Sensor Array and Electrode Selection for Non-Invasive Fetal ECG Extraction by ICA

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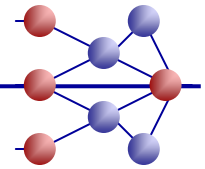


Outline

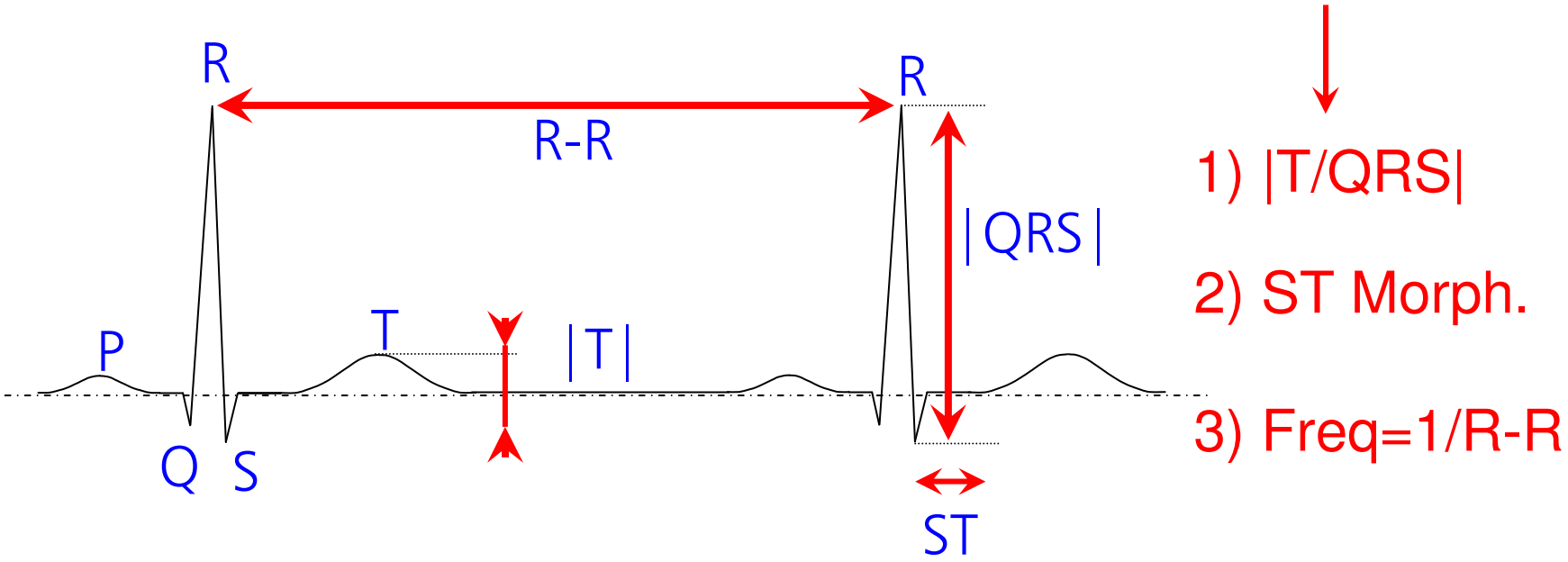
- Importance of FECG for Physicians
- Non-Invasive FECG Extraction by BSS
- Number and Location of Sensors ?
- Fetal Contribution Identification by Cond. PDF
- Fetal Contribution Identification by MI
- Sensor Selection Algorithm
- Conclusion

FECG Reduces Unnecessary Caesareans

- Sole Use of Fetal Heart Rate Variablility

  → Unnecessary Caesareans

- FECG : ↗ Accuracy Diagnosis



Measurement ?

- Invasive Measurements

  $\longrightarrow$ Scalp Electrode : it works !

