Event-based Robot Vision

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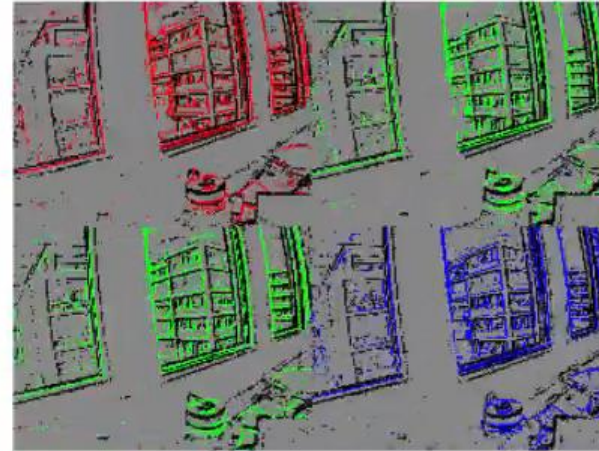# Color Event Cameras

Example: DVS with RGB Color Filter Array

DAVIS frames
(narrow dynamic range)

Events

High Dynamic Range?

No

Yes

Reconstructed intensity (with E2VID)

List of (prototype) cameras

- **Color-DAVIS** (using Color Filter Arrays - **CFA**s)

  - **C-DAVIS**: RGBW-VGA color frames and QVGA (320 x 240 pixels) monochrome events. ISCAS 2015

  - **SDAVIS192**: RGBW color filter array for frames and events (192 x 188 pixels, 1% contrast sensitivity). TBCAS 2018

  - **DAVIS346 color**: RGB color filter array for frames and events (346 x 260 pixels, 15% contrast sensitivity). TCAS-II 2018

- **Color ATIS** (using beam splitters)

  - RGB events (exposure measurement - EM)

RGBW color SDAVIS192

QE spectrum of SDAVIS assuming a conversion gain of 22.0 uV/e⁻

- Each pixel is sensitive to red (**R**), green (**G**), blue (**B**) or white (**W** = unfiltered) light

- RGBW color filter array for frames and events
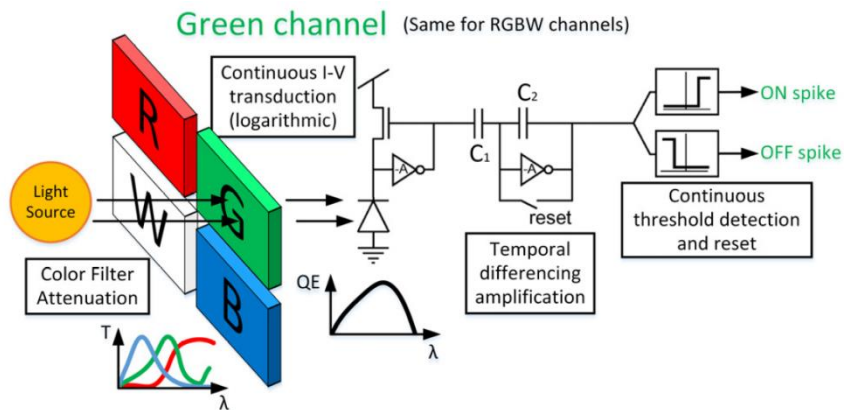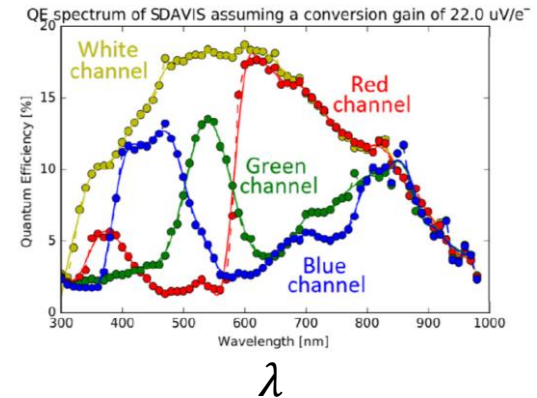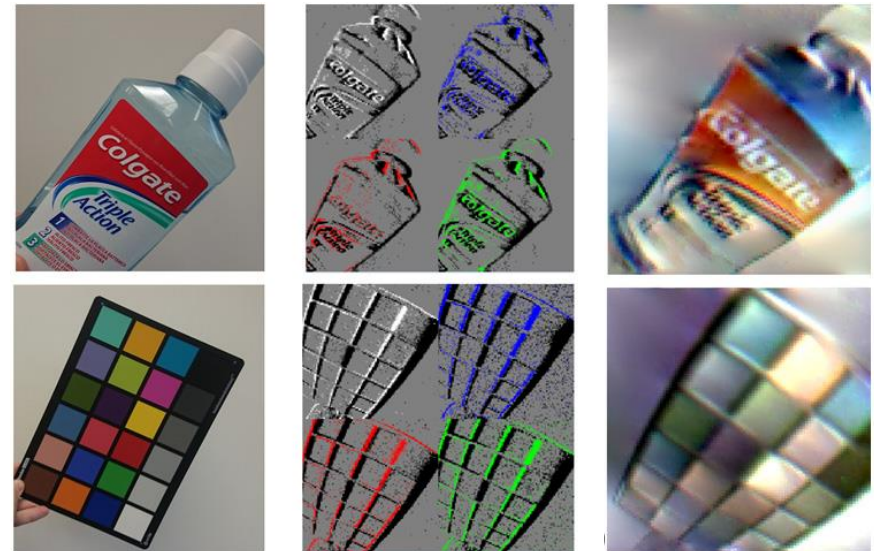 (192 x 188 pixels, **1%** contrast sensitivity)

