Geometry for computer Vision

Lecture 8: Rolling shutter and push-broom cameras

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- Rolling shutter and push-broom sensors
- RS geometry modelling
- Discussion of article
- Course projects and exam dates

Motivation

- Classical structure and motion (SaM) estimation assumes that all pixels in an image were taken at the same time.

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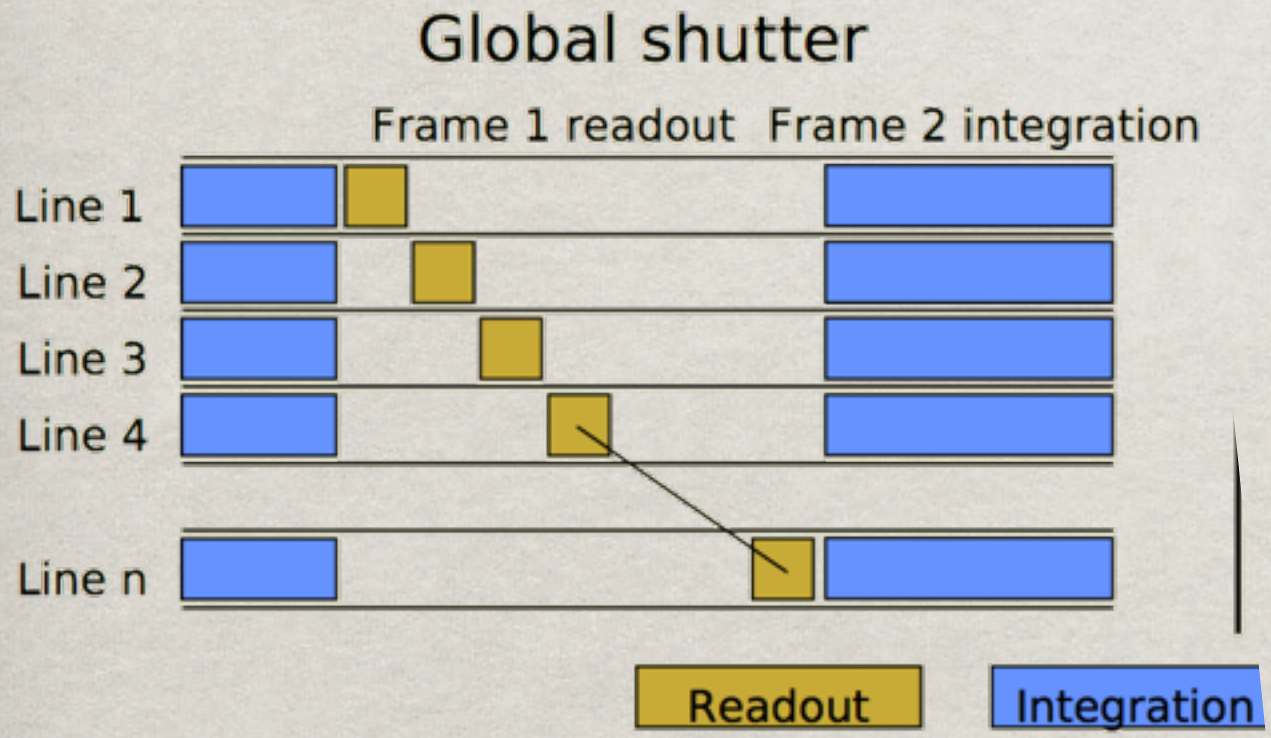
- Classical structure and motion (SaM) estimation assumes that all pixels in an image were taken at the same time.
- Not generally true.
- Most **CMOS** image chips have a row-by-row readout, and thus a *rolling shutter*
- Imaging systems in **remote sensing** often have line sensors aka. *push-broom* cameras

ROLLING SHUTTER

- Image rows are read sequentially



ROLLING SHUTTER

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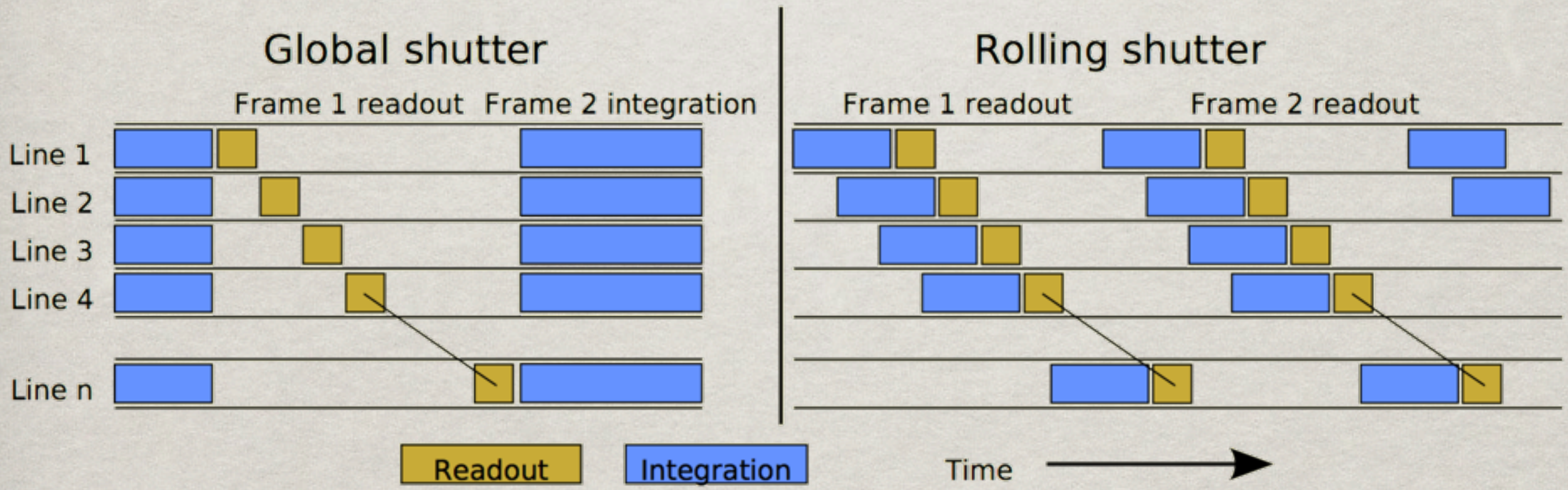

