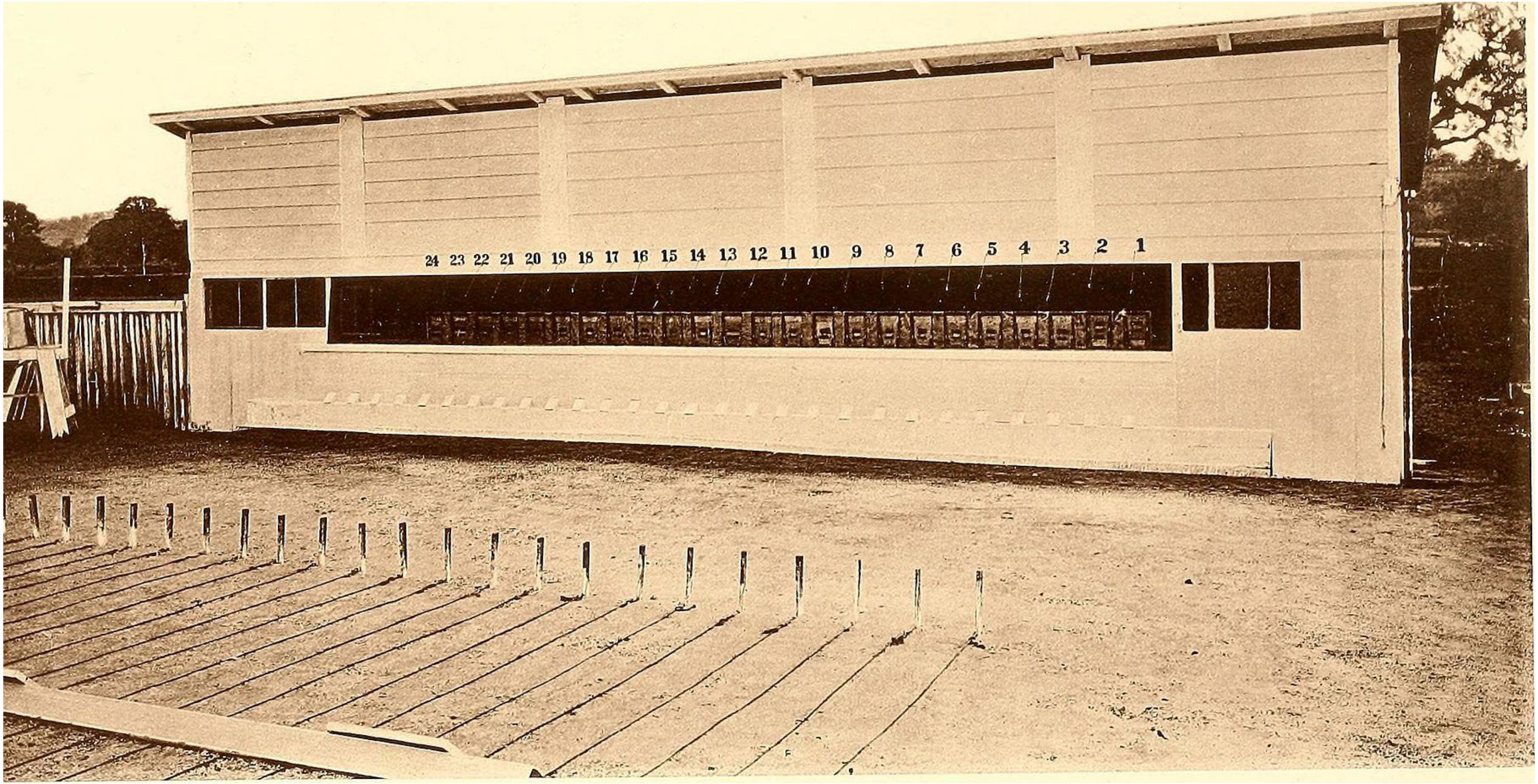
Silicon retina history, live demo, and whiteboard pixel design

Tobi Delbruck, Inst. of Neuroinformatics, UZH-ETH Zurich



Frame Cameras have Fundamental “latency vs. power” trade-off

Around 2010, Eric Fossum* defined “The perfect image sensor”

* one of the 3 fathers of modern CMOS camera chips

- Infinitely small pixels
- Infinite dynamic range
- Infinite frame rate

😀

- Infinite data rate
- Infinite redundancy
- Infinite power consumption

😟

Fukushima's *Reticon* & ***Neocognitron*** (1970-1987)

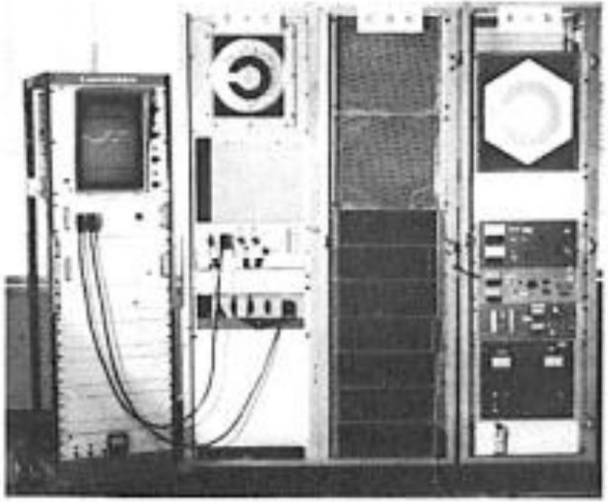


Fig. 4. Exterior view of the electronic model of the retina.

Kunihiko **Fukushima**

NHK Research Labs

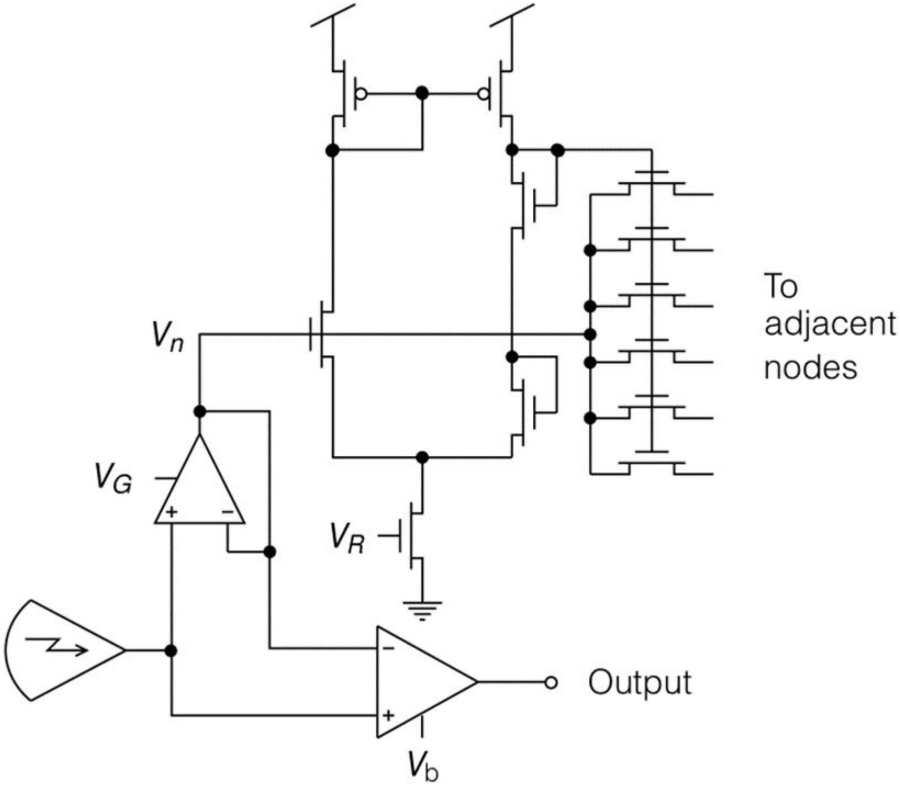
Fukushima, K., Yamaguchi, Y., Yasuda, M. & Nagata, S. An electronic model of the retina. *Proc. IEEE* (1970).

