From Autonomic Computing Concepts Learned from the Heart System Towards Modelling Challenges in eHealth

Jocelyne FAYN, INSERM, LYON, France
Interactions between:

- The cardiovascular system and the autonomic nervous system
- The sympathetic and para-sympathetic systems

Power Spectrum Density of the RR interval, the inverse of the heart rate, from the electrocardiogram

From Paul Horn. Autonomic computing: IBM’s Perspective on the State of Information Technology. 2001
The heart is an electric generator that acts as a current dipole which results from the polarization-depolarization of the cardiac cells.

What is an electrocardiogram or ECG?
From Autonomic Computing Concepts Learned from the Heart System . . .

J. Fayn, INSERM, Lyon, France - ICAS 2015, May 24 - 29, 2015 - Rome, Italy
The Main ECG Processing Steps

Baseline Drift Correction

Signal Filtering

Pattern Recognition of the Successive Beats

Median or Typical Beat Determination

Onset & Offset P, QRS, T Wave Delineation

The Different ECG Waves from a Heart Beat:
- **P** Atrial Depolarization
- **QRS** Ventricular Depolarization
- **T** Ventricular Repolarization

The ECG signal was the first biological signal analyzed by computer.
Some Figures about Heart Diseases

- Heart disease is one of the main causes of death in the world (World Health Organization)
- Because of the aging of the population, the number of cardiac deaths is steadily increasing
- Most of the cardiac deaths occur outside of the hospital
  The out-of-hospital to in-hospital health ratios range between 15.6 : 1 for the less than 50 to 2 : 1 for the elderly (more than 70)
- New strategies are needed to reduce the time before treatment.
- The ECG is still the main source of information for an early detection of cardiac events
- The ECG is easy to perform anywhere, at low cost. We have not yet extracted its information content, although a lot of research has been done.
What are the lessons?

Our vital system is context-aware.

Because it is self-adaptive, it is able to recover.

Self-governing avoids any damage thanks to the autonomic nervous system.

Balance between the sympathetic and parasympathetic systems.

Snapshot of a continuous ECG recording. From Ph Coumel, Paris, France

Because the telephone rings, there are sudden changes.
Another Figure of Heart disease

- The number of sudden cardiac deaths is important, even in young adults.

- In the French Alps, the rescue teams and emergency services are called for about 350 myocardial infarctions each year. (From Lucien Cadoz, ANPSP, National Association of 1st Aid in Mountains).
Self-Adaptation can be useful for cardiac risk prediction ...

Inverse Fourier transform of QT and RR, in the very low frequency domain.

The values of QT are following the RR changes with a delay of about 1 minute.
Self-Adaptation can be useful for cardiac risk prediction

By using artificial neural networks, we can obtain a non-linear model of \( QT = f(RR) \) specific to each individual.

But, the ECG is quite stable along the life of an adult, when no cardiac disease occurs.

So, if we apply later on this subject, the previously learned model on his own measurements, and if there are significant differences between the predicted and the measured values, it could be a sign of risk factor.

ECG **Self-Learning** could thus provide a wealth of information for cardiac risk prediction.
Common Standards for Quantitative Electrocardiography


Standards CEN/ISO
IEC 60601-2-51:2003
IEC 60601-2-25:2011

CSE Database Delivery
(~ 175 user teams in the world)
Contact: prubel.lyon@gmail.com

IEC

Electrodes
Cables
Amplification
Lead Switching
Analog-Digital Conversion
Data Compression & encoding
Data Formatting & Transmission
Data Storage
DBMS

ECG Measurement
ECG Interpretation & Diagnostic classification

CSE Processing Center, Lyon, France
Coordinator: Professor Paul Rubel
E-mail: paul.rubel@insERM.lyon.fr
Mobile: +33 6 09 26 64 29
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Encryption software by Odeti, Belgium
Common Standards for Quantitative Electrocardiography

**Phase 1**
- Original (n=250)
- Artificial (n=310)
  - Human wave recognition:
    - by board of referees
    - Delphi review process
  - Program comparison:
    - ten 12-lead programs
    - nine VCG programs

**Phase 2**
- Noise testing
- Recommendations

**Phase 3**
- Original (n=250)
- Artificial (n=250)

- Program + Referee analysis
- Recommendations

1. Pilot study
   - 3-lead ECG library
   - CSE datasets 1 2
   - Reference library
     - CSE atlas, tape

2. Extended study
   - Multilead ECG validated
   - pilot dataset 5 (n=250)
   - CSE Diagnostic Library
     (1220 ECGs)
   - Computer analysis:
     - nine 12-lead programs
     - six VCG programs
   - Referee interpretation:
     - ECG: eight cardiologists
     - VCG: five cardiologists

Measuring instrument
- calibration / standardisation

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CSE  ECG unary Diagnosis < 80 %

Why?

The main reason is inter-subject variability:
The human physiology is very diverse: Richness!

But, the ECG signal pattern is invariant during the life of each adult if no cardiac event occurs.

So, if there are ECG changes, it is an indication of a cardiac problem.

The ECG is a fingerprint!

How to improve?

Recommendations to perform Serial ECG analysis

Development of new methods

Serial ECG analysis

Taking into account The patient’s specificity

To increase the ECG Diagnosis Accuracy

Inter-subjects Variability

Signal Interferences

Sensor defaults
Self-Reference \[\Rightarrow\] Self-Representation

Taking the heart system of the patient as its own reference system to overcome the ECG variability which is not of cardiac origin

The CAVIAR Method
**Self-Reference & Self-Representation**

- Measurement of **QRS duration changes** at 1 month interval in a 720 healthy subjects population (~20 years old) **decreased ~ 60% in average.** 90% of the values are less than one sampling interval. Similar results are obtained for the QT interval.

