BIOSTEC 2024
17TH INTERNATIONAL JOINT CONFERENCE ON BIOMEDICAL ENGINEERING SYSTEMS AND TECHNOLOGIES
21 - 23 FEBRUARY, 2024
Rome, Italy
BIODEVICES
BIOIMAGING
BIOINFORMATICS
BIOSIGNALS
HEALTHINF

Connected Sensors for Health and Autonomy

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SOCIETAL AND TECHNOLOGICAL CONTEXT

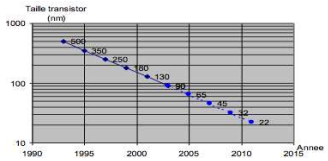
Context

Societal demands

Monitoring and assistance for chronically ill patients in mobility situations

Home teleassistance for the elderly

Technological developments



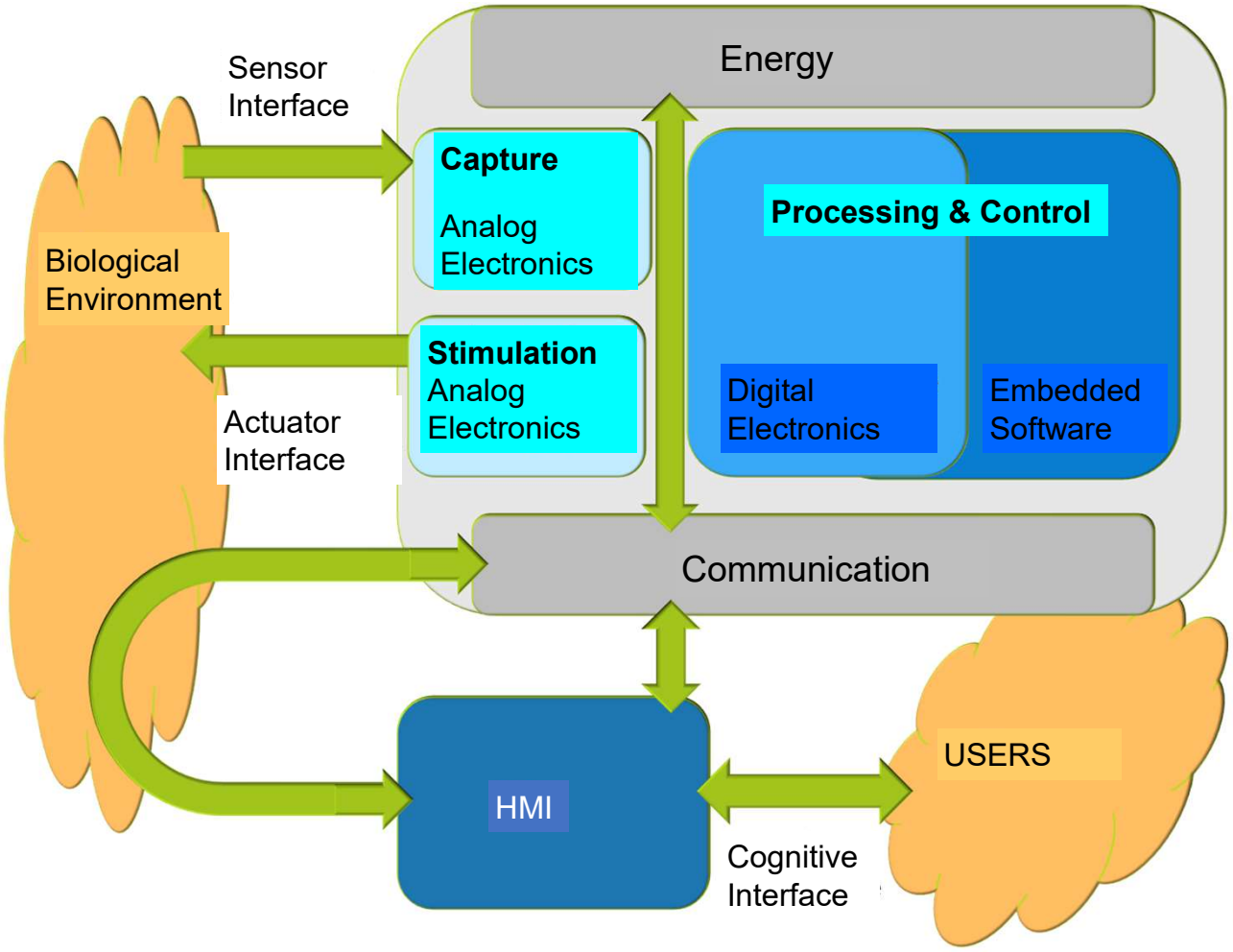
Health Embedded Systems (HES)

An electronic device that allows to measure and act on a living or inert biological environment in an autonomous and intelligent way.

An independent system, or an element of a more complex instrumentation, hierarchical and interactive, networked or not, interoperable or not, miniaturized or not, biocompatible or not, implanted or not.

** French : SES - Systèmes Embarqués pour la Santé*

HEALTH EMBEDDED SYSTEMS



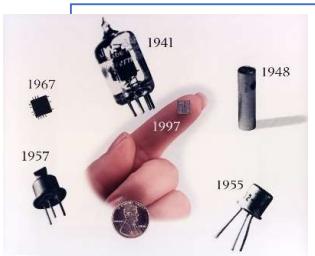
Report on key technologies (French Ministry Industry, 2015)

aviesan
alliance nationale pour les sciences de la vie et de la santé

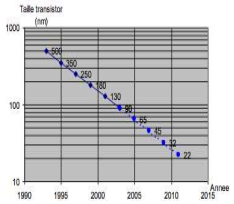
"Livre blanc des SES" 2017

EVOLUTION IN INFORMATION COMMUNICATION TECHNOLOGIES

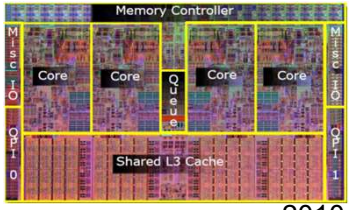
Yesterday | Today | Tomorrow



1947 (Bardeen et Brattain)



Moore Law



2010

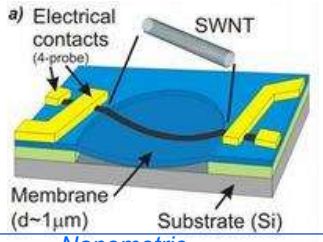
>2020

Millimetric

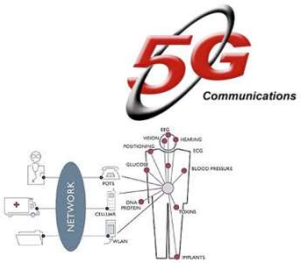
MEMS

Micrometric

NEMS



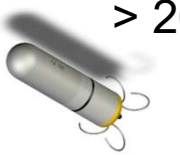
Nanometric

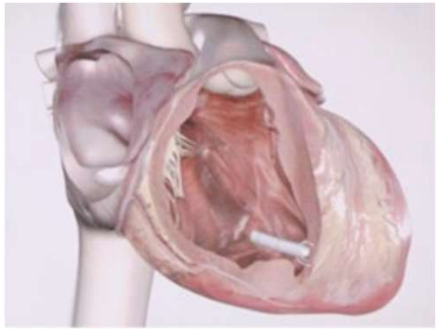


H.E.S. : Evolution of Health technologies

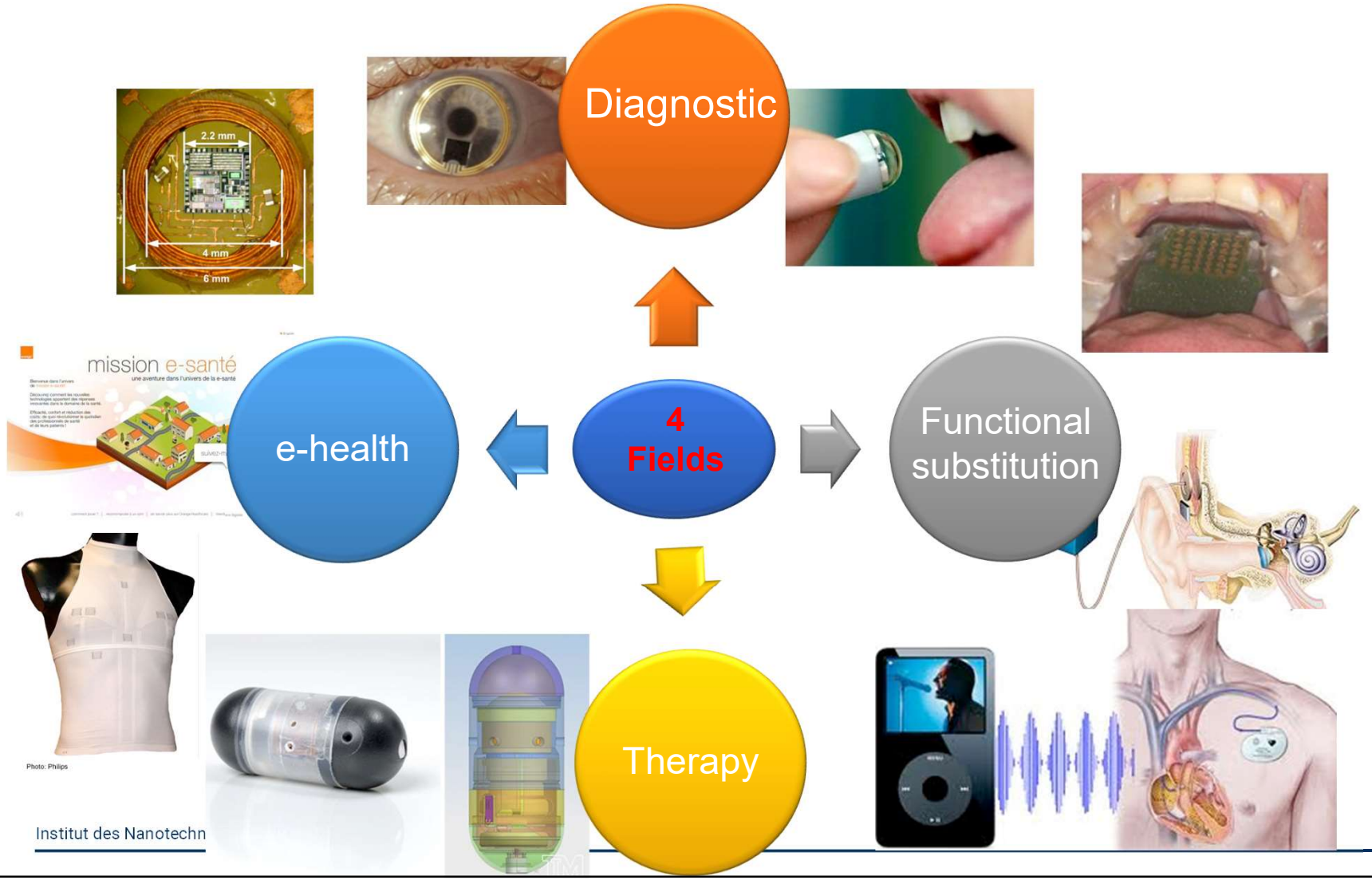
Yesterday | Today | Tomorrow

1958 | 2012 | > 2020



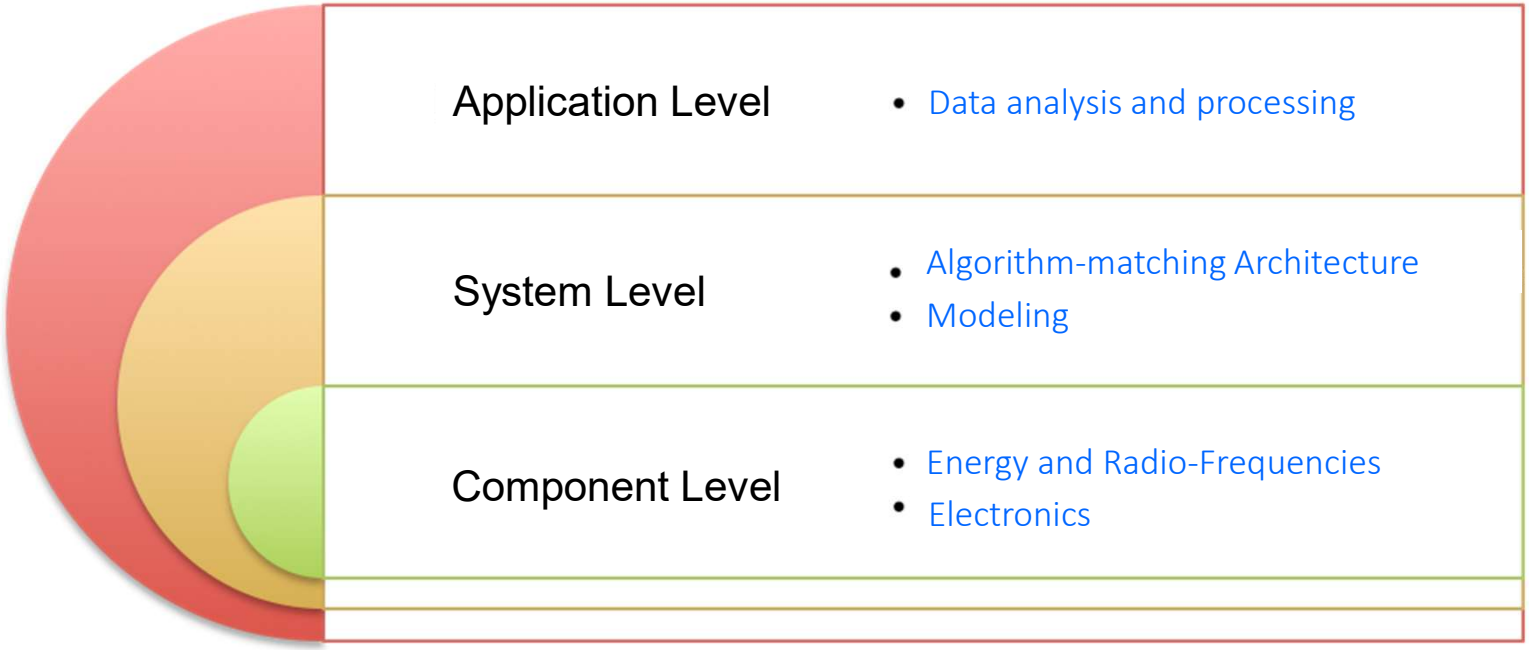


HEALTH EMBEDDED SYSTEMS



HEALTH EMBEDDED SYSTEMS

5 Scientific & Technical Issues

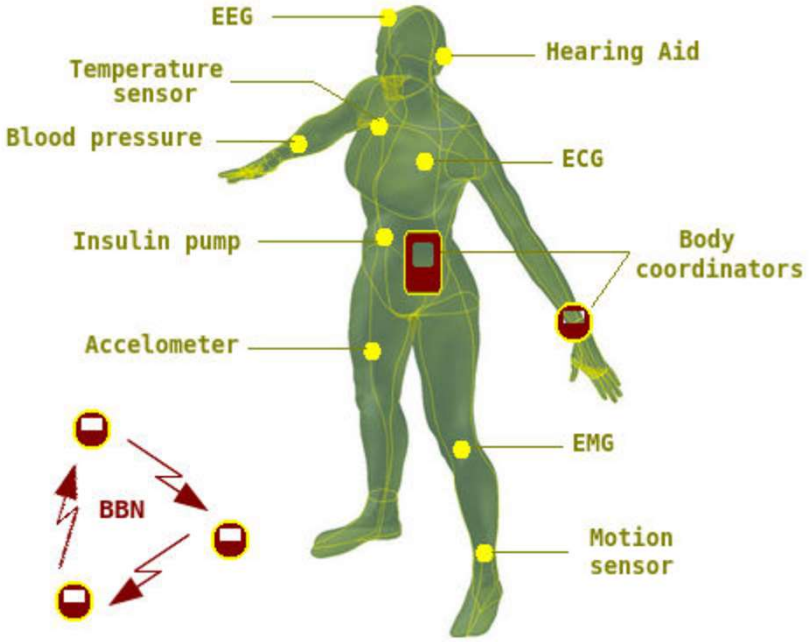


Technological opportunities

- What motivations ?
  - Sensors in Network : each sensors delivers a piece of information
  - Agregation/Fusion of information
  - Continuous Monitoring & Intervention