- Non-Invasive Methods
  - Earlier Analysis (no breaking required)
  - ↘ Fetal Stress
  - ↘ Sanitary Precautions Required

Blind Source Separation

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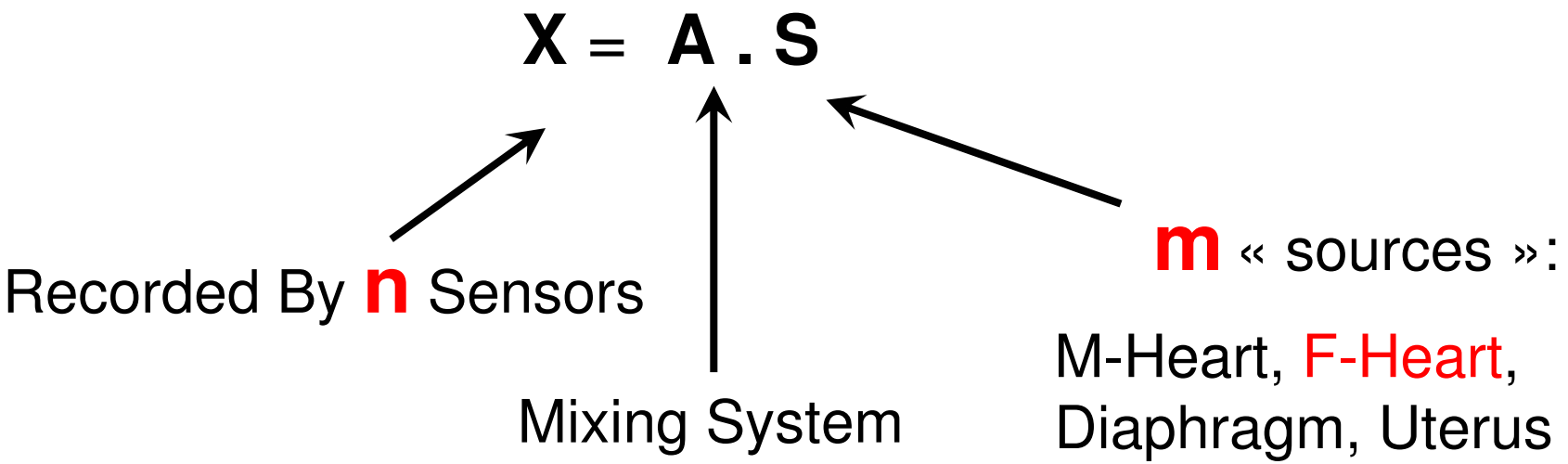
BSS can be achieved by ICA



Aim: To recover S by X without knowing A !

OK by ICA If « Si » Independent

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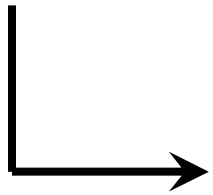
Interesting Sensors ?

Many sensors because

- Fetus Moves : Optimal Location ?
- Defficient Electrodes
- n>m for ICA

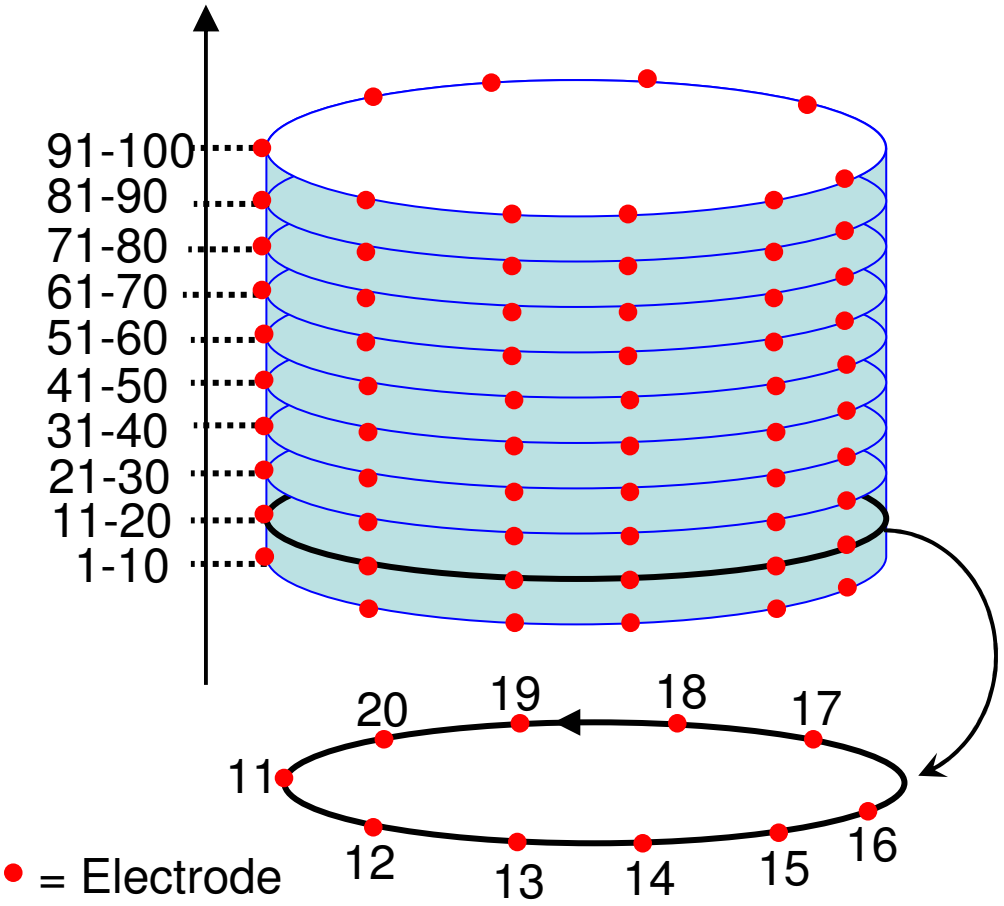
If Selection : how to identify interesting sensors (that drive FECG information) ?



