Technische Universität Berlin

EINSTEIN CENTER Digital Future

Event-based Robot Vision

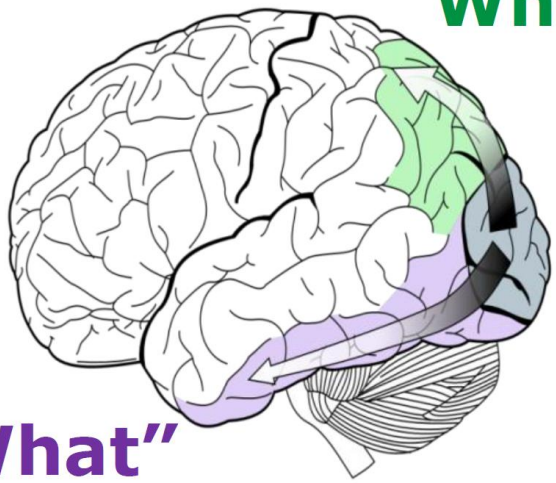
Prof. Dr. Guillermo Gallego
Chair: Robotic Interactive Perception

guillermo.gallego@tu-berlin.de

http://www.guillermogallego.es

Human Visual Perception

- Dorsal (Transient) visual pathway
- Ventral (Sustained) visual pathway



"Where"

Transient pathway
Magno cells
Motion
All over the retina
Fast

"What"

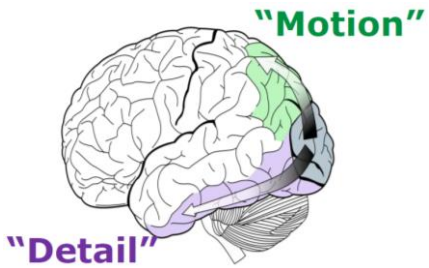
Sustained pathway
Parvo cells
Details
Fovea
Slow

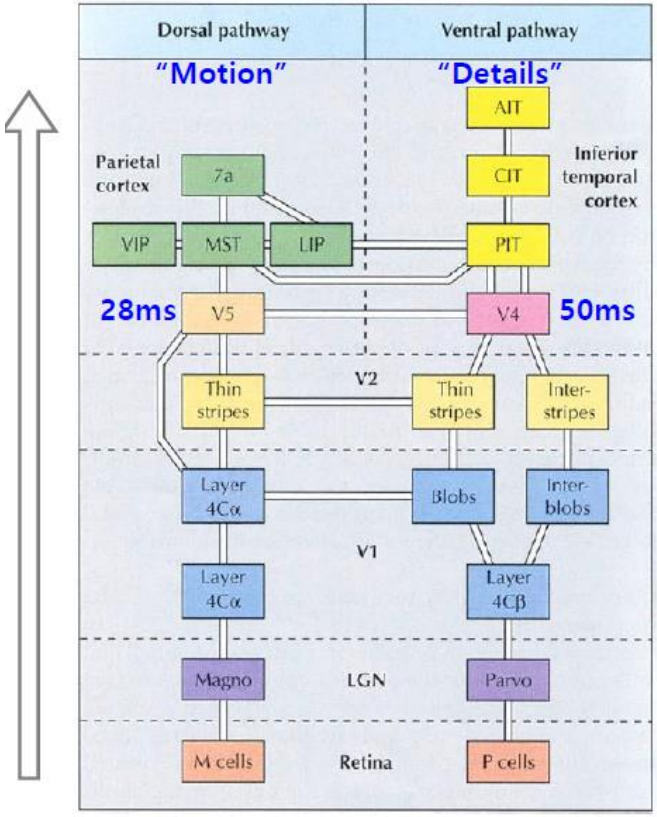
Color image

Events

Slide images courtesy of Wikipedia and E. Ryu

Pathways of Human Visual Processing





- **"Motion"** and **"Details"** are processed differently each other
  - "Motion" detection uses "edges"
  - "Details" recognition uses "shapes" and "colors"
  - **Ventral pathway ("Details") are deeper than Dorsal pathway ("Motion").**
    - "Motion" detection: <200ms
    - "Details recognition: 400~500ms

