Sampling Circuits for Non-Uniform Sampling and Processing for Low-Power Purpose

Event-Based Control, Circuits and Processing towards Ultra-Low Power Consumption

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Outlines

- **Non Uniform Sampling**
- Filtering with NUS signals
- Pattern Recognition
- NUS in 2D
- High-Level Synthesis for NUS
- Conclusion

Internet of Things Challenges

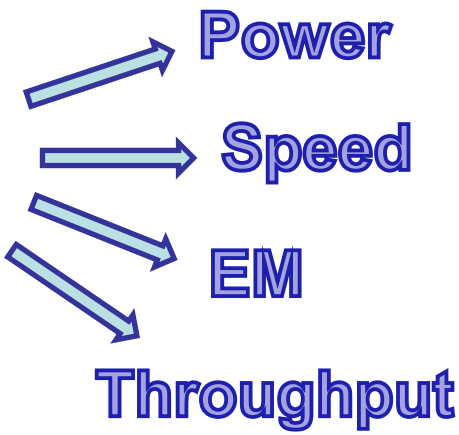
+ more data
+ more storage
+ more communications
+ more consumption

Nyquist-Shannon Theorem

Sampling is the success key

- Sampling based on the Shannon-Nyquist theorem
  - Efficient and general theory… **whatever the signals!**

- Smart sampling techniques
  - **More efficient** but less general approaches… for **specific signals**!

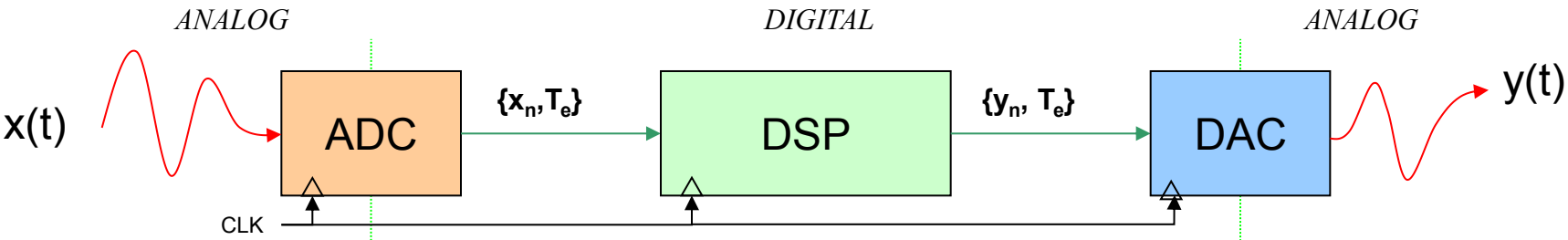


  - Need a more general mathematical framework
    - **F. Beutler**, "*Sampling Theorems and Bases in a Hilbert Space*", Information and Control, vol.4, 97-117,1961

- Sampling should be **specific to signals and applications**

What can we do?

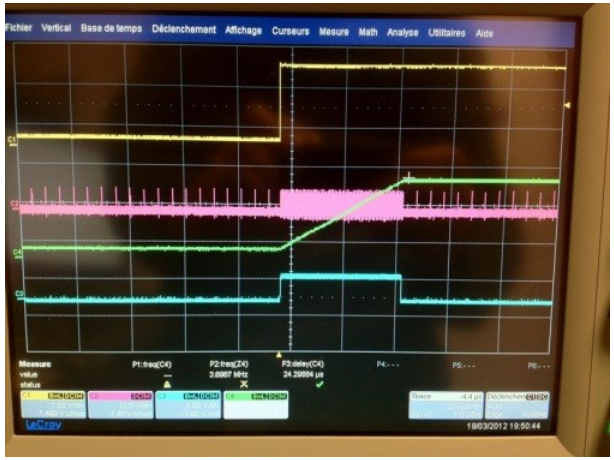
Uniform and Synchronous

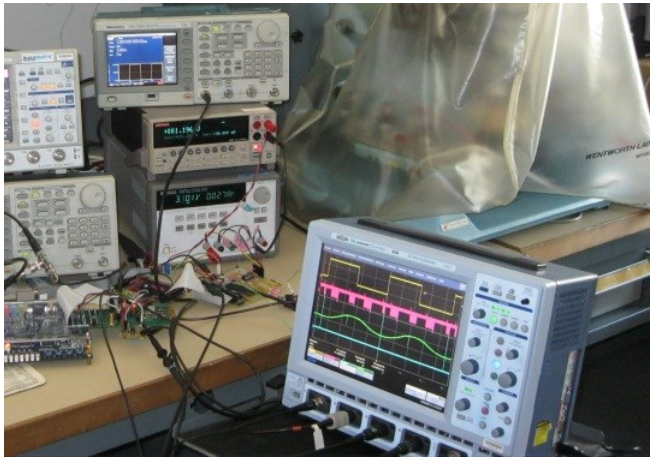


Non Uniform and Event-driven (Asynchronous)

What to expect?