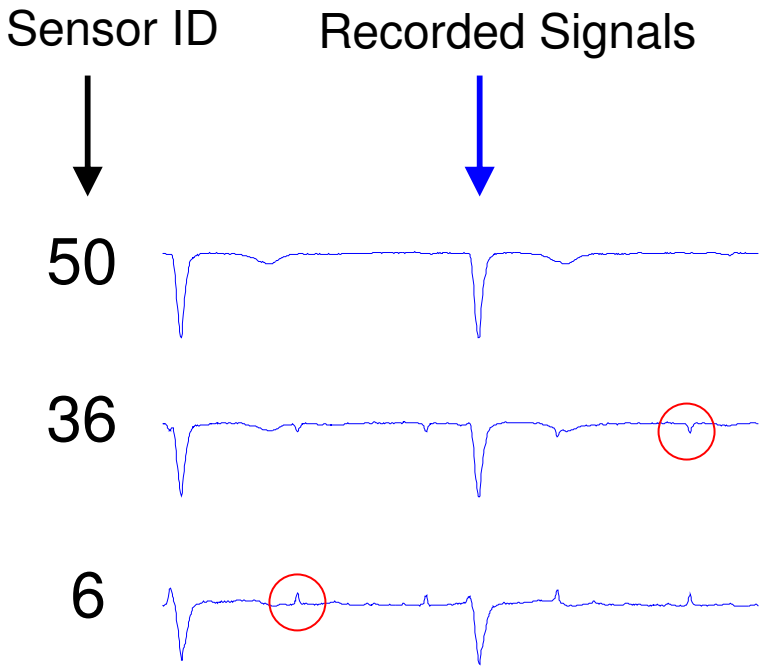
Measurements of
Fetal-Contributions
in each sensor

A Grid of Sensors

10x10 Grid around Abdomen



Simulated Signals on Virtual Grid !



Measurement of Fetal Contributions ?

