HDR videos acquisition

dr. Francesco Banterle

francesco.banterle@isti.cnr.it

How to capture?

- Videos are challenging:
  - We need to capture multiple frames at different exposure times
  - … and everything moves

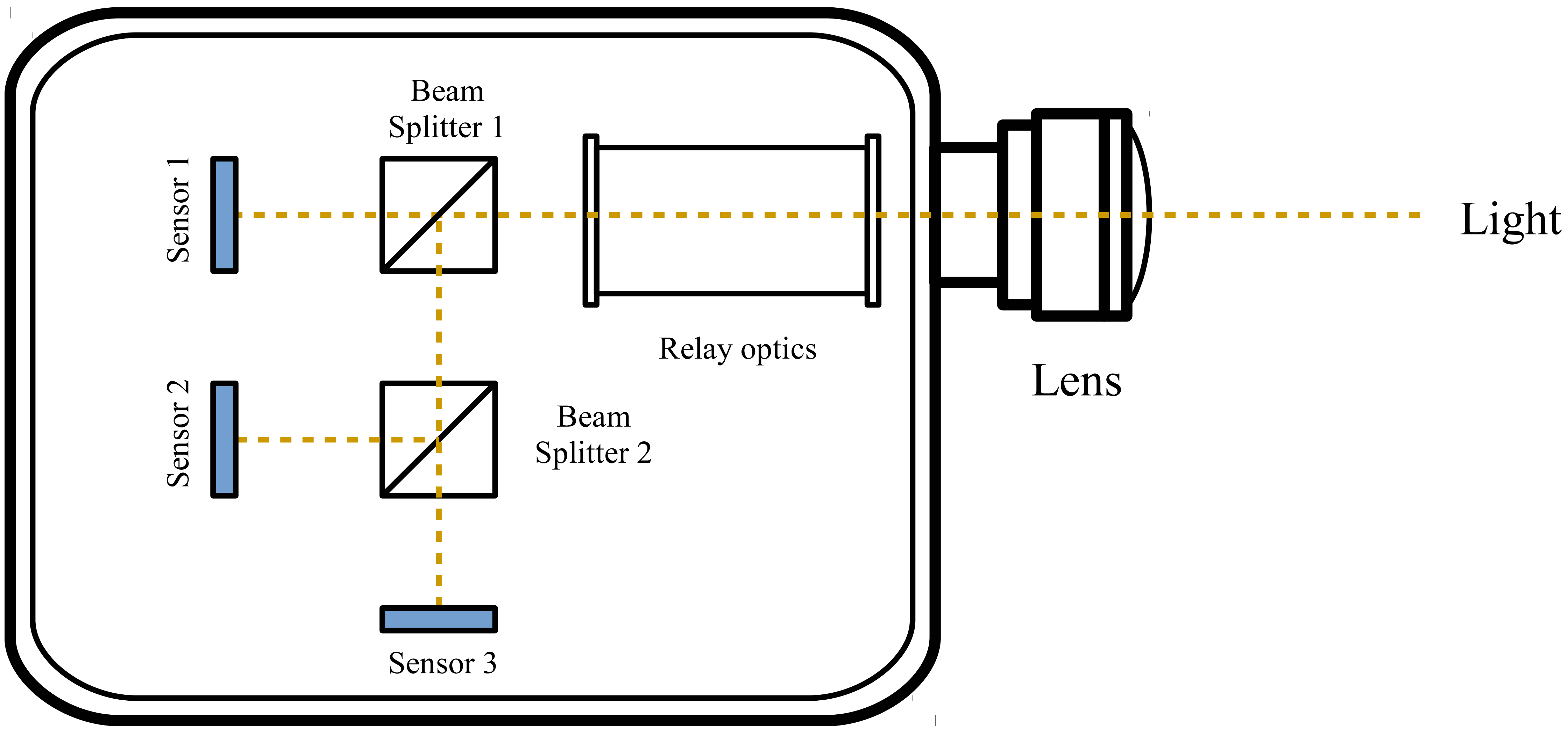
How to capture?

- Different technologies based on exposure bracketing:
  - beam-splitter; i.e. many sensors one lens
  - stereo/multi-view HDR capturing
  - varying exposure per pixel; i.e. bayer pattern
  - varying shutter speed

Multi-sensors cameras

- **Idea**: to use more sensors to capture the same scene
- The light path is divided using beam splitters:
    - careful alignment

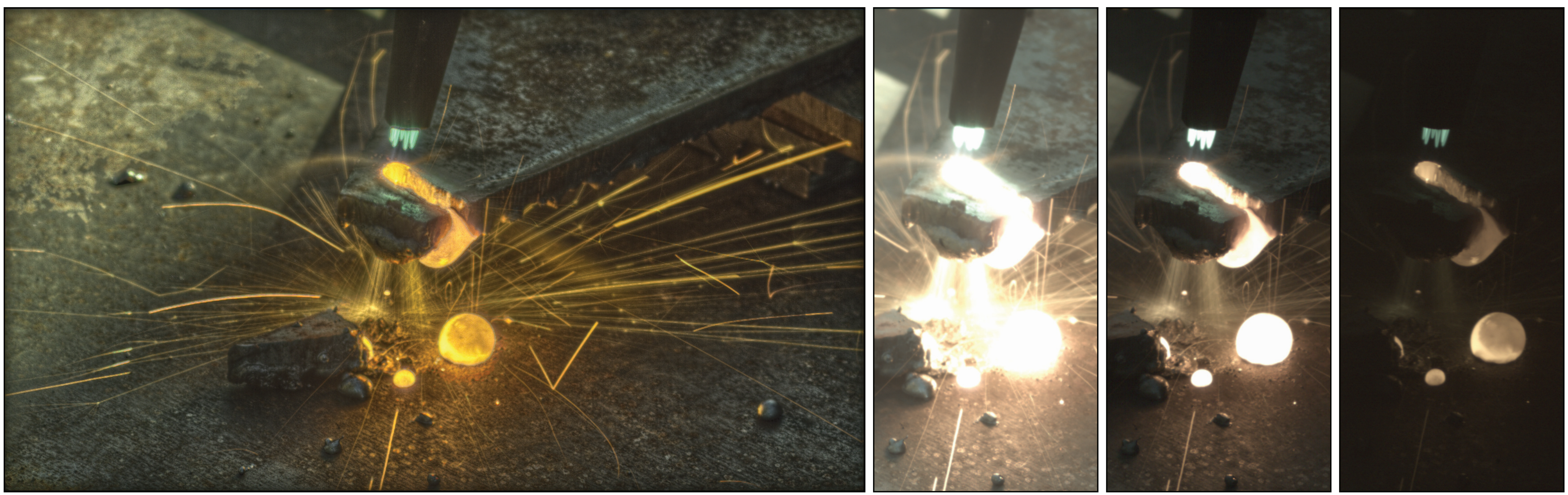
Multi-sensors cameras



Multi-sensors cameras

- Debayering after HDR-merging
  - why not before?
    - It can corrupt colors in saturated regions
    - It makes less visible sub-pixel misalignments of sensors

Multi-sensors cameras



“A Versatile HDR Video Production System”. Michael D. Tocci, Chris Kiser, Nora Tocci, Pradeep Sen. ACM SIGGRAPH 2011 Papers program.

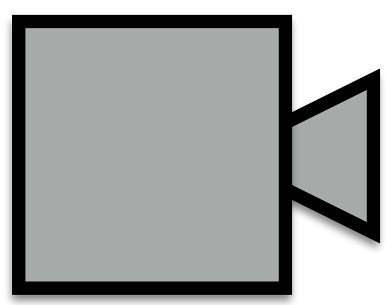
Multi-sensors cameras

- Advantages:
  - no ghosts
  - no misalignments
- Disadvantages:
  - high costs: sensors + calibration
  - fixed dynamic range that can be captured
  - reconstruction before debayering: complex reconstruction algorithms

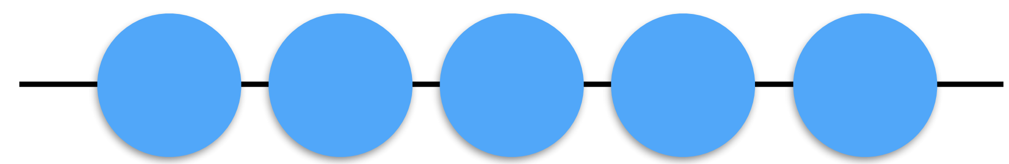
Multi-cameras systems

- **Idea**: to use more cameras in a rig to capture the same scene:
  - each camera has a different shutter-speed/ISO
  - A synchronization system is required