- **Activity reduction** for many signals (1 to 3 orders of magnitude)
- **Signal-dependent sampling** technique
- Dynamic activity selection (impossible if synchronous)
- **Direct processing of the non-uniform samples** (Filtering, spectral analysis, etc.)





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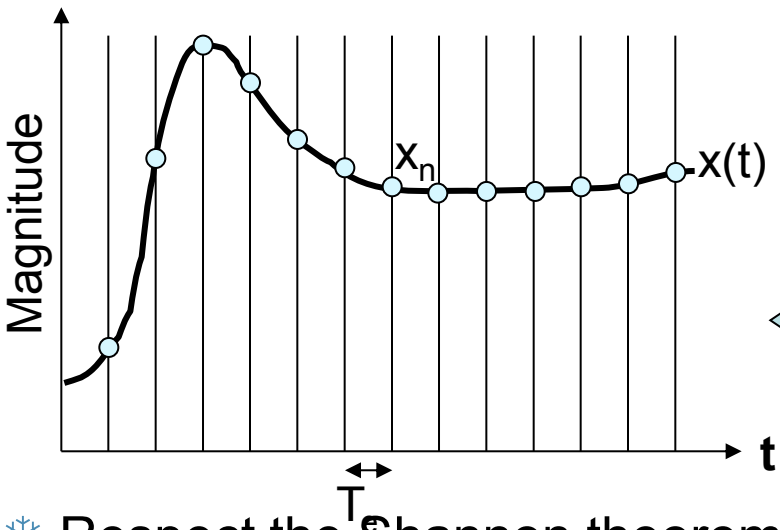
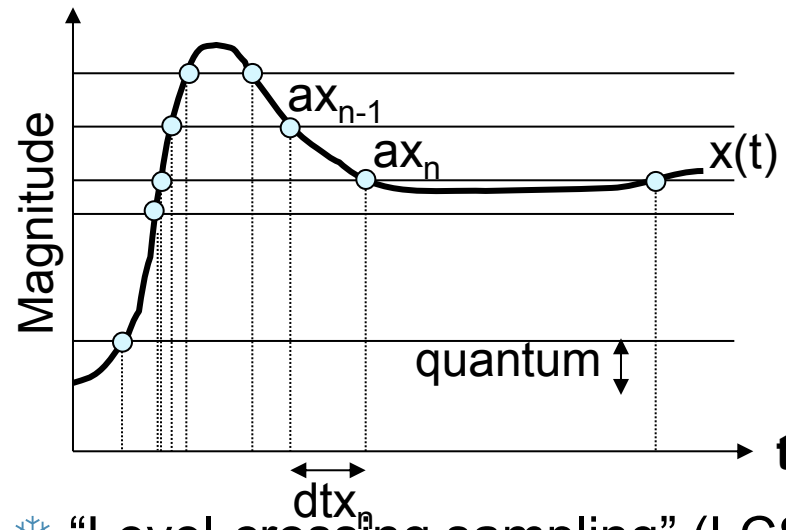
Sampling differently

Uniform sampling



Non uniform sampling



Dual

- Respect the Shannon theorem
- **Instants exactly known**
- Information: T_{sample}, { i_k }
- In an ADC: **Amplitude quantization**
- Many useless samples

- "Level-crossing sampling" (LCSS)
- **Amplitudes exactly known**
- Information: quanta, { dti_k }
- In an A-ADC: **Time quantization**
- Only useful samples

A-ADC testchip

Microphotography of the A-ADC
In CMOS 130 nm technology from
STMicroelectronics

E. Allier et al., 2003

Lowering in one step the **storage**, the **processing**, the **communications** and the **power consumption!**

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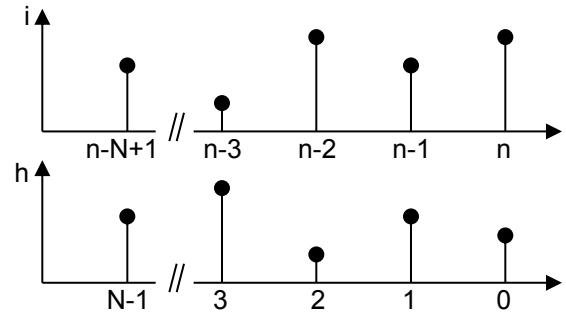
LCSS for filtering

$$o_n = \sum_{k=0}^{N-1} h_k * i_{n-k}$$



The instants are synchronized

Classical digital convolution product incompatible with non uniformly sampled signals

