Designing Ultra-Low Power Wearable Systems for the Internet-of-Things Era

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Wearable Systems are.. Many Things

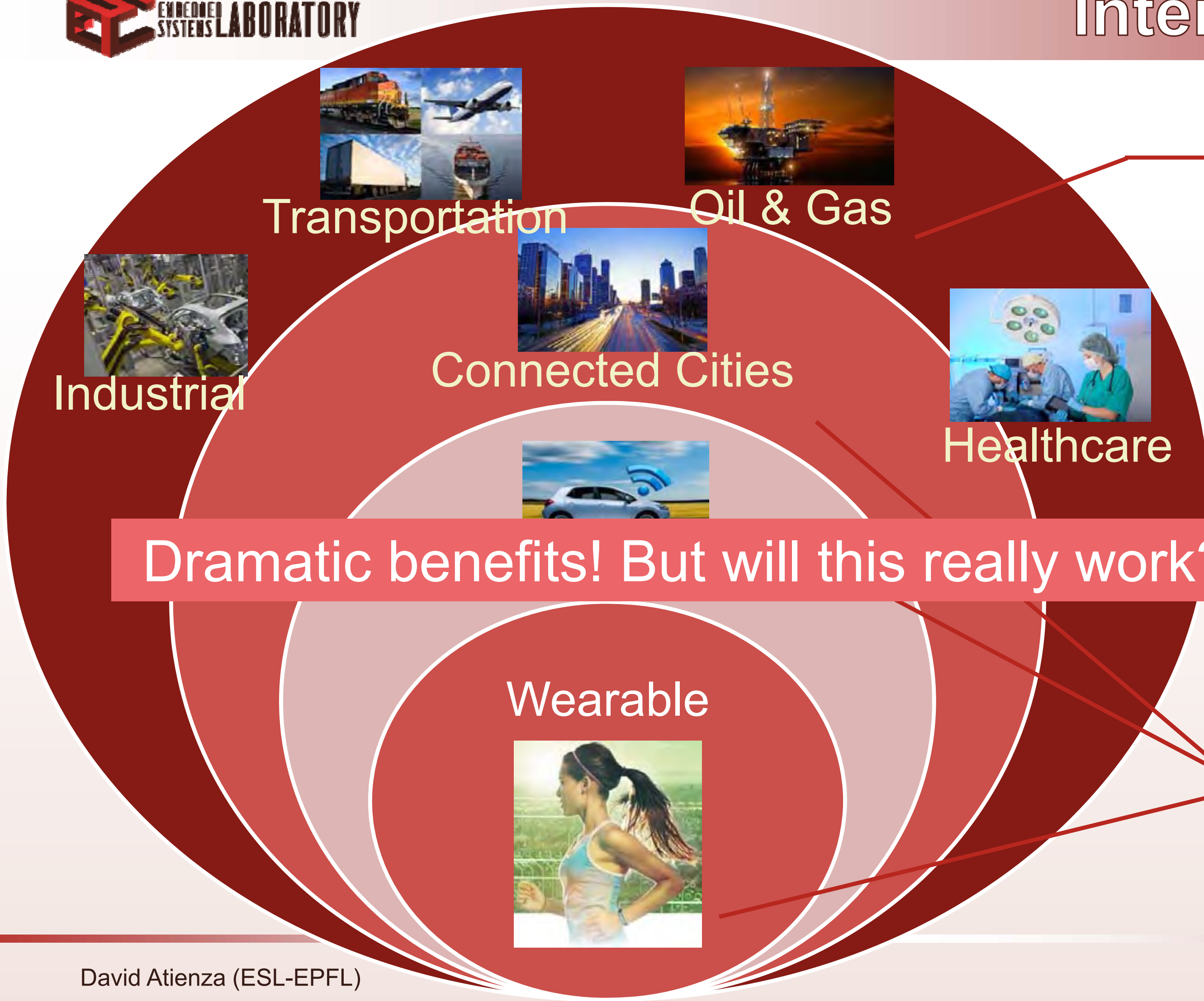
- Many different purposes… And complexities (today more than 3000 products)

[Courtesy: C. Henz]

Global Computing Convergence for new IoT Era

- Thanks to Moore's Law, after 50 years: Doubling transistors density each 18 months
- Future: connected, ubiquitous access with portable and wearable systems

Internet-of-Things (IoT)



Dramatic benefits! But will this really work?

Big Data Analytics Frameworks & Machine Learning Algorithms

Continuous system monitoring

[Source: Goldman Sachs Inv. Res.]

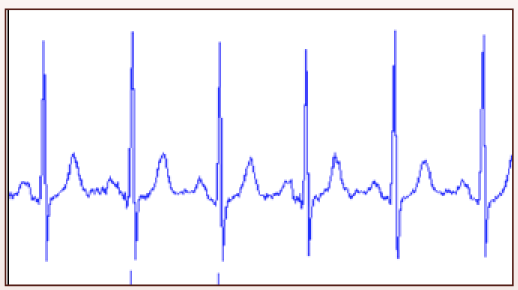
Wearable Systems in IoT Era to Rescue Our Healthcare

- Burden of disease shifted in recent years
  - Disorders with behavioral causes are key
  - Expected to be 75% of GDP by 2030 [McKinsey
- Two-fold paradigm shift in health delivery

Symptom-based	➔	**Preventive healthcare**
Hospital-centered	➔	**Person-centered**

