2012 SIAM Conference on Applied Linear Algebra
Minisimposium Application of compressed sensing in bio-medicine
Valencia, Spain, June 18th 2012

Evaluation of Compressed Sensing Impact in Cardiac Signals Processing and Transmission

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INSTITUIÇÕES ASSOCIADAS:

instituto de telecomunicações

creating and sharing knowledge for telecommunications

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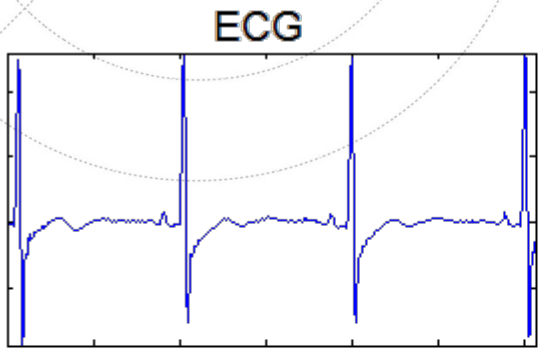
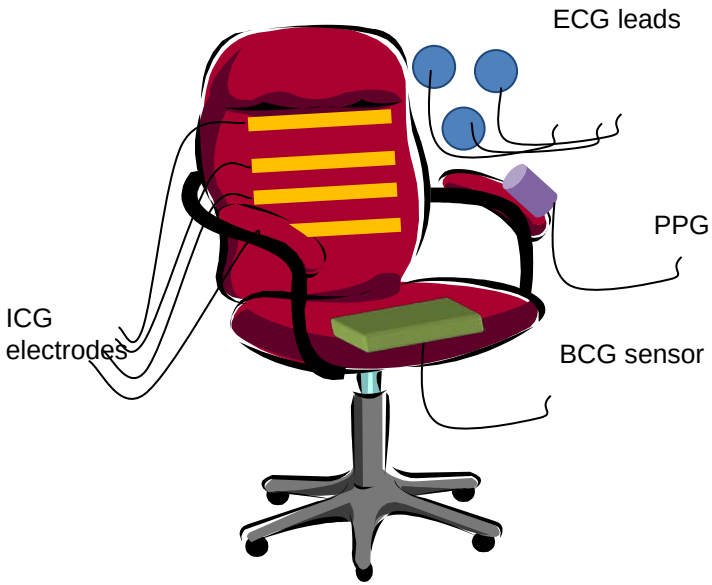
Motivation – Cardiac Signals

Electro, myocardium electrical stimulus





Motivation – Cardiac Signals

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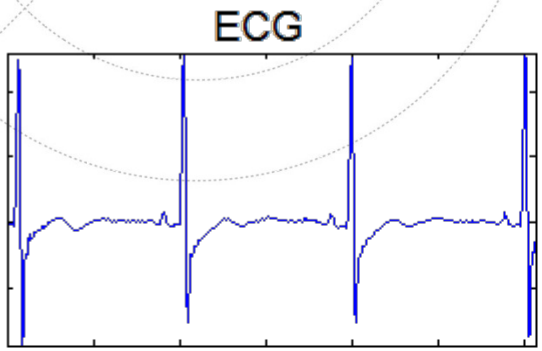
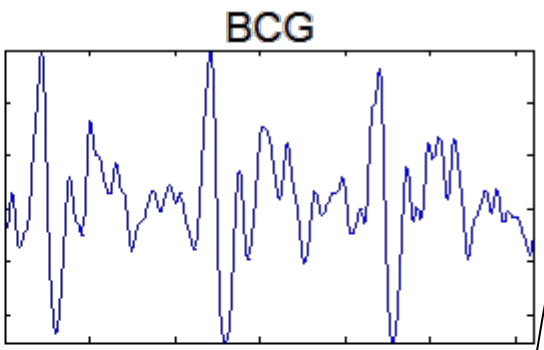
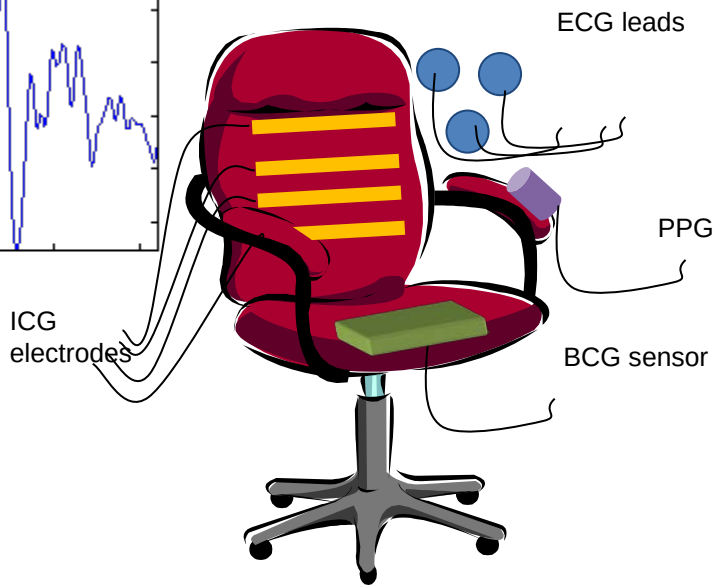
Ballisto, force variations during cardiac cycle







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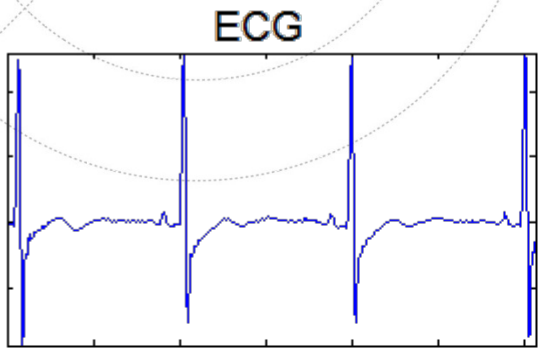
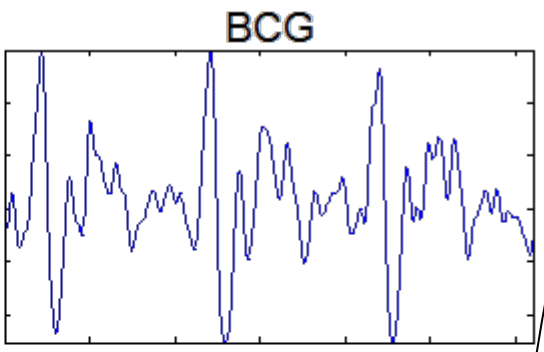
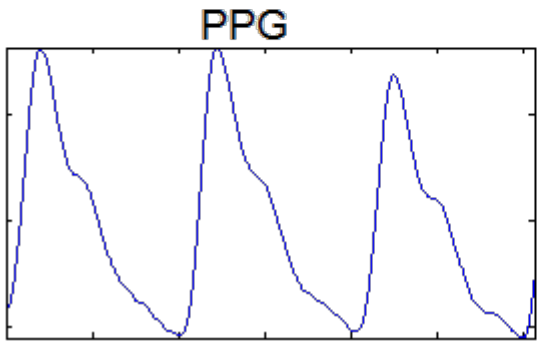
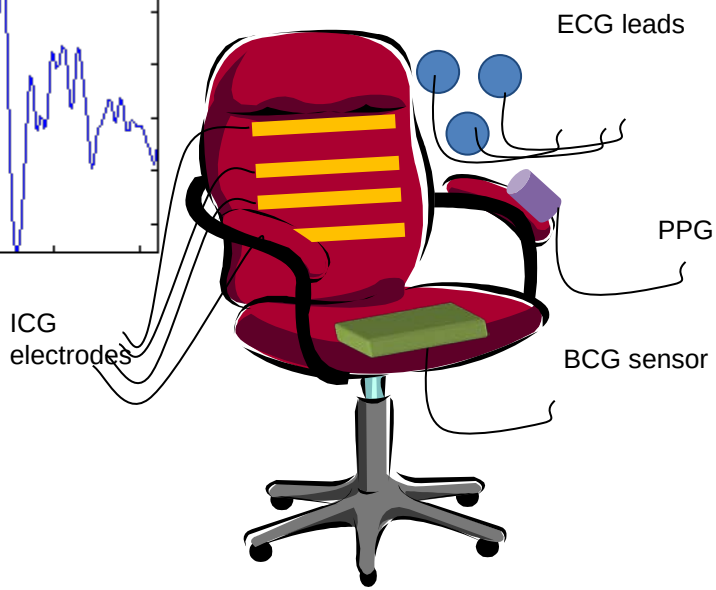
Photoplethys, tissues' transmittance of IR/R light due to blood absorption









Motivation – Cardiac Signals

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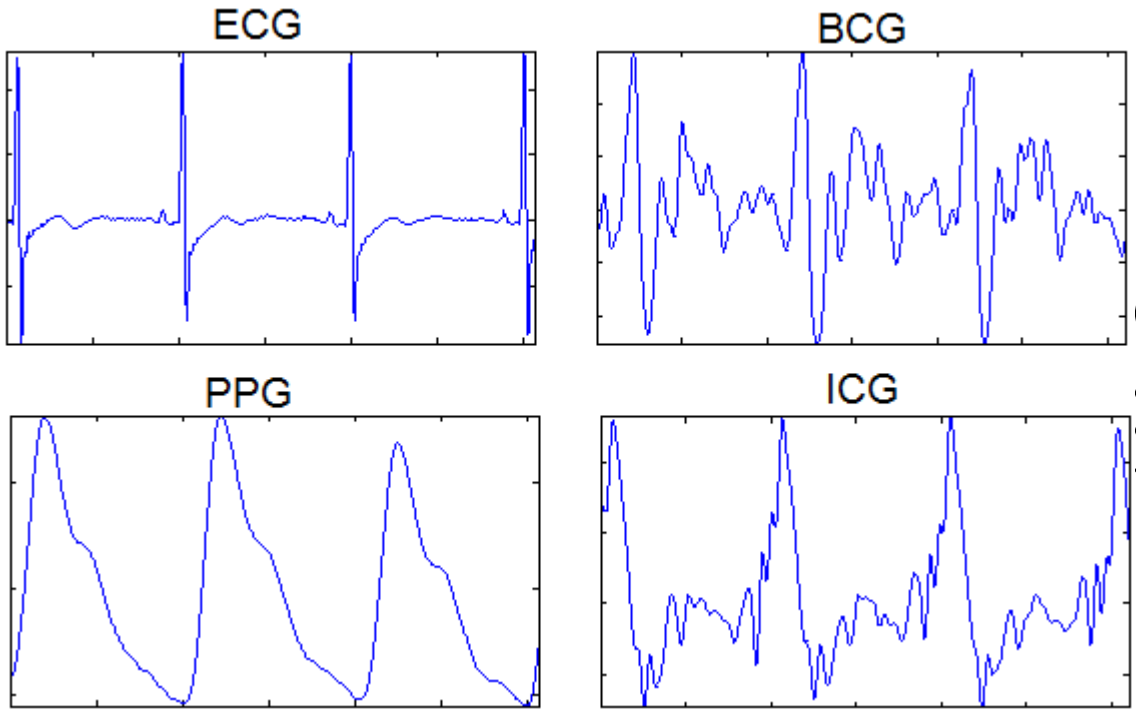
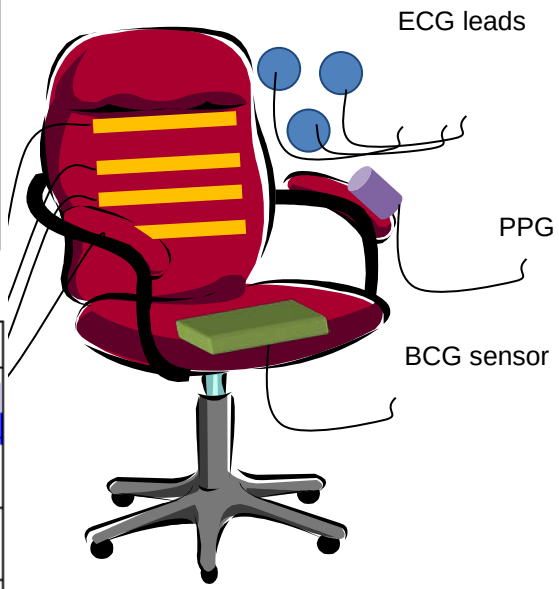
Impedance, impedance changes due to blood passage