Find a digital equation using the information contained in the time intervals

Async. Convolution Product

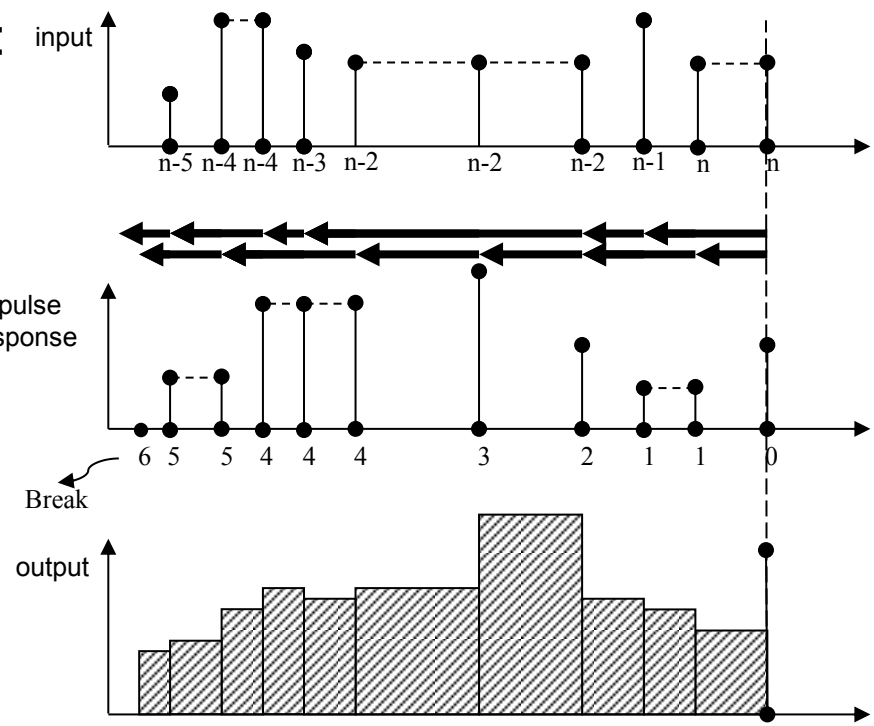
- Asynchronous convolution product:

$$o(t) = \int_{-\infty}^{+\infty} h(\tau)\, i(t-\tau)\, d\tau \quad \Rightarrow \quad o(t_n) = \int_{-\infty}^{+\infty} \hat{h}_n(\tau)\, \hat{i}_n(t_n - \tau)\, d\tau$$

- Asynchronous convolution algorithm:

$$\begin{cases} o_n = \sum \mathrm{dtmin}(dti_{n-k}, dth_j) * i_{n-k} * h_j \\ dto_n = dti_n \end{cases}$$

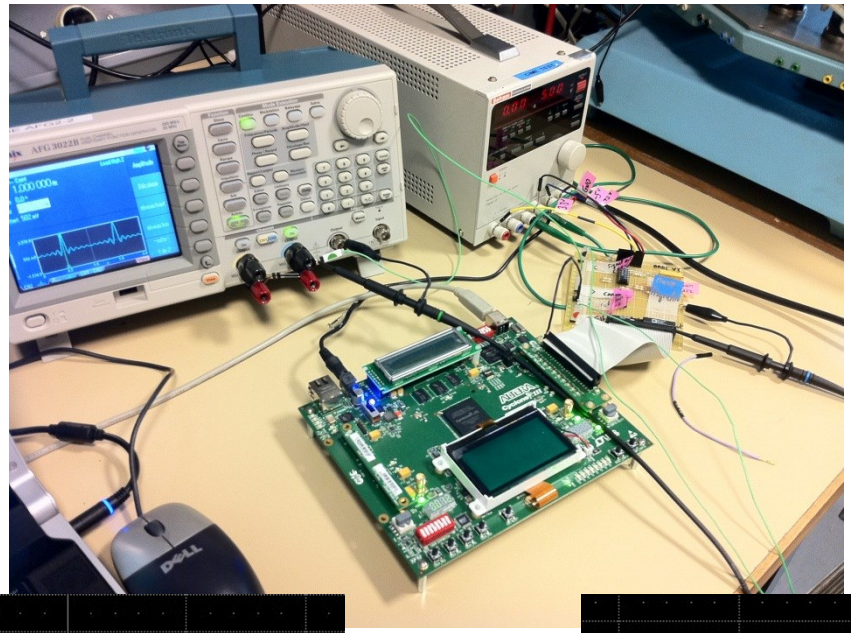
- if $\mathrm{dtmin} = dti_{n-k}$ then $dth_j = dth_j - dti_{n-k}$; $k = k + 1$,
- if $\mathrm{dtmin} = dth_j$ then $dti_{n-k} = dti_{n-k} - dth_j$; $j = j + 1$,
- if $\min = dth_j = dti_{n-k}$ then $k = k + 1$; $j = j + 1$.



