Robot Vision:
Stereo Matching
Depth cameras

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Outline

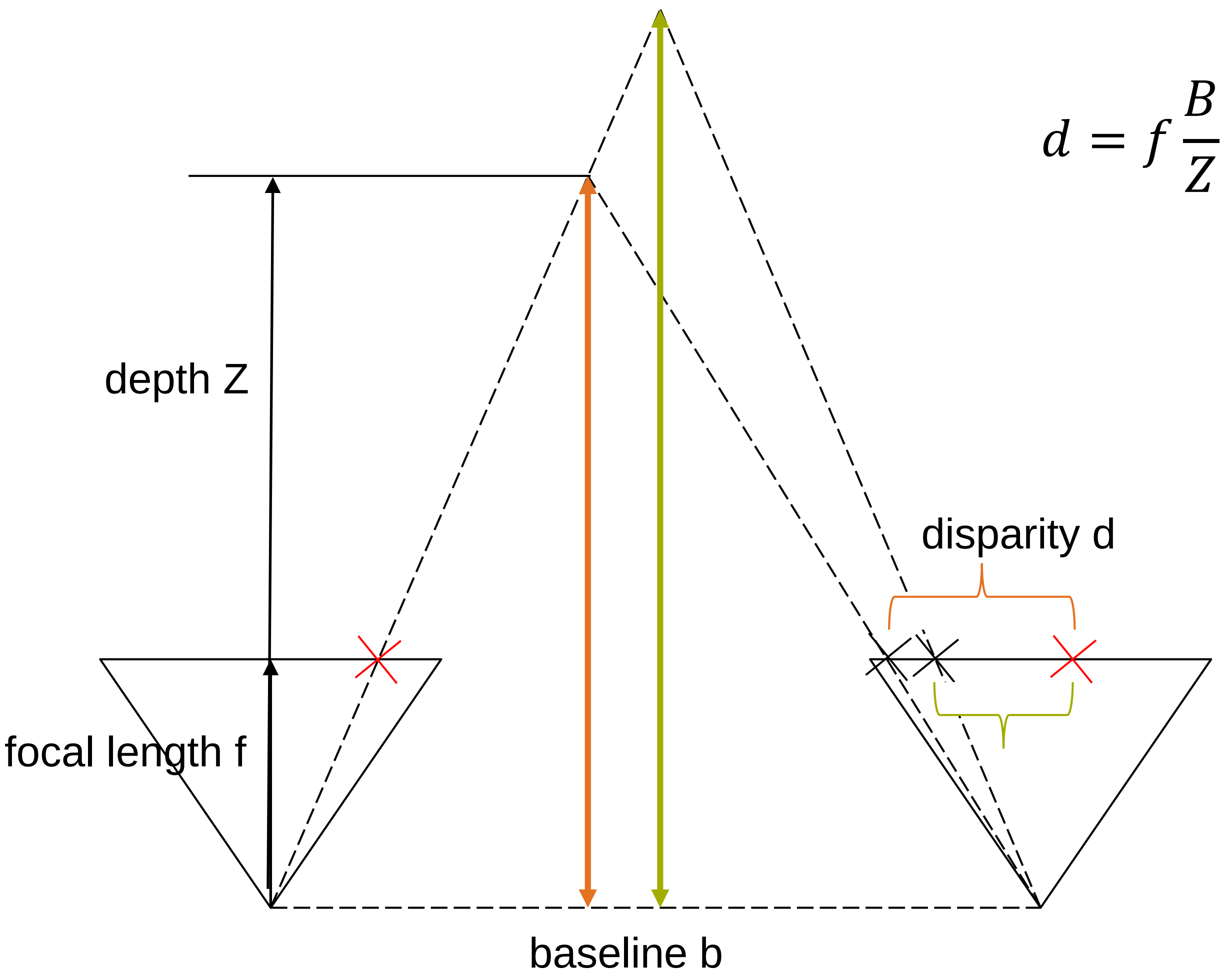
- Geometric relations for stereo matching
- Dense matching process
- Census Transform
- Semiglobal matching
- Depth cameras
  - Coded light
  - Kinect style depth cameras
  - TOF cameras

Dense matching

- SfM only gives sparse 3D data
- Only feature points (e.g. SURF) are triangulated – for most pixel no 3D data is computed
- Dense image matching computes a 3D point for every pixel in the image (1MP image leads to 1 million 3D points)
- Dense matching algorithms need camera poses as prerequisite

