ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

PHIDIAS
Ultra-Low-Power Holistic Design for Smart Bio-signals Computing Platforms

SEVENTH FRAMEWORK PROGRAMME

Phidias

Ultra-Low-Power Holistic Design for Smart Biosignals Computing Platforms

Dr. Giovanni Ansaloni

Embedded Systems Laboratory (ESL)
École Polytechnique Fédérale de Lausanne (EPFL)

ICT-Energy Community Workshop
Barcelona, April 23rd-25th, 2014

Outline

- Phidias consortium

- Investigated scenario
  - Wireless Body Sensor Nodes
  - Compressed Sensing
- Research lines
  - Low-power *digital* embedded bio-signals processing
  - Advanced *analog* sampling of bio-signals
  - Novel compression *algorithms* for bio-signals

Phidias project and consortium

- Goal: investigation of Compressed Sensing for low-power WBSN platforms
- FP7 FET project, 3 years
  - currently in its second year

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

novel CS algorithms
low-power digital platforms

europeanresearchservices gmbh

coordination and management

imec-nl
aspire invent achieve

analog components
ULP memories

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

reconfigurable interconnects
system integration

EPFL Role in Phidias

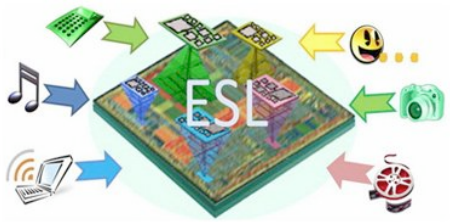
- EPFL is the leading partner of the project
- Two laboratories participating
  - LTS2 (prof. Pierre Vandergheynst) → signal processing
  - ESL (prof. David Atienza) → embedded systems

PHIDIAS
Ultra-Low-Power Holistic Design for Smart Bio-signals Computing Platforms

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

europeanresearchservices gmbh
coordination and management

LTS2
novel CS algorithms

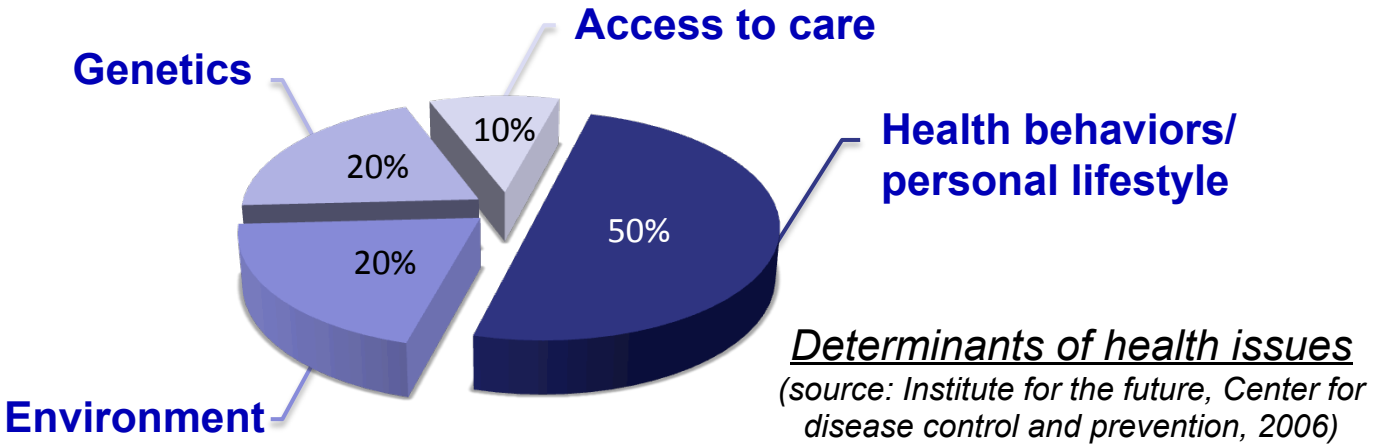


low-power digital platforms

imec-nl
aspire invent achieve
analog components ULP memories

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA
reconfigurable interconnects

Changes in healthcare landscape call for personalized healthcare



Determinants of health issues
(source: Institute for the future, Center for disease control and prevention, 2006)

