Réunion : Projet e-BaCCuSS

An Asynchronous Reading Architecture For An Event-Driven Image Sensor

Amani Darwish [1,2] , *Laurent Fesquet* [1,2], *Gilles Sicard* [3]

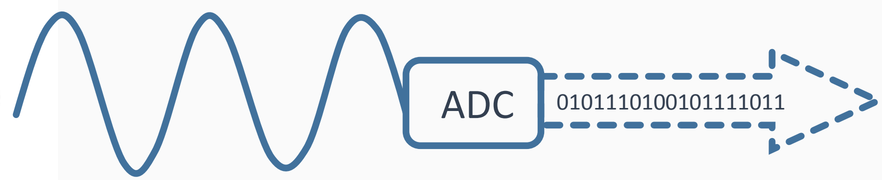
[1] **University Grenoble Alpes – TIMA** – Grenoble, France

[2] **CNRS – TIMA** – Grenoble, France

[3] **CEA – LETI**, Grenoble, France

Internet of Things Challenges

Nyquist-Shannon Theorem



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

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
  - Need a more general mathematical framework

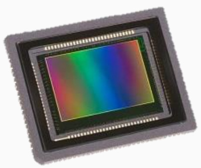
    F. Beutler, "*Sampling Theorems and Bases in a Hilbert Space*", Information and Control, vol.4, 97-117,1961

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

Power ↓ Speed ↑ EM ↓ Throughput ↓

Image Sensors

- Today not too much work for lowering IS consumption
- Some works for reducing the dataflow



- Non-uniform sampling techniques in 1D

- Could we apply similar techniques in 2D ?

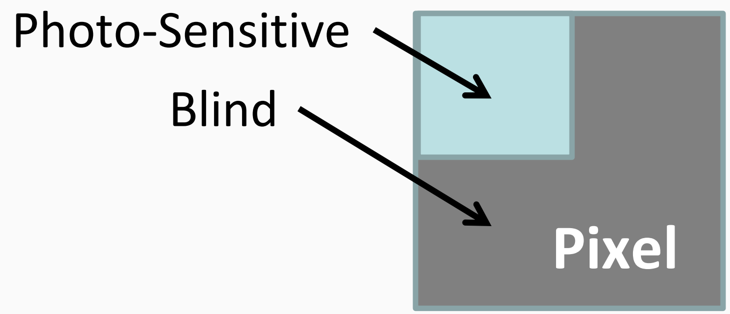
(Posch et al. 2008, 2011, Delbruck et al. 2004, Qi et al. 2004)