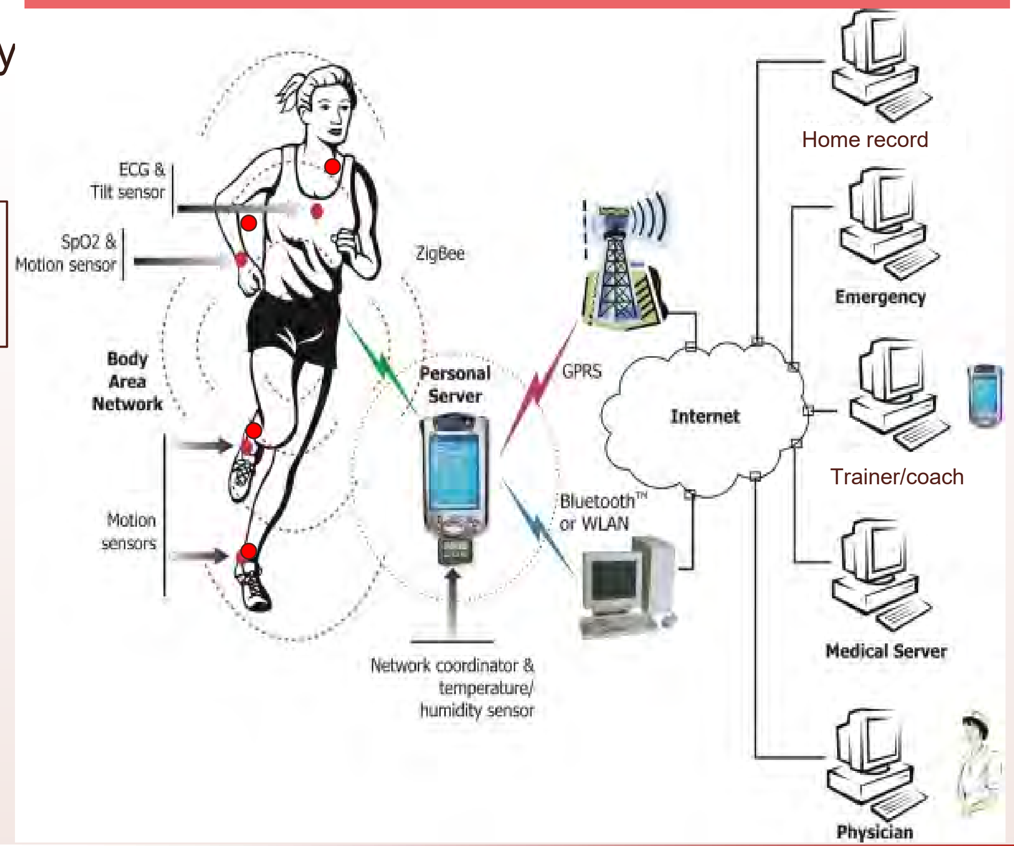
- Cardiovascular monitoring is key today…

ECG Holter data logger (clinical practice)



Resting Electrocardiogram (ECG)

Wearables in IoT era will relay information to the cloud and healthcare providers



State-of-the-Art Wearables Today

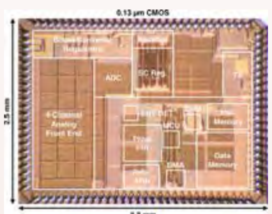
- Simple architectures connecting to a central hub

Shimmer
(shimmer, 2014)

Heart Rate Monitor
(Massagram, 2010)

Corventis's PiiX
(Corventis, 2014)

Toumaz's Sensium
(Wong, 2012)



ScottCare
(Zhang, 2012)

IMEC cardiac patch
(Yazicioglu,2009)

Holst Centre
(Masse, 2014)

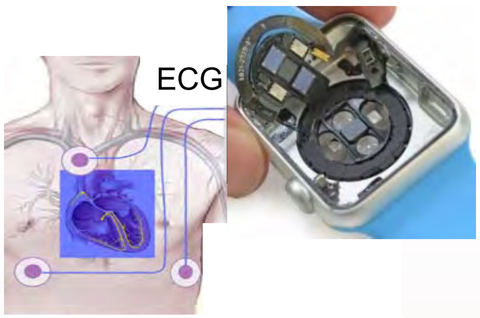
Apple Watch
(Apple Inc, 2015)

Raw biosignal or simple pre-filtering to concentrator (for processing) and graphical feedback system (smartphones)

- **TI MSP430 microcontroller**
  - 16-bit, 8MHz, 10KB RAM, 48KB Flash
  - ADC converters, DMA, HW multiplier
- **CC2420 radio**
  - 250 Kbps, ZigBee compliant
- **Sensors**
  - 3-channel ECG
  - Accerelometers and gyroscopes
  - GPS (optional)

- CONSTRAINTS:
  - No floating point operation
  - No hardware division
  - Limited memory
  - Limited computing power
  - Limited autonomy (rechargeable Li-polymer battery of 250 mAh)

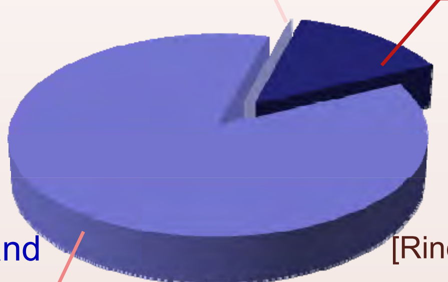
Long-Lived Wearables Require Major Design Shift



1. Reduce amount of data sent to concentrator
2. Can we embed automated analysis without compromising the system lifetime?

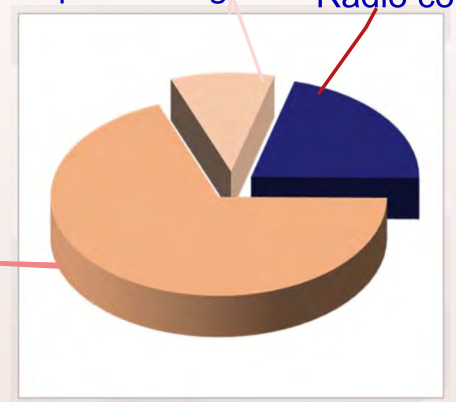
Under stringent processing and memory constraints… **Power!**

- This wireless 1-lead ECG streaming monitor lasts 134.6 h (2011)
  - Current wearable technology lasts 172.5 h (2015)