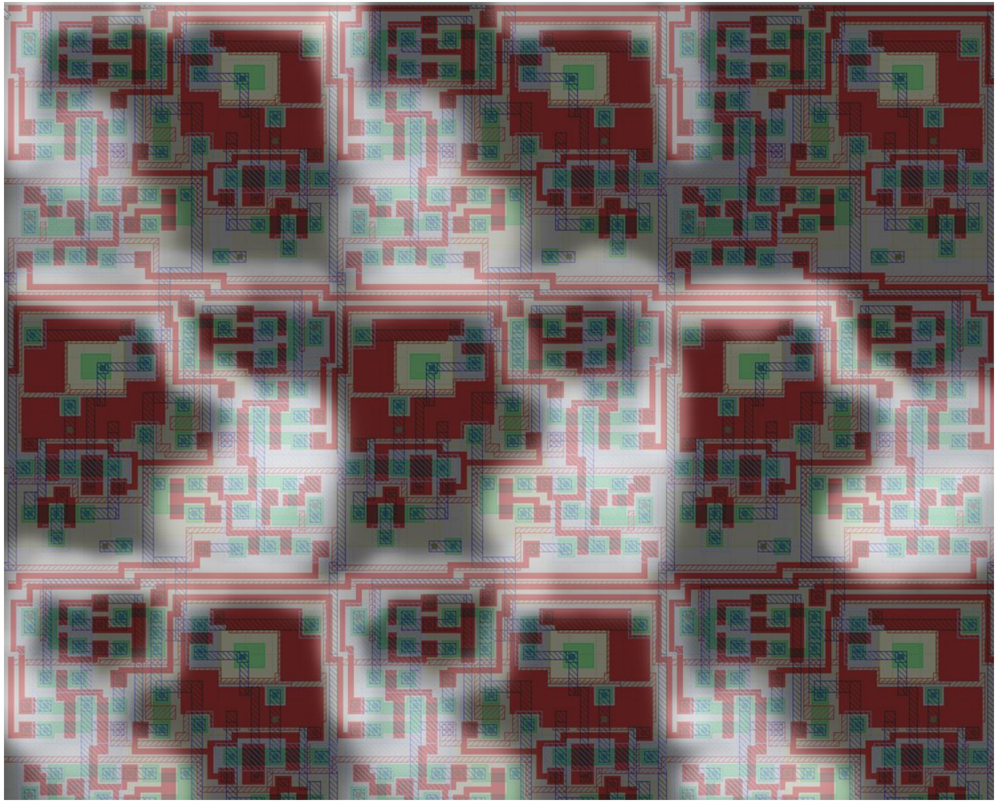
Fukushima's *Reticon* & ***Neocognitron*** (1970-1987)

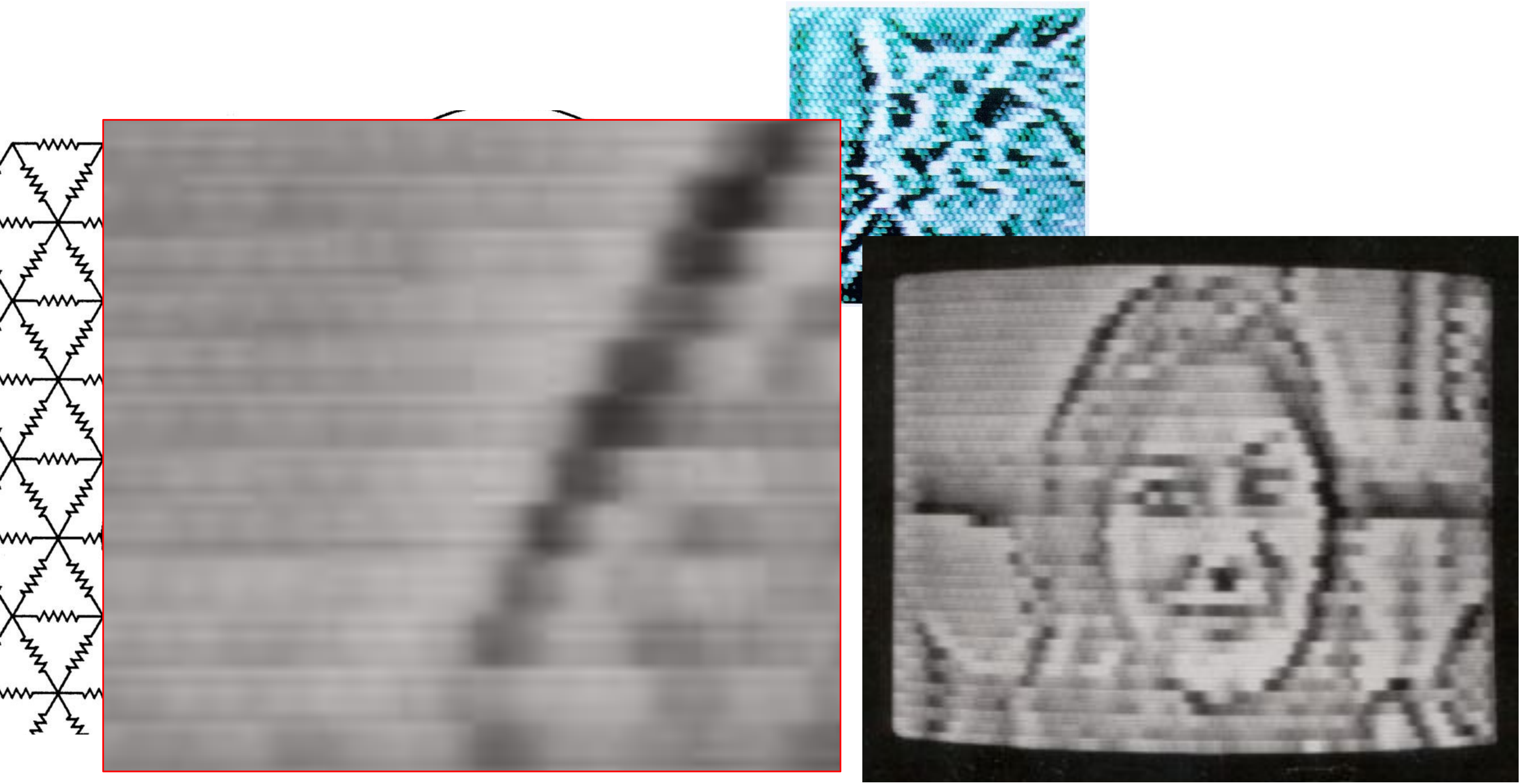
Kunihiko **Fukushima**
NHK Research Labs


Carver
Mead
Misha Mahowald

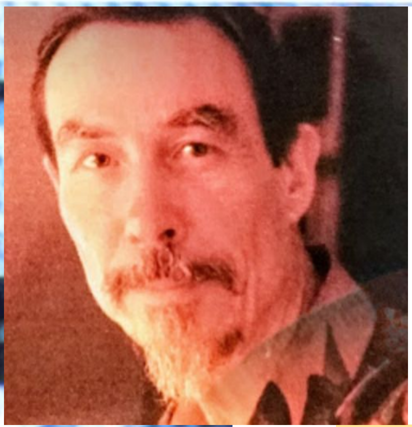
Surround was implemented with pseudoresistor network