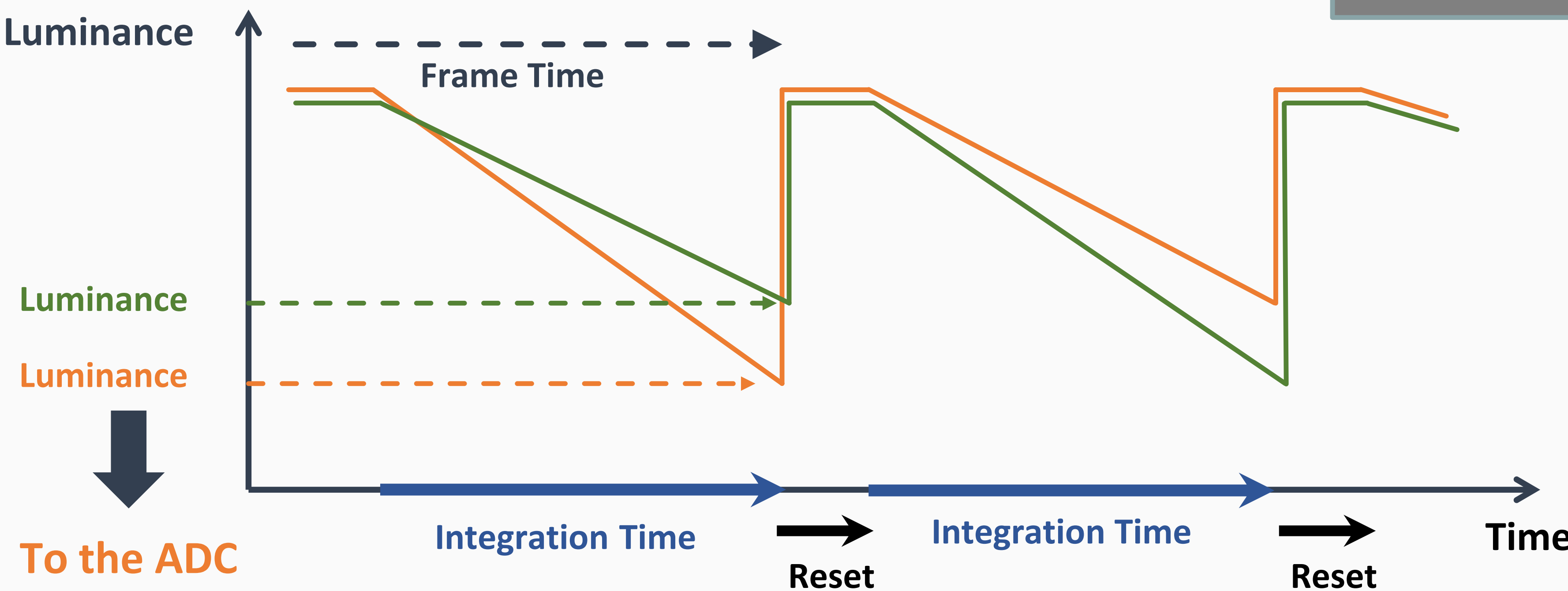
Outline

- Conventional Image Sensors
- Event-Driven Pixel
- Asynchronous Image Sensor
- The Proposed Asynchronous Image Sensor
- Simulation Results
- Conclusion and Perspectives

How does an Active Pixel Sensor (APS) works?

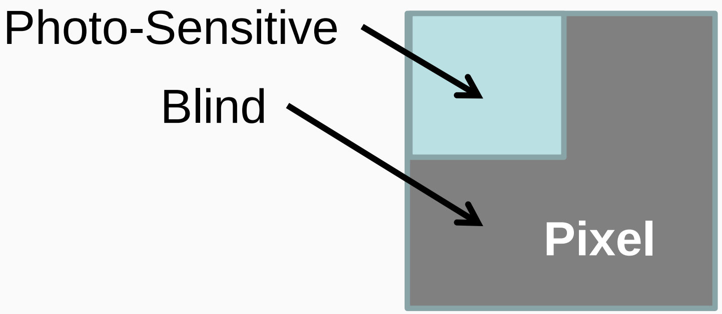
- Global Reset Phase
- Global Integration time
- Analog-to-Digital Converter



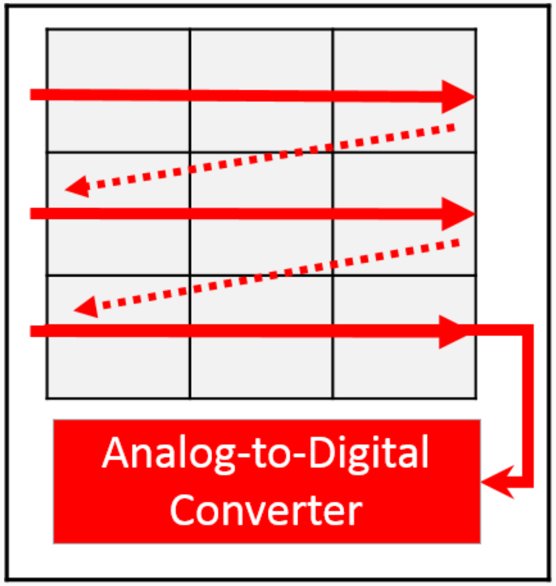


Conventional Image Sensor principles

- Based on **Photo-sensitive pixels**
- **All pixels are read in sequence**



- Larger the sensor
- Higher the throughput (fixed frame rate)
- Higher the ADC consumption



The ADC is the main contributor of power consumption

Limitations of an Active Pixel Sensor

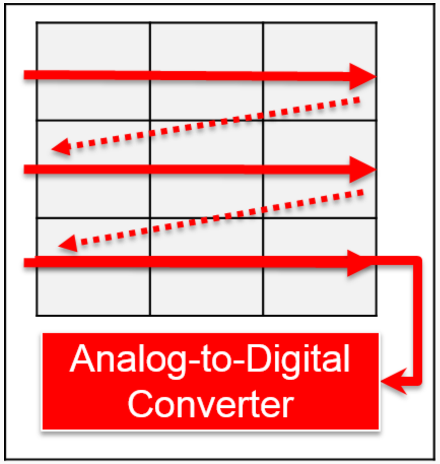
- Fixed Frame Rate
- High and redundant Dataflow