- **Improvement of diagnosis accuracy of ischemia:**

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<th>Conventional ST criteria</th>
<th>Spatiotemporal CAVIAR criteria</th>
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<td>SENSITIVITY (%)</td>
<td>60.0</td>
<td>97.7</td>
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<td>SPECIFICITY (%)</td>
<td>87.8</td>
<td>95.5</td>
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<td>TOTAL ACCURACY (%)</td>
<td>73.9</td>
<td>96.6</td>
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Each adult should have a reference ECG
SCP-ECG: Standard Communications Protocol for Computer-Assisted Electrocardiography

European Norm

ISO Standard
ISO/FDIS 11073–91064:2009

An open Protocol

S1: Patient Data / ECG Acquisition Data
S2: Huffman tables used in encoding of ECG data
S3: ECG lead definition
S4: QRS locations
S5: Encoded median data
S6: Residual signal or encoded rhythm data
S7: Global measurements
S8: Textual diagnosis from the interpretive device
S9: Manufacturer specific diagnostic & overreading data
S10: Lead measurement results
S11: Statement codes resulting from the interpretation

HEADER STATEMENT ······· STATEMENT
Confirmed Y/N Date Time Nbr of Stat. Seq nbr Length Stat field
mHealth: mobile Health and pHealth: personalized Health

A Personal Health System for an early detection of cardiac events to reduce the time between the first symptoms and the hospital admission

- It allows any citizen to record himself his own ECG anywhere and at any time.
- It’s an intelligent system with advanced ECG analysis and automatic interpretation.
- It embeds a web server to make the data available via a web browser from any computer of any physician who has the access rights.

mHealth: mobile Health and pHealth: personalized Health

Snapshot of the Information Model embedded in the Personal Health System
mHealth: mobile Health and pHealth: personalized Health

Self-care, Pervasive Computing & Ambient Intelligence
Self-Care and Self-Recording in pHealth

Self-Reference and Central Limit Theorem

ECG-12D

Committee of 50 neural nets

Net 1

Net 2

Net 50

Input

DI

DII

V2

Output

V1

V3

V4

V5

V6

Personnalized Transform Based on ANN

Generic Transform

ECG-3D
Autonomic and Grid Computing for Enhanced pHealth

Example of ECG autonomic decision-support performance in an emergency department for infarction detection

ROC curves – Test set – Unary analysis

988 patients

From Ohlson et al., Am. J. Cardiol., 2001
and Atoui et al., IEEE CISIS 2008: 583-8

High BP
Atherosclerosis
Diabetes
Smoking
Heart Disease
Infarction
Risk Factors

Bayesian Network

High risk \(\rightarrow\) Emergency alarm
Low risk \(\rightarrow\) Advice
Medium alarm \(\rightarrow\) Referring Physician
No problem

ECG interpretation Module

ANN1
ANN2
...
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“The most widely recognized elements of autonomic systems are the so-called self-* properties”, Dobson et al., Computer, IEEE Press, 2010

What are the lessons & future challenges?

- Concepts of context awareness and self-adaptation of the heart system
  - Self-governance of QT measurements in function of heart rate
    - The memory effect used for self-learning model design is fruitful for event risk prediction

- How can self-recording (or self-monitoring) in self-care in pHealth improve the quality of life, the quality of service for well-being?
  - Personalized health is a great challenge today with a lot of research in this field, from sensors technology, up to quality of service for decision delivery
  - False alarms must be reduced as much as possible. But, in medicine the human experts as well as the machines are not perfect

- How could the machine, as well as the human, benefit from its past experience?
  - Self-experimenting by self-learning leads to self-improvement. (ANN, KBR, CBR, …)
What are the lessons & future challenges?

- Personalization in pHealth is not just self-configuring or customization
- Concept of self-reference for serial ECG analysis and personalized ECG synthesis
  - Taking the individual as his own reference improves the results.
- Self-reference, the best model of personalization to empower autonomic computing?
  - The first step of the system design is to well define the scope of the problems and to come back to the source of the information which is considered.
  - This information has to be assessed into its own reference system. That leads to develop mathematical methods of self-representation of the analyzed data (ex. PCA in statistics where data are analyzed in their own space).
  - The constraint to assume is the capability of the system to continuously change the representation system or information model according to the data dynamicity
    → A challenge at run-time.
What are the lessons & future challenges?

- Enhance automated decision by using **Committees** of experts or reasoners
  - Use several methods or business process architectures in parallel to get the same decision. Taking the result of the **majority vote** will enhance the response.

- Enhance the capabilities of **Anticipation**: a future challenge?
  - For a prompt delivery of the relevant information, the user needs should be determined before the user expresses them.
  - Real time dynamic context analysis should contribute to reach this objective.
  - User habits and preferences tracking should contribute to provide personalized anticipated services. (Ex. of MMI in healthcare to overcome the physician's overload of information while browsing the medical records for finding the relevant data).

- Enhance Embedded **Intelligence**
  - Automation of dynamic information and knowledge models merging, driven by the citizen’s data and by artificial intelligence methods, in real time.

Thank You for Your Attention

jocelyne.fayn@inserm.fr