Embedded signal processing

SE != Esybio != TSI

- Assist patient's body to compensate a handicap
  - Prostesis/Exoskeleton control
  - Hormone regulation
- Symptomatic treatment
  - Deep Brain Stimulation (DBS) for parkinson
  - Epilepsy
- Health IT business
  - Retrieve physiological data from external sources

Constraints

- Power consumption (autonomy / heat)
- Low EM radiations (EMC)
- Robustness / security
  - Less critical for general public devices/apps

Limits

- Technlogical (previous slide)
- Regulations
  - Security rules apply to hardware in contact with patients
  - Software is not concerned
- Ethical

Common architectures

- All embedded :
  - Microcontroler + specific application (input or output)
  - Mixed signal ASIC
  - Expensive / purpose-specific
- e-gadget
  - Wireless sensor + smart [phone | watch | anything]
  - High security risk / not suitable for critic cases

Some of the existing

- Pacemaker
- Cochlear implants
- DBS devices
- Pet microchip implant
- Insulin pump
- ...

What does not exist (commercially) (yet)

- Sensitive feedback
  - For posthetic arms / legs
- Closed loop devices
  - Self adapting stimulation implant /
- Neuroinvasive device
  - Demonstrated efficient on :
    - Weight gain
    - Stress / nervousness
    - Sleep quality
    - Psychic equilibrium
    - ...