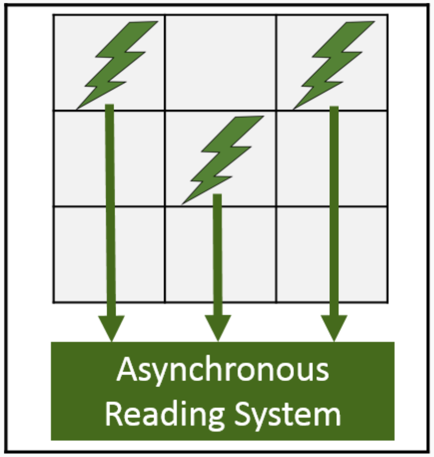
- Fixed Integration Time
- Limited Dynamic Range

- High Power consumption

We can do better !

Towards an Event-Driven IS in 2D





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

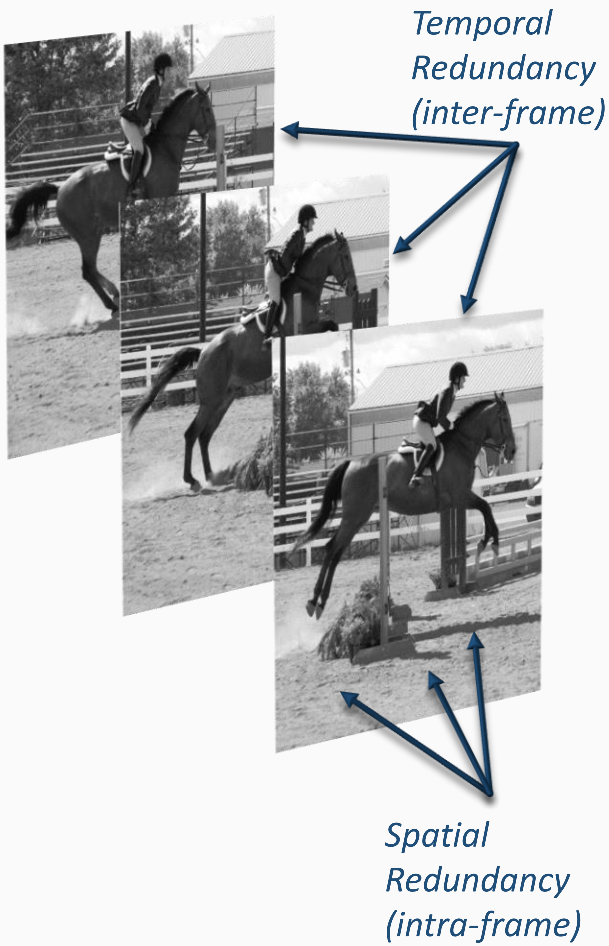
(Yue, Wu, and Wang 2014)
(Amhaz et al. 2011)

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

Spatial and Temporal Redundancy

I. Temporal Redundancy :
   Pixels in two videos frames that have the same values in the same location.

II. Spatial Redundancy :
   Pixels values that are duplicated within a still image



Changing the paradigm in a realistic manner

I. Remove the ADC to limit power consumption

- ✓ Use Time-to-Digital Conversion (TDC)

II. Reduce the dataflow without reducing the frame rate

- ✓ Suppress spatial and temporal redundancies
- ✓ Use Event-Driven logic (Asynchronous)

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Replacing the
Analog-to-Digital Conversion
by the
Time-to-Digital Conversion