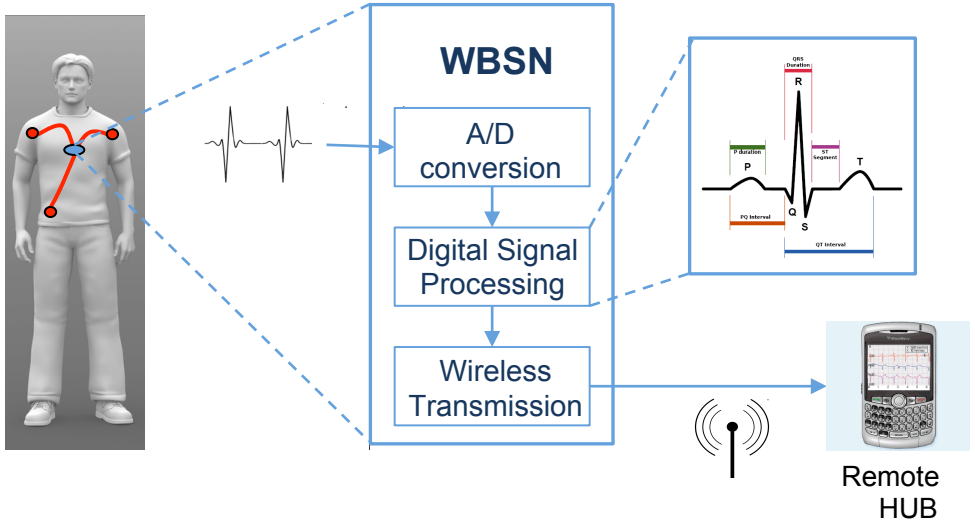
- Shifting from diseases caused by infectious organisms to disorders with behavioral causes.
- 50% of all deaths worldwide and economic fallout in billions, expected to be 75% of gross domestic product by 2030

- Change required in health delivery:

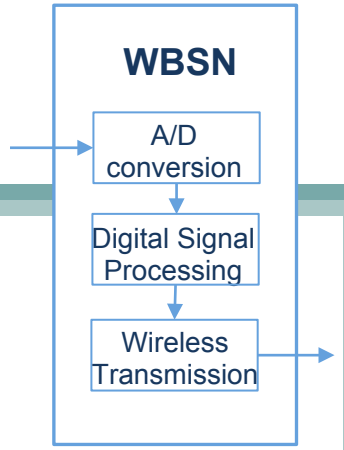
Symptom-based	→	**Preventive healthcare**
Hospital-centered sickcare	→	**Person-centered healthcare**

Wireless Body Sensor Nodes (WBSNs)

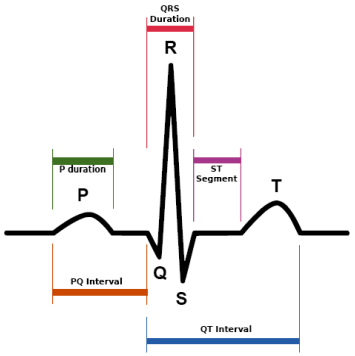
- Continuous monitoring of bio-signals
  - Respiration
  - Blood Flow
  - ECG
- Three phases
  - acquisition
  - processing
  - wireless transmission
- Energy efficiency is key
  - wearability
    → small battery
  - continuous monitoring