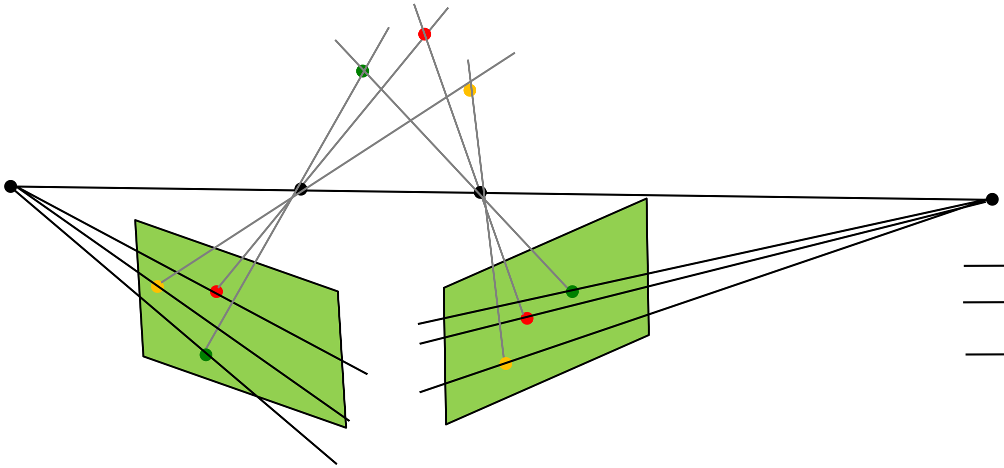
Geometric relation

- Stereo normal case
- Depth Z [m] can be computed from disparity d [pixel]

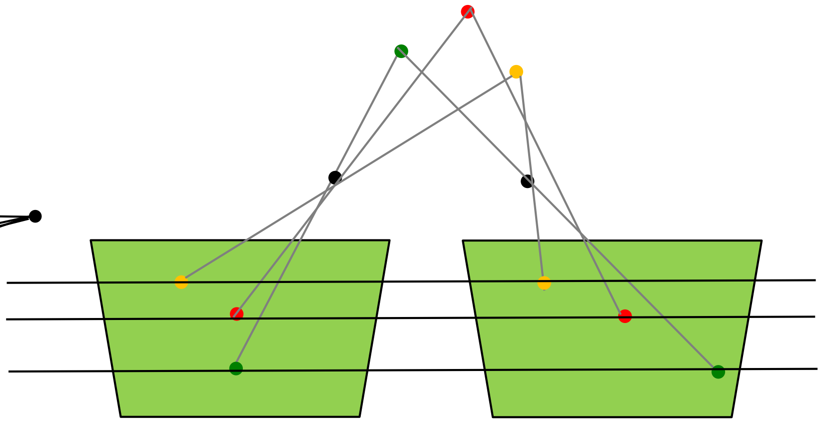


Rectification

- Image transformation to simplify the correspondence search
  - Makes all epipolar lines parallel
  - Image x-axis parallel to epipolar line
  - Corresponds to parallel camera configuration



Before rectification



„Stereo normal case“

Dense matching process

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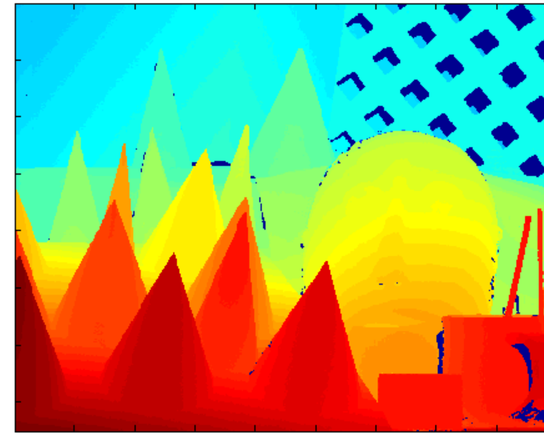


Left View

I_l

Right View *

I_r

Disparity image

D

- Estimate disparity (height) for all pixels in image left.
  - Evaluate correspondence measure for every possible pixel location on the line (e.g. NCC, SAD)

- Disparity *d*: Offset between pixel *p* in the left image and its corresponding pixel *q* in the right image.