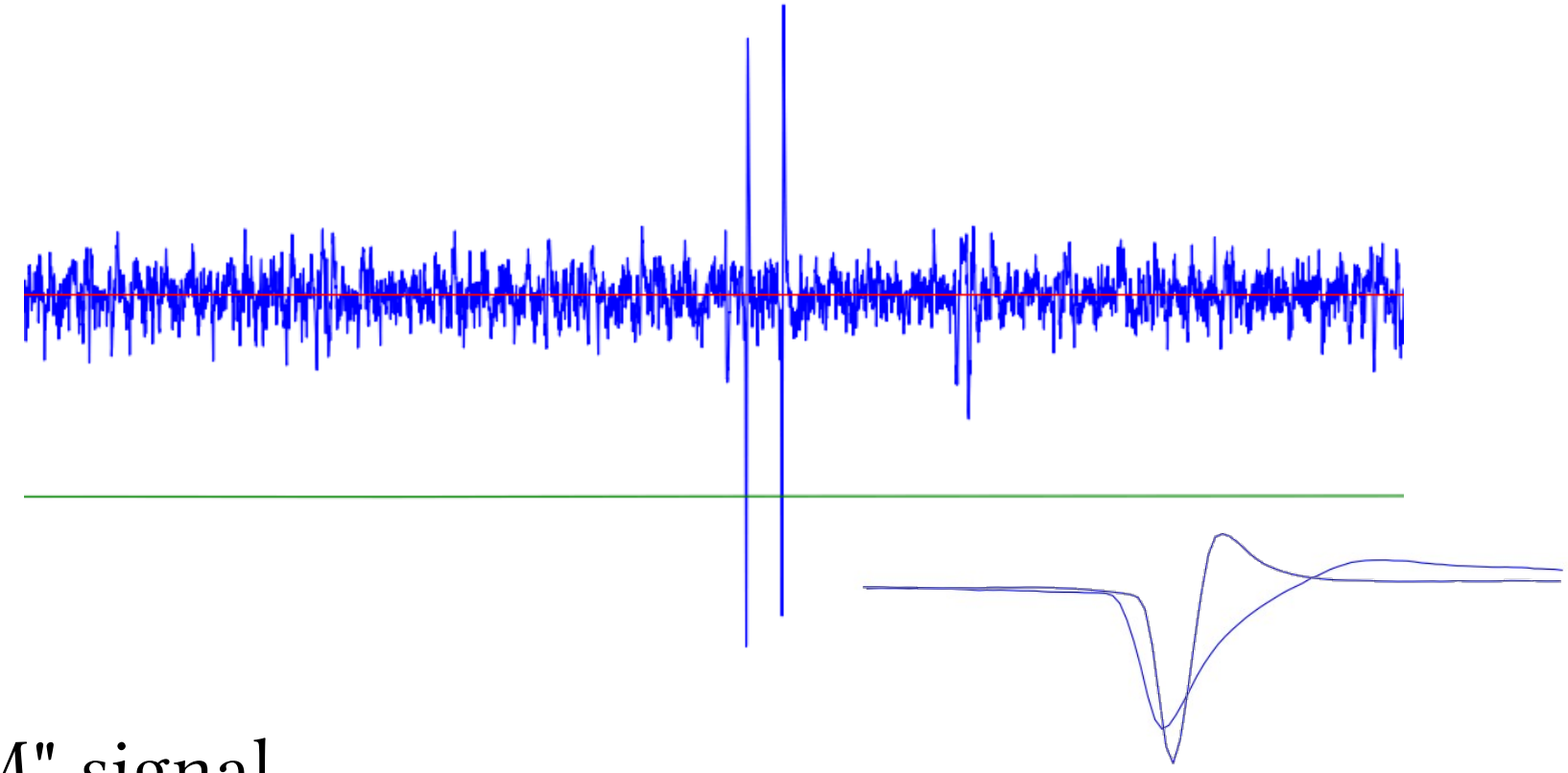
Conception d'un système

- High constraints, need for higly efficient architecture
  - Cost
  - Power consumption
  - Computation latency
- High diversity among individuals
  - High flexibility need (parameters)
  - Self adaptive systems
  - Fault tolerent systems / algorithms

Project objectives :

- Retreive data from biological activity
  - (mostly excitable cell biopotential)
- Provide an architecture that balances :
  - Latency
  - Computation power
  - Adaptation
- Tools :
  - On demand
  - Files are available in 3 fomats :
    - Binary (16b signed) / .csv (text) / matlab

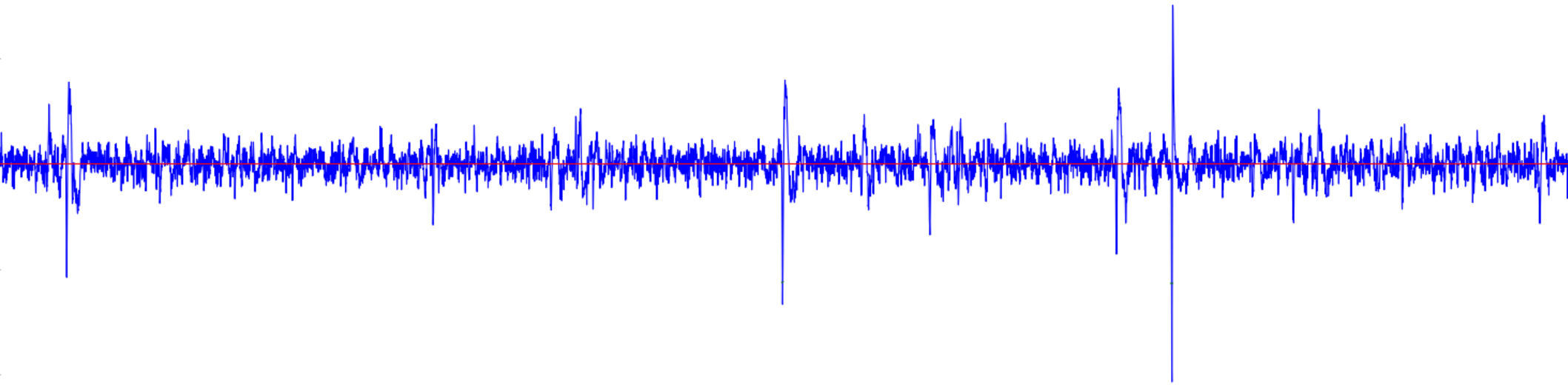
Topic #1 : spike sorting



- "ICM" signal
- Discriminate action potentials ...