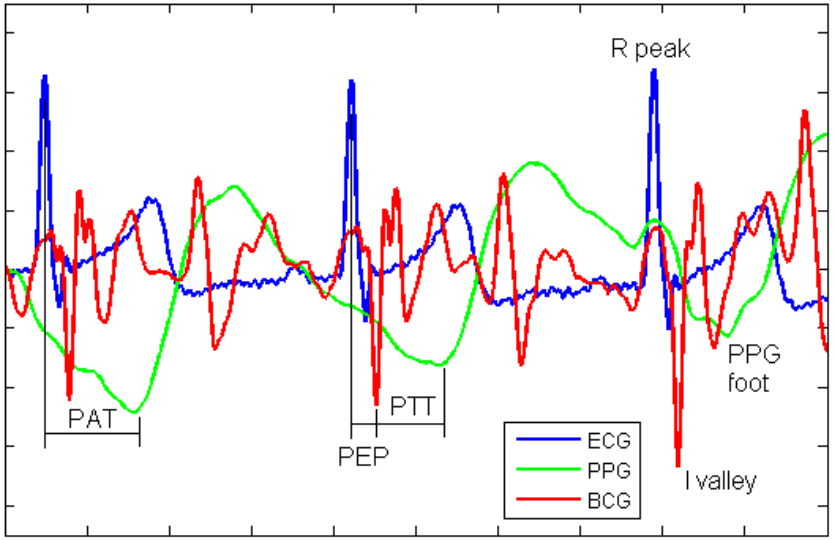
Motivation – Which relations?

ECG sync

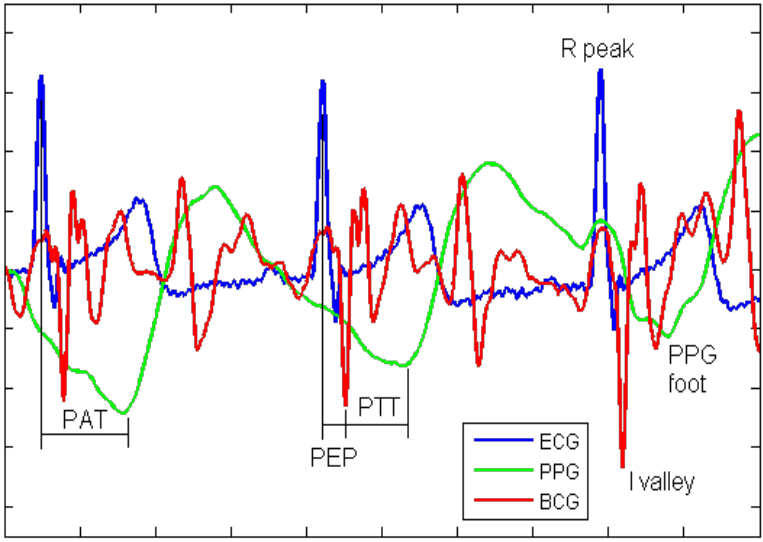
PPG max derivative => systolic blood pressure

BCG valley => cardiac output, stroke volume

ICG => left ventricular ejection time



Motivation – Which tradeoffs?



Information

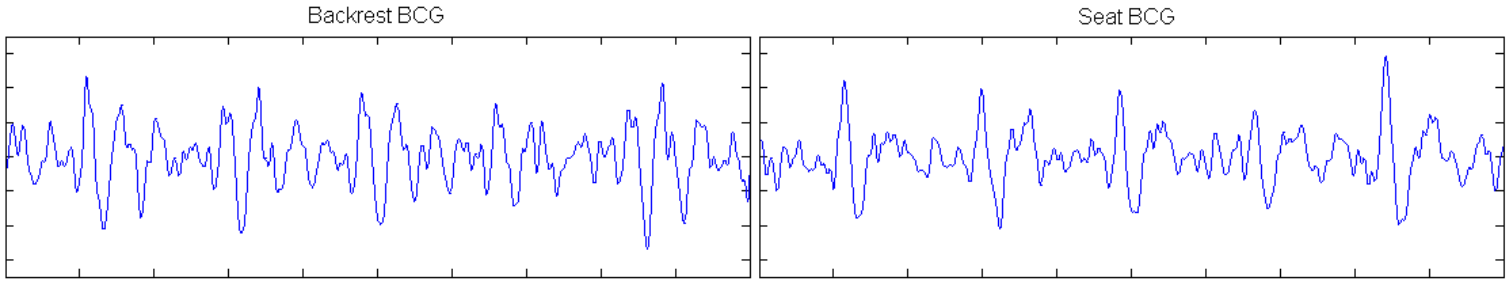
Blood Pressure, HRV, arrest?

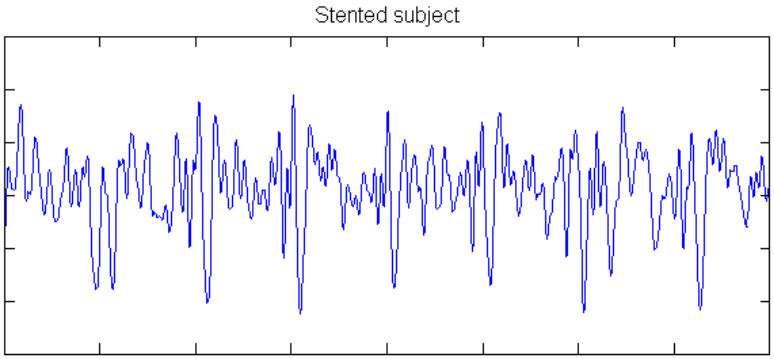
Problems

Artifact sensibility (motion, talk, breath)

Morphology dependent on measurement conditions

Medical staff demands exact signals





Teenager and subject with coronary stent

Approaches on CS

A time signal *x*, a vector composed of *N* samples, is *K*-sparse or compressible in a basis Ψ, represented by an *N* x *N* matrix in which each column is a basis vector ψ_i, if *x* can be well approximated by a linear combination of only *K* vectors of Ψ, with *K* significantly < *N*. Most (*N*–*K*) of the expansion coeffs α, in the representation $x = \Psi\alpha$ are negligible if compared to the dominant terms.

The signal can be reconstructed from a number of *M*, slightly >*K* but still <<N, linear projections of *x* onto another basis Φ incoherent with Ψ, where incoherency signifies that the elements of Φ cannot represent sparsely the elements of Ψ and vice-versa, $y = \Phi x = \Phi\Psi\alpha$

$x = \Psi\alpha$ has K non-zero $\alpha_i \Rightarrow x$ (of size $N>>K$) is K-sparse in Ψ

$y = \Phi x = \Phi\Psi\alpha$ ($M>K$ projections of x onto Φ) $\Rightarrow x$ is described by y

$M<<N$

$$\hat{\alpha} = \arg\min_{\alpha} \|\alpha\|_{l_1} \text{ subject to } \Phi\Psi\alpha = y$$

$$\hat{\alpha} = \arg\min_{\alpha} \|y - \Phi\Psi\alpha\|_{l_2}^{2} + \tau\|\alpha\|_{l_1}$$

Approaches on CS

Two-step Iterative Shrinkage/Thresholding

Two-step iterative shrinkage/thresholding algorithm overcoming the dependence on the linear observation operator by implementing a nonlinear two-step (or 2nd order) version of IST.

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Split Augmented Lagrangian Shrinkage Algorithm

Adapt of Bregman iterations. Constrained problem set to an unconstrained by adding the indicator function of the feasible set, the ellipsoid {x : ||Bx-y||<=ε}. Then a different constrained problem, by applying a variable splitting operation; finally the problem is attacked with an augmented Lagrangian (AL) scheme, a variant of the ADMM

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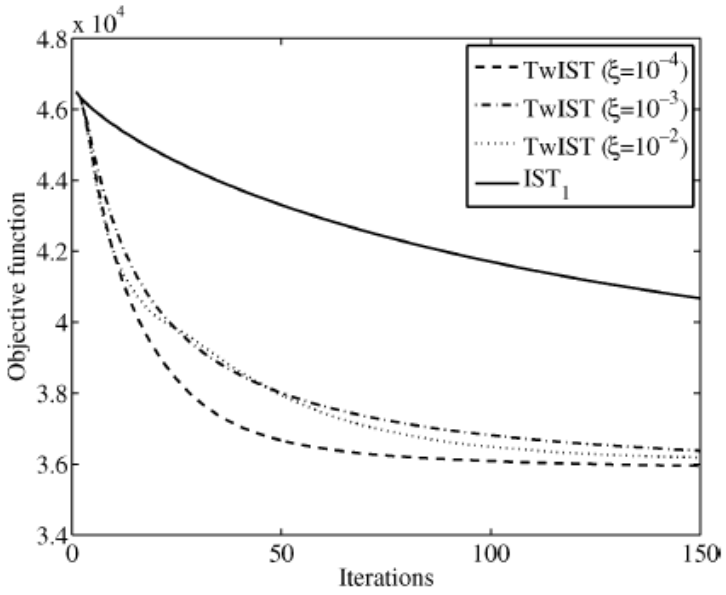
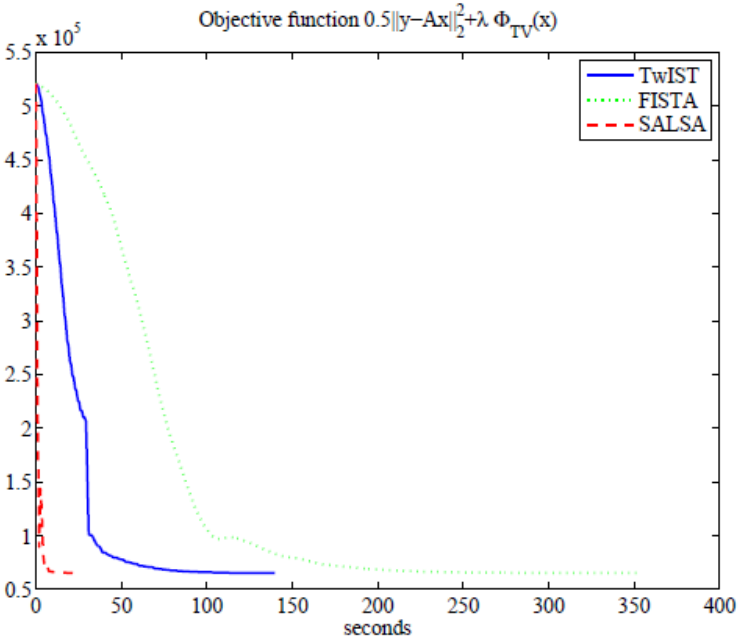
Sparse Reconstruction by Separable Approximation

