LIDARs for automotive and industrial applications

Lucio Carrara – Fastree3D CTO

lucio.carrara@fastree3d.com
+41 78 601 19 58

Fast. Digital. Simple.

Outline

1. **Set the problem**
(define characteristics)

2. **Rationale of a complete solution**
(Flash LIDAR SoC)

3. **Conclusions**
(ADAS solution is collaborative)

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1.4s

50km/h~28m

Sense ↔ Act

How to decrease latency?

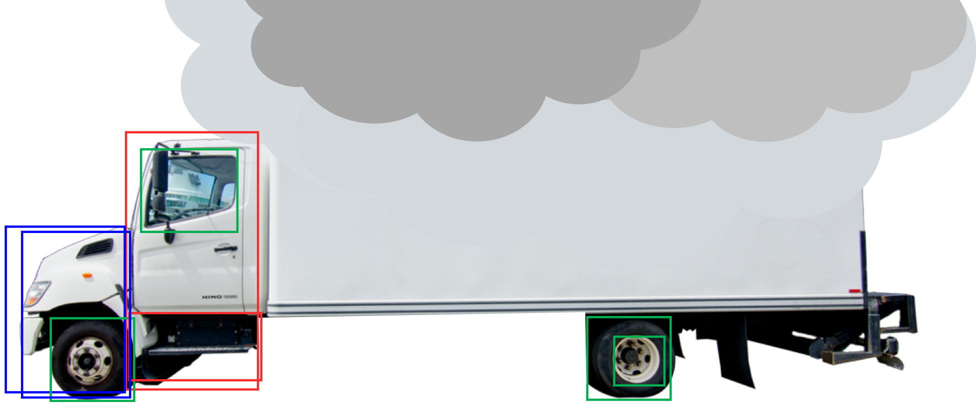
Automate the “sense, think and act”

Complementary Technologies

2D Imaging

Limitations:

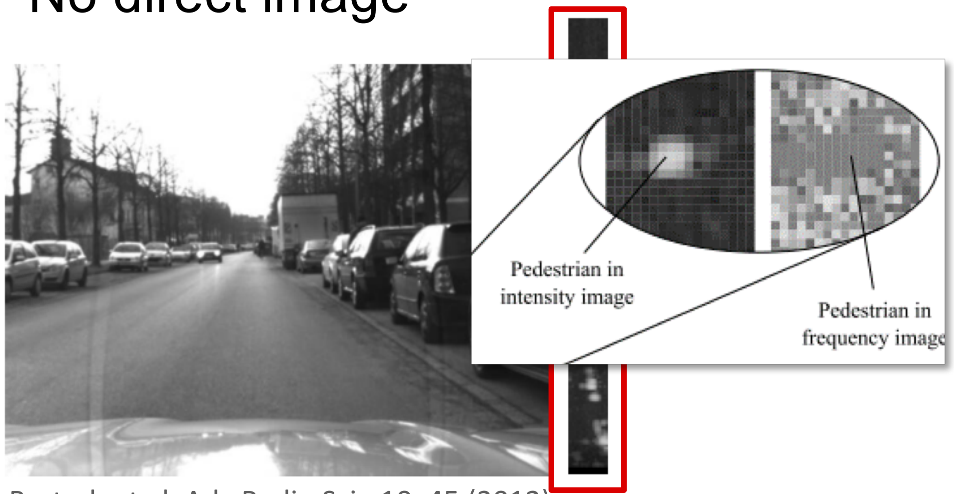
- Extreme illumination conditions
- Low contrast
- No direct depth information



Radar

Limitations:

- High noise
- Low resolution (±0.25m)
- No direct image



Bartsch et al, Adv Radio Sci., 10, 45 (2012)

Improving ADAS performance

Challenges in urban environment

- Reliability of data
- Acquisition speed
- Adverse illumination

Source : image Frost&Sullivan ; EuroNCAP 2016, NHSTA NCSA 2014-2015 ; NHSTA 0.5 casualty /min, 1 fatality / 2h

Outline

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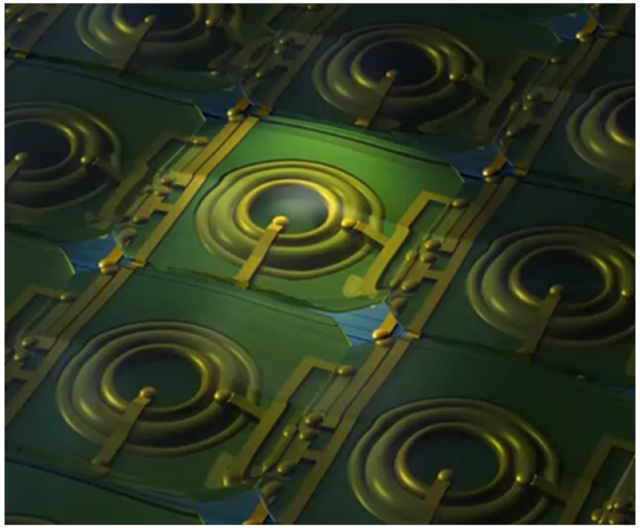
What would an ideal sensor look like?

Fast

- Detection
- Interpretation

Fast

- SPAD array (high sensitivity, native digital)



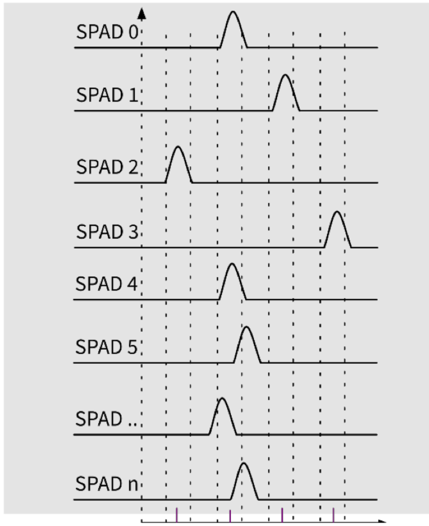
What would an ideal sensor look like?

Reliable

- In any condition
- Quality assessment

Reliable

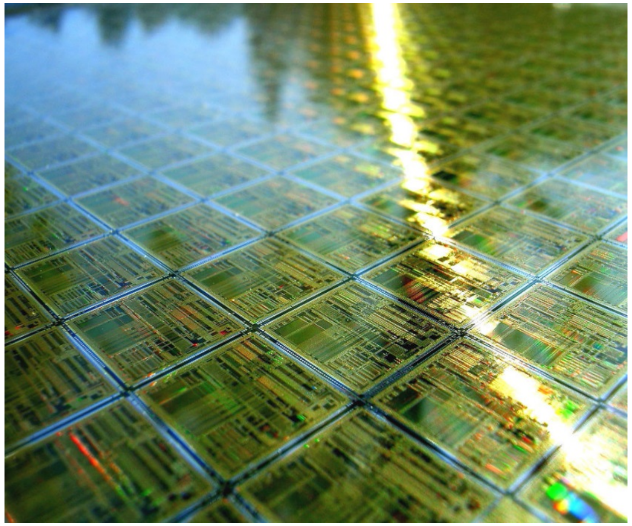
- Statistical approach (TCSPC)



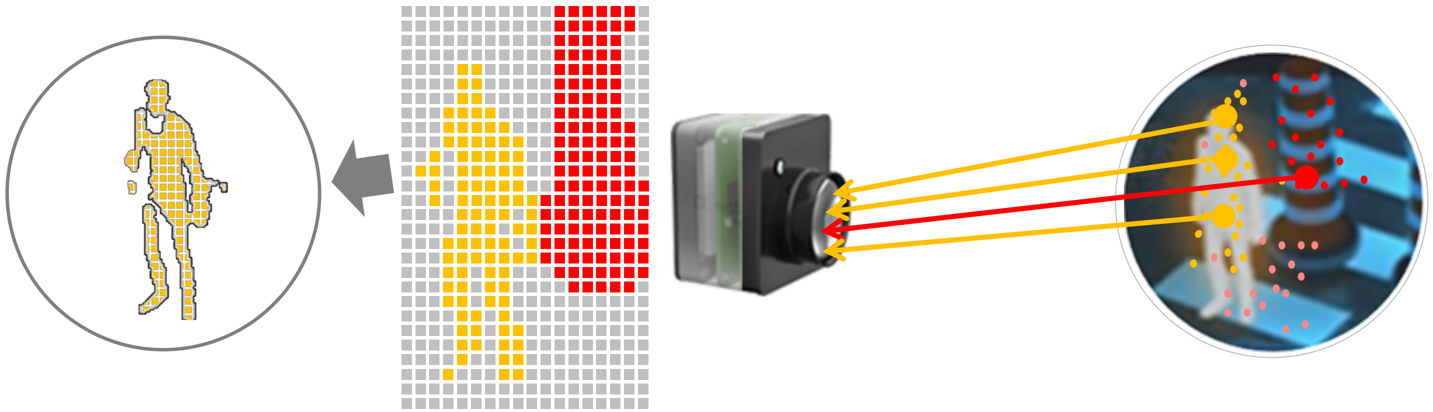
What would an ideal sensor look like?

