Event Computer Vision 10 years Assessment:
Where We Came From, Where We Are and Where We Are Heading To

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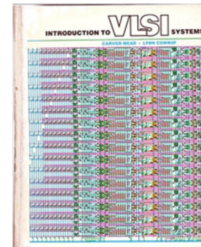
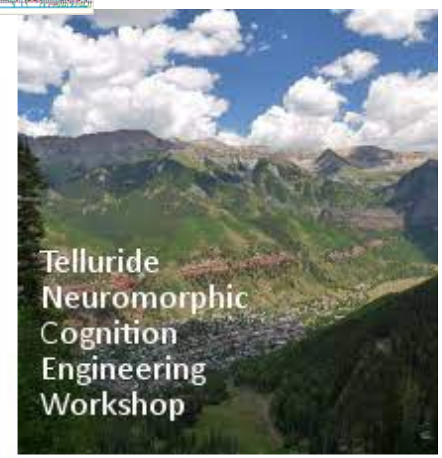
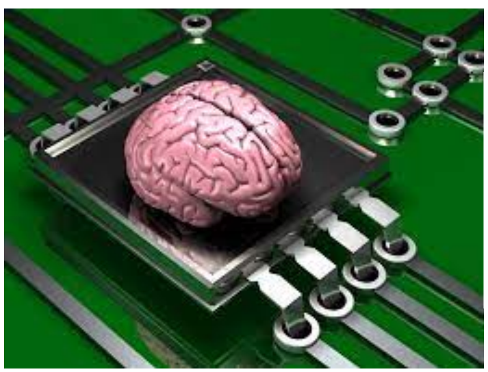
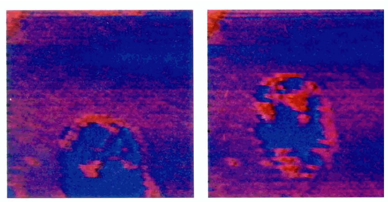
Where we came from…



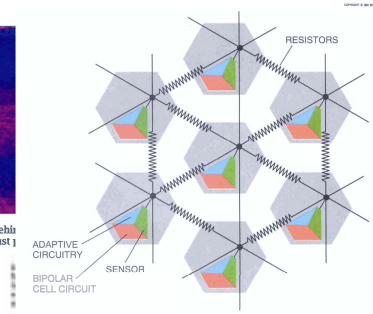


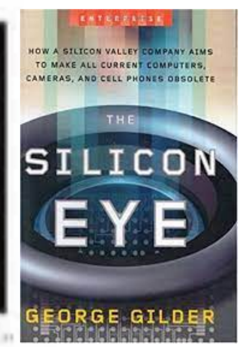
Mahowald/Mead retir





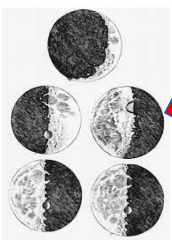
SOCCERBALL in motion shows how the delayed response of the horizontal cell network affects the retina's perception. The ball leaves behi spots have just



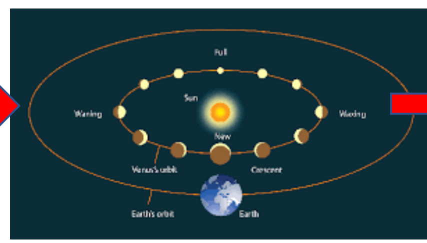


Where we came from…

A Chance to Move Perception from Engineering to Basic Science!



observe



understand

Relativistic orbital motion

- Light and bodies move on *geodetics* in the spacetime
- The 3D "shadow" of a geodetic in 4D is the *orbit*
- We need an equation for "straight lines" in spacetime!

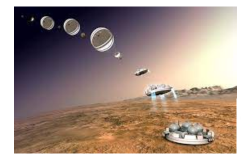
$$\frac{d}{d\tau}\left(\frac{\partial \mathcal{L}}{\partial \dot{\sigma}^i}\right) - \frac{\partial \mathcal{L}}{\partial \sigma^j} = 0$$

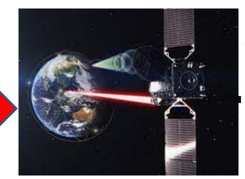
Euler-Lagrange equation

$$\mathcal{L} = \frac{1}{2} g_{ij} \dot{\sigma}^i \dot{\sigma}^j$$

The *metric tensor* g describes spacetime curvature, contains the Schwarzschild metric coefficients