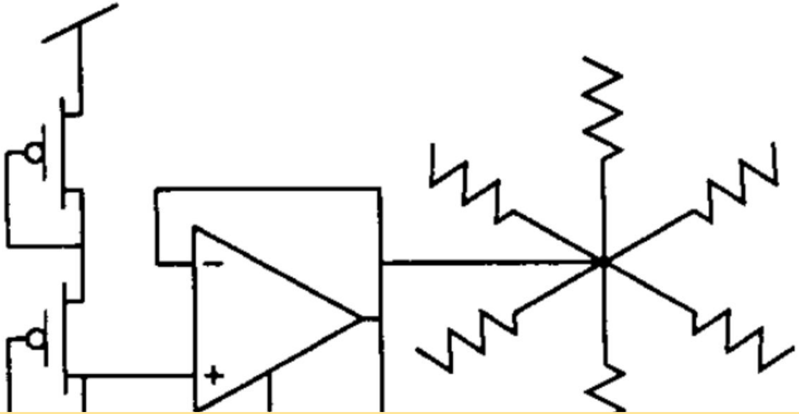


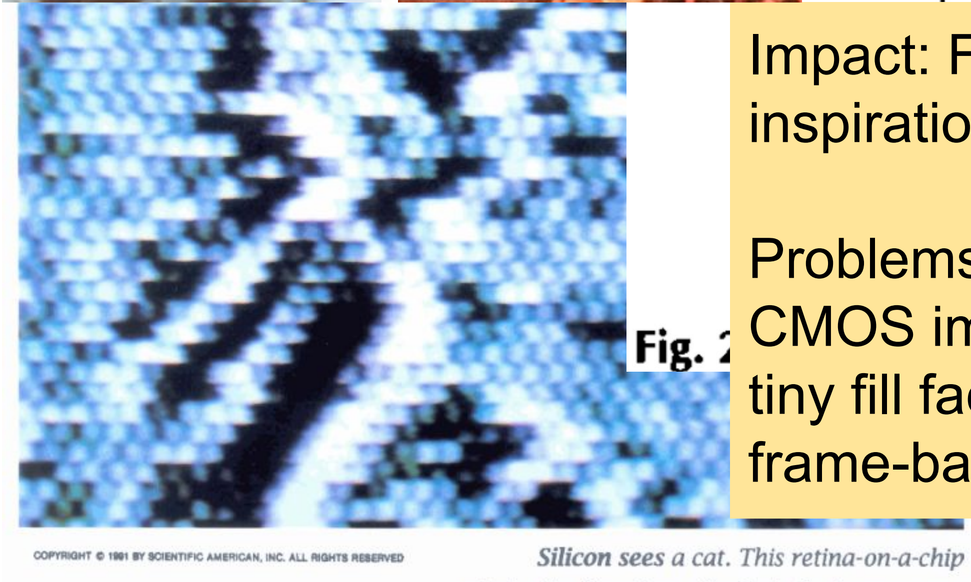




Mead, Carver A., and M. A. Mahowald. 1988. “A Silicon Model of Early Visual Processing.” *Neural Networks:* https://doi.org/10.1016/0893-6080(88)90024-X .



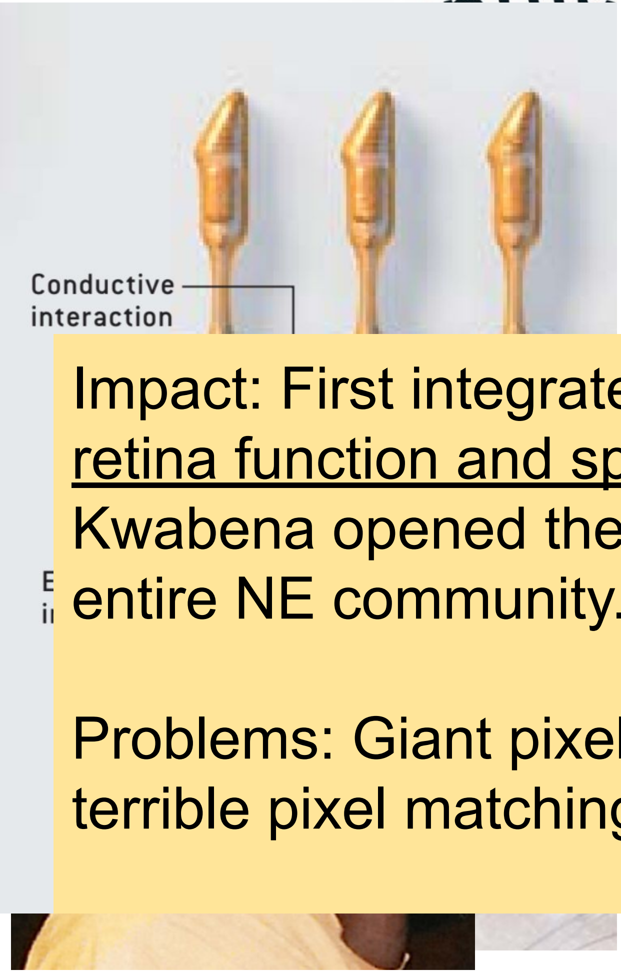


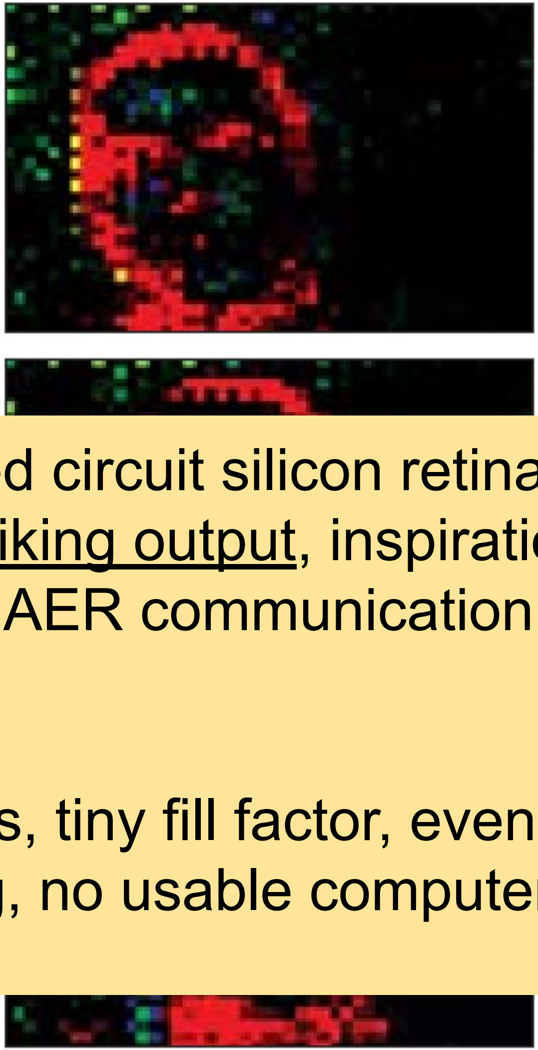


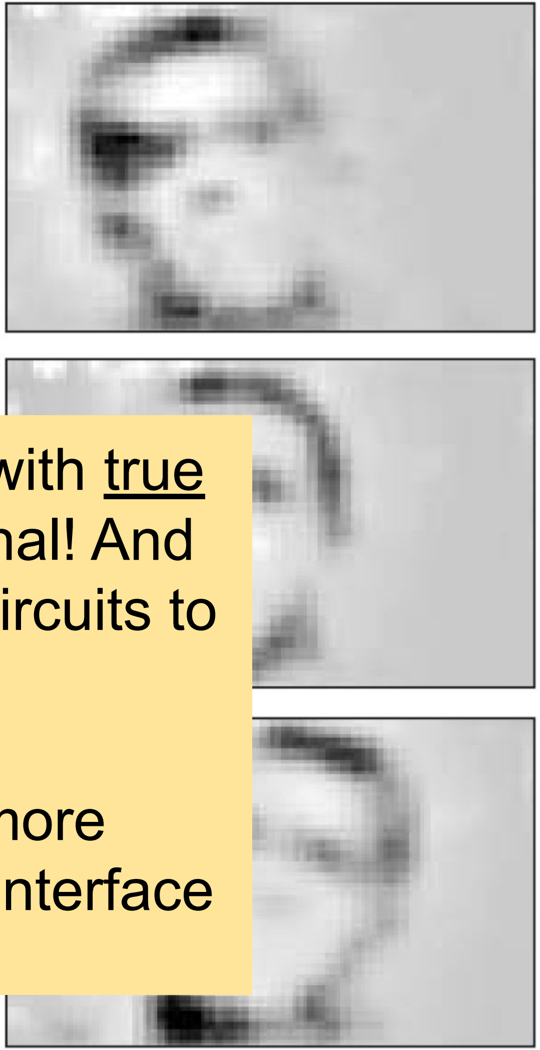
Impact: First integrated circuit silicon retina, inspirational!