Affordable
- Simple design
- Scalable

Affordable
- Flash LiDAR
- CMOS



An ideal Flash LIDAR sensor ?



Fast full scene capture

- > 100 fps
- 0-100 K Lux operation
- <1% σ_Z resolution
- >10 kpx arrays

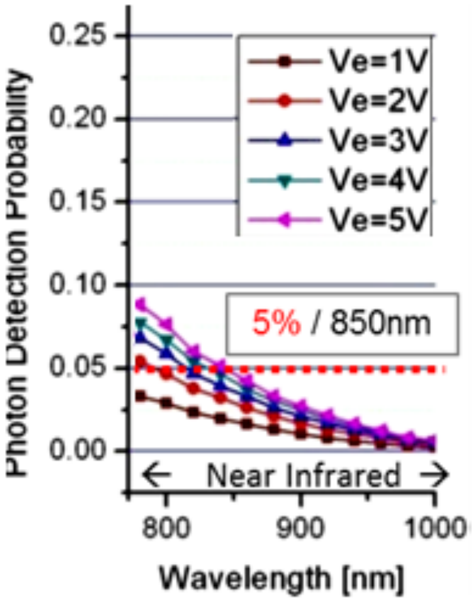
Illumination efficiency

- Power efficient
  (~ 30 m eye-safe range)
- Scene "Flash" illumination

Optimizing illumination for a given range

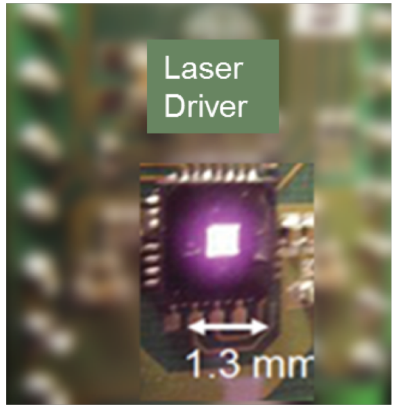
Photon detection efficiency

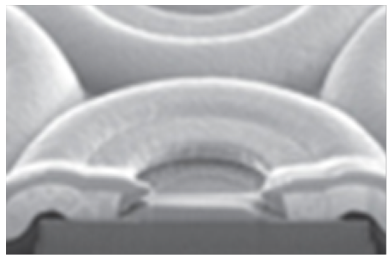
- ~ 5% PDE @ λ= 850 nm



Price performant illuminators

- VCSEL array illuminators





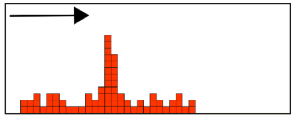
Parameters

- 8W peak
- < 2 ns pulses
- < 100 ms integration time
- PRR ~2 MHz
- 1-4 illumination sources

Source : EPFL; AMS/ Princeton photonics

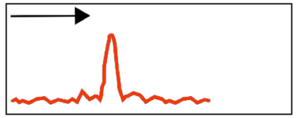
Direct ToF

Digital

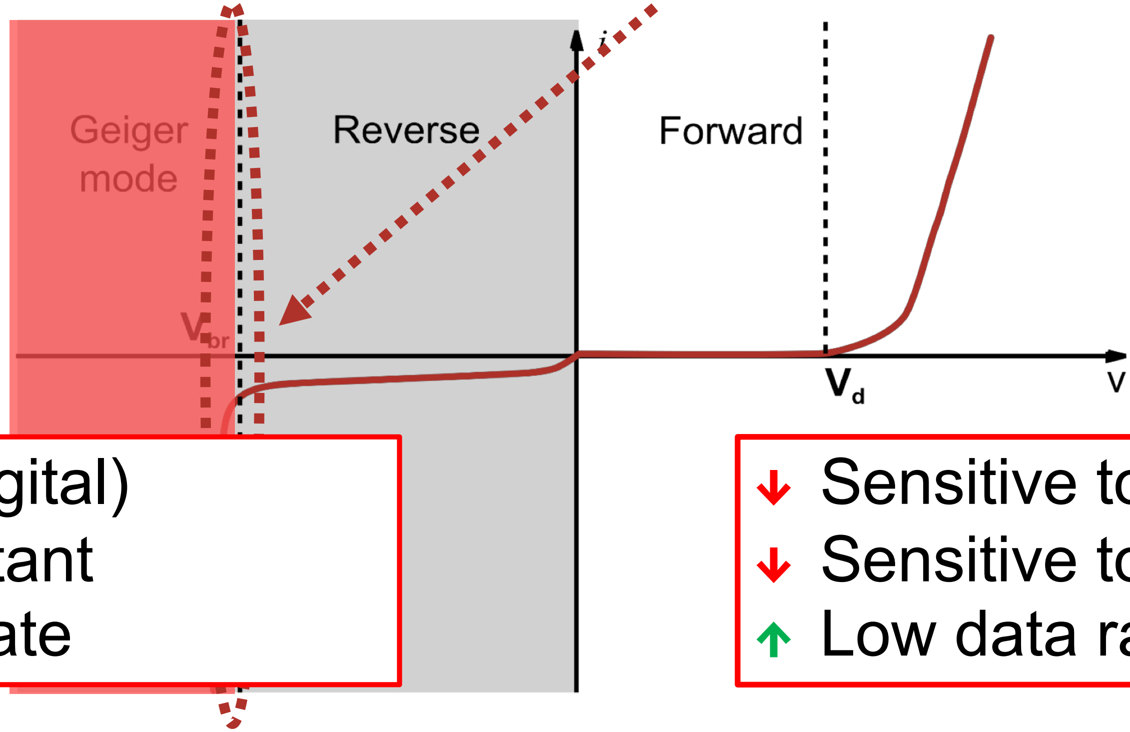


Single Photon Avalanche Diode (SPAD)

Analog



Avalanche Photo-Diode (APD)



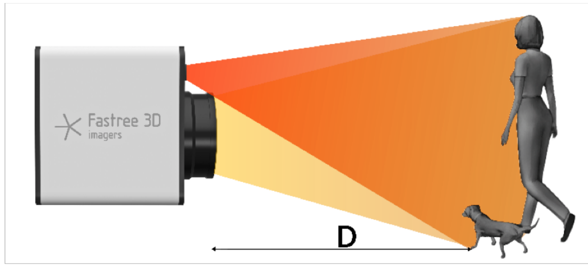
- ↑ Flexible (Digital)
- ↑ Noise resistant
- ↓ High data rate