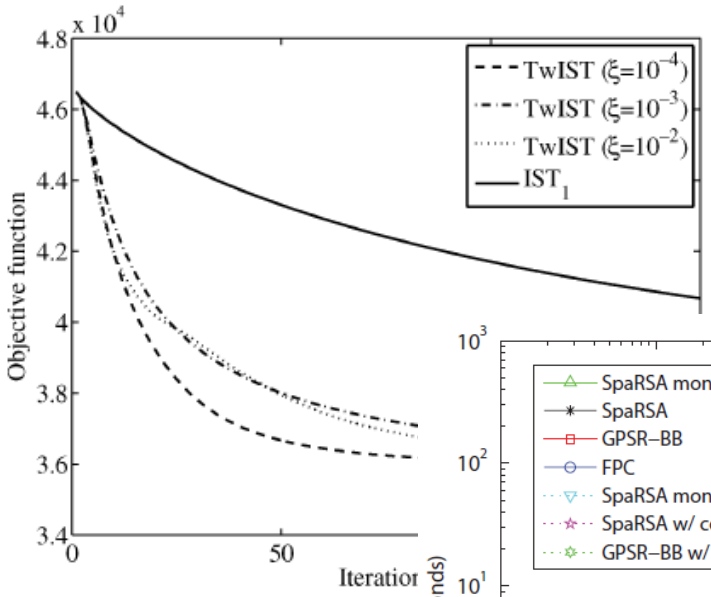
2011 IEEE SPS Best Paper Award. Optimization subproblem involving a quadratic term with diagonal Hessian plus the original sparsity-inducing regularizer; suitable for cases in which this subproblem can be solved much more rapidly than the original problem