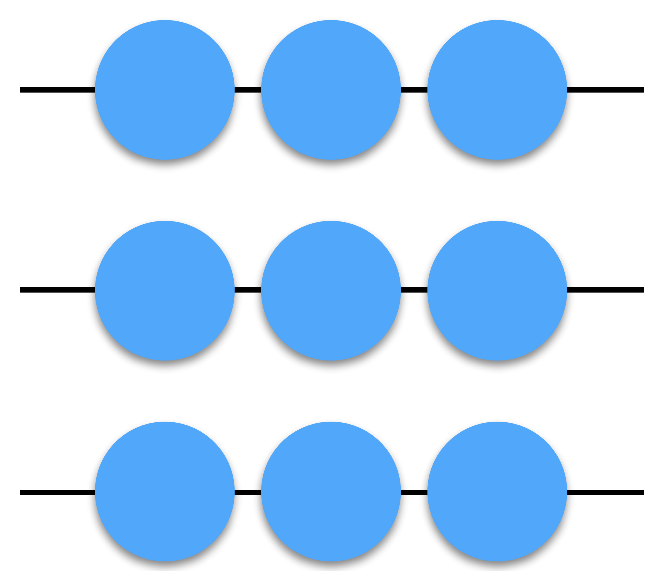
Multi-cameras systems



Camera



Linear pattern



Square pattern

Multi-cameras systems: Geometric Calibration

- Geometric calibration of each camera:
  - Intrinsic parameters: optical center, focale, pixel size in mm, field of view (angle), and aspect ratio.
  - Extrinsic parameters; world position: position and rotation

Multi-cameras systems: Alignment

- There is the need to align other images onto a reference image (well-exposed one again!)
- How?
  - Compute disparity map
  - Warp images

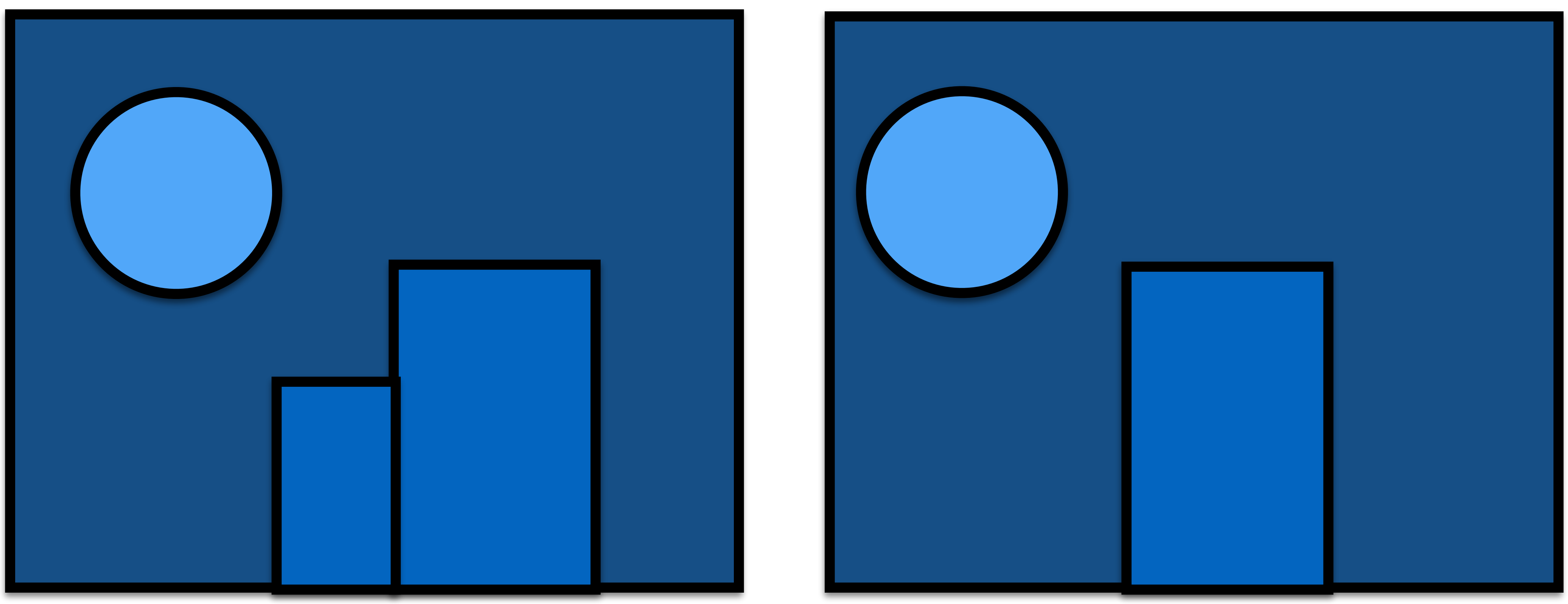
Multi-cameras systems: Disparity Computation

$$SSD(u,v,d) = \sum_{k=-n}^{n} \sum_{l=-m}^{m} \Big(I_1(u+k, v+l) - I_2(u+k+d, v+l) \Big)^2$$

