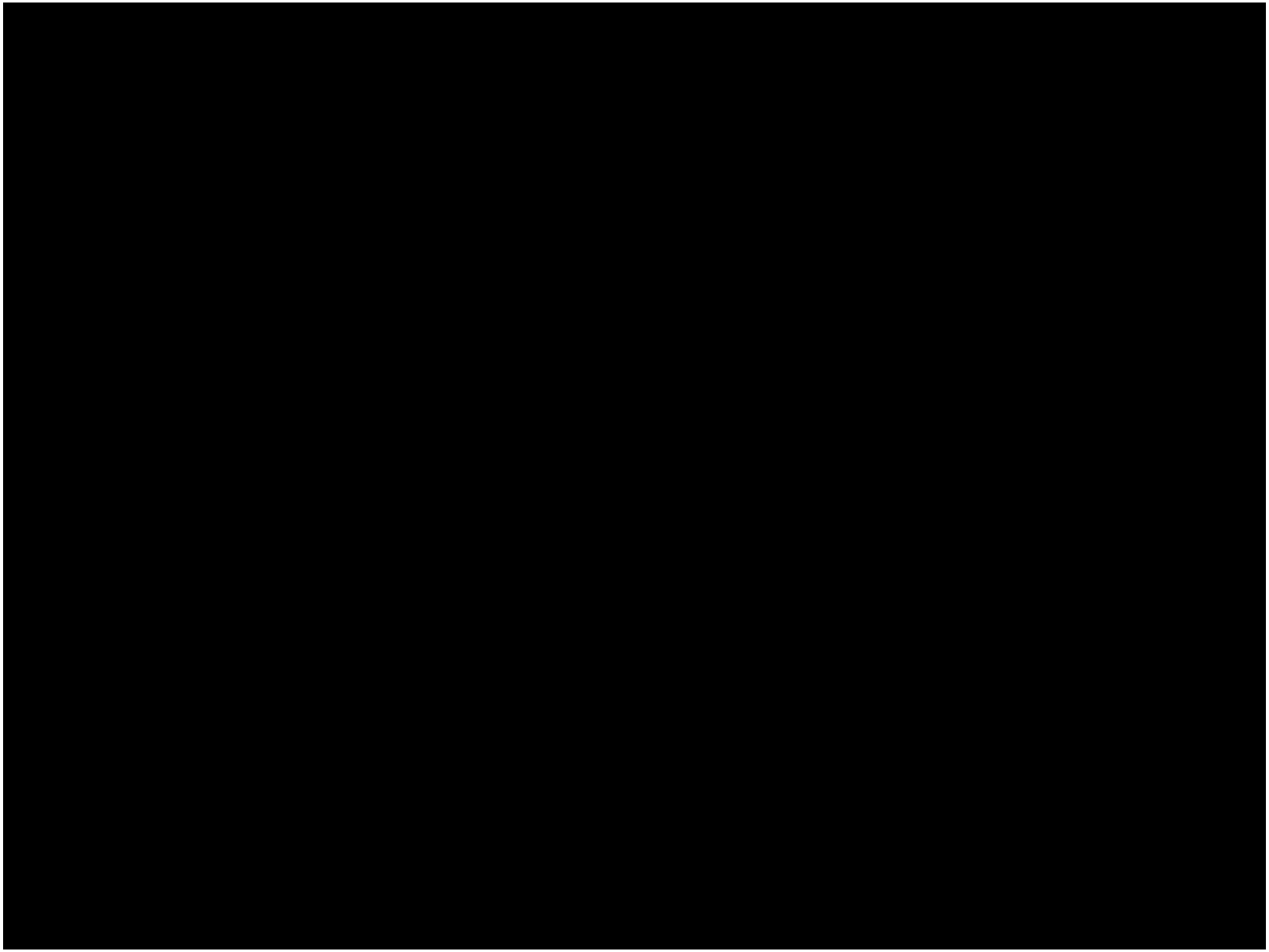
HM-space visualization

Modified radar plot: dodecagon (a twelve-sided polygon or 12-gon)

- 11 sides (sectors) of the polygon are dedicated to the main human organ systems.
- 12th sector kept for visualization of external environment and derived data.

Numbering	Name
Sector I.	Integumentary
Sector II.	Muscular
Sector III.	Skeletal
Sector IV.	Nervous
Sector V.	Circulatory
Sector VI.	Endocrine
Sector VII.	Respiratory
Sector VIII.	Lymphatic / Immune system
Sector IX.	Urinary/excretory
Sector X.	Reproductive
Sector XI.	Digestive
Sector XII.	External and derived parameters

Parameter and HM-space visualization



Dynamic population health state model in HM-space

The average health status of the population ($S_{*\text{-}AVG}$) can be defined as:

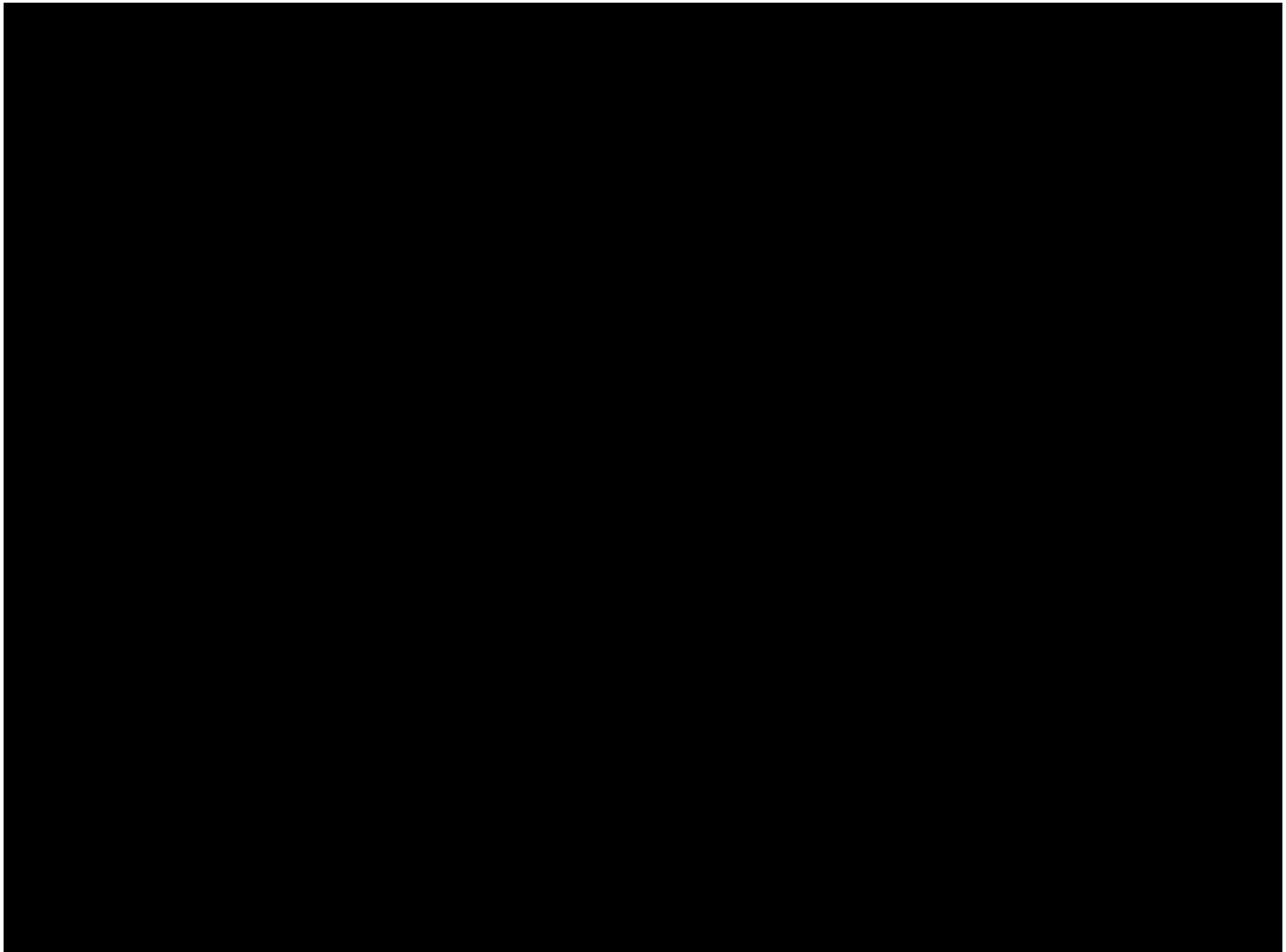
$$S_{*-AVG} = \frac{\sum_{j=1}^{Q*} S_j}{Q*} \longrightarrow S_{40M-AVG} = \frac{\sum_{j=1}^{Q_{40M}} S_j}{Q_{40M}}$$

,where Q is the size of the targeted population and Sj is the health state of an individual from the population.

Population level HM-space

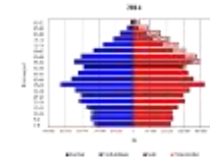
$$HM_{j*} = \frac{\sum_{j=1}^{P*} HM_j}{P*} = \frac{\sum_{j=1}^{P*}(\sum_{i=1}^{N_K} Si * w_i)}{P*} \qquad \sum_{i=1}^{N_K} w_i = 1$$

Population health state model visualization



Biotech Lab

Health state structure of the population



Visualize health parameters at population scale

- **Health pyramid :**Graphical illustration that shows the distribution of health state of various age groups in a population.
- **Health status vs. geolocation**: Can be used to determine the overall health state distribution of a population.

Conclusions

- eHealth and mHealth
  - can provide better services in optimized way
  - their definitions should vary at country level
- Realisation of eHealth requires plans, efforts, and resources
- If we can measure→ we can evaluate!
- Health assessment is a challenging task
  - Human health state model
  - Population health state model
- Measure patient remotely→collect data→ evaluate data

Conclusions (contd.)

- Implementing eHealth/mHealth strategies is difficult, and poses many questions
- There are good examples, case studies, services and solutions in Europe, , in Asia, and in the US
- A possibility to leapfrog instead to re-inventing the wheel → facilitate knowledge and technology transfer
  - Faster implementation
  - Skip a lot of technology dead -ends
  - Easier adaptation to local needs

Thank you for your attention…

Questions?

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