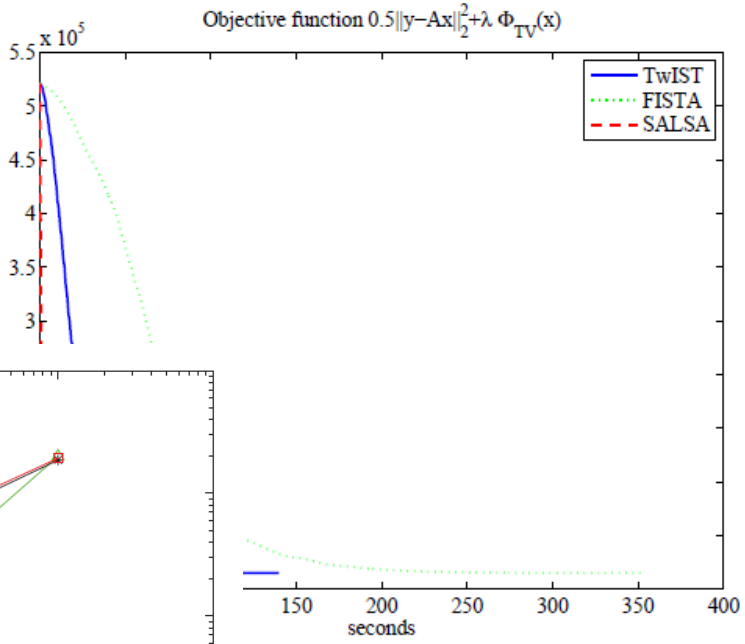
Approaches on CS

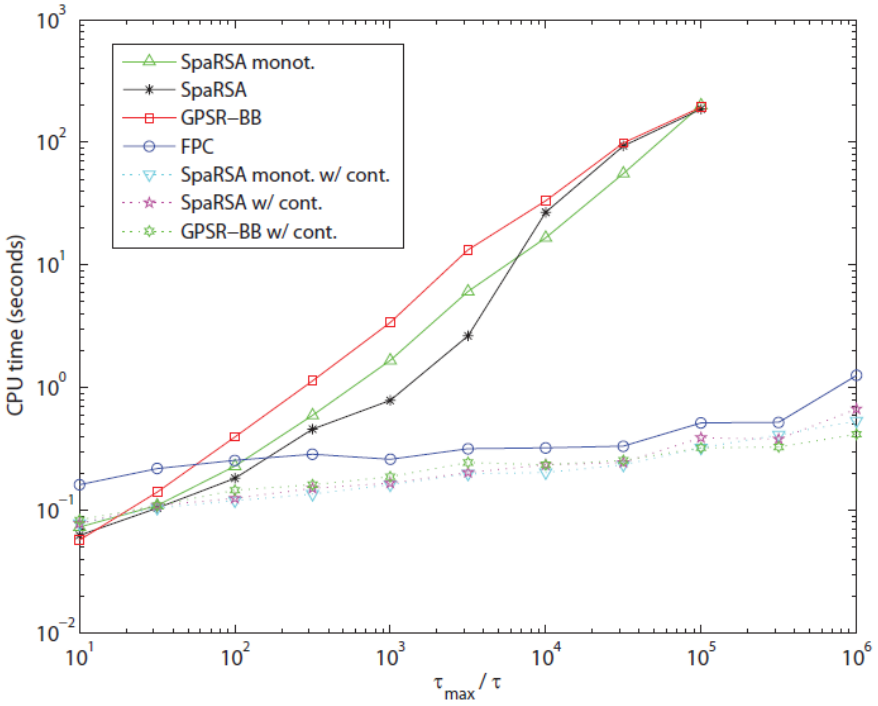




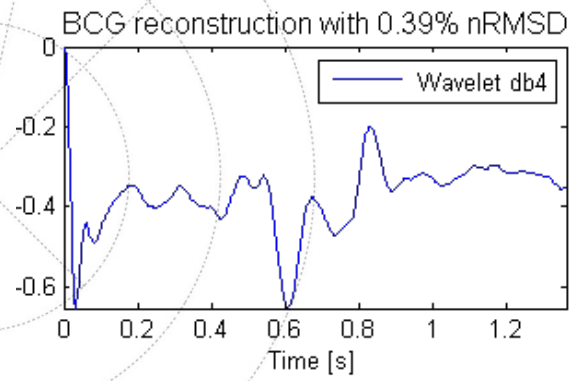
Approaches on CS

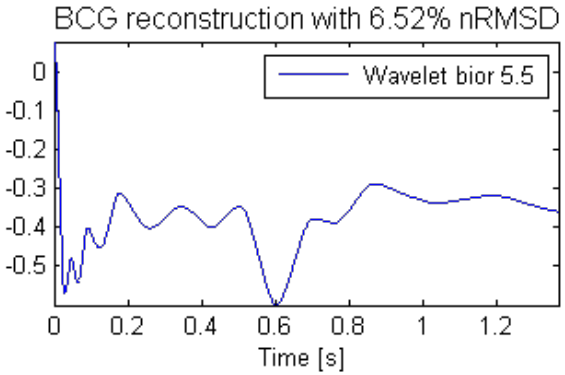


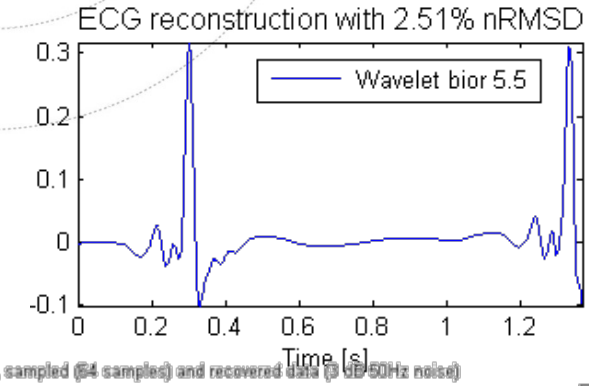


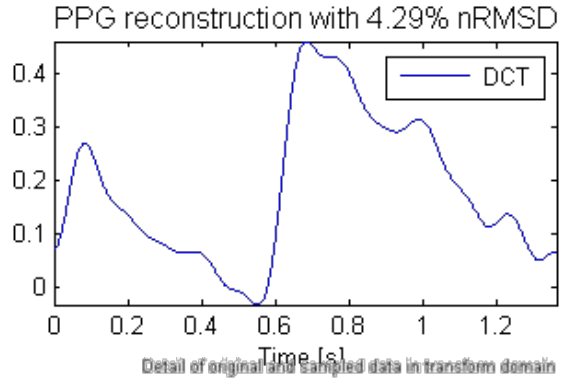


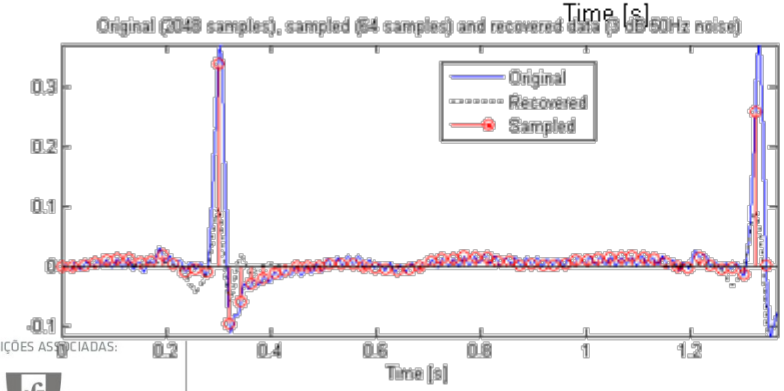
Cardiac Signals Processing

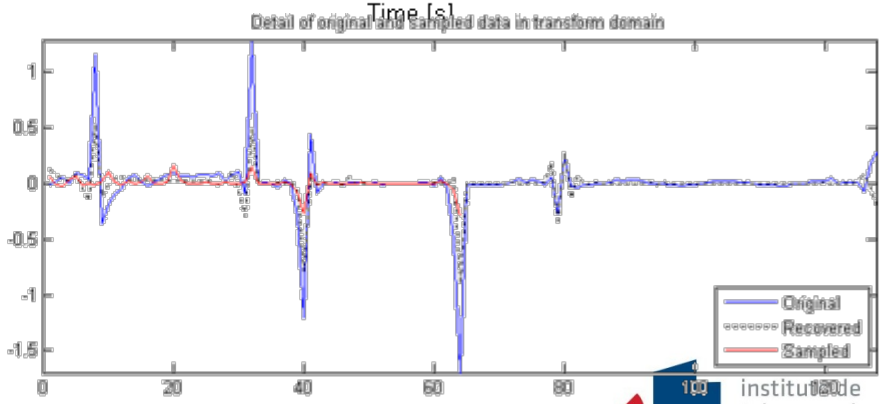




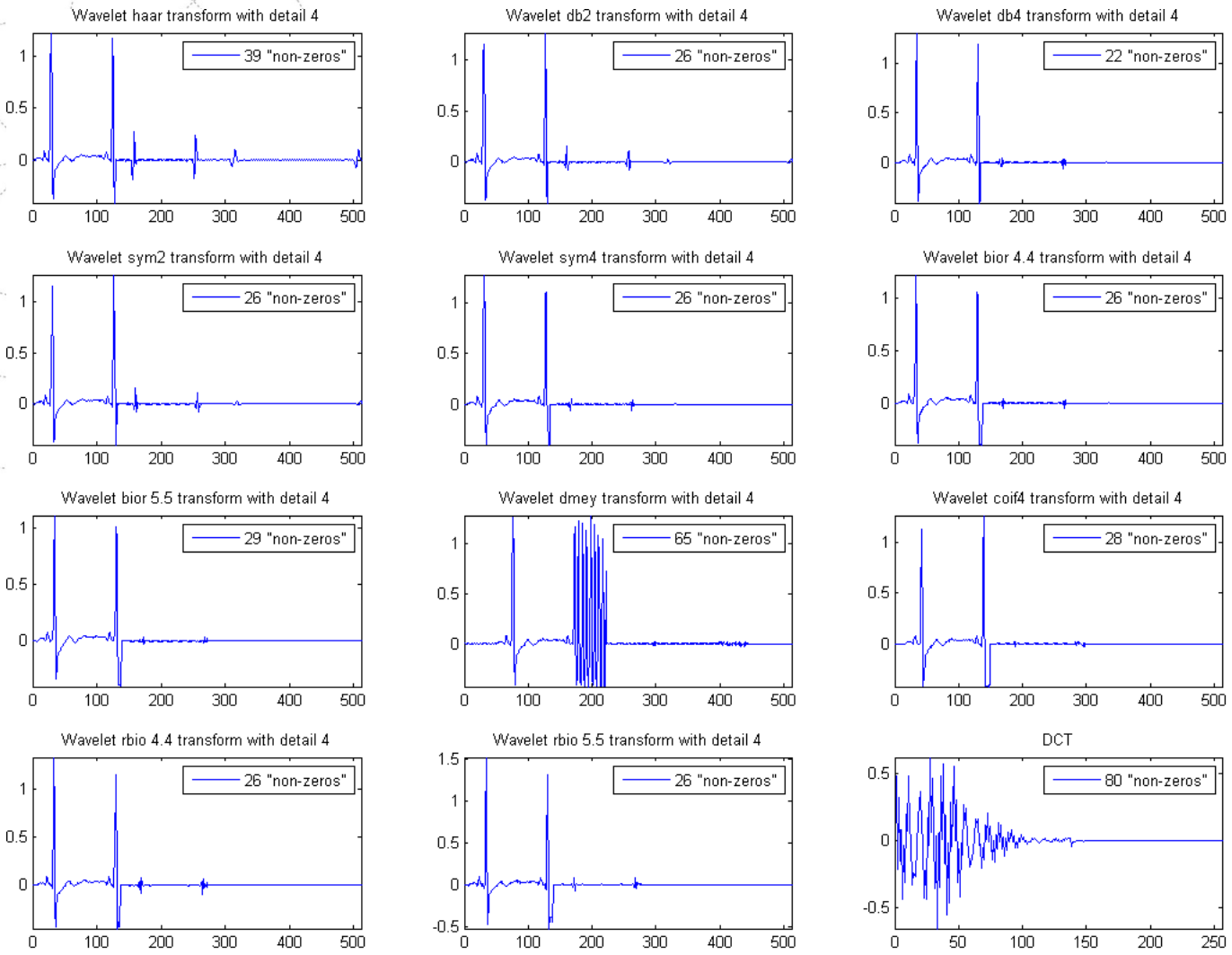




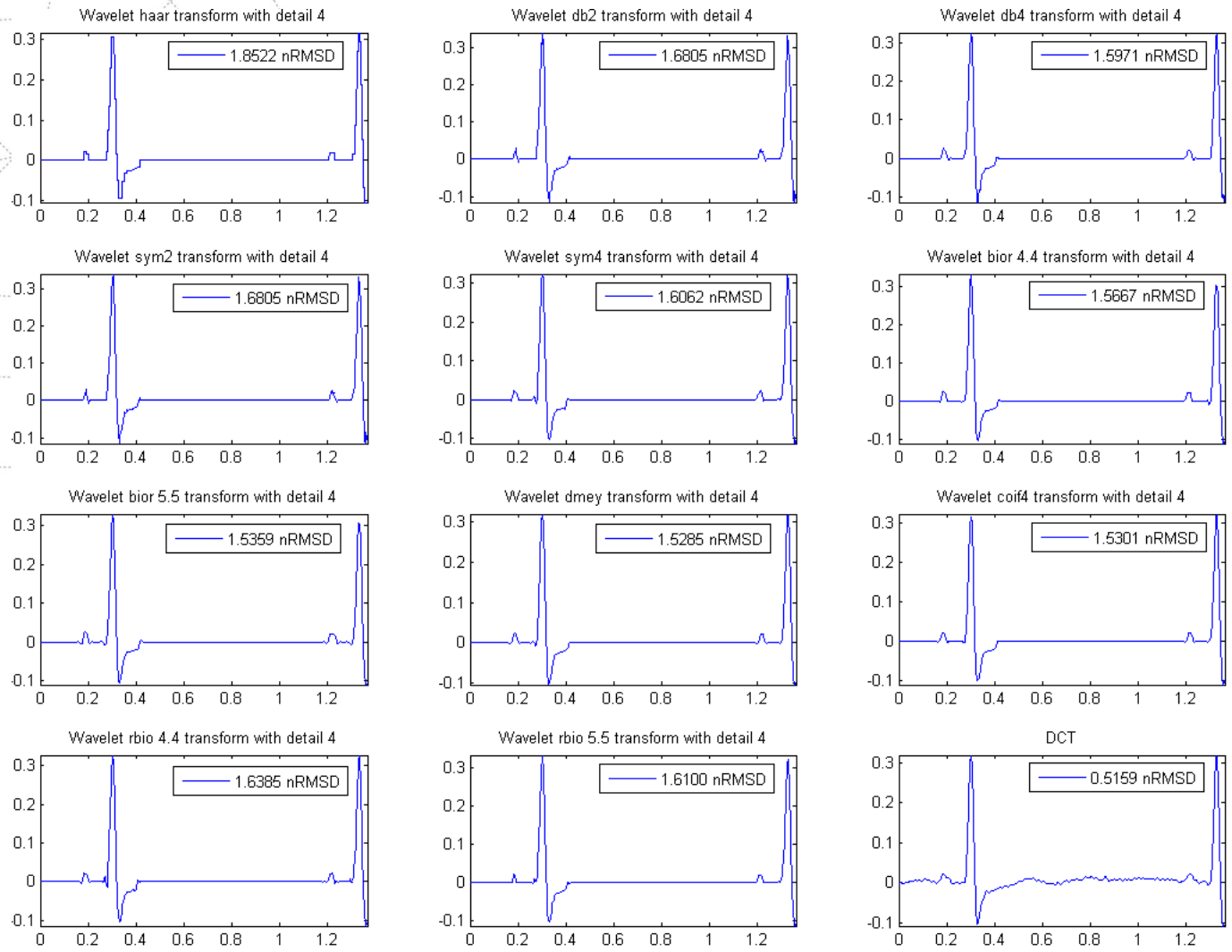




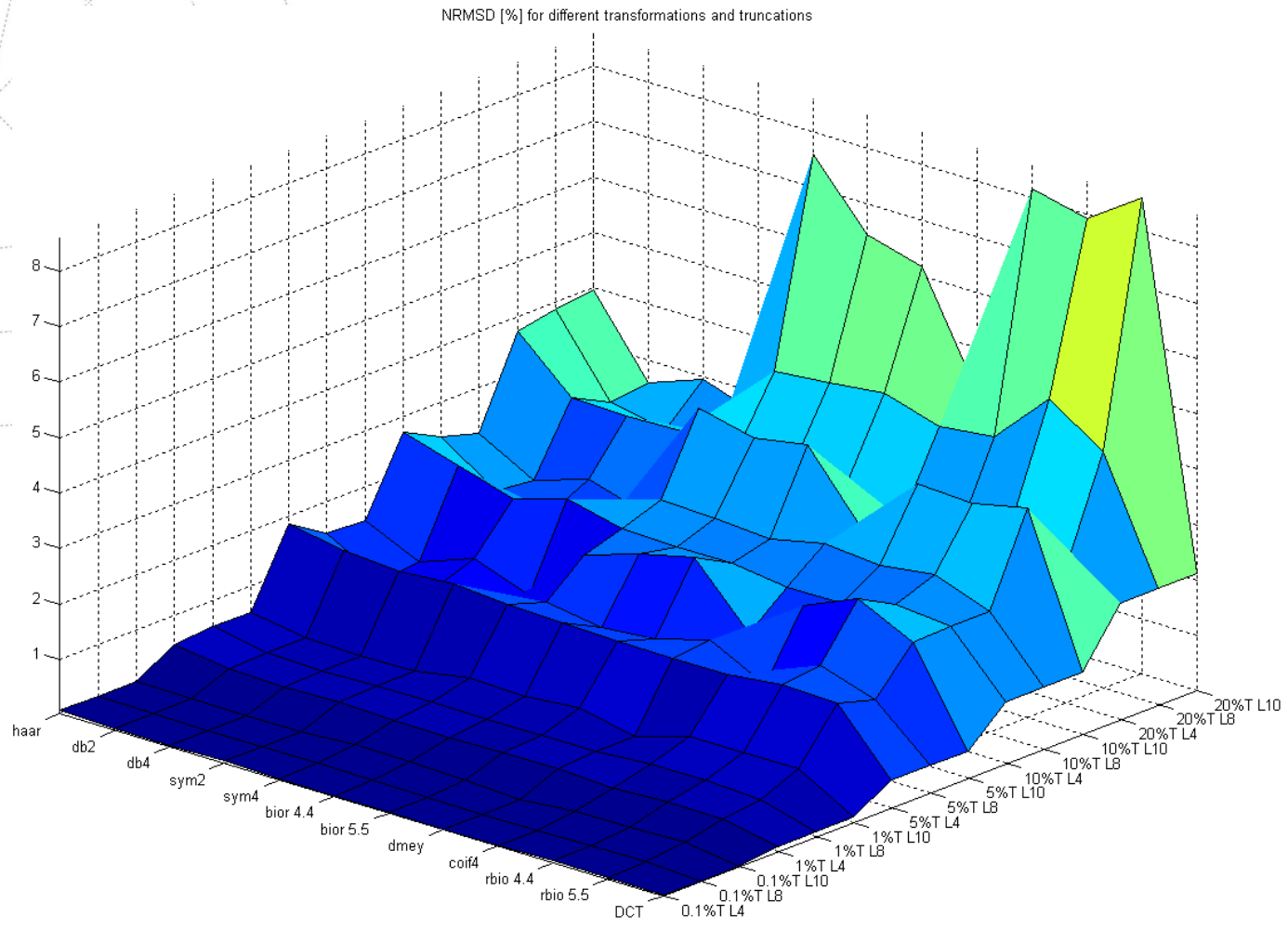
ECG – K


Wavelet haar transform with detail 4
39 "non-zeros"
Wavelet db2 transform with detail 4
26 "non-zeros"
Wavelet db4 transform with detail 4
22 "non-zeros"
Wavelet sym2 transform with detail 4
26 "non-zeros"
Wavelet sym4 transform with detail 4
26 "non-zeros"
Wavelet bior 4.4 transform with detail 4
26 "non-zeros"
Wavelet bior 5.5 transform with detail 4
29 "non-zeros"
Wavelet dmey transform with detail 4
65 "non-zeros"
Wavelet coif4 transform with detail 4
28 "non-zeros"
Wavelet rbio 4.4 transform with detail 4
26 "non-zeros"
Wavelet rbio 5.5 transform with detail 4
26 "non-zeros"
DCT
80 "non-zeros"

