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

Event Generation Model

Event Generation model(s)

- **Original** (pixelwise, non-linear, no noise)

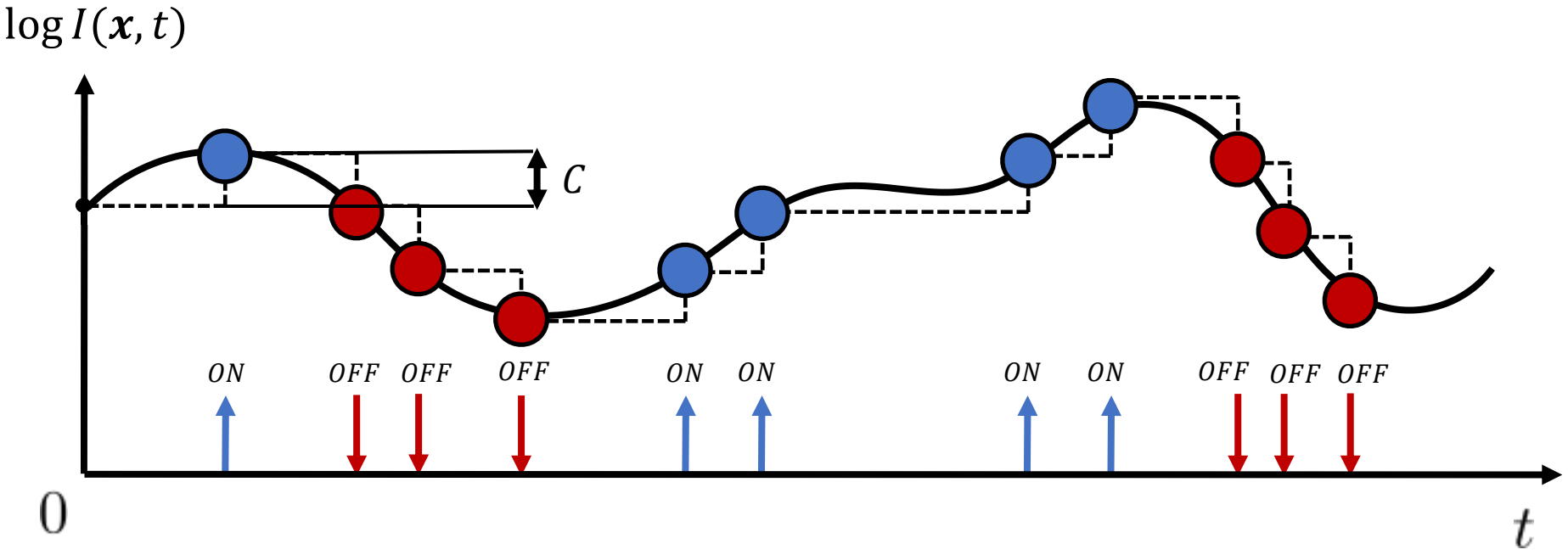
- **Linearized** (using brightness constancy)

- More **realistic** (incorporating noise)
  - Bell-shaped, Gaussian. In which variable?
  - Mixture model (“good” and “bad” measurements)
  - Dependent on more variables (such as refractory period)

Event Generation Model at a Pixel

An event is triggered at pixel $\boldsymbol{x}$ if:

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



Light (log *I*) is transduced into a stream of asynchronous events

What causes the events?

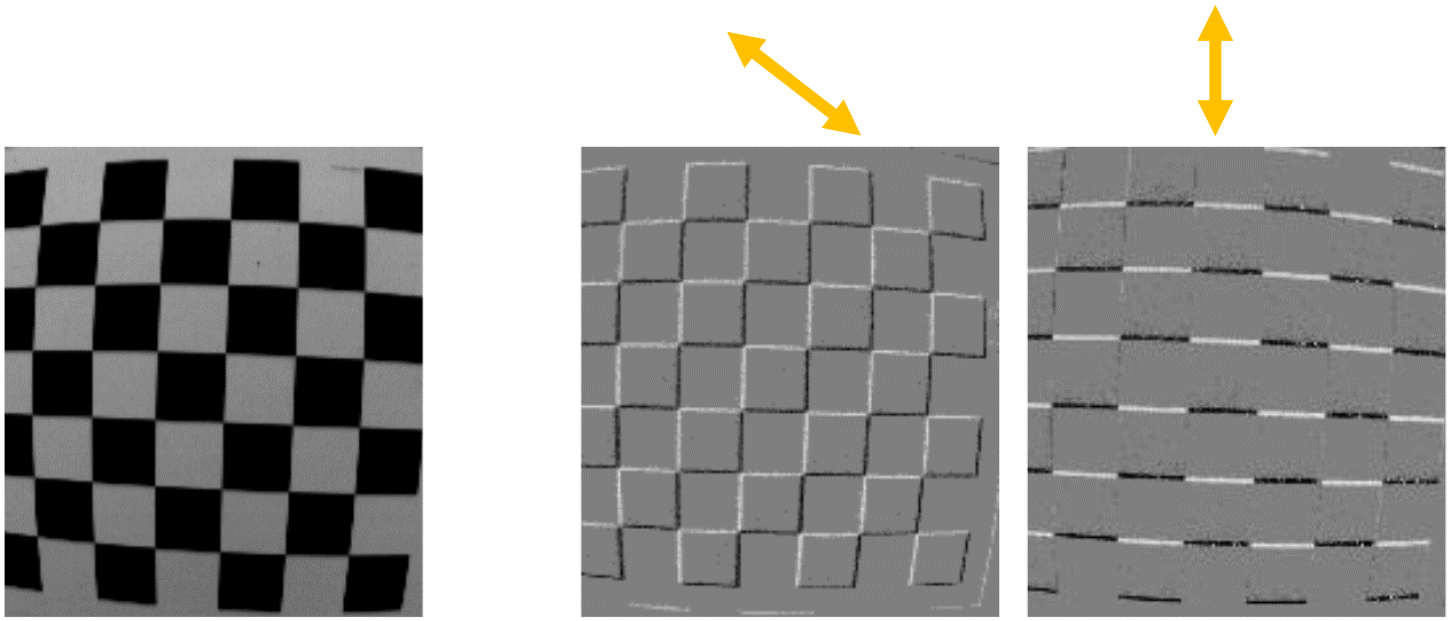
- DVS pixels measure brightness changes (i.e., temporal contrast)