- ↓ Sensitive to noise
- ↓ Sensitive to temperature
- ↑ Low data rate

Technology-Choice Consequences

SPAD Array

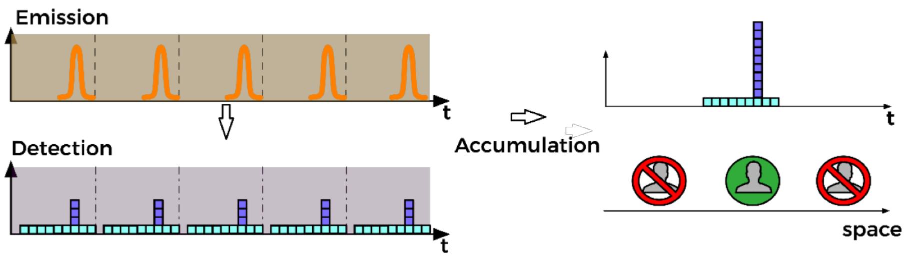
Flash imaging



- High sensitivity
- High data throughput

TCSPC

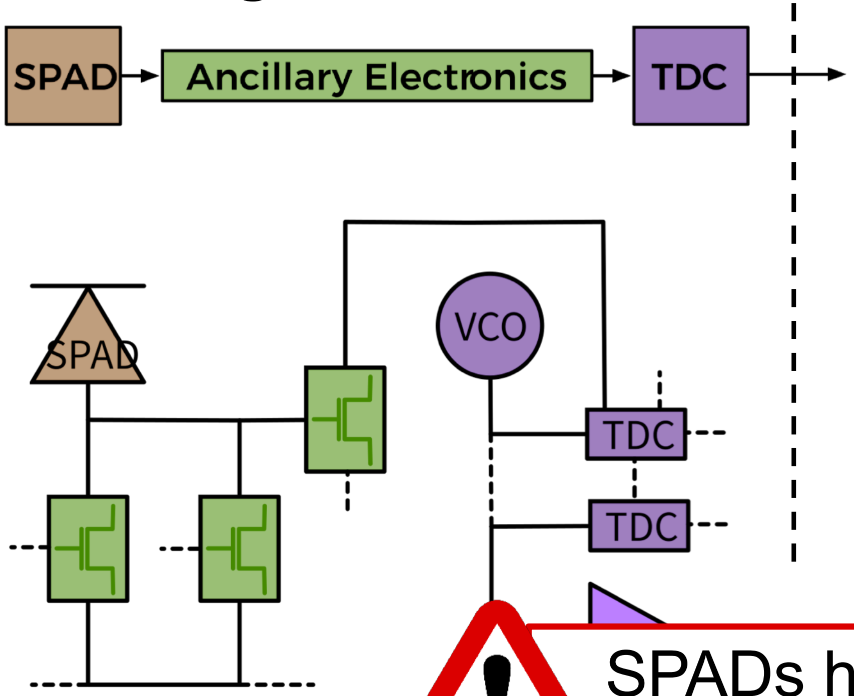
Time correlated measurements



- Statistical approach
- **Quality of results**

What sensor interface?

Sensing



Processing Options

a) Interface to CPU

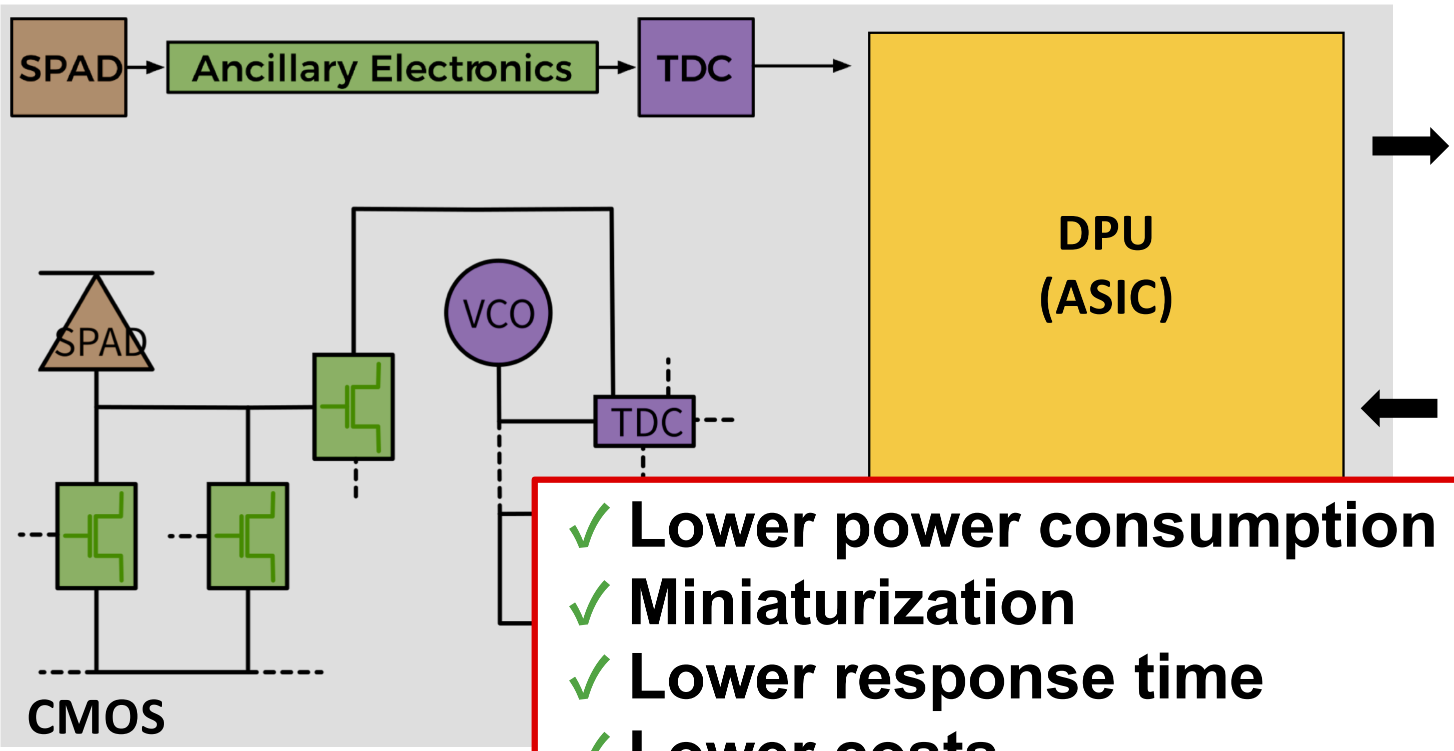
b) Interface to ASIC

c) SoC (monolithic integration)

SPADs have high data throughput!
~50Mbit/s/px

Technology-Choice Consequences

Monolithic Integration (SoC)



Histogram Compression

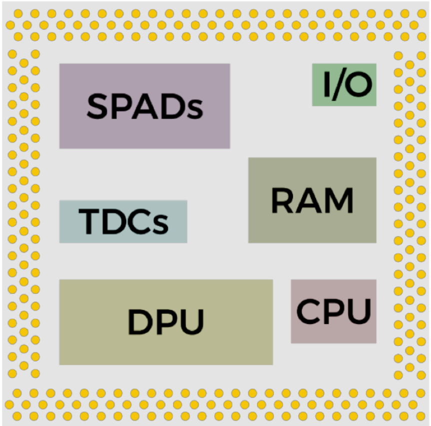
Local image processing

- ✓ **Lower power consumption**
- ✓ **Miniaturization**
- ✓ **Lower response time**
- ✓ **Lower costs**

System-level consequences

System on a Chip (SoC)

Monolithical integration



↑ **Reliability**

Point-Cloud tagged with quality of results

↑ **Flexibility**

Control over sensor SoC

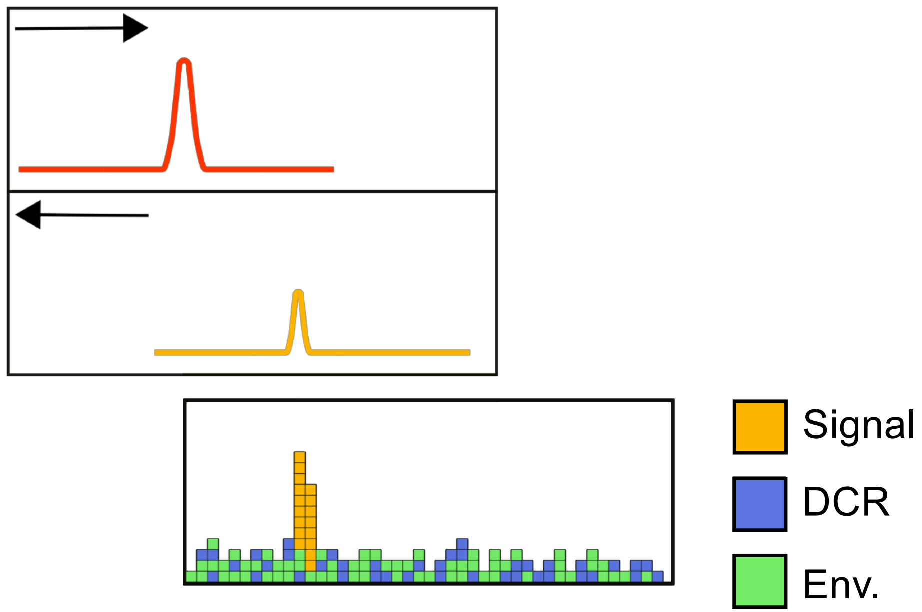
↑ **Affordability**

Flash LiDAR CMOS

Fastree 3D imagers

TCSPC

Contribution to the detection



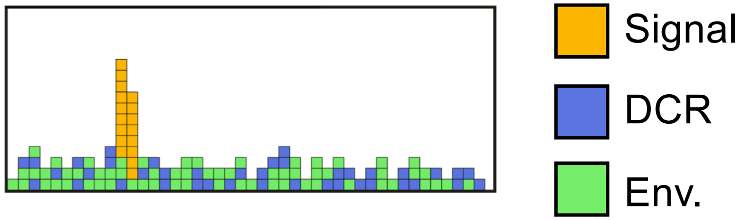
Origin of background:

- Dark Count Rate (DCR)
- Environmental photons

Not possible to distinguish them individually!