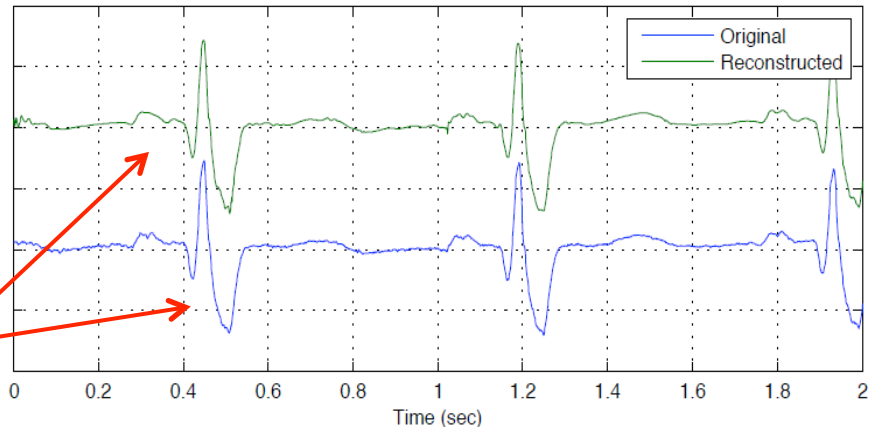
WBSNs energy trade-offs



- Efficiency across multiple dimensions
  - Processing strategy and algorithm
  - Design of analog front-end, ADC
  - Optimized digital platform
- computation energy vs. transmission energy
  → on-node signal analysis
  - Filtering, delineation, classification
  - Only analysis results are wirelessly transmitted



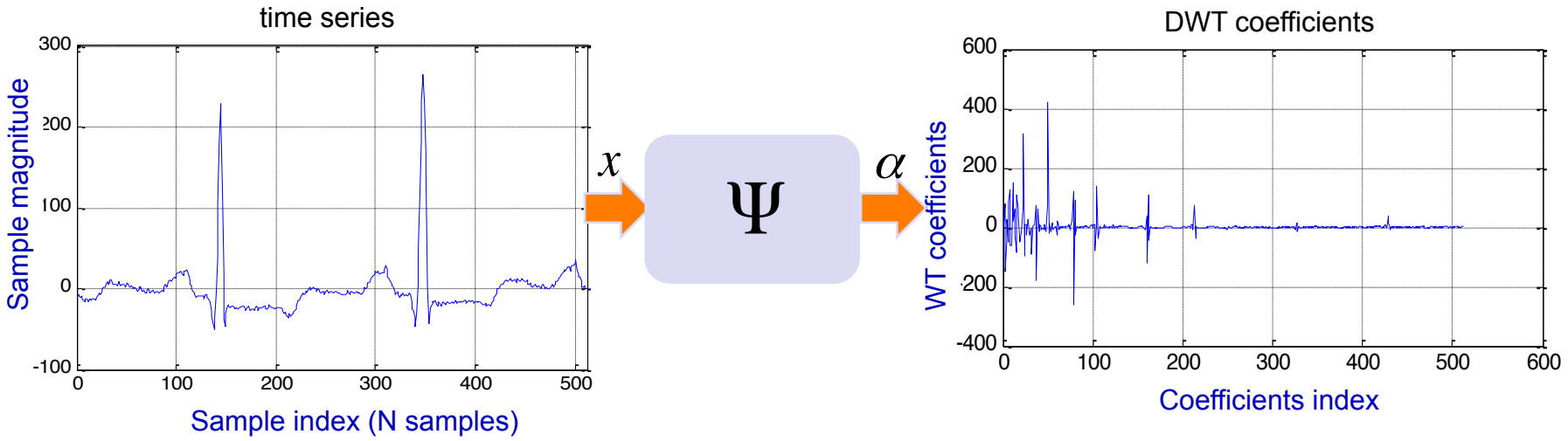
- sampling/computation energy vs. transmission energy
  → signal compression
  (Compressed Sensing)
  - Acquired signal can be recovered
  - Analogue or digital implementations



90% compression ratio

Compressed Sensing at a glance

- Bio-signals (e.g.: ECG) are highly sparse in the some domain (e.g.: wavelet)



- CS-based compression: collection of M(<<N) linear measurements

Measurement vector → $y_{M\times 1} = \Phi_{M\times N} \cdot x_{N\times 1}$ ← Measurement matrix (Gaussian random)