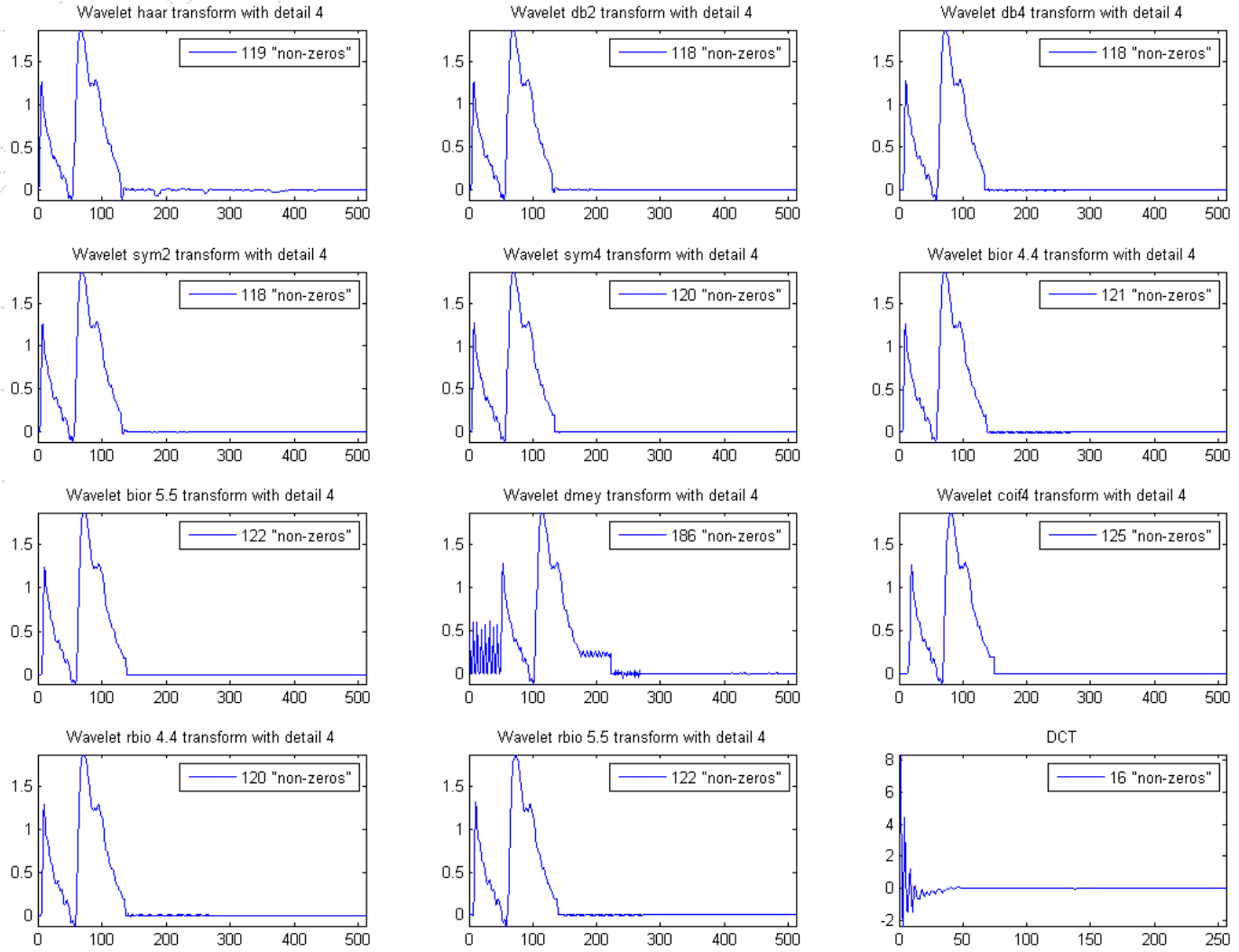
ECG – rec


Wavelet haar transform with detail 4
1.8522 nRMSD
Wavelet db2 transform with detail 4
1.6805 nRMSD
Wavelet db4 transform with detail 4
1.5971 nRMSD
Wavelet sym2 transform with detail 4
1.6805 nRMSD
Wavelet sym4 transform with detail 4
1.6062 nRMSD
Wavelet bior 4.4 transform with detail 4
1.5667 nRMSD
Wavelet bior 5.5 transform with detail 4
1.5359 nRMSD
Wavelet dmey transform with detail 4
1.5285 nRMSD
Wavelet coif4 transform with detail 4
1.5301 nRMSD
Wavelet rbio 4.4 transform with detail 4
1.6385 nRMSD
Wavelet rbio 5.5 transform with detail 4
1.6100 nRMSD
DCT
0.5159 nRMSD

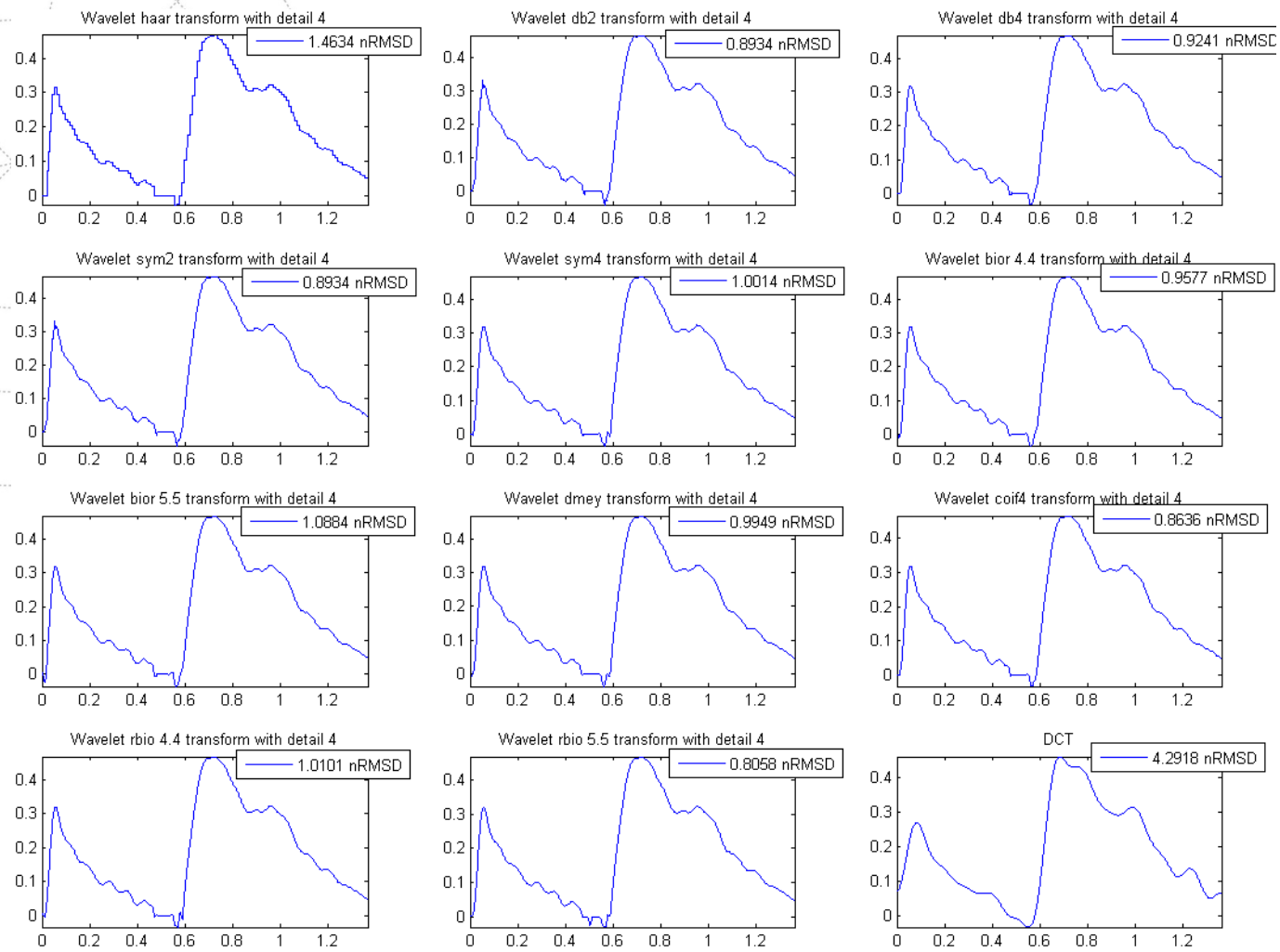
ECG – nRMSD


NRMSD [%] for different transformations and truncations
8
7
6
5
4
3
2
1
haar
db2
db4
sym2
sym4
bior 4.4
bior 5.5
dmey
coif4
rbio 4.4
rbio 5.5
DCT
0.1%T L4
0.1%T L8
0.1%T L10
1%T L4
1%T L8
1%T L10
5%T L4
5%T L8
5%T L10
10%T L4
10%T L8
10%T L10
20%T L4
20%T L8
20%T L10

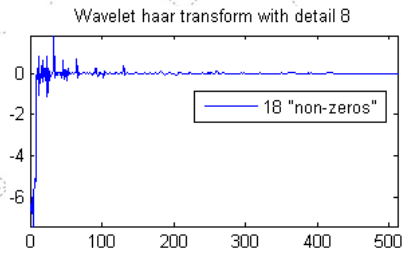
PG – K

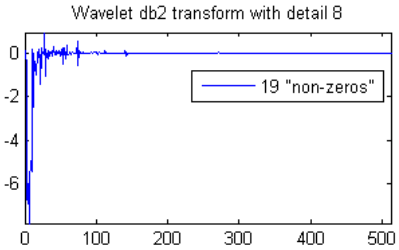

Wavelet haar transform with detail 4
119 "non-zeros"
Wavelet db2 transform with detail 4
118 "non-zeros"
Wavelet db4 transform with detail 4
118 "non-zeros"
Wavelet sym2 transform with detail 4
118 "non-zeros"
Wavelet sym4 transform with detail 4
120 "non-zeros"
Wavelet bior 4.4 transform with detail 4
121 "non-zeros"
Wavelet bior 5.5 transform with detail 4
122 "non-zeros"
Wavelet dmey transform with detail 4
186 "non-zeros"
Wavelet coif4 transform with detail 4
125 "non-zeros"
Wavelet rbio 4.4 transform with detail 4
120 "non-zeros"
Wavelet rbio 5.5 transform with detail 4
122 "non-zeros"
DCT
16 "non-zeros"

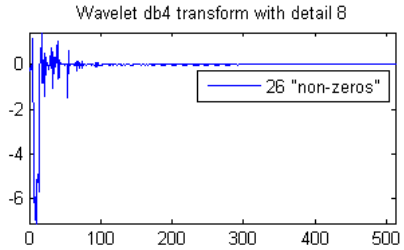
PG – rec

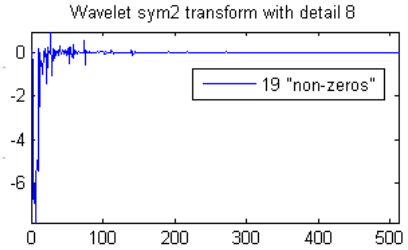

Wavelet haar transform with detail 4
1.4634 nRMSD
Wavelet db2 transform with detail 4
0.8934 nRMSD
Wavelet db4 transform with detail 4
0.9241 nRMSD
Wavelet sym2 transform with detail 4
0.8934 nRMSD
Wavelet sym4 transform with detail 4
1.0014 nRMSD
Wavelet bior 4.4 transform with detail 4
0.9577 nRMSD
Wavelet bior 5.5 transform with detail 4
1.0884 nRMSD
Wavelet dmey transform with detail 4
0.9949 nRMSD
Wavelet coif4 transform with detail 4
0.8636 nRMSD
Wavelet rbio 4.4 transform with detail 4
1.0101 nRMSD
Wavelet rbio 5.5 transform with detail 4
0.8058 nRMSD
DCT
4.2918 nRMSD