$$d_o(u,v) = \arg\min_{d} SSD(u,v,d)$$

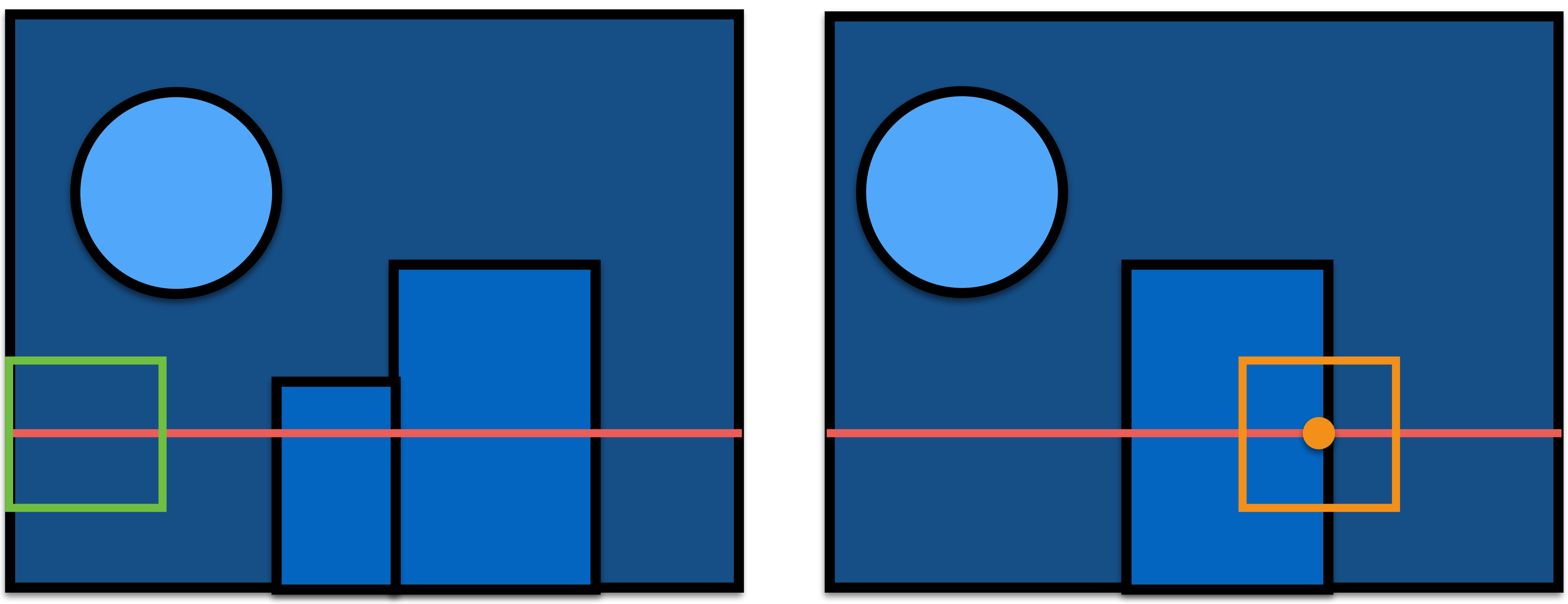
Note: typically $n = m$

Multi-cameras systems: Disparity Computation



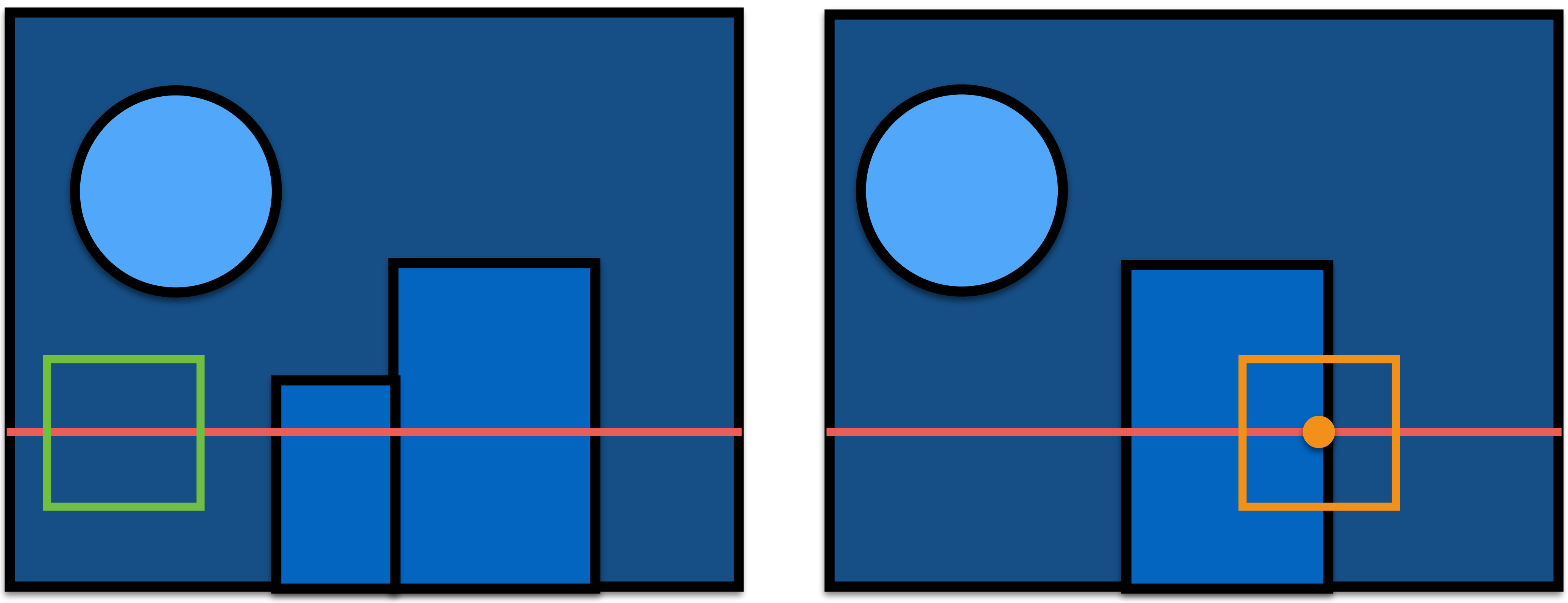
I_1 I_2

Multi-cameras systems: Disparity Computation



I_1 I_2

Multi-cameras systems: Disparity Computation



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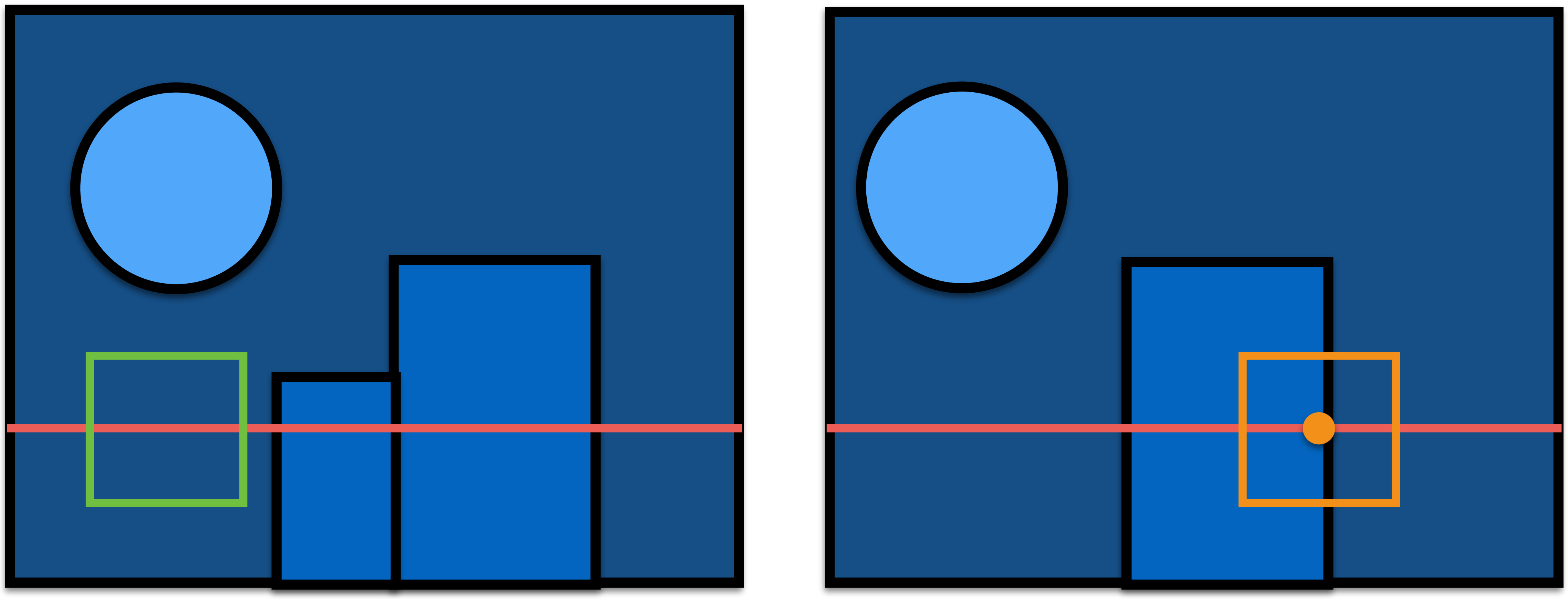
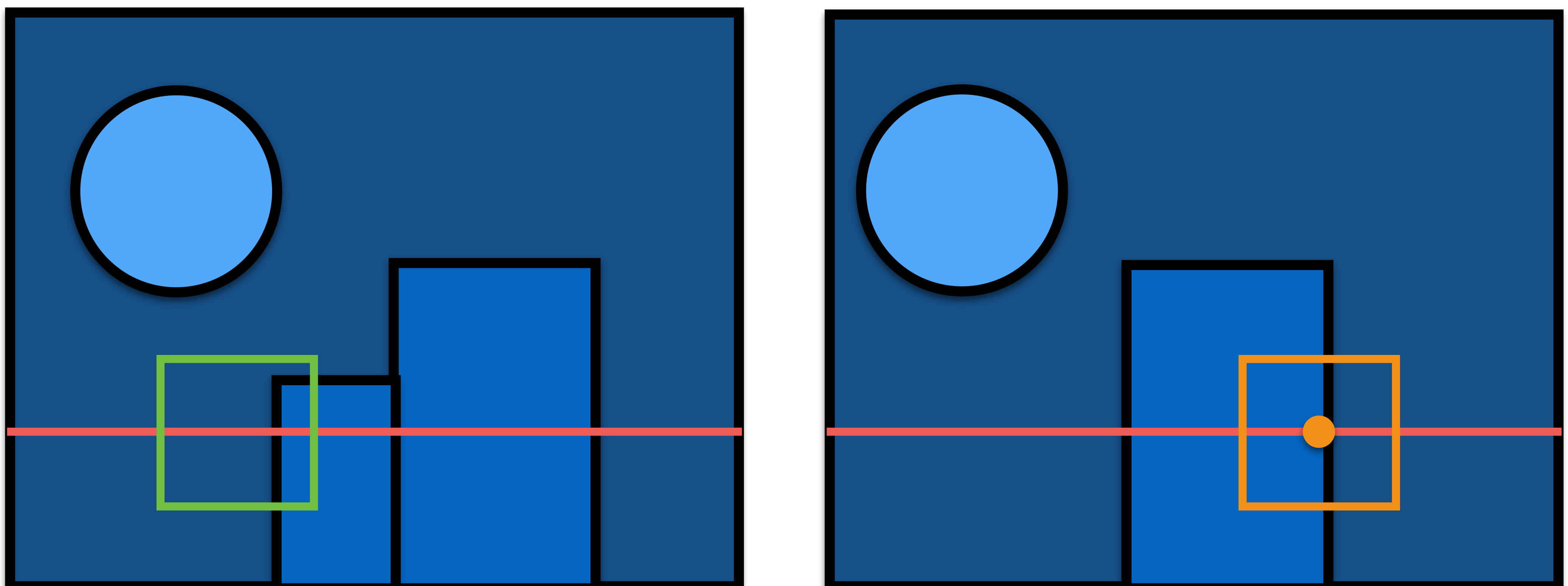