TCSPC

Contribution to the detection



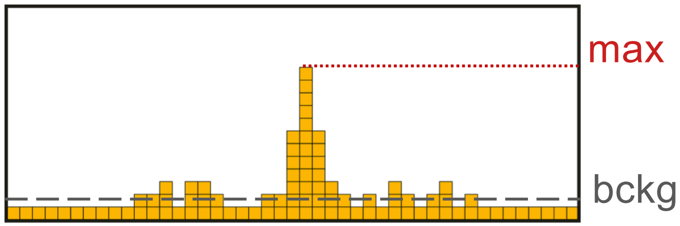
Statistics of the contributions:

- Signal → time-correlated
- DCR → uniform
- Env. → uniform

Accumulation over time allow to identify the signal!

Quality of Result

CPU-DPU Settings



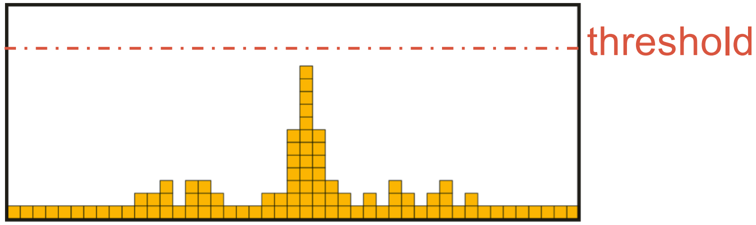
e.g. $QoR = \frac{max}{bckg}$

Control over :

- Threshold for the Quality of Result per pixel (QoR/px)

- Threshold to freeze readout

CPU-DPU Settings



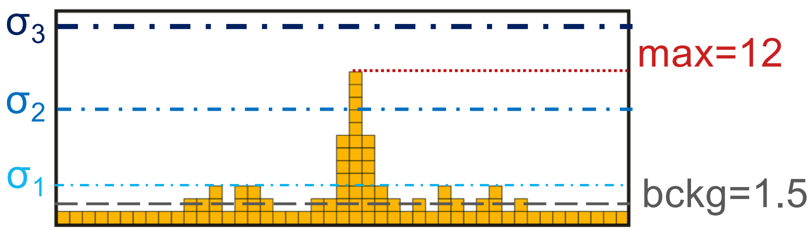
Control over :

- Threshold for the Quality of Result per pixel (QoR/px)
- Threshold to freeze readout