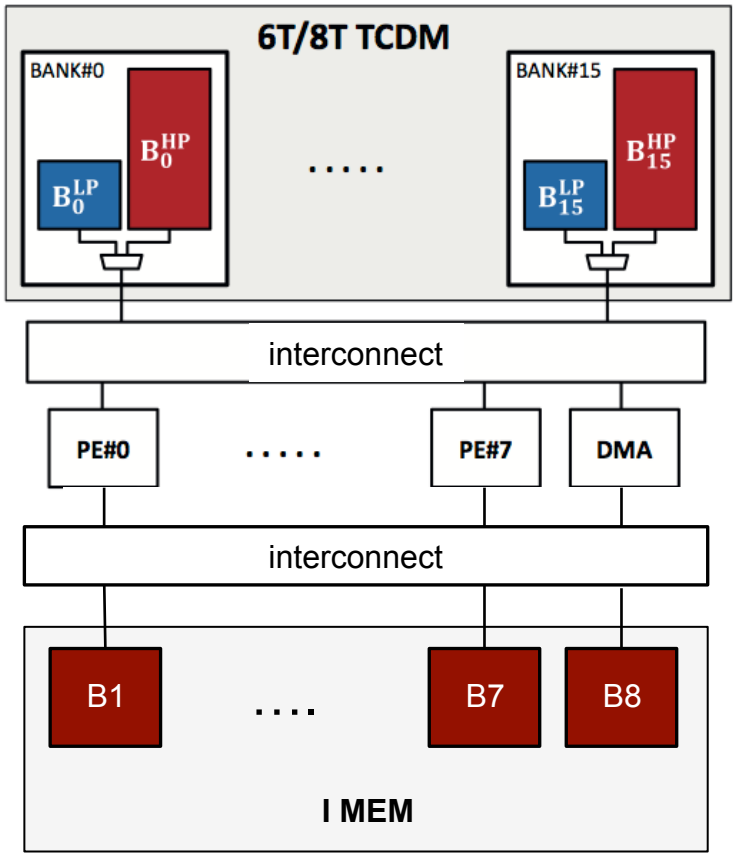
Original ECG vector

- CS reconstruction: convex optimization problem (at the receiver side!)

$$\min_{\tilde{\alpha}\in\Re^N} \left\|\tilde{\alpha}\right\|_1 \quad \text{Subject to:} \quad \left\|\Phi\Psi\tilde{\alpha} - y\right\|_2 \le \sigma$$

Digital Compressed Sensing

- Highly parallel workload (EPFL)
  - → Multi-core architecture
  - → Voltage/Frequency scaling
  - → Instruction/Data memory broadcasting[1]
- Interconnect latency is critical
  - → Programmable logarithmic interconnect (UNIBO)
- Memory is energy bottleneck
  - → Hybrid 6T/8T memories (UNIBO)[2]
  - → SCM memories (IMEC-NL)

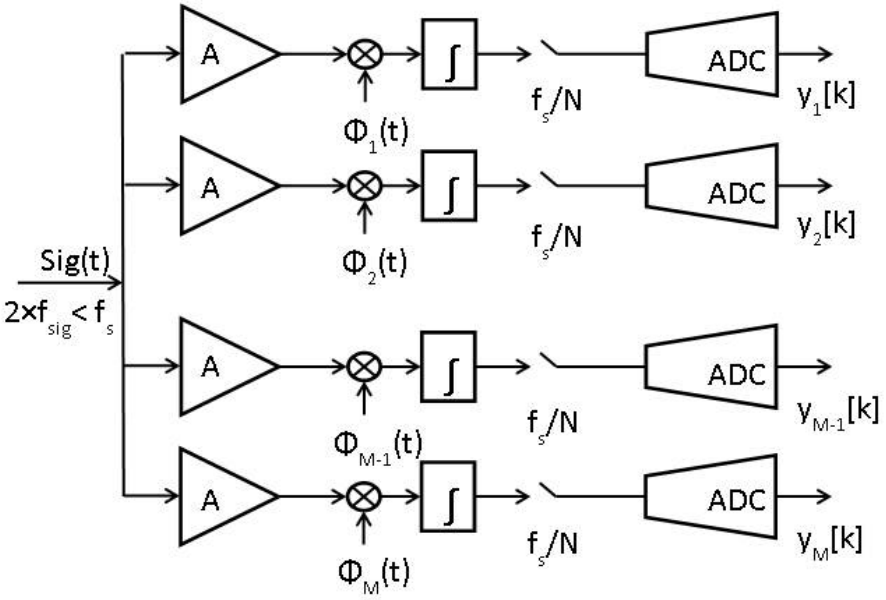


1. R. Braojos Lopez, I. Beretta, G. Ansaloni and D. Atienza Alonso, "*Hardware/Software Approach for Code Synchronization in Low-Power Multi-Core Sensor Nodes*", DATE 2014