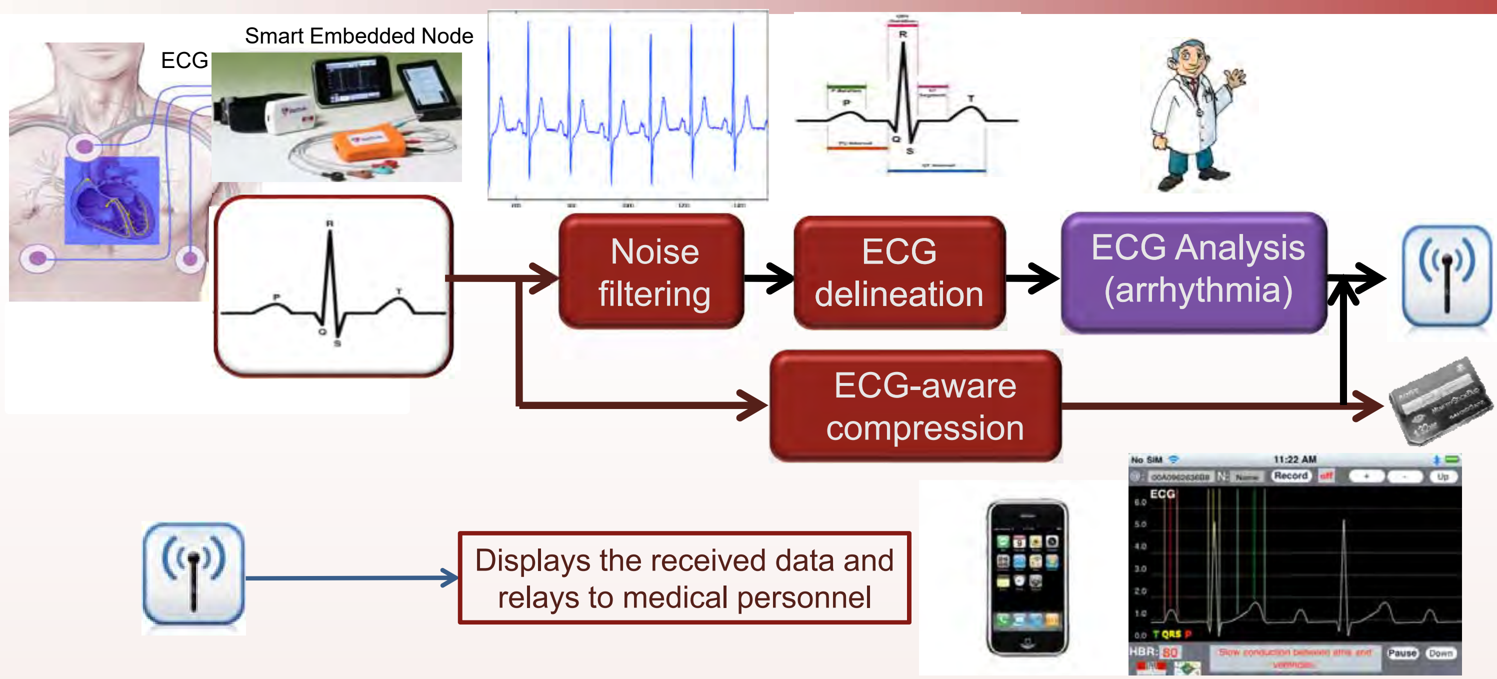


[Rincon et al., DATE '08 and TITB '11]

Energy consumption breakdown



Smart Wearable Systems for Autonomous Arrhythmia Monitoring



Software: wearable systems <u>can</u> implement multi-lead ECG analysis

- Filtering: Low-complexity methods using integer computing **(real-life tests on measured points)**
- Delineation: Multi-lead ECG arrhythmia analysis in real-time (**doctor support for quality loss**)
- Communication: exploit biosignal-related slow speed (**50% less comm. energy**)

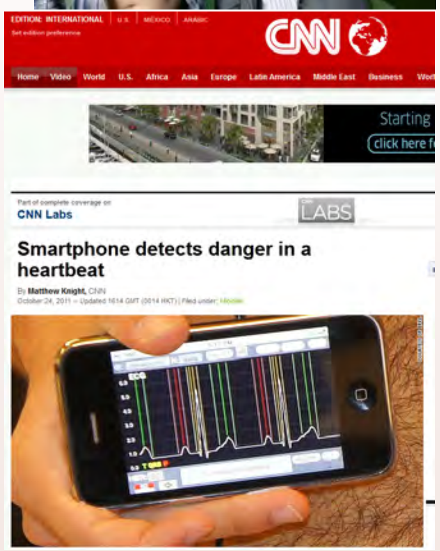
Personal Arrhythmia Smart Wearable Device

Advanced on-chip processing gives real-time information about heart health with **no impact on node lifetime**: more than 139 hours

See video at: http://esl.epfl.ch/cms/lang/en/pid/46016

New Smart Wearables Valuable For Medical Community: Start-Up Case

- Non-intrusive, include arrhythmia detection: reducing visits to doctor by 50-60% (4-week test)


EDITION: INTERNATIONAL | U.S. | MÉXICO | ARABIC

CNN

Home Video World U.S. Africa Asia Europe Latin America Middle East Business

Part of complete coverage on
CNN Labs

Smartphone detects danger in a heartbeat

By Matthew Knight, CNN


Date: 19.10.2011

Blick

Ein SMS vom Herz

Lausanne – Diagnose: Herzinfarkt. Der häufigsten Todesursache der Welt wird der Kampf angesagt, und zwar mit Schweizer Technik. Forscher der ETH Lausanne haben ein Gerät entwickelt, das den Herzrhythmus konstant überwachen kann. Falls eine Rhythmusstörung auftritt, **sendet das Gerät an Patient und Arzt per SMS oder E-Mail eine Warnung.** «Das System liefert sehr präzise Daten und verfügt über einen leistungsfähigen Akku mit einer Laufzeit von drei bis vier Wochen», sagt Forscher David Atienza.