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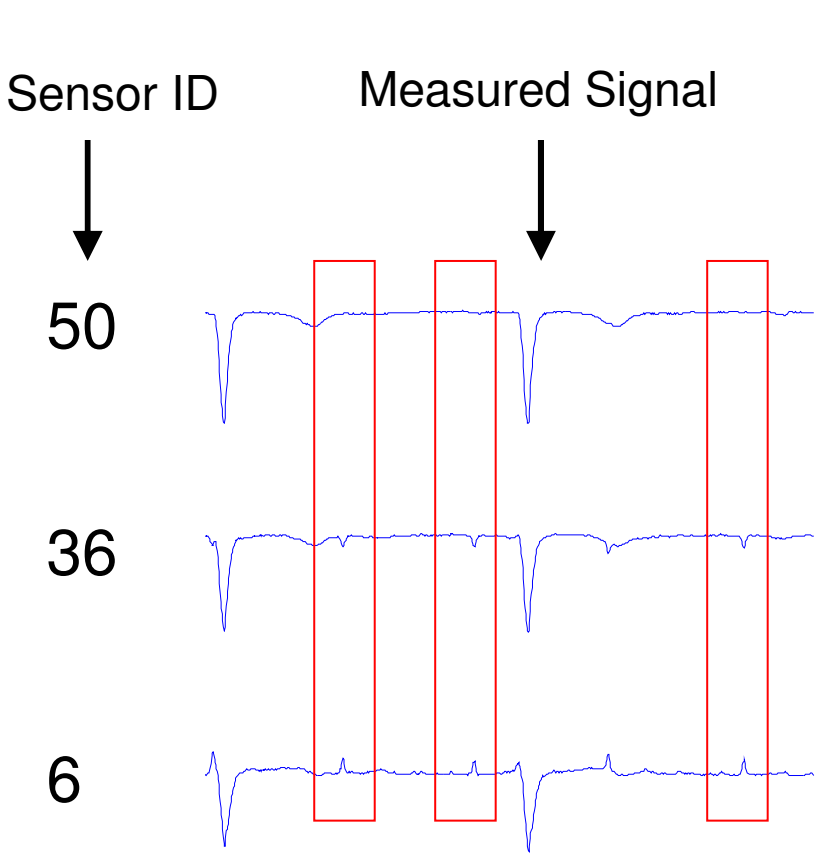
Fetal Contributions by CPDF

Conditional PDF of Xi with a Reference (ID 50)



Mother ECG (Available)

$$p(X_i \neq 0 | MECG = 0)$$

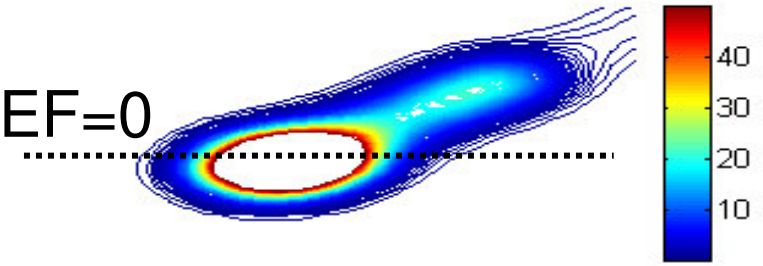
What About the Joint PDF ?

Fetal Contributions by CPDF

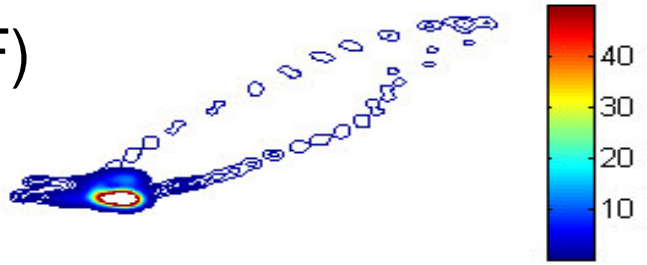
REF= pure MECG

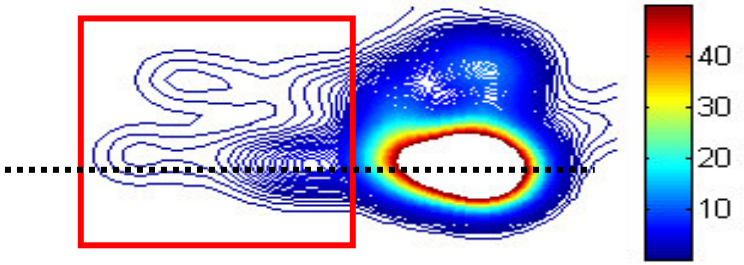
P(REF,REF)