Fig. 1 Simplified block diagram of DVS pixels with color filters. Graphs show CFA transmission coefficients T vs wavelength λ and photodiode QE vs λ.
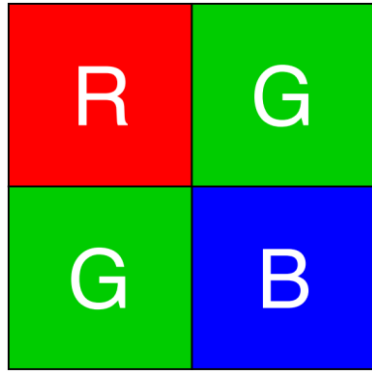

Scene   RGBW Events   Reconstructed intensity

Moeys et al., *Color Temporal Contrast Sensitivity in Dynamic Vision Sensors*, ISCAS 2017
Moeys et al., *A Sensitive Dynamic and Active Pixel Vision Sensor for Color or Neural Imaging Applications*, TBCAS 2018

DAVIS346 color

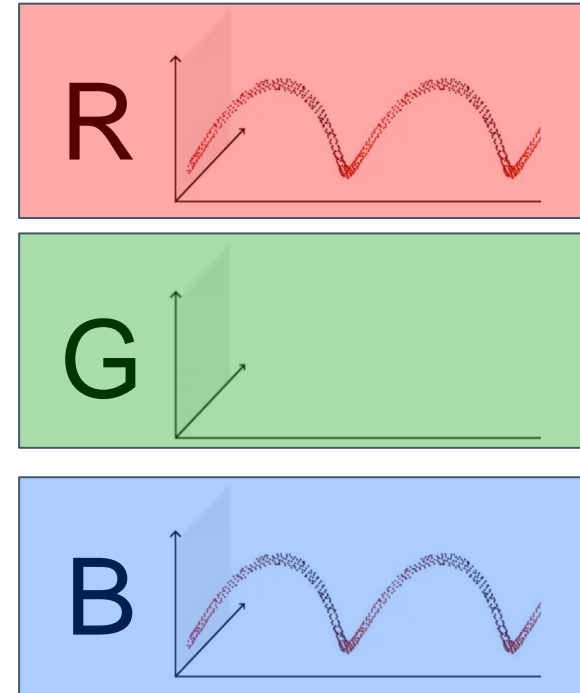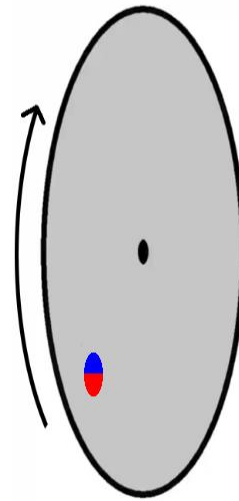- Each pixel is sensitive to red (R), green (G) or blue (B) light
- It transmits brightness changes in each color channel

