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ANALYSING SENSED DATA IN SMART ENVIRONMENTS

Sabato Mellone, PhD

Personal Health Systems Lab

DEI - University of Bologna

sabato.mellone@unibo.it

Smart Environments

What is a smart environment?

A Smart Environment is a place that has been enriched with technology (Smart Objects).

Smart (virtual and/or physical) Objects are objects that provides new/additional services and ways of interacting with people and other smart objects.

Smart Environments

A wristband counts your steps and notifies that you have achieved 50% of your daily target, is this “smart”?

Smart Environments

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NO!

A smart system would count your steps, verifies that you achieved 50% of your daily target but that you still have 4 hours in the afternoon to accomplish your goal, the weather outside is bad so it suggests you to train at home with an exergame and it estimates for how long you need to train in order to burn the same amount of calories!

Where are most of these results coming from?

- FARSEEING (EU FP7, http://farseeingresearch.eu/) aims to promote better prediction, prevention and support of older persons, by long-term analysis of behavioural and physiological data collected using Smartphones, wearable and environmental sensors: leading to self-adaptive responses. The FARSEEING repository is the world's largest fall repository (inertial sensor-based)

Where are most of these results coming from?

- CuPiD (EU FP7, http://www.cupid-project.eu/) project has a focus on people with Parkinson's Disease (PD) specifically on motor learning and rehabilitation principles. ICT-enabled systems have been developed to provide, in the home setting, personalized treatment. Motor rehabilitation programs include: i) exergaming, ii) training of walking and iii) training for preventing Freezing of Gait episodes

Smart Environments

Possible ingredients for such an original recipe:

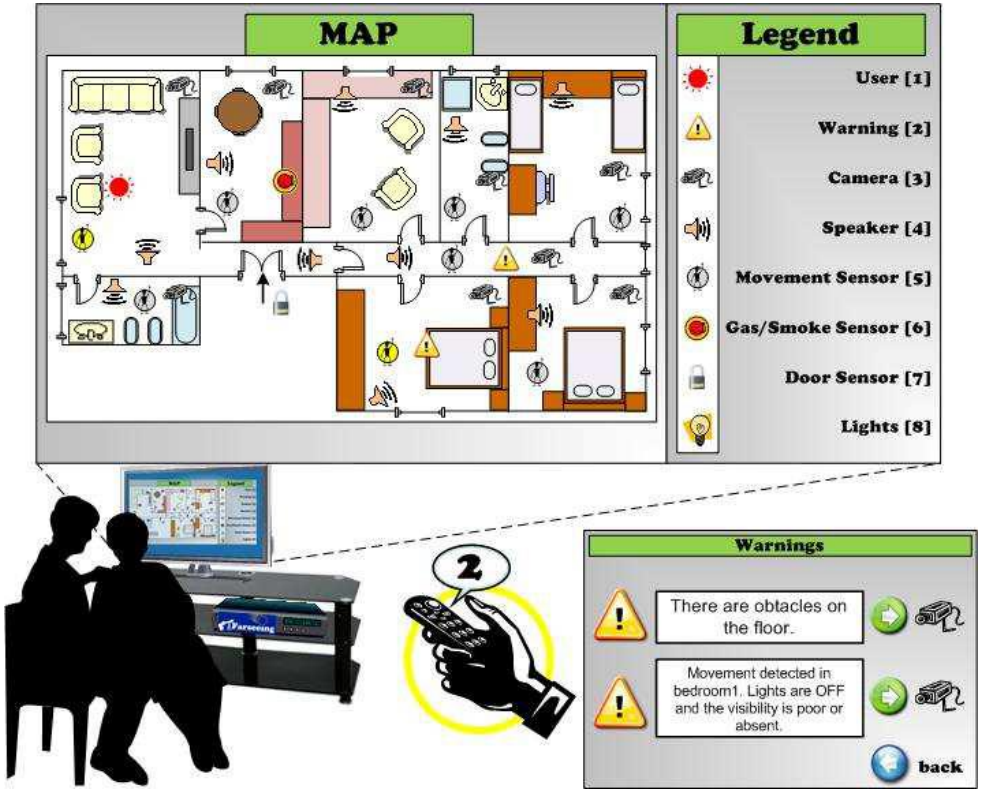
- Home control and automation systems
- Wearable systems
- Portable/mobile devices

Home Control and Automation

- Home Control and Automation (HCA) systems are often modular and offer the flexibility and dependability to make life easier.

Home Control and Automation

- HCA systems can integrate a variety of environmental sensors that allow early detection and warning of equipment failures or conditions that exceed user-defined limits.

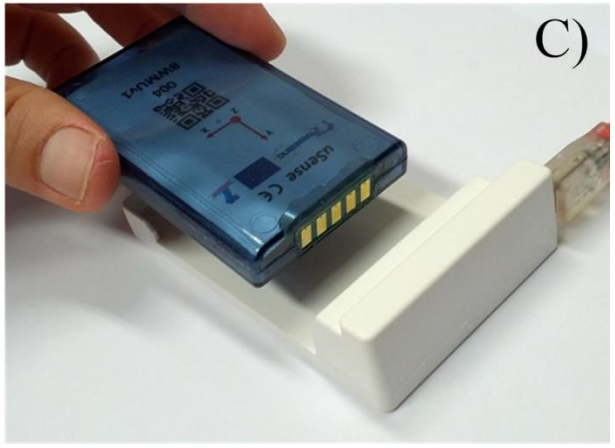


Home Control and Automation

- Every aspect of the home environment can be monitored and controlled both indoor and remotely through remote controls, touch screen panels, personal computers, tablets, or even smartphones.

Wearable/Portable systems

- Wearable sensor systems for health monitoring are an emerging trend and are expected to enable proactive personal health management and better treatment of various medical conditions.



Smarthome?

Contrary to visions that consider home automation and personal health systems as a mean to replace or to simplify the subject control and actions, in the **FARSEEING** and **CUPID** approach smartphones, wearable sensors, and home based technology are used to stimulate the user by making life mentally and physically more challenging but without losing comfort.

The Smarthome

- A smarthome system in FARSEEING is equipped with a “Scenario Programmer”. It is possible to define and compose a set of conditional rules defining **“what”**, **“when”**, and **“if”** perform specific actions

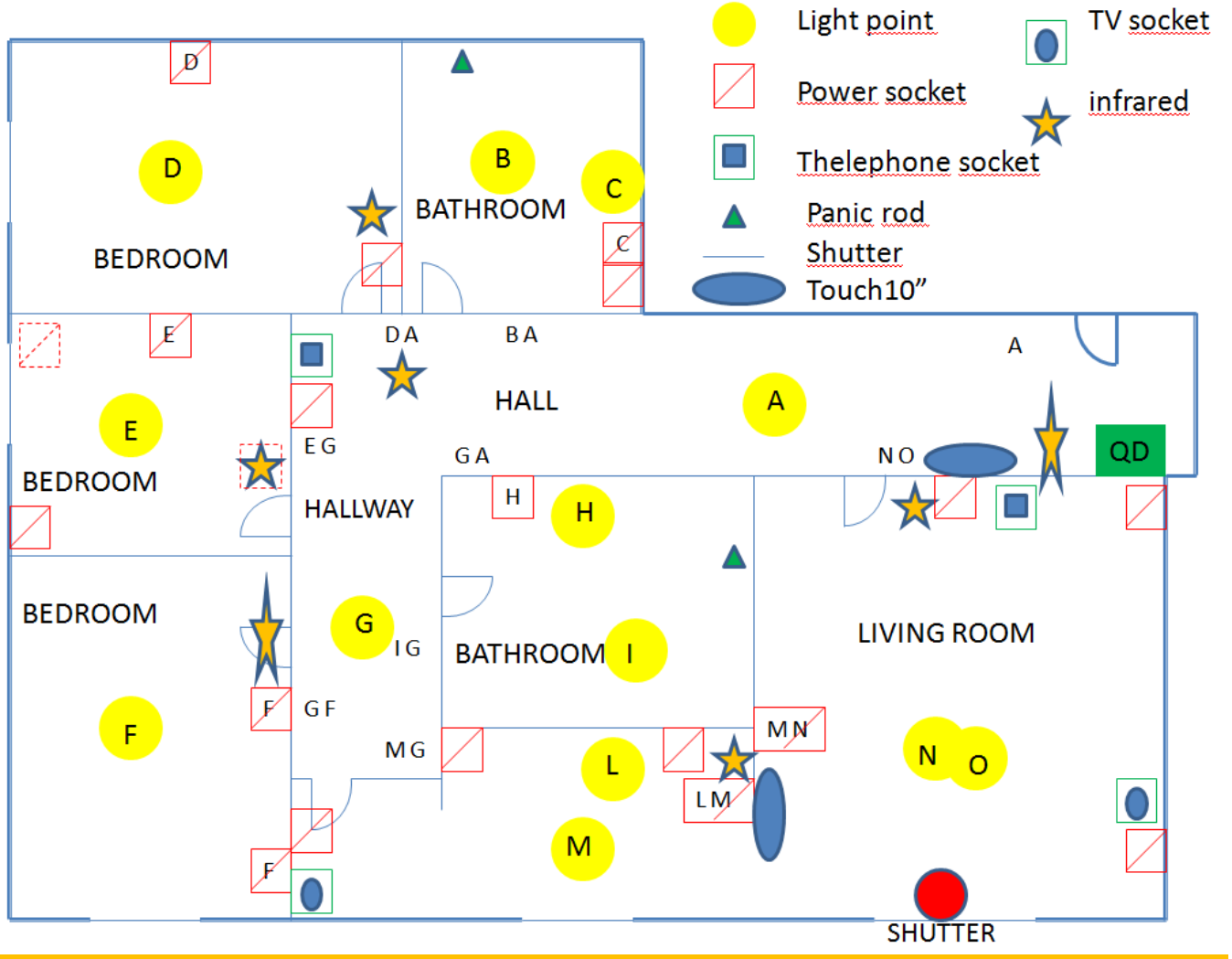
- The execution of a scenario can be triggered by the user but also by external events like the opening of a door, a detected movement, a temperature change, or a detected fall.

The FARSEEING Smartbox

The Smartbox is basically a PC–based platform running multiple software modules in parallel:

- an FTP server used for remotely retrieving information/reports about the user
- sending commands to the home automation system in order to activate specific scenarios
- monitoring and logging of the status of all the peripherals including any interaction between the user and the system
- generating reports about indoor and outdoor mobility of the user

Smarthome Installation



Light point
TV socket
Power socket
infrared
Thelephone socket
Panic rod
Shutter
Touch10”
C
A
QD
NO
HALLWAY
BEDROOM
G
IG
BATHROOM
I
LIVING ROOM
F
GF
MG
MN
N
O
LM
M
SHUTTER