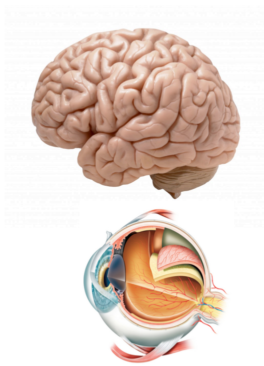
model

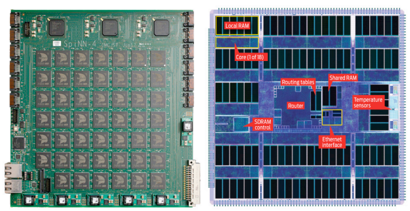




application

Where we came from…





Physiology ⇄

- Models
- Hardware

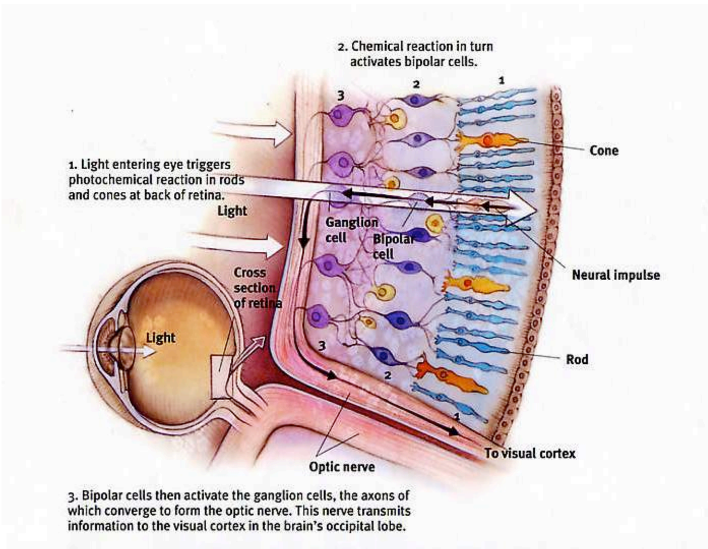
⇄

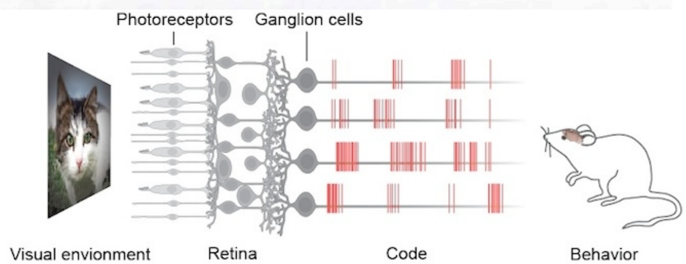
- Cognition
- Robotics
- Computation
- BMI

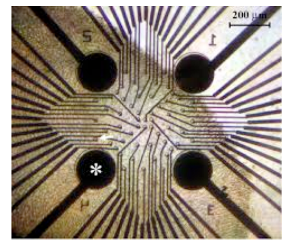
- Develop new bidirectional methodology to understand the brain
- Merging Computational and Biological Vision
- Importance of applications in Brain-Machine Interfaces

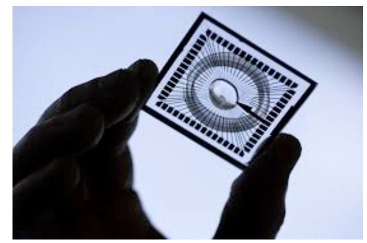
Where we came from…

The retina: “the most approachable portion of the Brain”



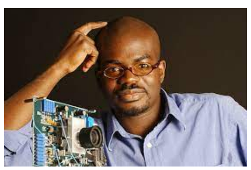






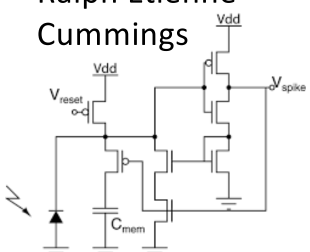
Where we came from…

Event-based Cameras: A Long Incremental Quest

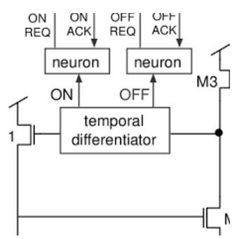


Kwabena Boahen

Ralph Etienne-Cummings



Jorg Kramer



Patrick Lichtsteiner
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Christoph Posch
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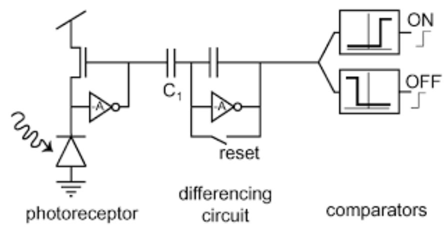
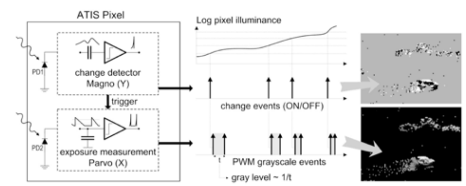
Tobi Delbruck
ETH Zurich