LE TEMPS

Santé

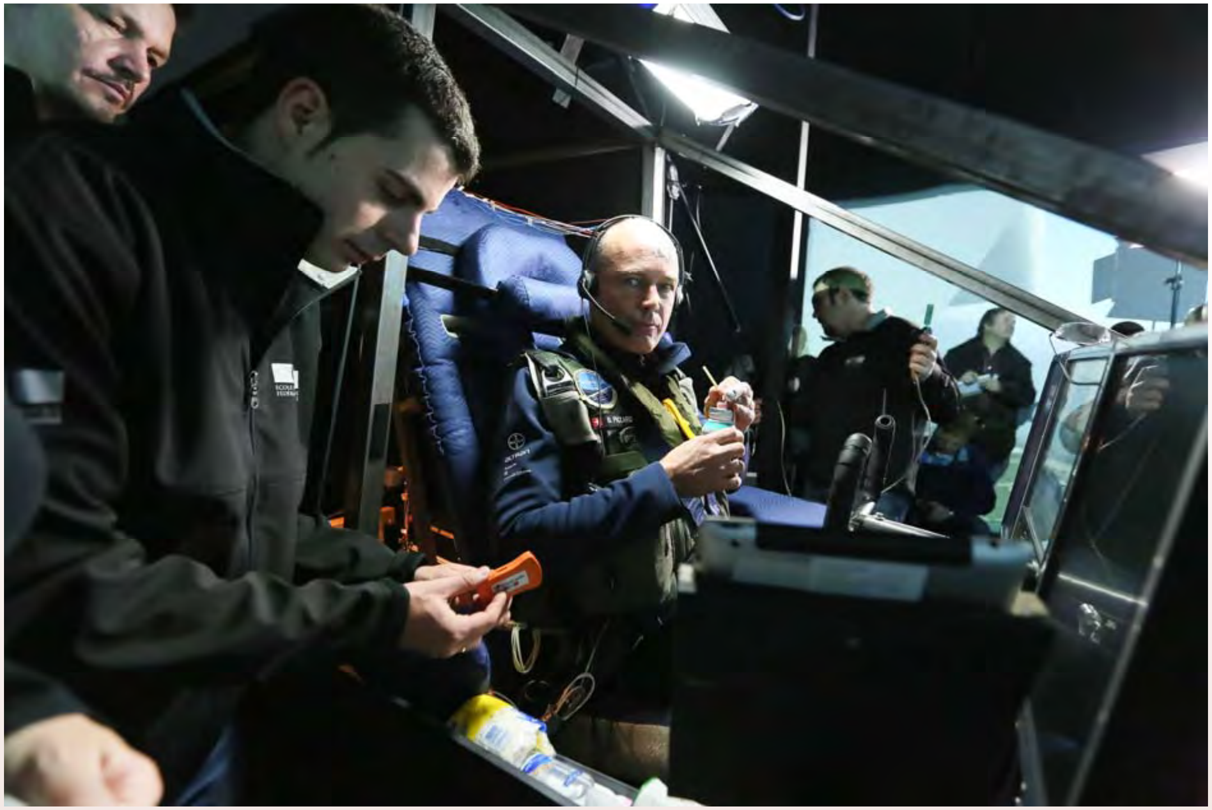
Notre cœur sur écoute

L'Ecole polytechnique de Lausanne (EPFL) a annoncé mardi la mise au point d'un appareil de détection des anomalies cardiaques. Les informations seront directement transmises par SMS ou par e-mail au patient et au personnel médical. (ATS)

So Smart Wearables are possible!

Using ESL-SmartCardia Technology with Solar Impulse

- Monitoring pilots using wearables as “doctor in the cockpit”

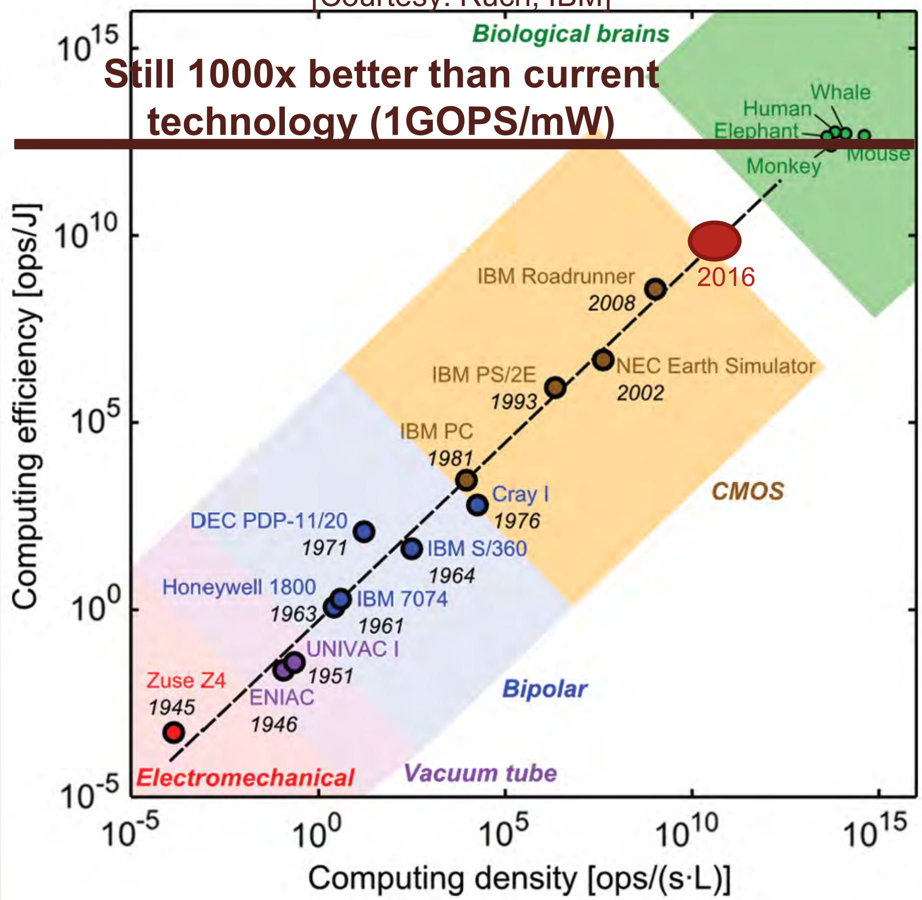


See video at: https://www.youtube.com/watch?v=cPW-2AtRwgM

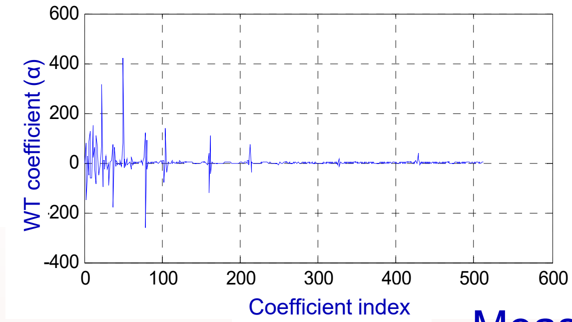
But Just the Beginning… "Smarter" Wearables Coming