M. J. Tovée, Current Biology, Dec. 1994

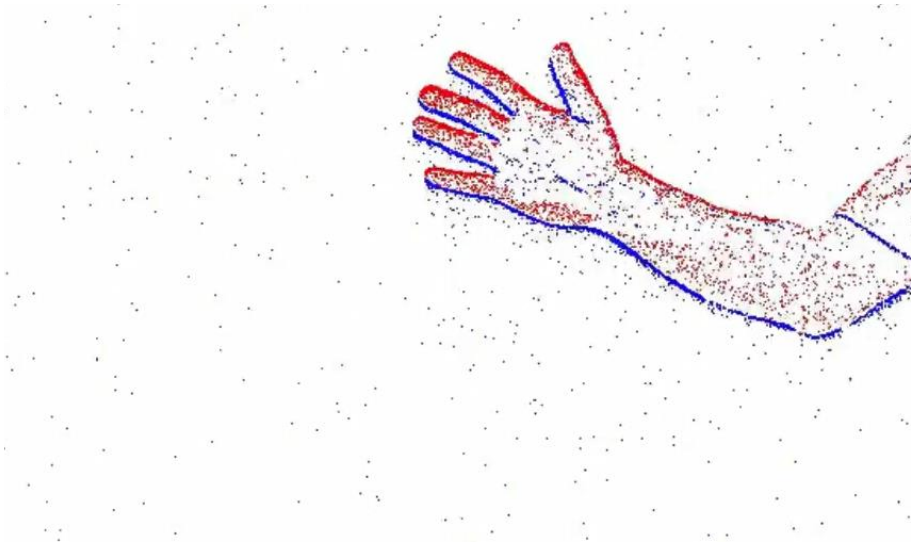
M. J. Tovée , Current Biology, Dec. 1994

Event camera. Static camera

- Events are caused by moving edges on the retina

Standard Camera

Event Camera (ON, OFF events)