Daniel Matolin



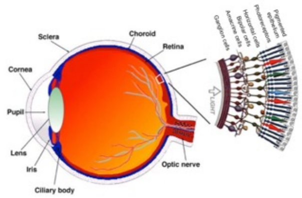
2000 2004 2008

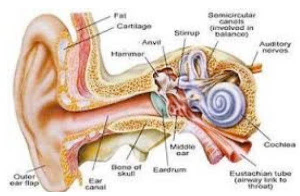
Where we are …

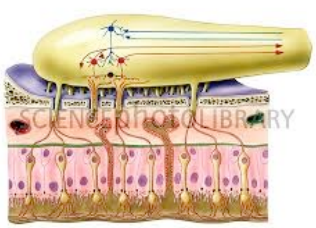
Event-Based Cameras V1.0: Panorama

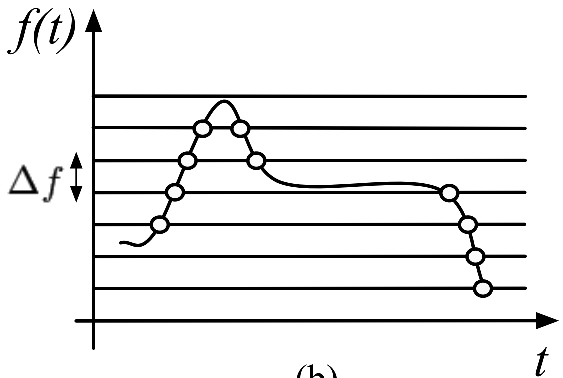
- Event-based cameras have become <u>**a commodity**</u>