Wall-mounted Touchscreen

Movement Sensor plus a power socket

Power sockets and Switches

The Smarthome User Interface

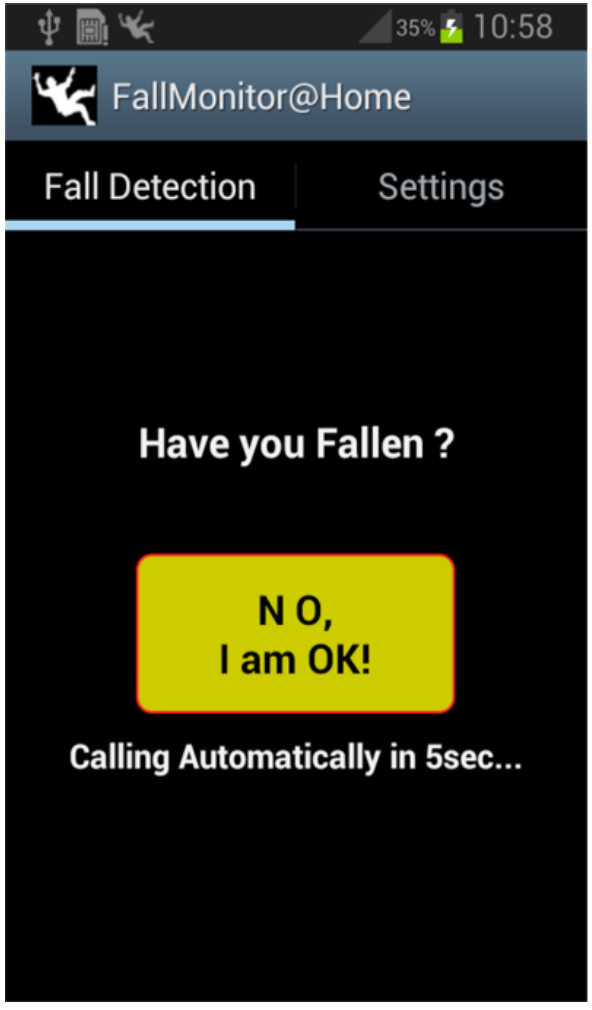
The Smartphone

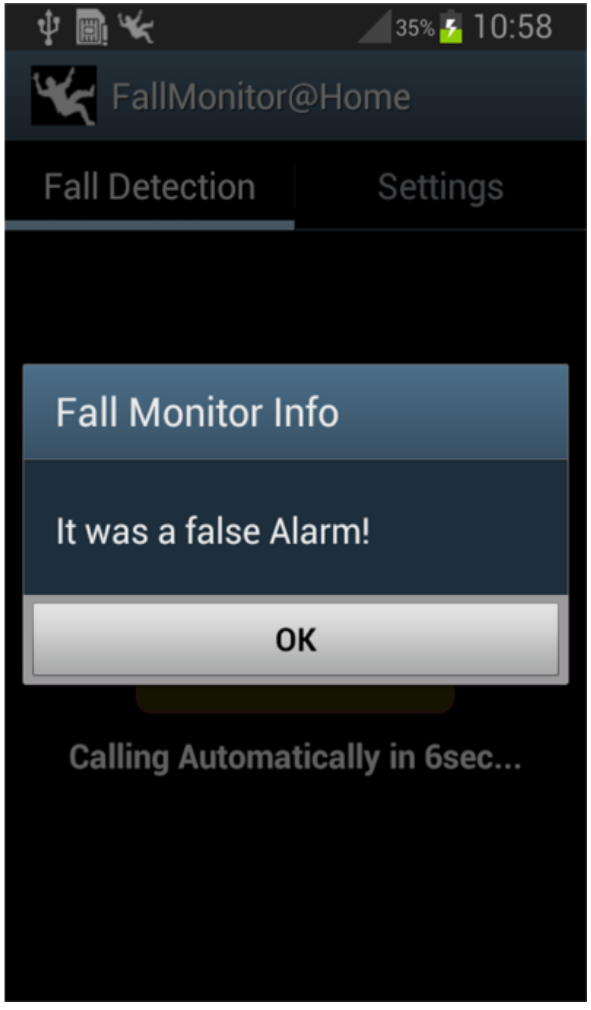
- Smartphones in FARSEEING are used for:

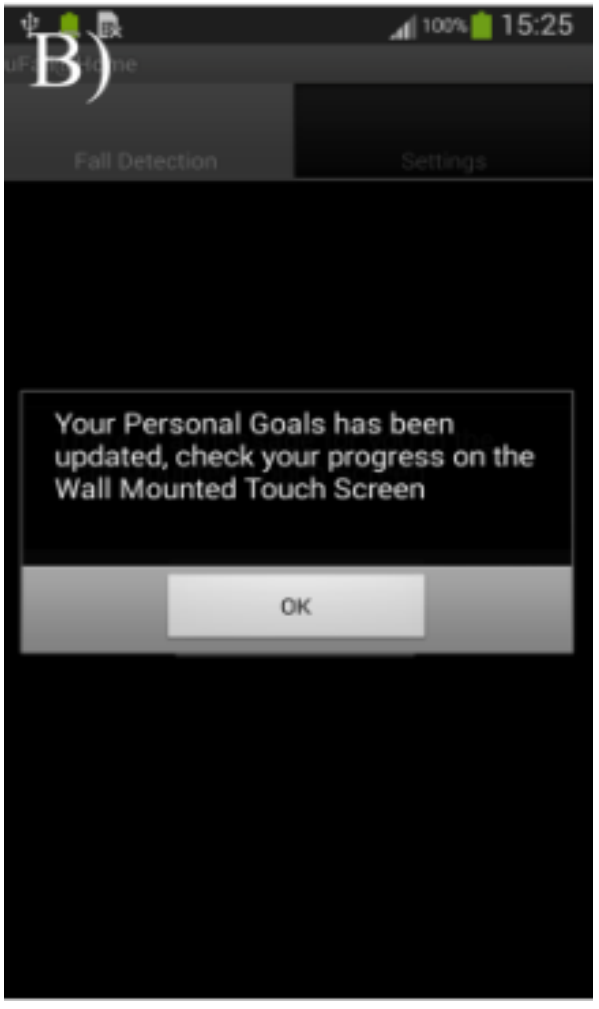
1. continuously monitor the user's physical activity
2. real-time fall detection which is synchronized with a remote server for alarm management
3. interacting with the home automation system