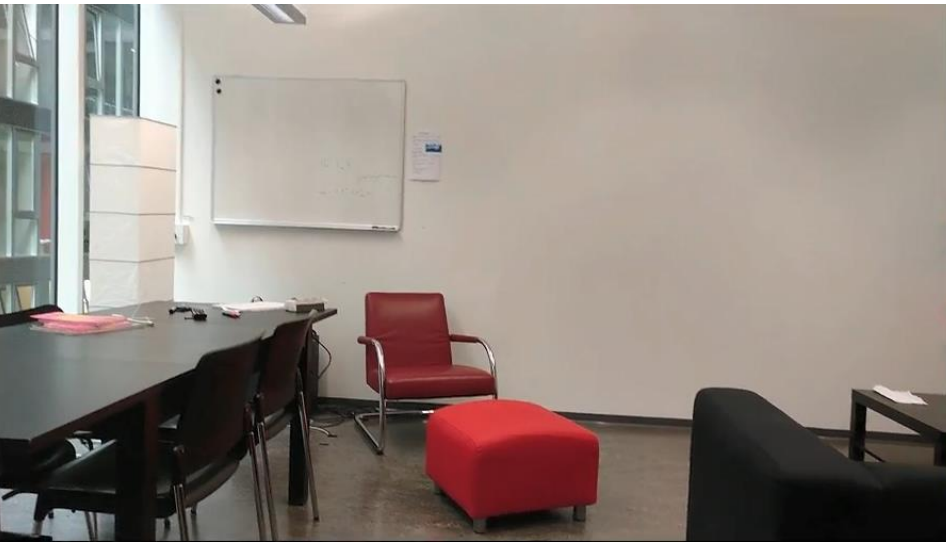


Video courtesy of D. Gehrig, ECCV 2018

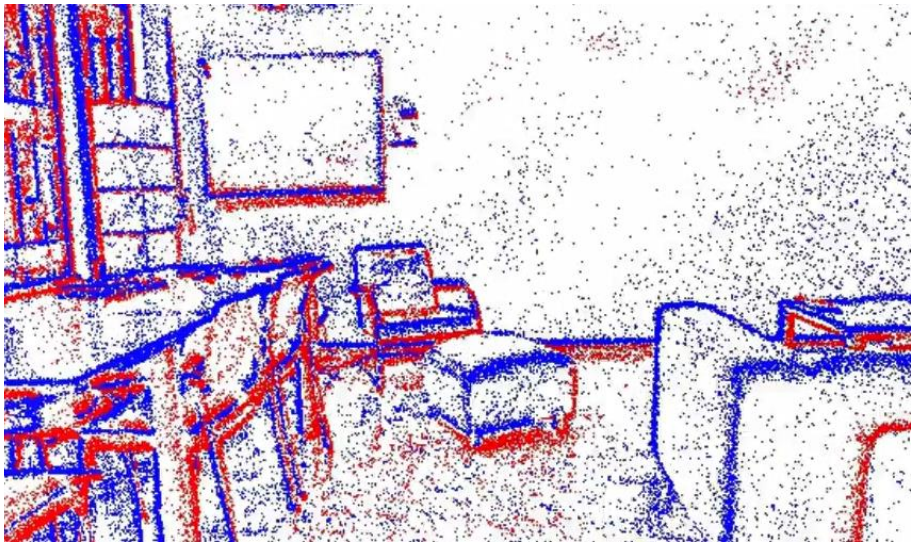
Event camera. Moving camera

- Events are caused by moving edges on the retina
- When the camera moves, events are triggered everywhere

Standard Camera



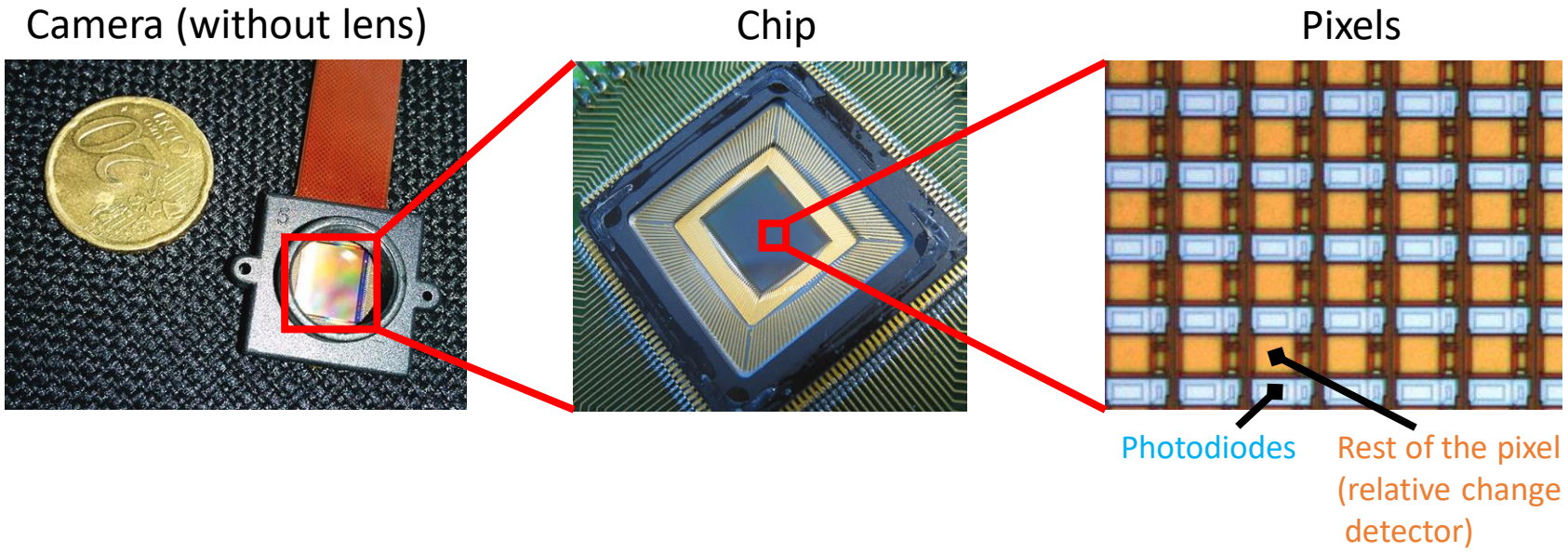
Event Camera (ON, OFF events)