Changing the way we read and encode the pixel information

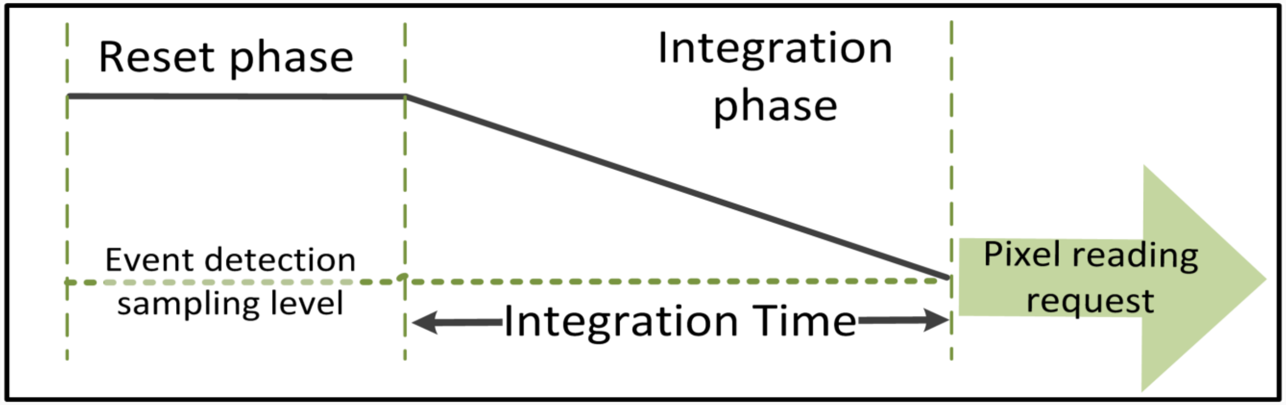
The Event-Driven Pixel

- Based on Event-Detection

- Time to first spike encoding *(Rullen & Thorpe 2001)*
  - 1-level crossing sampling scheme

- Low Throughput
  - **All read data is relevant**

Event-Driven Pixel behavior



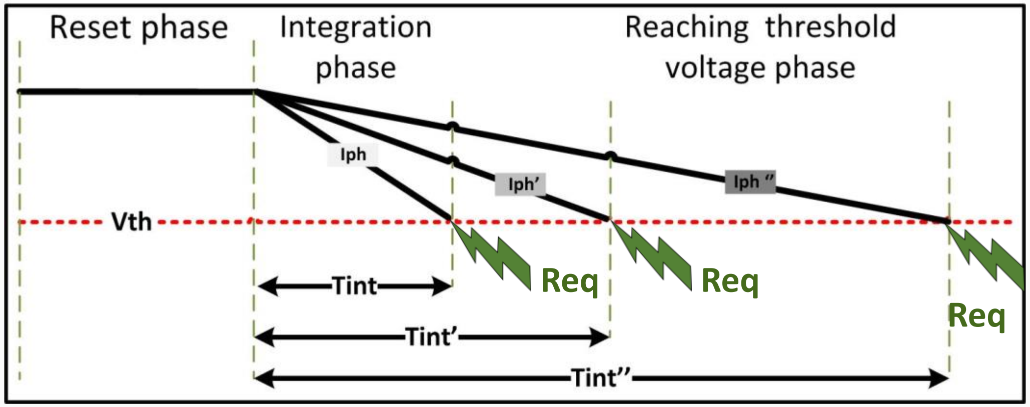
- One Sampling Level Scheme

- The Pixel initiates the reading phase once an event is detected

- Pixel Self Control Mode

What are the advantages of using an Event-Driven Pixel

- Unique Integration Time per pixel
- Optimal Dynamic Range
- Adaptive Frame Rate
- Low Power Consumption
- Adaptive sensitivity depending on luminosity conditions



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Event-Based Readout Circuit

State of Art

I. Non-deterministic:

- Requires an Arbiter
- Power Consumption
- Timing Error
- Higher area
  (arbiter size increases exponentially with the array size)

(Park et al. 2014)
(Posch, Matolin, and Wohlgenannt 2011)
(Posch, Matolin, and Wohlgenannt 2008)
(Shoushun et al. 2007)
(Qi, Guo, and Harris 2004)
(Lichtsteiner, Delbruck, and Kramer 2004)
(Kramer 2002)

II. Deterministic:

- No Arbiter
- Fully asynchronous design (with handshake)