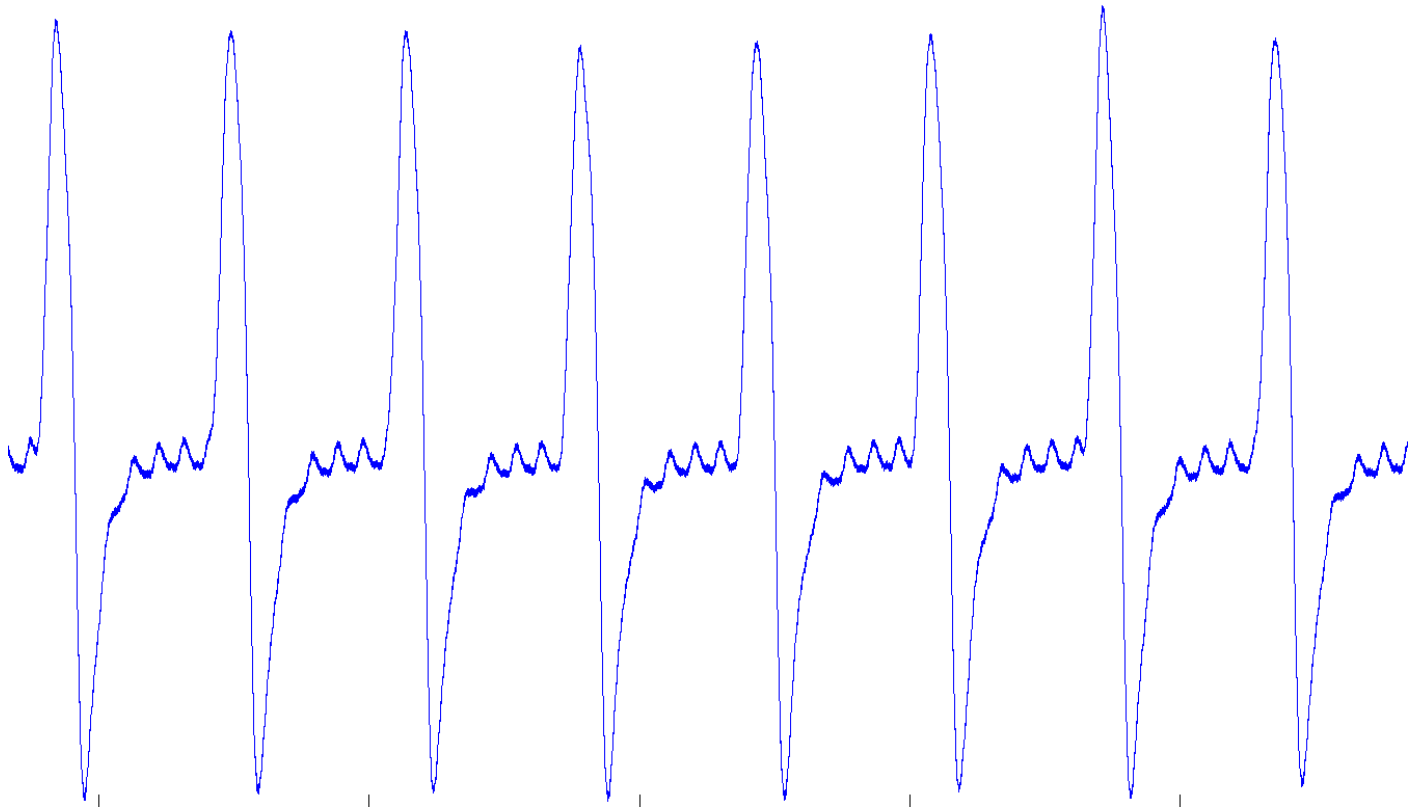
... by category

Topic #2 : "low spike" detection