Waist case belt used for wearning the smartphone

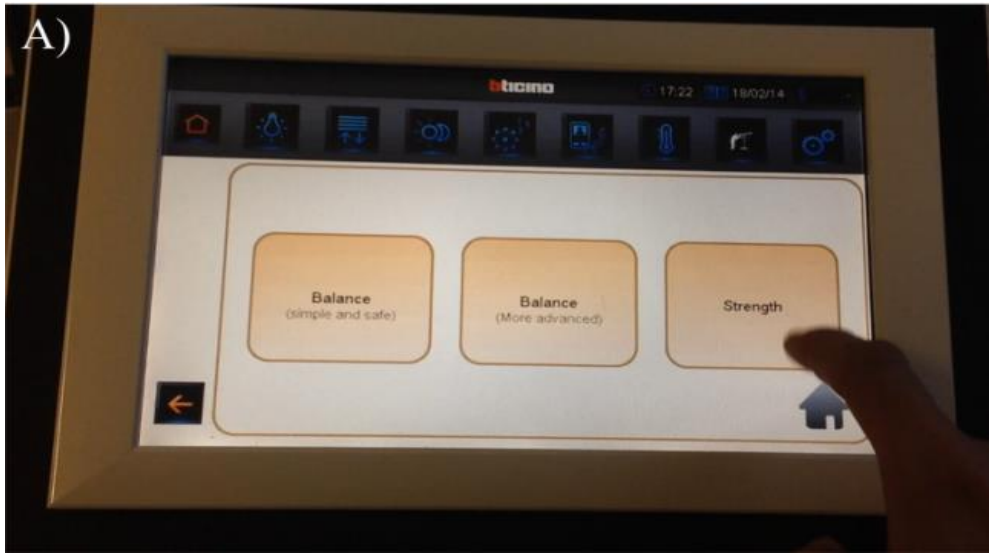
The Smartphone User Interface

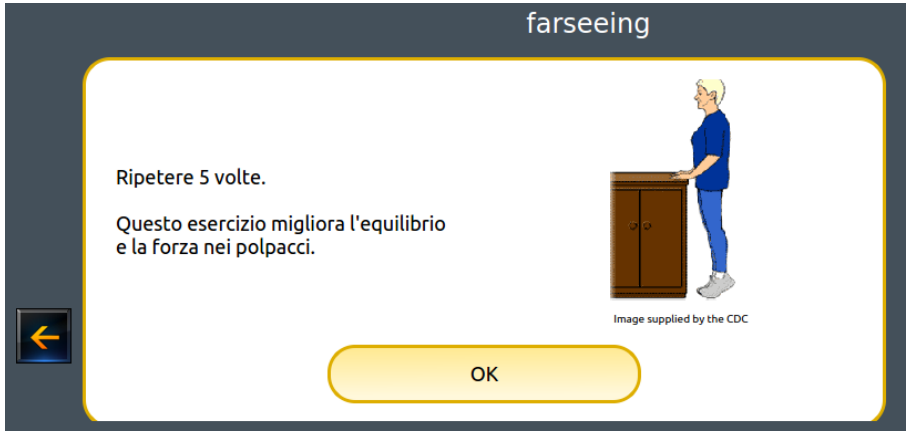




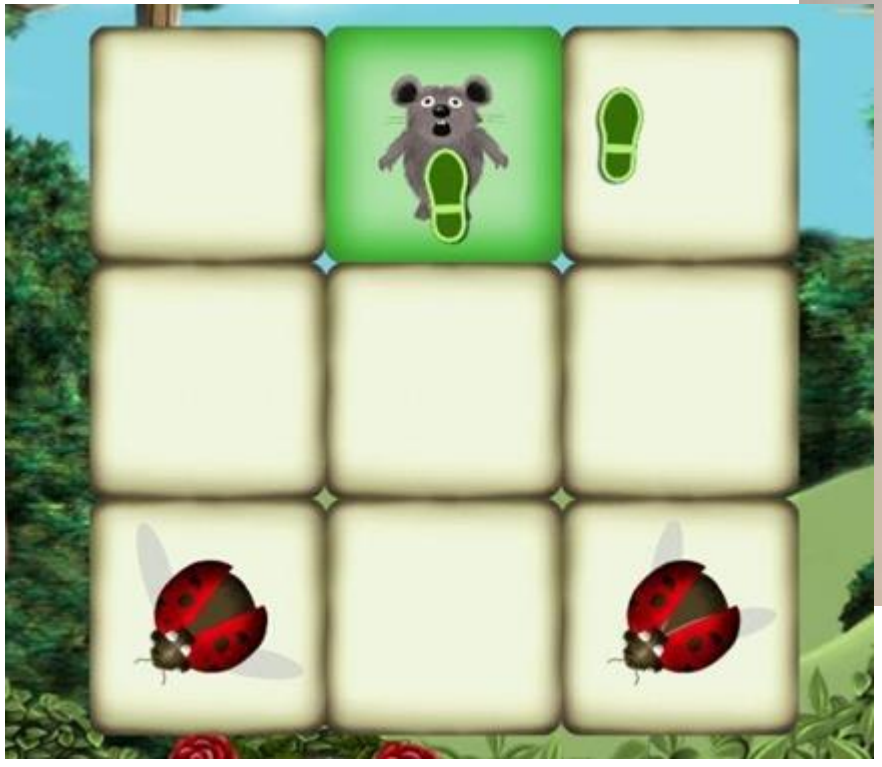


Scenarios: Exercise

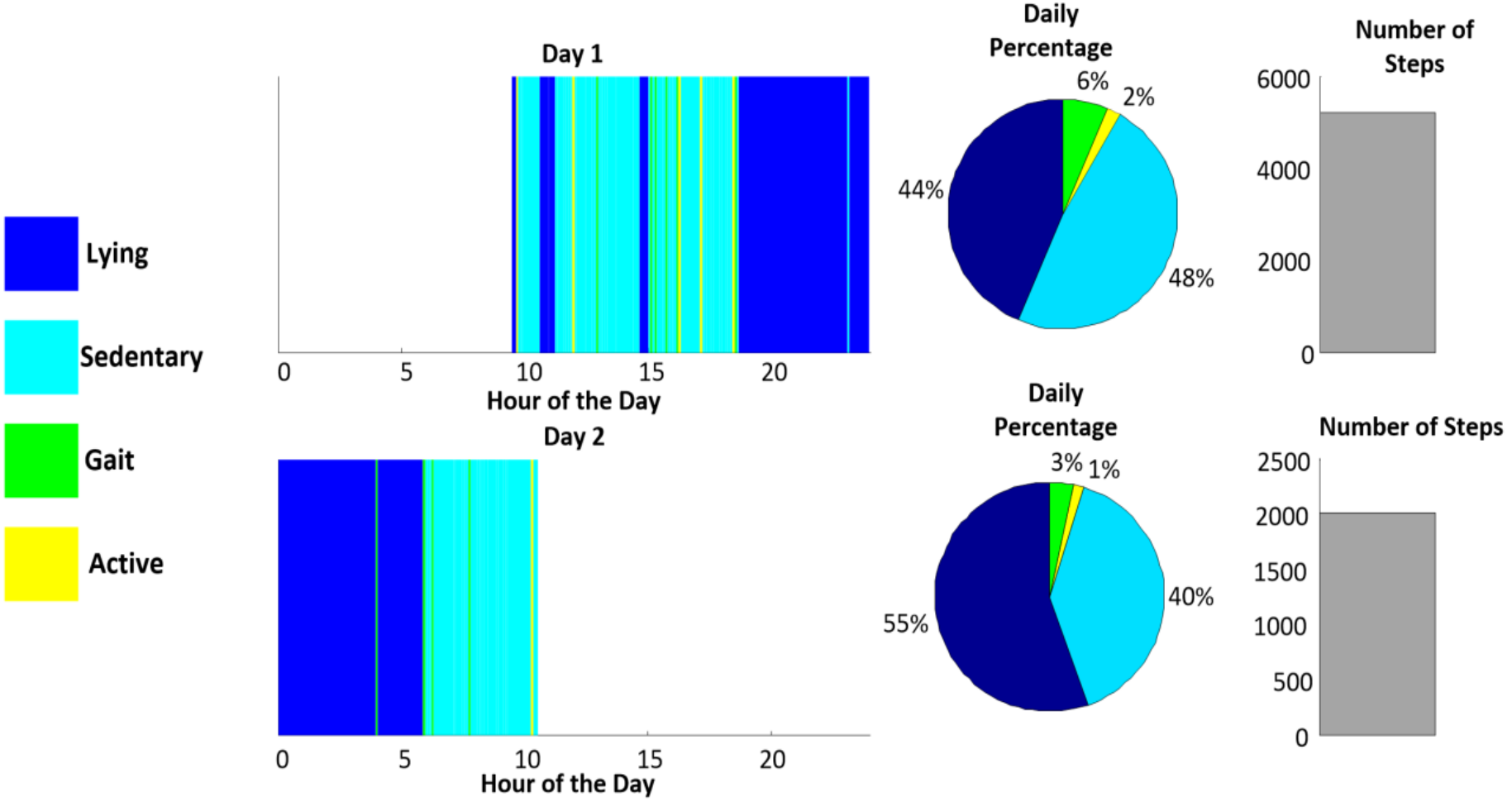




Scenarios: Exergame-based Exercise

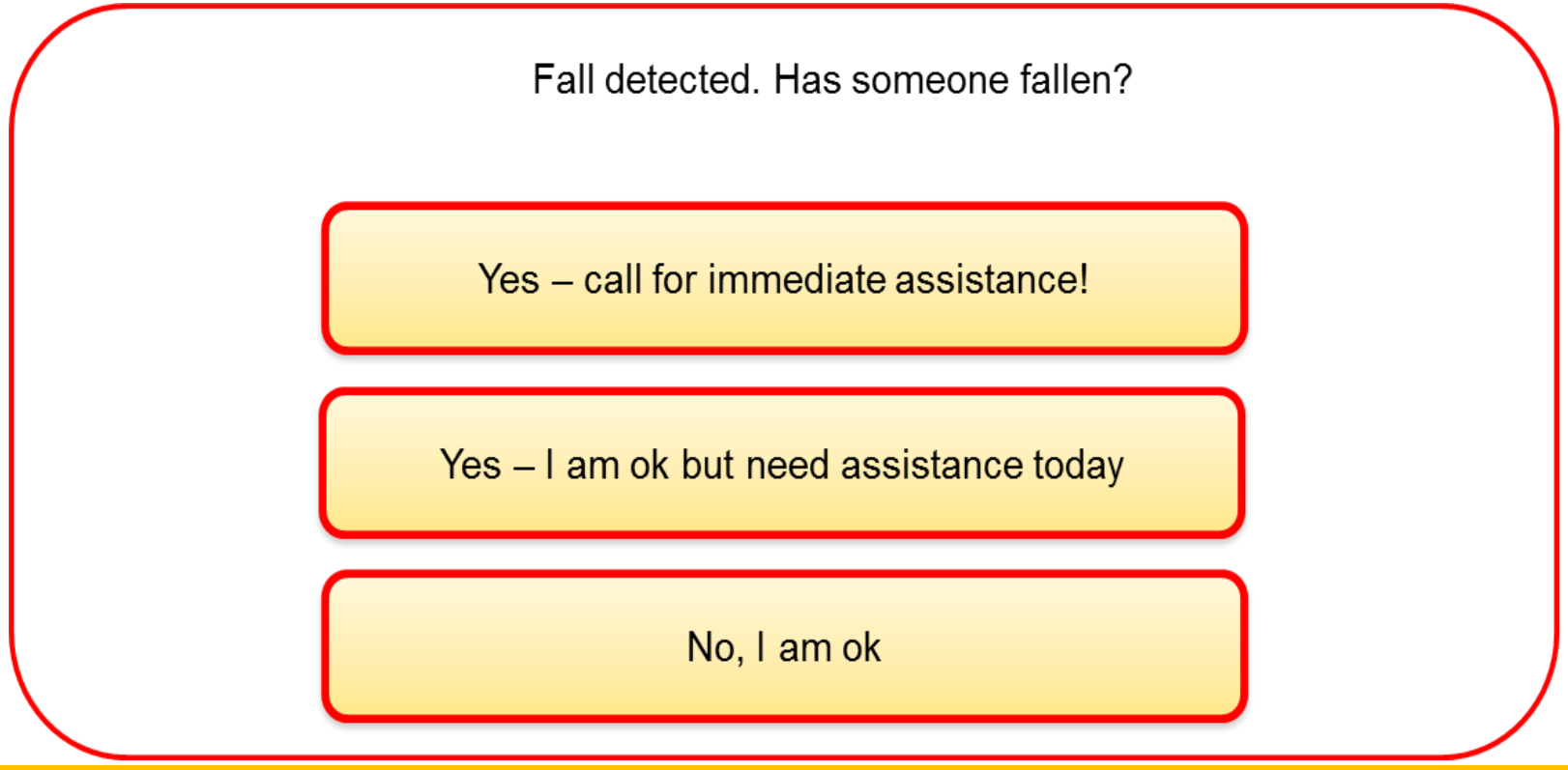


Scenarios: Walking



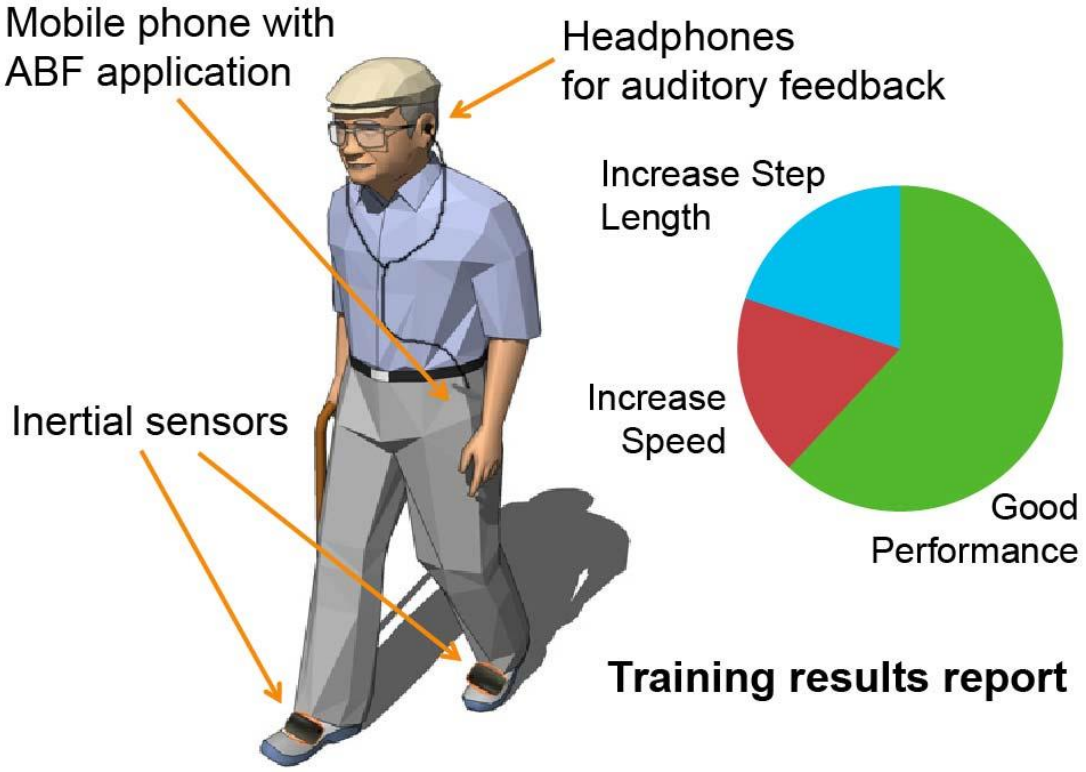
Scenarios: Fall Detection

- **Fall detection:** when a fall is detected by the smartphone a message is sent to the home automation system which also activates the wall mounted touchscreen.



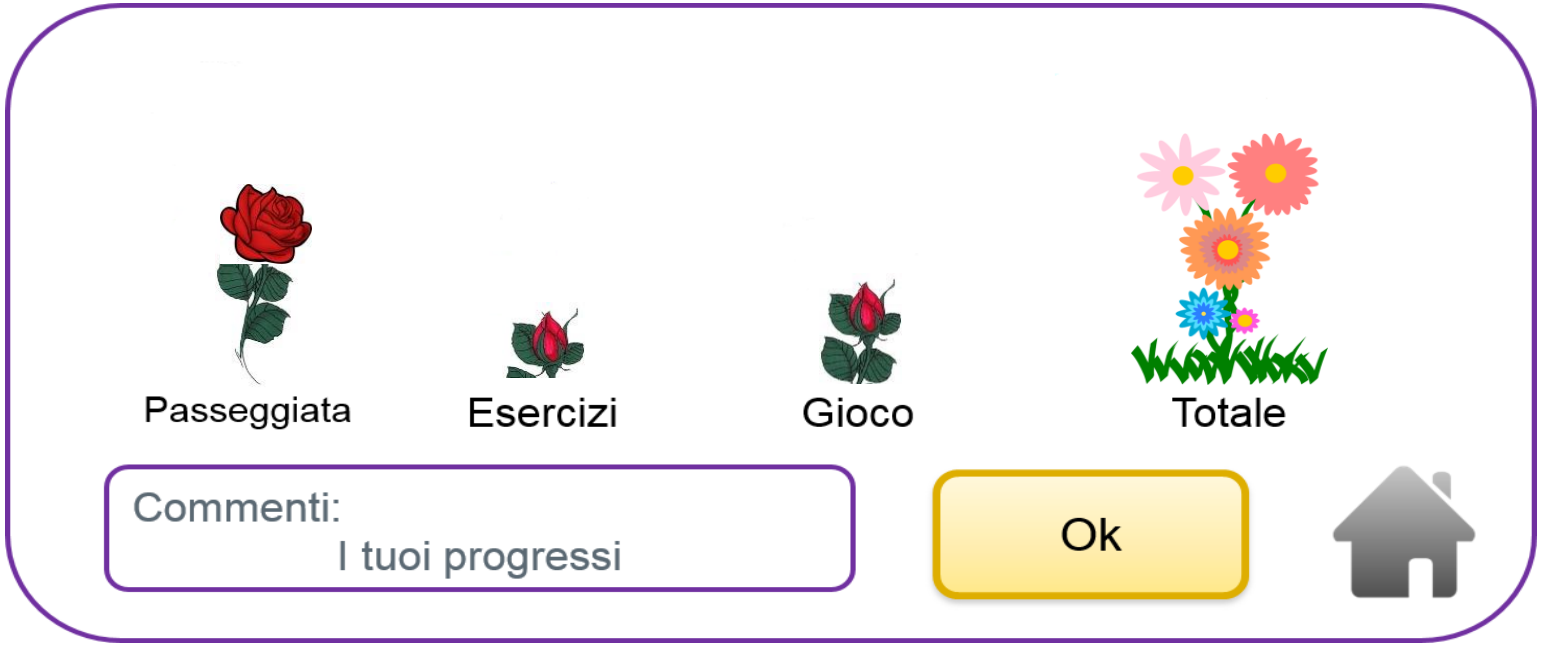
Scenarios: rehabilitation at home

- Biofeedback's working principle is based on information from the body coded into an appropriate signal and provided back to the user in real time.



Personal Goals

- The wall mounted touchscreen also shows the status/progress of the personal goals of the user. Feedback messages are delivered in the form of a growing garden with specific elements being awarded on the basis of the task completed on a daily basis.



Complete Architecture

Telemedical Service

CuPiD Telemedical Service (daily reports)

Smart-Home

FARSEEING Repository

Internet

MY HOME bticino

BUS SCS

Ethernet

Smartbox

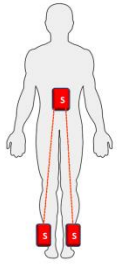
Passive RFID Tags

Ethernet

RFID system

Gait Training/Rehabilitation

Freezing of Gait Prediction/ Detection (auditory cueing)



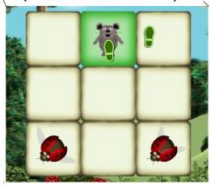
Smartphones

Smartphone Docking

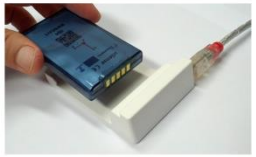
FARSEEING

TV/Monitor

Exergame (Camera Based)



Wearable Unit



Wearable Unit Docking

Exergame (Wearable sensors-based)

Touch'n'Explode

Stepping Tiles

Up'n'Down.