(Fesquet, Darwish and Sicard 2015)
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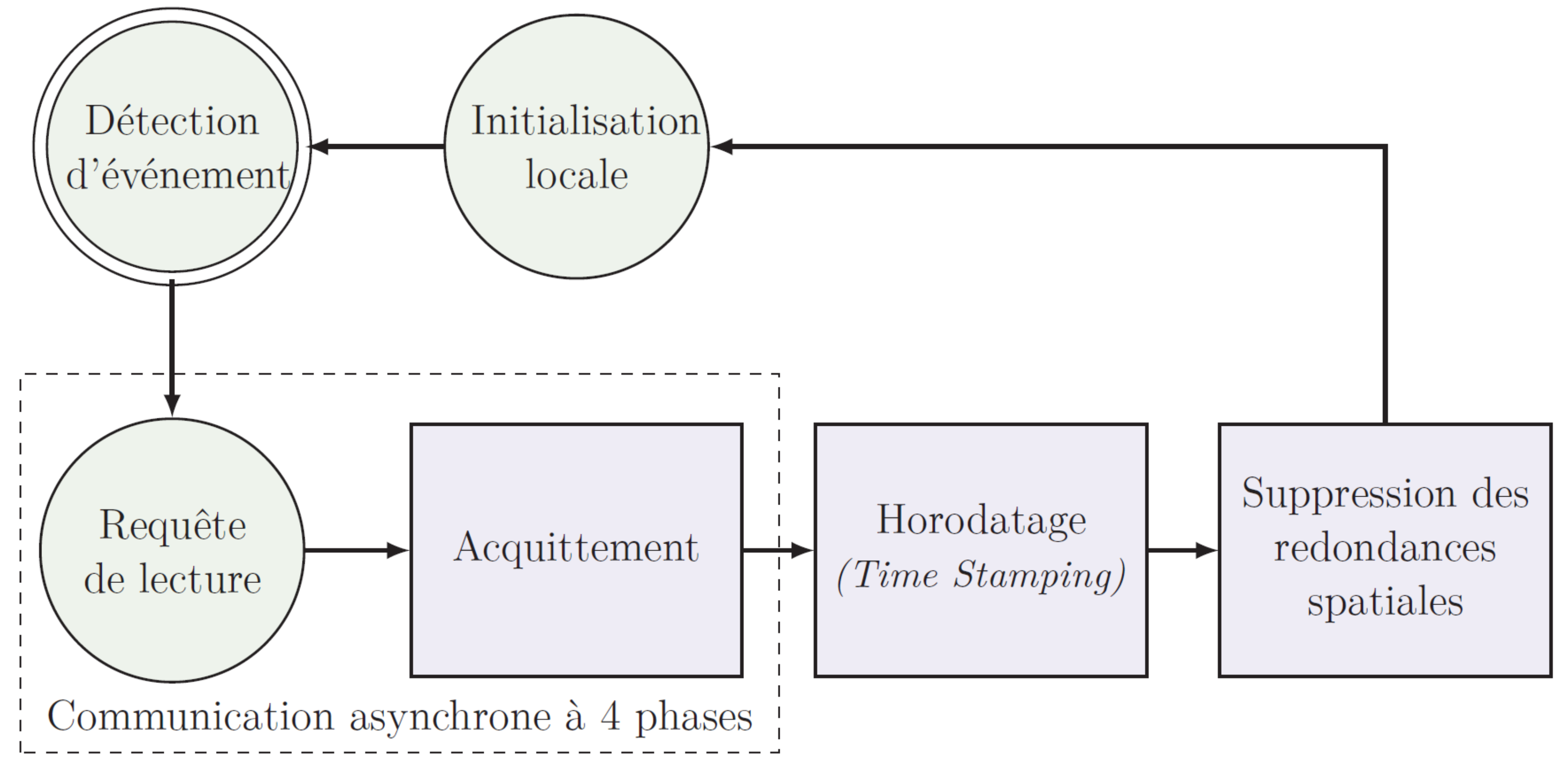
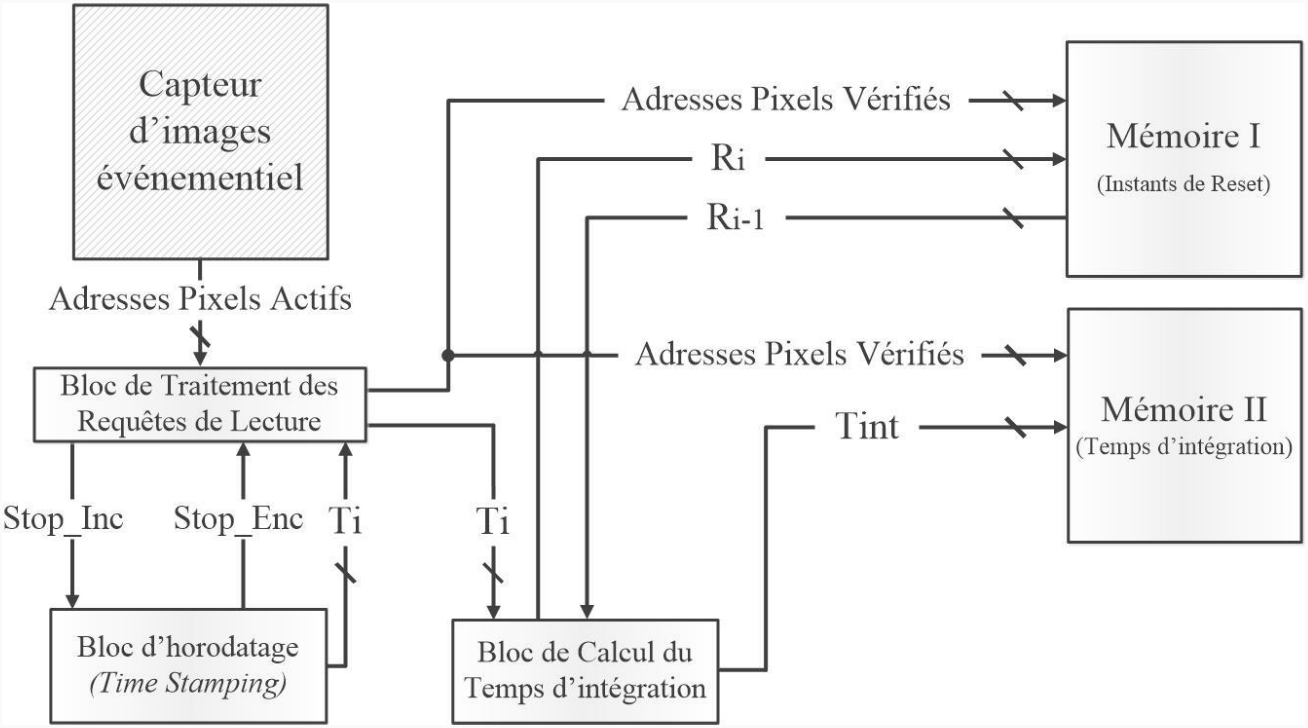
Pixel Reading Sequence