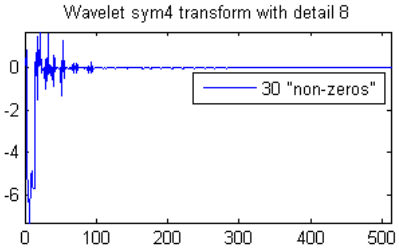
BCG – K

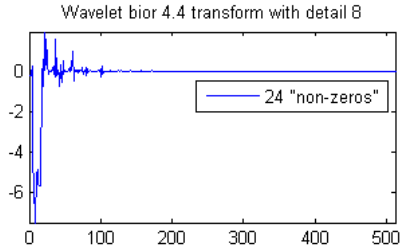

Wavelet haar transform with detail 8
18 "non-zeros"

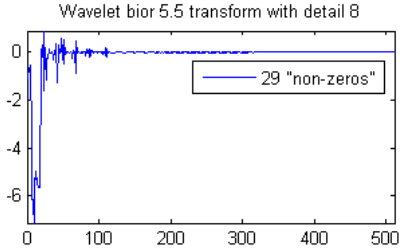

Wavelet db2 transform with detail 8
19 "non-zeros"

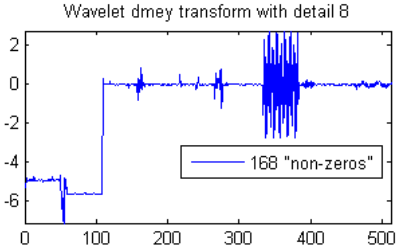

Wavelet db4 transform with detail 8
26 "non-zeros"

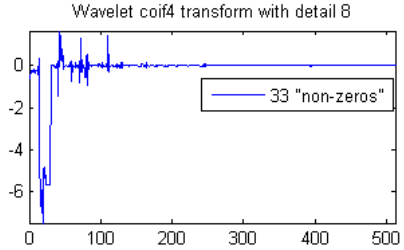

Wavelet sym2 transform with detail 8
19 "non-zeros"

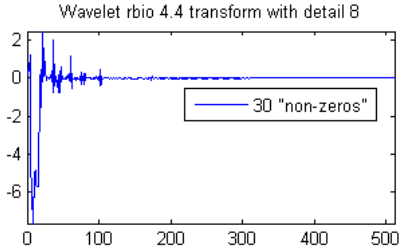

Wavelet sym4 transform with detail 8
30 "non-zeros"

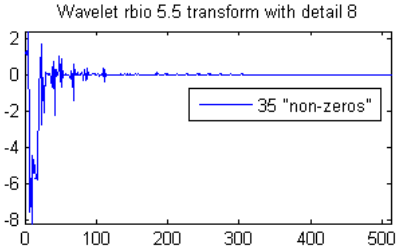

Wavelet bior 4.4 transform with detail 8
24 "non-zeros"

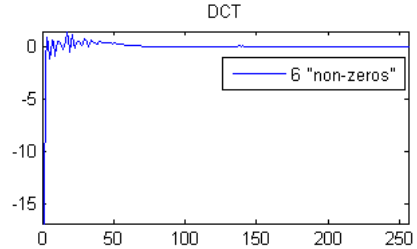

Wavelet bior 5.5 transform with detail 8
29 "non-zeros"


Wavelet dmey transform with detail 8
168 "non-zeros"

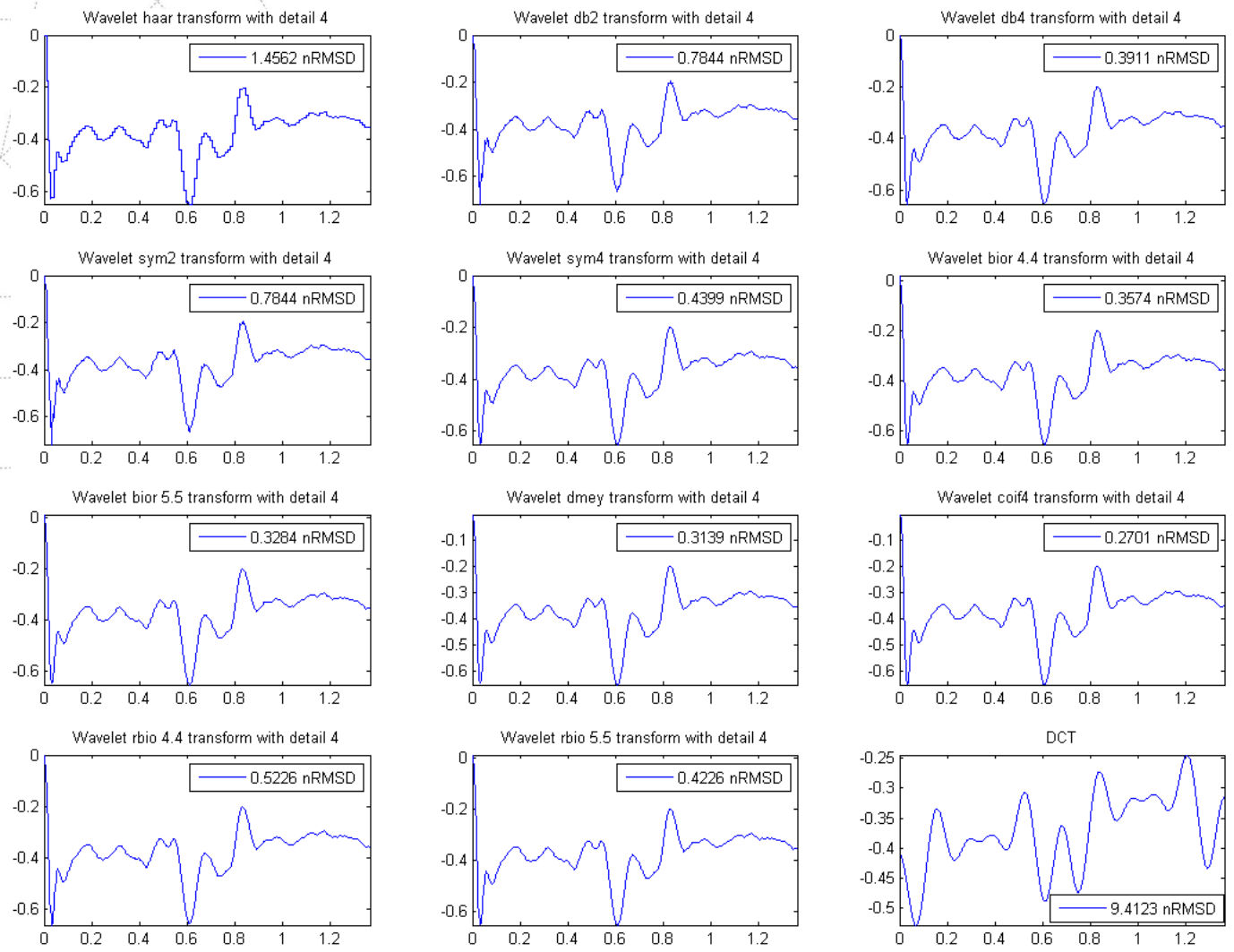

Wavelet coif4 transform with detail 8
33 "non-zeros"


Wavelet rbio 4.4 transform with detail 8
30 "non-zeros"

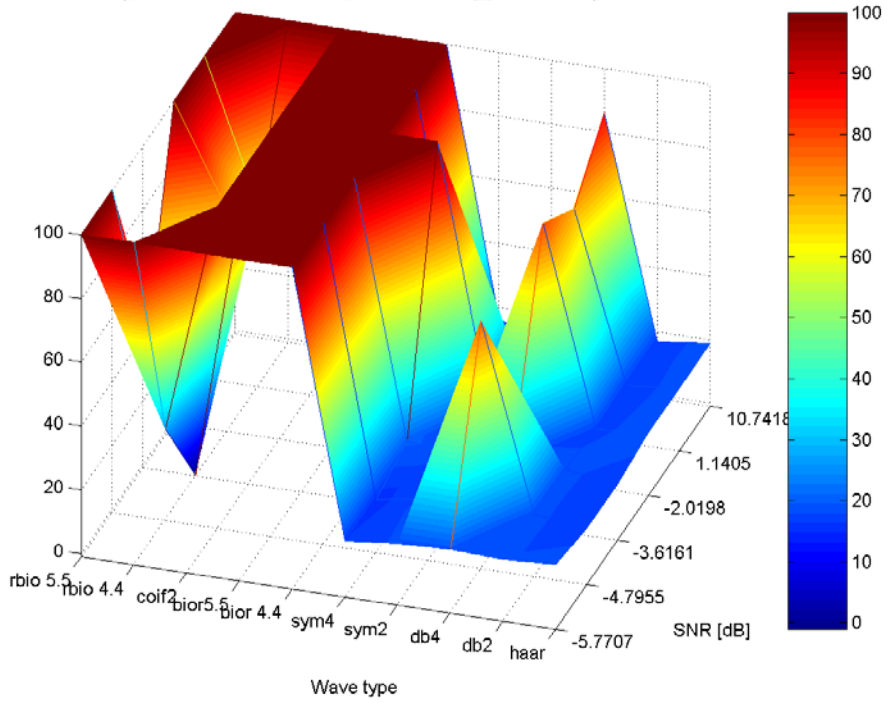

Wavelet rbio 5.5 transform with detail 8
35 "non-zeros"

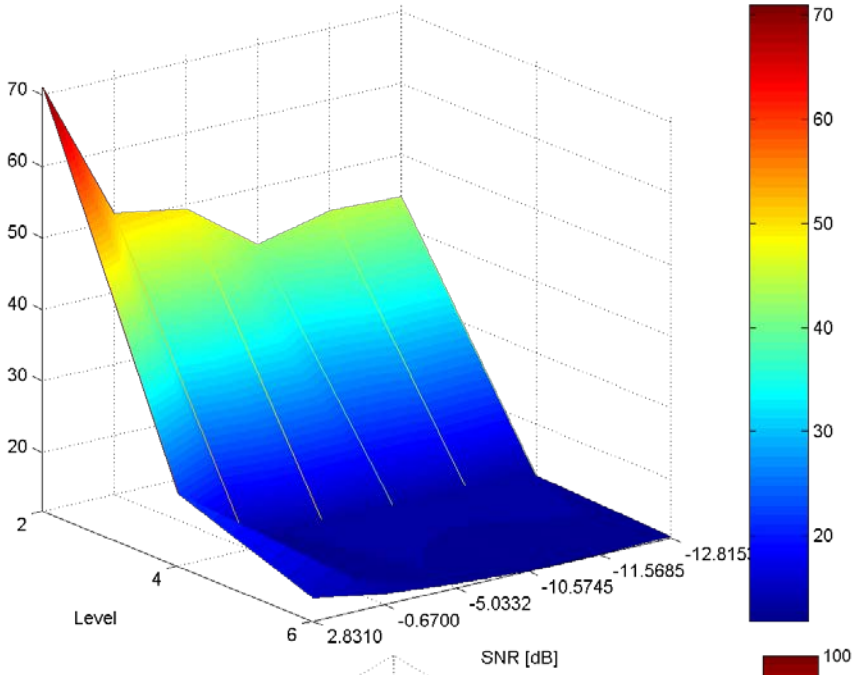

DCT
6 "non-zeros"