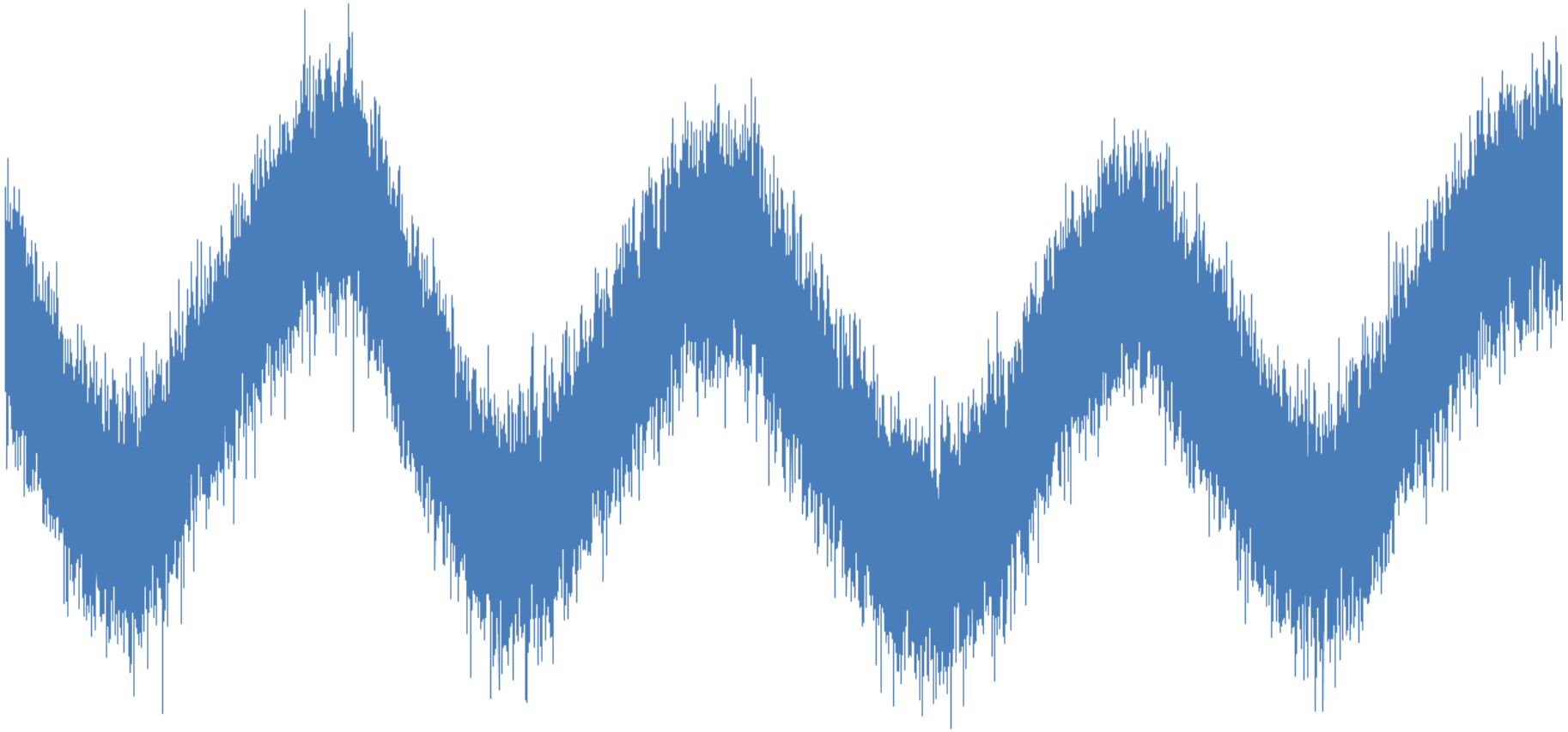
- "ICM" signal
- Detect occurence of smaller spikes, big spikes are the reference...