- Great progress in last 50 years
  - We have reached 1M ops (MOPS)/mW for wearable systems
- Good energy-scalable computing, but biological systems can do even better
  - Energy efficiency: specialized computing
  - Highly parallel
  - Discard unnecessary data

[Courtesy: Ruch, IBM]



- Using CS it is sufficient to collect *M* (<<*N*) linear random measurements (samples)

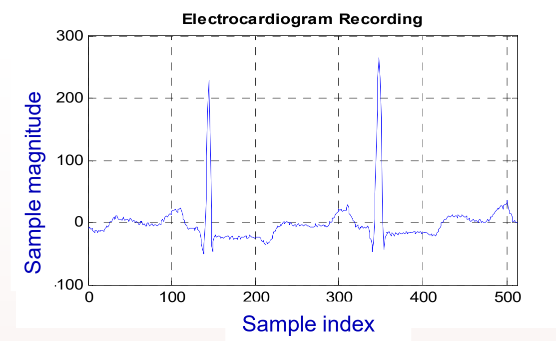


Measurement/Sensing matrix (Gaussian random matrix)

$$y_{M\times 1} = \Phi_{M\times N} \cdot x_{N\times 1}$$

Measurement vector

ECG vector

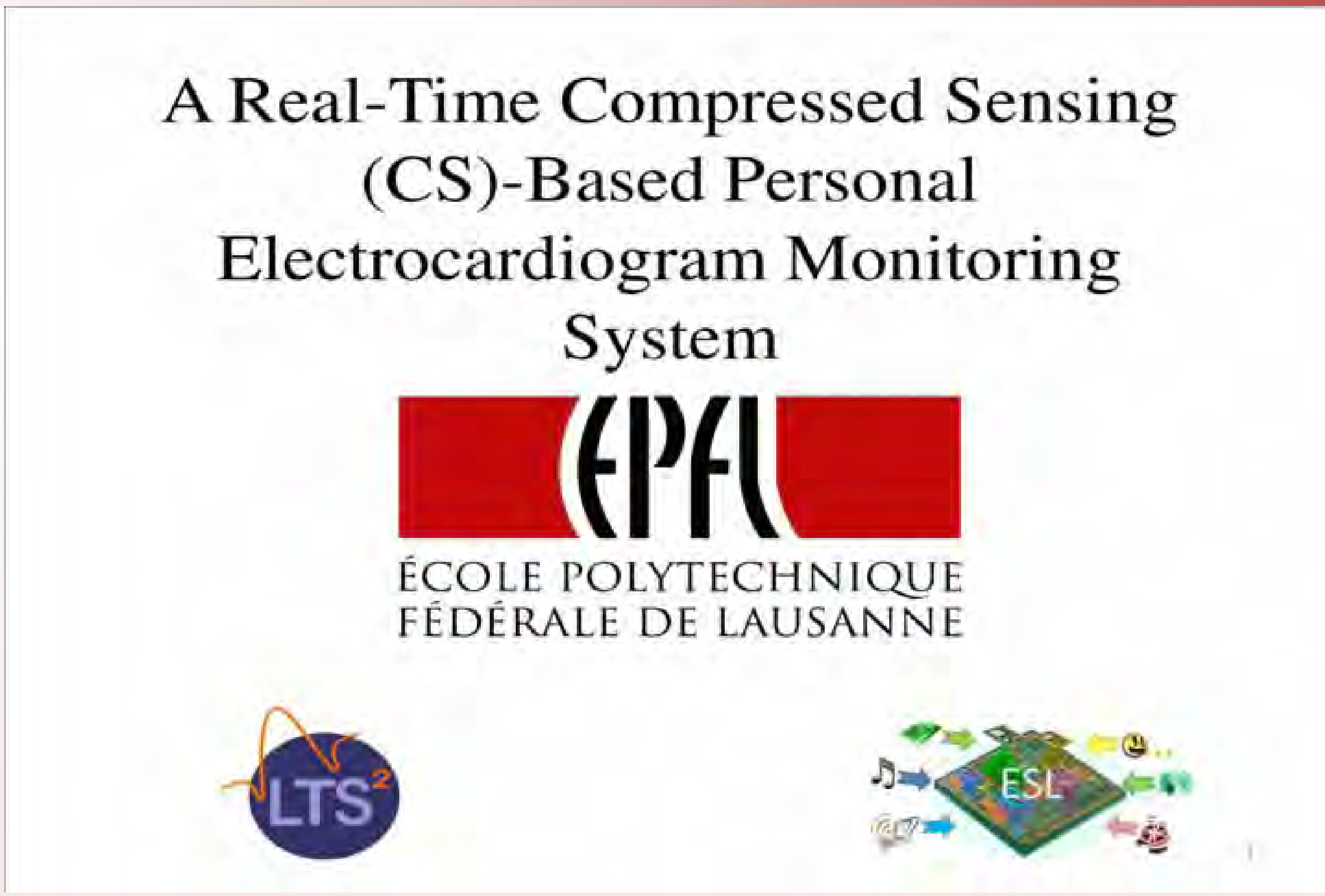


- Then, α

CS is attractive for real-time ECG compression on resource-constrained WBSN, but what about **biosignal degradation** due to CS reconstruction (in real-time)?