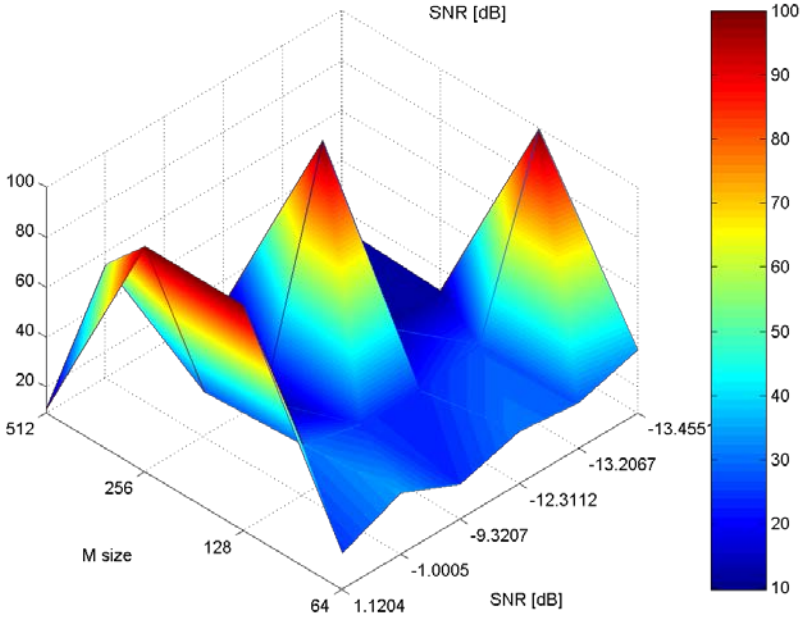
BCG – rec


Wavelet haar transform with detail 4
1.4562 nRMSD
Wavelet db2 transform with detail 4
0.7844 nRMSD
Wavelet db4 transform with detail 4
0.3911 nRMSD
Wavelet sym2 transform with detail 4
0.7844 nRMSD
Wavelet sym4 transform with detail 4
0.4399 nRMSD
Wavelet bior 4.4 transform with detail 4
0.3574 nRMSD
Wavelet bior 5.5 transform with detail 4
0.3284 nRMSD
Wavelet dmey transform with detail 4
0.3139 nRMSD
Wavelet coif4 transform with detail 4
0.2701 nRMSD
Wavelet rbio 4.4 transform with detail 4
0.5226 nRMSD
Wavelet rbio 5.5 transform with detail 4
0.4226 nRMSD
DCT
9.4123 nRMSD

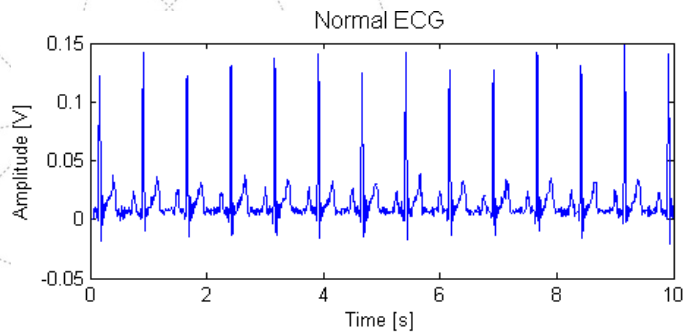
Noise?

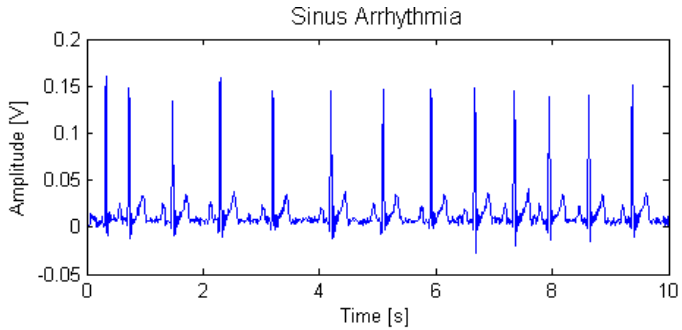

100
80
60
40
20
0
rbio 5.5
rbio 4.4
coif2
bior5.5
bior 4.4
sym4
sym2
db4
db2
haar
Wave type
10.7418
1.1405
-2.0198
-3.6161
-4.7955
-5.7707
SNR [dB]
100
90
80
70
60
50
40
30
20
10
0

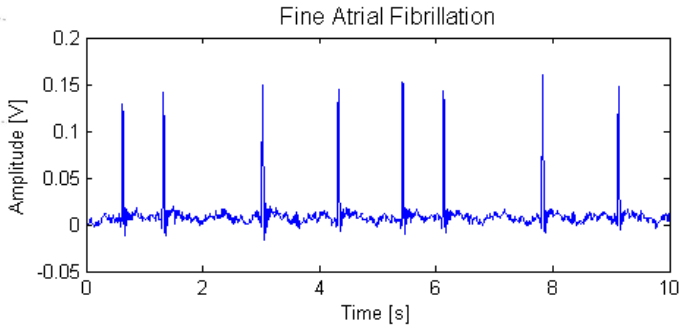

70
60
50
40
30
20
2
4
6
Level
2.8310
-0.6700
-5.0332
-10.5745
-11.5685
-12.815
SNR [dB]
70
60
50
40
30
20

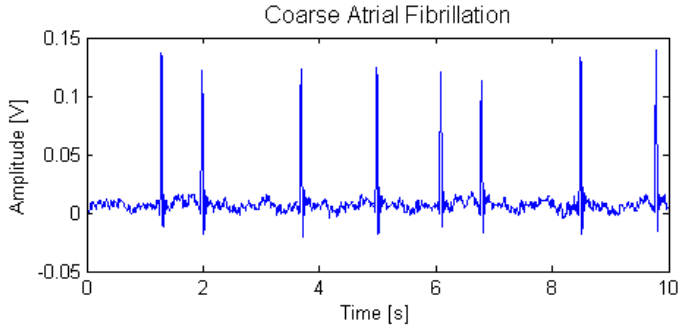

100
80
60
40
20
512
256
128
64
M size
1.1204
-1.0005
-9.3207
-12.3112
-13.2067
-13.455
SNR [dB]
100
90
80
70
60
50
40
30
20
10

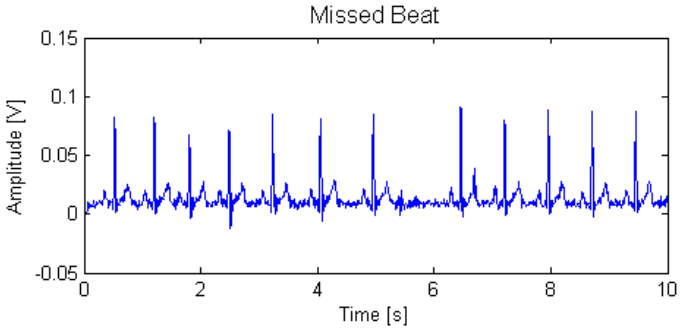
Diseases?

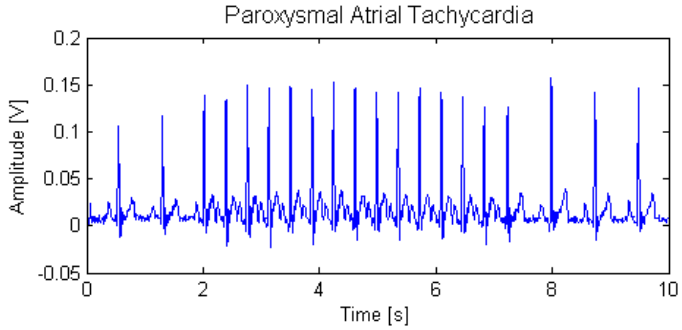

Normal ECG
Amplitude [V]
Time [s]


Sinus Arrhythmia
Amplitude [V]
Time [s]


Fine Atrial Fibrillation
Amplitude [V]
Time [s]


Coarse Atrial Fibrillation
Amplitude [V]
Time [s]


Missed Beat
Amplitude [V]
Time [s]


Paroxysmal Atrial Tachycardia
Amplitude [V]
Time [s]