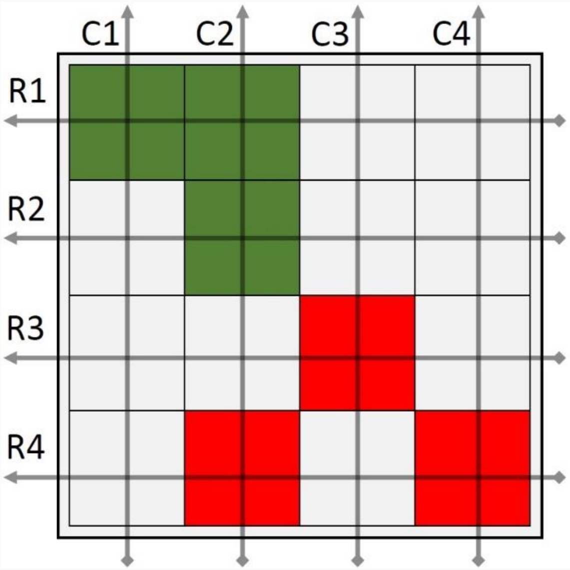
Asynchronous Readout Architecture

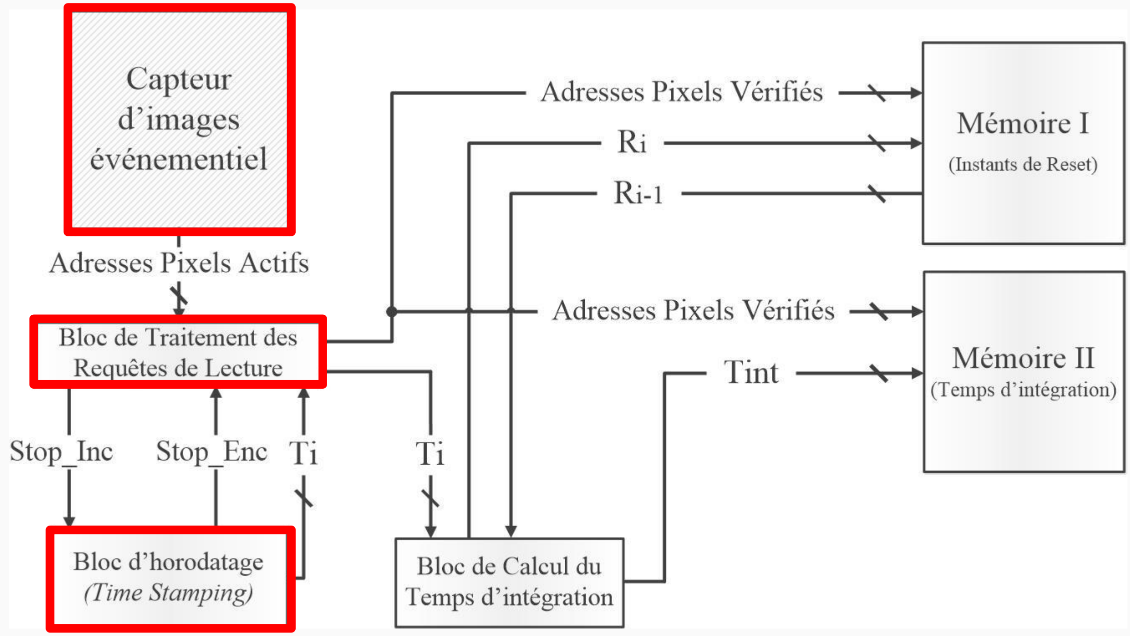


- Asynchronous Pixel behavior (~45 transistors)
- Self-Resetting Pixel
- Time to Digital Conversion
- High Temporal Resolution
- Two Memory Blocks
- Full Asynchronous Digital Design