Topic #3 : heart frequency monitoring



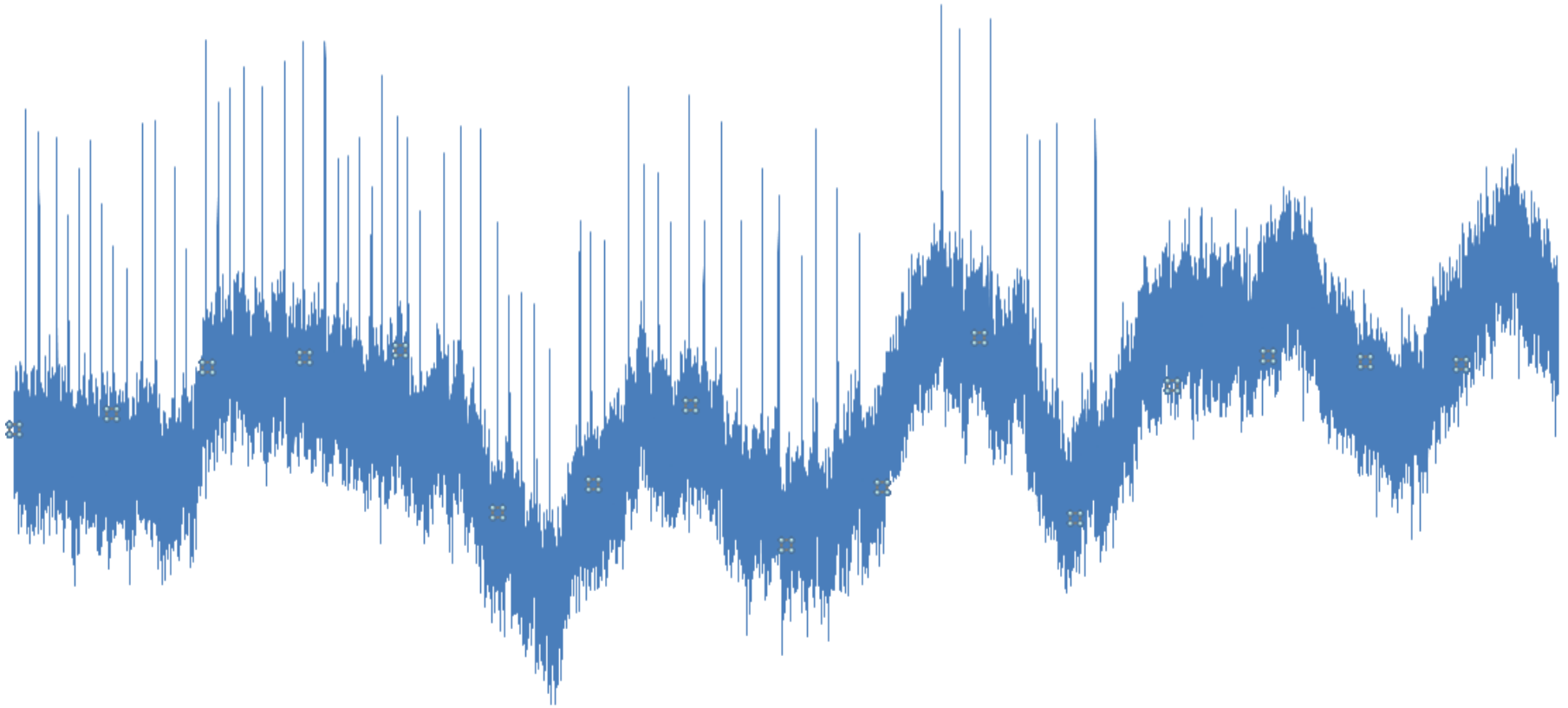
- Rat breath stream measurement.
- Retreive heart rythm