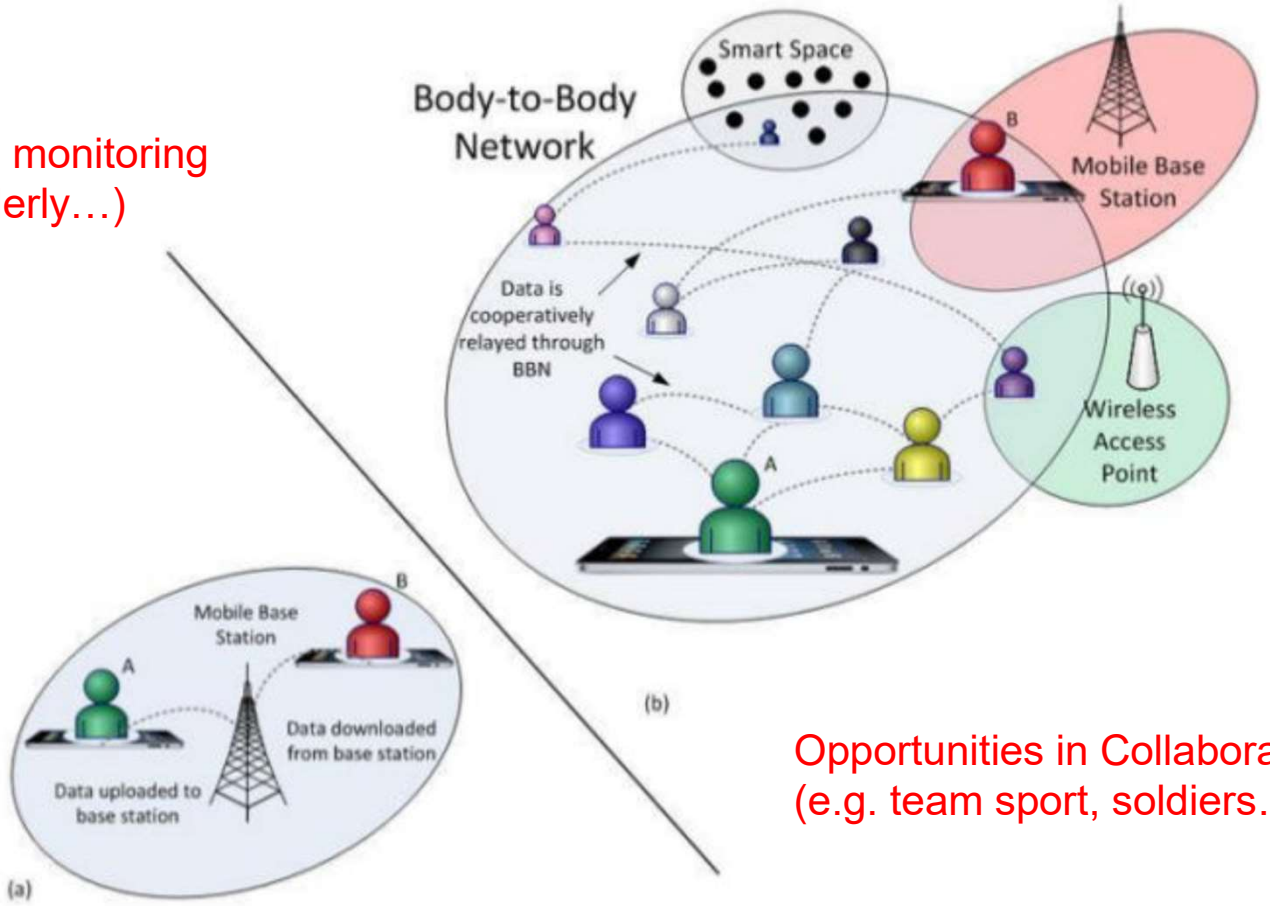
- Body Array Network of sensors : BAN
- Wireless Body Array Network of sensors : WBAN

- The personal web access point :
  - The Smartphone…



LAN-Local Array Network

Opportunities in Remote monitoring
(e.g. isolated worker, elderly…)



Wireless BAN

Opportunities in Collaborative interactions
(e.g. team sport, soldiers…)

Agenda

- Contributions of continuous and ambulatory monitoring
- An opportunity to expand our knowledge
- Alerts and alarms
- Measurement sites on the human subject
- Technological opportunities
- Limitations of the technology
- Technological risks
- The human factor
- The Living Lab approach
- Feedback from experience
- Research directions

Contributions of continuous and ambulatory monitoring

Contribution of continuous and ambulatory monitoring

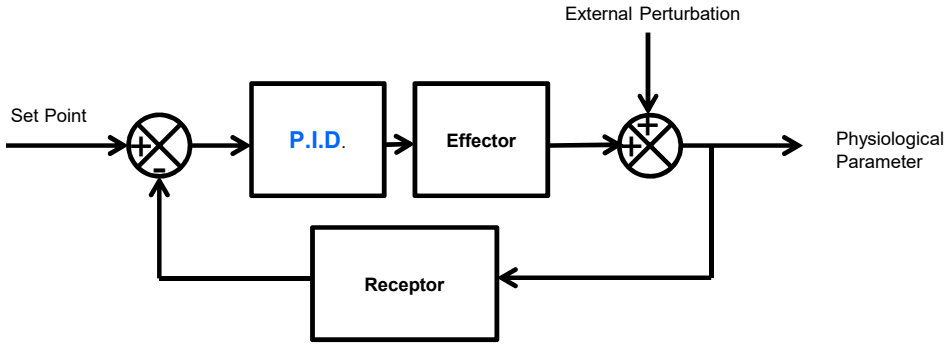
The human body: a complex automated machine

- The human body requires only one conscious action to function: Eating!

« All vital mechanisms, however varied they may be, always have a single aim: to maintain the unity of the conditions of life in the inner environment. » **Claude BERNARD** *Introduction à l'étude de la médecine expérimentale* (1865)

French Physiologist **Claude Bernard** (1813 –78)

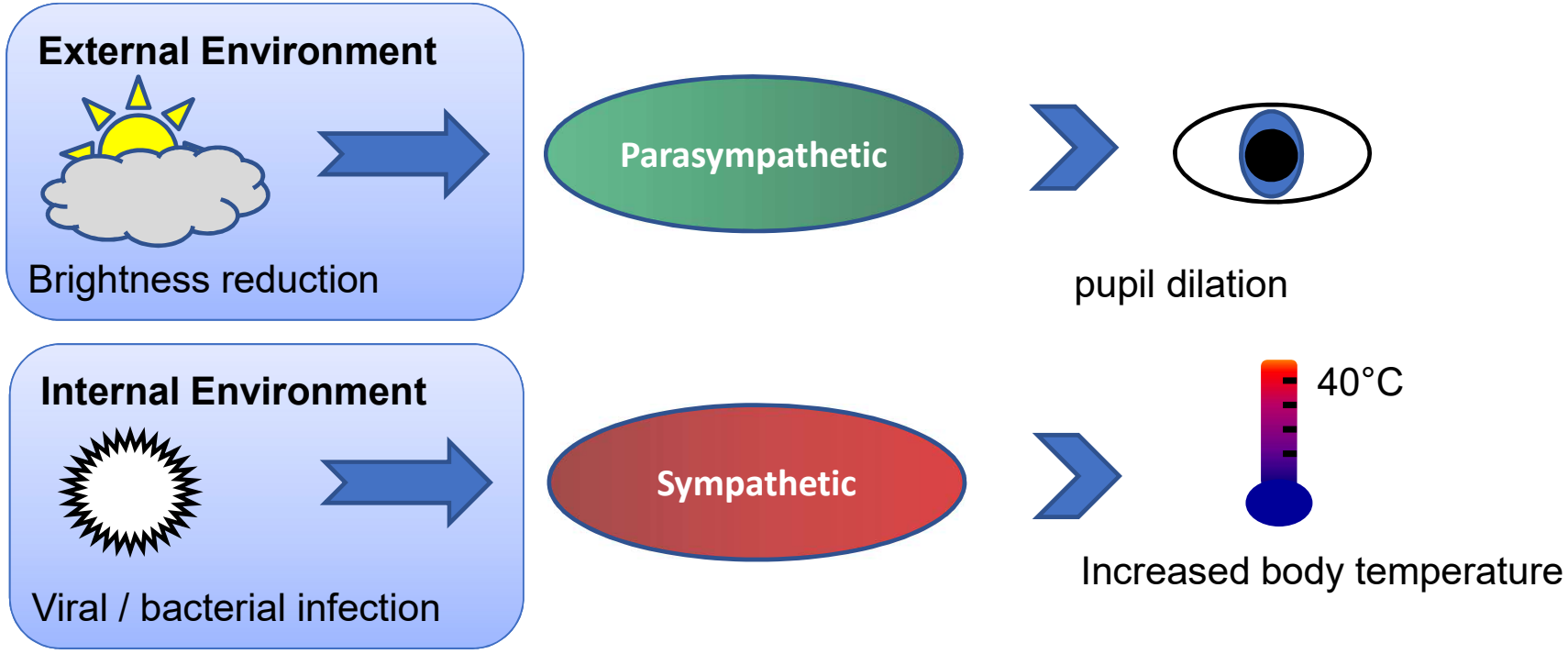
Homeostasis :
Maintaining the balance of the body's functioning despite internal or external variations in the environment



Good Health :
Free from disease or injury
→ a well functionning Homeostasis

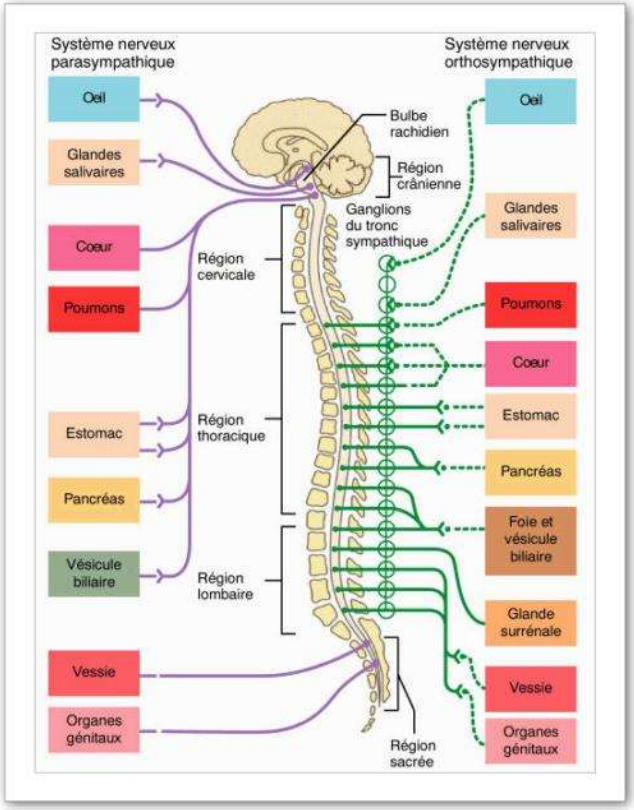
Contribution of continuous and ambulatory monitoring

- Any change in the internal and external environments causes activations of the sympathetic and parasympathetic systems



Contribution of continuous and ambulatory monitoring

- The autonomic (vegetative, automatic) nervous system ensures the unconscious regulation of body functions



- Cardiac Frequency
- Arterial Pressure
- Brain Temperature
- Pupil Dilation
- Digestion
- Sphincters Control
- Respiration
- Etc.

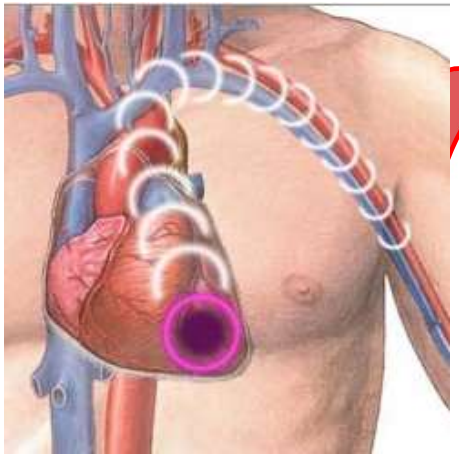
- A pathology leads to an imbalance of the internal environment
- compensated by an action of the ANS Re-balancing through homeostasis
- Is this action measurable?

Contribution of continuous and ambulatory monitoring

Consequences of increasing longevity :

- we are living longer ...with our chronic diseases (prevalence)
- Decline of main bio-physiological capacities
- Significant reduction of activities and social interactions

Cardiovascular pathologies



80% in +65 suffer Hypotension Orthostatic

Sensorial alterations

Motor response ↘
Vision Acuity ↘
Vestibulars deficiencies

Troubles in Activities

Reduction in autonomy

Contribution of continuous and ambulatory monitoring

ADL: Activities of Daily Living
IADL: Instrumented ADL

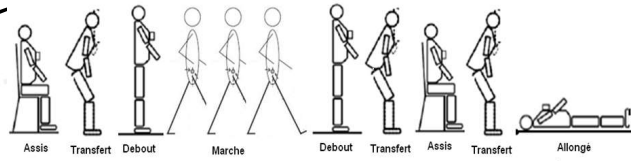
HOMEOSTASIS

Must be healthy

ACTIVITY

Must be Active

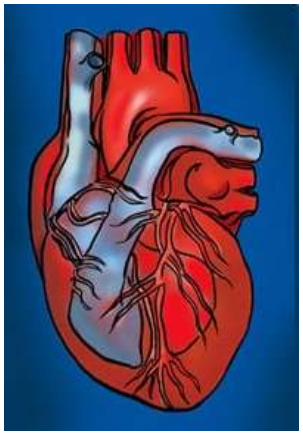
AUTONOMY



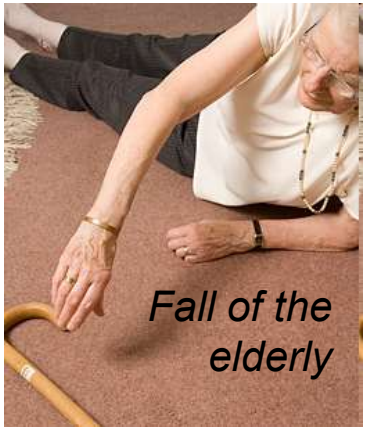
Contribution of continuous ambulatory monitoring

- Financial burden to the community
- Psychological costs : cancellation of our own projects
- Social costs : desintegrate intergenerational relationships
- **People wish to stay in their own socio environment**

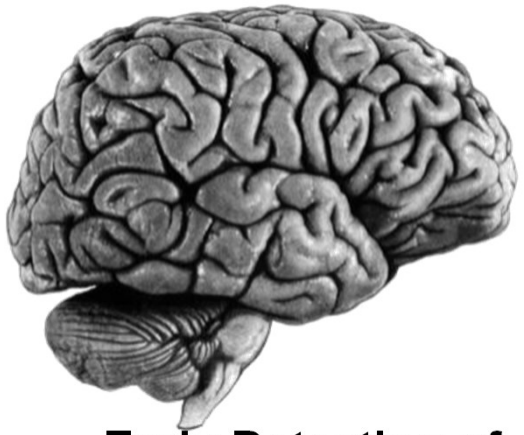
Elderly living independently in their own home are facing RISKS



Heart Attack



Prevent Risk situations



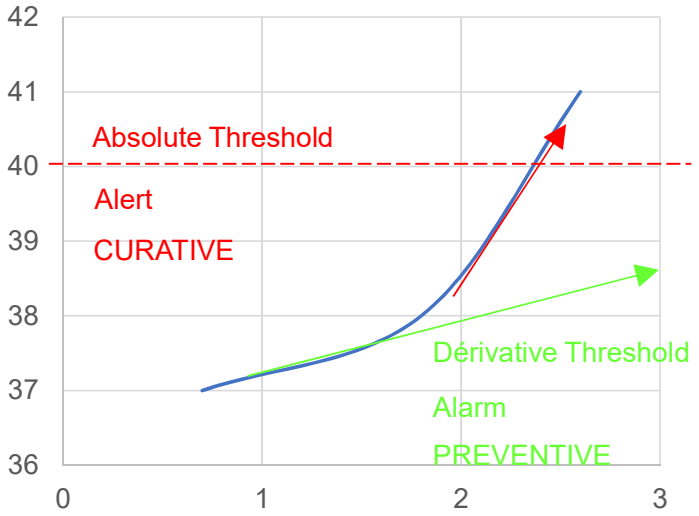
Early Detection of the loss in autonomy

Information directly within the environment → pervasive perception

Alerts et Alarms

Alerts versus Alarms

- Alerts:
  - Exceeding a threshold: physiological parameter, activity level...
  - Absolute value threshold
  - Real time temporality
  - Immediate intervention→ Curative