How do we suppress Spatial Redundancy ?

4 x 4 image sensor





(Darwish, Fesquet, and Sicard 2014)
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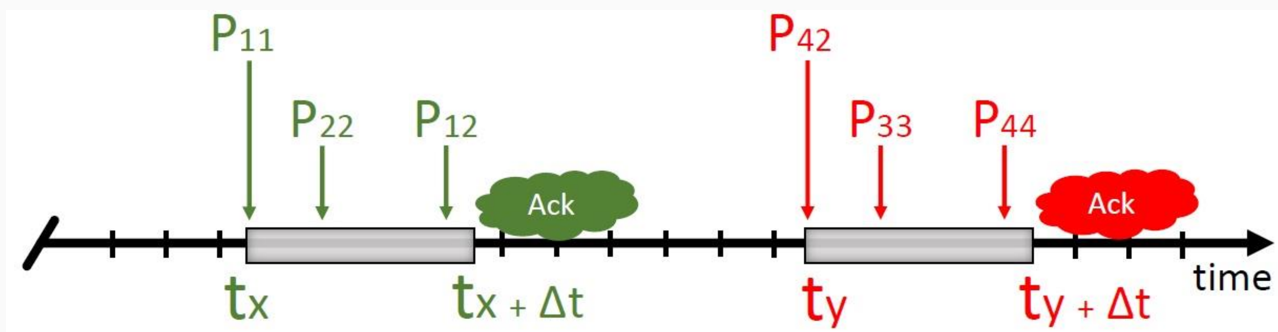
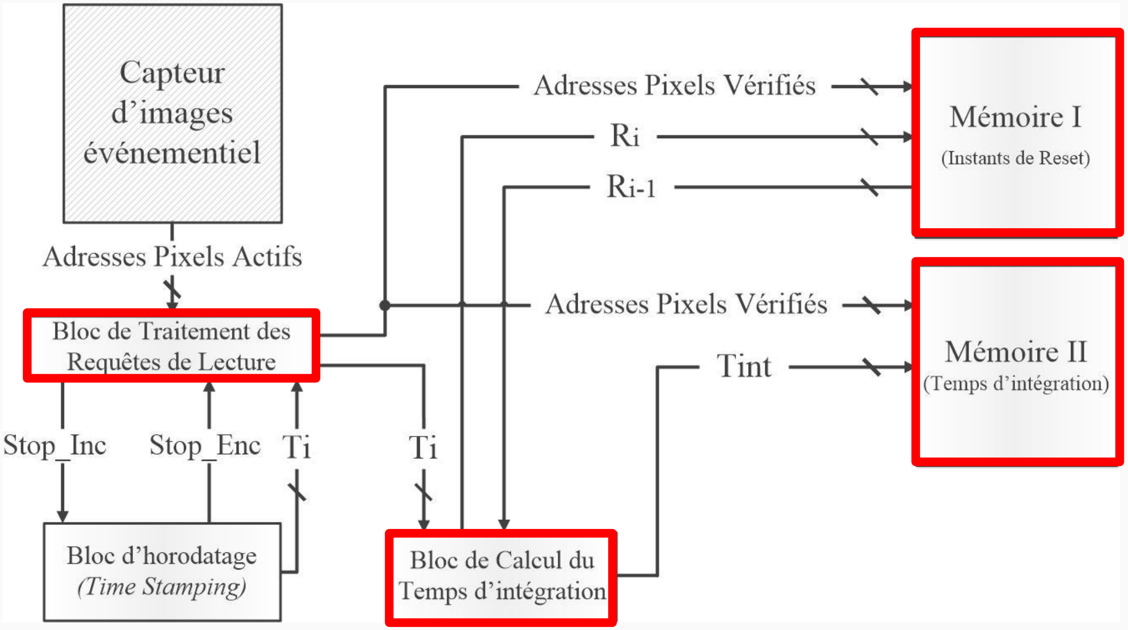
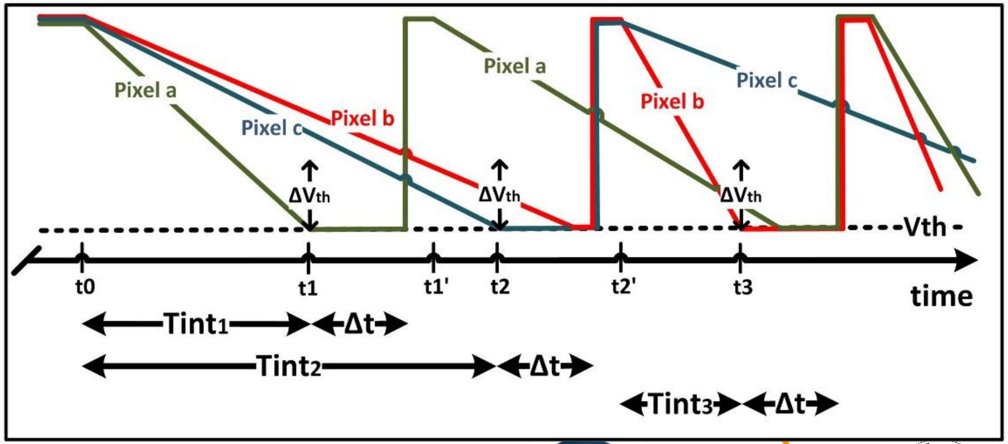