Event Acquisition

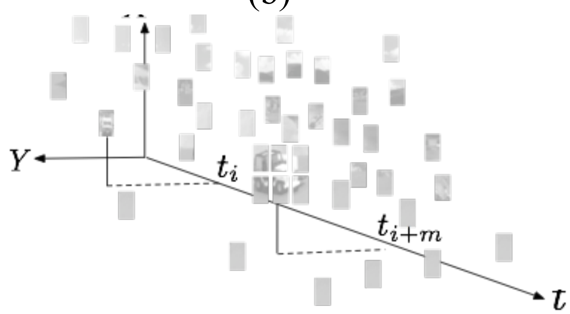


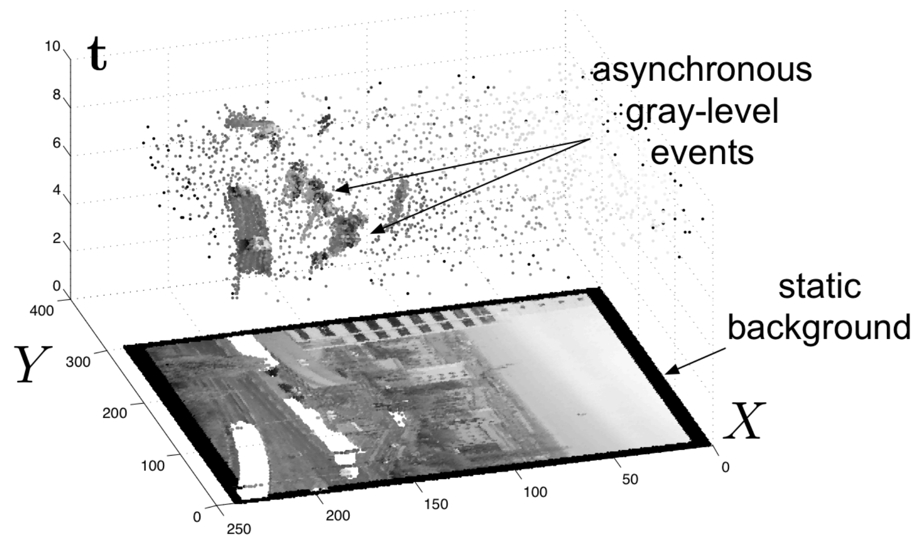






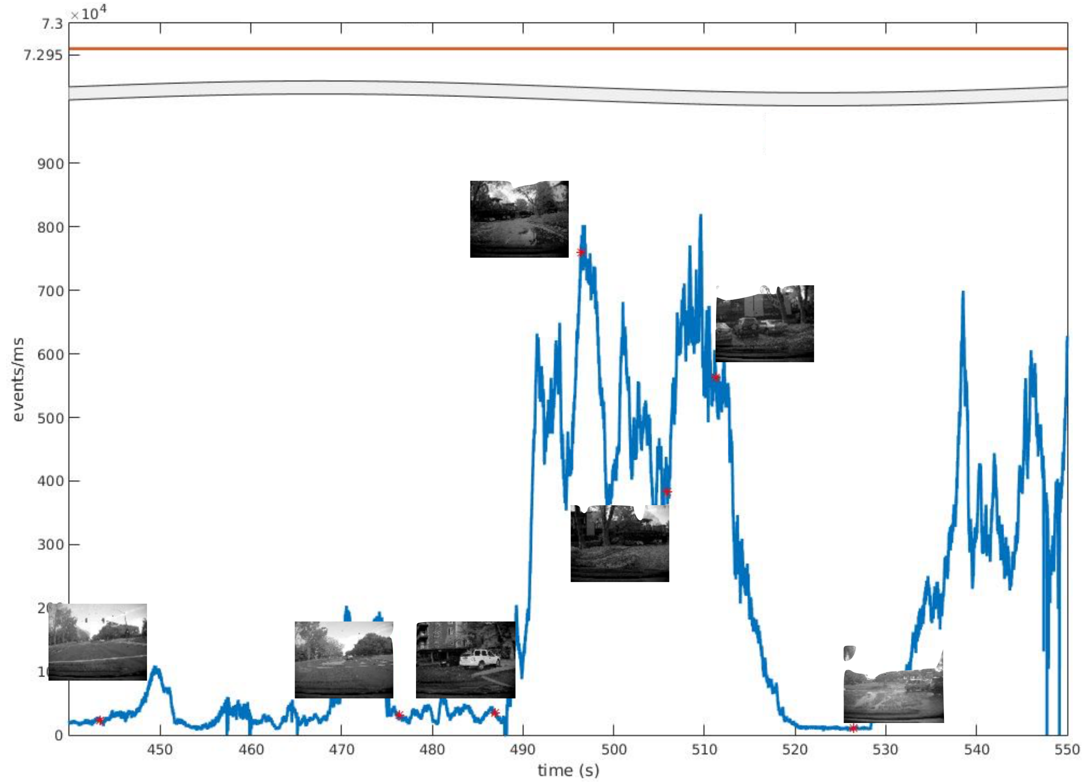
(b)





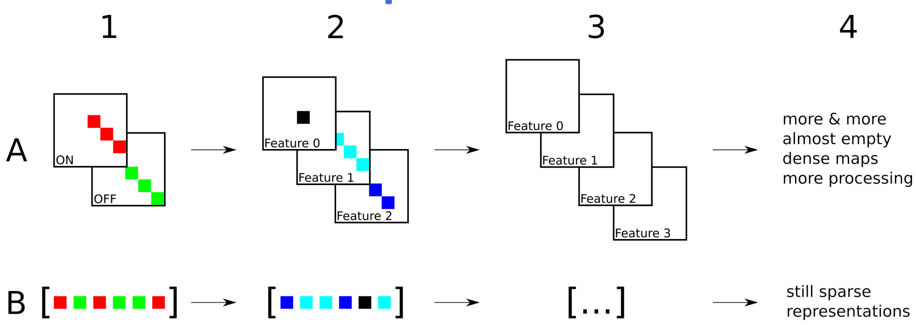