REF=0

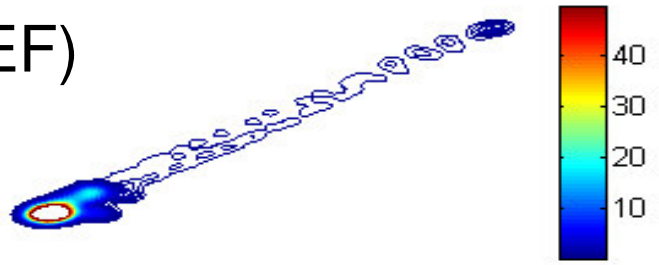


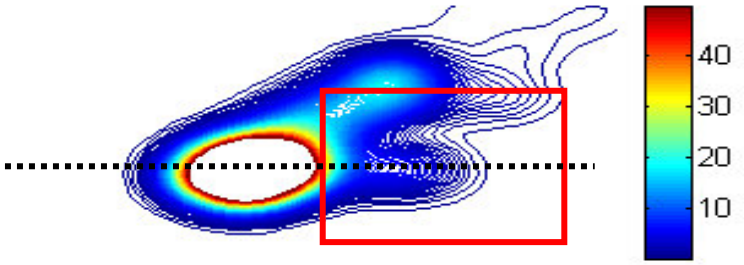
P(6,REF)





P(36,REF)





What if Offset in MECG ?

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Fetal Contributions by MI (1/3)

Mutual Information :

$$I(X,Y) = \int p(X,Y) \log \frac{p(X,Y)}{p_x(X)p_y(Y)}$$

Properties

I(X,Y) >0 for all (X,Y)

I(X,Y) Max for X=Y

I(X,Y)=0 if and only if X and Y independent

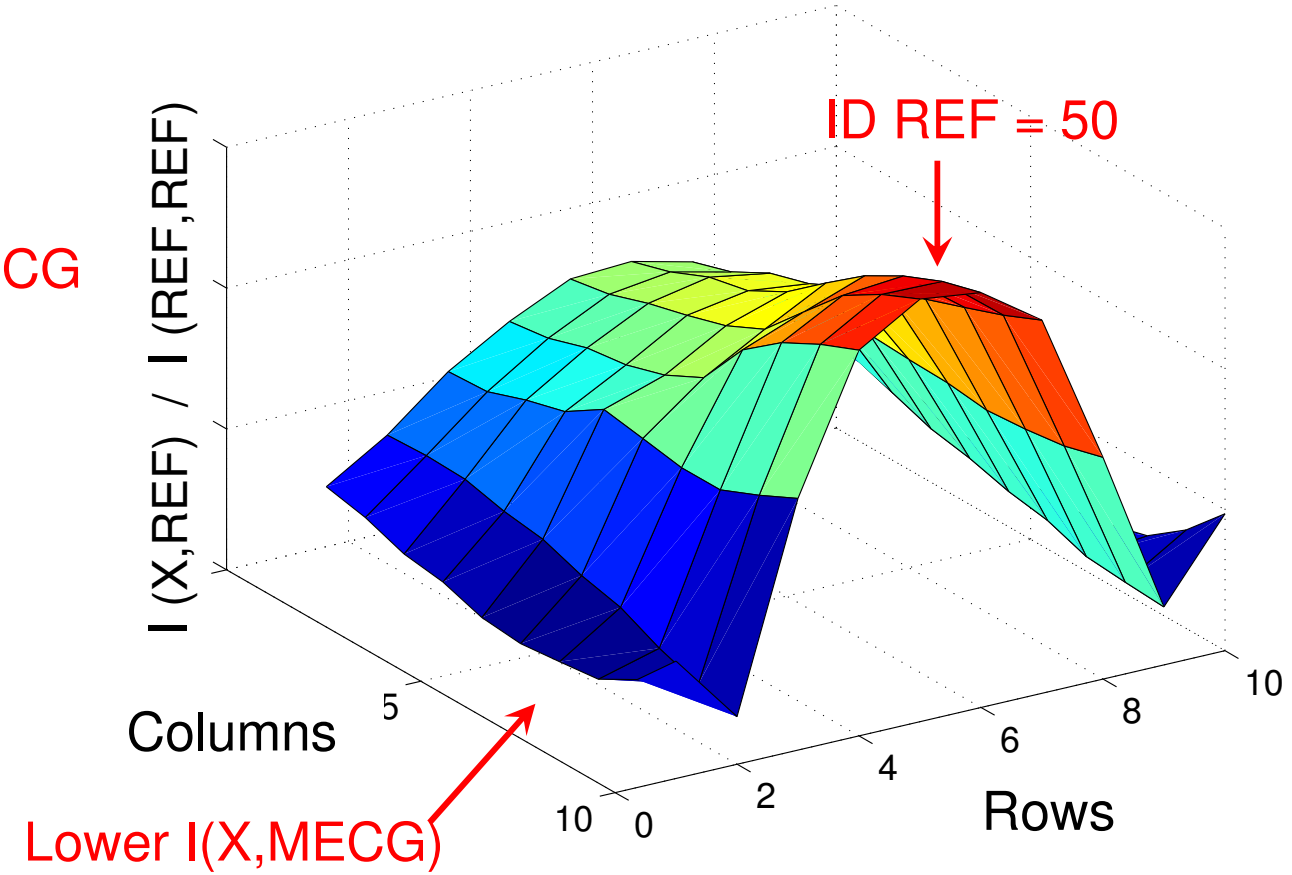
Meaning Divergence between PDF (Kullback Leibler)