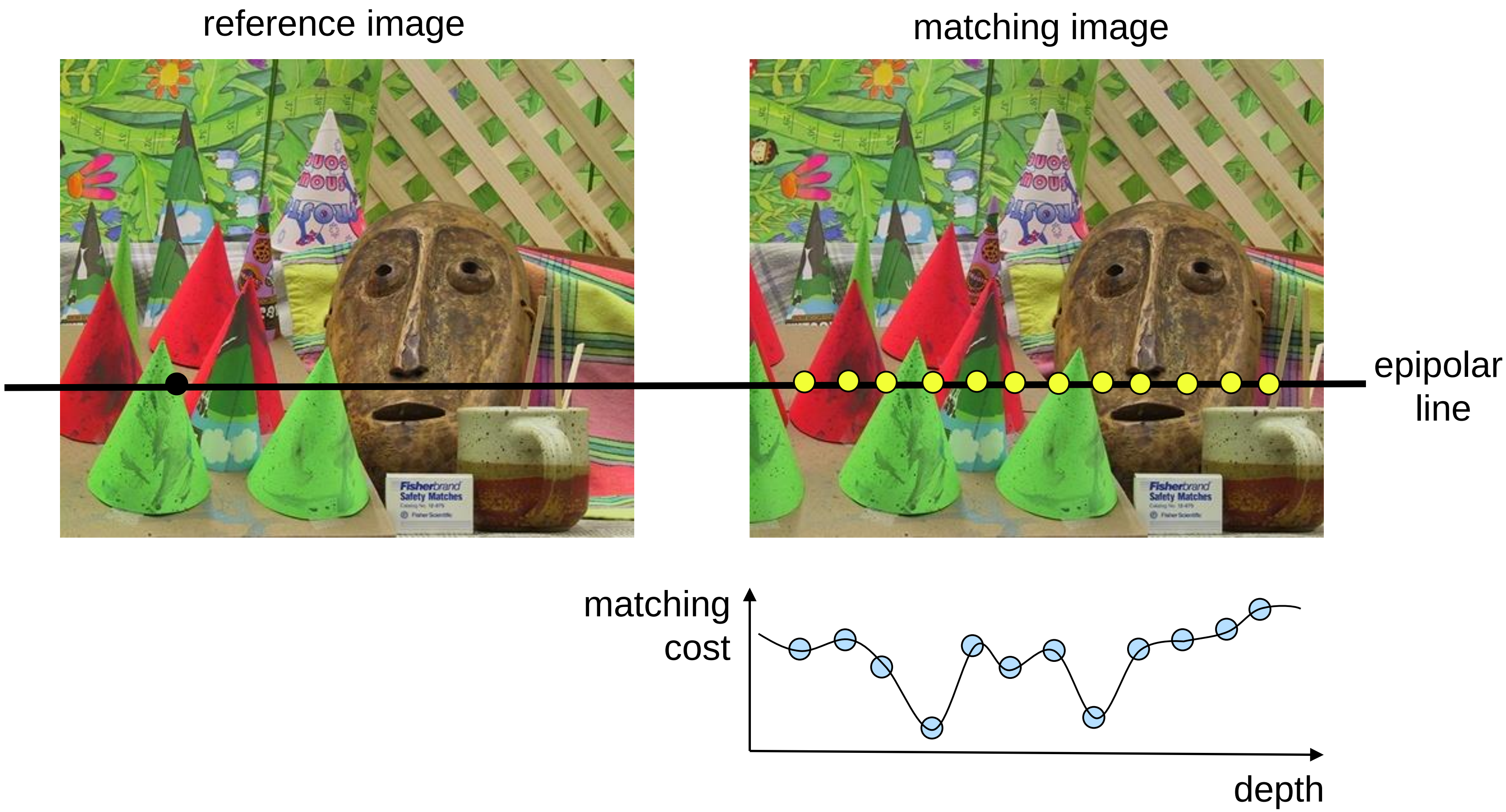
Census Transform

- A popular block matching cost
- Good robustness to image changes (e.g. brightness)
- Matching cost is computed by comparing bit strings using the Hamming distance (**efficient**)
- Bit strings encode if a pixel within a window is greater or less than the central pixel