Networking

Lossy transmissions cannot attain interpolation

Zero mean-signals => E[x]=0

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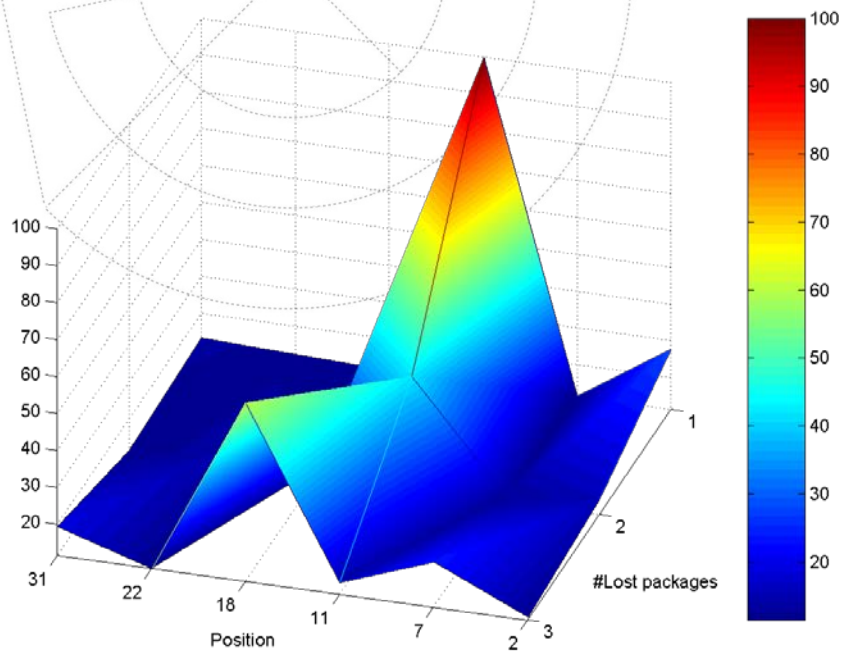
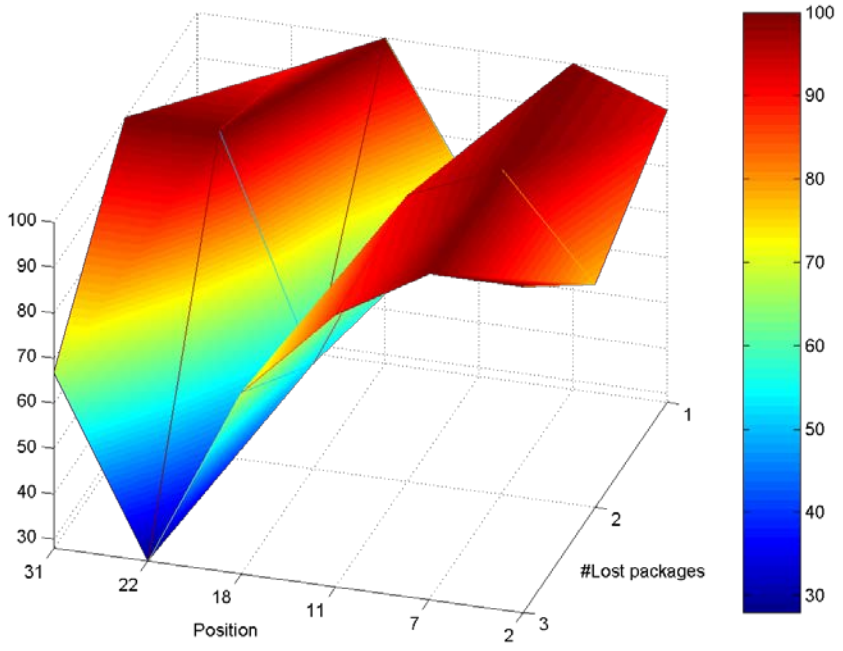
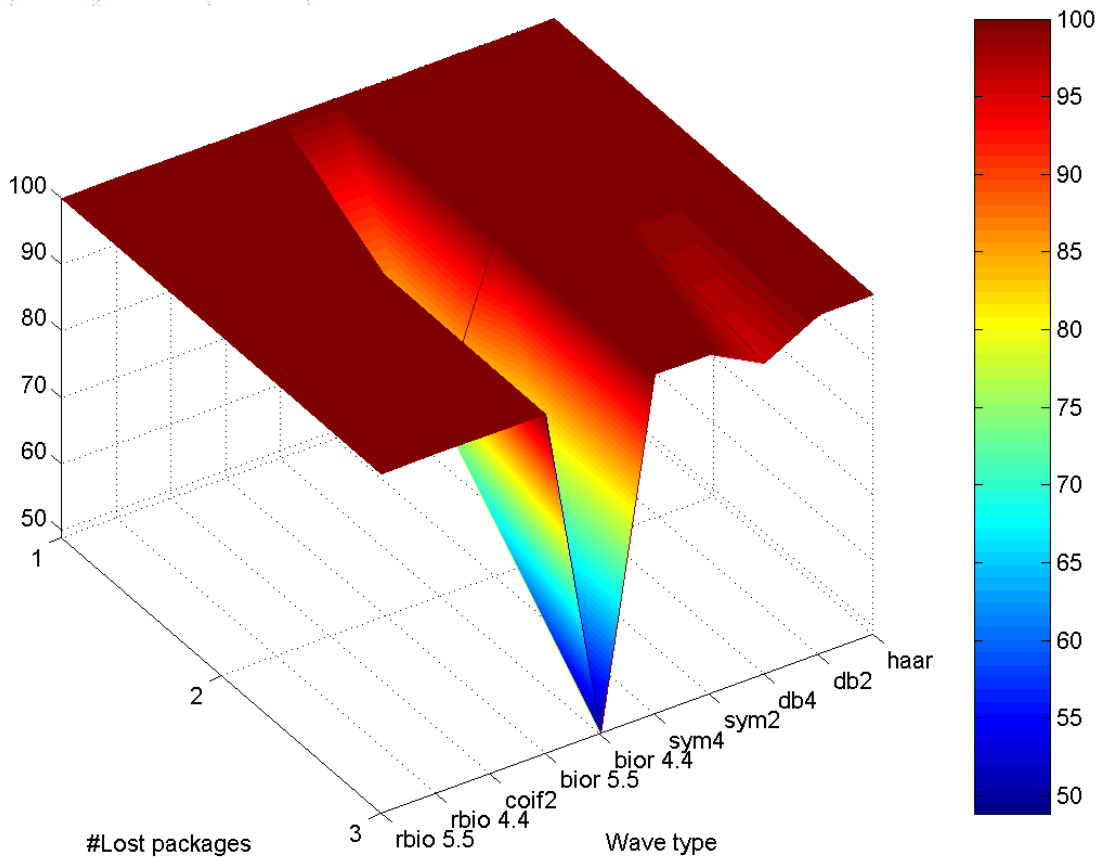




Samples have variable importance, but hints on their value are vital

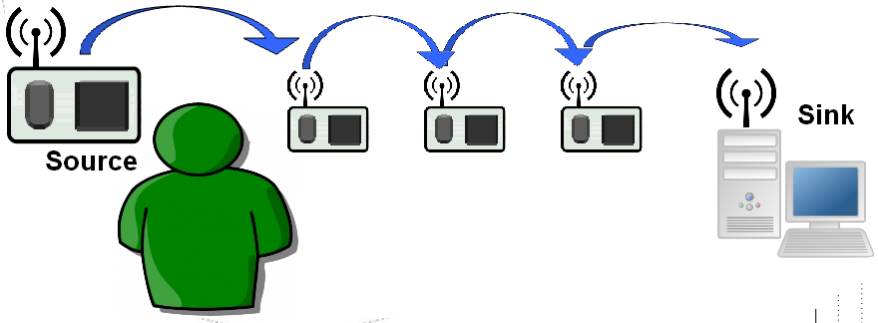
Networking



Samples have variable importance, but hints on their value are vital

Networking

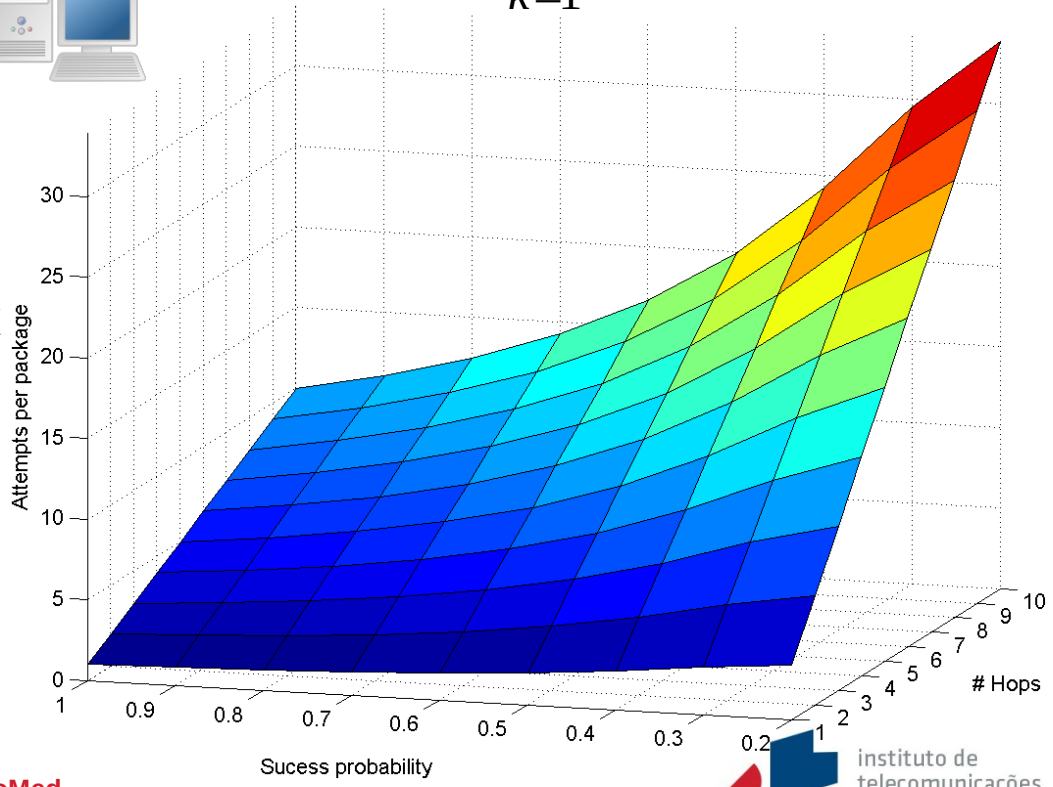
All packets needed, so, if random losses occur, with *p* probability, and at most *k* attempts, to cross *h* hops



$$\#Att = h \times \sum_{k=1}^{10} kp(1-p)^{k-1}$$

p=50%
k=10
h=4

7.9 att/pack



Compression of 8:1…

Networking

Power consumption in sensor nodes is dominated by radio (10:1 vs MCU only)

Lowering the amount of data to acquire/process reduces MCU power

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Use compressed sensing even respecting Nyquist rate, to virtually increase sampling freq

Projection in the sensor allows transmission of colored noise (security)

Networking

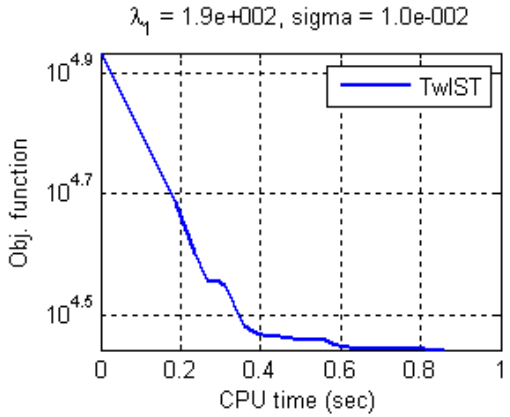
In practical terms…

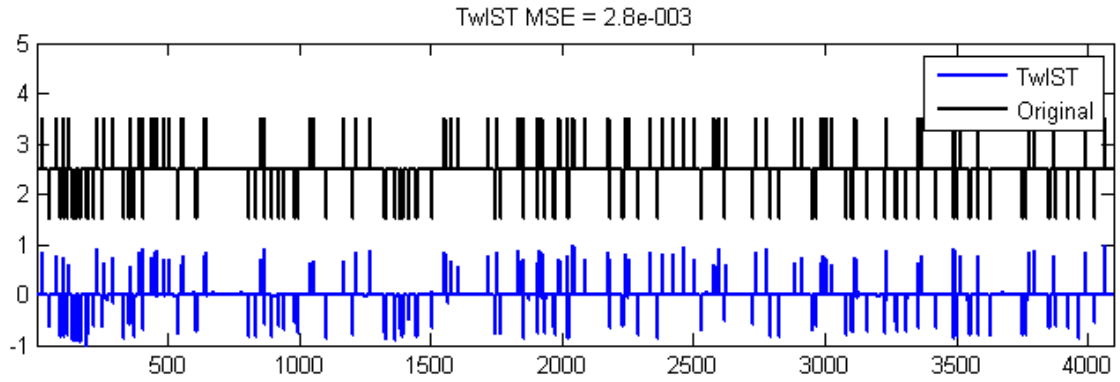
Conclusions

1. ECG, PPG, ICG, and BCG are signals with heavy-tailed distributions on several different WT
2. If a restrict percentage of the WT coefficients is accurately recovered (K≈20), the signal can be reconstructed w/ concern
3. Biorthogonal 4.4 and 5.5 and their respective reverse, and Coiflet offer the worst rec result
4. Symlets 2&4 and Daubechies 2 &4 offer the best reconstructions, although having about the same compressibility
5. Small variations in TwIST regularization parameter (ξ) and WT level to be introduced according to the signal

Conclusions

6. TCP-type protocols are mandatory, no data may be lost
7. Impulsive signals (ECG and BCG) are less penalized than PPG
8. Compression ratios around 8 will be enough to improve real wireless networks lifetime
9. Reconstruction within non-displaying nodes is not profitable
10. There is a bottleneck due to compression representativeness, time of response in emergency, amount of data in each packet, and overall network security





Thank You!

And grants of Fundação para a Ciência e Tecnologia :

SFRH/BD/46772/2008

RIPD/APD/109639/2009

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INSTITUTO SUPERIOR TÉCNICO

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creating and sharing knowledge for telecommunications

Reference list

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