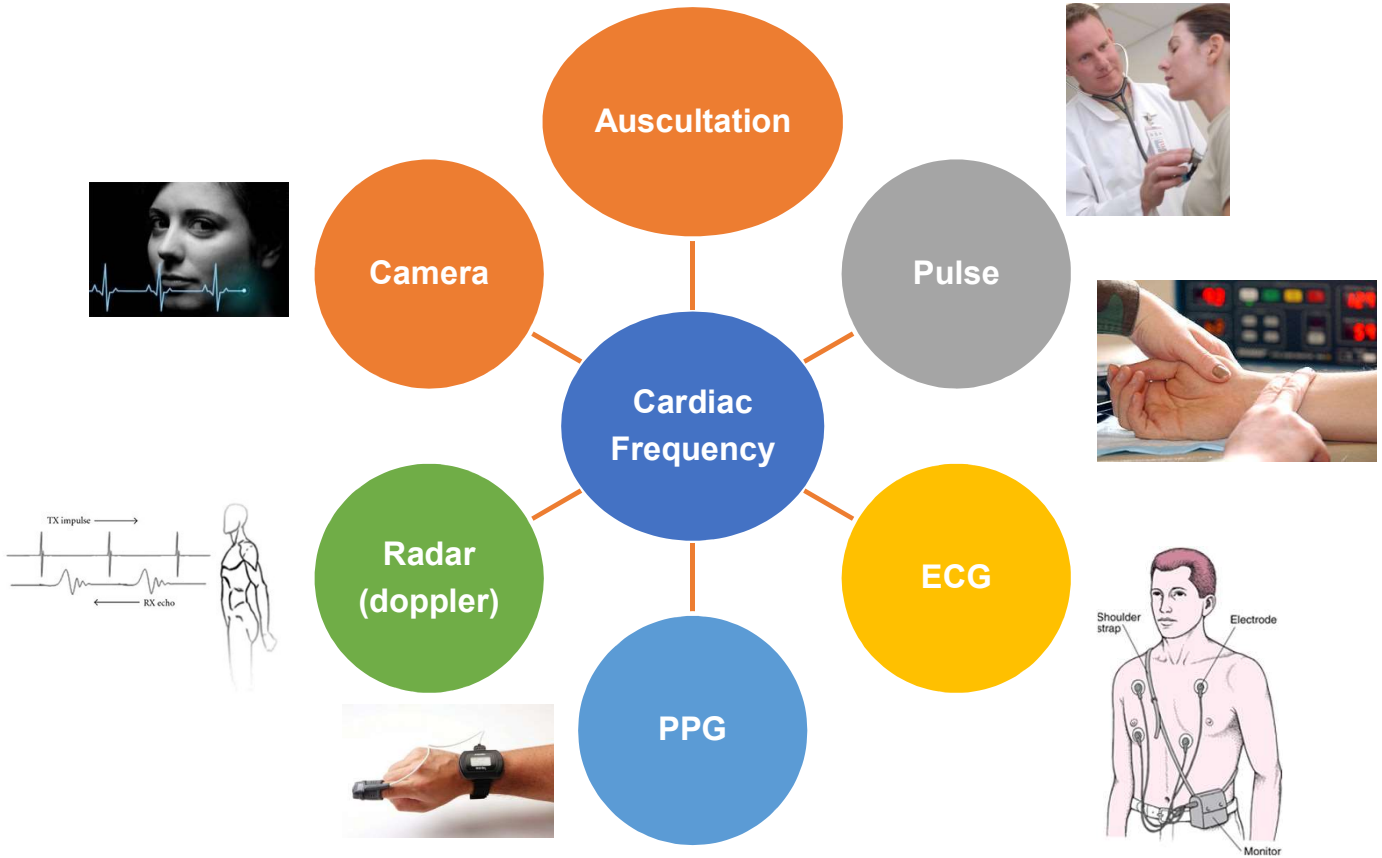


- Alarms:
  - Malignant trend established over a long period: weight loss, lifestyle changes, etc.
  - Threshold on derivative
  - Not real time Temporality
  - not immediate Implementation of appropriate corrective measures → Preventive

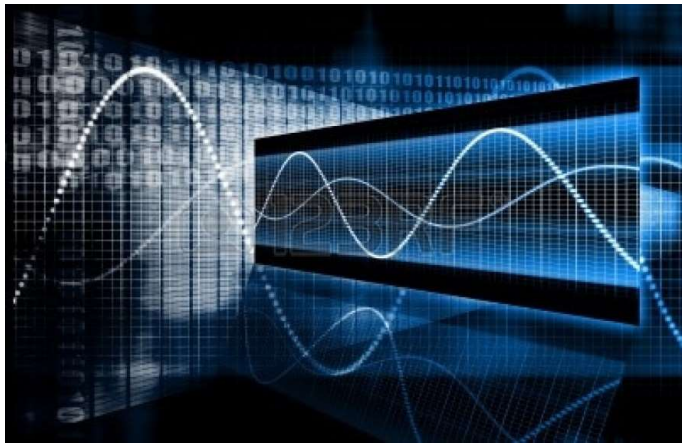
An opportunity to expand our knowledge

An opportunity to expand our knowledge

- An example of a physiological function that can be measured by various bio-signals: the heart rate



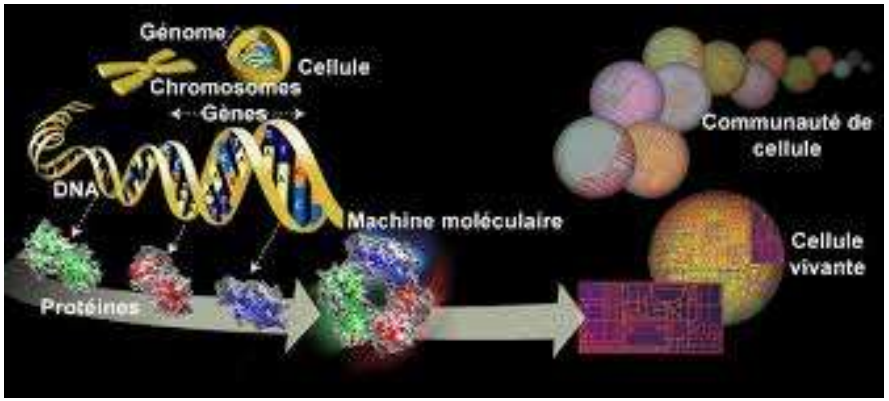
An opportunity to expand our knowledge



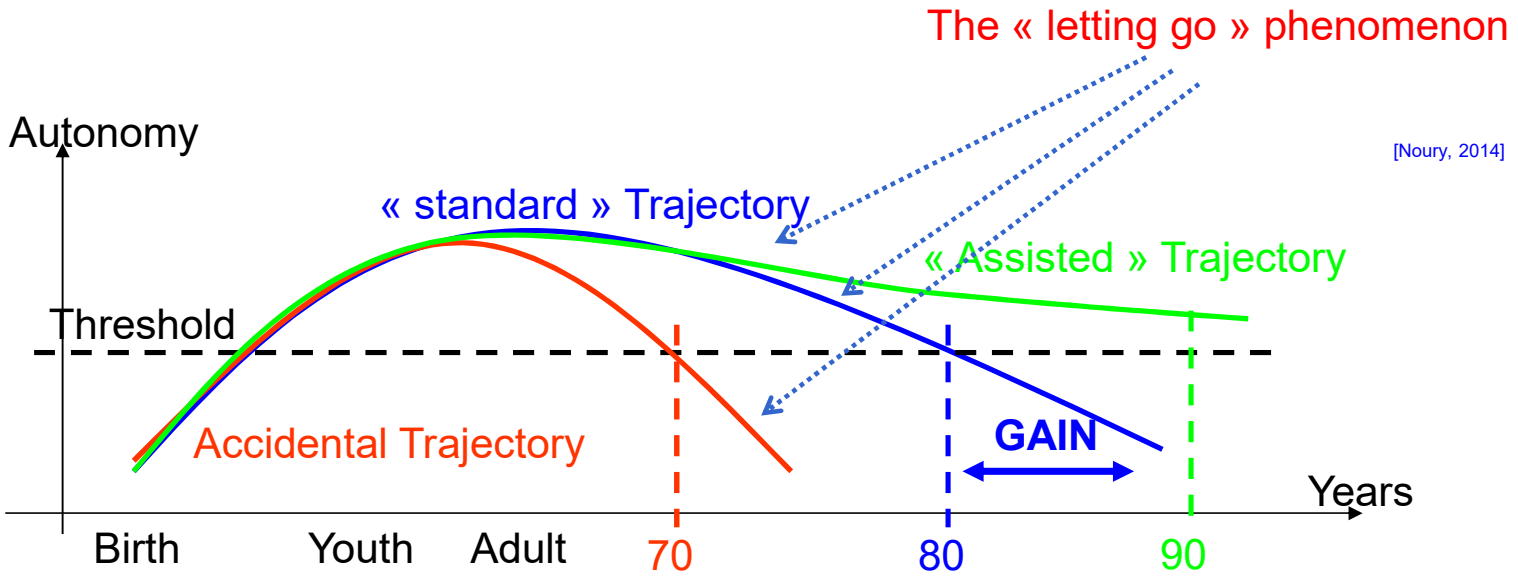
Potential for new discoveries on human physiology with the possibility to explore huge longitudinal databases collected inside the home environment on large cohorts

? Can you imagine

- *10 years recording of physiological signals*
- *63 millions humans*
- *Data Mining on large Data Bases*
- *AI , Deep Learning, …*



An opportunity to expand our knowledge



→ Prevention and early detection of functional decline through monitoring of physiology and activity ?

Measurement sites on the human subject

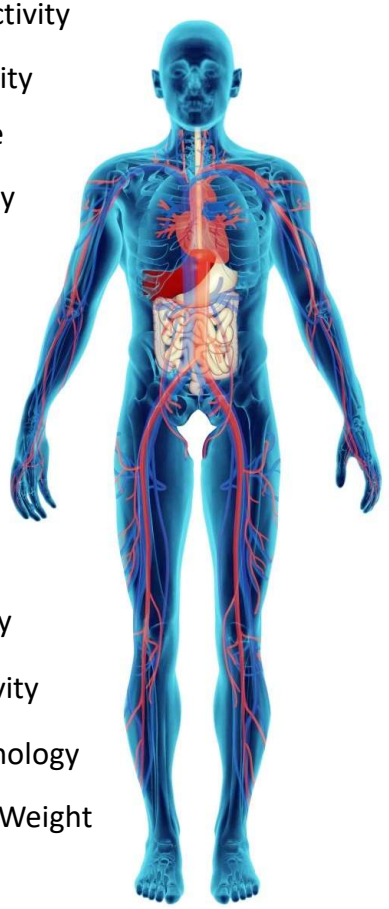
Sites de mesure sur le sujet humain

- What can be measured and where ?

The skin is a surface that covers the entire body (1.5 – 2.3m²)

The skin is opposite the vital organs and peripheral physiological functions

Privileged operating surface



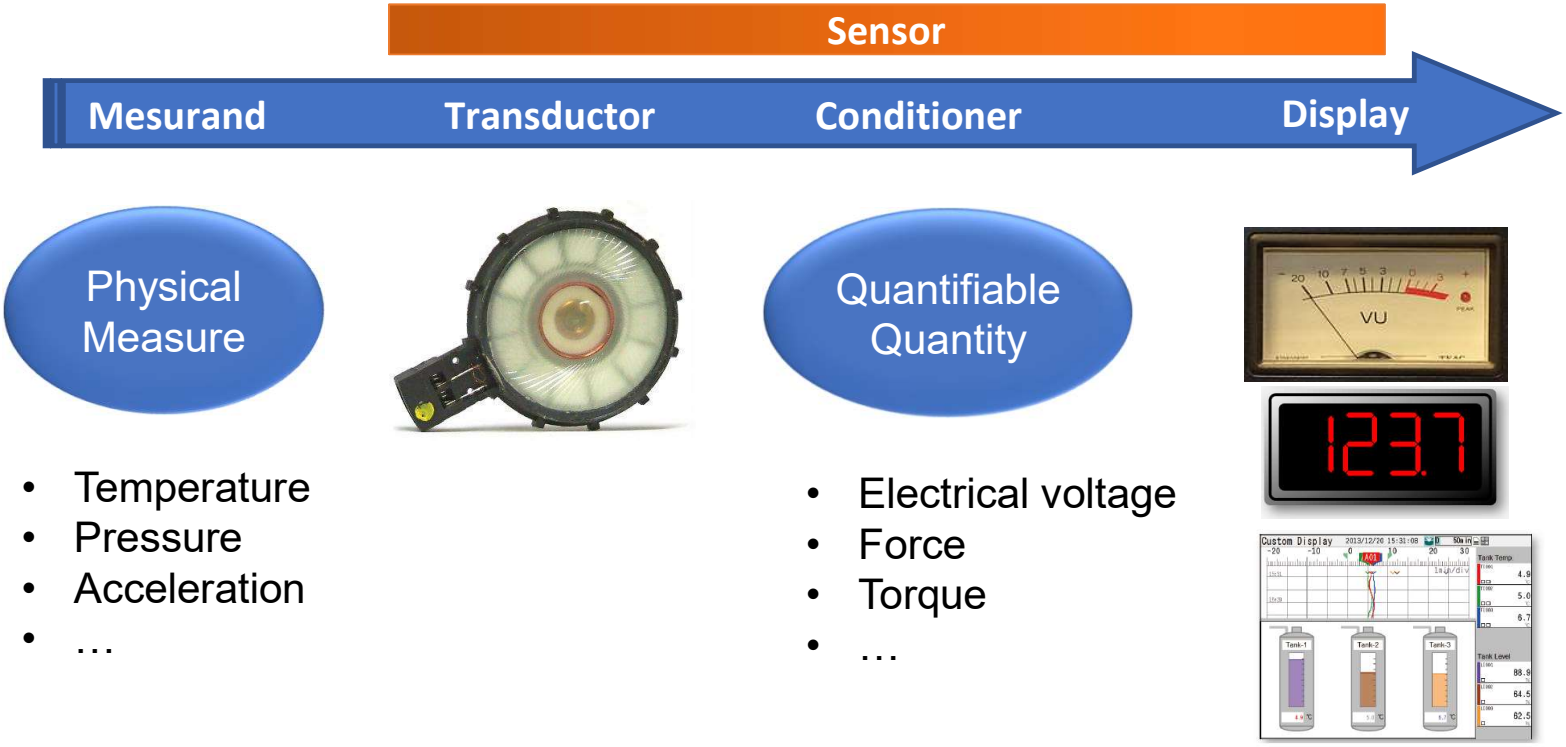
Brain Activity	EEG
Eye Activity	
Emotional response	EOG
Respiratory frequency	
Cardiac Frequency	ECG
Muscle sounds	PPG
Blood flow	Impedance
Moisturizing and coloring the skin	
Body temperature	Thermometry
Electrodermal activity	
Muscular activity	Kinematics
Morphology	EMG
Weight	

Technological opportunities

Technological opportunities

- Transduction and sensors: what to measure with?

The 5 senses of the Physician do not provide numerical values!
The measurement must be quantified...

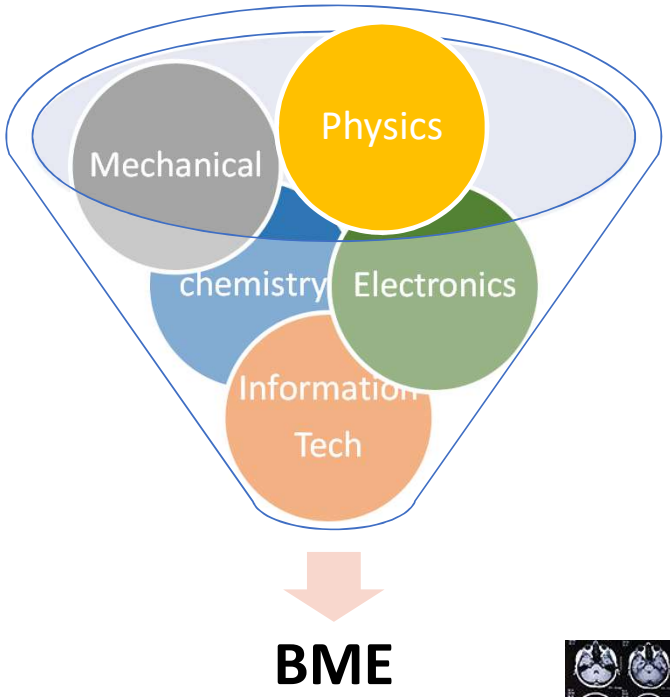


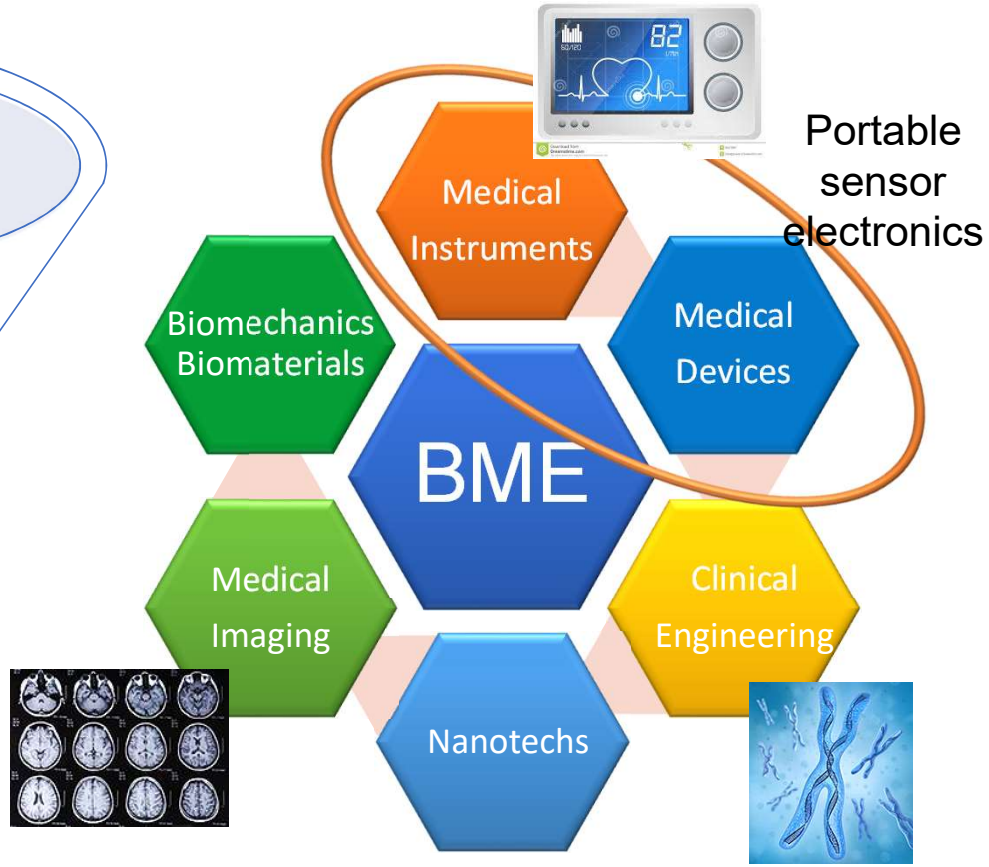
- Temperature
- Pressure
- Acceleration
- …