Scenarios

Scenarios

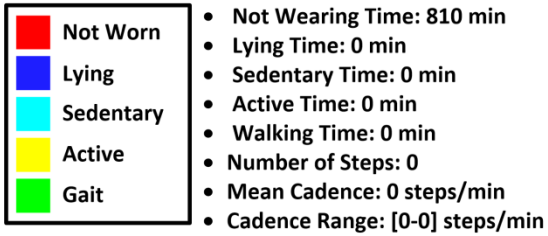

!
YOUR FATHER MAY BE IN TROUBLE, PRESS X TO ACCESS THE NEAREST CAMERA! OR PRESS Y TO CALL HIM!
PARSEENS
Hello Charles, Yes I just fell but I am fine and up off the floor uninjured.
Hi Dad, are you all right?

Scenarios

Scenarios

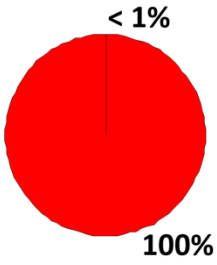

1
Mr. Brown, can you hear me?
2
FARSEEING speaking. Mr. Brown needs help...
3
SOS received, we are going!
4
We arrive
no one is
answerin
5
I am opening the front door
6
OK, we are going in!

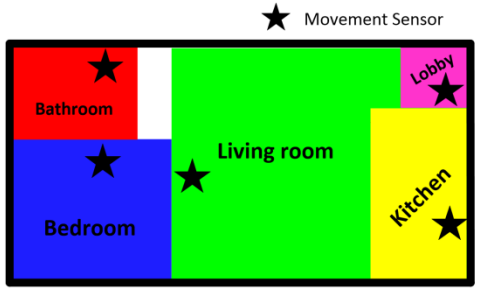
What we can get out of this architecture?



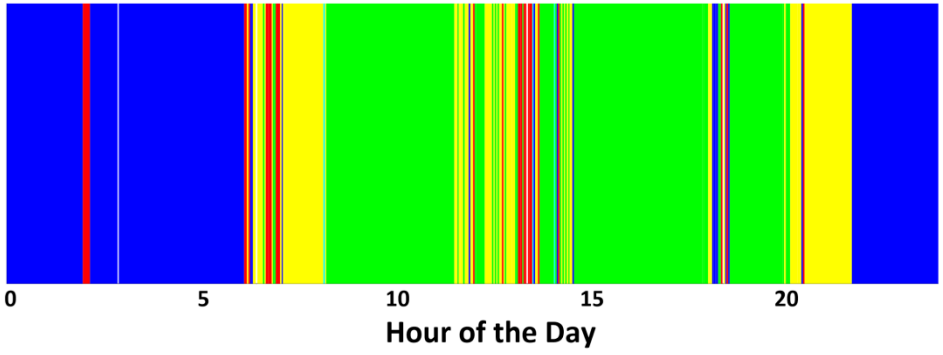
- Not Wearing Time: 810 min
- Lying Time: 0 min
- Sedentary Time: 0 min
- Active Time: 0 min
- Walking Time: 0 min
- Number of Steps: 0
- Mean Cadence: 0 steps/min
- Cadence Range: [0-0] steps/min

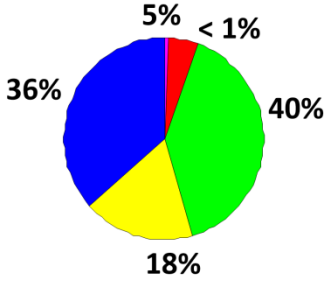
• Activity Monitoring





• Room Occupancy





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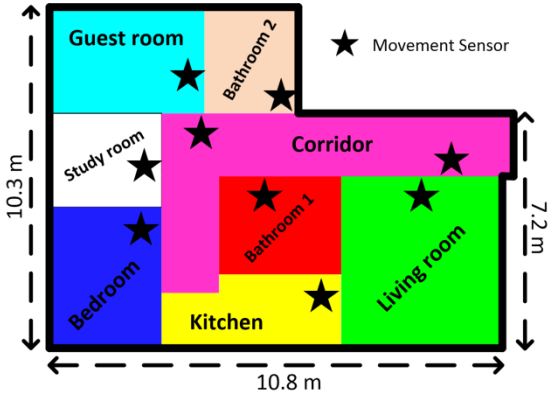

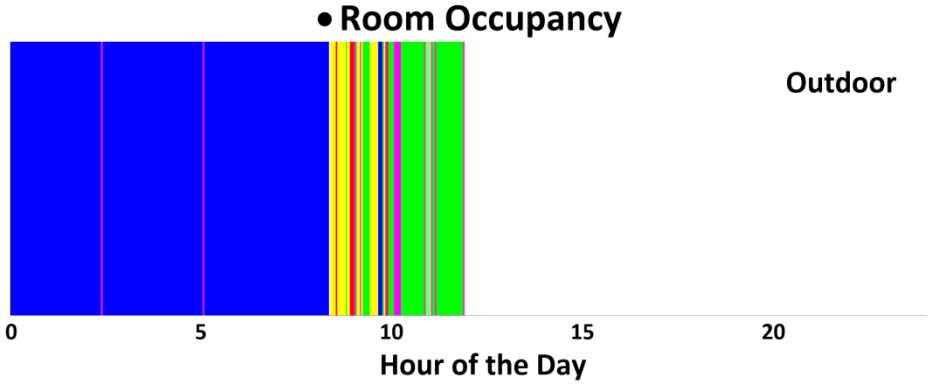

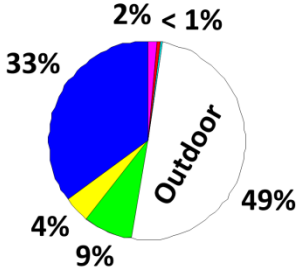

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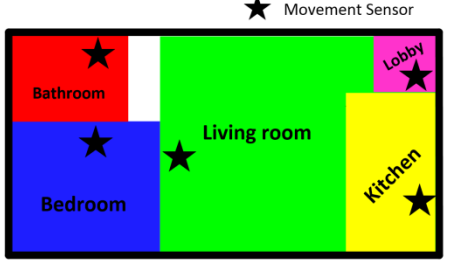

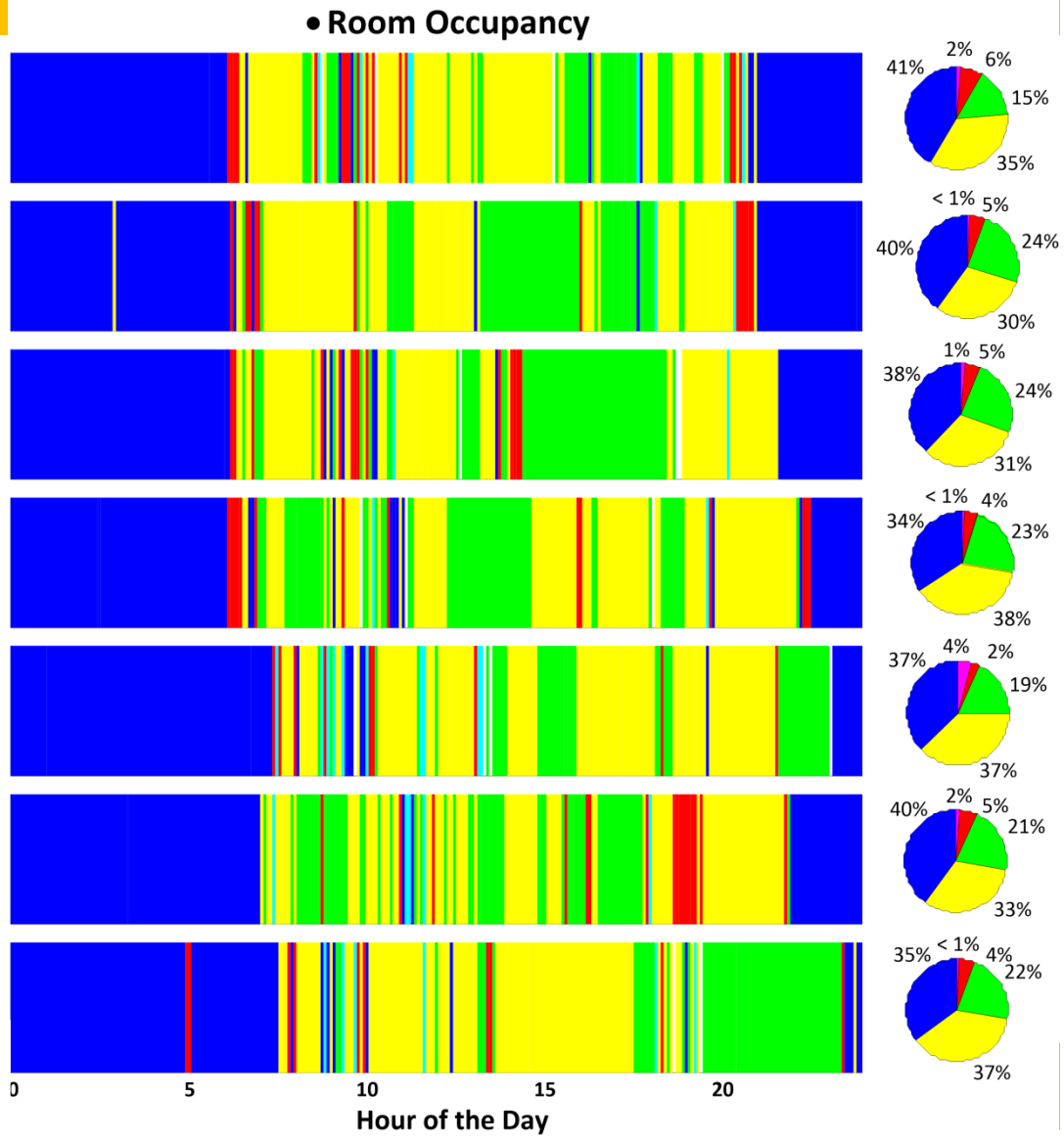

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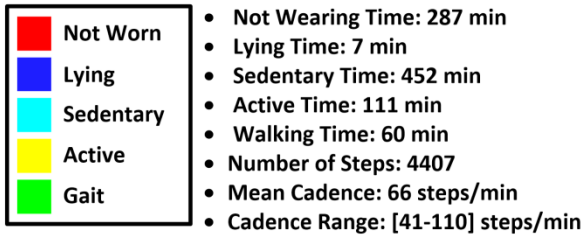
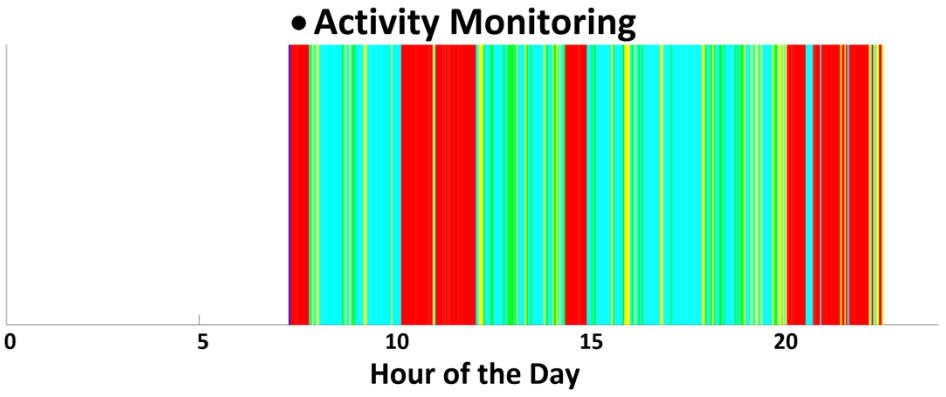
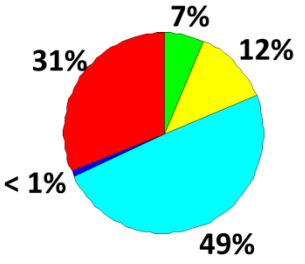
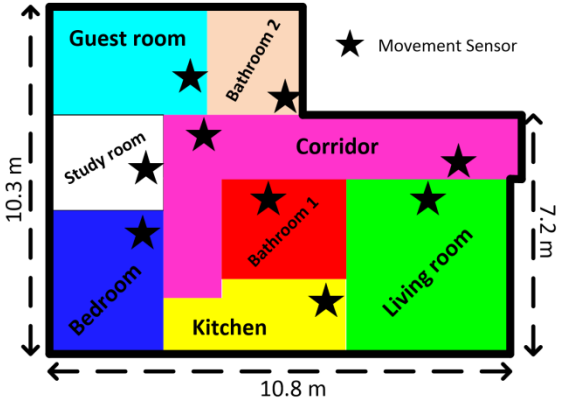
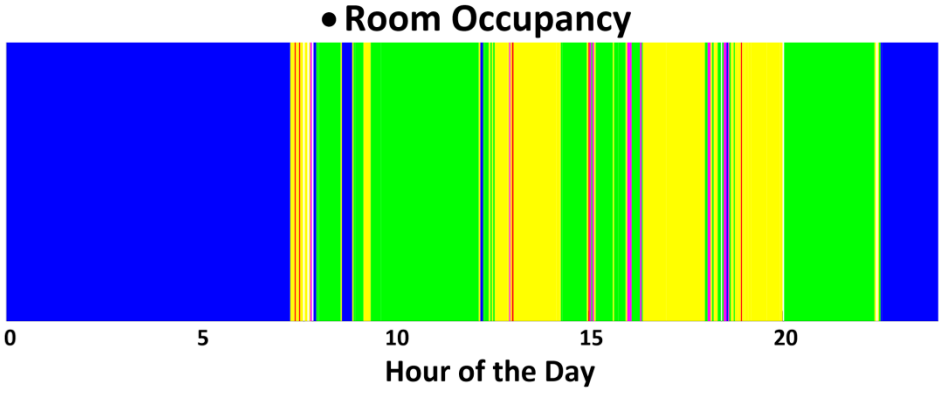