I_1 I_2

Multi-cameras systems: Disparity Computation



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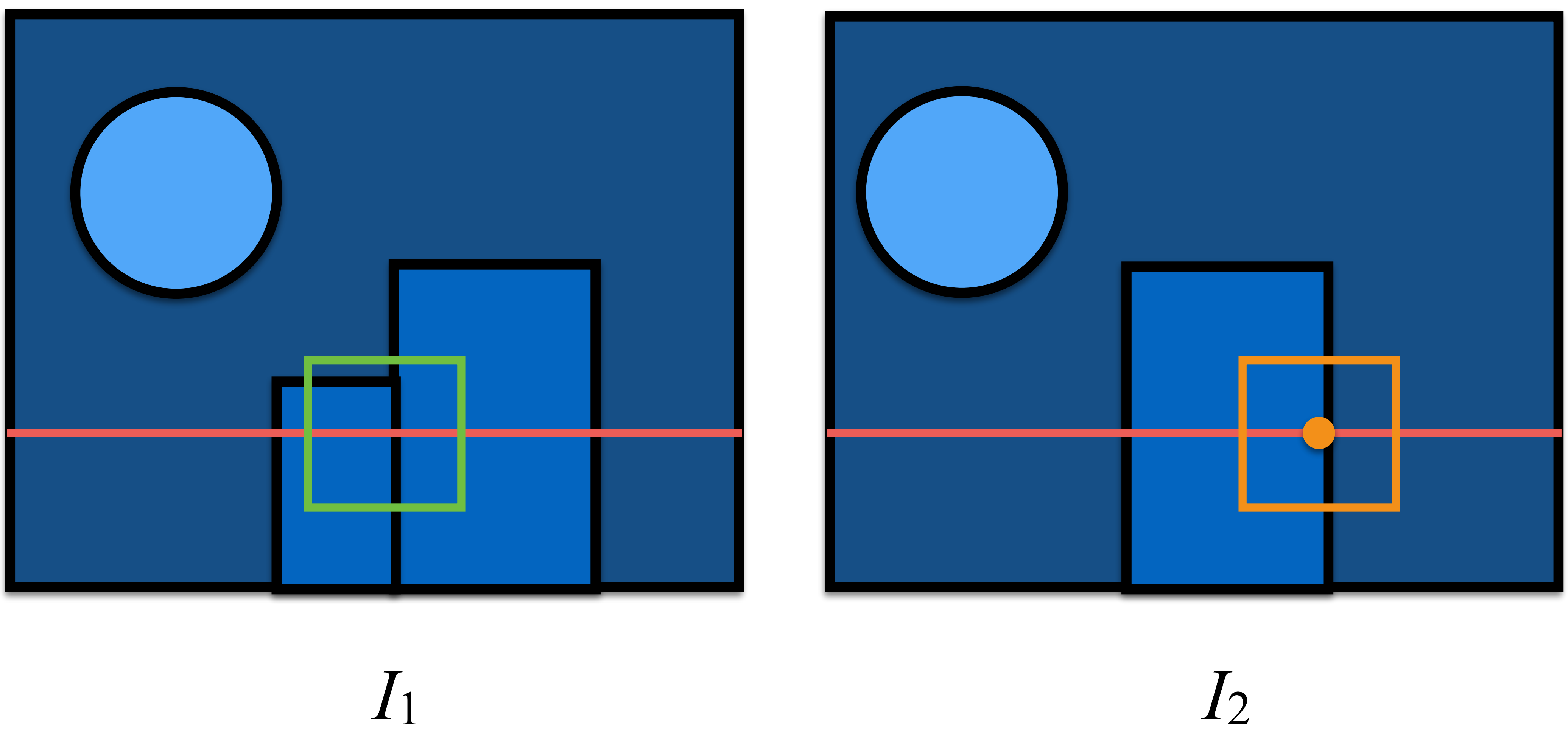
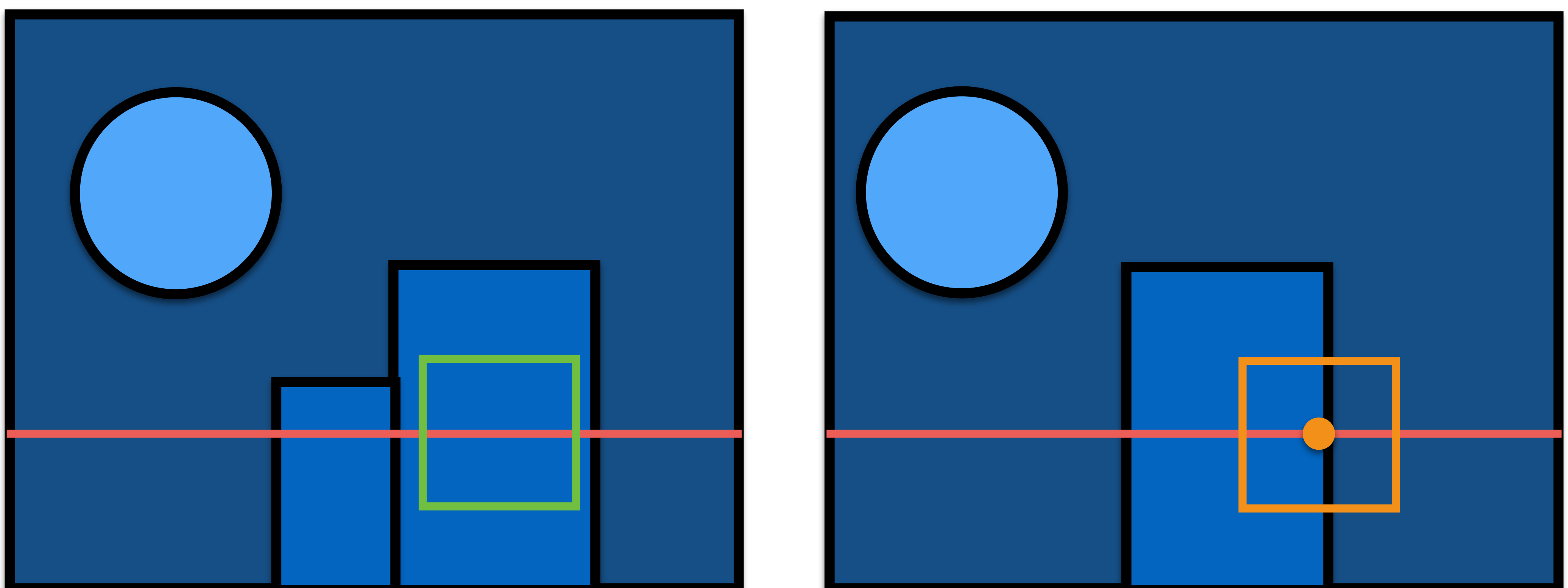
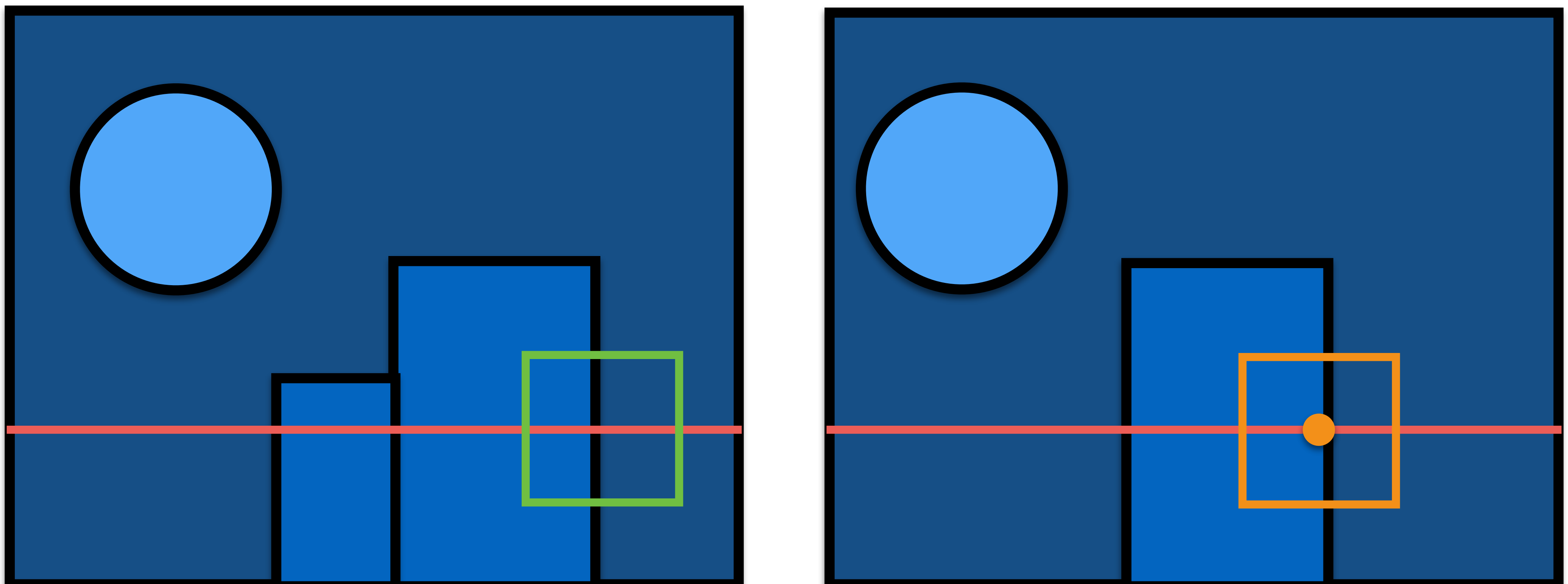