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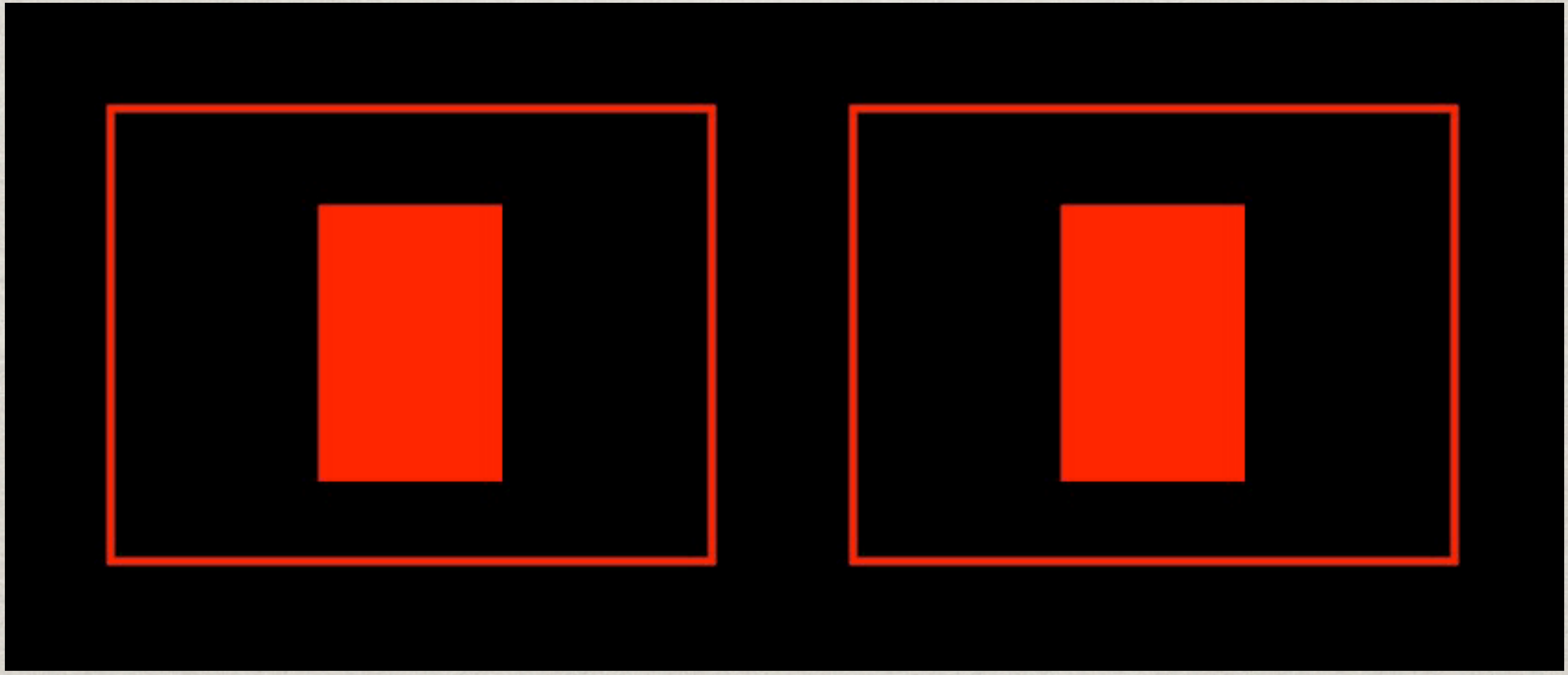
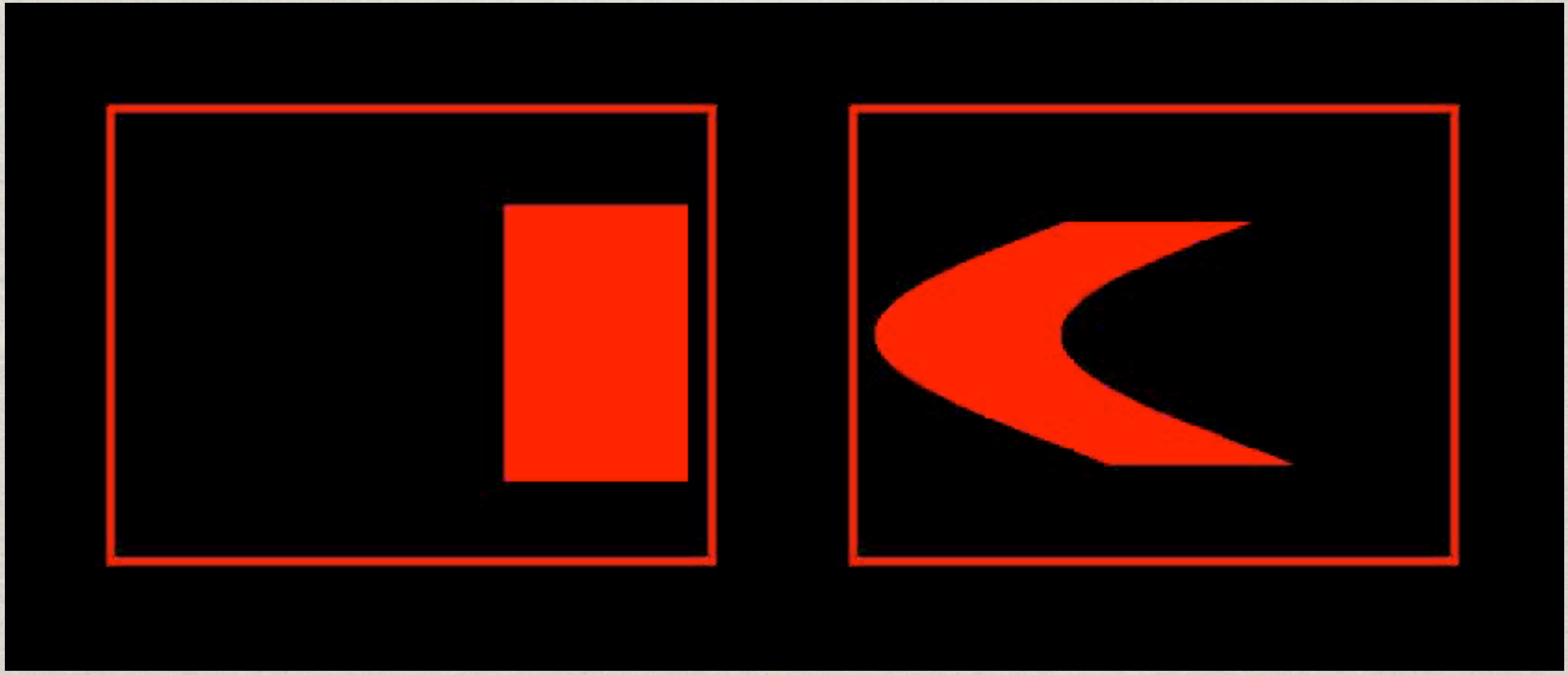