Problems: Developed same time as first CMOS image sensors, but had huge pixels, tiny fill factor, terrible pixel matching, and frame-based redundant output

[Silicon retina paper from Scientific American, Misha Mahowald and Carver Mead, 1991]





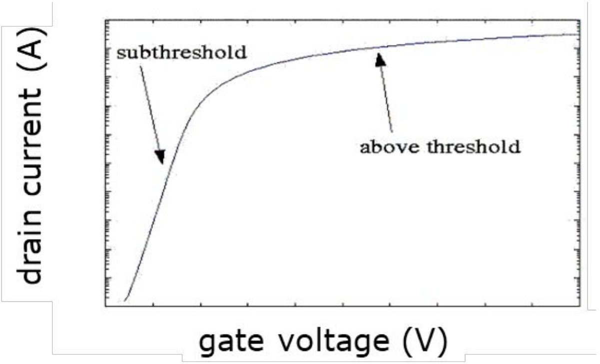


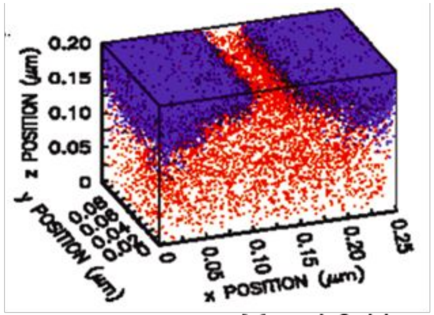
Impact: First integrated circuit silicon retina with <u>true retina function and spiking output</u>, inspirational! And Kwabena opened the AER communication circuits to entire NE community.

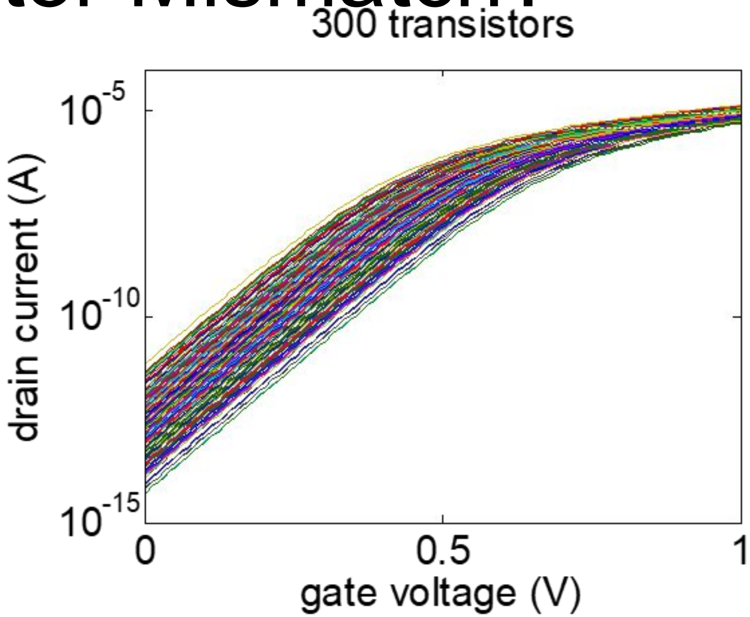
Problems: Giant pixels, tiny fill factor, even more terrible pixel matching, no usable computer interface

Question: what is Transistor Mismatch?

Transfer curve of 1 transistor

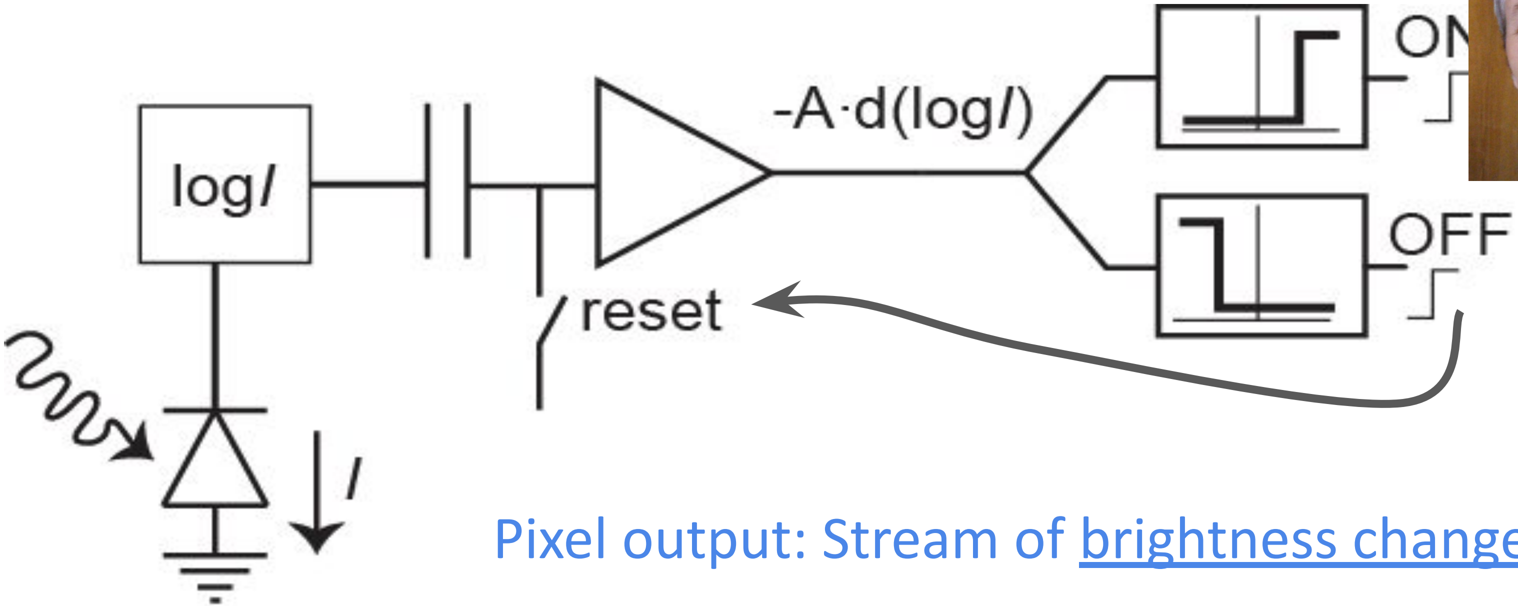






Mead & Hoeneison, 1972

Dynamic Vision Sensor (**DVS**) pixel (2005)

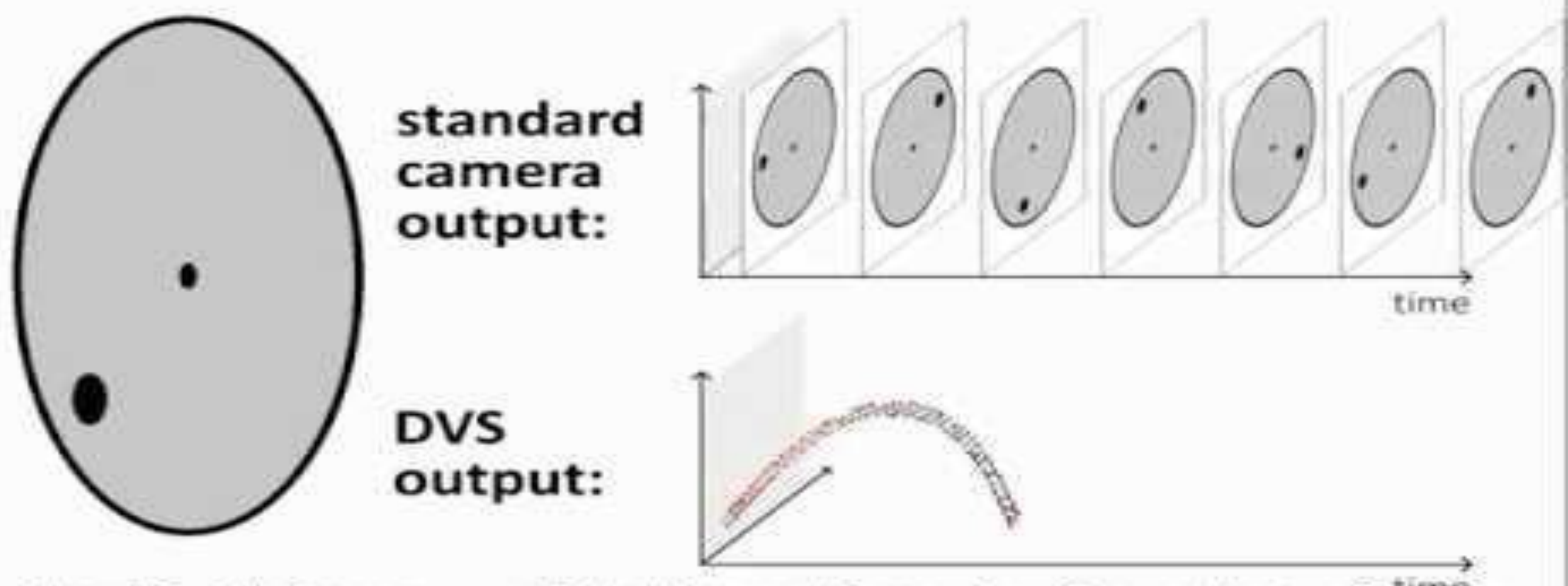


Pixel output: Stream of brightness change events

photoreceptor differencing comparators

From Rodieck 1998

64x64 Event-Driven Logarithmic Temporal Derivative Silicon Retina, (2005)
P. Lichtsteiner and T. Delbruck, Intl Image Sensor Workshop