Multi-cameras systems: Disparity Computation



I_1 I_2

Multi-cameras systems: Disparity Computation



I_1 I_2

Multi-cameras systems: disparity computation

http://vision.middlebury.edu/stereo/data/

Multi-cameras systems: disparity computation

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Multi-cameras systems: warping

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Multi-sensors cameras

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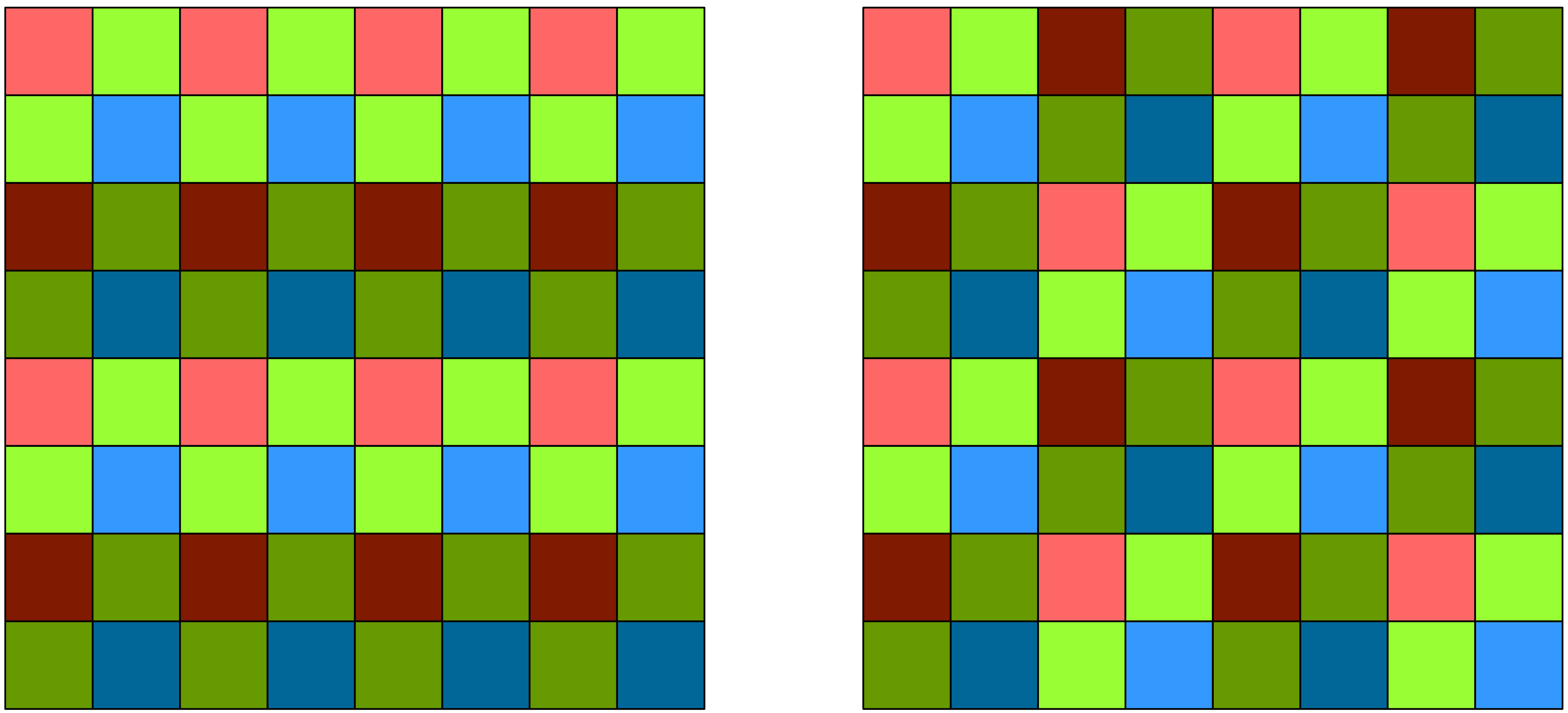
  - no ghosts
- Disadvantages:
  - misalignments + occlusions
  - high costs: sensors + sync
  - fixed dynamic range that can be captured

Varying exposure per pixel

- **Idea**: to apply bayer pattern not only for RGB colors but also to exposure
- Two possible solutions:
  - varying gain
  - a mask with varying neutral density filters:
    - shutter time is not modified!