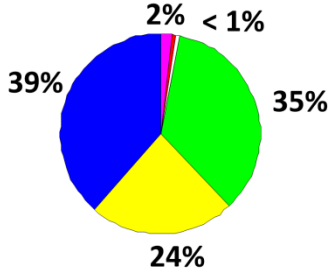
- Not Wearing Time: 287 min
- Lying Time: 7 min
- Sedentary Time: 452 min
- Active Time: 111 min
- Walking Time: 60 min
- Number of Steps: 4407
- Mean Cadence: 66 steps/min
- Cadence Range: [41-110] steps/min











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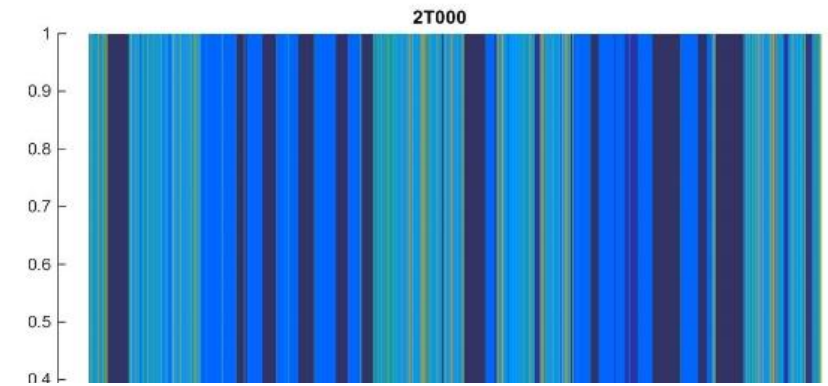
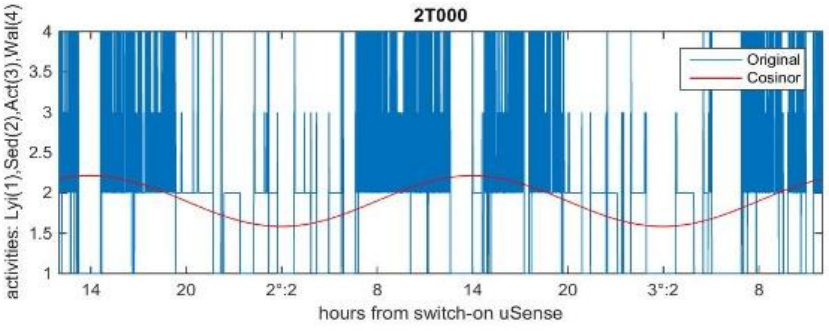
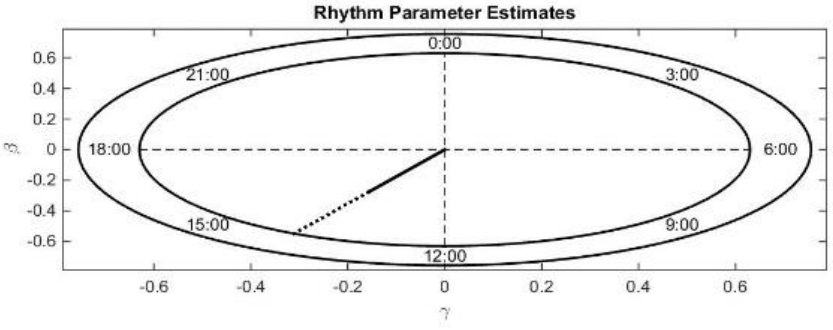
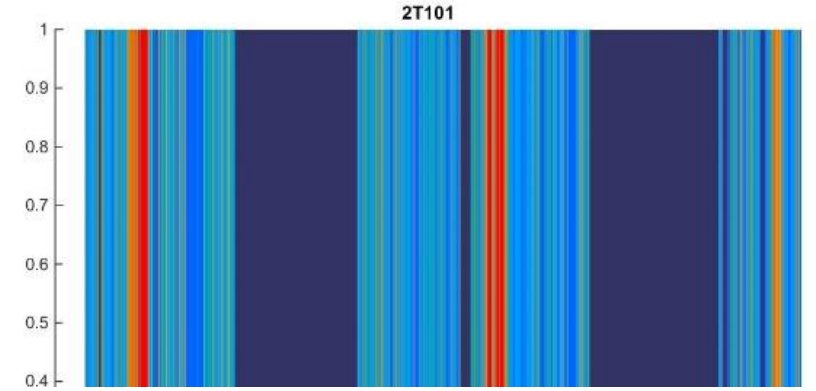
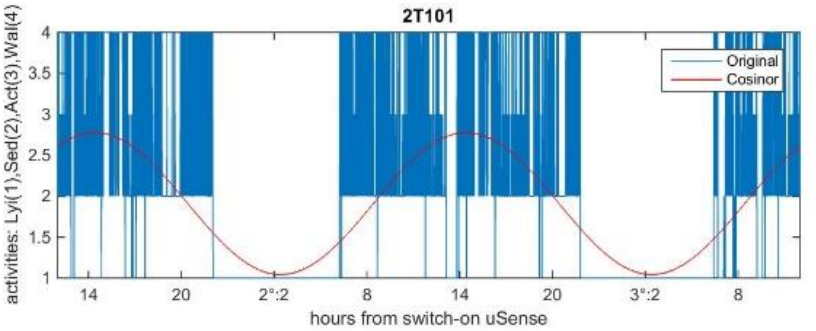
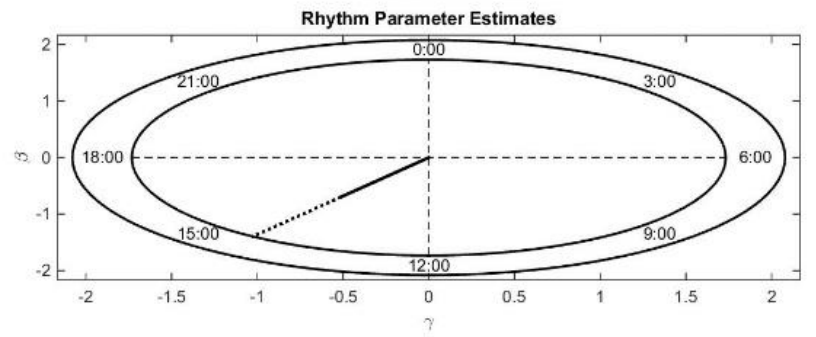




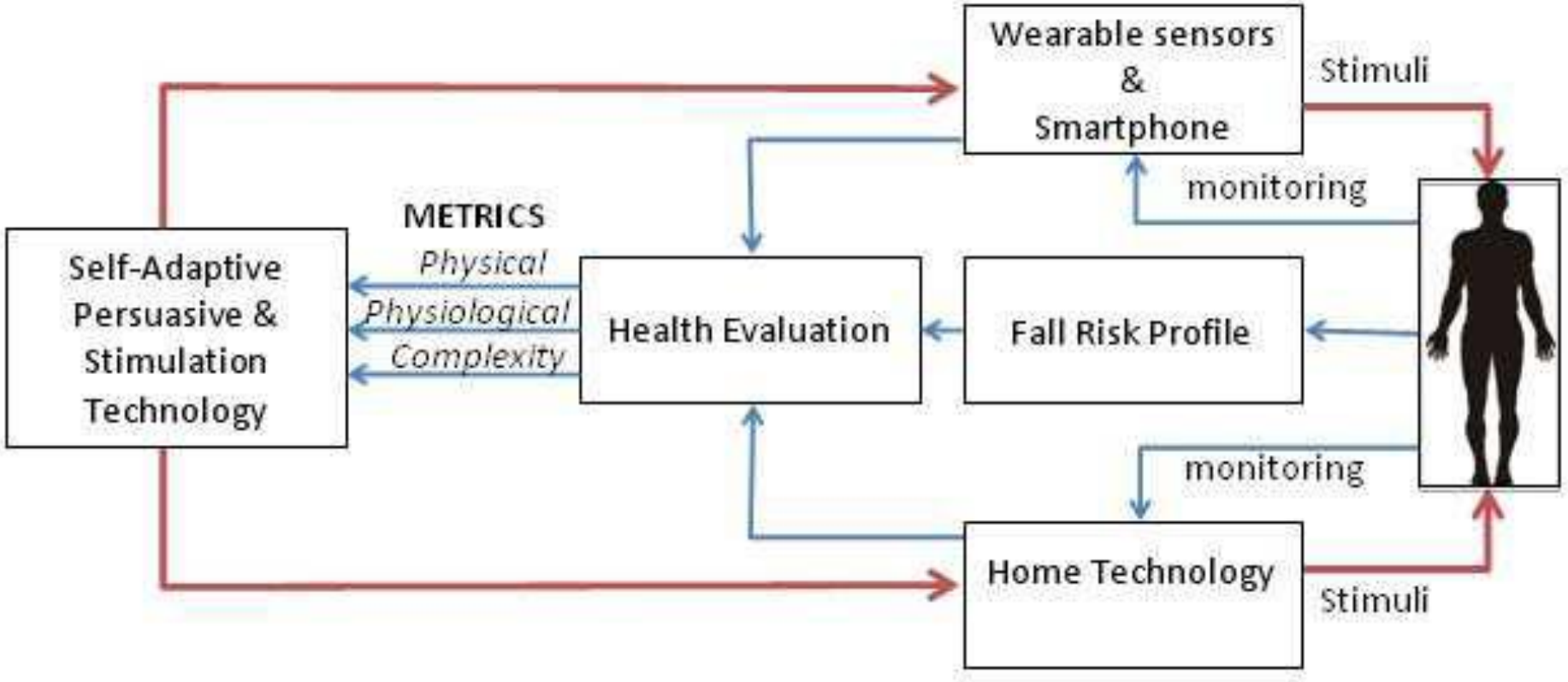








When a model is well defined...