- Electrical voltage
- Force
- Torque
- …

Technological opportunities

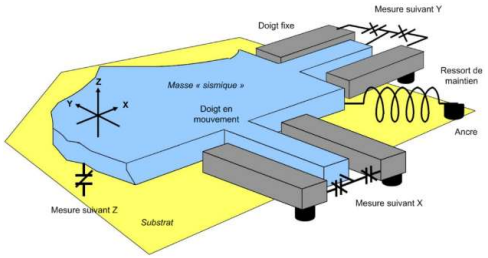
- Bio-Medical Engineering: developing diagnostic and therapeutic tools for human health
- A technological and industrial approach at the crossroads of many scientific sectors

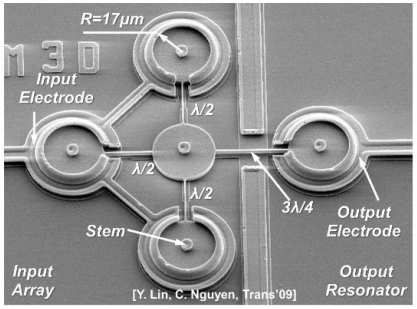




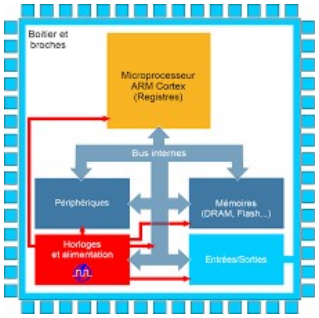
Technological opportunities

- From MEMS to NEMS : Microsensors → Nanosensors?
  - Size
  - Power Consumption
  - Costs





- Microcontrollers:
  - µP + analog peripherals + time management)
  - µ-DSP (specializing in signal processing)
  - High-density integrated memories
  - On-board signal processing



- Information and Communication Technologies
  - The global network INTERNET
  - Democratization of wireless communications
  - Connected objects: Internet of Things

Communications technologies opportunities

- On-body sensor network: BAN
- Wireless body sensor network: WBAN

- What's in it for me?
  - Each sensor provides a piece of information
  - Information fusion
  - Real-time remote monitoring

- The personal access point to the web: The smartphone...

Technological opportunities

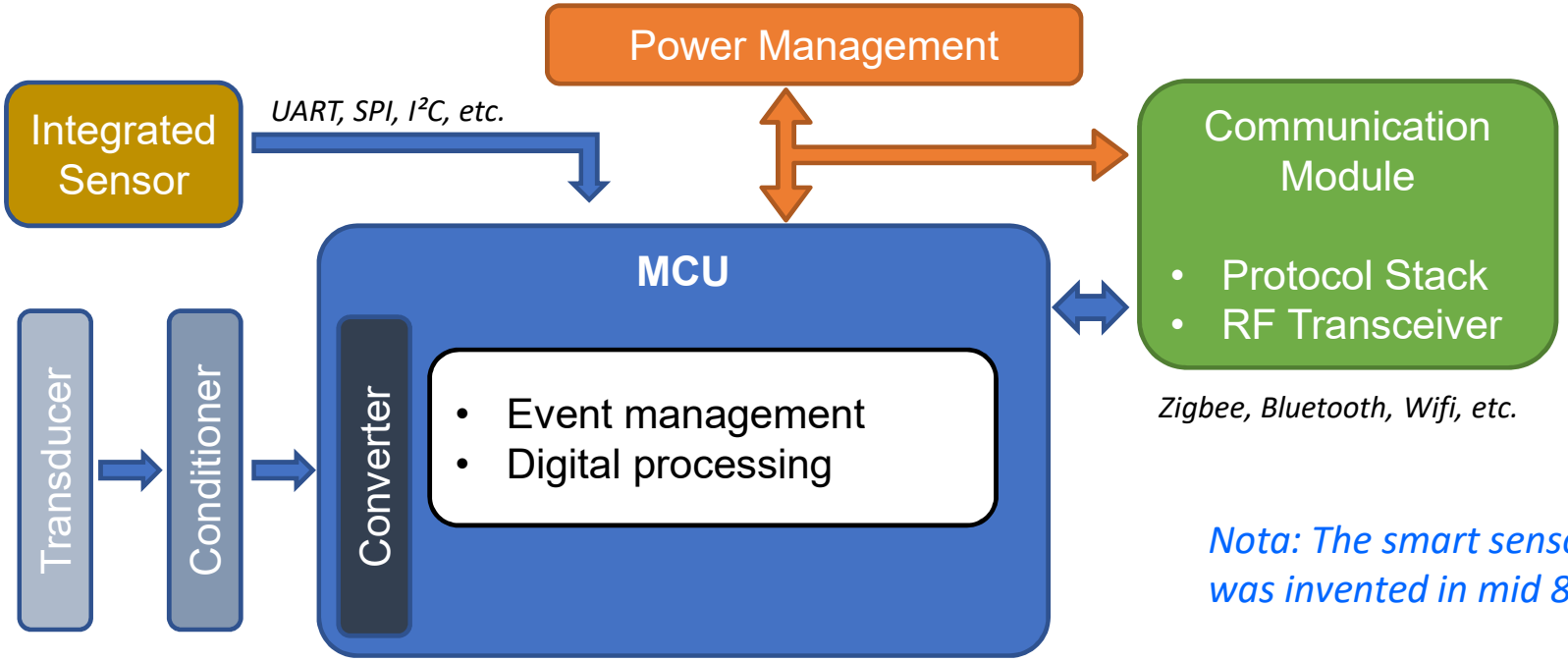
Smartphone is a Gateway of WBAN

- fully interoperable connectivity for WBAN
  - Access connection to wide area network (distant servers) even when “on the move”
  - WiFi and BT 2.1 did not suit WBAN
  - BT 4 presents advantages for long-term scenarios

- Enables mobile biofeedback for user
  - Easy development of various monitoring and training applications using WBAN indicators
  - Provides framework for fast-designable and fast-deployable application and their evaluation

Electronics for portable Biomedical Sensors

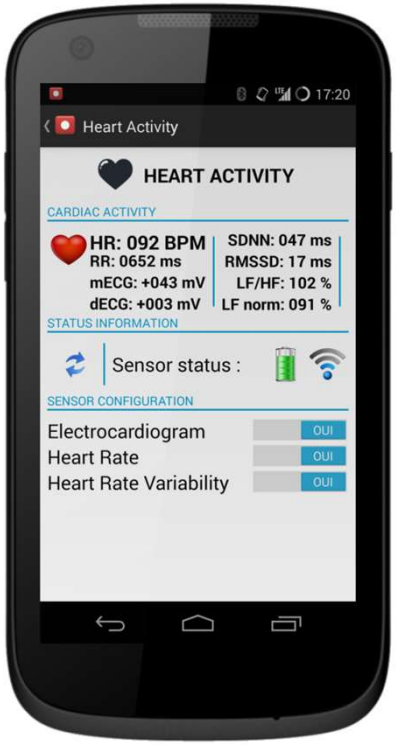
- Generic electronic architecture of a portable biomedical sensor :
  - Contains the electronics required for measurement conditioning and transmission
  - Information production
  - Built-in tests
  - Usually no built-in display



Nota: The smart sensor concept was invented in mid 80s…

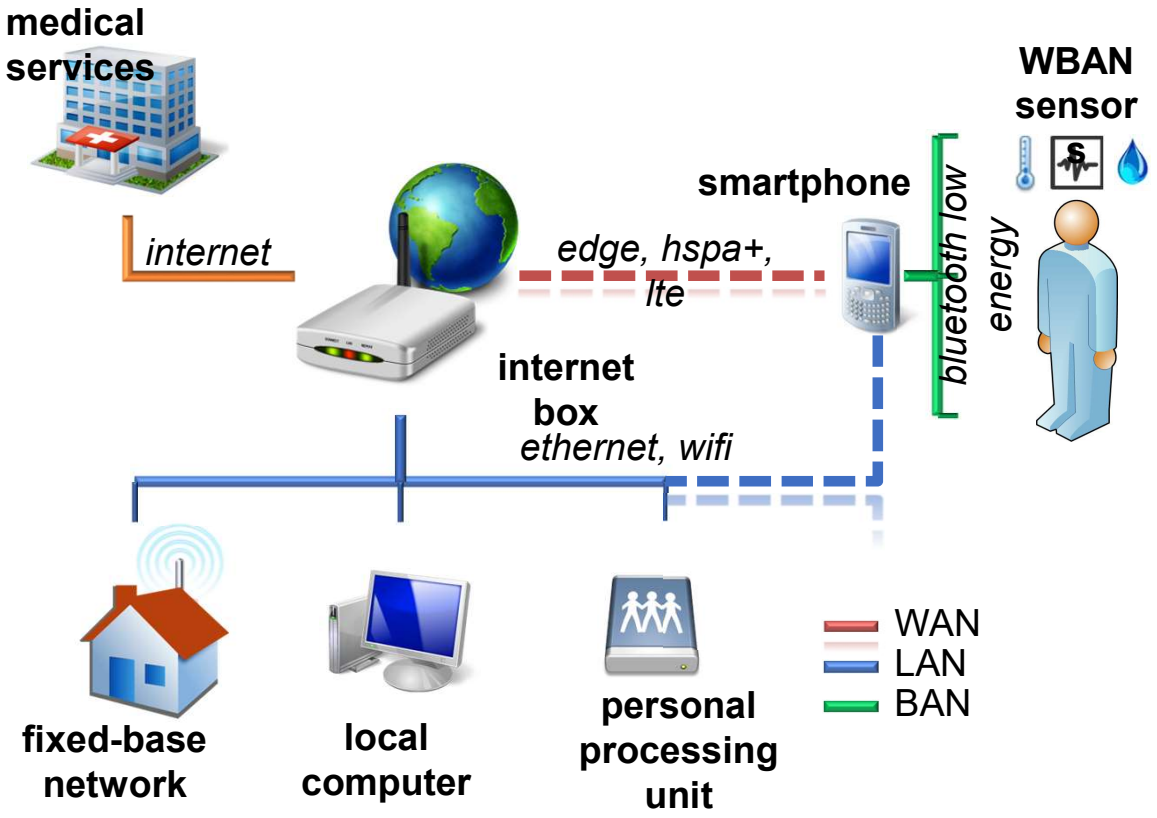
Electronics for portable Biomedical Sensors

- Example : REC@MED Heart Activity



Technological opportunities

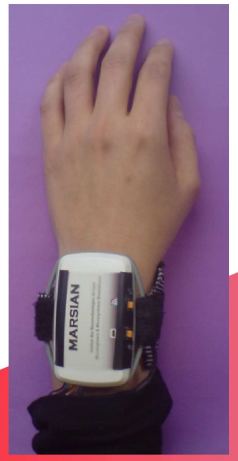
Integrating WBAN into long-term, continuous monitoring applications

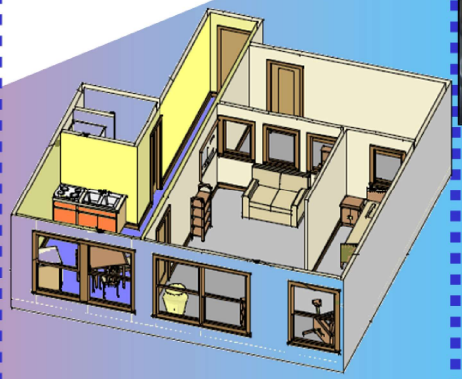


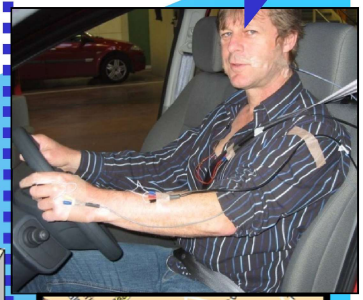
From smart sensors to smart homes

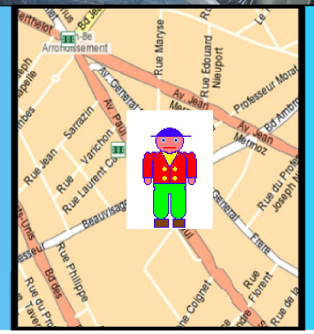
Non-invasive sensors

Exo sensors, actimetry, localization, identification









Sensor

Wrist device

Smart clothes

Smart home, Circadian rhythm

Ambulatory measurement

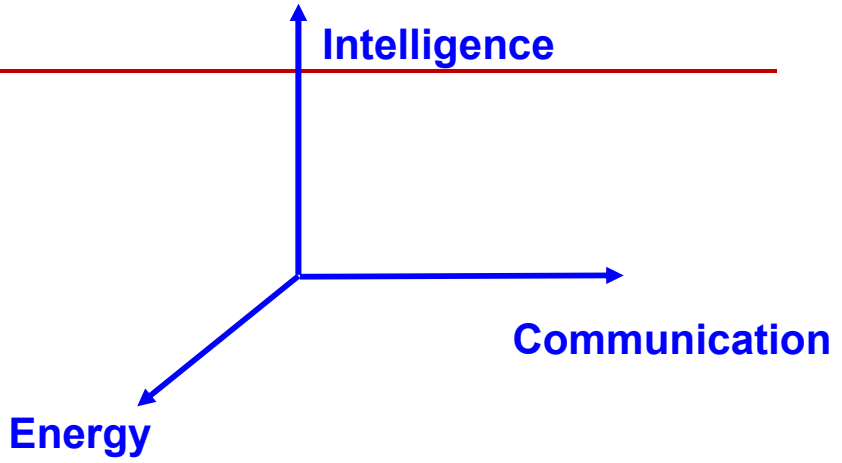
Limitations of the technology

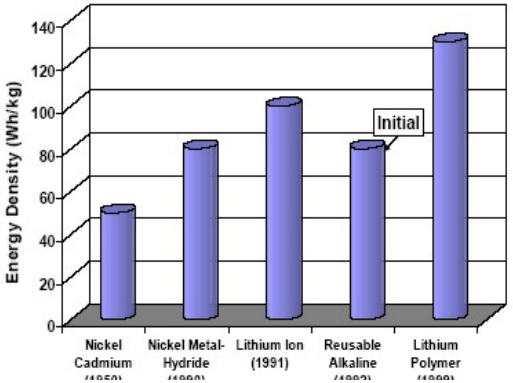
Technology limits

- Limited « Autonomy » :

- Limited on-board energy:
  - Batteries and cells
  - "Energy Harvesting”

  (Mech, Piezo, Thermal, hydrogen fuel cell, Rectena)
- Limited on-board resources:
  - computing capacity,
  - memory capacity
- Limited Communications:
  - limited bandwidth,
  - limited coverage (distance*power relationship)





Energy density of material	*KWH/kg*
Gasoline	14
Lead-Acid	0.04
Li polymer	0.15

Technology limitations

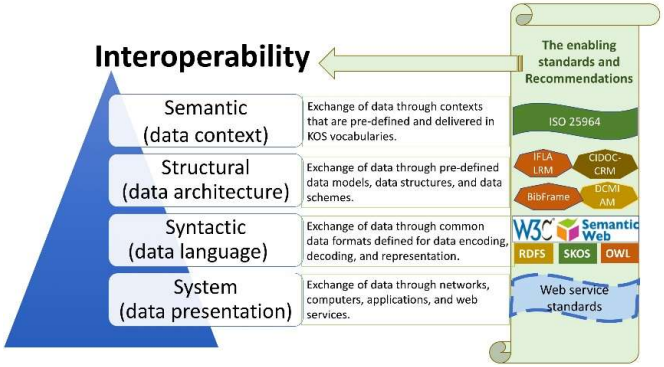
- Limited memory and calculation capacities.
  - Real-time" processing over limited time windows that "slip" with each new acquisition of a piece of information.
  - Algorithms must not use the "future" of the signal (not yet available !).
  - Calculations must be able to be performed, in a very short time, on small arithmetic units handling numbers coded on a reduced number of bits (8-16 bits).