- Information is sent when it happens
- When nothing happens, nothing is sent or processed
- Sparse information coding
- Time is the most valuable information

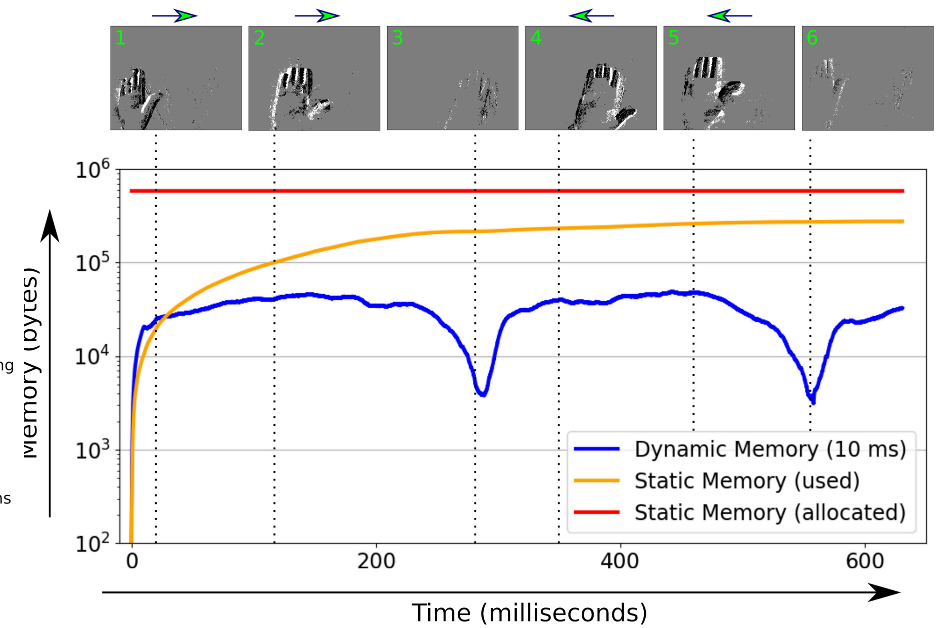
Properties Event Based sensors?