I(X,Y) low ➔ X and Y independent (i.e. « different »)

Fetal Contributions by MI (2/3)

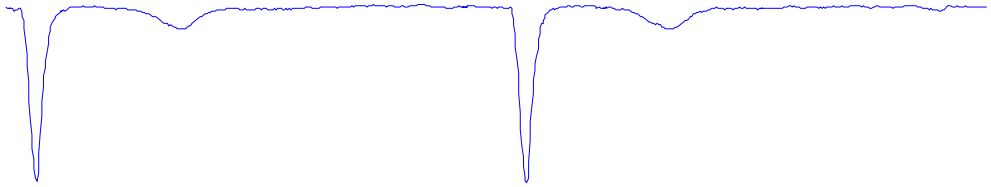
Test : Sensors Analysis by **I**(Xi,REF)

REF= pure MECG



Fetal Contributions by MI (3/3)

ID REF = 50



Lower **I**(X*,REF):
ID X*= 6

I(X,MECG) Measures Fetal Contributions !!!

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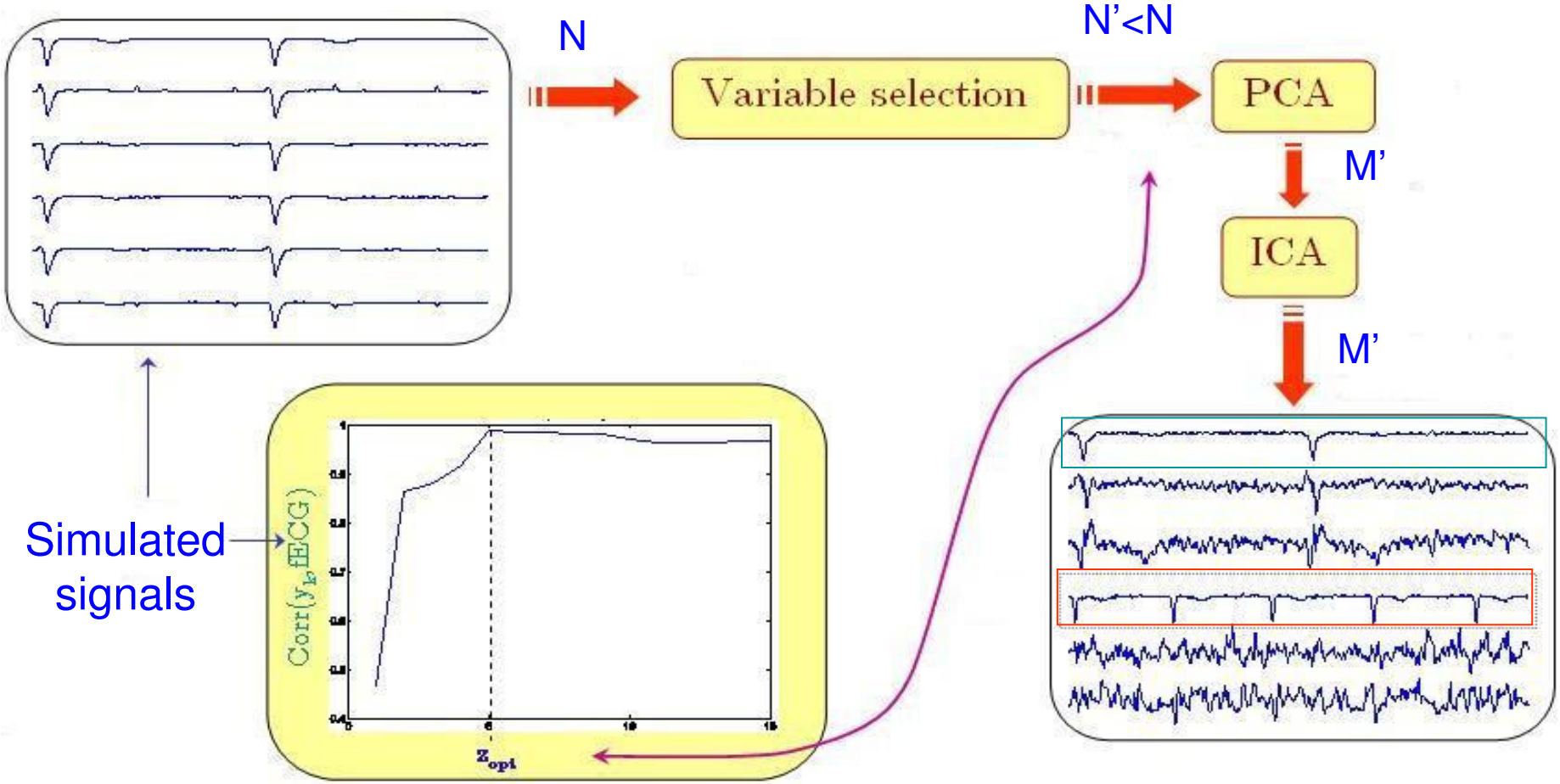
Sensor selection algorithm (1/2)