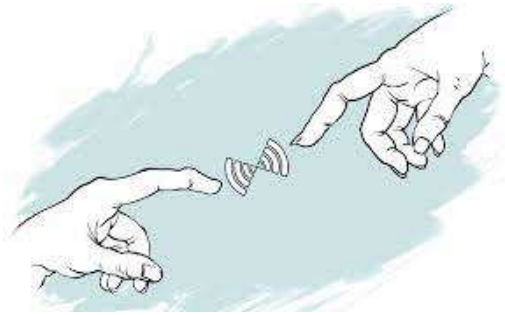
- For example, an ECG signal:
  - Bandwidth 250 Hz, sampled at 500 Hz (Shannon),
  - the µP has 2 ms to convert the samples into digital values and carry out the various filtering and extraction operations on the signal's characteristics.
  - For an 8-bit microcontroller, clocked at 4 MHz, this means that only 2,000 elementary operations are possible to carry out all the processing (including a large number of data manipulations).

Technological risks

Technological risks

- Preservation of data integrity (RGPD)
  - during transport,
  - during storage
- Data access protection (RGPD)
  - during transport,
  - during storage
- Non Interoperability
  - Communication
  - Data format
- Other technical risks
  - Technology dependency/addiction (what to do in case of dysfunction?)
  - Digital divide
  - Electromagnetic exposition



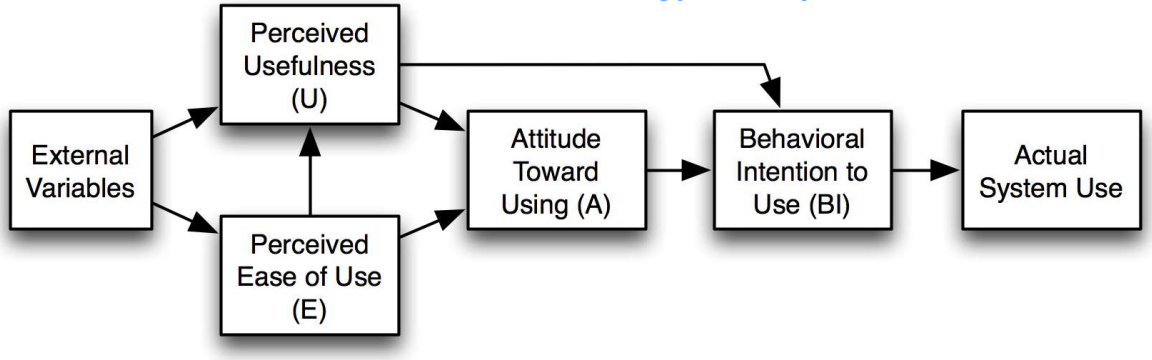


The human factor

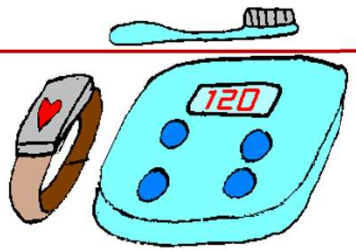
The Human factor

- Acceptance:
  - Affordance
  - Perception of utility
  - Perception of utilisability
  - Atitude toward using
  - Behavioral intension to use
- Drop out:
  - Long term Compliance
  - Perceived usefulness
  - ludic aspects (serious games)

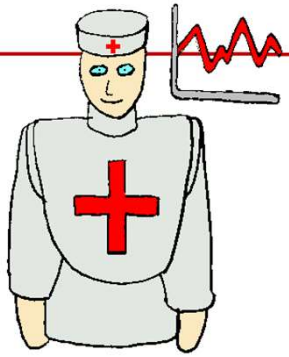
The Technology Acceptance Model



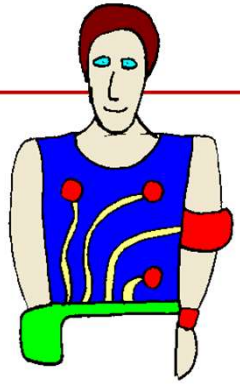
The Living Lab approach



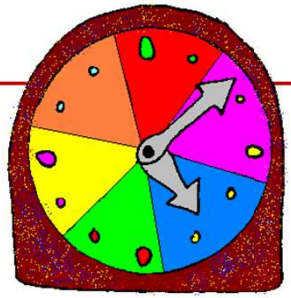
Home instrumentation



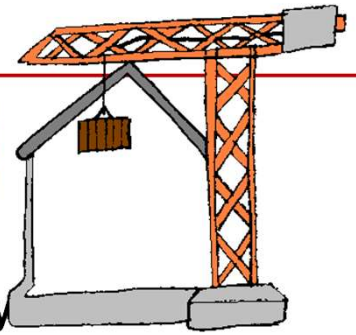
Social service
General Practitioner
Specialist



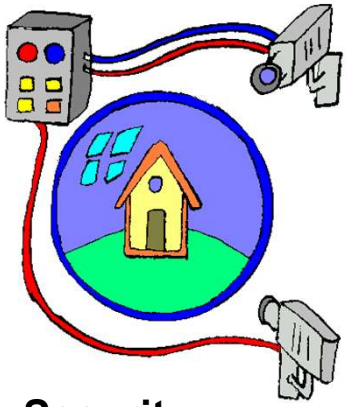
Biomedical
Research
Sensor, Actionneur
Micro instrument
Material,Textile,…



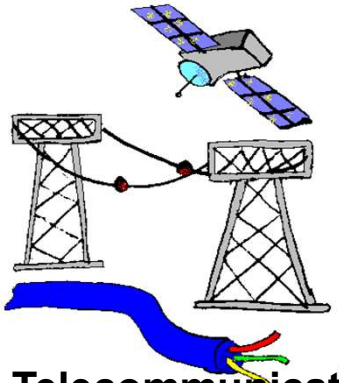
Chronobiology
Diagnosis
Therapy
Pharmacology
Micro pump



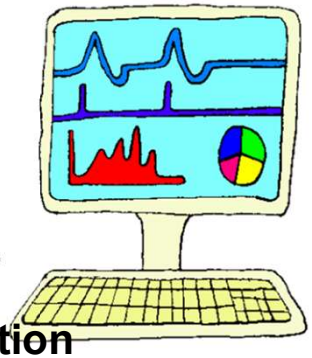
Architecture
Ergonomy
Design
Building



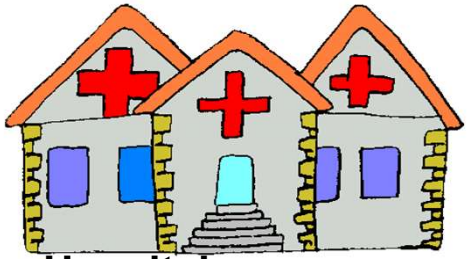
Security



Telecommunication
Specialist



Imagery



Hospital
Age Service
Specialist Services
Service Societies

Lobbies

Ethic

Legislation

Financing

Living Lab in a nutshell

- The 2 facets of a Living Lab :
  - A place for creativity: encouraging ideation with users, who are confronted with mock-ups.
  - A place for evaluating systems and services, with intensive means of gathering objective information.

Living Lab in a nutshell

"A Living LAB focuses on

experimentation and co-creation in real and virtual environments between users and researchers, companies and public institutions in order to define and develop together new public and community systems, new products, new services or new business models".

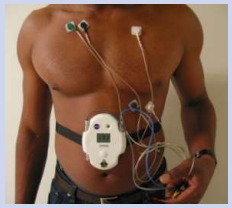
- **Encourage/Ease**
  - Design optimization
  - Innovation
  - Technology Transfer Effectiveness/Success
  - Proof of Concept
  - Education/Training
  - Advertising
  - Financing

- **Benefits for Users**
  - Researchers
  - Manufacturers
  - Political decision-makers
  - Students

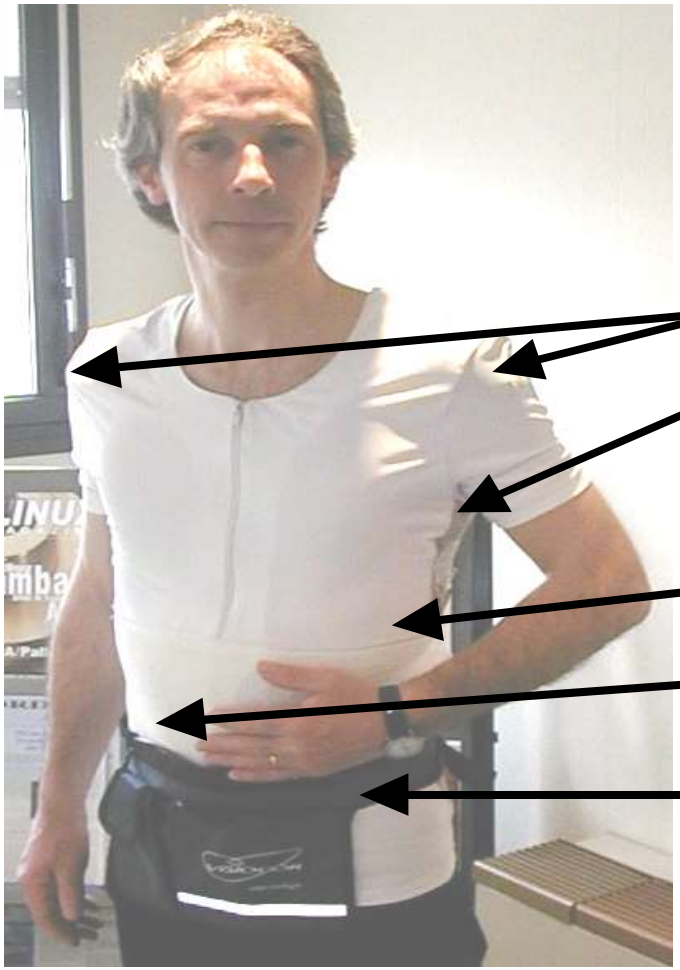
Feedback from experience

Technological developements for Health

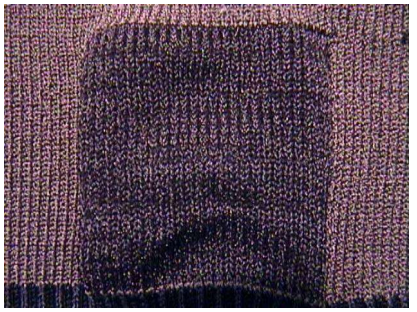
Short, medium and long term monitoring of cardiac parameters

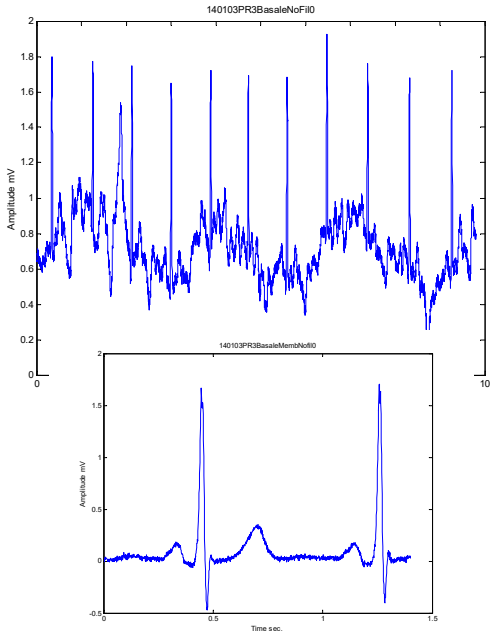
Court Terme	Moyen Terme	Long Terme
• Systèmes de type « Holter » modifiés • Quelques heures	• Systèmes de type « Patch » • Jusqu'à une semaine	• Systèmes de type vêtements intelligents • Plus d'une semaine
 	 	 
Cardionet ***Lifeguard***	***Netguard*** ***Intelesens***	***Cardionet*** ***Lifeguard***
✓ Qualité de la mesure ✓ Résolution numérique et temporelle élevée ✗ Confort et acceptabilité ✗ Peu adapté au long terme	✓ Qualité de la mesure ✓ Confort accru ✗ Irritabilité de la peau ✗ Requiert un design d'électrodes spécifique	✓ Confort et acceptabilité ✓ Monitoring continu et longue durée ✗ Robustesse du capteur ✗ Qualité de la mesure

Technological opportunities



Projet VTAMN





Activity Trackers

Smart Tracker

- Steps, calories, altitude and distance
- Phases of sleep
- Connectivity : WIFI, Bluetooth

Fit Bit

Bracelet Jawbone

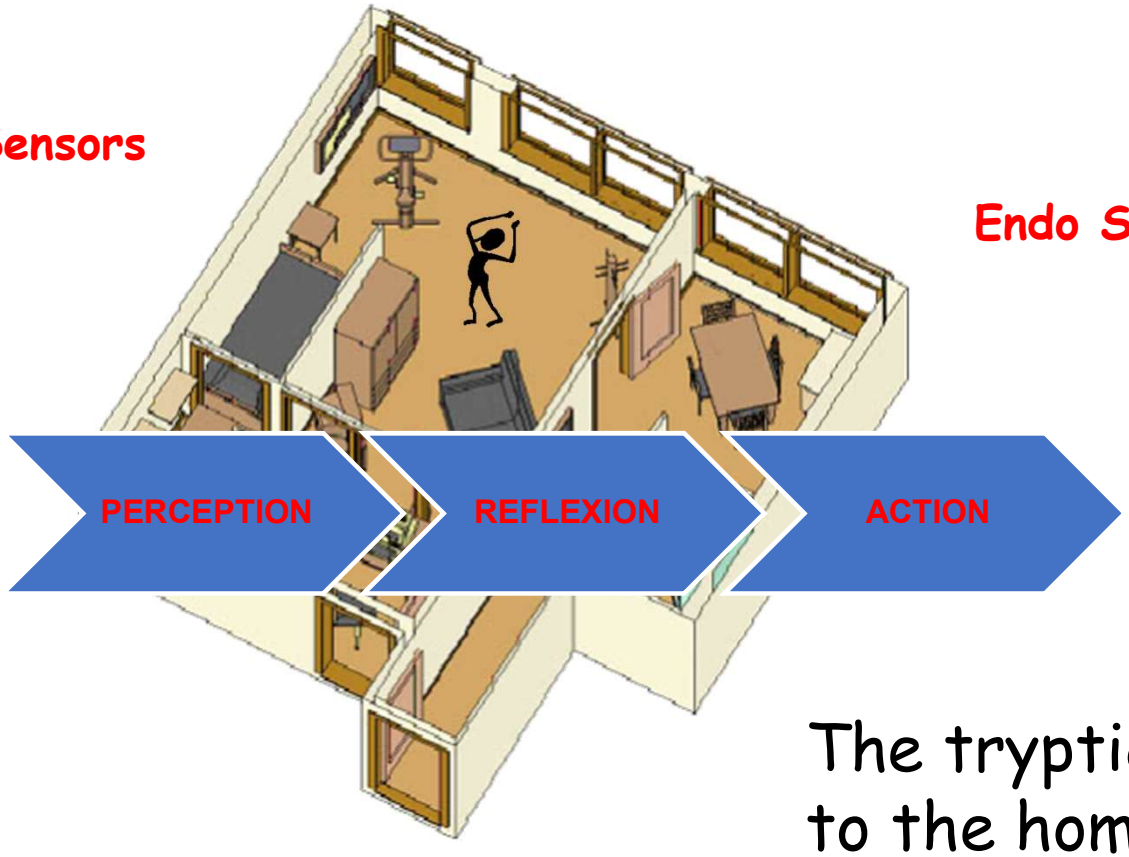
E4 WristBand

PPG (heart rate variability),
GSR (Emotions),
IR (skin temperature)

Technological developments

Health Domotics : distributed sensors in home

Exo Sensors



Endo Sensors

The tryptic of robotics is adapted to the home seen as an exo-squeleton

PERCEPTION with distributed sensors on local network (LAN)