2. D. Bortolotti, A. Bartolini, C. Weis, D. Rossi and L. Benini, "*Hybrid Memory Architecture for Voltage Scaling in Ultra-Low-Power Multi-Core Biomedical Processors*", DATE 2014

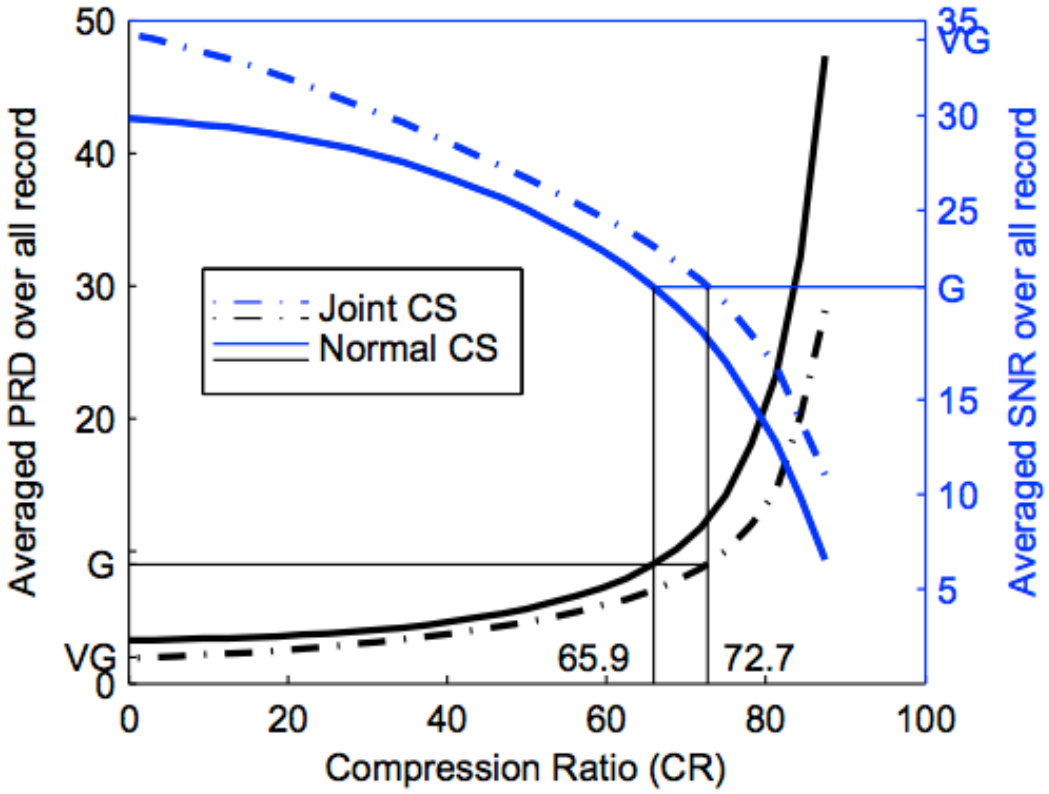
Analogue Compressed Sensing

- Multi-channel with random modulation
  - mixer + integrate & dump
- Sampling frequency: fs/N
- Careful choice and design of
  - amplifiers
  - mixers
  - ADCs
- Tape-out from IMEC-NL in June



A novel CS algorithm: joint reconstruction[1]

- Bio-signals are usually acquired from multiple correlated sources
  - 3- 12- 15- leads ECG
- Joint reconstruction
  - group sparsity
  - L_1/L_2 norm
- Lower Compression Ratio can be achieved for a given SNR
  - → CR proportional to transmission bandwidth and energy



1. H. Mamaghanian, G. Ansaloni, D. Atienza and P. Vandergheynst , "*Power-Efficient Joint Compressed Sensing of Multi-Lead ECG Signals*", ICASSP 2014, accepted paper

Phidias project at-a-glance

- Advanced models for analogue and digital Compressed Sensing
- Novel methods for CS reconstructions
- Ultra-low-power platforms dedicated to CS
- Novel analogue CS implementations