Varying exposure per pixel

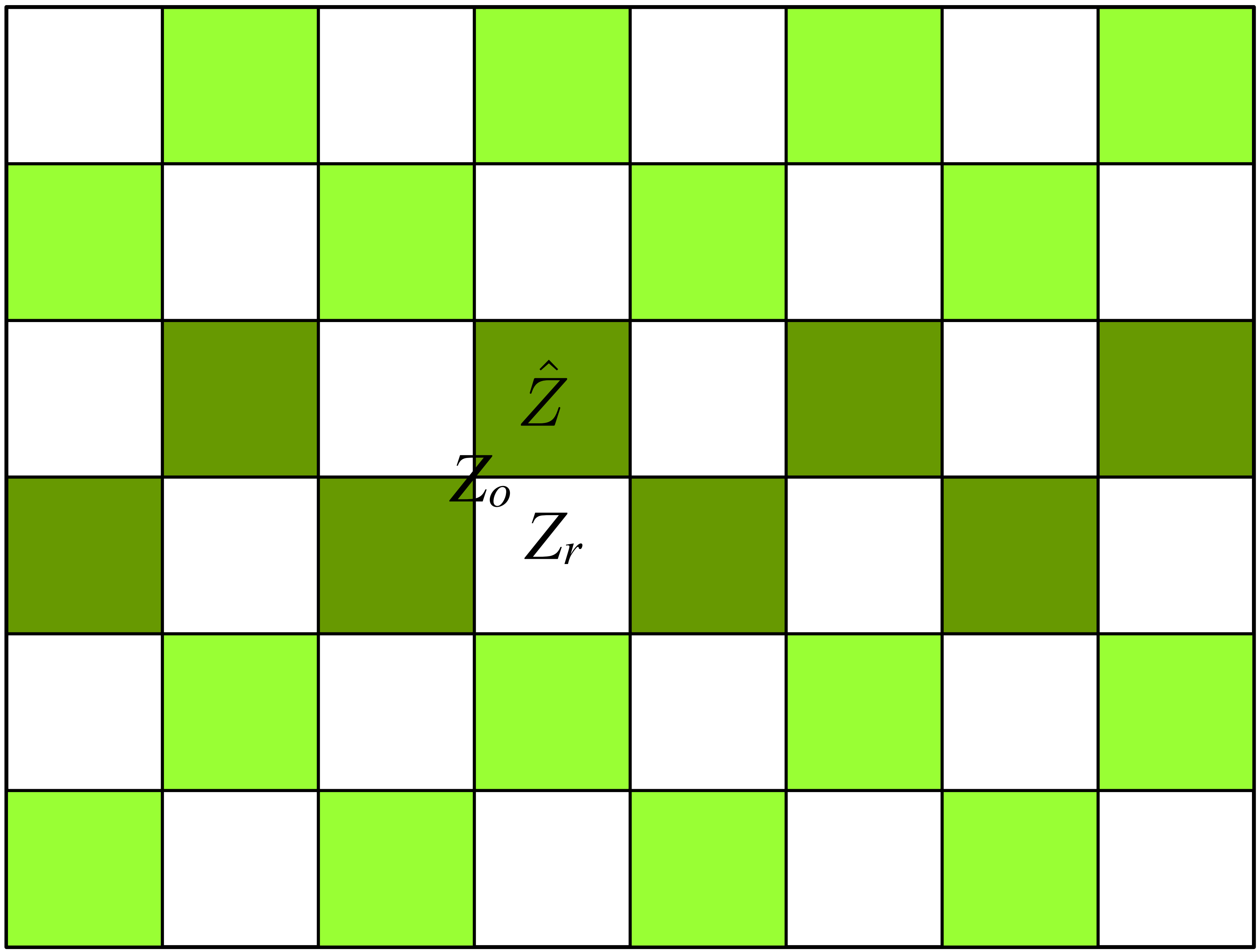


interleaved rows　　　　checkboard pattern

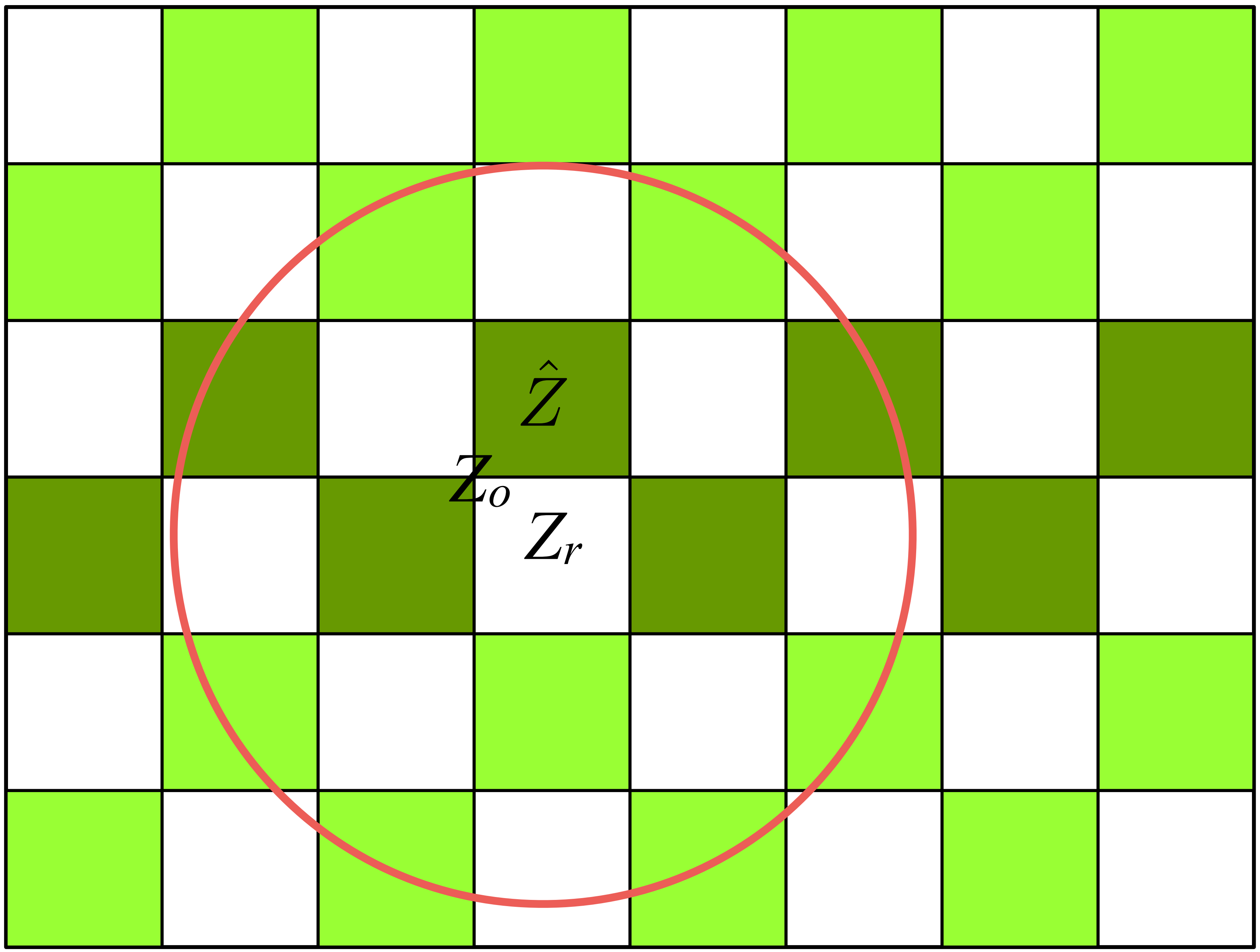
Varying exposure per pixel

Varying exposure per pixel

Varying exposure per pixel: reconstruction



Varying exposure per pixel: reconstruction



Varying exposure per pixel: reconstruction

- How can reconstruction be carried out?
- Linear interpolation can lead to artifacts
- Cubic interpolation; close to ideal sinc:

$$Z_r(x,y) = \sum_{i=0}^{3}\sum_{j=0}^{3} f(1.5-i, 1.5-j) Z_o(x-1.5+i, y-1.5+j)$$

Reconstructed Kernel Signal

Varying exposure per pixel: reconstruction

- Let’s see the matrix form:

$$\mathbf{Z}_r = \mathbf{F}\mathbf{Z}_o$$

$$\hat{\mathbf{Z}} = \mathbf{F}\mathbf{Z}_o$$

$$\mathbf{Z}_o = \mathbf{F}^{-}\hat{\mathbf{Z}} \qquad \mathbf{F}^{-} = \mathbf{F}^T(\mathbf{F}\mathbf{F}^T)^{-1}$$

Varying exposure per pixel

Varying exposure per pixel

Varying exposure per pixel

Varying exposure per pixel

- Advantages:
  - low cost hardware: programmable videocameras; e.g. Canon DSLR with Magic Lantern
  - no ghosts
  - no misalignments
- Disadvantages:
  - limited to 2-3 exposure images
  - masks may be expensive to manufacture and difficult to align to an existing bayer pattern

Varying Shutter Speed

- **Idea**: to program the shutter speed or ISO; i.e. varying it at each frame
- Requirements:
  - high frame rate videocamera
  - programmable hardware

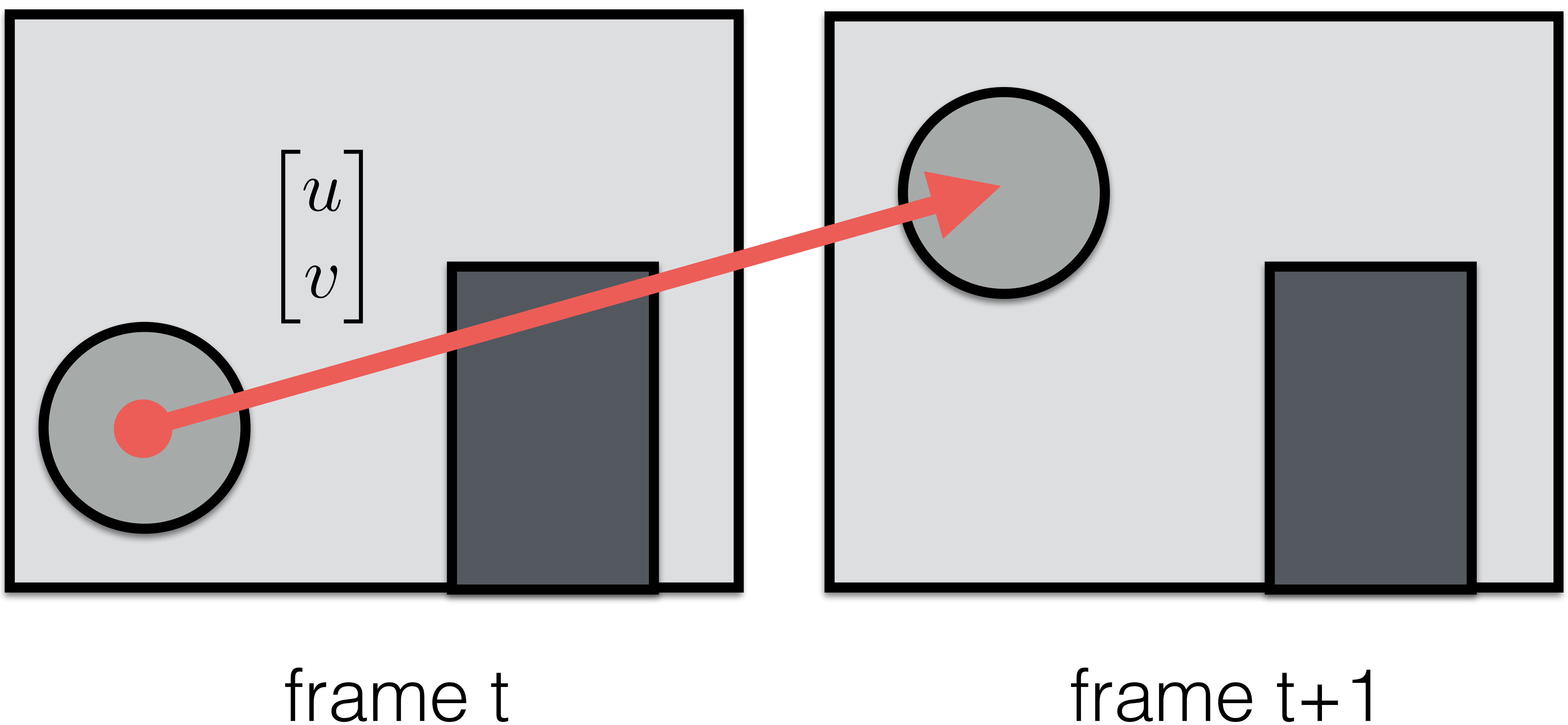
Varying Shutter Speed

Courtesy of Jonas Unger

Varying Shutter Speed: reconstruction

- There is the need to align other images onto a reference image (well-exposed one again!)
- How?
  - Compute Motion Estimation
  - Warp images