- Amount of Data generated from a moving car per 10 miliseconds

Generating Frames is non optimal





Dataset (Mean Event Rate & Sensor Size)	**PokerDVS** 170.4 ev/ms 35x35			**N-MNIST** 13.6 ev/ms 28x28			**DvsGesture** 56.9 ev/ms 128x128			**NavGesture-walk** 188.6 ev/ms 304x240		
1. Time Window (ms)	**1**	**10**	**100**	**1**	**10**	**100**	**1**	**10**	**100**	**1**	**10**	**100**
2. Mean Number of events in TW (percentage of active pixels)	101 (8%)	390 (32%)	486 (40%)	22 (3%)	84 (11%)	229 (29%)	53 (<1%)	340 (2%)	1751 (11%)	285 (<1%)	2818 (4%)	13279 (18%)
3. Max Number of events in TW (percentage of active pixels)	356 (29%)	848 (69%)	1052 (86%)	223 (28%)	312 (40%)	597 (76%)	467 (3%)	2056 (13%)	9191 (56%)	2599 (4%)	18296 (25%)	68128 (93%)
4. Working Memory Size (kB) Dynamic - Average case	0.8	3.1	3.9	0.2	0.7	1.8	0.4	2.7	14.0	2.3	22.5	106.2
5. Working Memory Size (kB) Dynamic - Worst case	2.8	6.8	8.4	1.8	2.5	4.8	3.7	16.4	73.5	20.8	146.3	545.0
6. Allocated Memory Size (kB)	9.8	9.8	9.8	6.3	6.3	6.3	131	131	131	584	584	584
7. Memory ratio dynamic/static (Average Case)	8%	32%	40%	3%	11%	29%	1%	2%	11%	1%	4%	18%
8. Memory ratio dynamic/static (Worst Case)	29%	69%	86%	28%	40%	76%	3%	13%	56%	4%	25%	93%

Computer vision:
the impossible trade off of power vs frame rate

Too many data | Too slow | Light-dependent

over-sampling

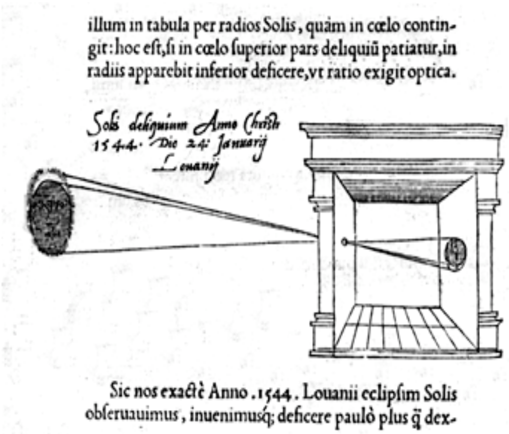
- redundant useless data
- power and resource hungry: need to acquire/transmit/store/process

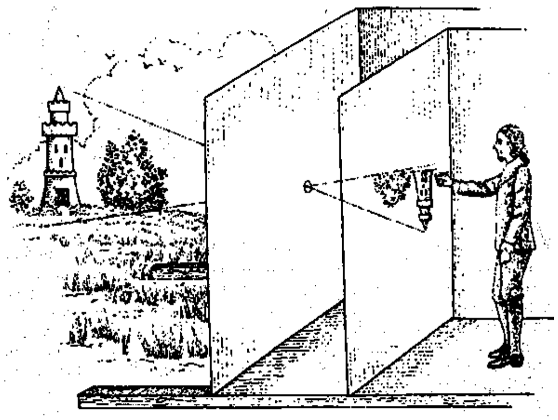
under-sampling

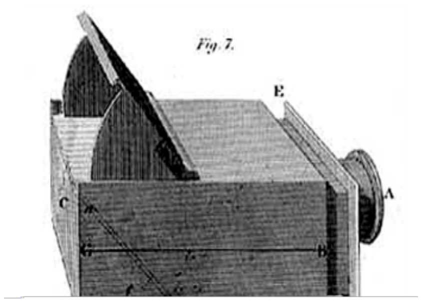
- motion blur
- displacement between frames