Experimental setup

Aeschlimann et al., 06

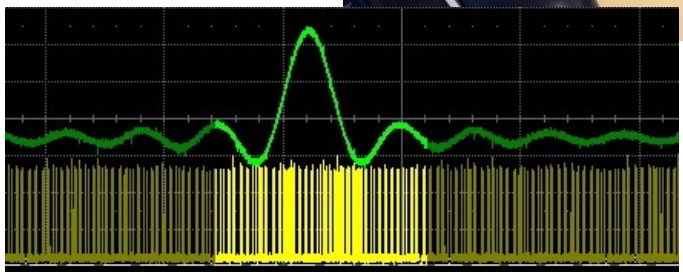
Beyrouthy et al., 11



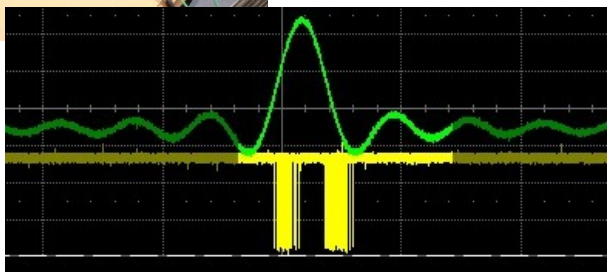
Asynchronous FIR Filter

+

A-ADC.



Synchronous ADC



Asynchronous ADC

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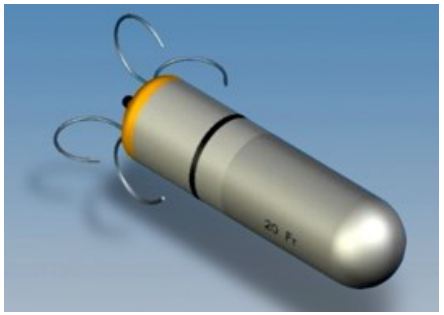
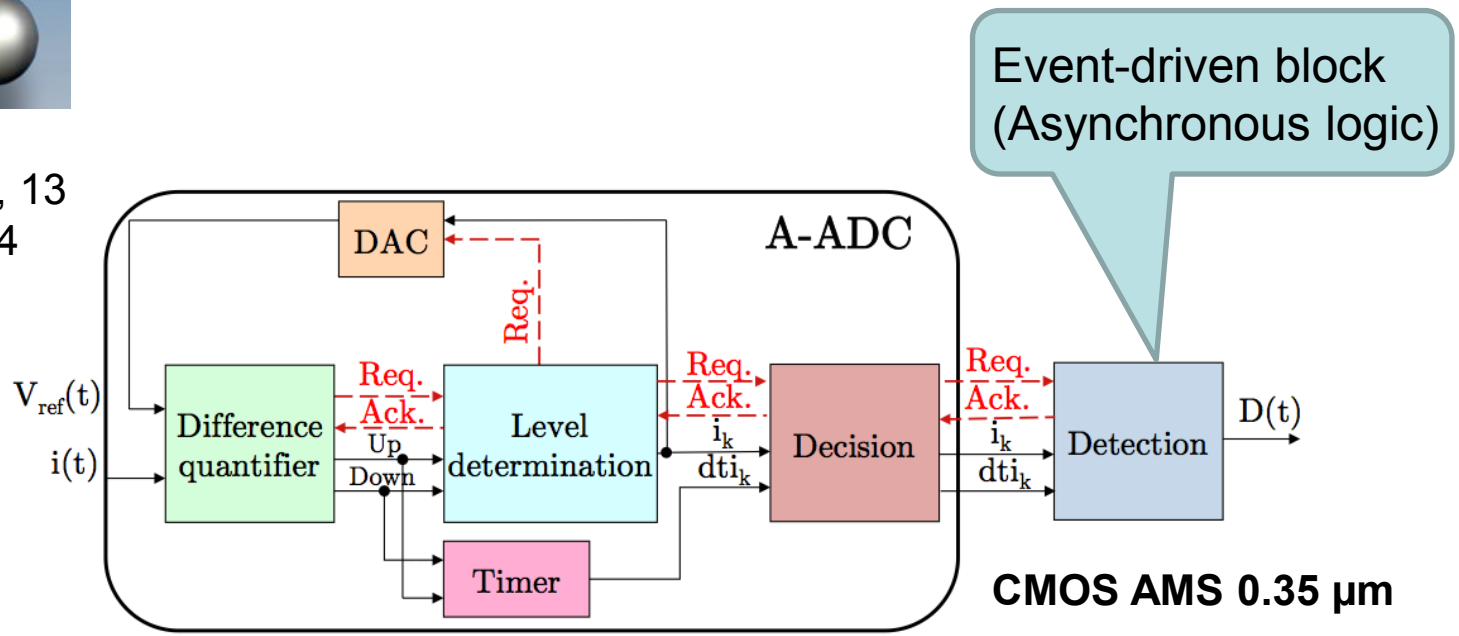
A successful experiment