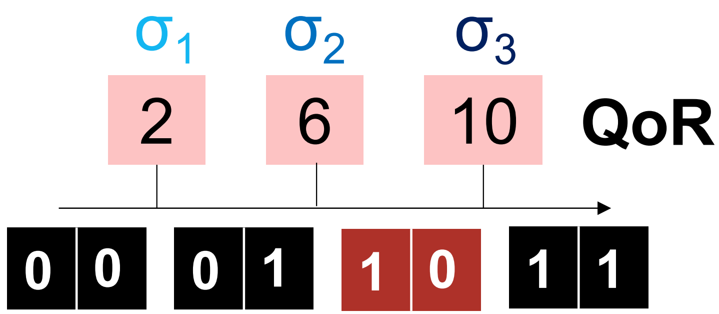
Quality of Result

Distance- QoR

2-bit encoded → 4 possibilities



e.g. QoR= $\frac{max}{bckg} = \frac{12}{1.5} = 8$



Flexibility: data types

Distance

Flexibility: data types

Distance

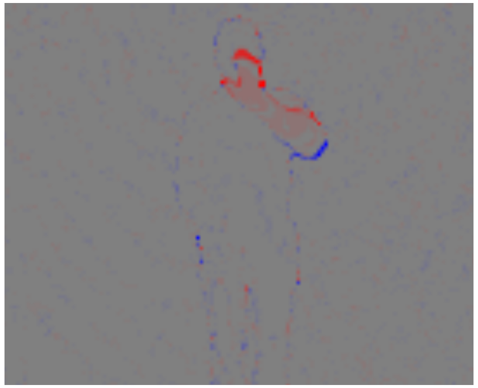
Intensity

Flexibility: data types

Distance

Intensity

Speed

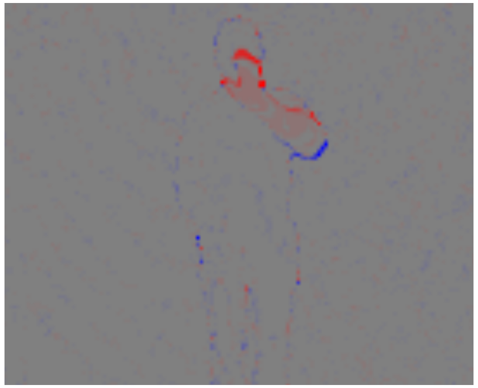


Flexibility: data types

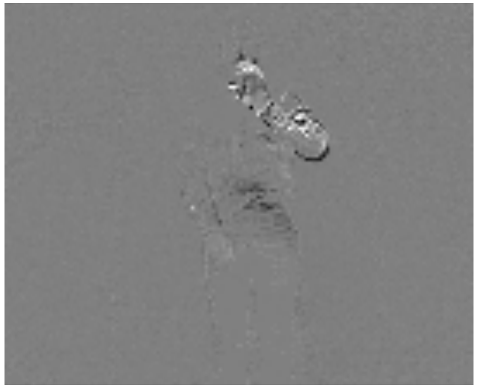
Distance

Intensity

Speed

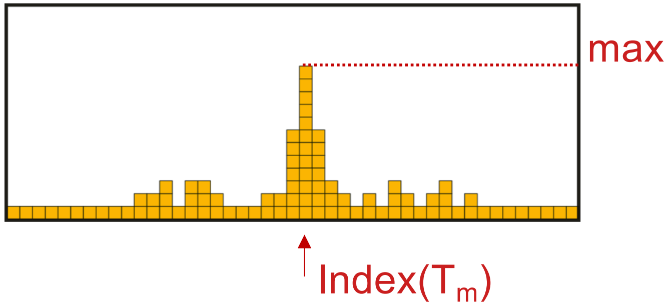


Motion



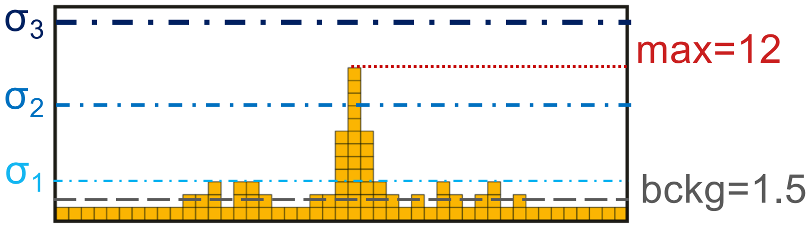
SoC

Distance



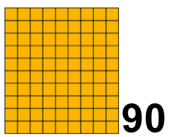
$$d = Index(T_m) * 50\text{ps}$$

Quality



$$QoR = f_\sigma\left(\frac{max}{bckg}\right)$$

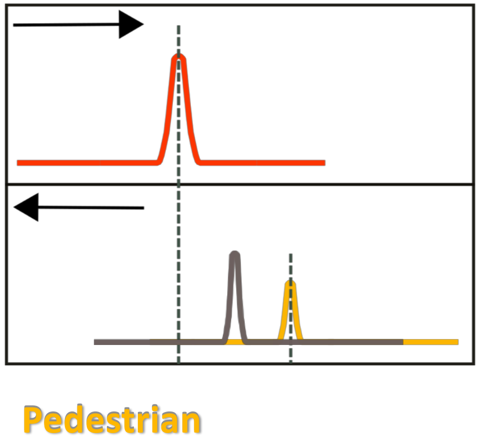
Intensity



$$I = \sum_{i=0}^{n} T_i$$

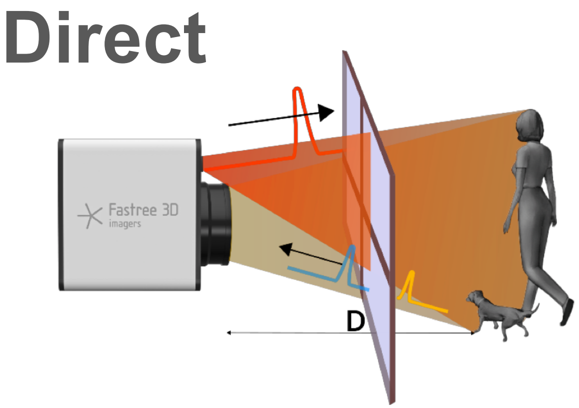
Challenges in TCSPC devices

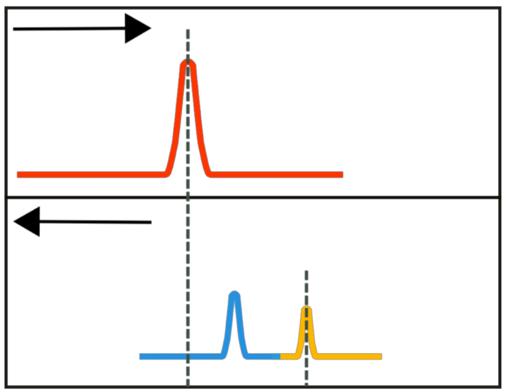
Multi-Camera problem



False positives could be injected by other cameras.
Not reliable anymore!!!

Multipath problem



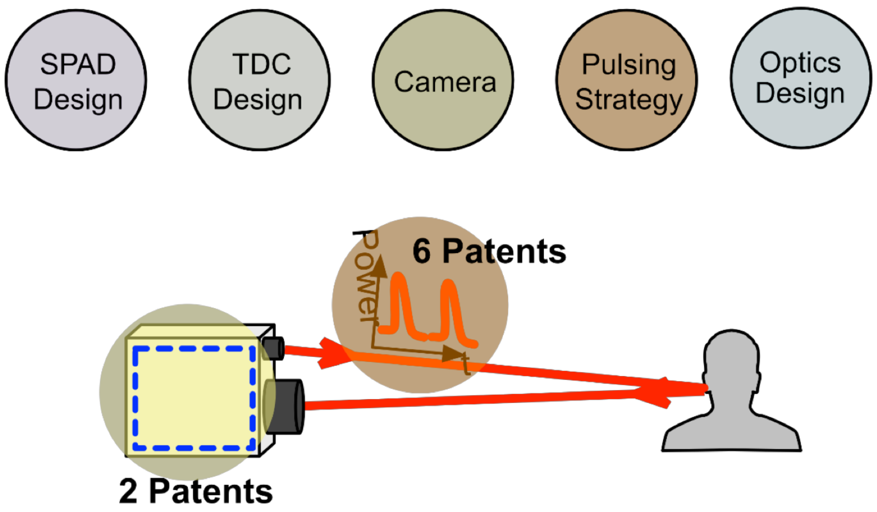


Multiple reflection effect:

- Create a sequence of pulses
- The back-scattered pulses are spaced over time (no overlap)
- Their intensity is proportional to the reflectivity of the objects.

Illuminators' role

Multi-Camera problem



Developed proprietary solutions

- Scalable to n-cameras interaction.
- No supervision/intra-camera communication needed.
- Low power.

Outline

1 **Set the problem**
(define characteristics)

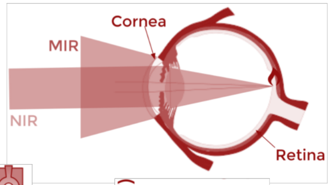
2 **Rationale of a complete solution**
(Flash LIDAR SoC)

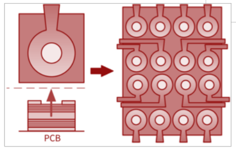
3 **Conclusions**
(ADAS solution is collaborative)

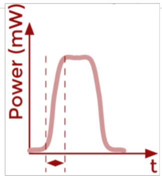
Adaptive Flash LIDAR implementation

Illumination

Eye-Safety

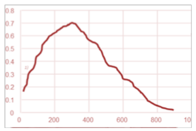






VCSEL arrays

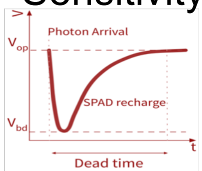
Detection



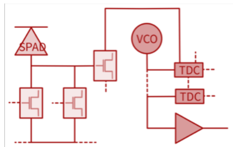
Sensitivity

SPADs

Miniaturization



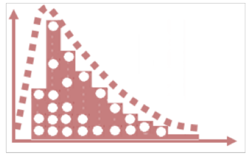
Speed



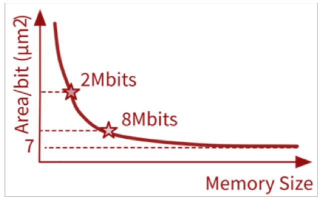
Resolution

Digital processing

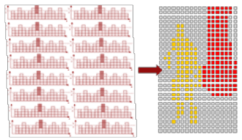
Timing resolution algorithms



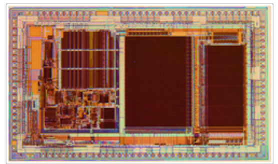
SoC / DSP resource optimization



Point cloud generation



Software / Hardware partition



Direct Time of Flight

with Single Photon Detector

Data processing

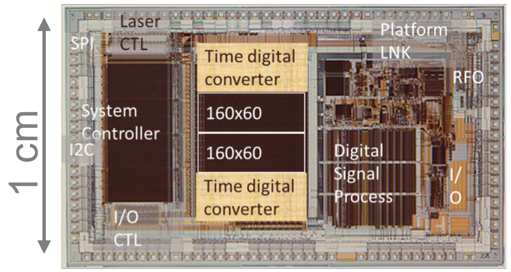
- **System on Chip**
- Averaging / compression

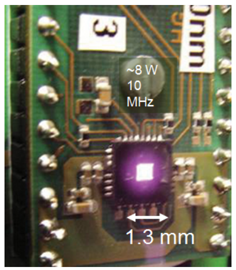
Laser

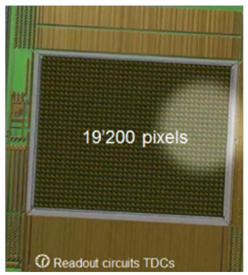
- **Pulsed laser array**
- VCSEL array
- Fast < 3ns >2MHz

Single photon detector

- **Single photon detector (SPAD)**
- Time digital converter 50ps
- High frame rate > 100 fps