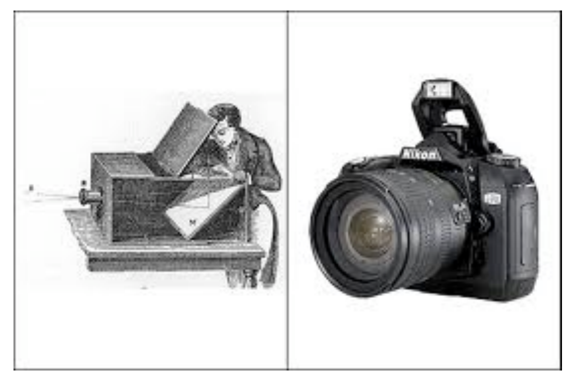
High Power & High Latency

Origins of Imaging







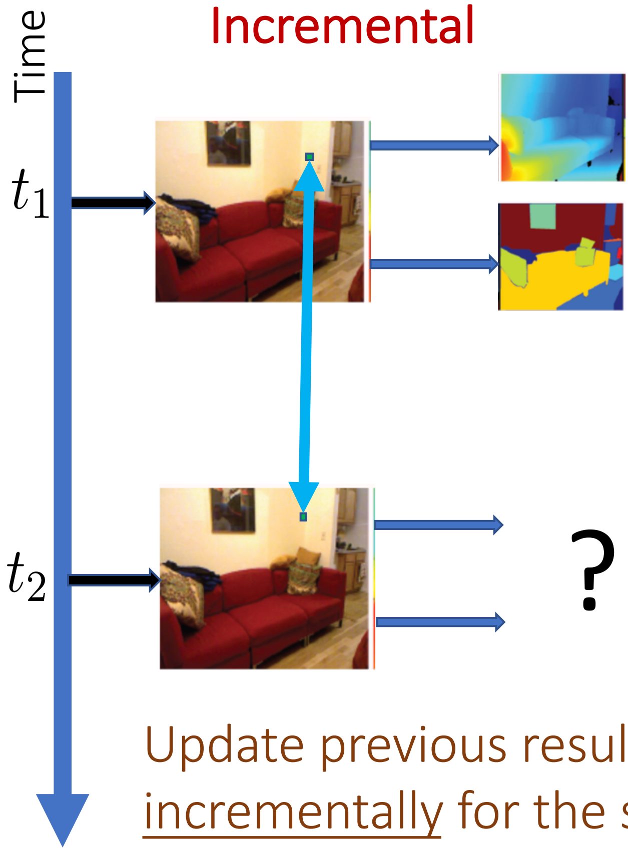


Event Computation

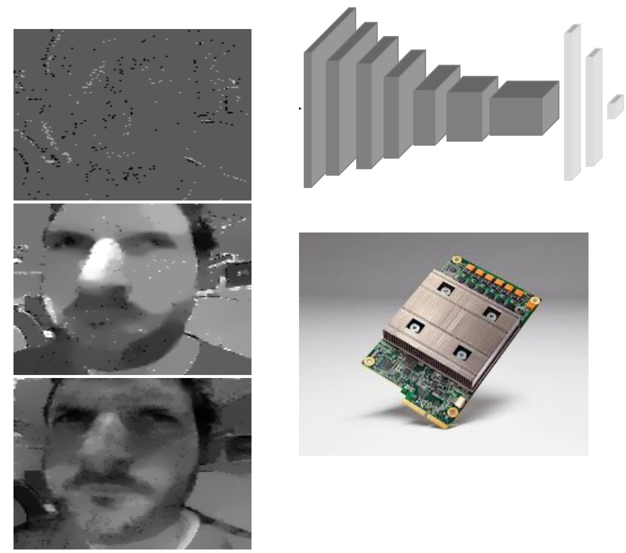
Incremental

VS

Batch or Frame

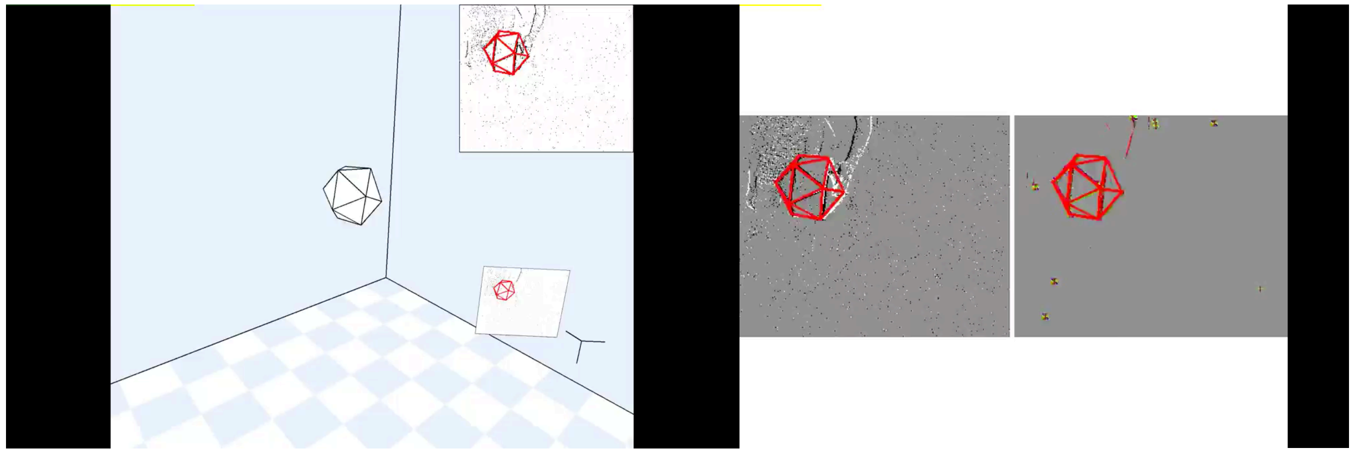


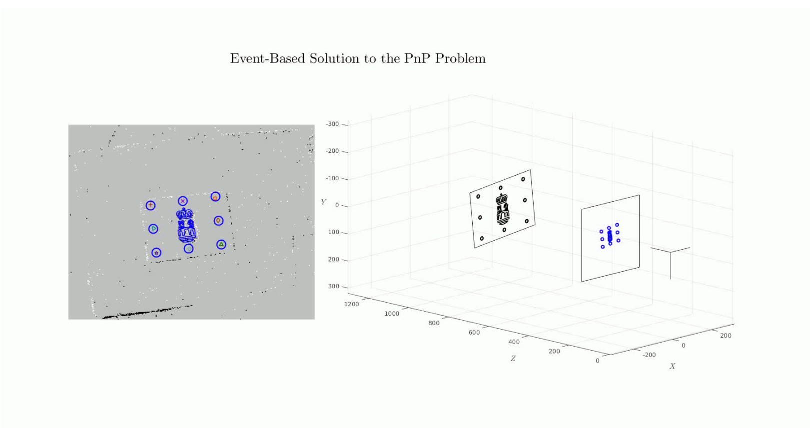
Update previous result <u>incrementally</u> for the single pixel change



Compute the new 1 pixel-change frame and compute result using <u>the whole frame</u>

Incremental Event Vision: everything can be written as an incremental event process