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

- These changes could be due to a **varying light** (e.g., LED)
- However, assuming **constant illumination**... what causes the events?

  ⇒ **moving edges** in the scene

- Can we say more? Observe the **spatial** patterns of events:



What causes the events?

Going from temporal contrast to spatial information:

- An event is generated if $\Delta L \coloneqq L(t_k) - L(t_k - \Delta t) = \pm C$
- For a short time: $\Delta L \approx \frac{\partial L}{\partial t} \Delta t$
- Assuming **brightness constancy**

$$0 = \frac{dL(\boldsymbol{x}(t),t)}{dt} = \nabla L \cdot \frac{d\boldsymbol{x}}{dt} + \frac{\partial L}{\partial t}$$ (this is just the chain rule)

  where $\dot{\boldsymbol{x}} = d\boldsymbol{x}/dt$ (a velocity $\boldsymbol{v}$), we may work out $\frac{\partial L}{\partial t} = -\nabla L \cdot \dot{\boldsymbol{x}}$

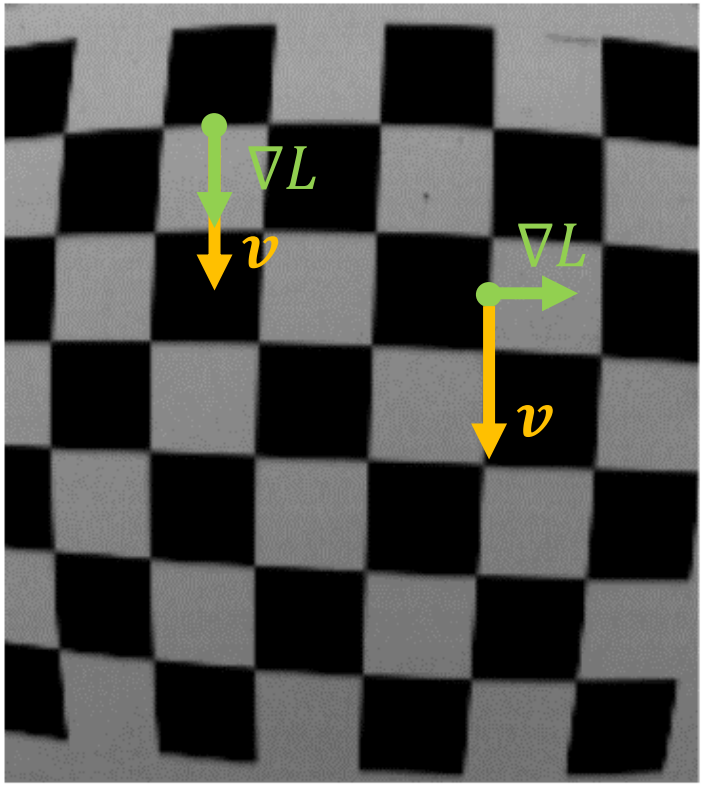
- Substituting:

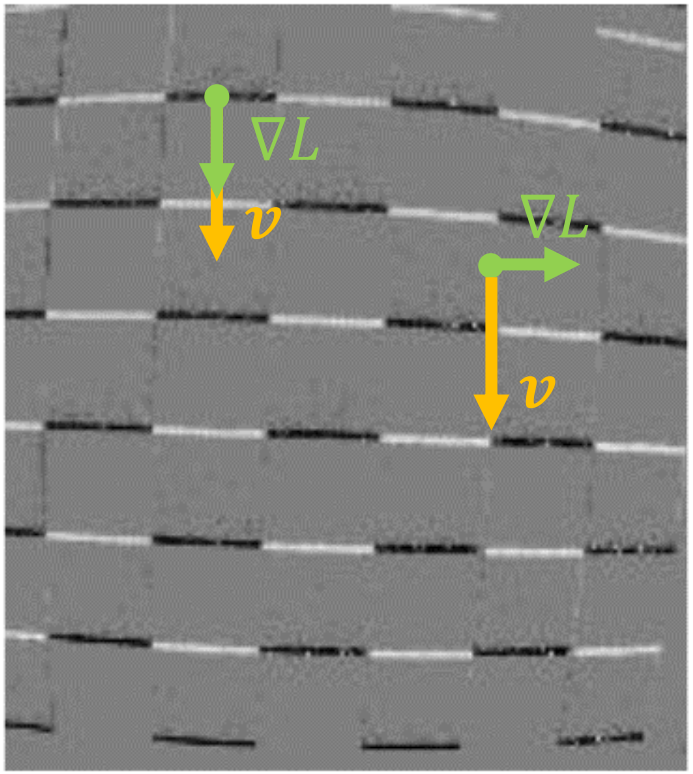
$$\Delta L \approx -\nabla L \cdot \boldsymbol{v} \Delta t$$

  - Brightness change is **caused** by brightness gradient **moving** with a velocity $\boldsymbol{v}$ on the image plane, over a displacement $\Delta \boldsymbol{x} \coloneqq \boldsymbol{v} \Delta t$
  - If brightness gradient $\perp$ motion ⇒ no event is generated
  - If brightness gradient $\parallel$ motion ⇒ event is generated fastest

Review the earlier example

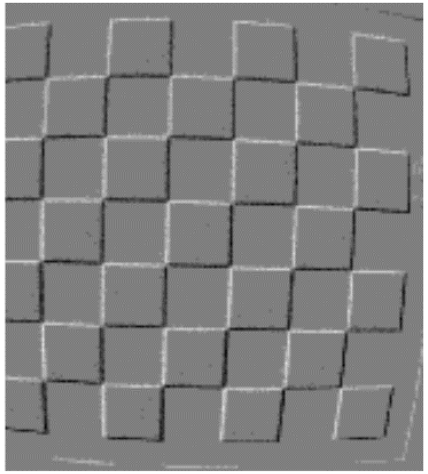
- If brightness gradient ⊥ motion ⇒ no event is generated
- If brightness gradient || motion ⇒ event is generated fastest





Event Generation

- In conclusion, for constant illumination, events are caused by **moving edges**.
- When we accumulate the events pixelwise what we see is the **trace of the edge** as it **moved and generated events**. (This is not “motion blur”)



- Some methods exploit the linearized model; others do not

More Realistic Event Generation Model

- A probabilistic model:

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

Replace this constant with
a **probability distribution**

Measured JSSC 2008

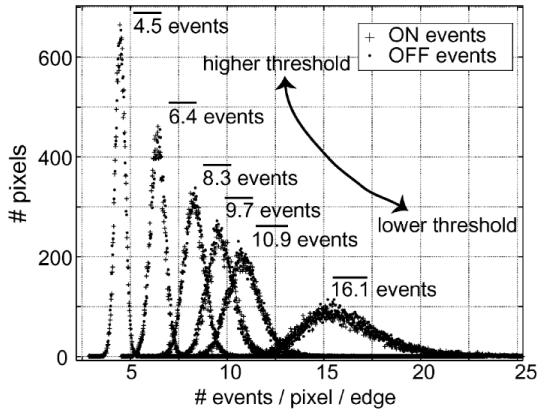
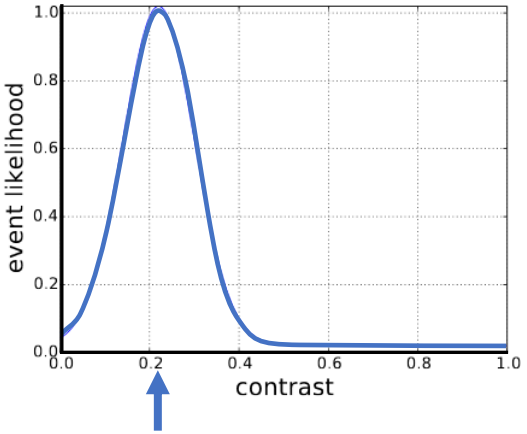


Fig. 6. Distributions in the number of events recorded per pass of the bar for 40 repetitions of the 15:1 contrast bar sweeping over the array, e.g., for the highest threshold setting there are an average of 4.5 ON and 4.5 OFF events per ON and OFF edge.

Modeled BMVC 2014



C “average” or “mode”

References

- Section 2.4 of Event-based Vision: A Survey, TPAMI 2020
- Papers on event noise measuring or modeling:
  - JSSC 2008 – Journal paper about DVS
  - BMVC 2014, arXiv 2015, ICCP 2017, TPAMI 2018
  - Further reading:"V2E: From video frames to realistic DVS event camera streams", arXiv 2020.
- Classical computer vision books for the topic of brightness constancy.