DAVIS346 Red Color

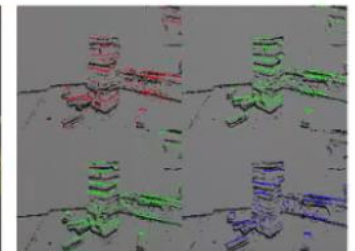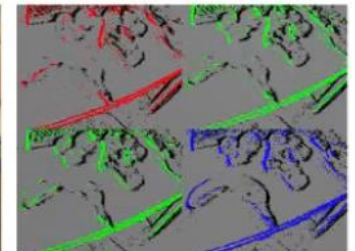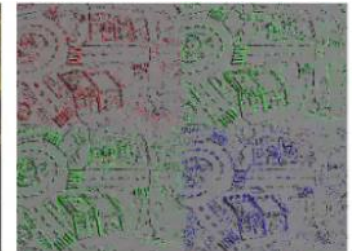Bayer filter mosaic

Taverni et al., Front and back illuminated Dynamic and Active Pixel Vision Sensors comparison, TCAS-II 2018
Scheerlinck et al., Color Event Camera Dataset, CVPR Workshops 2019. http://rpg.ifi.uzh.ch/CED.html

Color Event Camera Dataset

- 50 minutes footage of DAVIS **frames** and **color events**.

- Wide variety of scenes

- Wide variety of lighting: from low light (0.8 lux)
  to direct sunlight (10,000 lux)

- HDR scenes

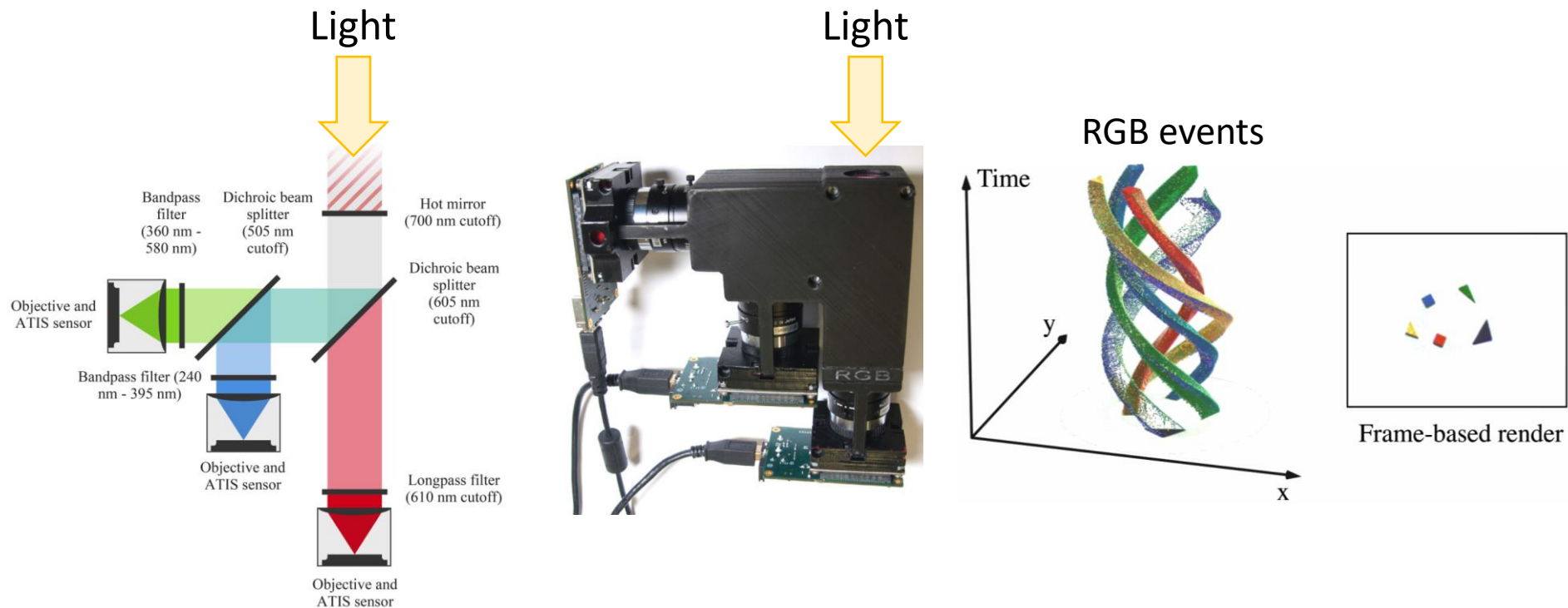- High speed, 6-DOF motions

- Recorded with a DAVIS346 color

DAVIS frame   Events

Scheerlinck et al., Color Event Camera Dataset, CVPR Workshops 2019. http://rpg.ifi.uzh.ch/CED.html