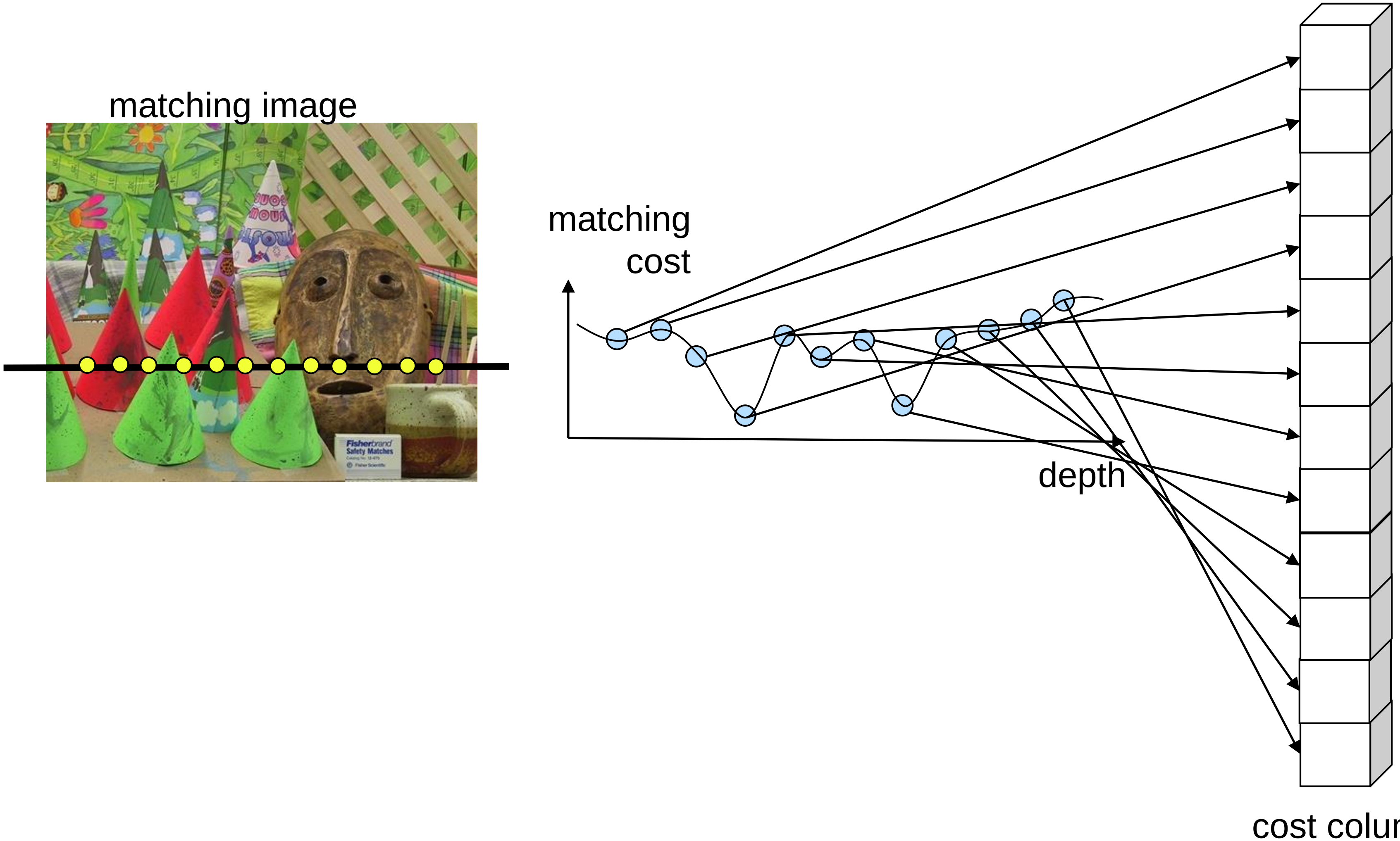
89	63	72
67	**55**	64
58	51	49

00000011

Dense matching process

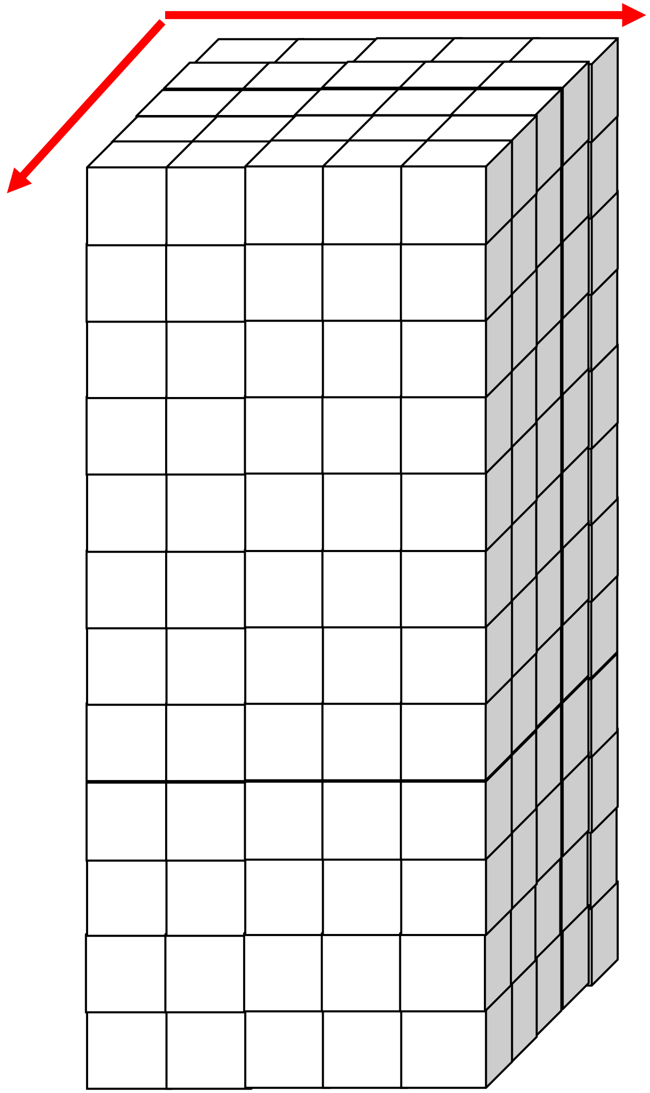


Dense matching process

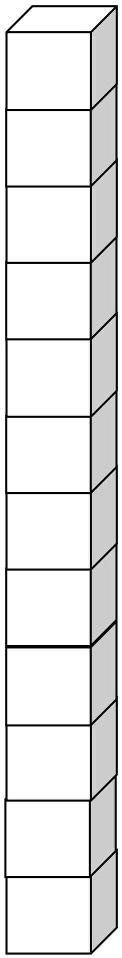


Dense matching process

matching image

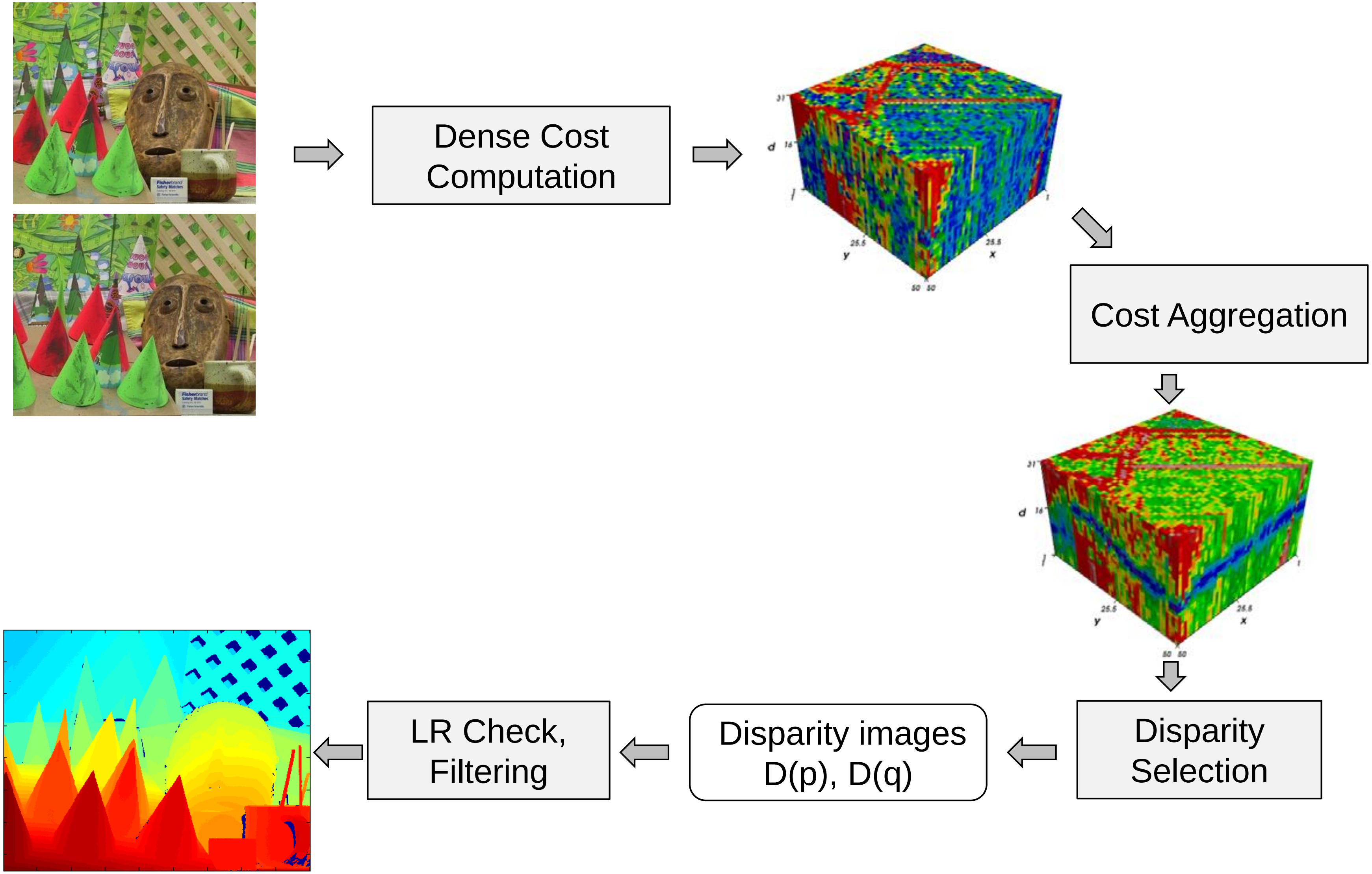


cost volume



cost column

Semiglobal matching