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

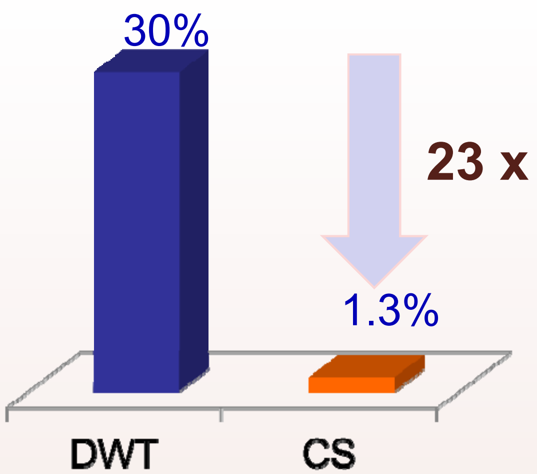
CS-Based ECG Sensor (only 30% of ECG data kept)



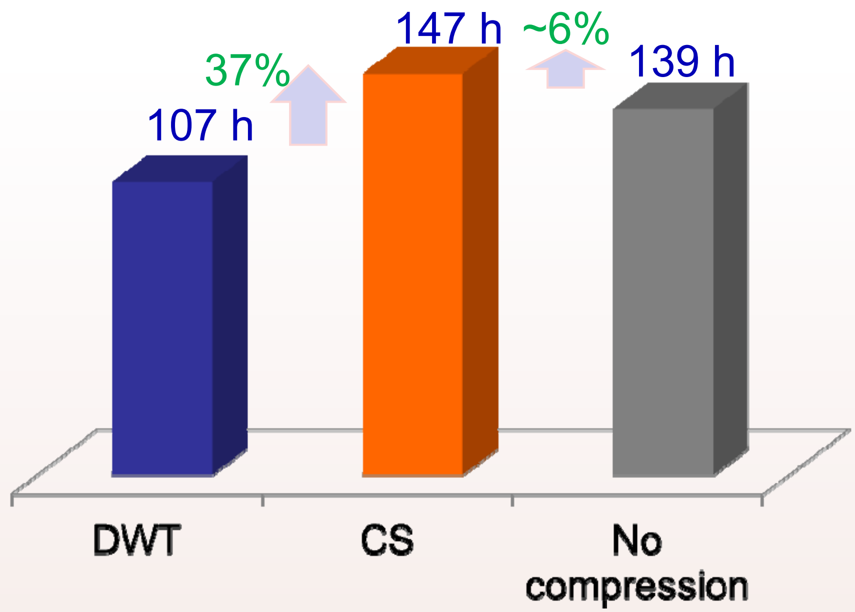
See video at: http://esl.epfl.ch/page-42817.html

CS Gives 23-Fold Reduction in Execution Time, But Limited Lifetime extension

Code execution time



Node lifetime

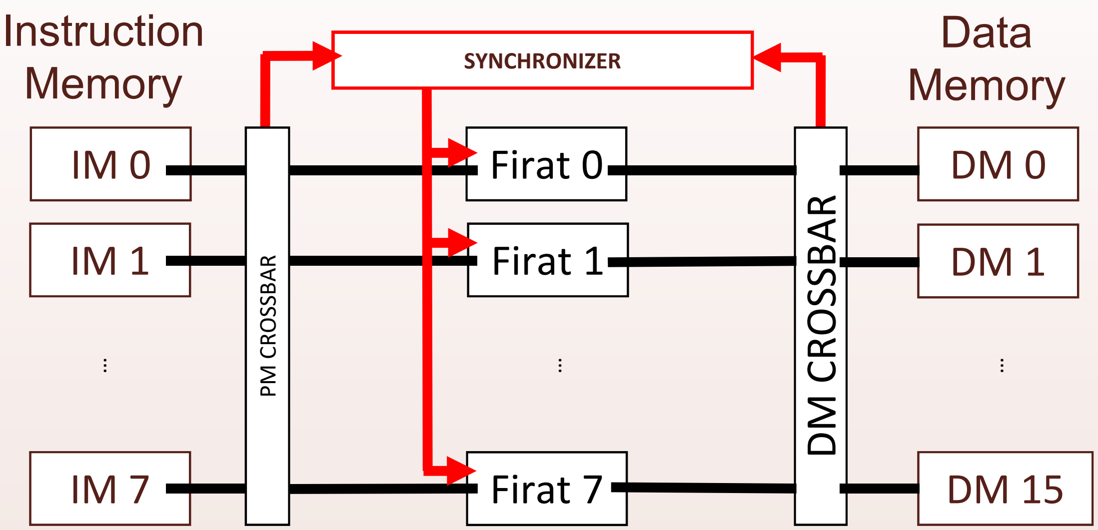


Limited gains because the used generic microcontroller is not optimized for ultra-low-power DSP and CS-based **operations in biological signals**

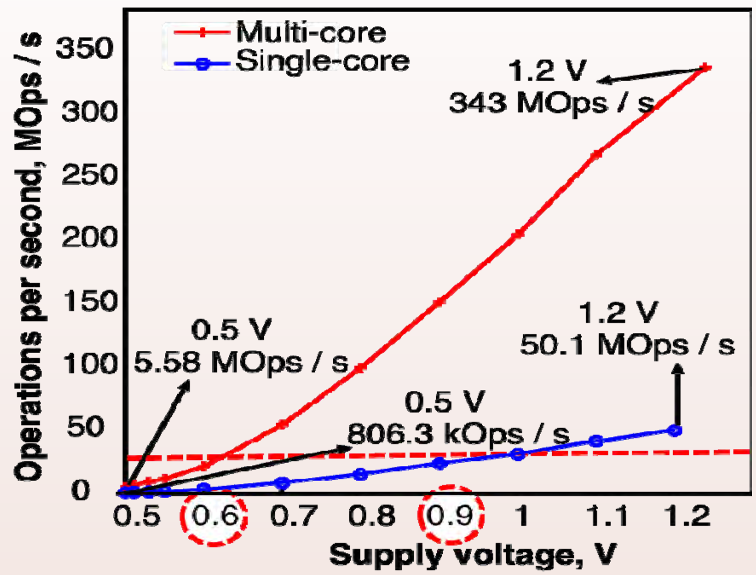
- Exploit features of multi-lead ECG **(~2x lifetime)**

Hardware: MPSoC fulfils workloads at 50% lower power than single-core wearables, finally smart wearables show true potential!