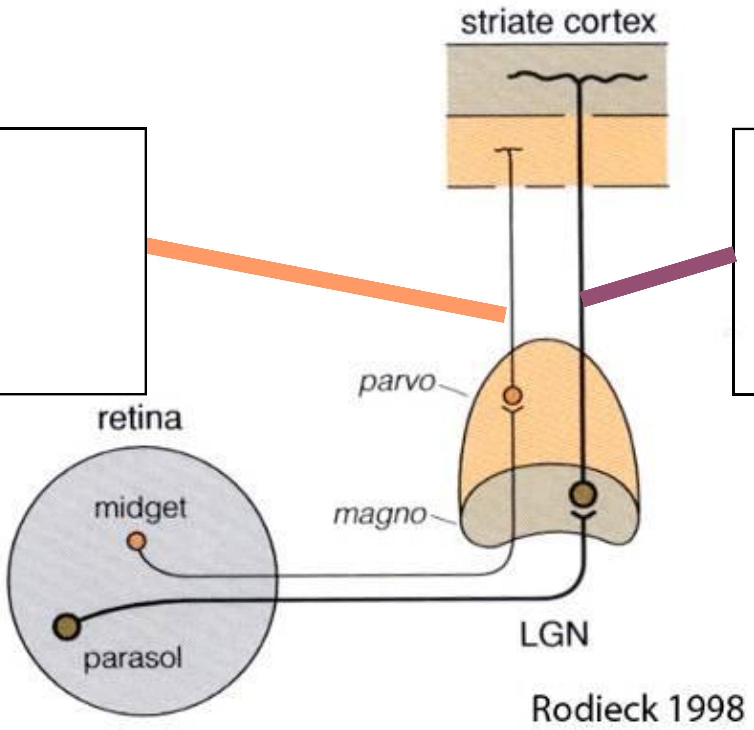


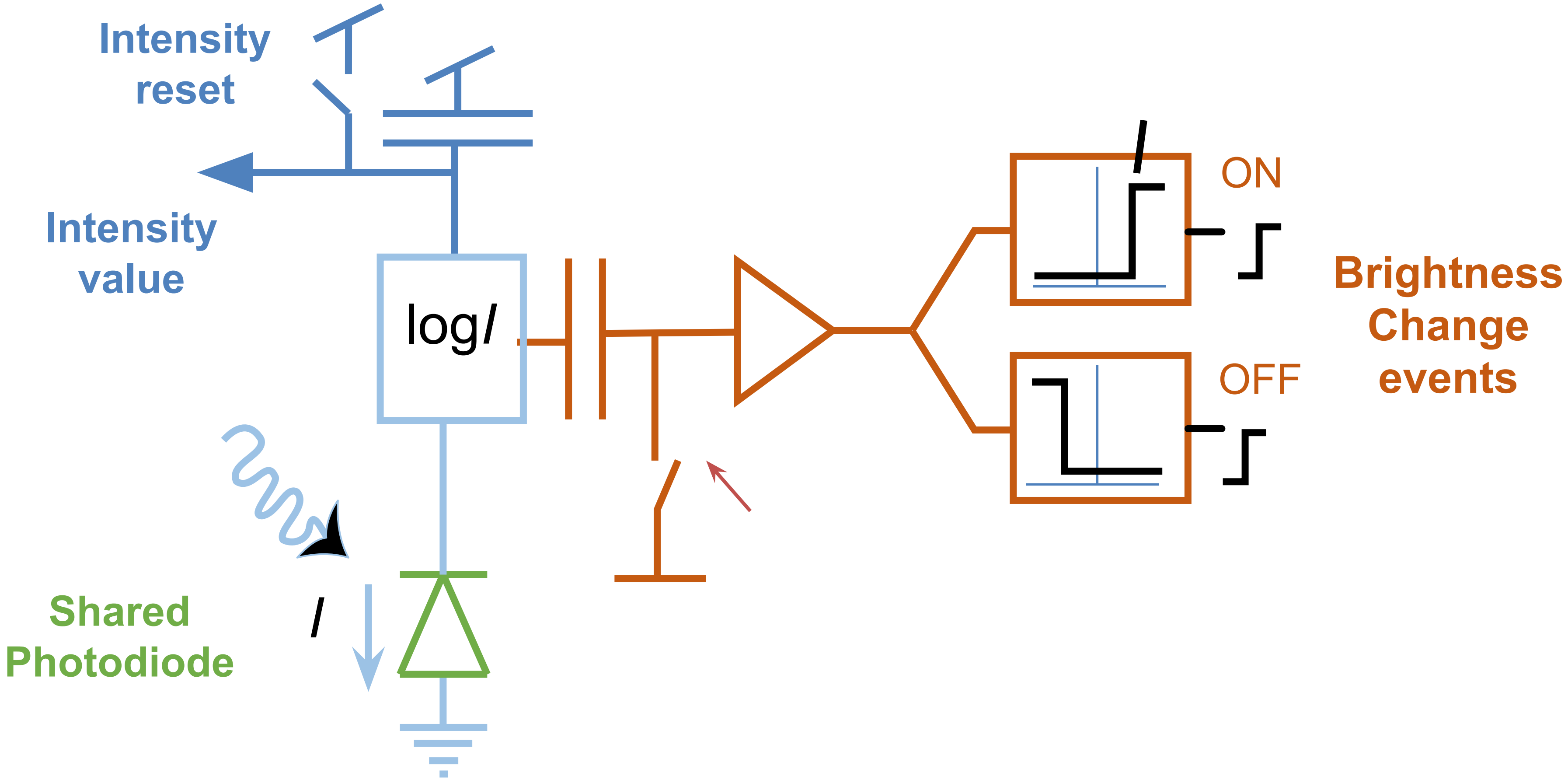
video: Davide Scaramuzza, Robotics and Perception Group, Univ. of Zürich