SenSelec $(\mathcal{S}, Ref, n)$

1 $S_1^\star \leftarrow S_{Ref}$ //*reference electrode*
2 $\mathcal{S} \leftarrow \mathcal{S}/\{S_{Ref}\}$
3 $\mathcal{S}^\star \leftarrow \{S_1^\star\}$
4 **for** $k \leftarrow 2$ **to** n **do**
5 | **for** $i \leftarrow 1$ **to** $100-(k-1)$ **do**
6 | | $\mathcal{C}(i) \leftarrow \sum_{j=1}^{k-1} I(X_j^\star, X_i | S_i \in \mathcal{S})$ //*cost function*
7 | $j \leftarrow argmin_i(\mathcal{C})$ //*ID of winner sensor*
8 | $S_k^\star \leftarrow S_j$ //*winner sensor*
9 | $\mathcal{S} \leftarrow \mathcal{S}/\{S_j\}$ //*removing winner sensor*
10 | $\mathcal{S}^\star \leftarrow \mathcal{S}^\star \bigcup \{S_k^\star\}$ //*update selected subset*
11 **Return** $\mathcal{S}^\star$; //*set of selected sensors*

Fig. 2. Electrode selection algorithm. The cost function $\mathcal{C}$ is based on the mutual information between the selected and unselected electrodes.

Sensor selection algorithm (2/2)



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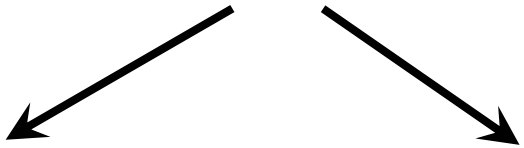
Conclusion

- Non-Invasive FECG is important
- Number and Location of External Sensors ?

  → A belt of many sensors !
- Selection among this grid : Fetal Contribution
- ~~FFT~~ ? Fails if Freq (M-Heart) = Freq (F-Heart)



P(X|MECG=0)

What if Offsets ?

I(X,MECG) ⟷ Distances between PDF patterns !

Future work and open questions

- How many signals have we to select ?
- A method that removes ‘bad’ signals ?
- Relavance of I(.,.) if noisy signals ?
- Test on real signals