- Exploit technology progress: Multi-Processor SoC (MPSoC) for biosignals
  - Parallel computing for each lead, data broadcast and special hardware synchronizers

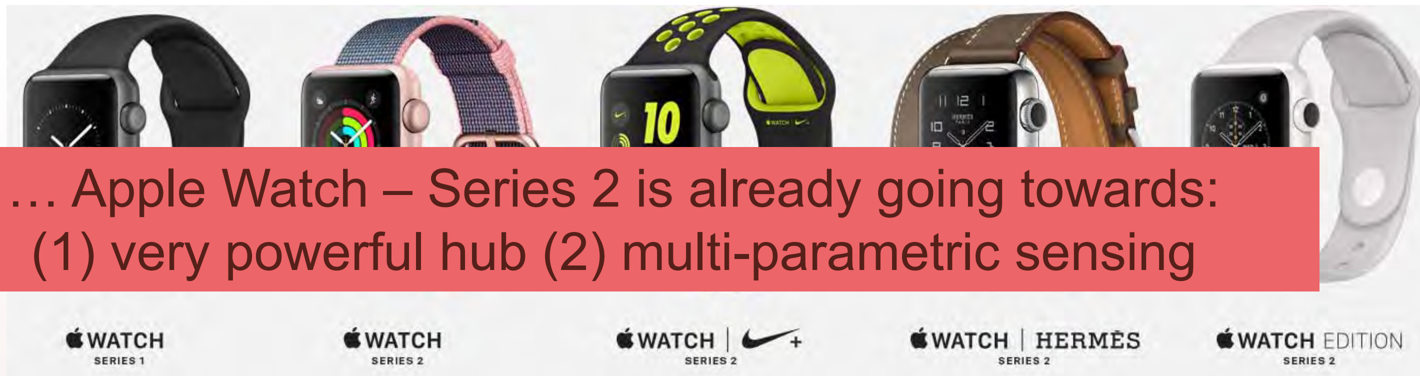


[Braojos et al, DATE'14]



Apple Watch – Series 2: More Powerful and Customizable Interface

- New smart watches target to be your Personal (All-Day) Assistant
  - Develop new interfaces with lights, sounds and vibrations…New flavors and customizable



… Apple Watch – Series 2 is already going towards:
(1) very powerful hub (2) multi-parametric sensing

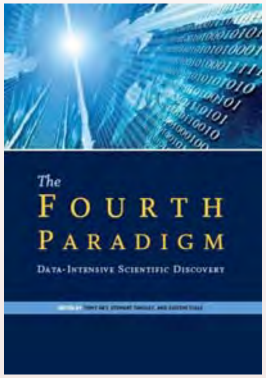
- Even more powerful, targeting intuitive interfaces than reading the screen
  - **Dual-core S2 processor** (2x processing, same size)
  - All sensors from Generation 1 + Built-in GPS, extra accessories for sports (water resist)
  - Screen with 1000 nits of brightness (>2x more luminosity)… News by colors interfaces
  - Force Touch: actions based on strength of touch on screen

Connected Wearables (Big Data): Improving Services

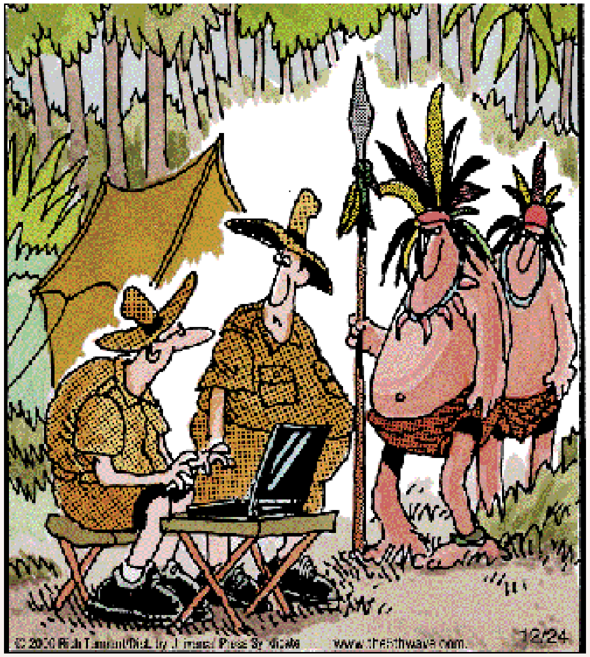
- Our lives unimaginable without being connected and using on-line services
  - Everybody connected everywhere

- **Big Data**: 110x data growth in ten years [Economist]
  - Monetizing data for commerce, health or services
  - 50% economic value in developed countries

- Science entering "4th paradigm"
  - Analytics using computing systems on sensors, instruments, human data, etc.
  - Complements theory, empirical science and simulation to understand our complex world



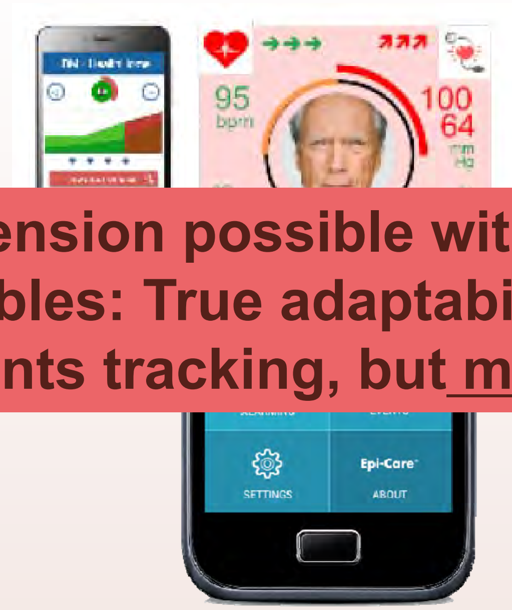
[source: Microsoft Research]