Physiology

Tensiometer

Weight scale

Oxymeter

Smart Textiles

Presence sensors

Activity

Context

Ambient Sensors

Microphones

*1998

REFLEXION with distributed intelligence on the (W)LAN network

Physiology

Tensiometer

Weight scale

Oxymeter

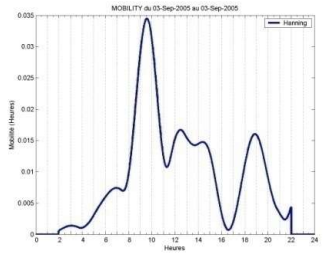
Smart Textiles

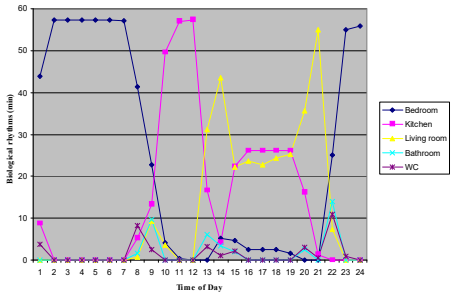
Presence sensors

Activity

Context

Ambient Sensors





Microphones

REACTION with distributed actuators on the LAN network

Physiology

Tensiometer

Weight scale

Oxymeter

Smart Textiles

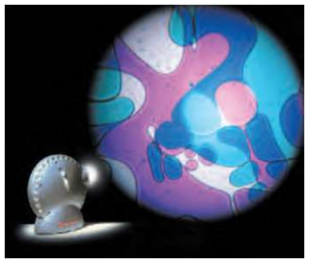
Presence sensors

Activity

Context

Ambient Sensors: Temp, Hygro, Noise, light level

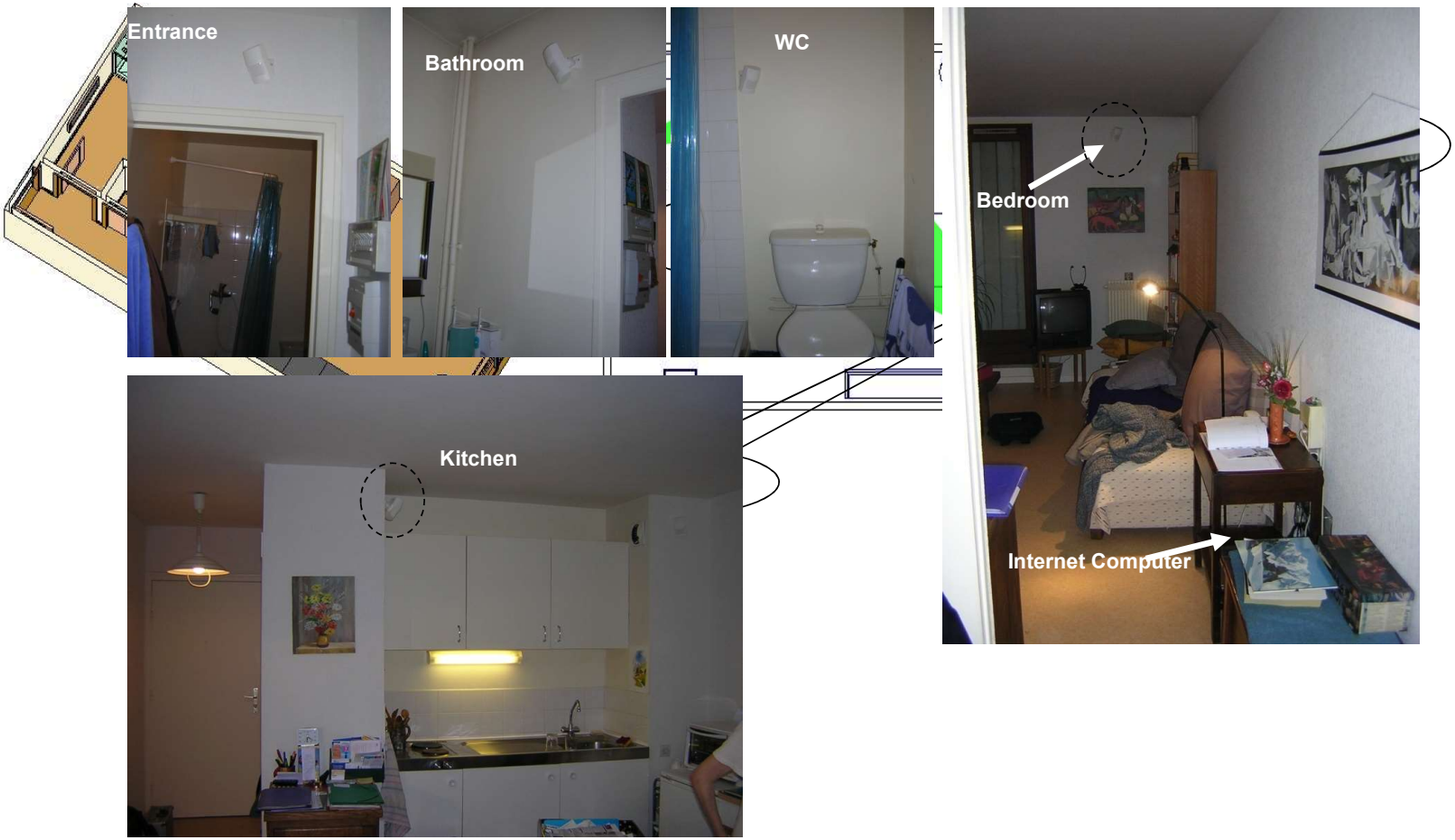
Connected appliances



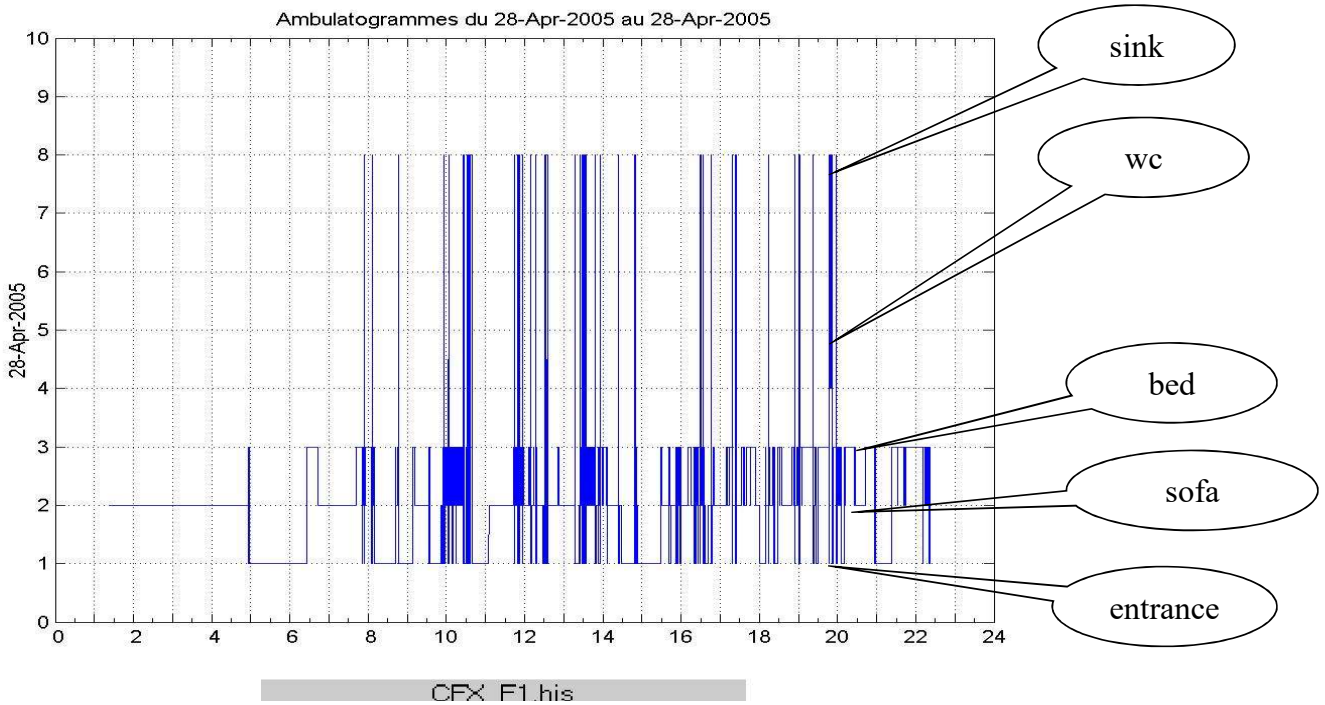
SNOEZELEN (Snuffelen + Doezelen)
light therapy, music therapy, aromatherapy

Microphones

Experimental Platforms of project AILISA



Daily « Ambulatogram »



Ambulatogram : a direct view of daily activity.

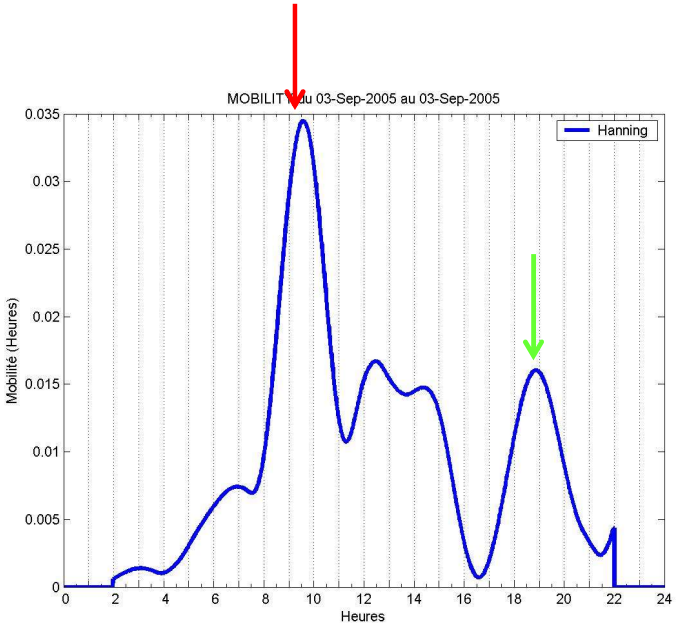
Horizontal : time of day (0 à 24h)

Vertical : area (1-Entrance / 2-Living room / 3-bed / 4-wc / 8-sink)

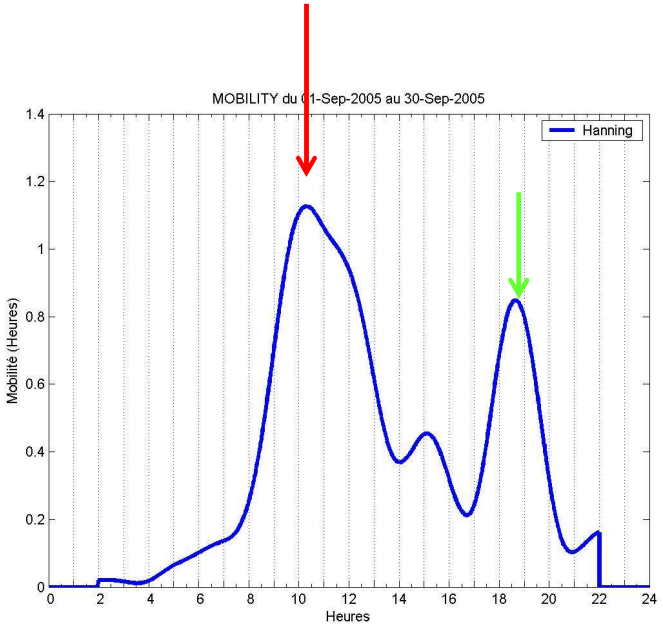
[Le Bellego and Noury,**2006**]

Profile of “Motility”…

Density of transitions between rooms along the day



Daily Mobility



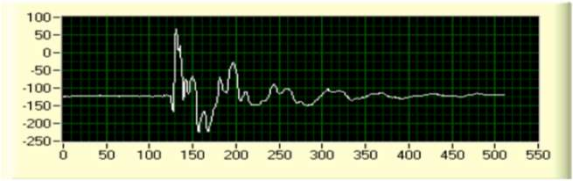
Monthly Mobility

M@PA : human electrical activity

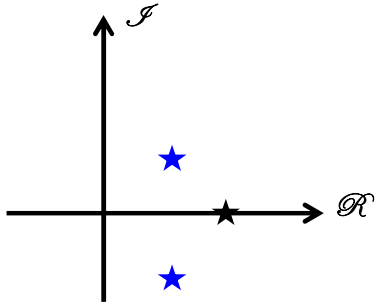
- A single system placed in the electrical cabinet detects on/off of some selected electrical devices

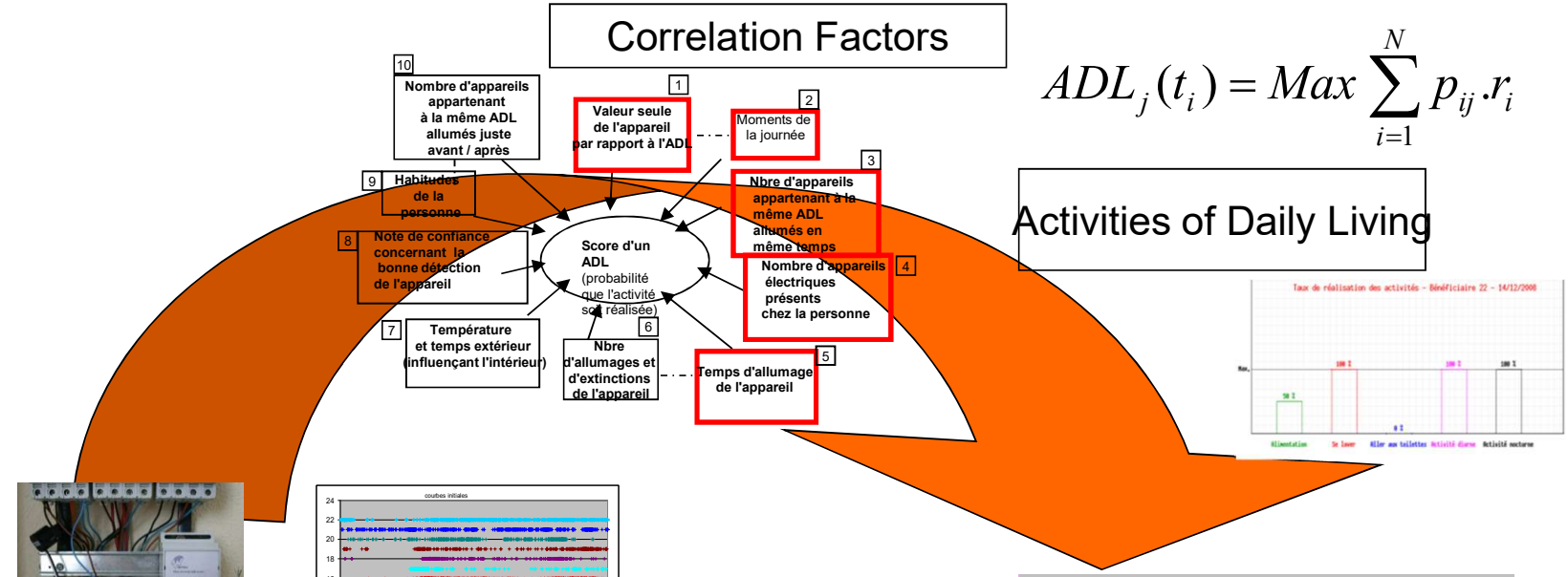
(Active/Reactive Power & signal generated when switched On/Off)

- → Each electrical device is turned into a sensor



Signature of an Electrical Device





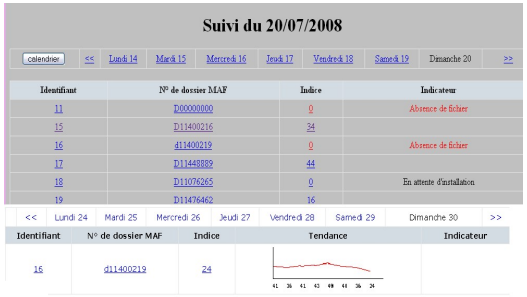
$$ADL_j(t_i) = Max \sum_{i=1}^{N} p_{ij}.r_i$$