Static Scene

Captured Image

ROLLING SHUTTER

- Image rows are read sequentially



Dynamic Scene Captured Image

ROLLING SHUTTER

- Actually quite common
- Many **camcorders** have RS

Canon HV30

Panasonic HDC-SD300

Sony HDR HC1

ROLLING SHUTTER

- Actually quite common
- Almost all camera **cellphones** have RS

Apple iPhone 3GS   HTC Desire   Sony-Ericsson W890i

Push-Broom Sensors

- A push broom

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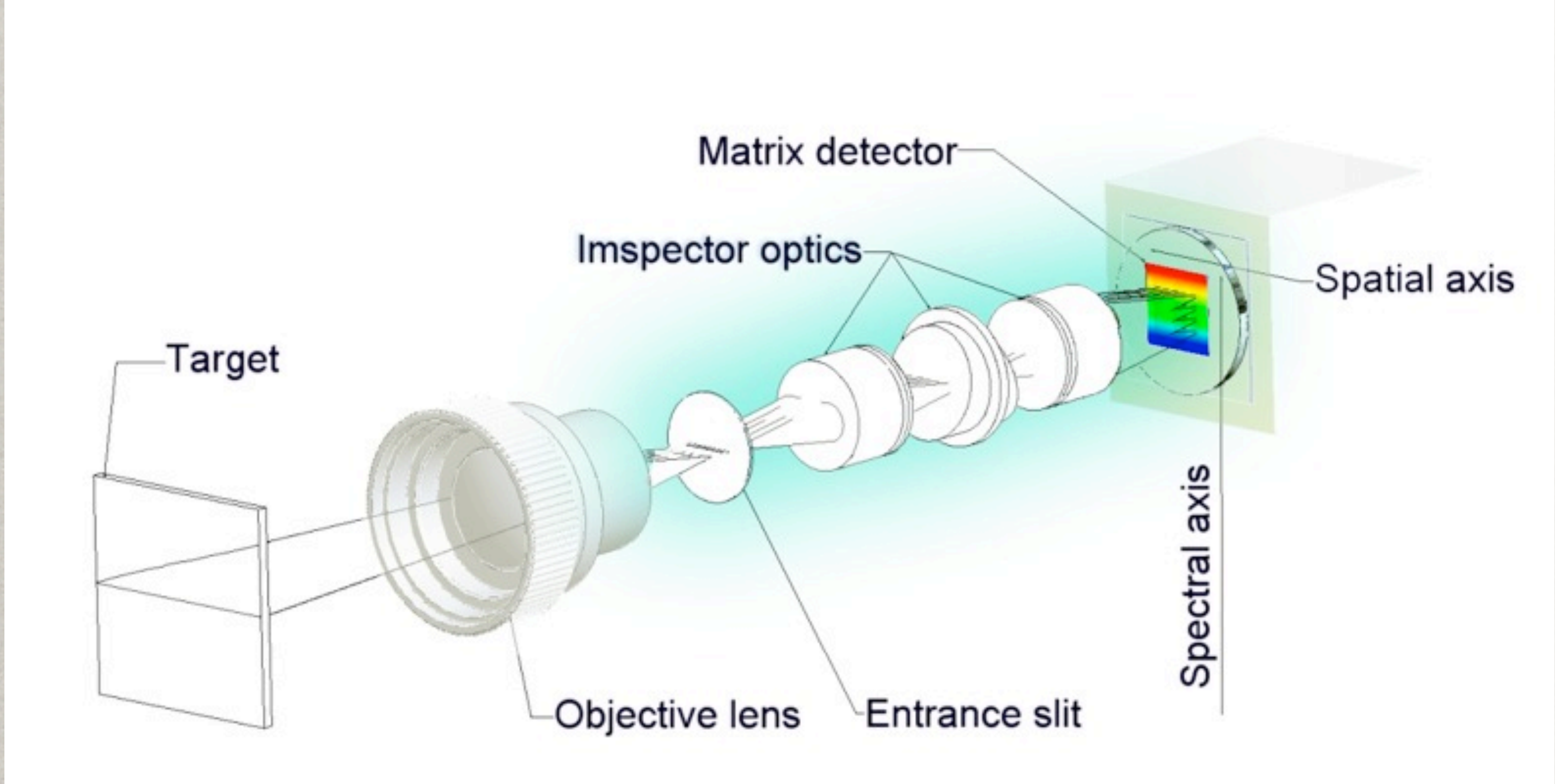
- A push-broom sensor is a 1D image sensor that acquires 2D images by moving.