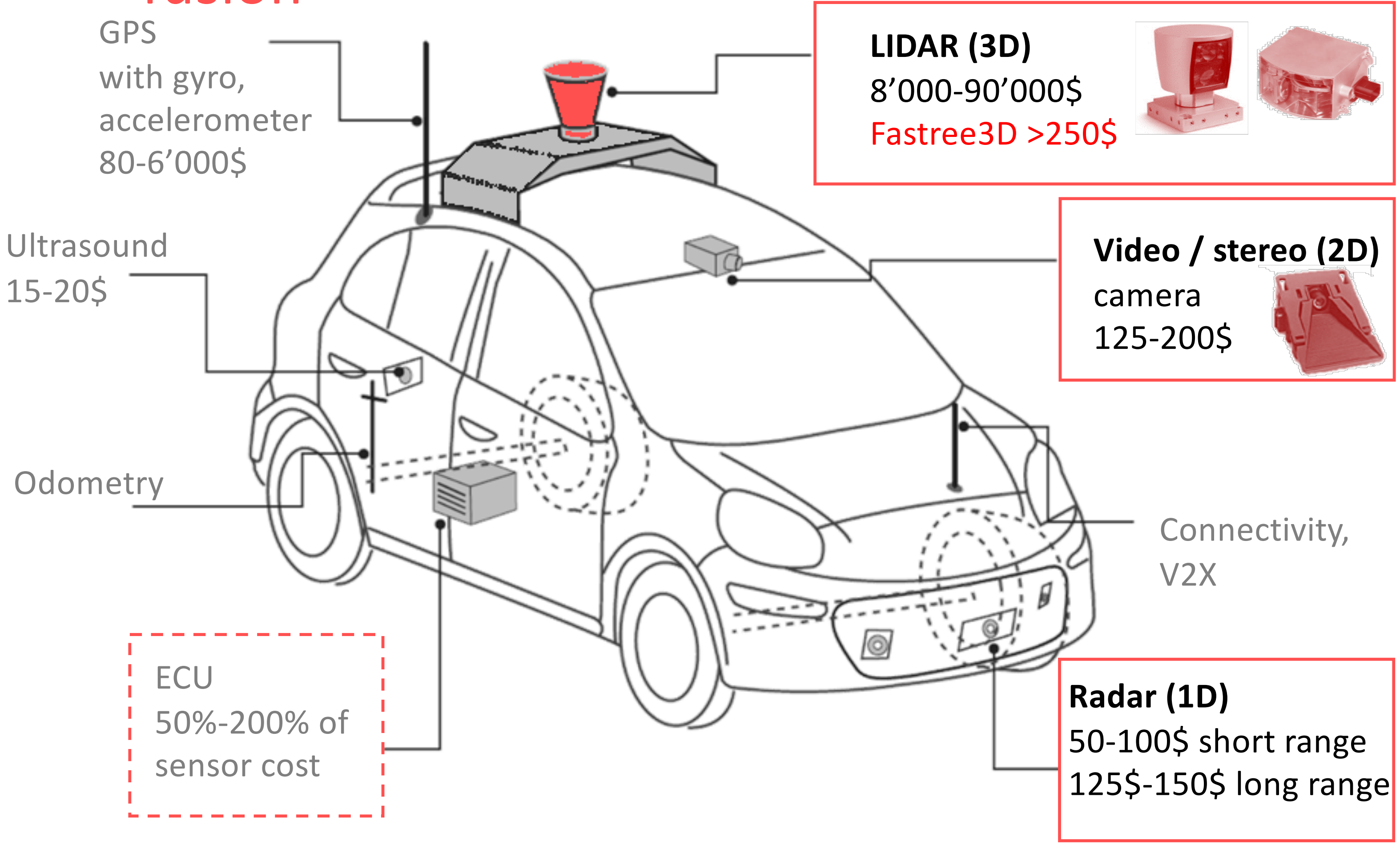






14 patents
(4 granted)

Enabling automotive sensor fusion



Source : Boston Consulting Group, 2015 (adapted)

Fastree3D im-agers

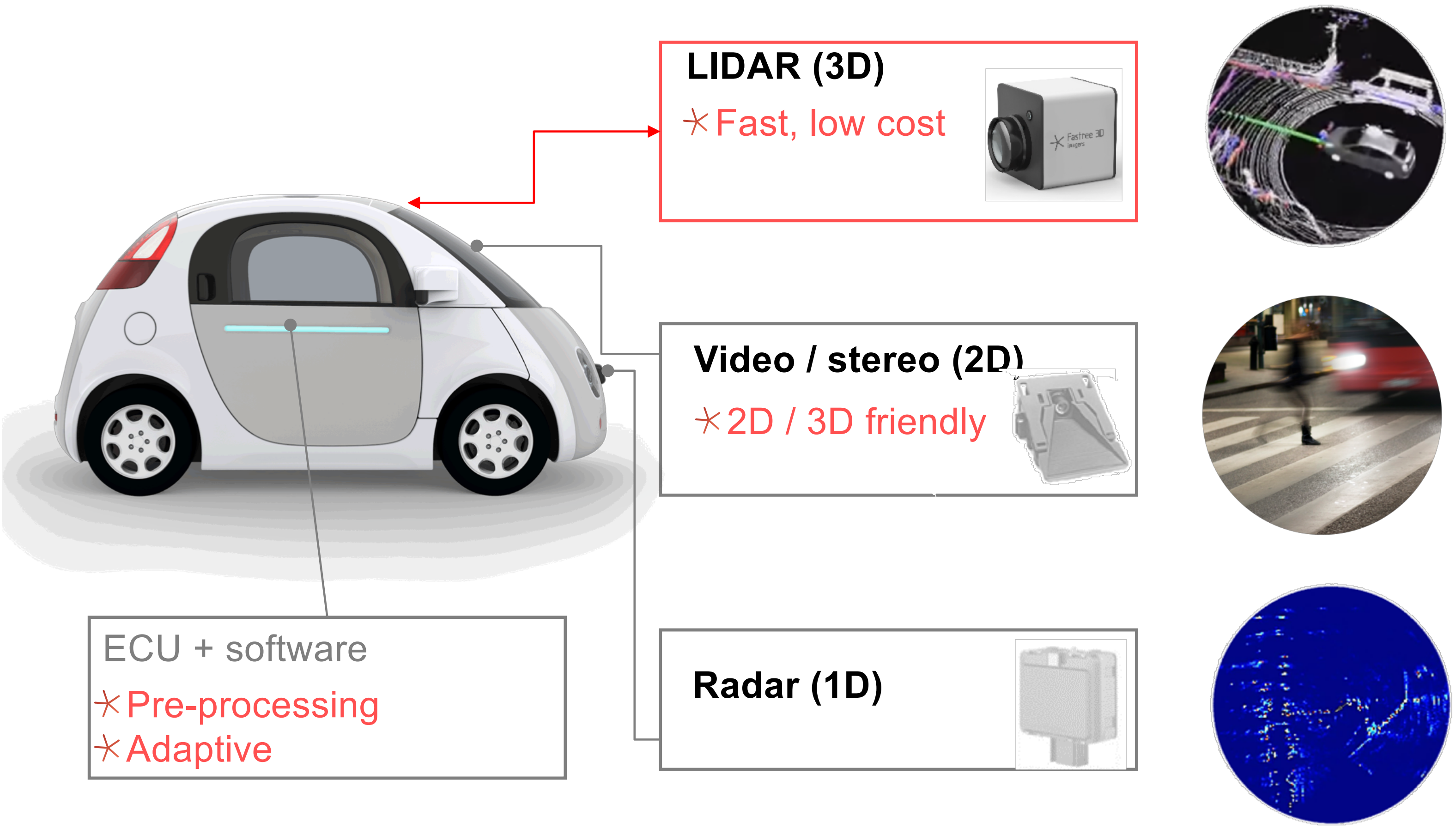
LIDARs for automotive and industrial applications

Lucio Carrara – Fastree3D CTO

lucio.carrara@fastree3d.com
+41 78 601 19 58

Fast. Digital. Simple.

Use case : sensor fusion



Source : Boston Consulting Group, 2015 (adapted), image Google (sensors adapted)