Activities of Daily Living

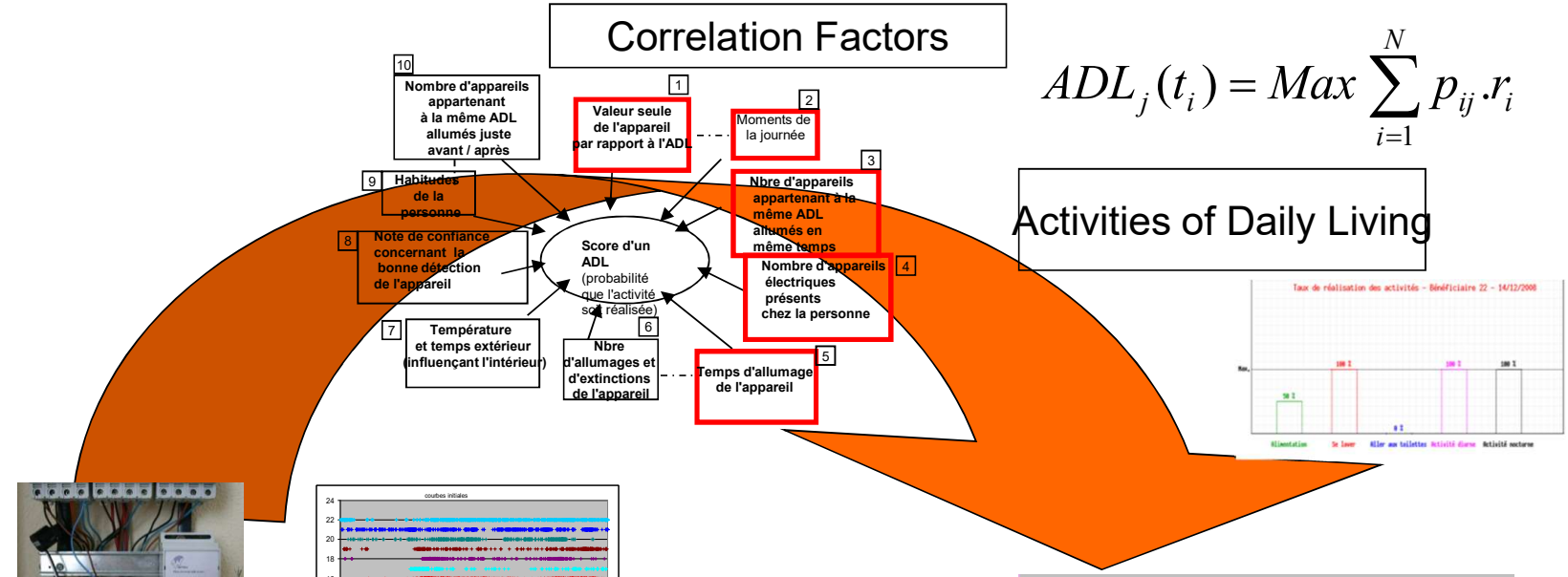
1 Unique sensor

Data Records

Electrical Signatures



$$Ind = REF - ADL_{(day)}$$



$$ADL_j(t_i) = Max \sum_{i=1}^{N} p_{ij}.r_i$$

Activities of Daily Living

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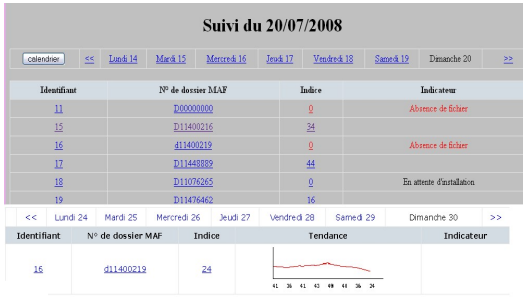
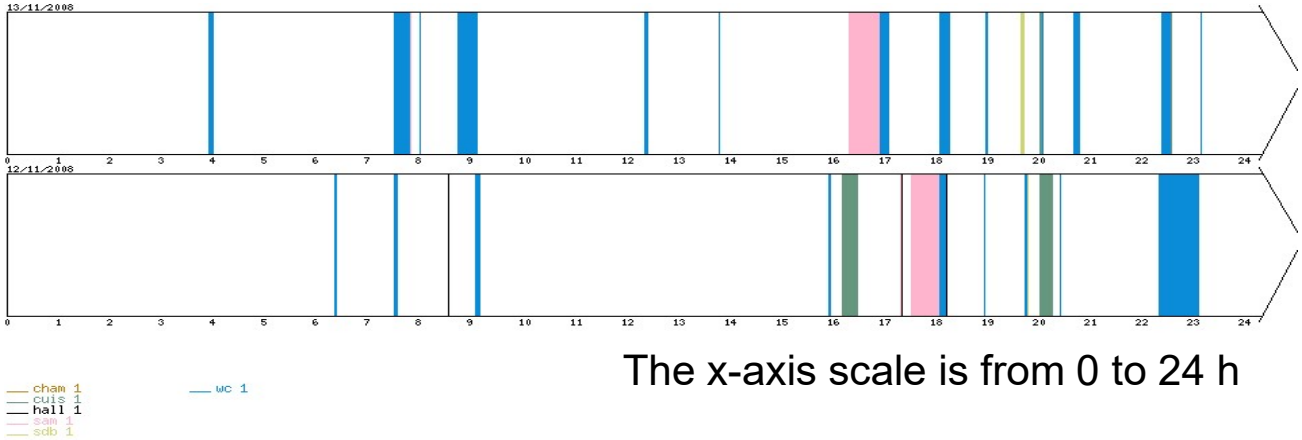
Data Records

Electrical Signatures



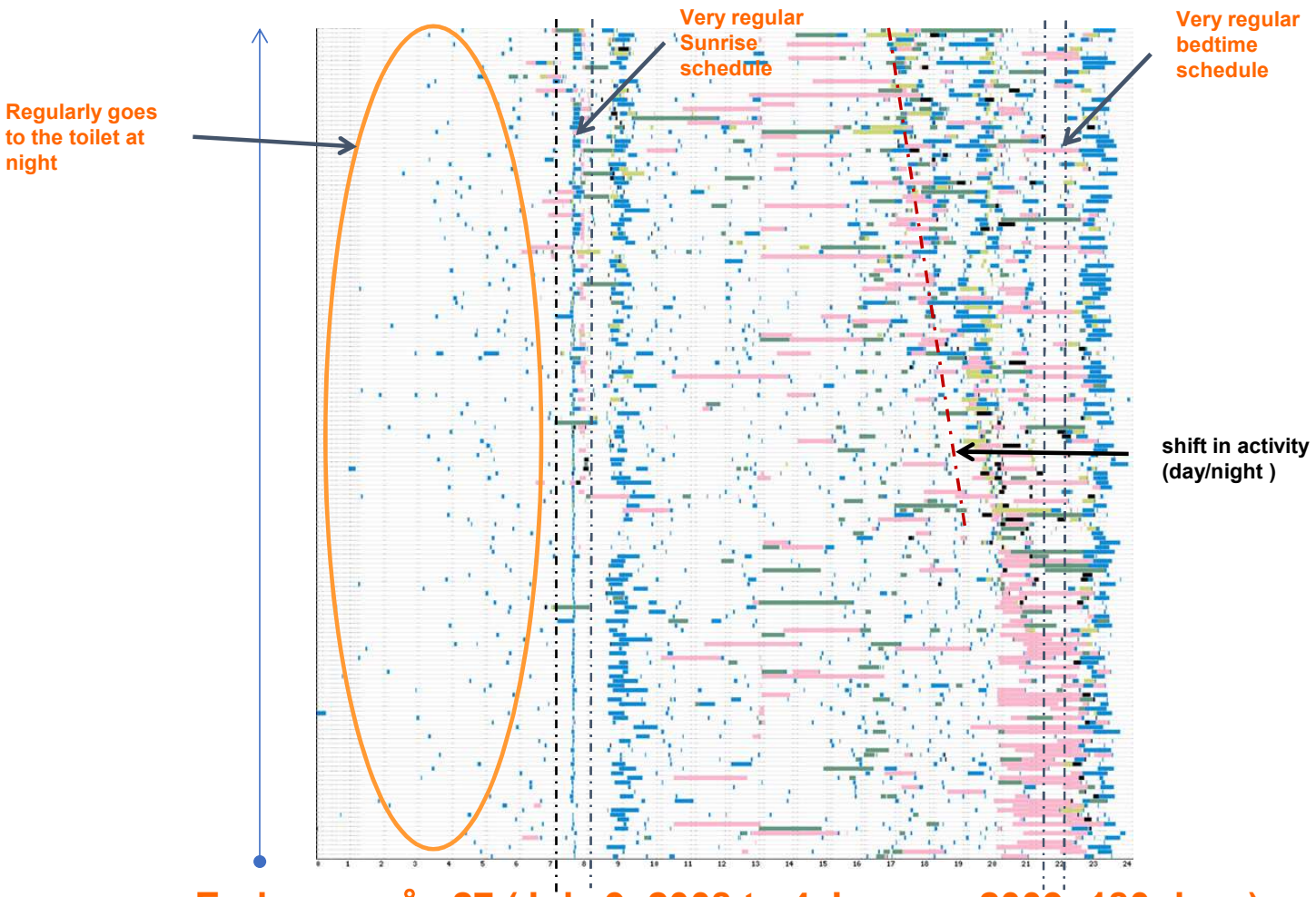
$$Ind = REF - ADL_{(day)}$$

Temporal analysis allows a fine analysis of what happened at home

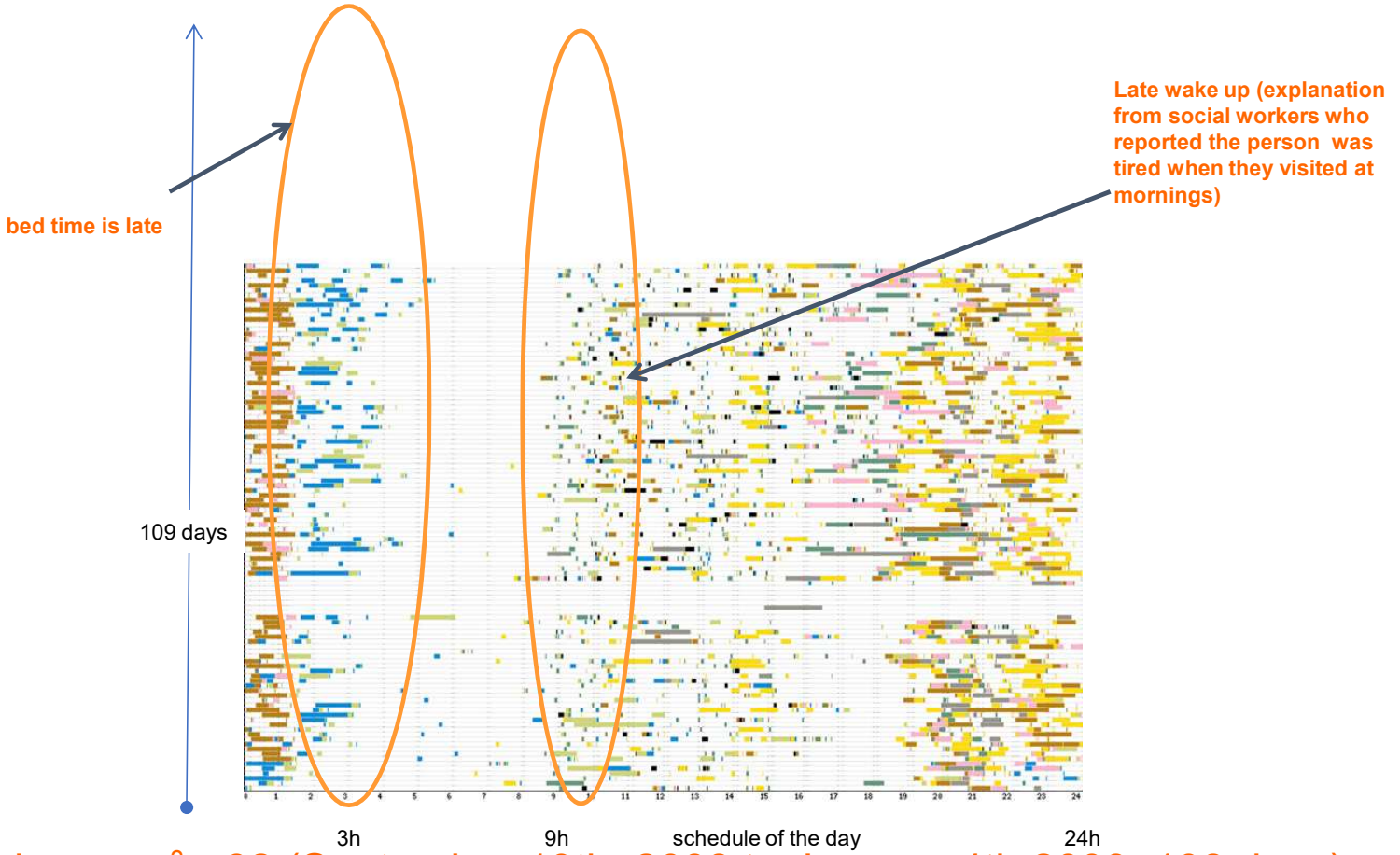


The x-axis scale is from 0 to 24 h

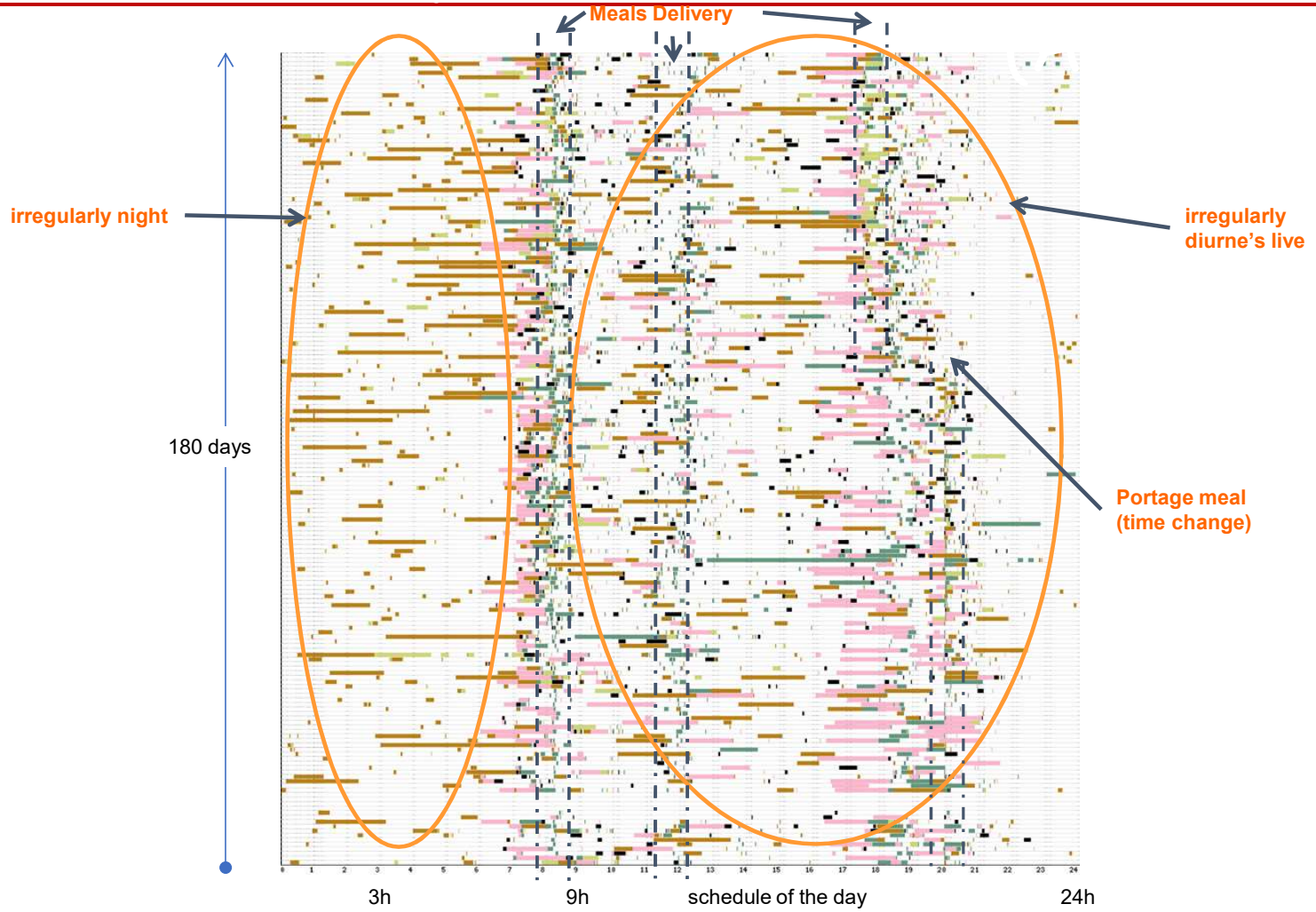
- The chart of the occupation represents the place supposed to be occupied by the beneficiary (between electrical ignition and extinction – ON/OFF- in the same room).
- A color for each room (the same for all recipients).