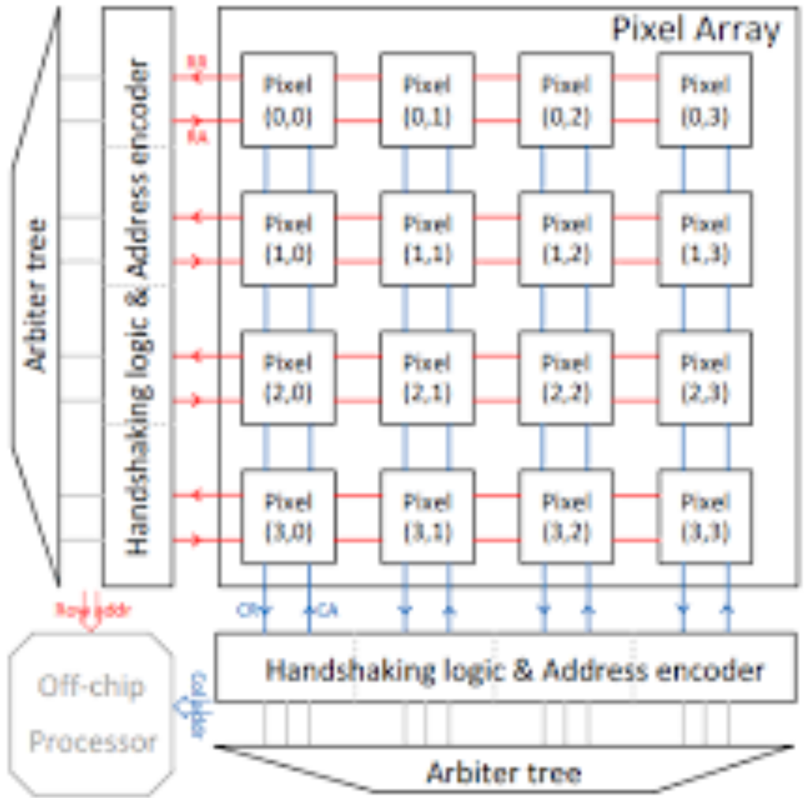




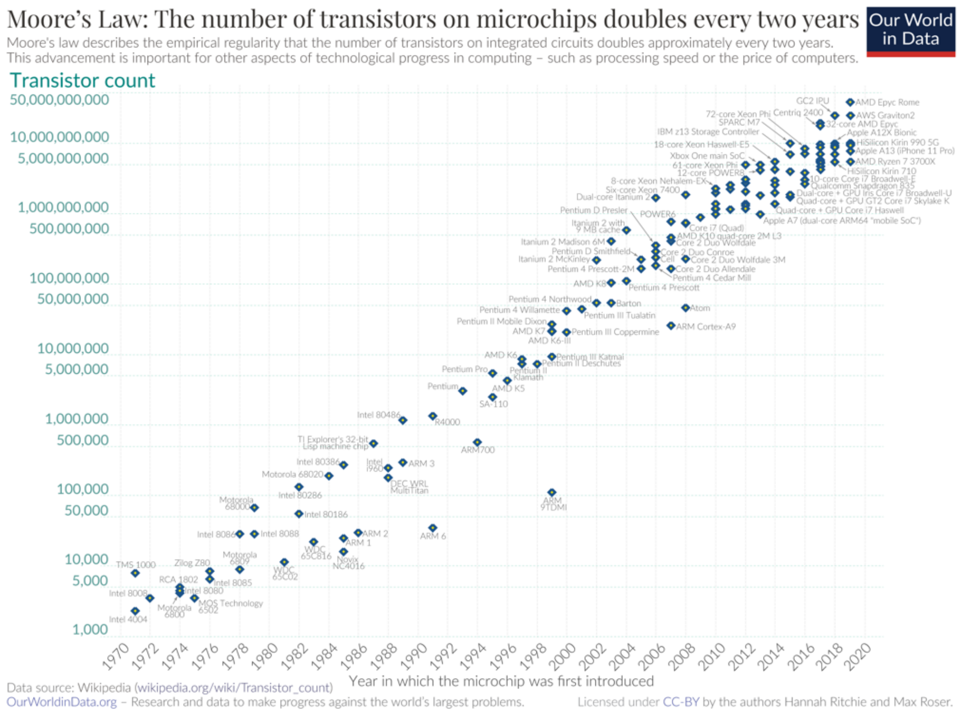
Where we are heading to

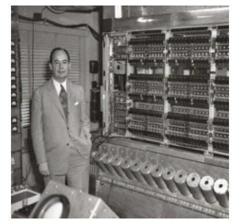
Replace arbitrers

- Current locks are caused by the arbitrer that scrambles event times and makes computation difficult
- Event Cameras are becoming compressed Imagers.

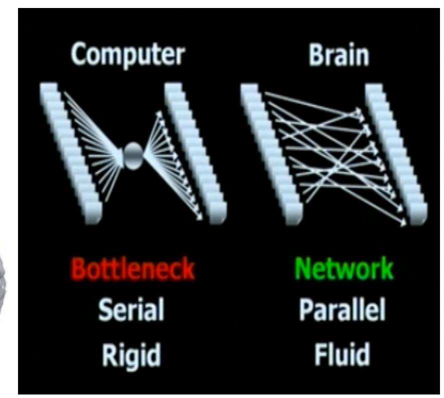


Where we are heading to: the promise





Von Neumann bottleneck



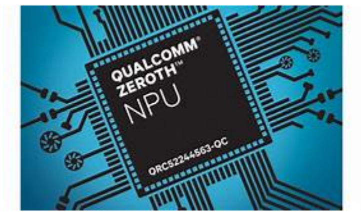
Plateau in current main stream computing technologies

Promise of a new path solving for:

Low Power and Latency

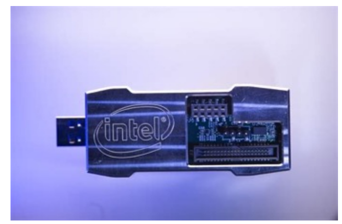
Where we are heading to

Existing Neuromorphic Processing Hardware is based on what we know of the brain



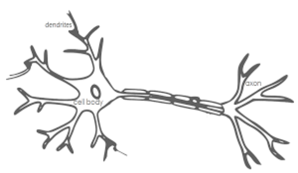
Qualcomm Zeroth (2013)

IBM TrueNorth (2014)

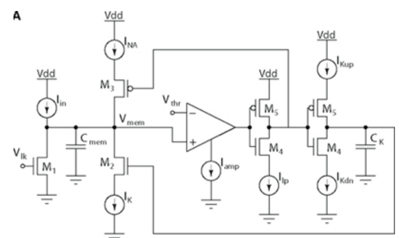


Intel Loihi (2017)

BrainChip (2019)



replicate



Existing hardware is based on the concept of replicating biological neurons into silicon

Limited use cases!

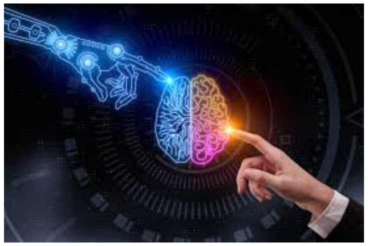
Where we are heading to

Replicating nature's solutions is not always the optimal path to solve an engineering problem.

Understanding rather than replicating

There is a need to find the right level of abstraction

Where We Are Heading To



- We should explore new forms of events' acquisition
- Find a better link between images and events and see how to connect with decades of CV without losing the advantages of events
- We need a dedicated processor adapted to the temporal precision and sparseness of data of events and the amount of generated data
- Event cameras are the future if we explore their temporal properties
- New kind of engineers that undertstand neurosciences where « biological » events are studied