ATIS Color Camera

- 3 ATIS cameras, 3 color filters and 2 beam splitters
- The cameras share the same field of view (FOV)

Light

Light

RGB events
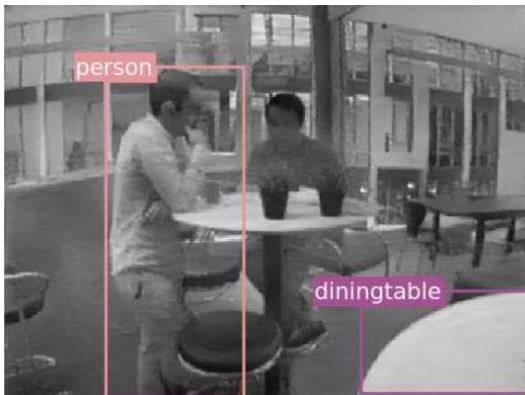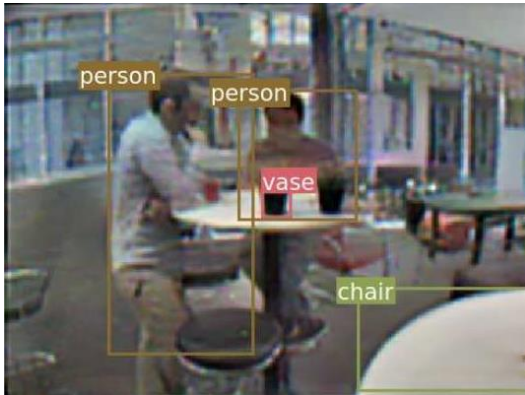
Frame-based render

Using ATISs, grayscale events (exposure measurement) become **RGB events:** $e = (x, y, t, r, g, b)$

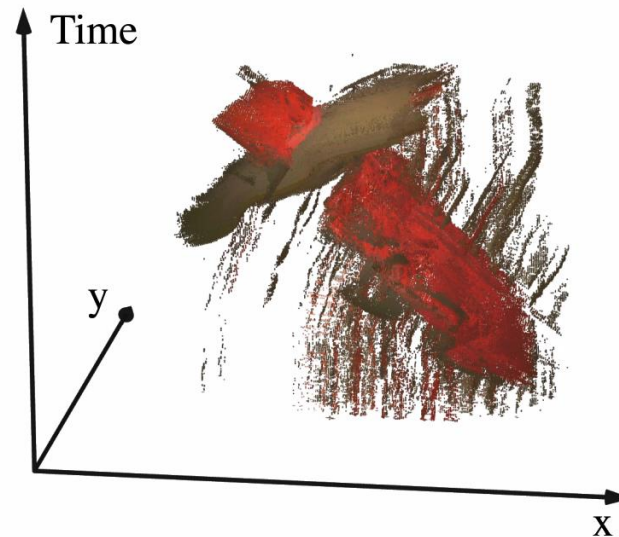Marcireau et al., *Event-Based Color Segmentation With a High Dynamic Range Sensor*. Front. Neurosci., 2018

Applications

- Intensity reconstruction (HDR, high-speed…)
- Object recognition improves with color
- Microscopy imaging (neurons sensitive to calcium)

Object detection / recognition

Segmentation using color cues

Frame-based render

References

Reading:

- SDAVIS192:
  - Moeys et al., *A Sensitive Dynamic and Active Pixel Vision Sensor for Color or Neural Imaging Applications*, TBCAS 2018
  - Moeys et al., *Color Temporal Contrast Sensitivity in Dynamic Vision Sensors*, ISCAS 2017. Check out the supplementary material (3 videos in the paper references)

- DAVIS346 color:
  - Taverni et al., Front and back illuminated Dynamic and Active Pixel Vision Sensors comparison, TCAS-II 2018

- Color ATIS:
  - Marcireau et al., *Event-Based Color Segmentation With a High Dynamic Range Sensor*. Front. Neurosci., 2018. Check out the supplementary material (3 videos)