- Context of the medical implants
- Activity patient measurements

T. Le Pelleter et al., 13
L. Fesquet et al., 14
E. Allier et al. 05

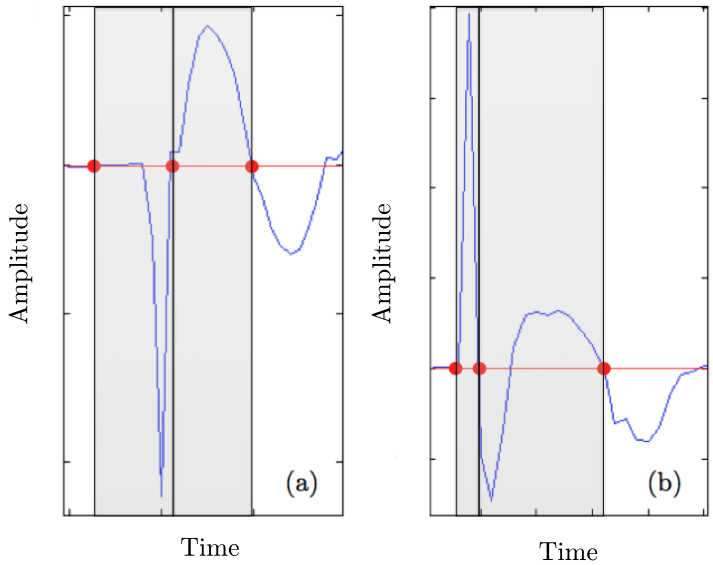


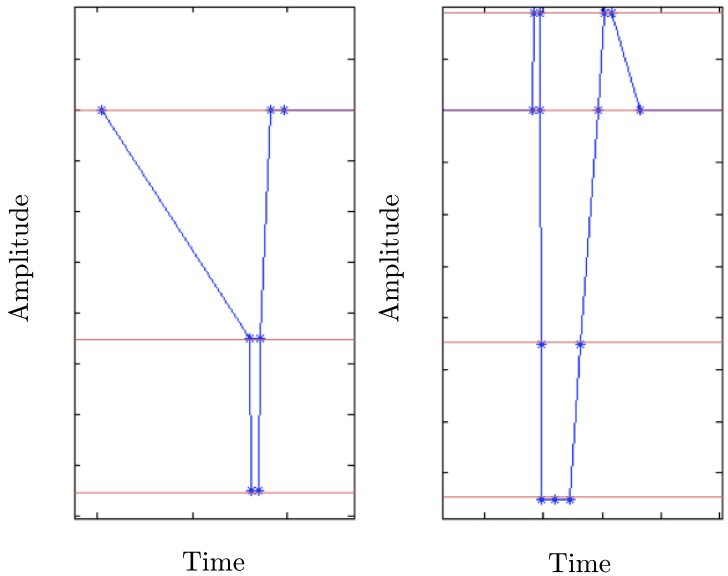
CMOS AMS 0.35 µm

Experiments based on **real physiological signals** (recorded on the patients)

Pattern Recognigtion

- Pattern: **two peaks** with **opposite signs**
- A **peak** is considered as a **subpattern (sequence detection)**