Push-Broom Sensors

- Example: Imspec sensor used at FOI



Push-Broom Sensors

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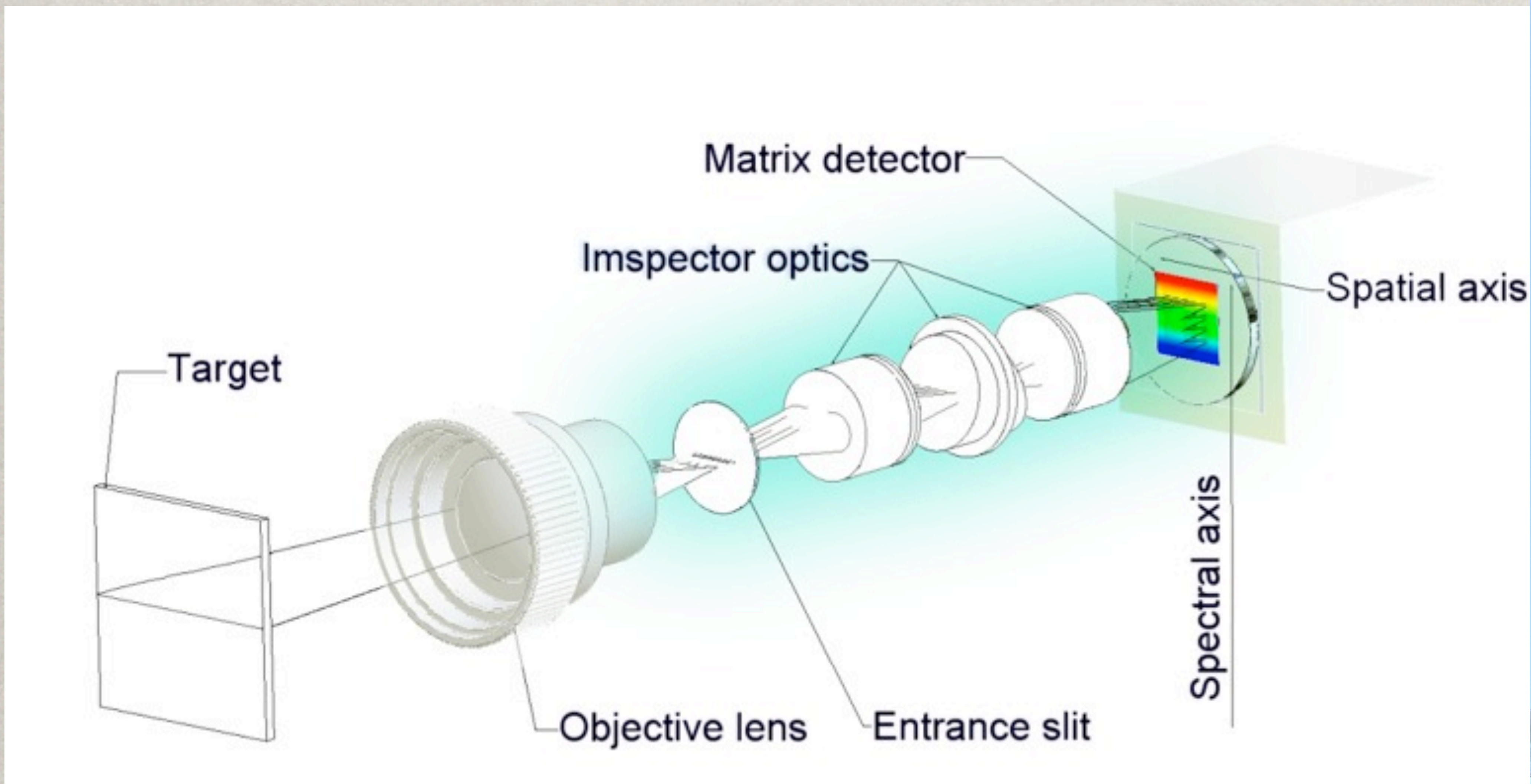
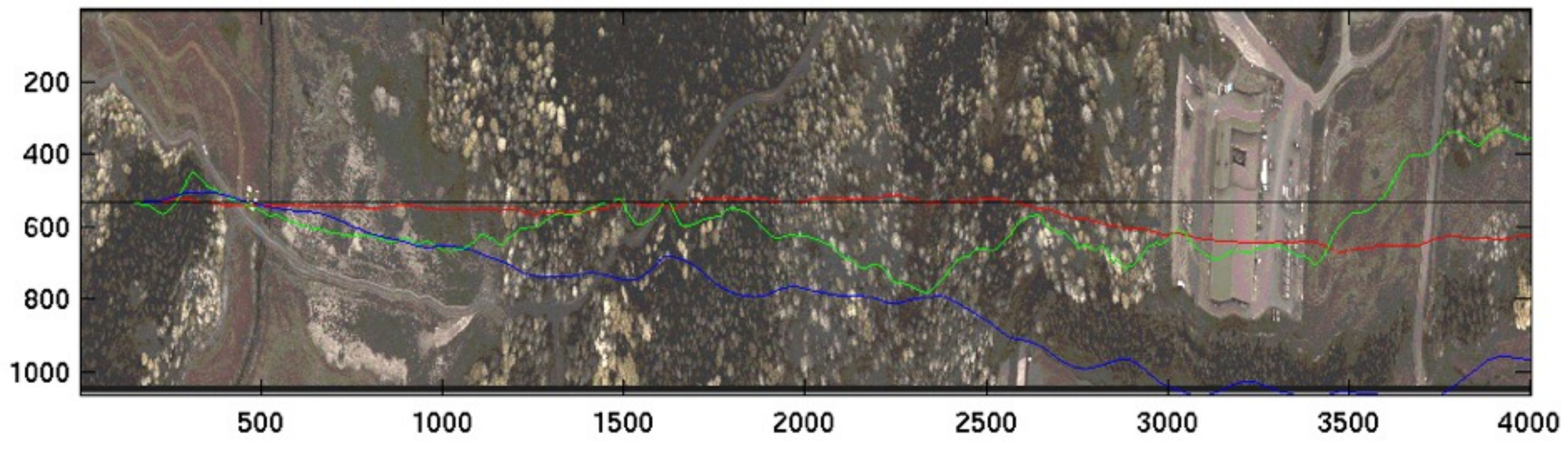