Sustained and Transient Pathways

Sustained pathway
Color selective
High spatial resolution
Slow

Transient pathway
Monochromatic
Low spatial resolution
Fast

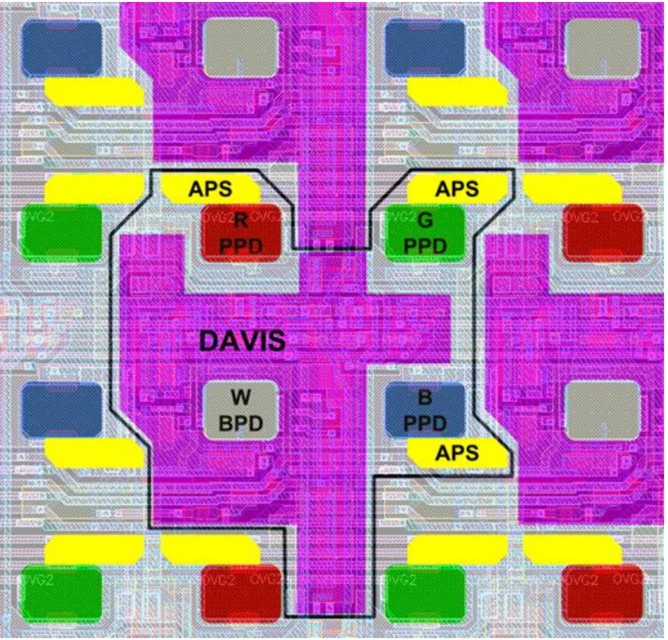


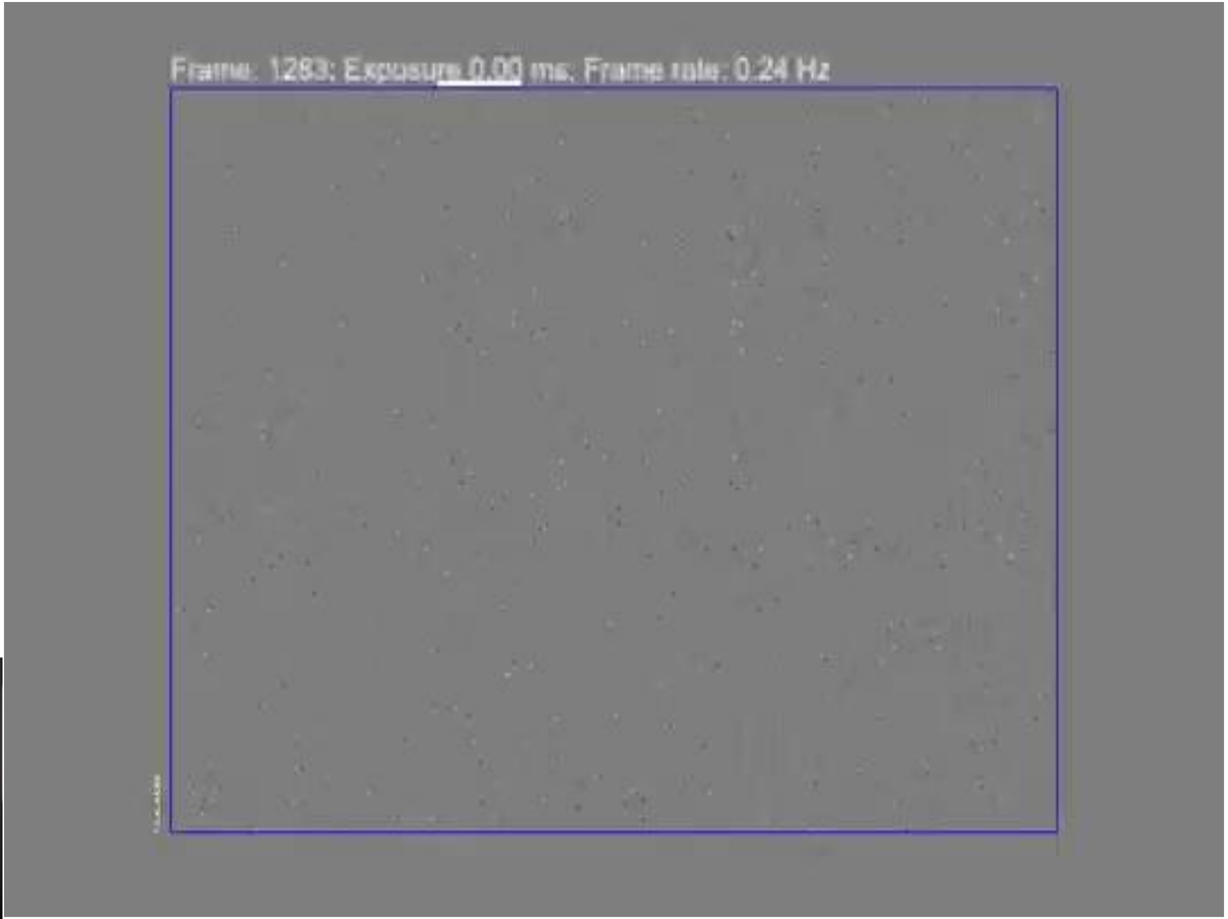

Intensity reset
Intensity value
log$I$
ON
OFF
Brightness Change events
Shared Photodiode
I

DAVIS (2014)

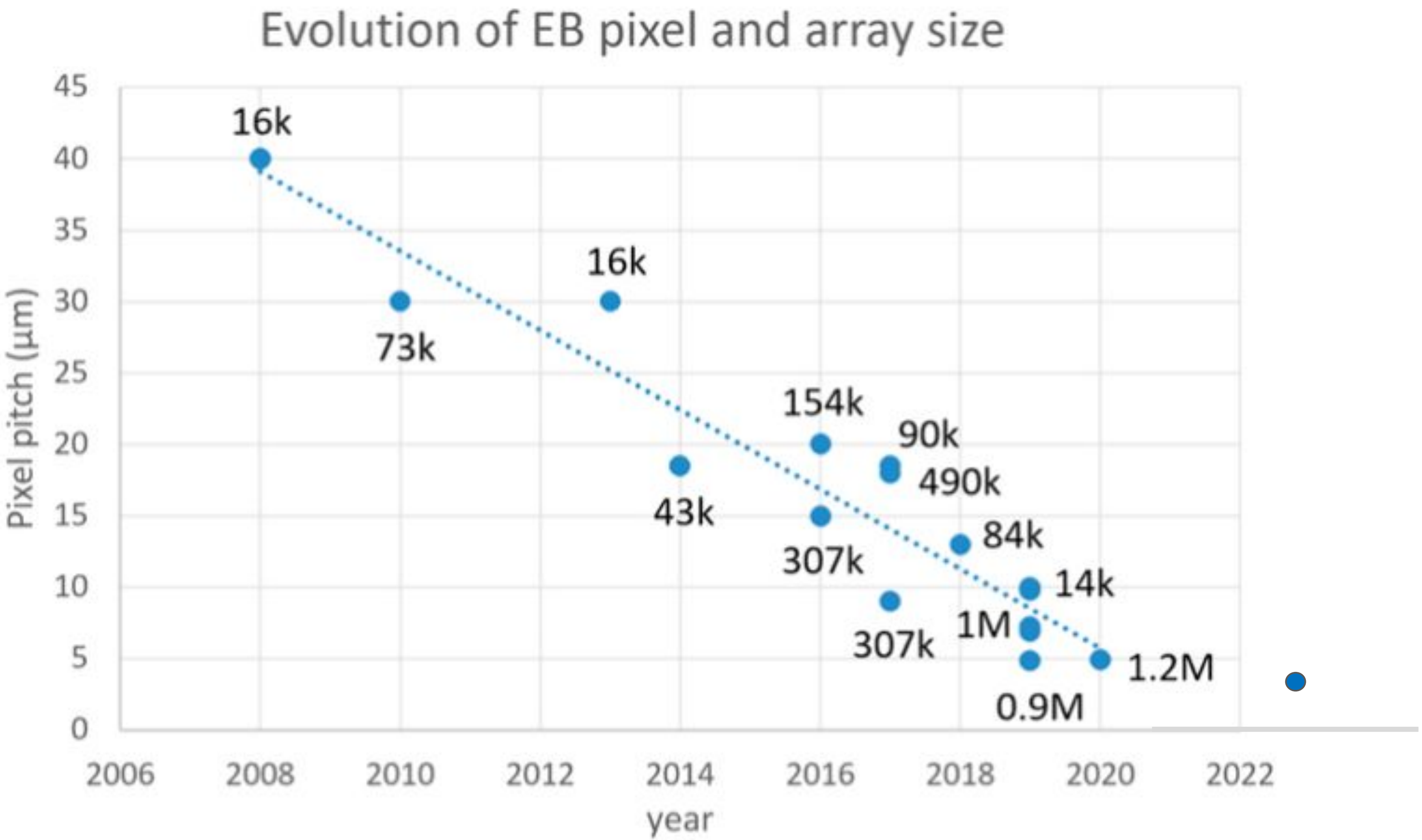
Brandli, C., Berner, R., Yang, M., Liu, S. & Delbruck, T. **A 240 × 180 130 dB 3 µs Latency Global Shutter Spatiotemporal Vision Sensor.** *IEEE J. Solid-State Circuits* (2014).