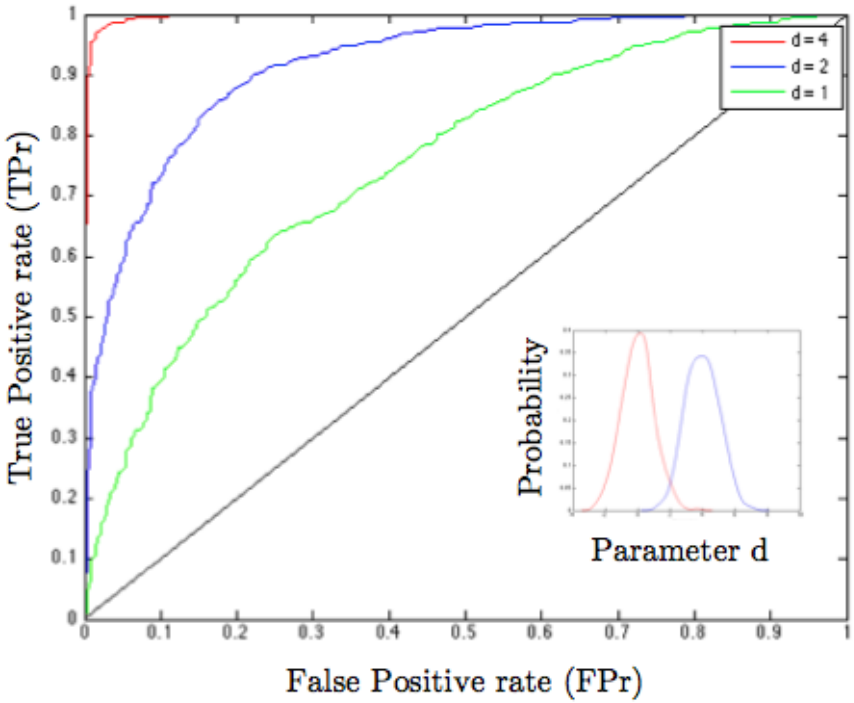




Pattern Recognition

- Finding a **threshold** that separates the **density function of true and false subpatterns**
- **Thresholds** determined with the **ROC curve**

- **Optimal thresholds are** generated by the **farthest** ROC points from the **diagonal**
- **Only 4 thresholds**



What we learned
with the experiment

- **Be more specific** to signals and applications
- **Non-general approach**, but **reproducible**

With the medical

- No pre-processing
- **Less than 1% of data** compared to the uniform sampling
- **3 orders of magnitude reduction** on power

- **Non-uniform sampling well adapted to sporadic signals**

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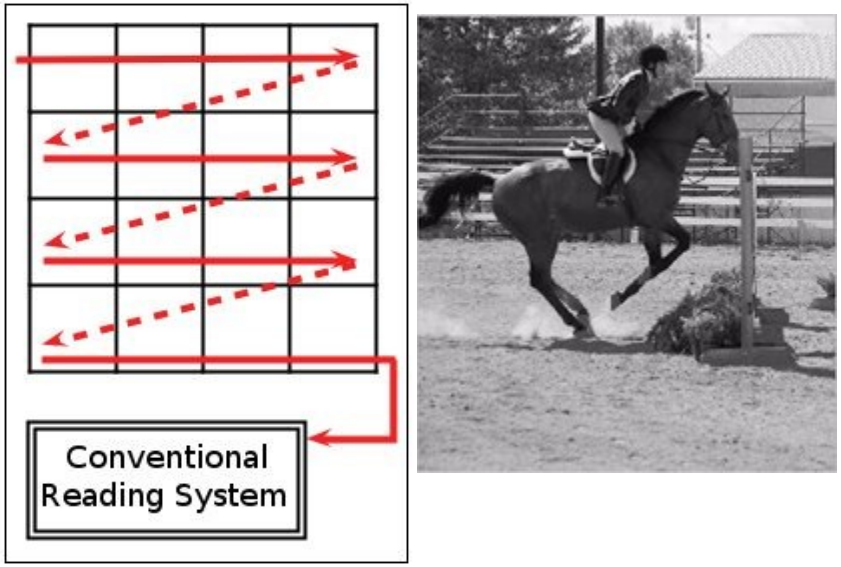
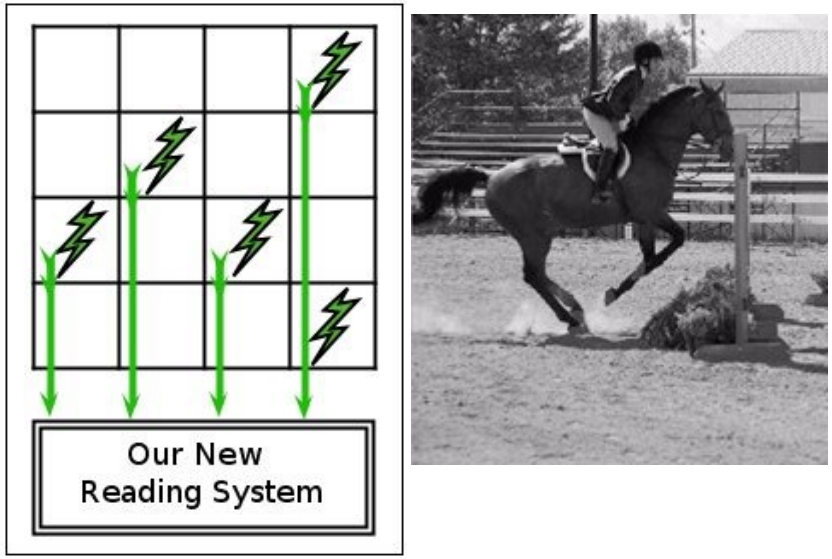
Towards an event-driven ADC in 2D