Video courtesy of D. Gehrig, ECCV 2018

Giving Machines Humanlike eyes

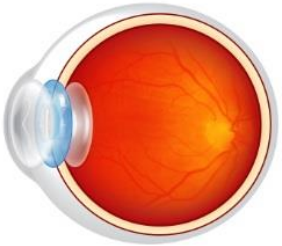
Posch et al. IEEE Spectrum is a good introductory reading to the topic

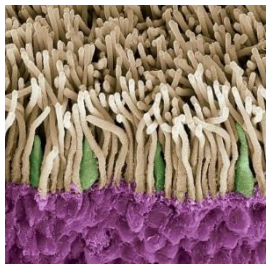


Posch et al. *Giving Machines Humanlike Eyes*, IEEE Spectrum, 52(12):44-49, 2015. PDF

Bio-inspiration in Human Visual System

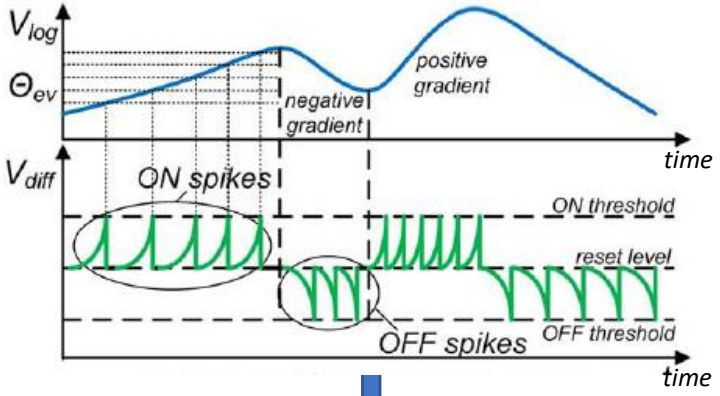
- Modeling the dorsal pathway



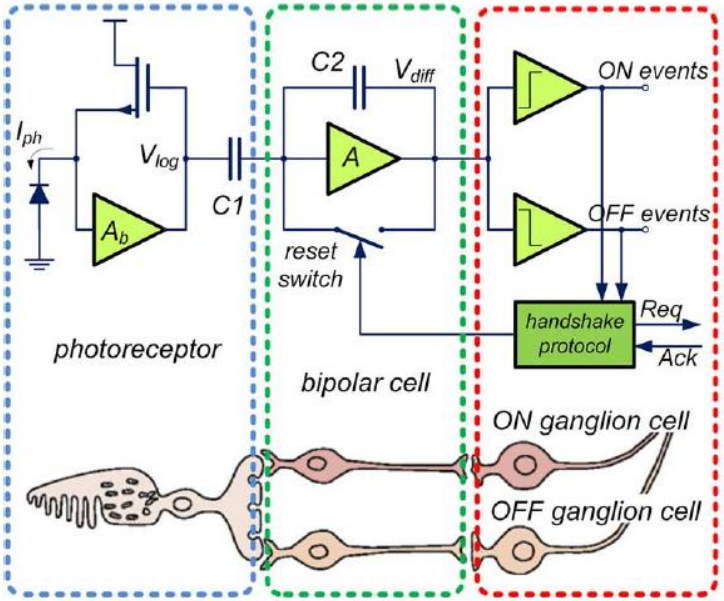


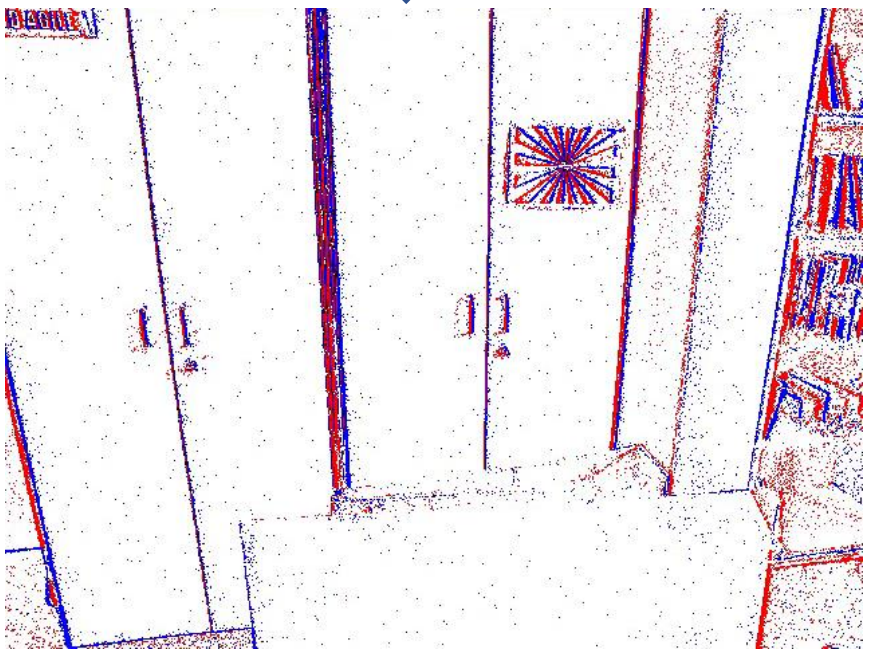
photoreceptors

Brightness signal at a pixel



Pixel design