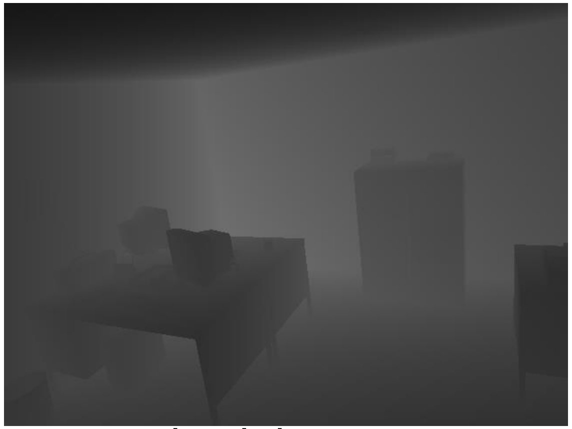


[Heiko Hirschmüller (2008), Stereo Processing by Semi-Global Matching and Mutual Information, in IEEE PAMI, Volume 30(2), February 2008, pp. 328-341.]

Depth cameras - Overview

- Depth cameras or RGBD cameras directly output an RGB image and a depth image
- Principles:
  - Stereo cameras with onboard processing
    - DJI Guidance, Roboception, Perceptin
  - Structured Light
    - Coded light – Projector-camera system
    - Random patterns – Stereo system with active lighting
    - Kinect-style methods – Projector-camera system with fixed random projection
  - TOF cameras – time of flight principle
- Huge importance for mobile robotics