Color: CDAVIS (2015)





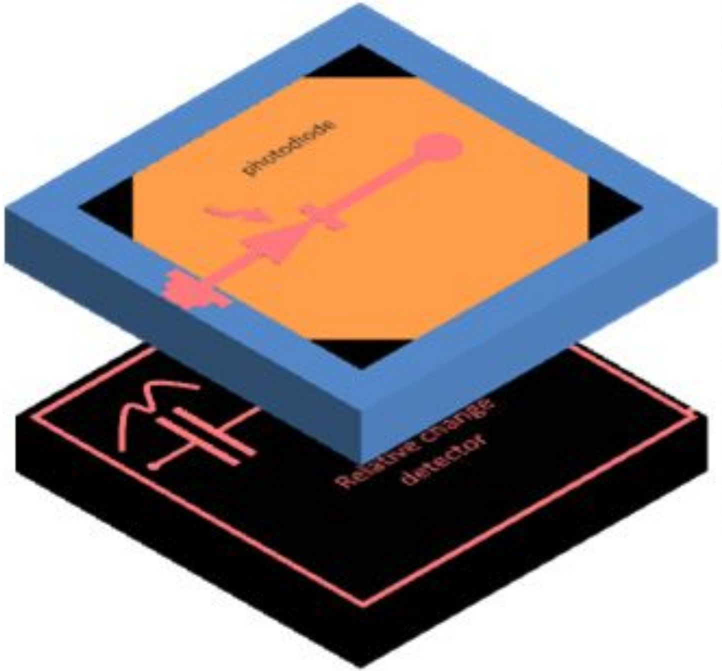
Li, C. *et al.* **An RGBW Color VGA Rolling and Global Shutter Dynamic and Active-Pixel Vision Sensor**. in *2015 International Image Sensor Workshop*.



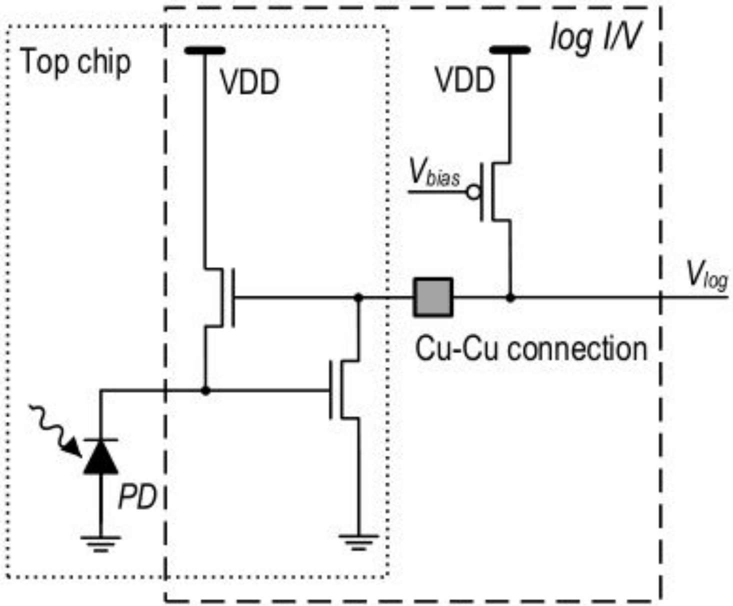
Christensen, D. V. *et al.* 202 Roadmap on Neuromorphic Computing and Engineering. at <https://arxiv.org/ftp/arxiv/papers/2105/2105.05956.pdf >

Example of stacked pixel DVS (2020)

90nm BI CIS
on 40nm CMOS
4.9µm pitch
>77% fill factor

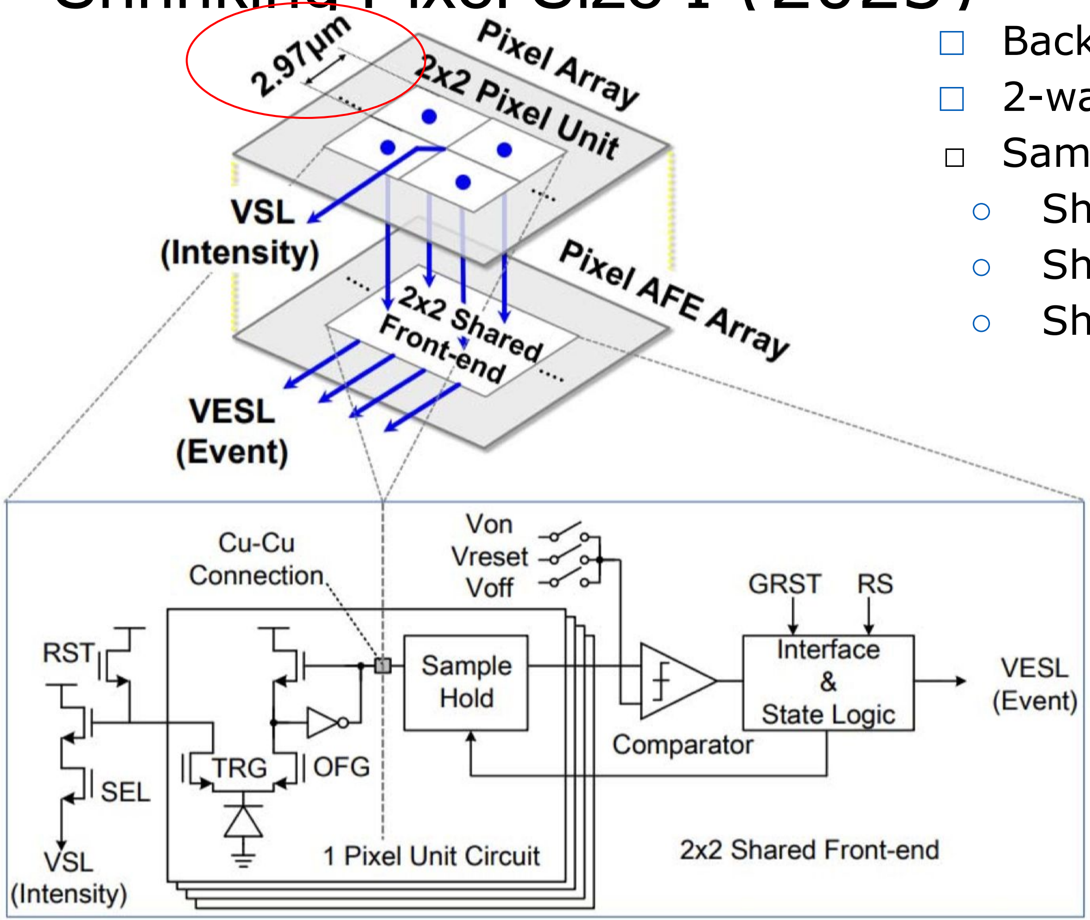


Finateu ISSCC 2020



All other pixel circuits
(**~50T**) on bottom CMOS

Shrinking Pixel Size I (2023)