Push-Broom Sensors

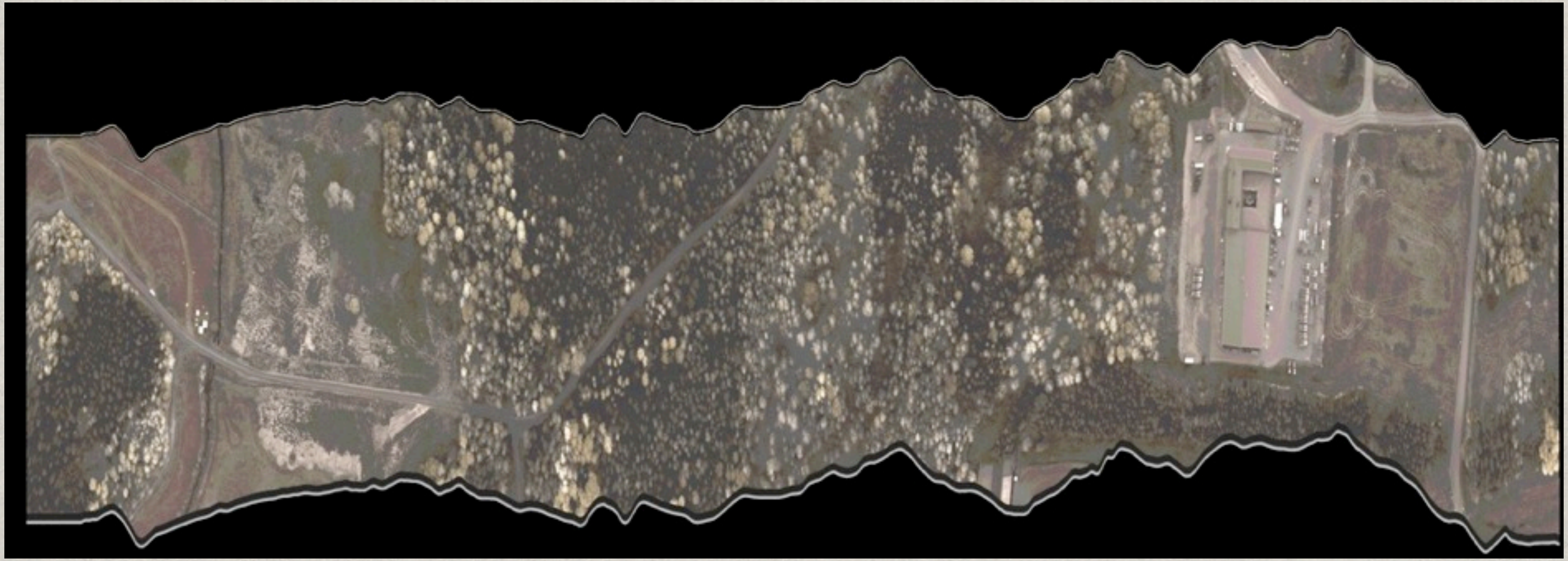
- 3 or ~60 output bands from sensor, registered with a 3dof gyro signal



Data from FOI Sensor systems

Push-Broom Sensors

- Gyro based compensation (rotation only)



ROLLING SHUTTER CAMERA MODEL

- Push-broom geometry can be viewed as a special case of rolling shutter geometry
- With a PB sensor, only one (very long) image is acquired
- With a general RS video camera, many frames in sequence are captured.