RGB image

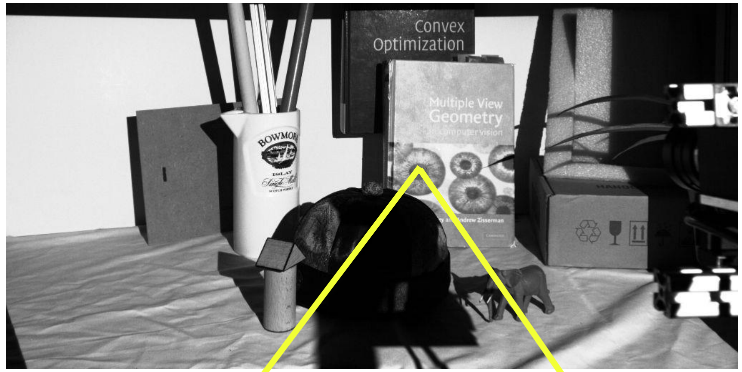


depth image

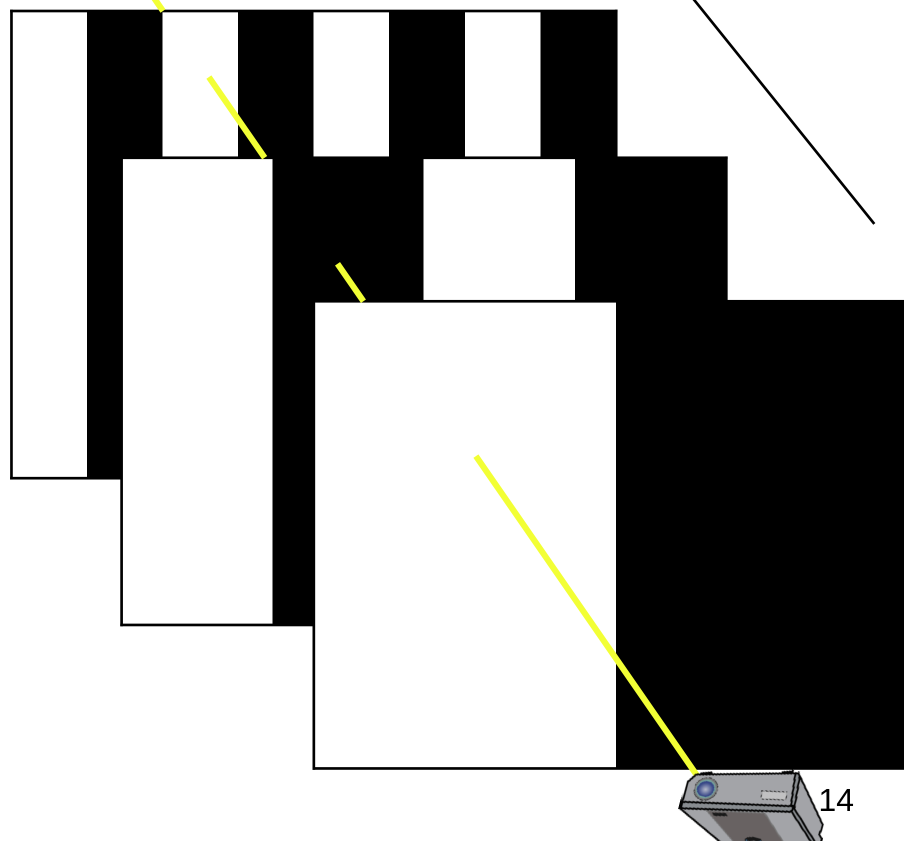
Coded Light

- A projector-camera system where a projector outputs stripe patterns (e.g. binary pattern)
- The pattern solves the correspondence problem in stereo matching
- Projector and camera need to be calibrated
- The stripes are coded and encode directly a unique position of a corresponding pixel in the projector.