Varying Shutter Speed: Motion Estimation



$$I_t(i, i) = I_{t+1}(i + u, i + v)$$

Varying Shutter Speed: Motion Estimation

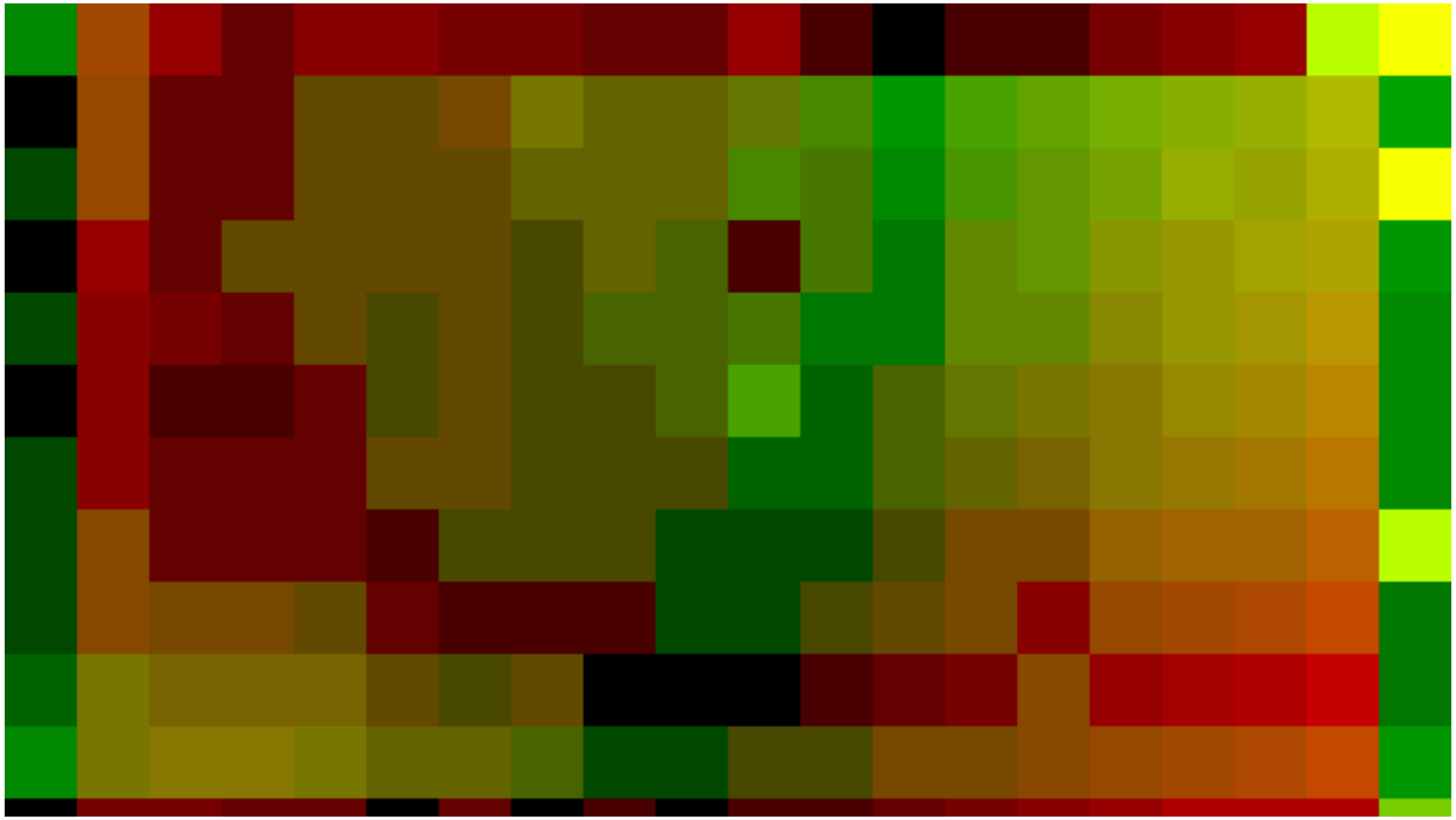
$$SSD(i,j,u,v) = \sum_{k=-n}^{n} \sum_{l=-m}^{m} \Big(I_1(i+k, j+l) - I_2(i+k+u, j+l+v) \Big)^2$$

$$OF_o(i,j) = \arg\min_{u,v} SSD(i,j,u,v)$$

Note: this is a generalization of the disparity problem

Varying Shutter Speed: Motion Estimation

Image courtesy of Jonas Unger



per block motion estimation

Varying Shutter Speed: Warp

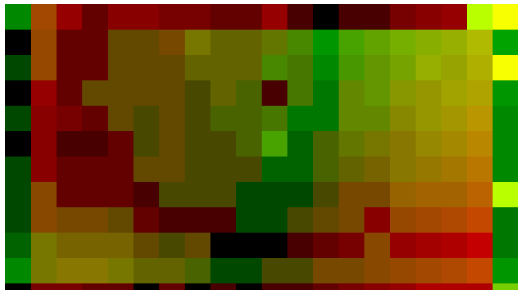
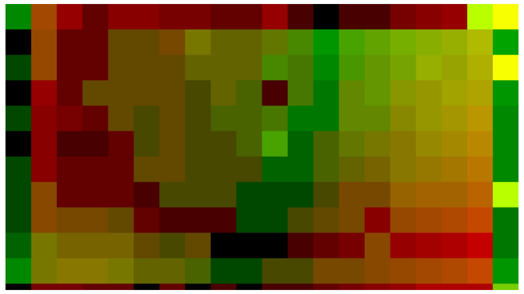


Image courtesy of Jonas Unger

Varying Shutter Speed: Warp



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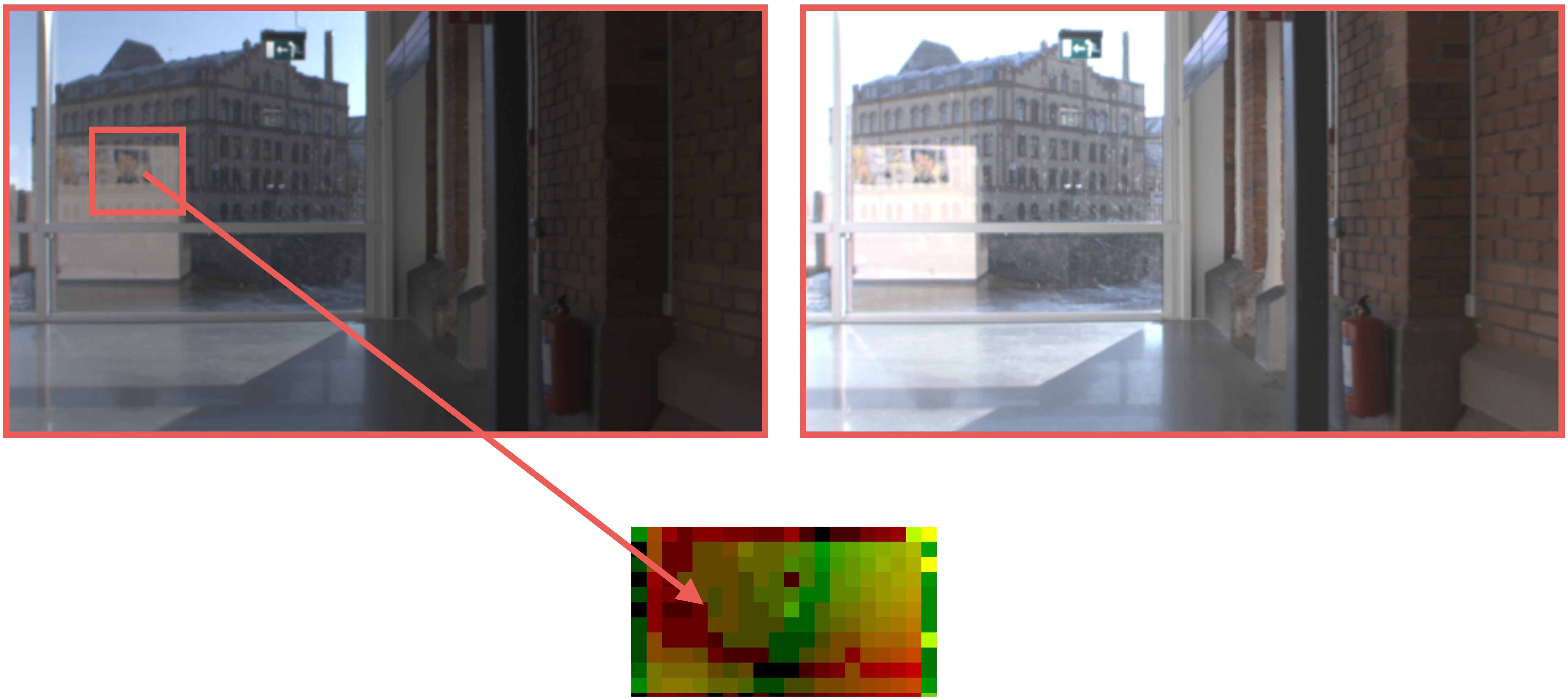