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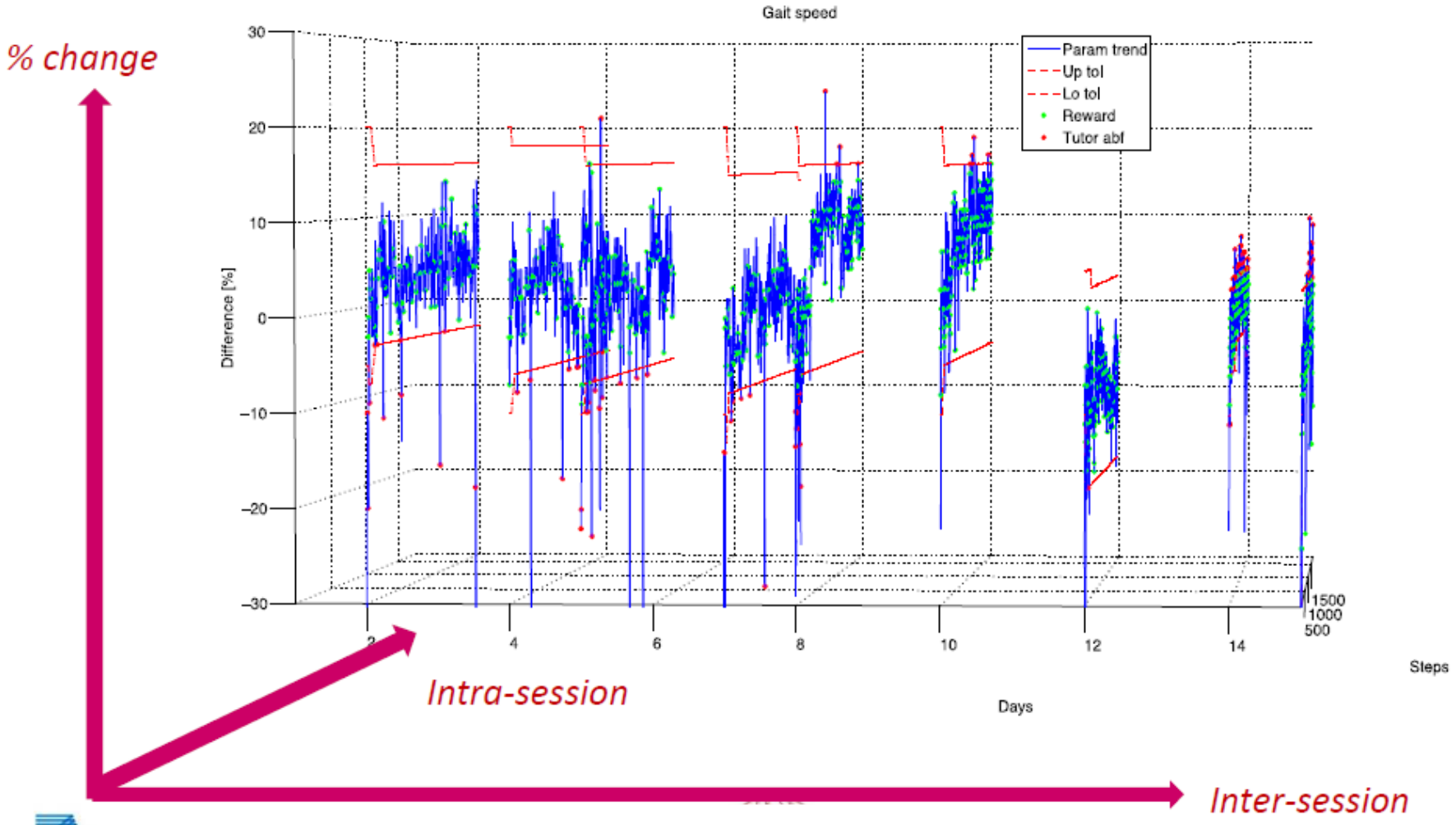
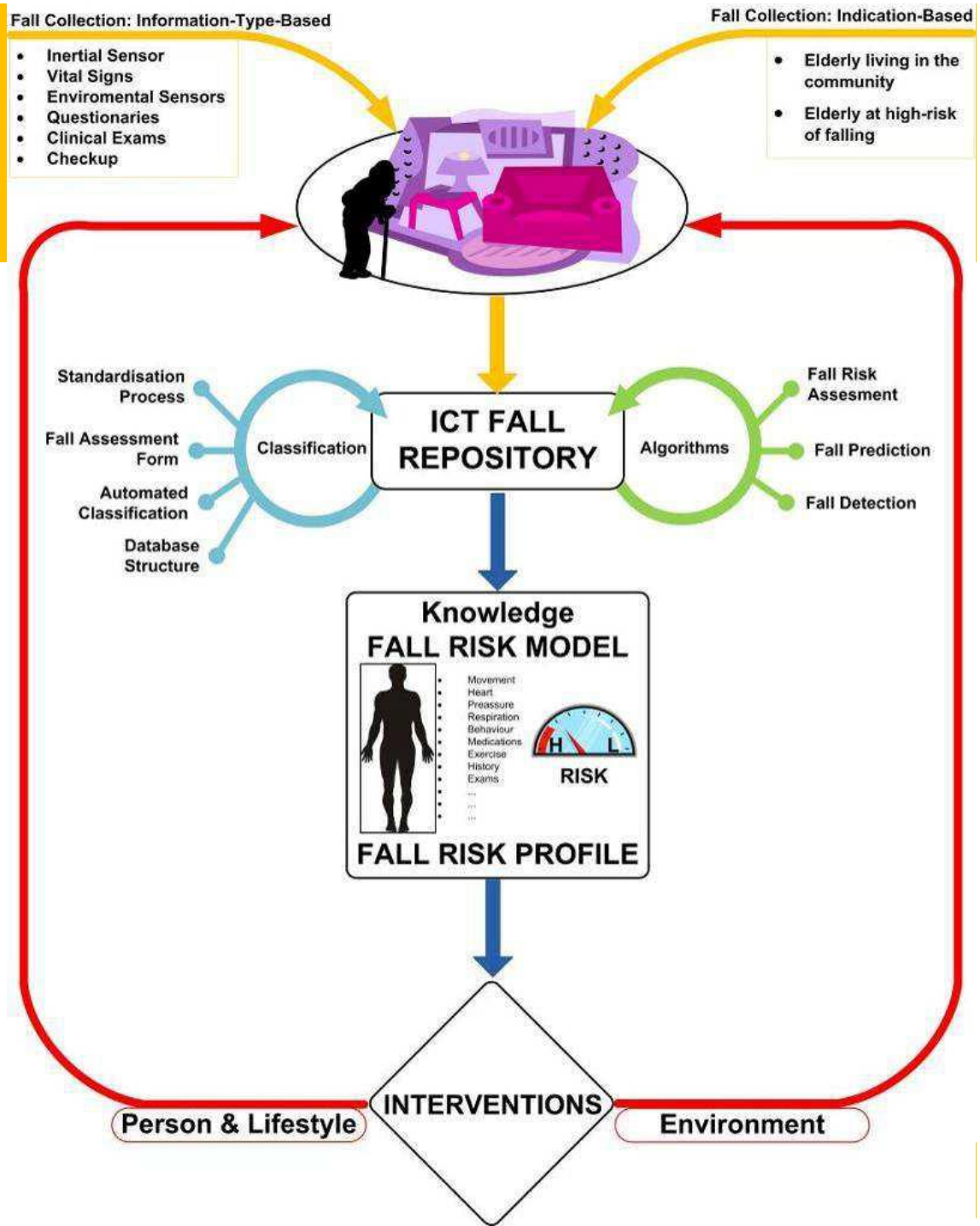


What do we do now?



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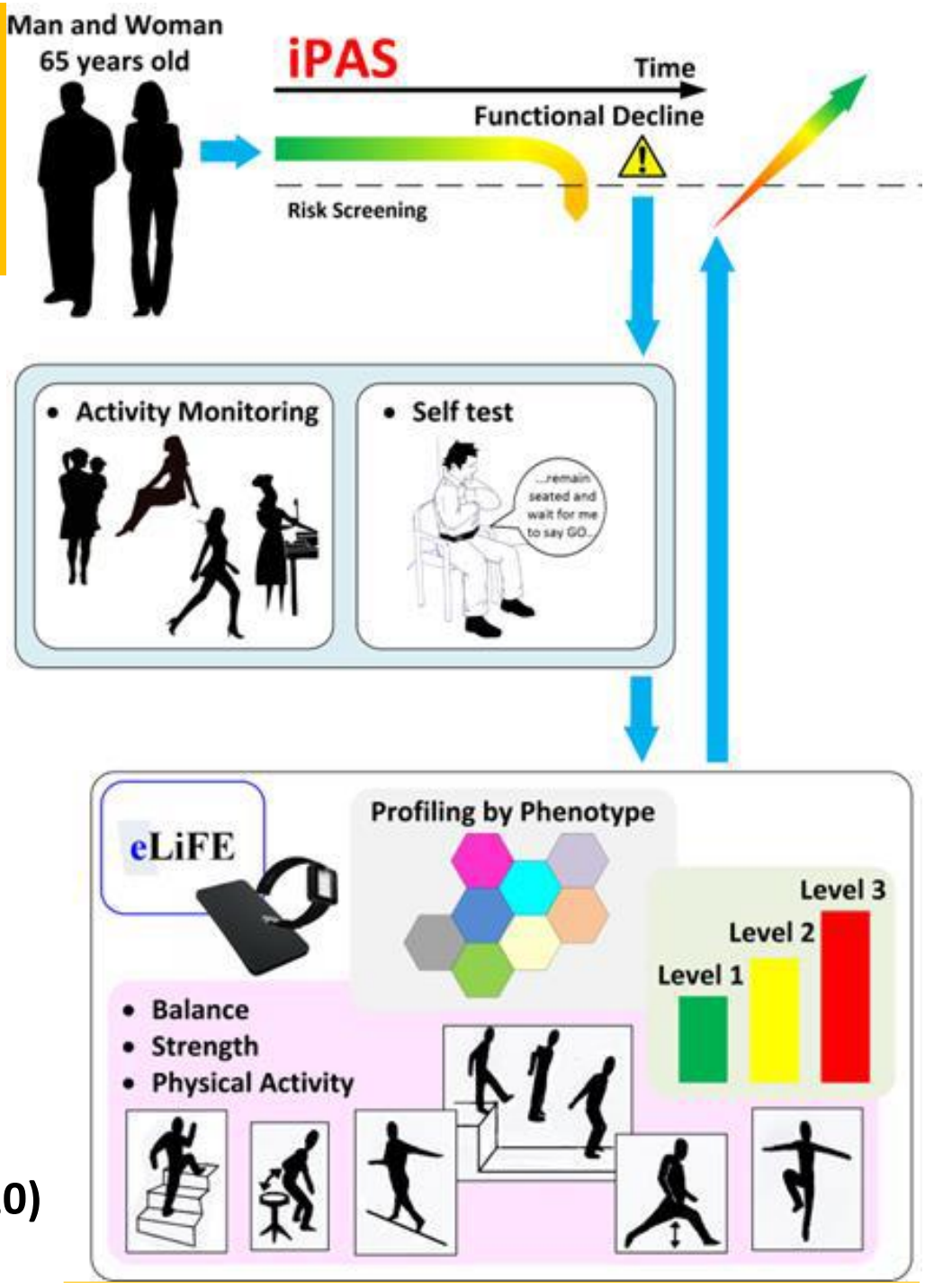
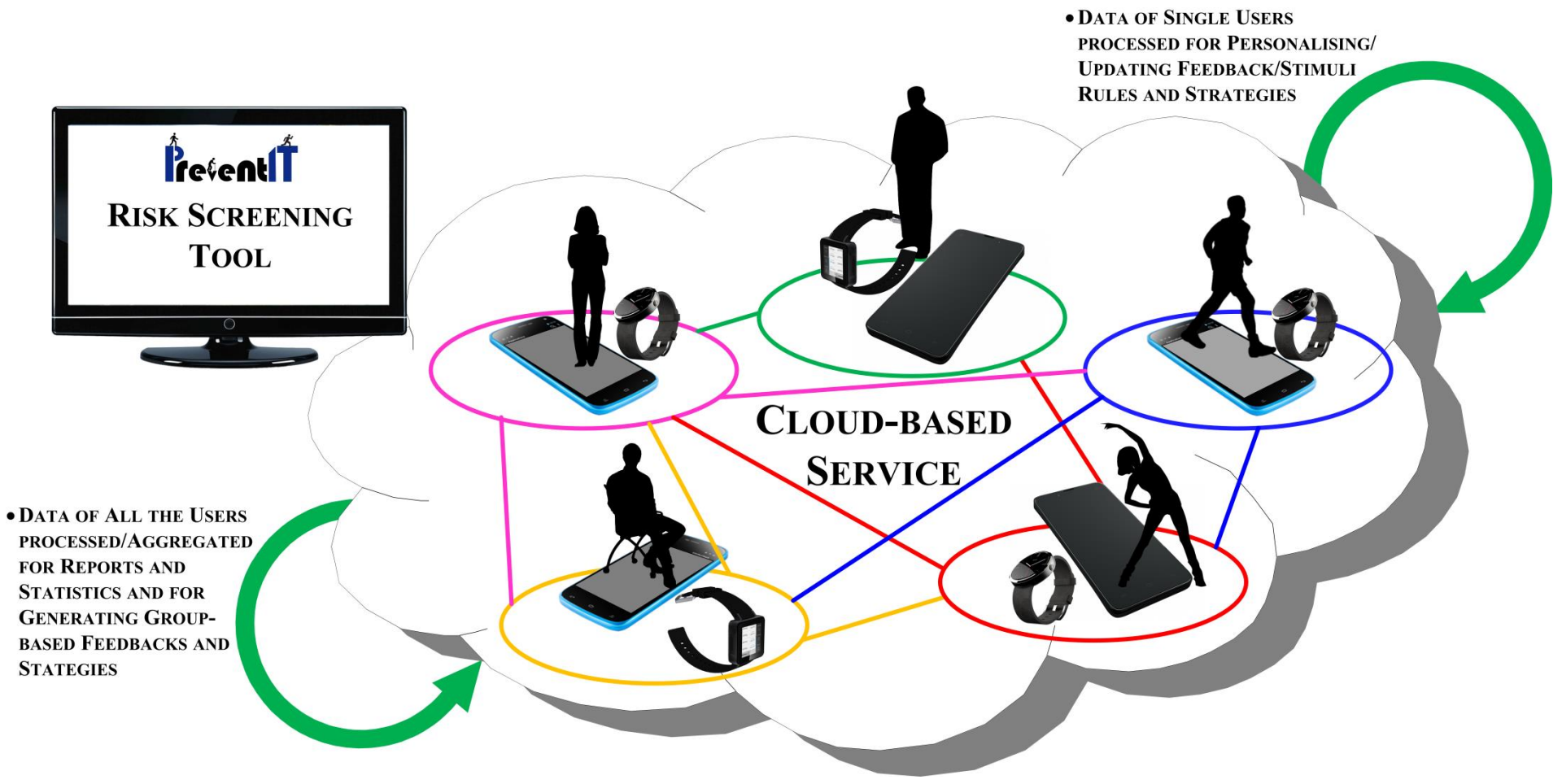


PreventIT (EU H2020)

What do we do now?