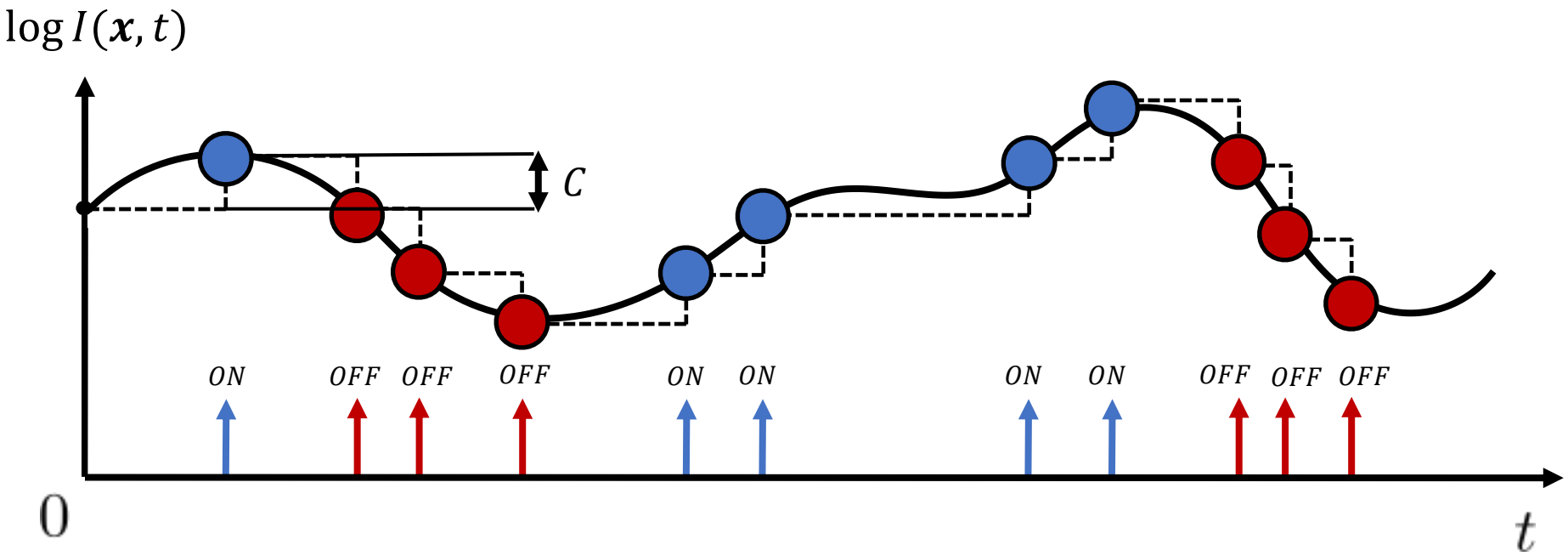
Images from Posch et al. Proc IEEE 2014 and theworldcloseup.com

Events (ON, OFF) binned into images for visualization

Event generation model

- Consider the intensity at a **single pixel** $\boldsymbol{x}$…

$$\log I(\boldsymbol{x}, t) - \log I(\boldsymbol{x}, t - \Delta t) = \pm C$$



Incident light at the pixel is converted (“transduced”) into a train of **asynchronous** events

Lichtsteiner et al., *A 128x128 120dB 15μs latency asynchronous temporal contrast vision sensor*, IEEE JSSC, 2008. Animation by A. Censi

What is an event?