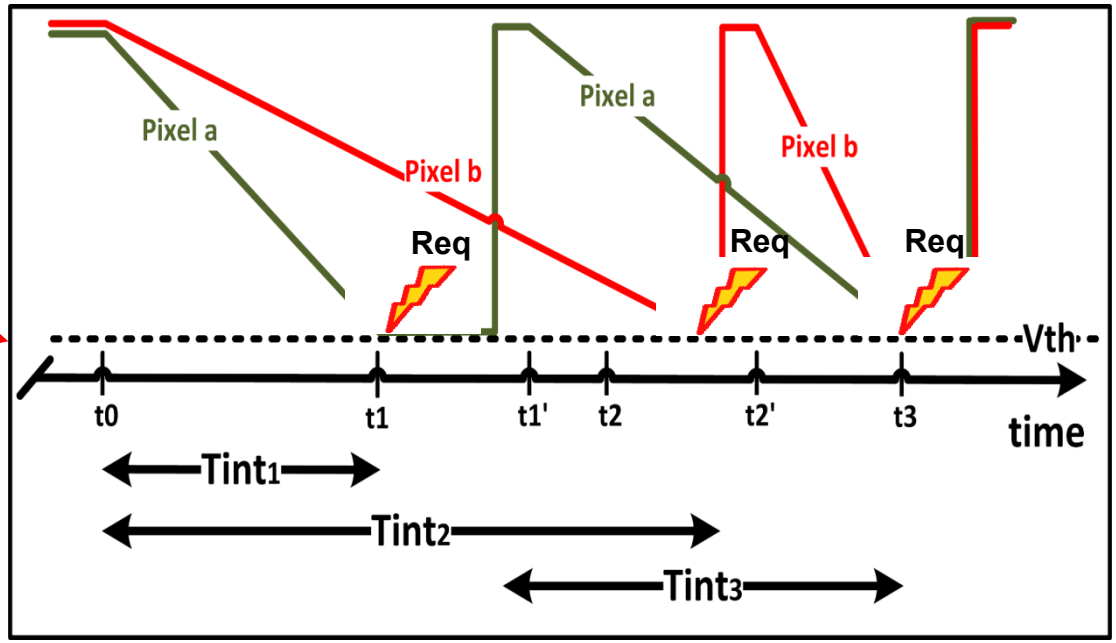


- Fully sequential reading
- High Throughput (worst case)
- Need of data compression

- Event-based reading
- Low Throughput
- Management of spatio-temporal redundancies

Pixel behavior

Adjust the image sensor sensitivity
=
High Dynamic range



- Based on **event-detection**
- **1-level crossing sampling** scheme
- A unique integration time per pixel
- **Time to first spike** encoding

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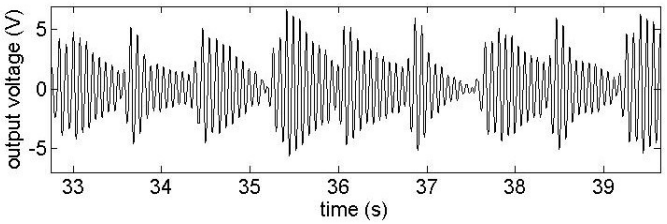
High Level Synthesis