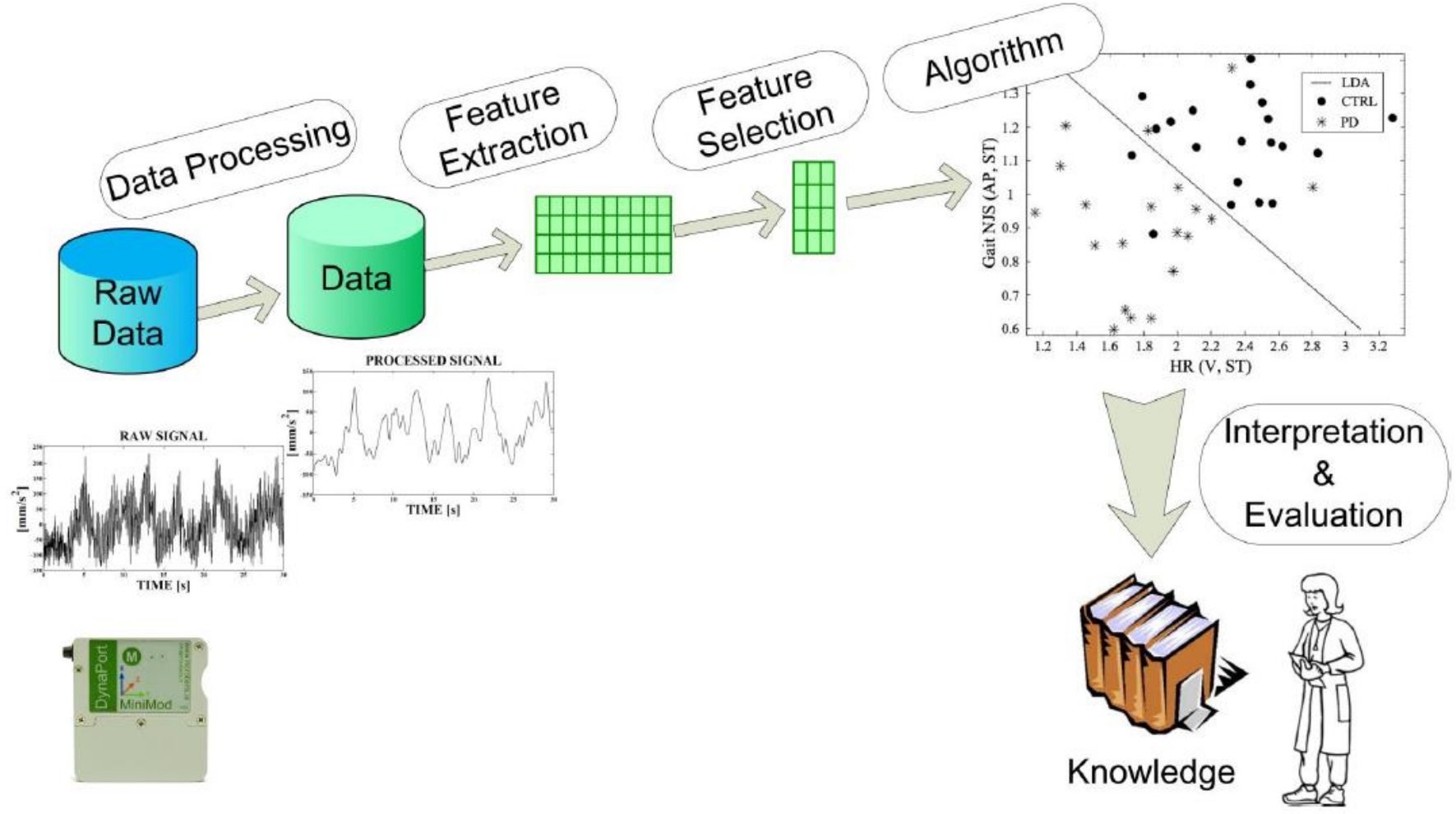


Data Mining

- The nontrivial **extraction** of **implicit**, **previously unknown** and potentially **useful information** from data [Frawley, 1992]

- Data mining is the process of **selecting**, exploring and modeling **large amount of data** in order to discover **unknown patterns** or relationships which provide a **clear** and **useful result** to the data analyst [Giudici, 2003]

Data Mining


Data Processing
Feature Extraction
Feature Selection
Algorithm
Raw Data
Data
PROCESSED SIGNAL
RAW SIGNAL
TIME [s]
TIME [s]
LDA
CTRL
PD
Gait NJS (AP, ST)
HR (V, ST)
Interpretation & Evaluation
Knowledge