Topic #4 : slow waves measurement



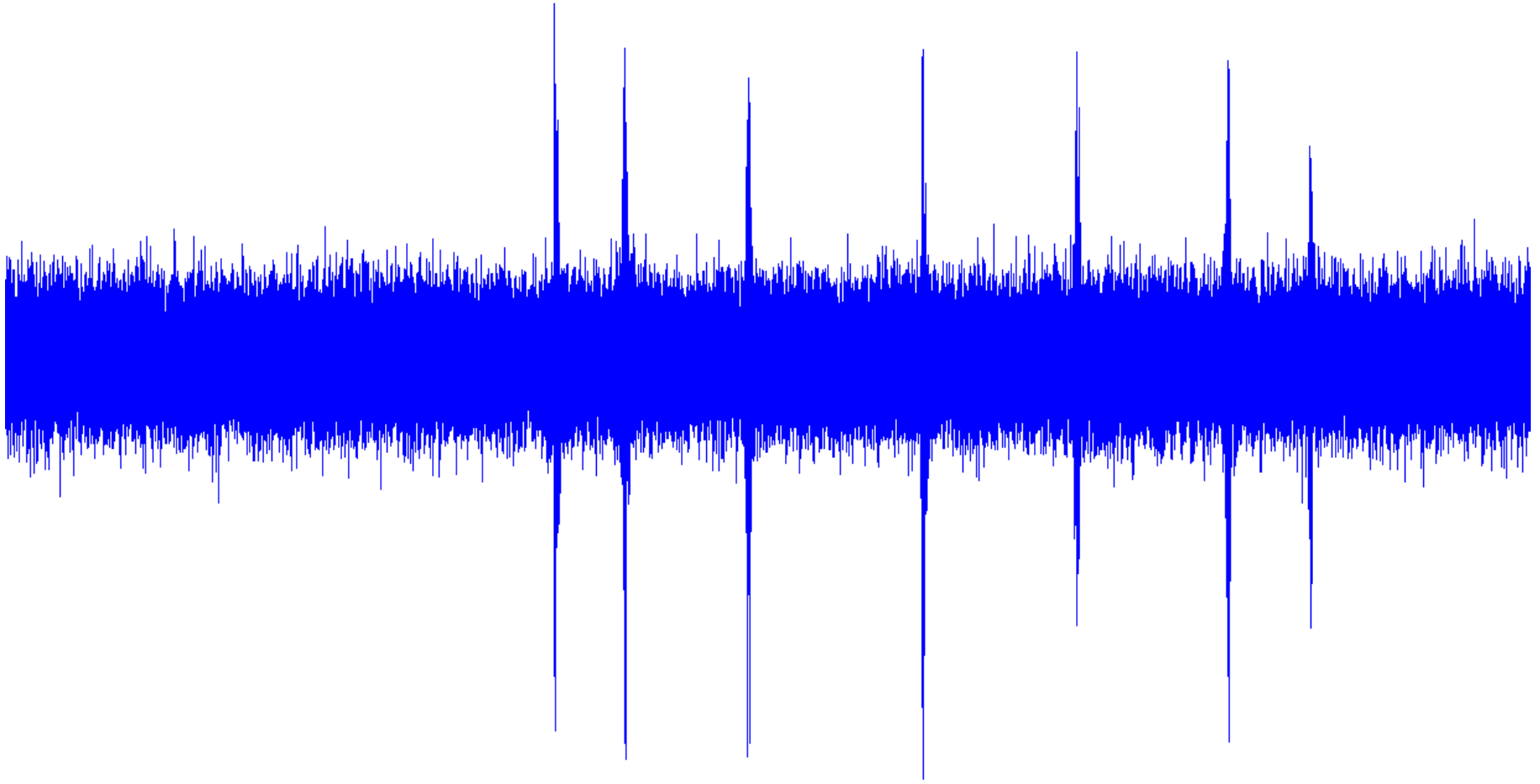
- Pancreatic cells
- Retrieve low freqency signals characteristics

Topic #5 : spike detect. on noisy signal



- Pancreatic cells
- Detect spikes (fig is not representative)

Topic #6 : spikes detection on MEA



- Neuron cultures on microelectrode arrays (low SNR)
- Detect (ugly) spikes

Topic #7 : spike correlation

- Data from spikes detected on MEA ()
- Detect functionnal correlations
  - Retreive who is connect with who ?