Each event

$$e = (x, y, t, p)$$

conveys four quantities of the brightness change:

- **Pixel coordinates** $\boldsymbol{x} = (x, y)$
- **Timestamp** t (with μs resolution)
- **Sign** of the brightness change:
  - Brightness increase ↔ Positive (“ON”) event.
  - Brightness decrease ↔ Negative (“OFF”) event.

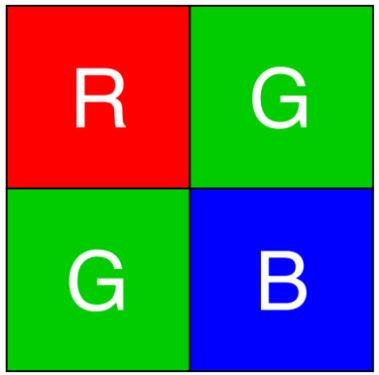
Also called “**polarity**”

$$p = \mathrm{sgn}\left(\frac{\partial I(x, y, t)}{\partial t}\right) \in \{+1, -1\} \text{ (binary)}$$

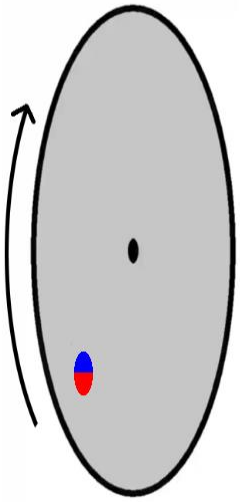
Color Event Camera

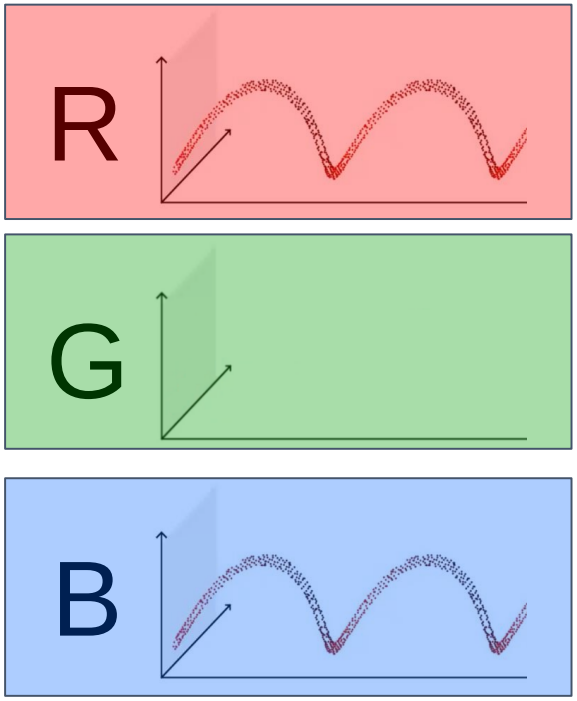
- Each pixel is sensitive to red (R), green (G) or blue (B) light
- It transmits brightness changes in each color channel

DAVIS346 Red Color



Bayer filter mosaic





Taverni et al., Front and back illuminated Dynamic and Active Pixel Vision Sensors comparison, TCAS-II 2018.

Color Event Camera Dataset (and Simulator), CVPRW 2019. http://rpg.ifi.uzh.ch/CED.html

References

Reading:

- The List of Event-based Vision Resources has a section on sensor designs & bio-inspiration, with papers:
  - Posch et al., *Retinomorphic Event-Based Vision Sensors: Bioinspired Cameras With Spiking Output*, Proc. IEEE, 2014. PDF
  - Posch et al. *Giving Machines Humanlike Eyes*, IEEE Spectrum, 52(12):44-49, 2015. PDF
- Goldstein, *Sensation and Perception*, 2017. Chapter 2.
- Wikipedia: Two-streams hypothesis. https://en.wikipedia.org/wiki/Two-streams_hypothesis