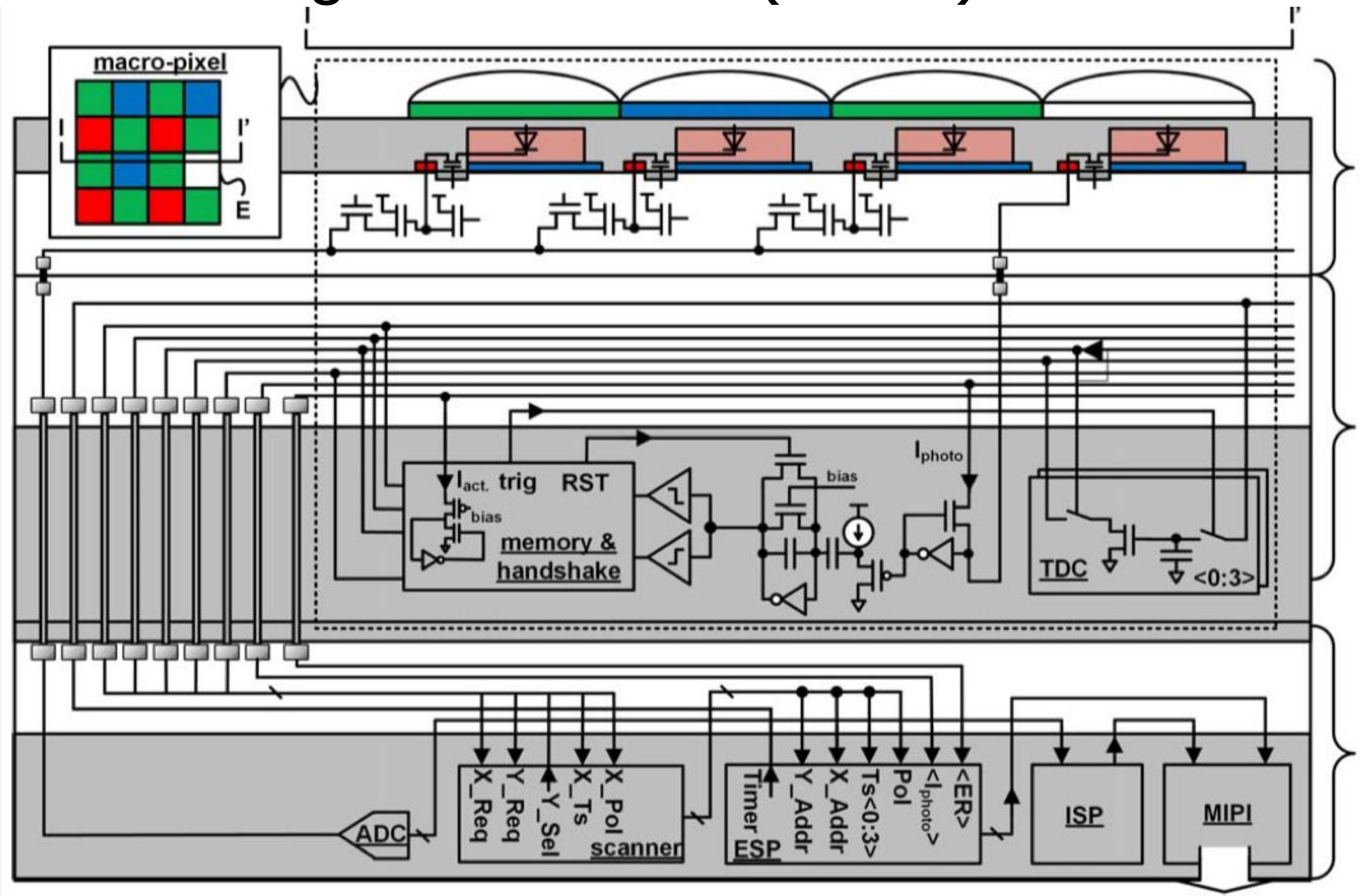


- Backside illumination
- 2-wafer stacking
- Sampled (not async)
  - Shared PD for APS & DVS
  - Shared AFE for 2x2 pixels
  - Shared comparator for ON & OFF

Raphael Berner

Sony, ISSCC 2023

Shrinking Pixel Size II (2023)



- Backside illumination
- **3-wafer stacking**

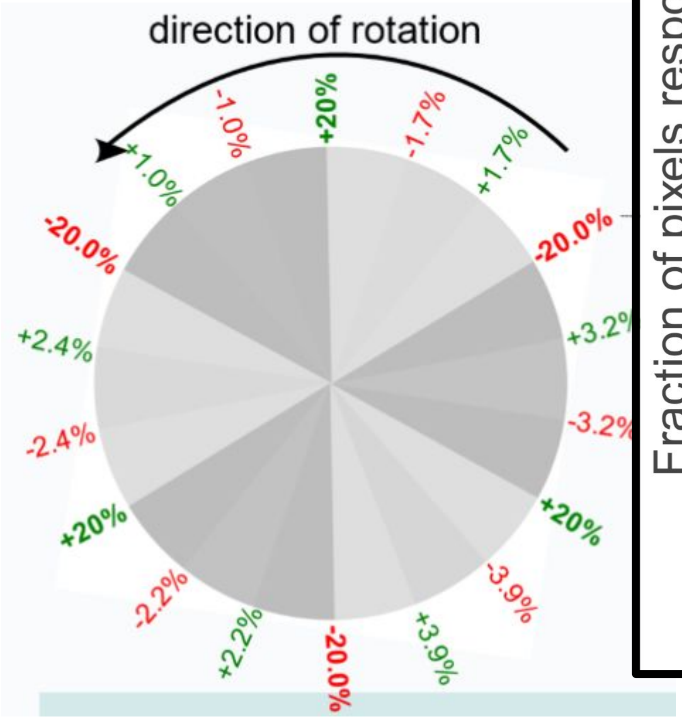
OmniVision, ISSCC 2023

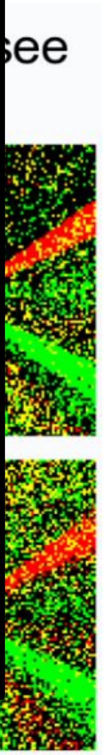
SciDVS - a scientific event camera (2024)

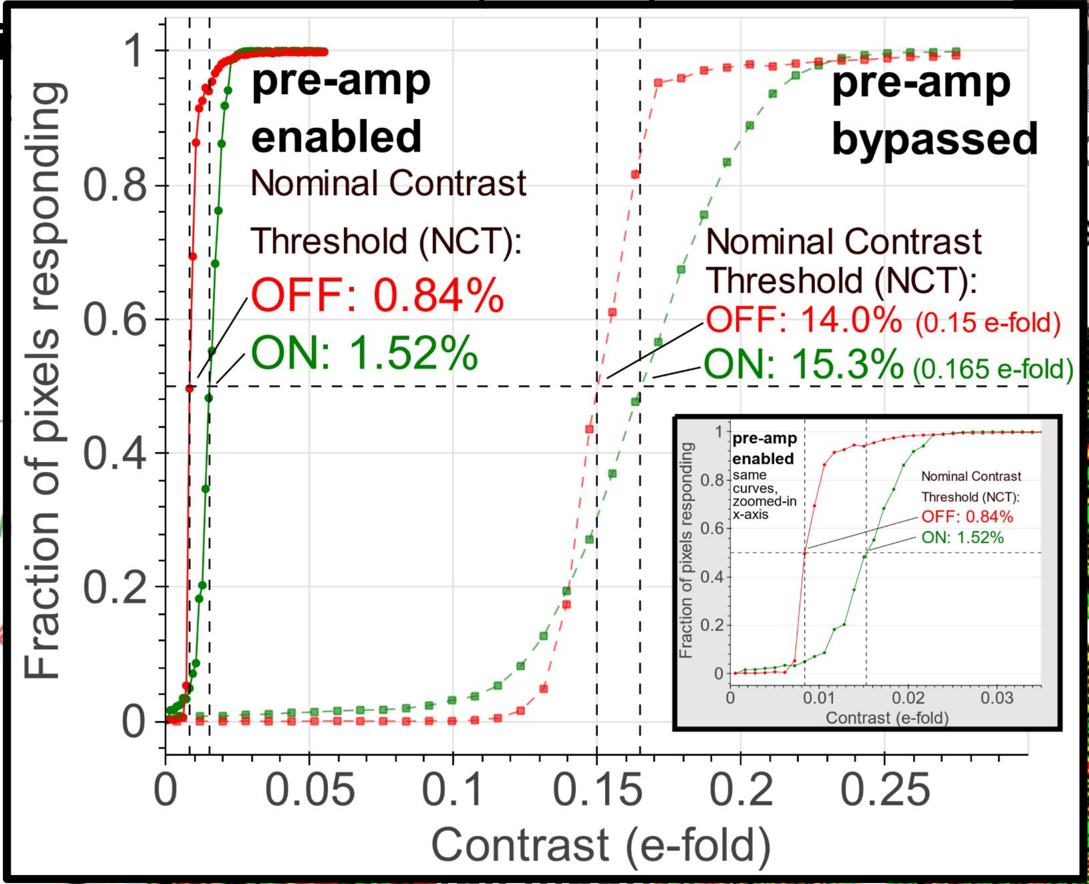
Adds **adaptive preamplifi**

and has better bandwidth

Graca








DVS color mode GrayLevel: Each event causes linear change in brightness
2.6X speed-up
0 special events

Demo time


Embedded Pencil
Balancer