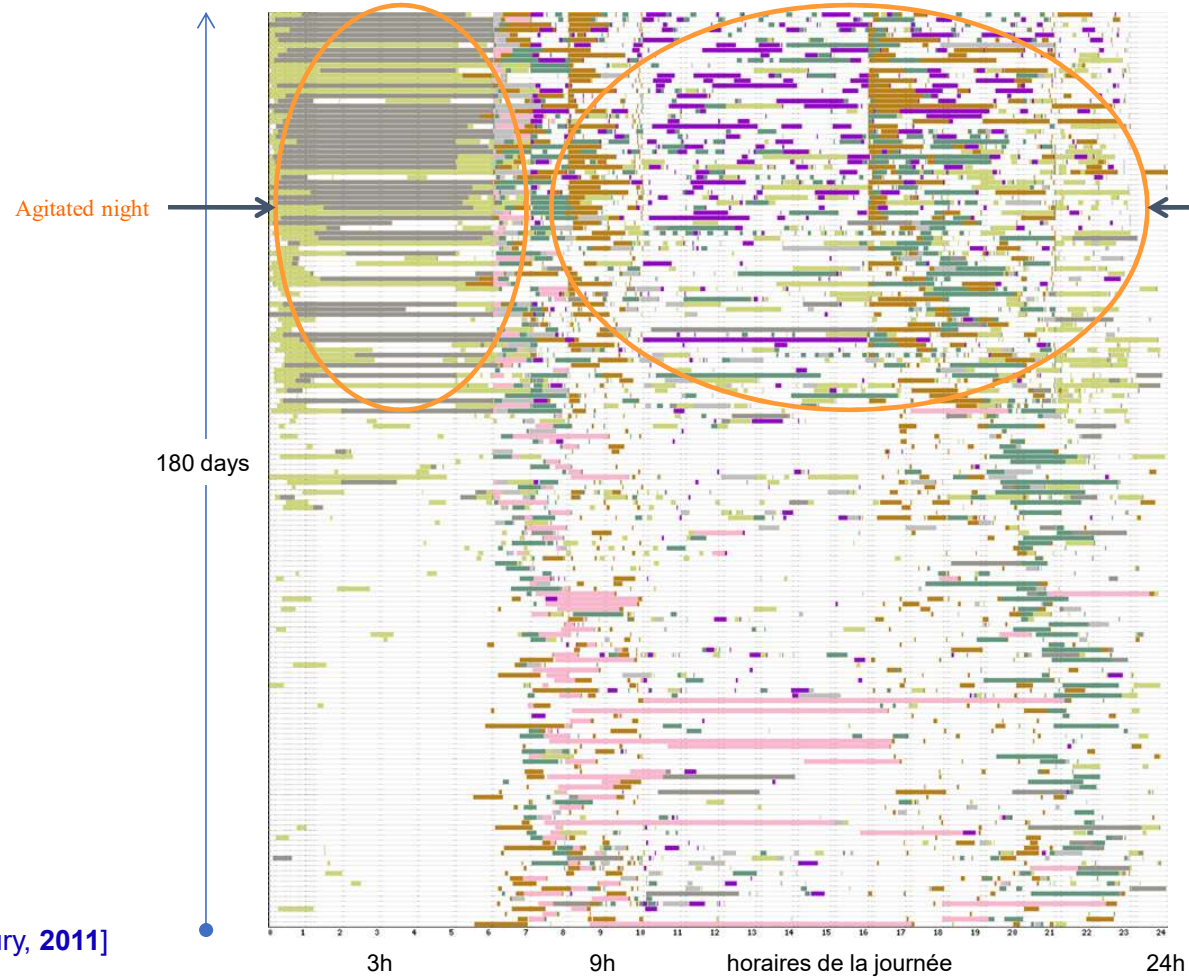
End user n ° 27 (July 9, 2008 to 4 January 2009: 180 days)



End user n ° 32 (September 19th, 2008 to January 4th 2009: 108 days)



End user n ° 11 (July 9th, 2008 to January 4th 2009: 180 days)



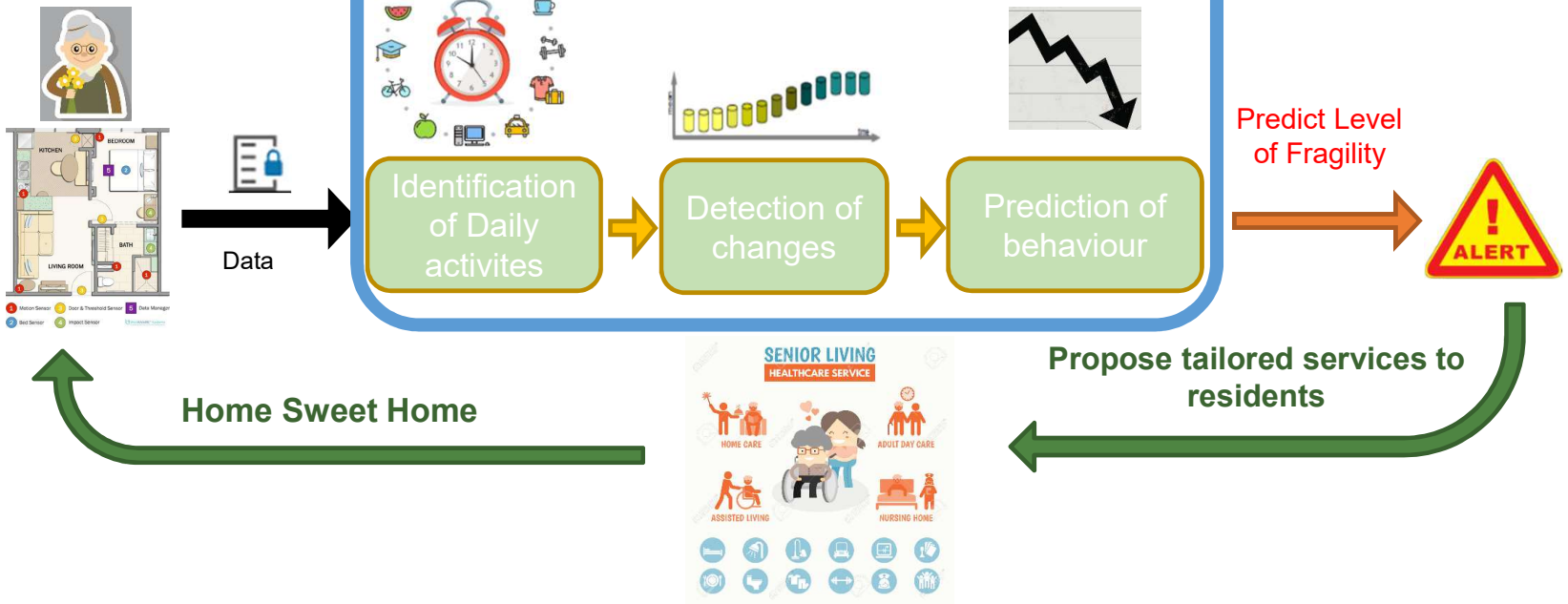
End user n ° 20 (July 9, 2008 to 4 January 2009: 180 days)

[Noury, **2011**]

You dreamed it, Linky did it !

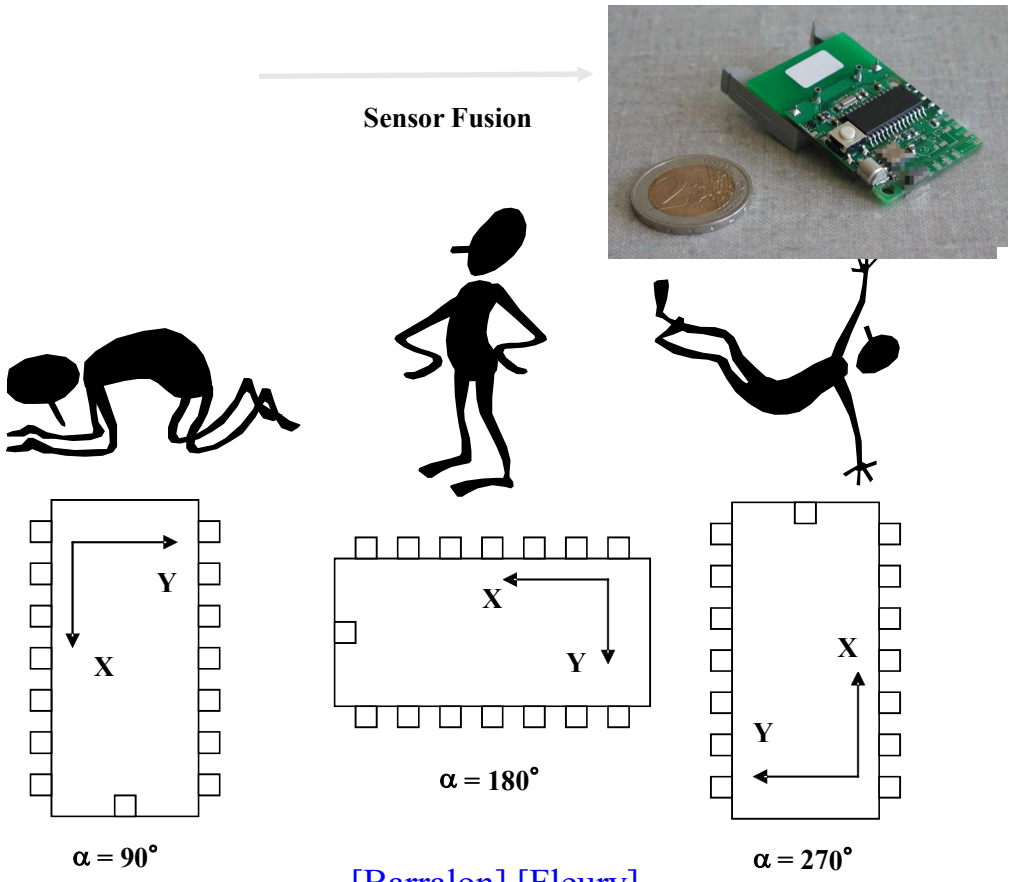
Is there a camera in the LINKY Hub ?

Proposed methodology

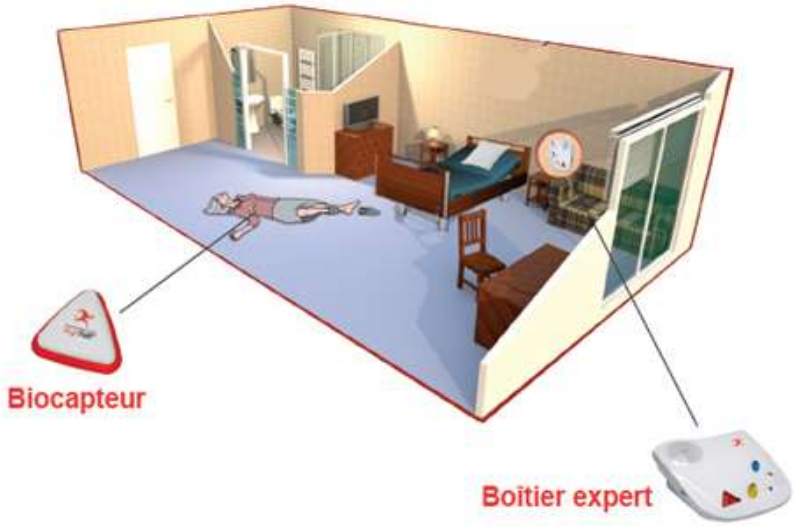


[Azefack, 2020]

Data fusion of inertial wearable sensors in connected home



[Barralon] [Fleury]



Fall in Elderly

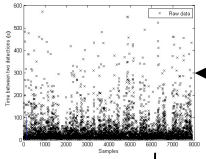
Each Hour counts

Vigi'Fall®

and relief are there...

VIGI'FALL : An Integrated System

Door open detection



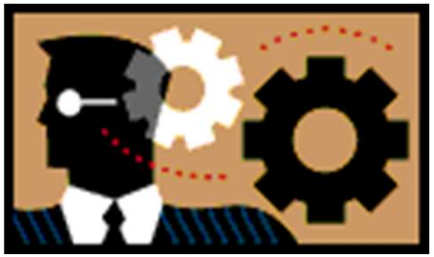
Statistics on movements

Local Box

Alarm

PIR sensors

Biosensor

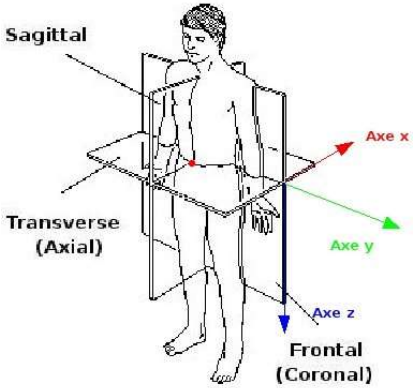


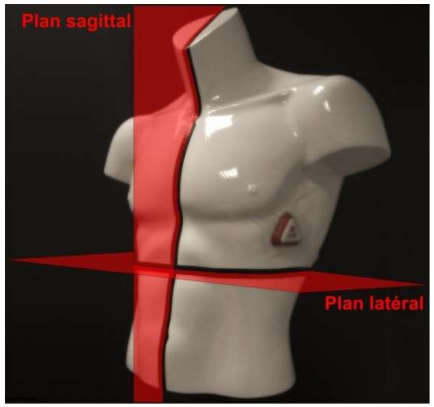
Algorithm GATeM

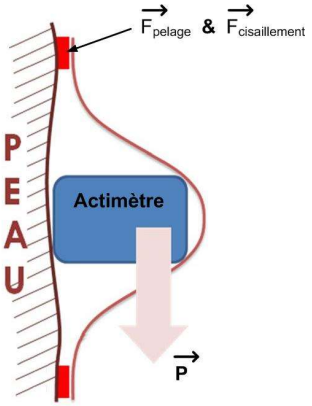
The actimetric patch

➲ **constraints**

- ➢ less **stigmatisation** => non visible
- ➢ Detection of **postures**
- ➢ Good **acceptability** [F. Bloch, 2011]
- ➢ Significants **Signals** of « Fall » [Kangas, 2008] et [Aziz, 2011]
- ➢ **7 Days-24h** duty (showering, night sleep)







Technological opportunities

INNOVATIVE, RELIABLE SOLUTION

AVANTAGES - CLES

- Fiabilité > 98 %
- Port permanent
- Détecte tous types de chute

INDICATIONS

- Pers. âgées ou handicapées
- Dépendantes
- Fragiles

Research directions…

Some directions

Horizon 2020 - societal challenge 1

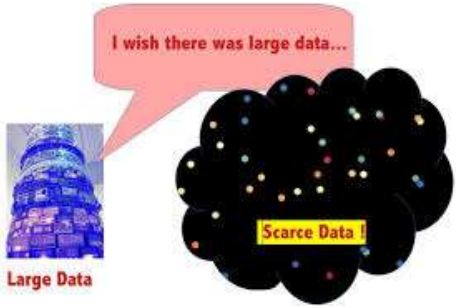
Transforming Health and Care

Curatif	Acute care	Long-term-care	Preventif
Médecine de spécialité	Single Diseases	Multiple chronic conditions	Multi-pathologies
Patient Passif	Passive Patient	Active consumer	Patient Consom-Acteur
Hospitalo-centrisme	Institutional care	Home care	Santé à domicile
Médecine de masse	Generic Approach	Personalised Care	Santé personnalisée (pHealth)

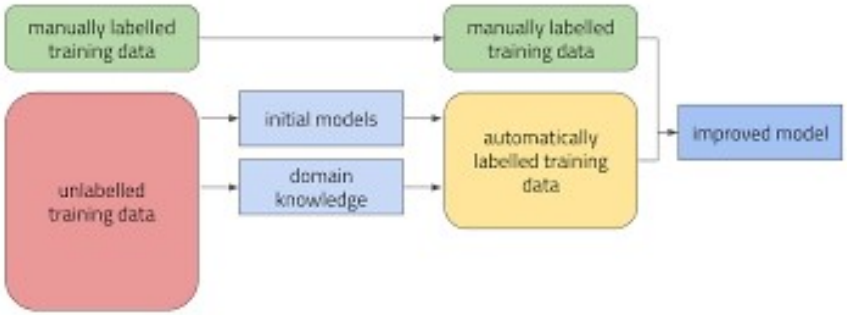
Some Directions

- SC1-PM-15-2017: « *Personnalised coaching for well-being and care of people as they age* »
  - Empowering and motivating people in need of quidance
  - Improve and maintain their independence, physical state, well being, socialisation
  - Cooperation with carers
  - POC « Virtual Coach »
- Many tentatives….
  - **universAAL (FP7); http://www.universaal.info**
  - **ACTIVAGE (H2020); http://www.activageproject.eu**
  - **AAL4ALL http://www.aal4all.org/**
  - ….
- …. a journey that will ultimately converge ?

Big Data versus Low Data



Spying Methods Inspiration



Data Modelling

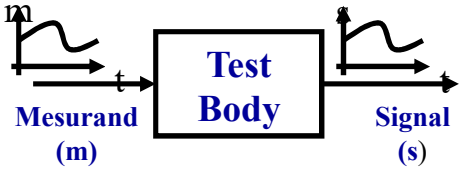
Technological hijacking

- any object can produce data ?

Your smartphone can :
- localise you
- Analyse your communications activity
- Measure your metabolic activity

Your domotics can :
- Learn your habits
- Analyse your activity
- Measure your metabolic activity

- any material can generate data ?



Slight impact
Low level sound

Strong impact
High level sound

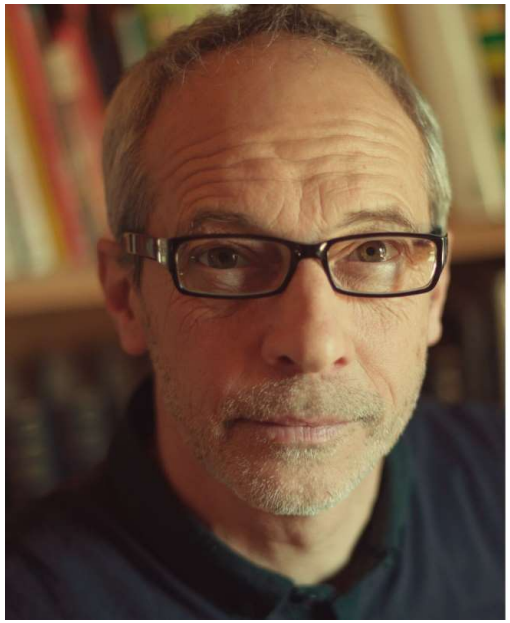
Spying Methods Inspiration

Pr Norbert Noury

- Distinguished Professor at University Claude Bernard, Lyon 1, France
- Director MSc « Regulatory Affairs of MD » Polytech Lyon 1
- Director BSc « Technologies for Healthcare » IUT University Lyon 1

- Member of the department of Biomedical Engineering at Polytech Lyon, the school of Engineering of University Lyon,
- Lectures in Electronics and Medical Devices

- Research activities in *Biomedical Sensors Group* at lab. INL-INSA Lyon, UMR CNRS 5270,
- Expert in smart sensors, eHealth, Ambient Assisted Living environments, Ubiquitous Health monitoring systems



- 21 Phd thesis guided in Health Engineering.
- IEEE Senior Member (2006),
- Past President French Chapter IEEE EMBS (2015-2019).
- H Index =38 (+ 250 scientific papers)

Merci pour votre attention !