Back Up

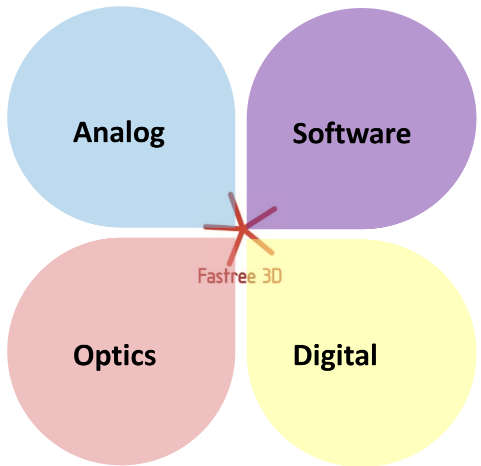
SPAD Data Throughput

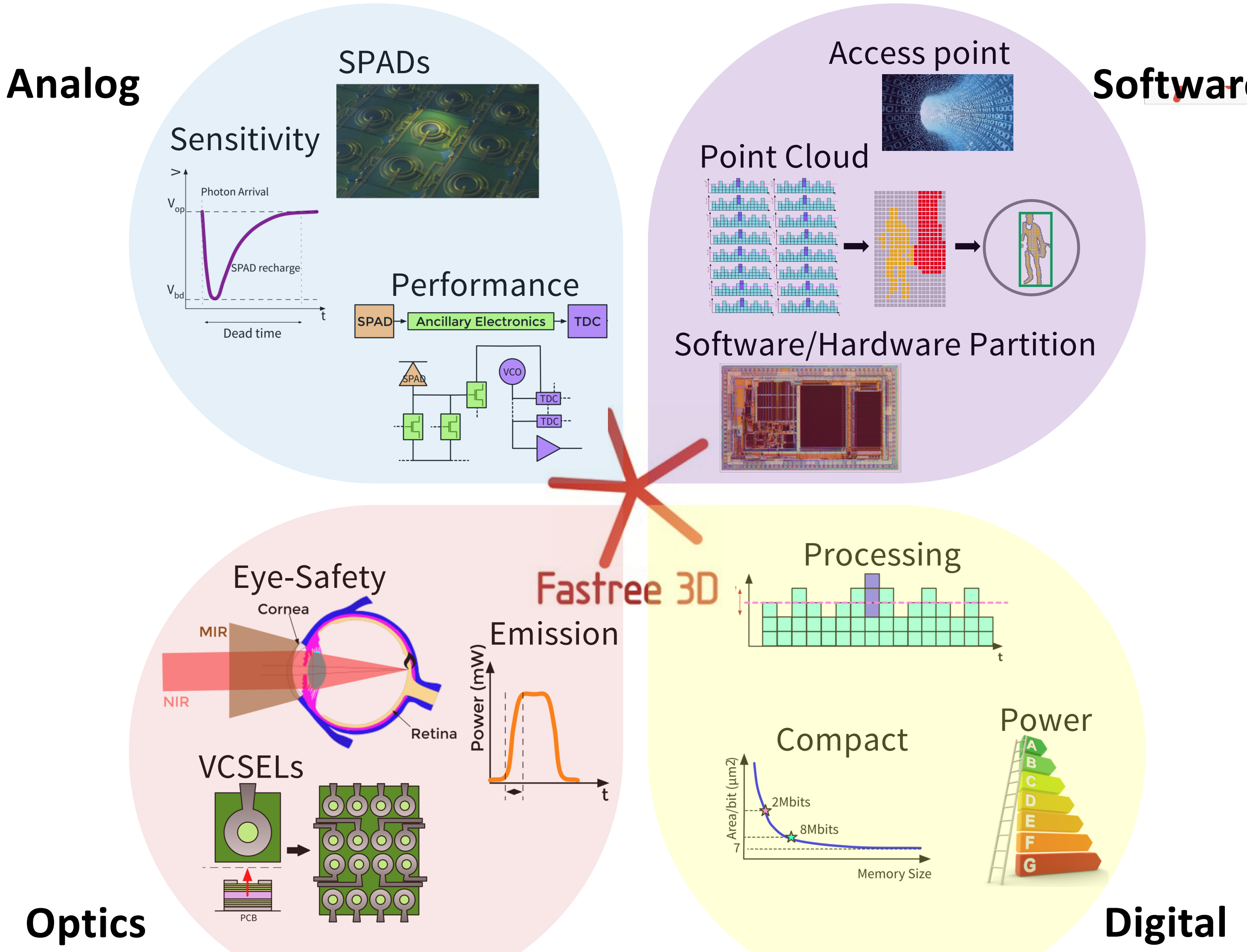
- Timestamps/s * N^r bits/timestamp=Data throughput
  40MHz * 13bit~50Mbit

- Timestamps/s= pulsing freq (e.g. 40MHz) which determines range ambiguity

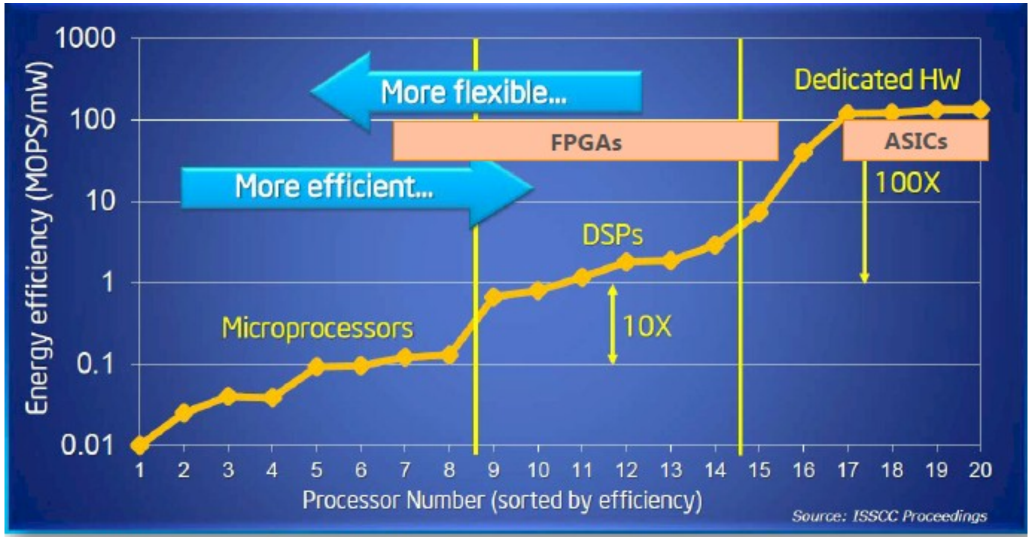
Topics

Performance of a LiDAR is given by how much power we can emit, how sensitive we can detect, while keeping data throughput manageable and low power consumption. All in a compact solution.

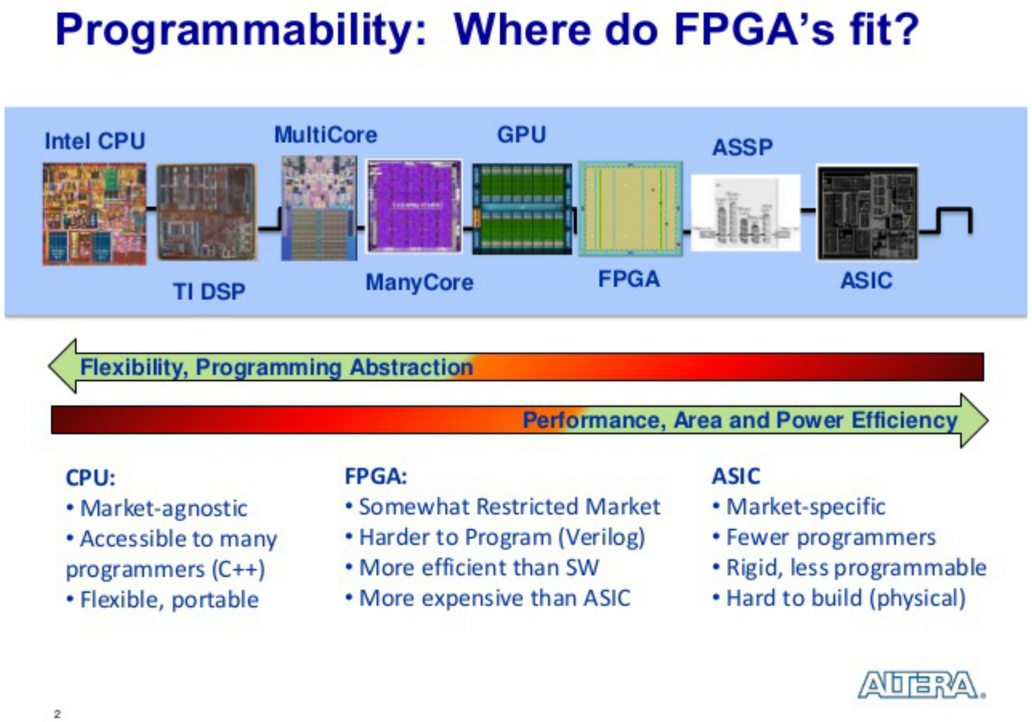



Analog
SPADs
Sensitivity
Photon Arrival
SPAD recharge
Dead time
Performance
SPAD
Ancillary Electronics
TDC
VCO
Software
Access point
Point Cloud
Software/Hardware Partition
Fastree 3D
Eye-Safety
Cornea
MIR
NIR
Retina
Emission
Power (mW)
VCSELs
PCB
Optics
Processing
Compact
Area/bit (µm2)
2Mbits
8Mbits
Memory Size
Power
A
B
C
D
E
F
G
Digital