Coded light



pattern changed over time

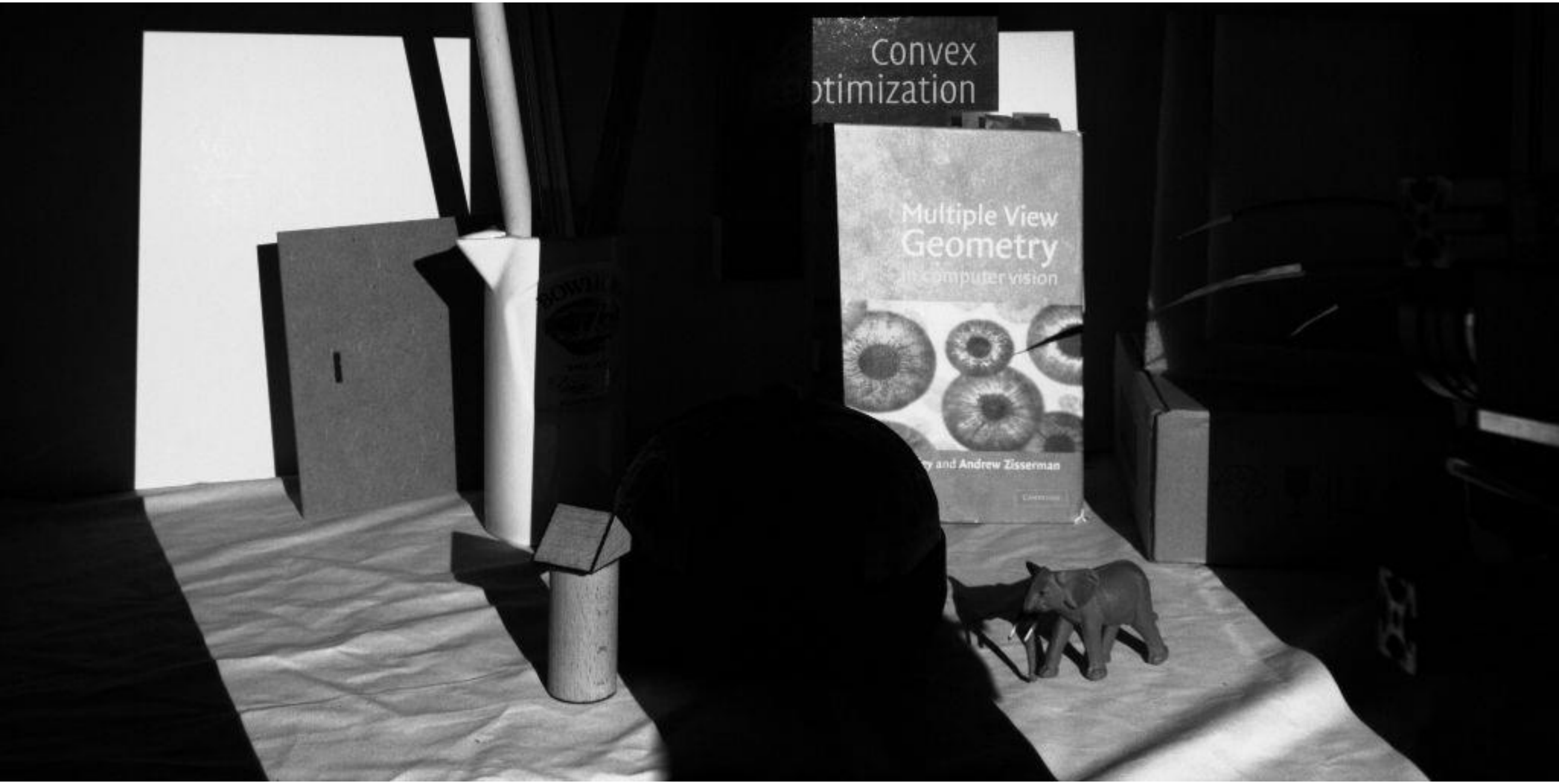


sequence of dark/light pattern defines a code word for a position and thus a unique position in the projector

Coded light


Convex
Optimization
Multiple View
Geometry
and Andrew Zisserman

Coded light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Multiple View
Geometry
in computer vision
and Andrew Zisserman

Coded light

Coded light

Coded light

Coded light

Random patterns

- Stereo camera system cannot measure depth in textureless/homogeneous areas
- Solution: Project random pattern as texture to ease stereo matching
- Typically this is done in infrared spectrum such that it is not visible for users
- Such a system works in the dark as well

- Example: Intel Realsense
- Standard stereo system (2 calibrated cameras)
- 1 IR projector for stripe-type pattern
- Works outdoors as well, then the pattern is not visible due to strong sunlight (then it just works like standard stereo matching)

Kinect style method

- Kinect is a projector-camera system with onboard depth processing
- Projects a **known** static IR-dot pattern
- Depth is computed from a combination of depth from stereo and depth from focus
- The system also contains an RGB camera
- Sensors is often called a RGBD sensor

The elements of a depth sensor

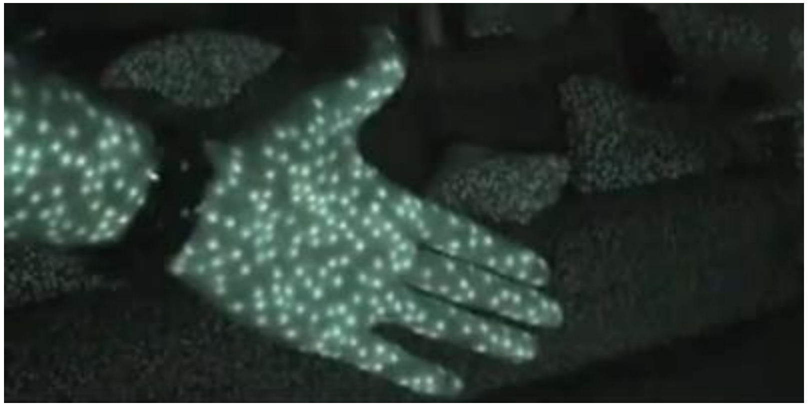

image of IR pattern

Time-of-flight cameras

- Does not work on the stereo (triangulation) principle but with time-of-flight principle
- Principle:
  - Sends out NIR light (no spatial coding)
  - Sensor array measures response
  - Distance is measured by measuring time between emitting and receiving the light (pulsed or continuous wave method)

- Typically do not provide synchronized color image but a reflectance image
- Example: PMD Flex (224 x 171px resolution)

Time-of-flight cameras – Continuous wave method

- Camera emits NIR light where amplitude is a sine wave.
- Phase shift is measured between emitted and received light
- Phase shift can be converted into distance

$$d = \frac{c}{4\pi f}\Delta\phi$$