Same Reading Request Group, Different Instant of Reset

- For each pixel, we :
  - Save Instant of request
  - Calculate the Integration Time using the last instant of reset
- No spatial redundancy
- Reduced image data flow





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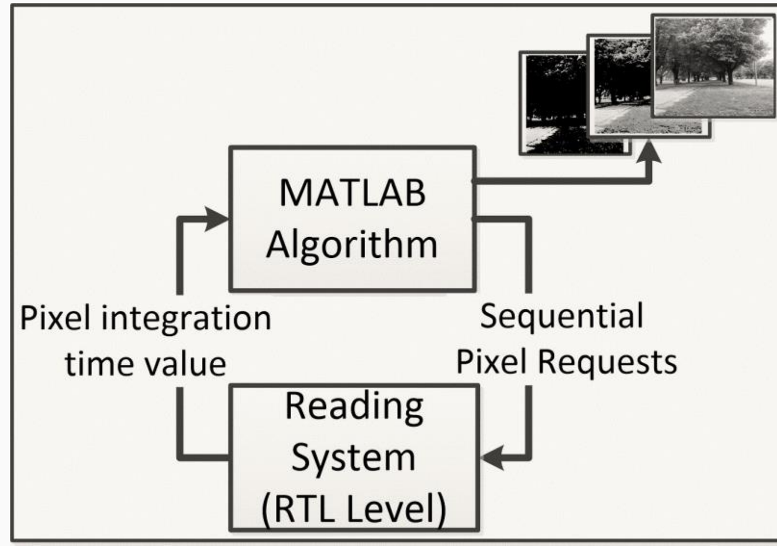
Register-Transfer-Level Simulation

MATLAB generates
the reading request flow

RTL Level
Reading system

MATLAB constructs images
using
Integration Time values



Resultant Image Evaluation :

1. SSIM: Structural Similarity *(Wang et al. 2004)*
2. PSNR: Peak-Signal-to-Noise Ratio

Simulation results

Picture Sample	1	2	3	4
SSIM	0.869	0.943	0.925	0.978
PSNR	43.23 dB	41.97 dB	42.98 dB	43.22 dB
% of the original data flow	15.5 %	4.23 %	0.47 %	3.88 %

Low data flow rate

- **High PSNR** (greater then **40 dB**)
- **High SSIM Values** (greater then **0.8**)

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Conclusion and Perspectives

Conclusion :

- **1-level crossing sampling** in 2D
- Adjustable resolution and dynamic range (Time Stamping)
- Adaptive architecture to light conditions (Sampling Level)
- Image **data flow reduction** (Gain > 94 %)
- **Event-driven** digital circuitry

Perspectives:

- Image sensor fabrication and test
- Directly process the sparse image data flow

Non-uniform sampling is the future of digital universe!

Thanks for your attention