ROLLING SHUTTER CAMERA MODEL

- Recall the regular pin-hole camera

$$\mathbf{x} \sim \mathbf{K}[\mathbf{R}|\mathbf{t}]\mathbf{X}$$

ROLLING SHUTTER CAMERA MODEL

- Recall the regular pin-hole camera

$$\mathbf{x} \sim \mathbf{K}[\mathbf{R}|\mathbf{t}]\mathbf{X}$$

- Instead we now have

$$\mathbf{x} \sim \mathbf{K}[\mathbf{R}(\tau)|\mathbf{t}(\tau)]\mathbf{X}$$

- where $\tau - \tau_0 \propto x_2/x_3$
(i.e. time is proportional to image row)

- Static world assumption, and frame of reference duality (as usual)

ROLLING SHUTTER CAMERA MODEL

- RS cameras are characterised by their ***readout time*** $\tau_r = (\tau(\texttt{row2}) - \tau(\texttt{row1})) * \texttt{rows}$

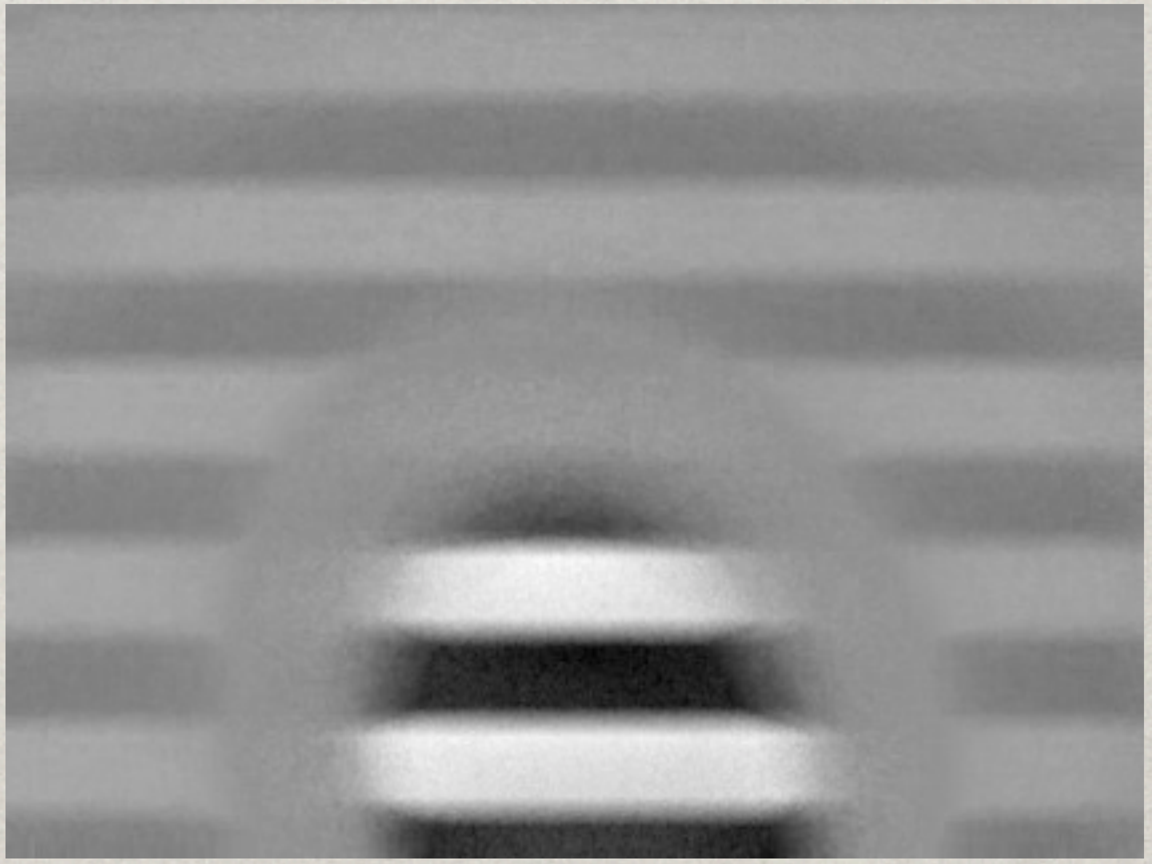
- A global shutter (GS) camera has a zero readout time (i.e. the lower the better).