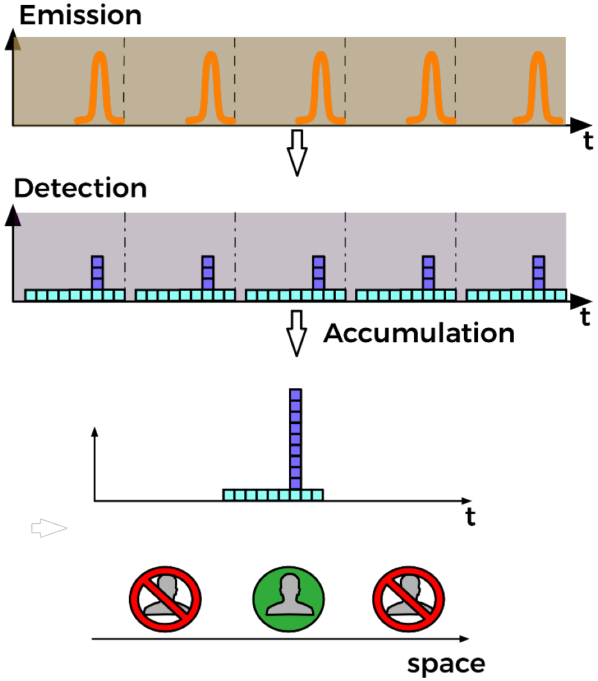
SoC Trends

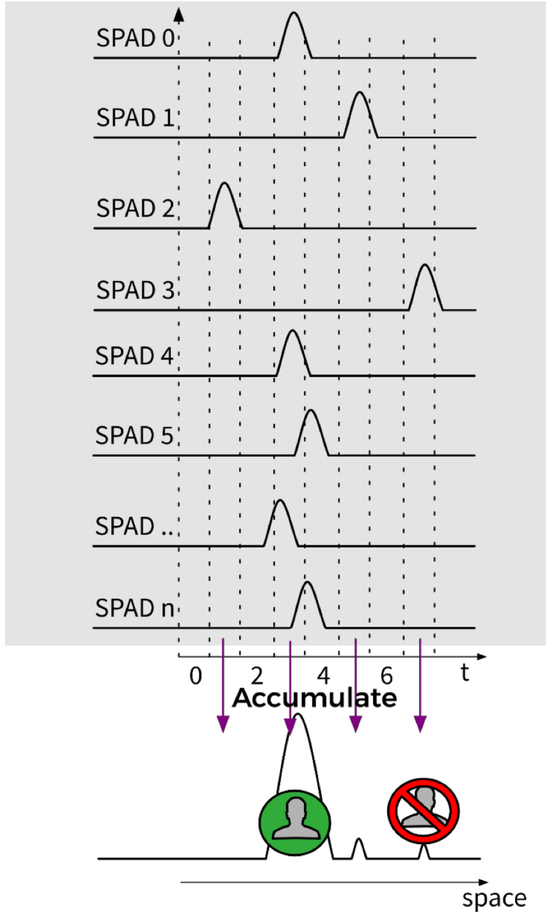


Source: Bob Broderson, Berkeley Wireless group



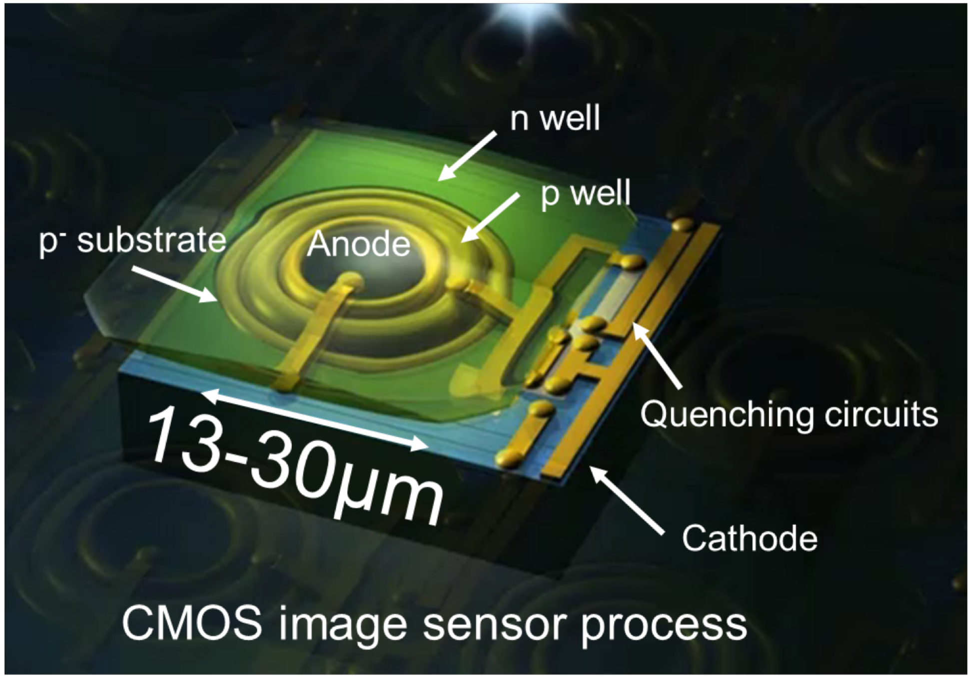
Time Correlate Single Photon Counting (TCSPC)





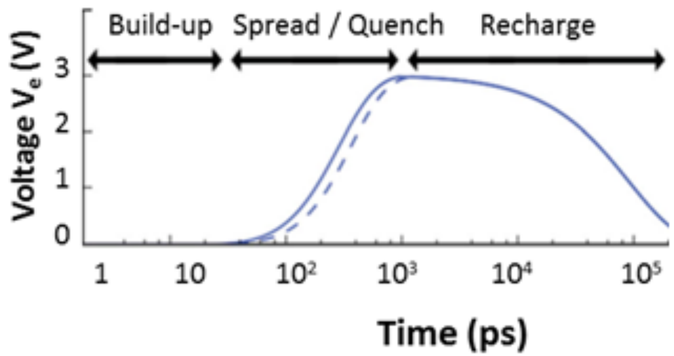
Single photon detection

SPAD pixel



High detection rate

- Short avalanche cycle



T_{quench} = *10 ps (10•10⁻⁹ s)*

T_{cycle} = *250 ns* ⇒ f_{max} = *4 MHz*

Source : http://aqua.epfl.ch/page-96286-en.html ; Edoardo Charbon Philosophical Transactions of the Royal Society, 2014;372:201301

Single photon arrays implementation

Miniaturization

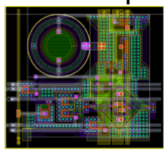
0.35µm CMOS

130 nm CMOS

65nm CMOS

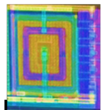
Pitch size

Pitch 25µm **



FF=9%
(43% line)

Pitch 15-30µm
*



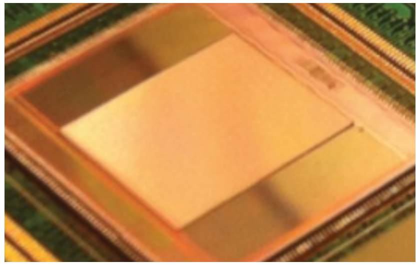
FF
>25%

Pitch 24µm
*

FF=35%

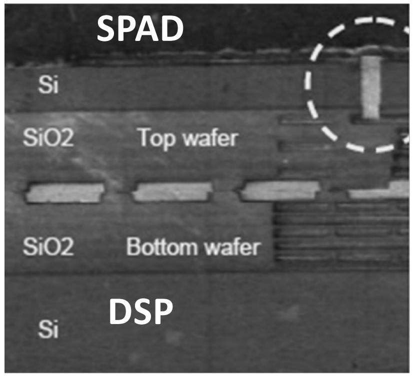
Fill factor

Arrays



Time correlated information.

3D circuits



TSV
5µm

- FF >90%
- Pitch 25µm
- DSP <65nm

Source:Fastree3D SA ST Microelectronics, SPADnet/Megaframe projects EPFL ;