Hardware platforms

- Small microcontroler : PIC16F84
  - 8bits, 1 Minstr./s, 68B RAM
  - Migration possible if insuffisance demonstrated
- Big microcontroller (AT91SAM7)
  - 32bits, 48Minstr./s, 128kB RAM
- FPGA (prototyping)
  - 100MHz working frequency
  - No hardware resource limitations

Objective of the project

- Provide a strategy to solve the topic with the hardware assigned
- Time is not sufficient to provide a fully working project !

Expected results

- Digital architecture/strategy
  - No point in getting a working system
- Parameters list
  - Which are fixed ? Tunable ? Auto determined ?

    Why ? How ?
- Latency estimation
  - Expressed in computation time / passed samples
- Hardware cost
  - Microcontroller : RAM requirements / working frequency
  - FPGA : Flip-Flops / RAM amount / multipliers

Evaluation

- Defence
  - Defence itself (10mn)
  - Discussion with mates/teacher (15mn)

- This is NOT
  - A project aimed to signal processing : no working device is expected
  - A programming / writing project : only planned resource usage is expected

Data

- www.bornat.fr/enseirbsignals
- Login : csi
- Pwd : **********

- Project attribution

Some recalls (or maybe not)

- Signal processing techniques...
  - Fixed point computation
  - Filters

Data representation

- float/double:
  - 1 mantiss of fixed size (23 to 52 bits)
  - 1 exponent of fixed size (8 to 11 bits)
    - Useful to tell where the "*decimal*" point is
  - Pros :
    - Represent huge or tiny values(10^{38} to 10^{-38})
  - Cons :
    - Limited number of significant digits
      - Not possible to increment by 1 from 0 to 10^{18}
      - Complex computing structures
        - No simple logic to perform addition/substraction

Data representation

- integer / long / char :
  - Sequence of bits that represent positive powers of 2
  - Pros :
    - Simple/cheap computation structures (combinatory equations)
    - Precision is absolute
  - Issues :
    - Only suitable for integer values
    - Quantization noise (bad precision for values close to 0)

Data representation

- In between : fixed point
  - Sequence of bits that represent powers of 2 (which can be negative)
  - Pros :
    - (almost) same as integers
    - Much lower quantization noise
  - Issues :
    - Cannot represent values below the value of LSB. (but LSB value is known by design)
    - Complex

Filter

- In digital signal processing:
  any function that relies on (future or past) samples from a signal
- In real life:
  any function that relies on a finite number of (~~future or~~ past) samples from a signal
- Examples :
  - $y_n = (x_n + x_{n-1})/2$ (low pass)
  - $y_n = x_{n-10}$ (shifter)

FIR ? IIR ?

- FIR :
  - Simplest : $y_n = ax_n + bx_{n-1} + cx_{n-2} + dx_{n-3} + \ldots$
  - Generic notation:

    $y_n = a_0 x_n + a_1 x_{n-1} + a_2 x_{n-2} + a_3 x_{n-3} + \ldots$

    order = 4

  - Can achieve ideal behaviors
  - Computationnally expensive

FIR ? IIR ?

- IIR :
  - Generic notation:

$$y_n = a_0 x_n + a_1 x_{n-1} + a_2 x_{n-2} + a_3 x_{n-3} + \ldots + b_1 y_{n-1} + b_2 y_{n-2} + b_3 y_{n-3} + \ldots$$

  - Digitization of analog filters
    - Suffer from the same drawbacks
  - Computationnally efficient
  - Potentially unstable
    - Mostly, gathering of 2^{nd} order subfilters (cells)