ROLLING SHUTTER CAMERA MODEL

- RS cameras are characterised by their ***readout time*** $\tau_r = (\tau(\texttt{row2}) - \tau(\texttt{row1})) * \texttt{rows}$
- A global shutter (GS) camera has a zero readout time (i.e. the lower the better).
- For a given framerate *f*, we have $\tau_r \leq 1/f$
- The discrepancy is called the ***inter-frame delay*** $\tau_d = 1/f - \tau_r$

ROLLING SHUTTER CAMERA MODEL

- The readout time can be obtained as $t_r = N_r/(Tf_o)$ by imaging a flashing LED with known frequency f_o and measuring the imaged period T (see today's paper)



ROLLING SHUTTER STEREO

- If we observe a point in two views, we can do triangulation (if motion is known)

$$\begin{aligned} \mathbf{x}_1 &\sim \mathbf{K}_1[\mathbf{R}(\tau_1)|\mathbf{t}(\tau_1)]\mathbf{X} \\ \mathbf{x}_2 &\sim \mathbf{K}_2[\mathbf{R}(\tau_2)|\mathbf{t}(\tau_2)]\mathbf{X} \end{aligned} \quad \Rightarrow \quad \begin{aligned} \mathbf{0} &\sim \mathbf{x}_1 \times \mathbf{P}_1\mathbf{X} \\ \mathbf{0} &\sim \mathbf{x}_2 \times \mathbf{P}_2\mathbf{X} \end{aligned}$$

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- 3D SaM from a rolling-shutter image pair is possible, using bundle adjustment: [Ait-Aider&Berry ICCV09]

$$J(\{\mathbf{X}_n\}_{n=1}^N, \mathbf{R}, \mathbf{t}) = \sum_{n=1}^{N} ||\mathbf{x}_{1,n} - \hat{\mathbf{x}}_{1,n}||^2 + ||\mathbf{x}_{2,n} - \hat{\mathbf{x}}_{2,n}||^2$$

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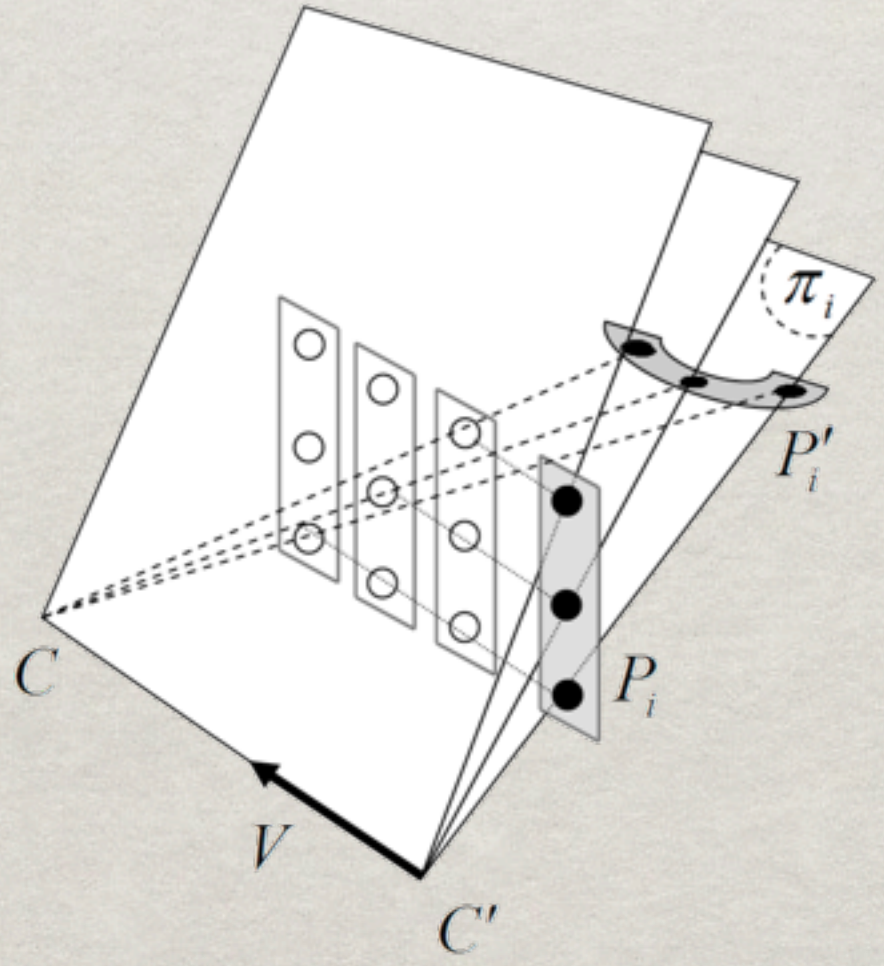
- Each correspondence gives us 4 equations (**Why?**)

- Assuming that **R**,**t** *change linearly* with time, we have 5+3N unknowns for N correspondences. Thus $N \geq 5$

ROLLING SHUTTER STEREO

- Degenerate motion [**Ait-Aider&Berry ICCV09**]:



- Motion causes points to stay on the same line.