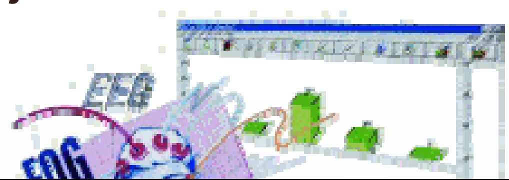


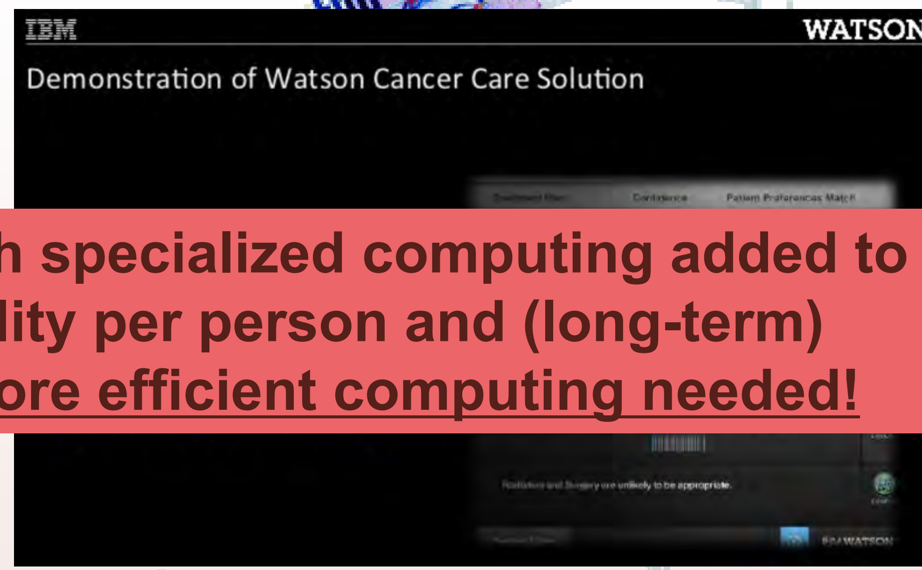
"He saw your laptop and wants to know if he can check his Hotmail."

New Possibilities in Wearables: Multi-Parametric and Big Data

- Multiple applications for smart multi-core wearables, just a few:
  - Accurate sleep apnea
  - Epilepsy prediction (non-invasive)
  - Brain cancer or drugs analysis





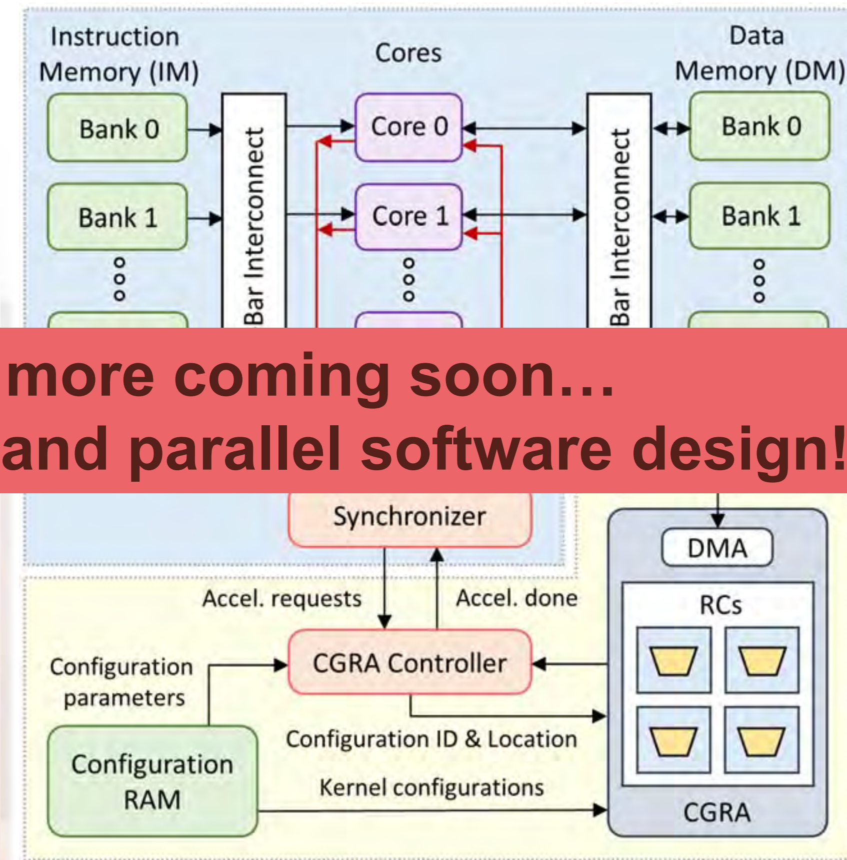


New dimension possible with specialized computing added to wearables: True adaptability per person and (long-term) treatments tracking, but <u>more efficient computing needed!</u>

- **Homogeneous MPSoC architecture**
  - Parallel execution
  - Low clock frequency enabled
  - **But not optimized for intensive (repetitive) tasks**
- **Brain training: "HW specialization"**
  - Highly energy efficient

Promising exploration field, more coming soon…
Lots to do in computer architecture and parallel software design!

- **Low-power heterogeneous MPSoC reconfigurable architecture**
  - Based on a **Coarse-Grained Reconfigurable Array (CGRA)**
    - High energy efficiency
    - High configurability / flexibility



[Duch et al., BioCAS 2016]

Conclusions

- Wearable devices are getting everywhere… Embedded on everybody
  - Powerful: MPSoC architectures and Apps
  - But not low-power… **To be designed with care!**

- New smart wearables… Smart watches
  - Systems tend to get truly autonomous
  - Customizable and intuitive interfaces
  - Even "smarter" thanks to big data feedback

- Luckily lots of research to get there still, thanks Mr. Spock's for initial idea! **Tri-corder**

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