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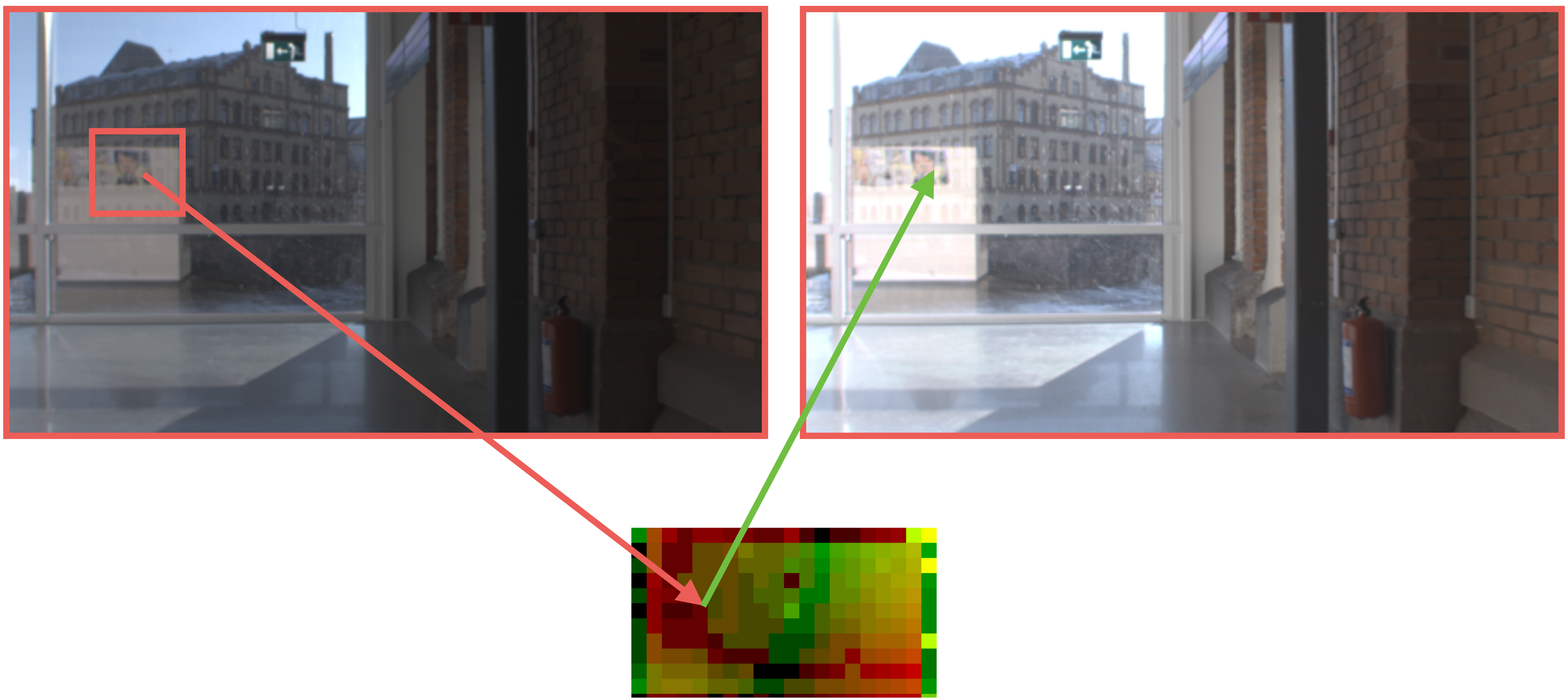

Image courtesy of Jonas Unger

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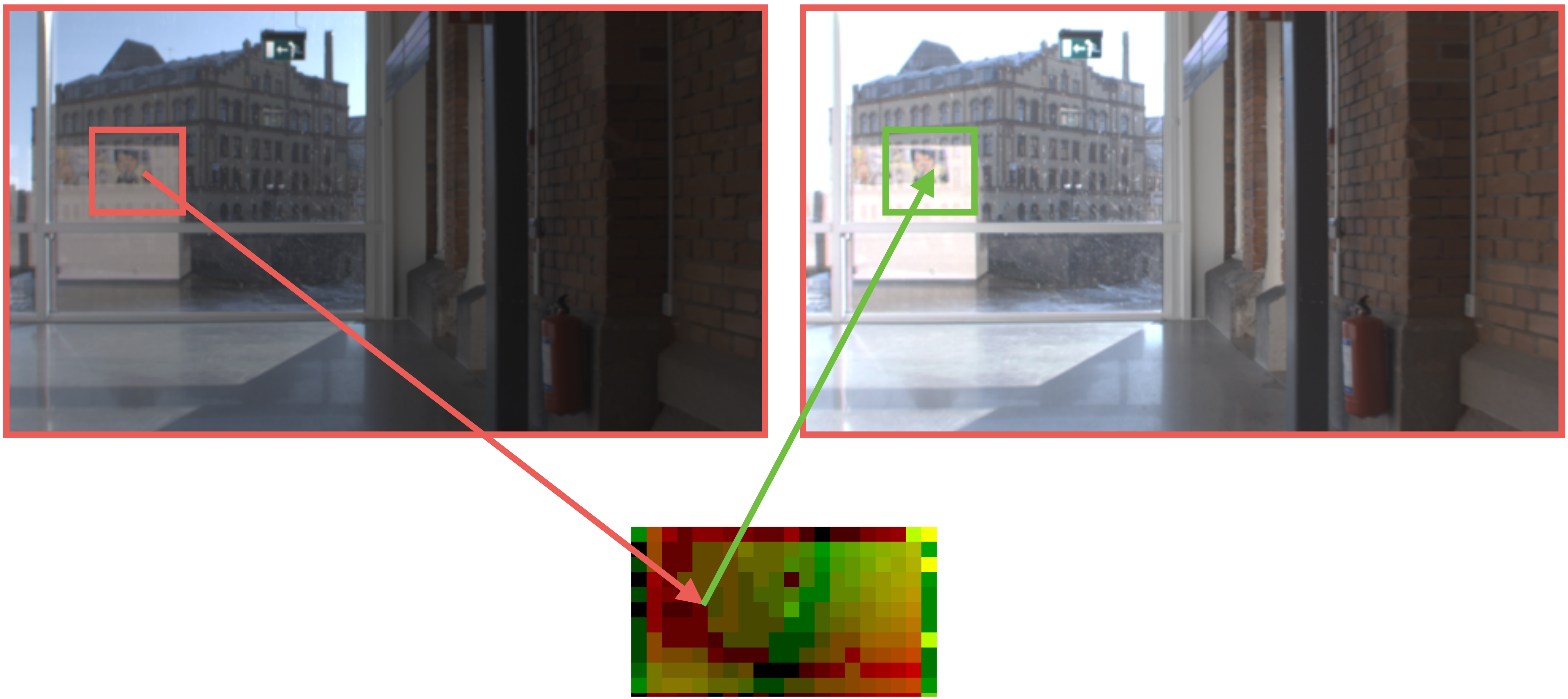

Image courtesy of Jonas Unger

Varying Shutter Speed: Warp

- Advantages:
    - low cost hardware: high frame rate and programmable videocameras; e.g. Canon DSLR with Magic Lantern
- Disadvantages:
    - limited to 2-3 exposure images
    - moving camera and scene:
        - camera alignment
        - moving scene

Questions?