ROLLING SHUTTER STEREO

- Under degeneracy, motion and structure can be interchanged freely.
- On top of this we have the scale ambiguity from regular SaM.
- Ait-Ader&Berry settle for SaM with one RS camera and one GS camera.
- There may be other degenerate cases as well

ROLLING SHUTTER RECTIFICATION

- Rotation homography approximation:

$$\mathbf{x}_1 = \mathbf{K}_1\mathbf{R}(\mathbf{x}_1)\mathbf{X} \qquad \mathbf{x}_1 = \mathbf{H}\mathbf{x}_2$$
$$\Rightarrow$$
$$\mathbf{x}_2 = \mathbf{K}_2\mathbf{R}(\mathbf{x}_2)\mathbf{X} \qquad \mathbf{H} = \mathbf{K}_1\mathbf{R}(\mathbf{x}_1)\mathbf{R}^T(\mathbf{x}_2)\mathbf{K}_2^{-1}$$

- Valid if the distance to imaged objects is large compared to the baseline

ROLLING SHUTTER RECTIFICATION

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- Valid if the distance to imaged objects is large compared to the baseline

- Allows estimation of rotations across a sequence of frames given correspondences, using BA

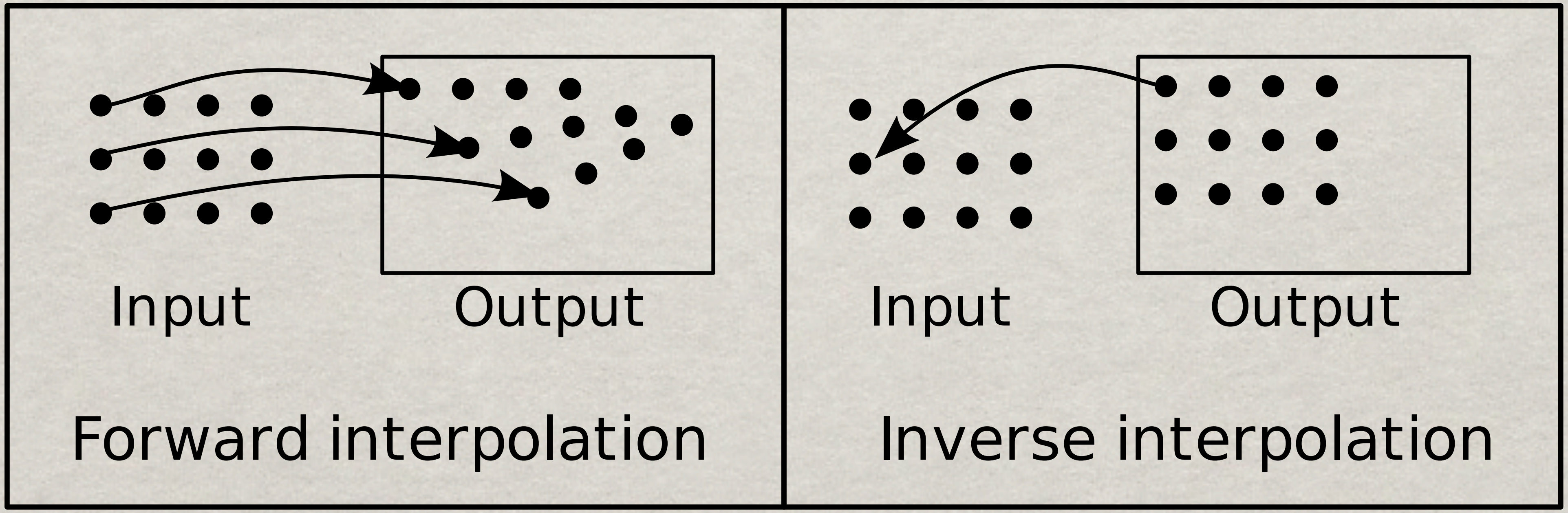
$$J = \sum_{k=1}^{K} d(\mathbf{x}_{1,k}, \mathbf{H}\mathbf{x}_{2,k})^2 + d(\mathbf{x}_{2,k}, \mathbf{H}^{-1}\mathbf{x}_{1,k})^2$$

ROLLING SHUTTER RECTIFICATION

- Once we know the rotations **R** and the intrinsics **K**, rectifiction from a single frame is possible

$$\mathbf{x}' = \mathbf{K}\mathbf{R}_o^T\mathbf{R}(\mathbf{x})\mathbf{K}^{-1}\mathbf{x}$$

- This is *forward interpolation*, which is slightly more accurate than regular inverse interpolation



ROLLING SHUTTER RECTIFICATION

- Frame from HTC Desire camera (input)

ROLLING SHUTTER RECTIFICATION

- Frame from HTC Desire camera (rectified)

ROLLING SHUTTER RECTIFICATION

- Frame from iPhone 3GS camera (input)

ROLLING SHUTTER RECTIFICATION

- Frame from iPhone 3GS camera (rectified)

ROLLING SHUTTER RECTIFICATION

- Frame from SE W890i camera (input)

ROLLING SHUTTER RECTIFICATION

- Frame from SE W890i camera (rectified)

ROLLING SHUTTER RECTIFICATION

- If RS rectification is combined with image stabilisation, we could implement Steadicam Smoothee™ in software.

Discussion

- Discussion of the paper:
  Forssén and Ringaby, *Rectifying rolling shutter video from hand-held devices*, CVPR 2010

Projects

- Fairly small project, 2hp
- Implement an algorithm (preferrably related to your own research)
- Write a 2 page report.
- Discuss with Klas or Per-Erik before you start!
- No explicit deadline. But don't wait too long!

Project examples

- DEGENSAC
- Rotation Smoothing
- Rotation interpolation
- 3D reconstruction
- PROSAC
- Absolute orientation (Horn)
- + your own suggestion

Exam

- Short < 2h
- Explanation of concepts
- Based on the slides, and the discussed papers
- Nothing from the course book that was not covered in the lectures.
- > 2/3 correct answers = pass.

Exam dates

- Exam will take place in August
- Suggestions of dates will be sent out shortly