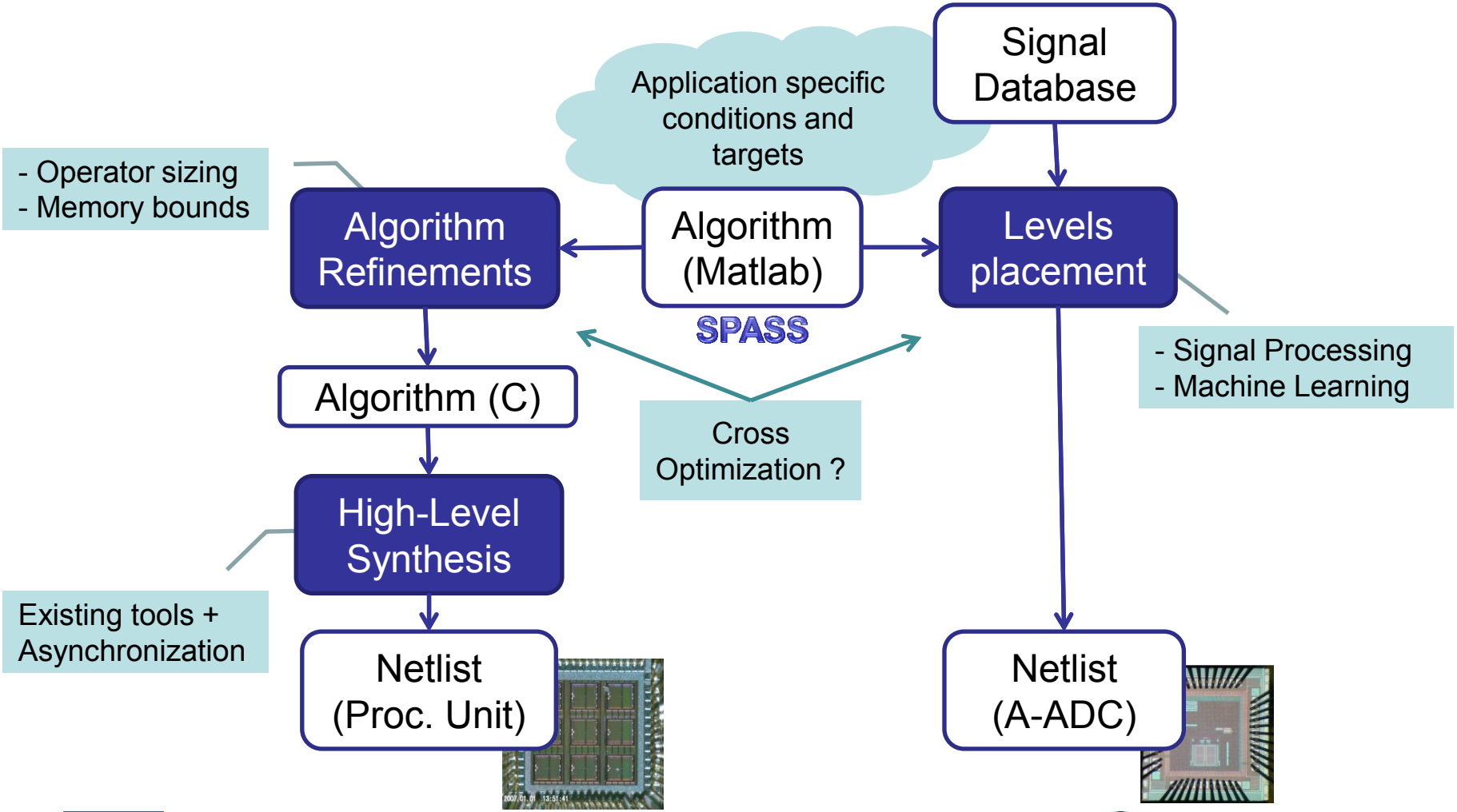
- Needs for Quick prototyping (HW) of control or signal processing chains



- Evaluate signals and applications in Matlab (SPASS)
- **Determine the levels for LCSS**
- **Automatically generate ADCs**
- **Automatically refine the Matlab model to target event-based circuits** (Asynchronous High-Level Synthesis)

Design flow for ultra-low power

Non-uniform sampling (level-crossing) and Asynchronous circuits



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General Conclusion

- Lesson 1: **Determine** the most efficient sampling!
- Lesson 2: Fit well **Event-Driven Circuits** (asynchronous)
- Lesson 3: **Ultra-Low Power**
- Less samples means:
  - Less computation, less storage, less communications,
  - **less power**

A greener approach of digital processing and more generally of the IoT

Non-uniform sampling is the future of digital universe!

Thanks for your attention