Data Mining: Various Techniques

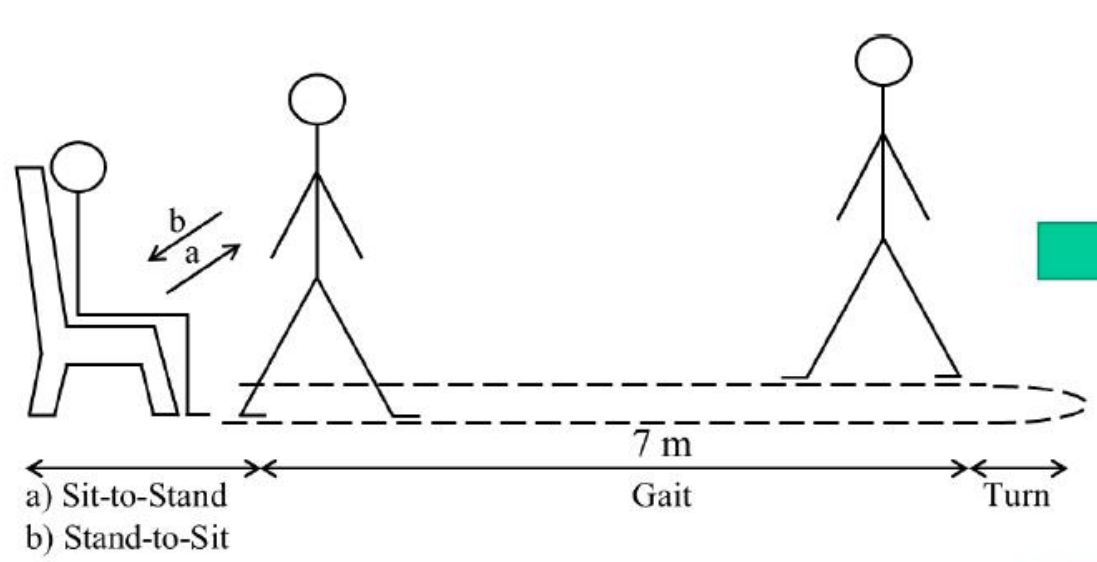
- Classification
- Regression

} Supervised

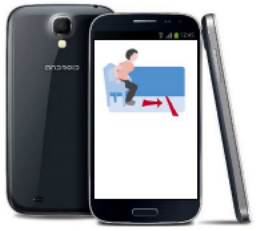
- Clustering
- Anomaly detection

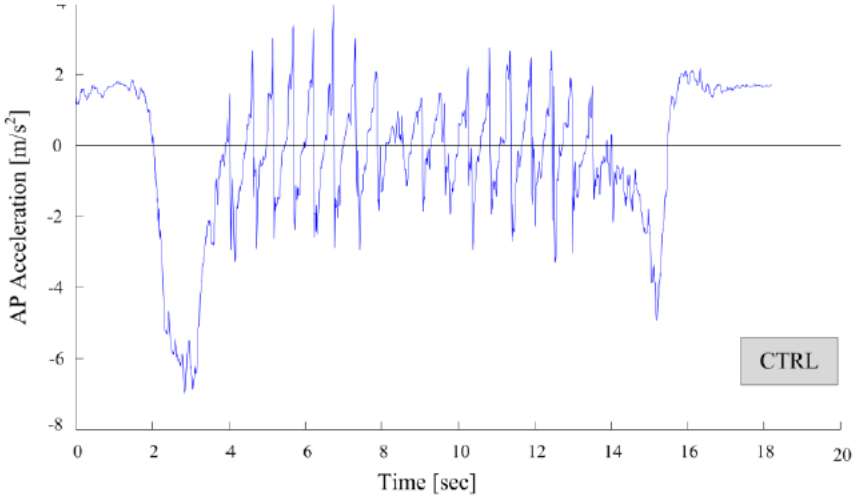
} Unsupervised

Feature Extraction: The Instrumented Timed Up and Go Test



Feature Extraction: The Instrumented Timed Up and Go Test

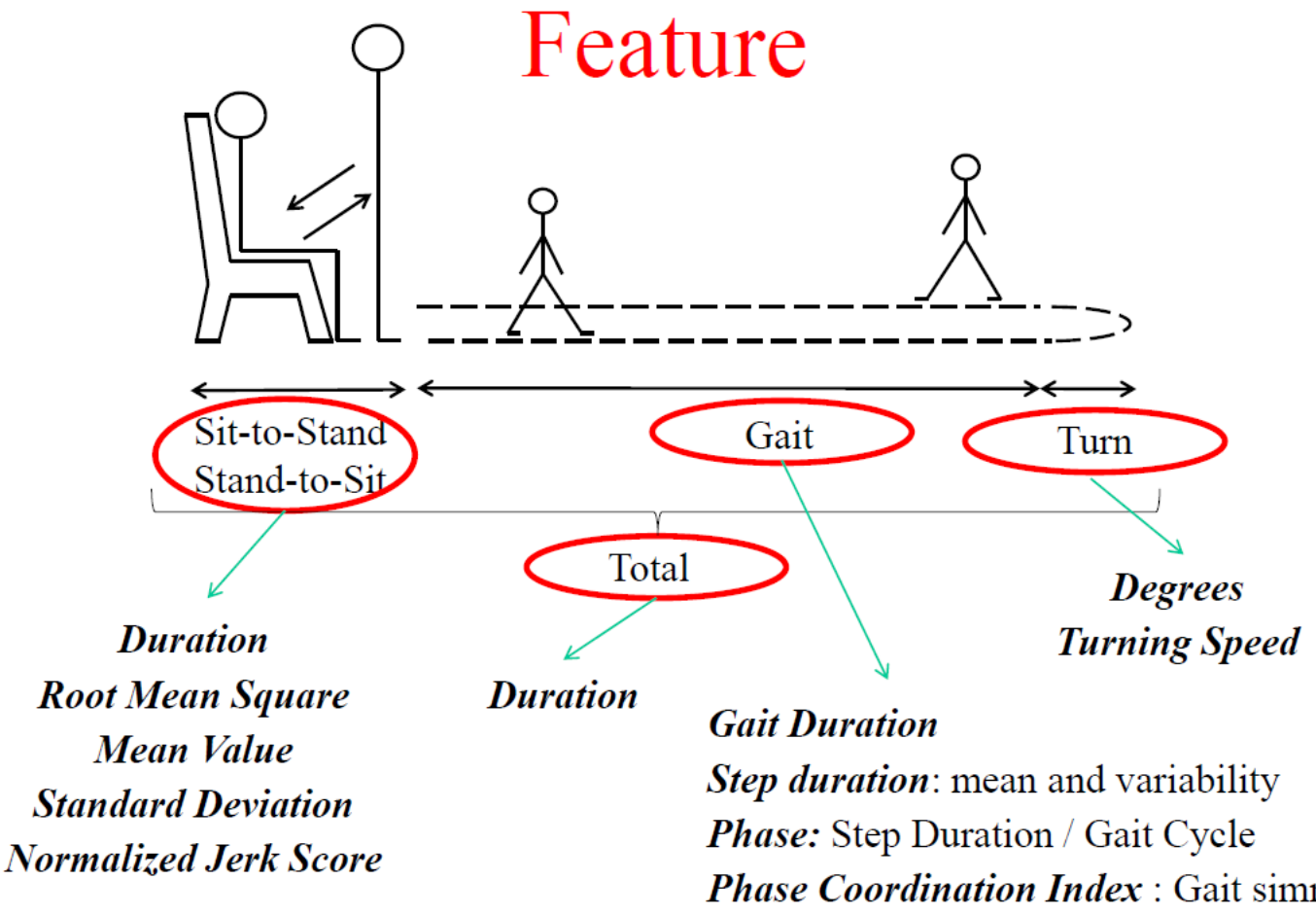




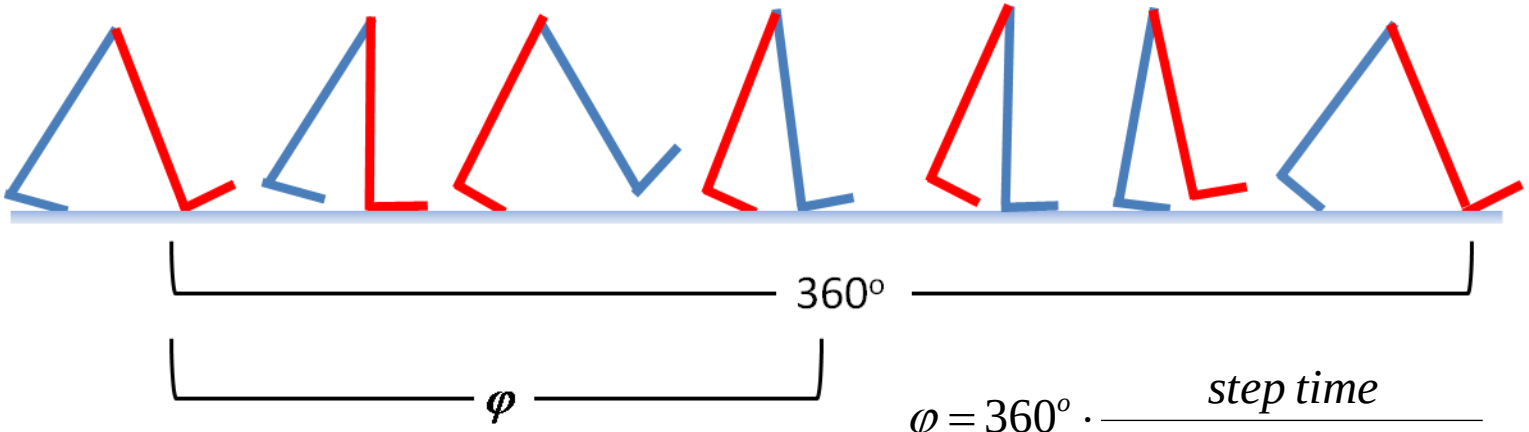
Processing (filtering, segmentation…)

Extraction of Descriptive Features from the signals

Feature Extraction: The Instrumented Timed Up and Go Test



Coordination/Simmetry?



$$\varphi = 360^{o} \cdot \frac{step\ time}{gait\ cycle\ duration}$$

Phase Coordination Index (PCI). PCI measures gait coordination (i.e., the accuracy and consistency of the phase generation).

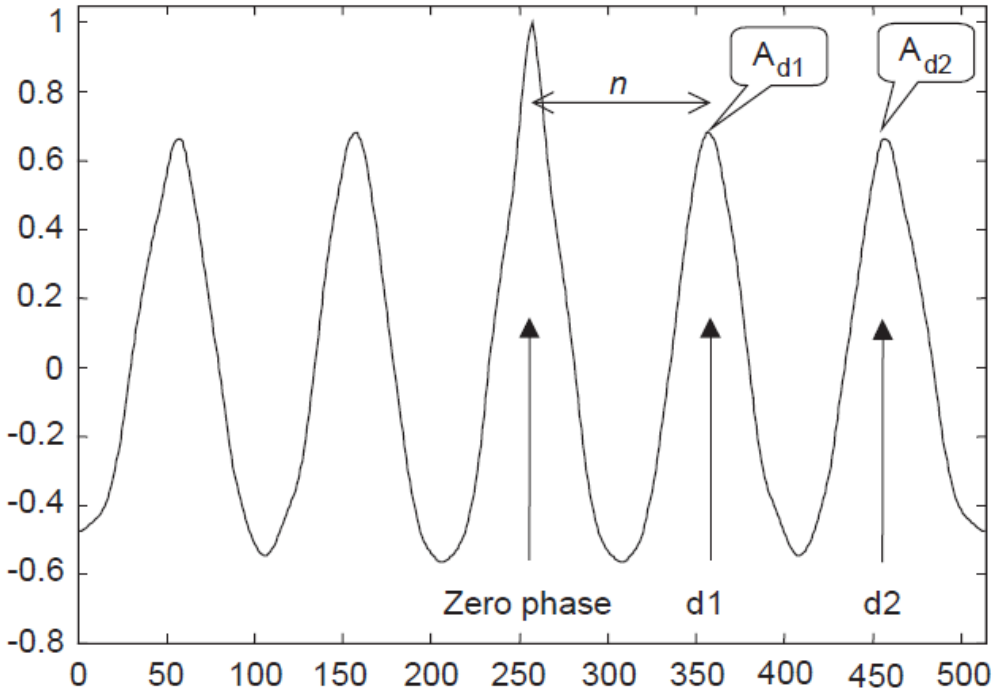
$$PCI = Phase\ \ CV + 100 \cdot \frac{\frac{1}{N}\sum_{i=1}^{N} |\varphi_i - 180^{\circ}|}{180^{\circ}}$$

***Plotnik et al*, 2007**

Coordination/Simmetry?

Step and Stride Regularity can be assessed by means of signal autocorrelation.

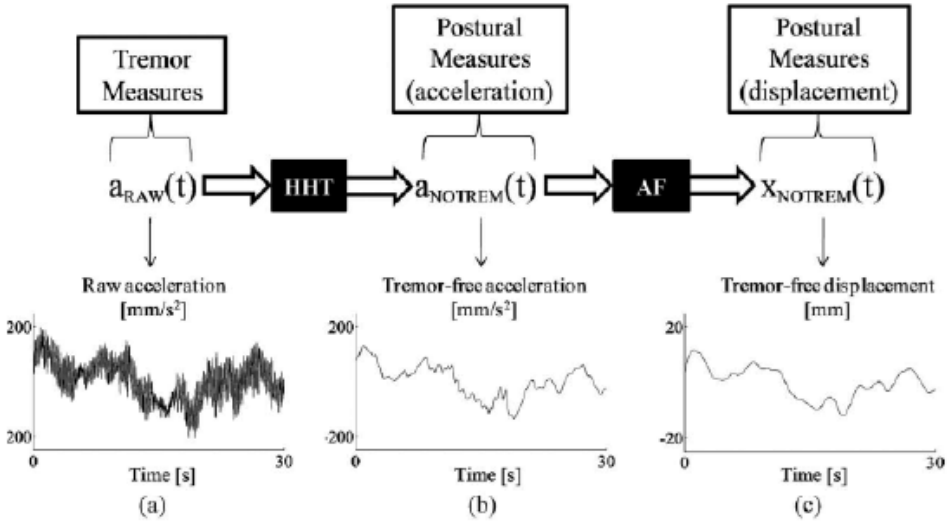
The ratio between Step Regularity (Ad1) and Stride Regularity (Ad2) is used as a measure of simmetry



$$Simmetry = \frac{Ad1}{Ad2}$$

***Moe-Nilssen et al*, 2004**

What typically happens…



QS CONDITIONS

Acronym	Description	Perturbed postural sub-system
EO	Eyes Open on a rigid surface	None
EC	Eyes Closed on a rigid surface	Visual
EODT	Eyes Open with Dual Task on a rigid surface	Attention
EOF	Eyes Open on a Foam-rubber support	Somato-sensory
ECF	Eyes Closed on a Foam-rubber support	Somato-sensory + Visual

Many sensor axis and conditions…

Tremor Measures	Domain	Description	Directions
Power HF	Frequency	Fraction of power of the signal for high frequencies (between 4 and 7 Hz) [%]	AP, ML
Peak HF	Frequency	Frequency of the maximum of the PSD for high frequencies (> 4 Hz) [Hz]	AP, ML
RHL	Frequency	Power ratio of the high (3.5 – 15 Hz) to low (0.15 – 3.5 Hz) frequency components (unitless)	AP, ML
Postural Measures (acceleration)	**Domain**	**Description**	
F50	Frequency	50% power frequency: frequency containing 50% of the total power [Hz]	AP, ML
F95	Frequency	95% power frequency: frequency containing 95% of the total power [Hz]	AP, ML
CF	Frequency	Centroidal Frequency: the frequency at which spectral mass is concentrated [Hz]	AP, ML
FD	Frequency	Frequency Dispersion: a unitless measure of the variability of the PSD frequency content (zero for pure sinusoid, increases with spectral bandwidth to one) (unitless)	AP, ML
Entropy	Frequency	Power spectrum entropy of acceleration (unitless)	AP, ML
JI	Time	Jerk Index: a function of the time derivative of the acceleration; it is commonly viewed as an index of smoothness [mm^2/s^5]	AP, ML
NJI*	Time	Normalized Jerk Index: JI is normalized by dividing it by SP^2 [$1/s^5$]	AP, ML
Postural Measures (displacement)	**Domain**	**Description**	
MD	Time	Mean Distance from center of CoM trajectory [mm]	AP, ML
RMS	Time	Root Mean Square distance from center of CoM trajectory [mm]	AP, ML
Range	Time	Range of CoM displacement [mm]	AP, ML
SP	Time	Sway Path: total CoM trajectory length [mm]	AP, ML
MV	Time	Mean Velocity of the CoM, computed as the median value of the absolute value of the time series obtained through the derivative of the displacement [mm/s]	AP, ML
SA	Time	Sway Area: area included in CoM displacement per unit of time [mm^2/s]	planar
CEA	Time	Confidence Ellipse Area: area of 95% confidence ellipse [mm^2]	planar
mSCEA	Time	Minor Semiaxis of CEA [mm]	planar

Hundreds of Variables!!!

Dimensionality Reduction

There are many possible approaches:

- Correlation Analysis
- Principal Component Analysis (PCA)
- Backward Feature Elimination
- Etc.

Dimensionality Reduction and Human Interpretable Information

- **Factor analysis**: it can be used in order to reduce the large number of variables in the dataset and for underlining the structure in the relationships between features (unobserved variables)

Dimensionality Reduction and Human Interpretable Information

feature	E.V.	factor	ADL	IADL	CESD	FEAR	PA	FALL	HG	PR	TMT	SPPB
FACTOR ANALYSIS OF THE EXTREME VALUES OF THE FEATURES												
• Sedentary time % • Active time % • Walking time %	0.13	Activity Level	-0.13	-0.13	**-0.16**	-0.15	**0.28**	0.13	-0.09	**0.17**	0.03	**0.21**
• Mean turning velocity (95) • Peak turning velocity (95)	0.12	Turning Velocity	-0.13	-0.14	-0.01	-0.11	**0.26**	-0.06	**0.16**	0.12	**-0.20**	**0.48**
• St. Dev. step duration (5) • CV step duration (5)	0.11	Gait Variability	-0.10	-0.05	0.03	-0.08	0.04	-0.03	-0.03	0.02	0.05	0.00
• AP Harmonic Ratio (95) • AP step regularity (95) • V step regularity (95)	0.10	Gait Regularity	-0.09	-0.11	-0.08	-0.02	0.07	0.01	**0.18**	**0.15**	0.03	**0.19**
• ML Harmonic Ratio (95) • ML step regularity (95)	0.09	ML Gait Regularity	-0.07	-0.13	0.07	0.03	-0.07	-0.09	0.01	-0.15	0.06	0.02
• Mean turning duration (5)	0.07	Turning Duration	0.02	-0.07	0.01	0.01	-0.06	-0.09	-0.01	-0.08	0.10	0.02
• Step duration (5) • Coordination Index (5)	0.06	Sprint	-0.03	0.11	0.06	0.09	-0.03	0.06	-0.09	0.05	0.00	0.01
• Cadence (95)	0.04	Cadence	0.03	0.05	0.08	-0.04	0.03	-0.10	-0.08	**-0.16**	0.11	**-0.16**

[Live Demo]

Thanks for your attention