Camera Drones
Lecture – 3D data generation

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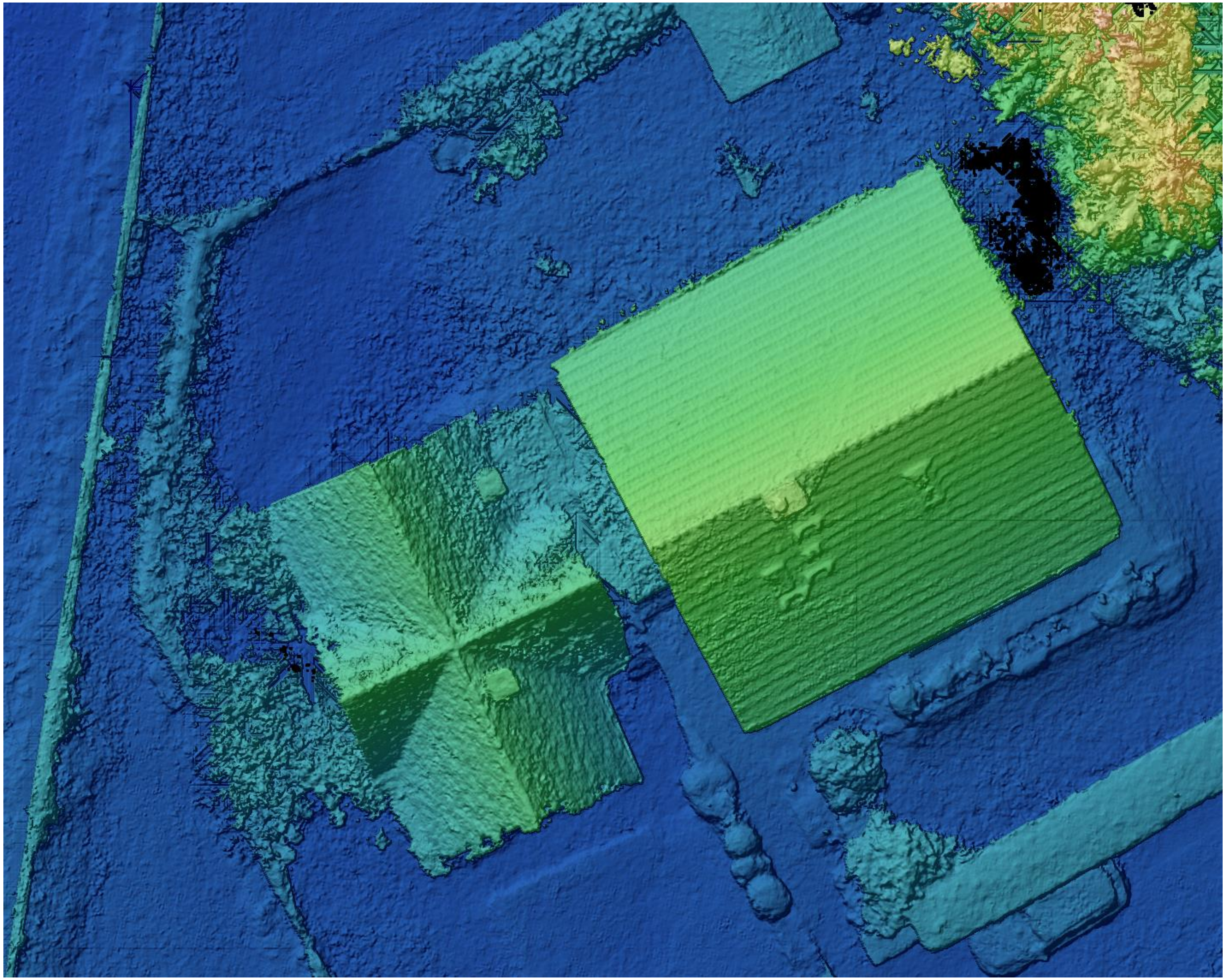
WS 2020

Outline

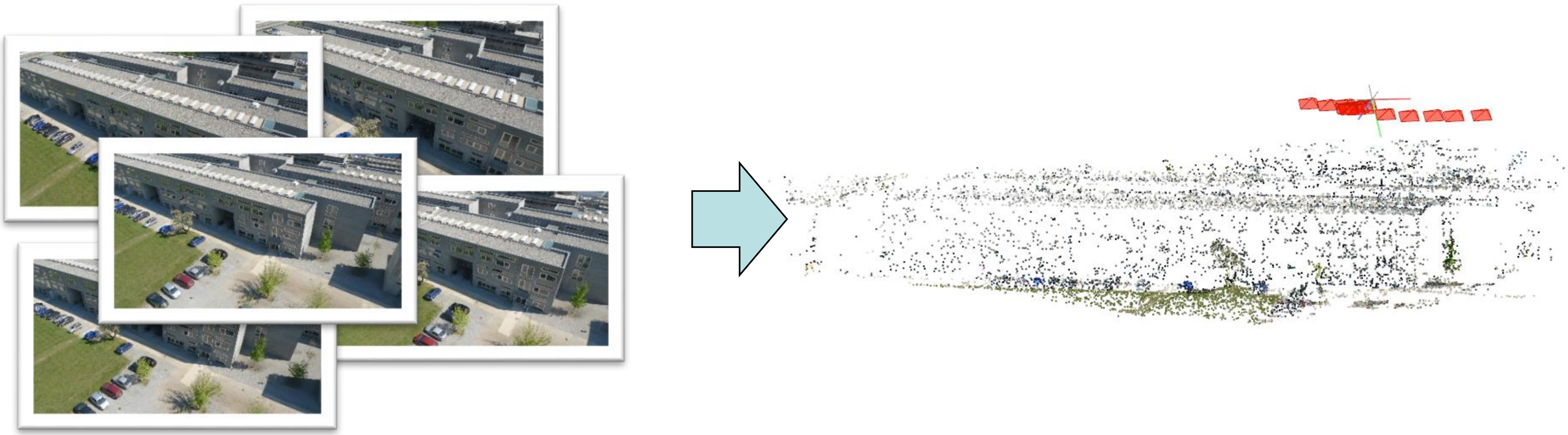
- Structure-from-Motion
  - SfM introduction
  - SfM concept
  - Feature matching
  - Camera pose estimation
  - Bundle adjustment
- Dense matching
- Data products (Orthophoto, DSM)

DSM



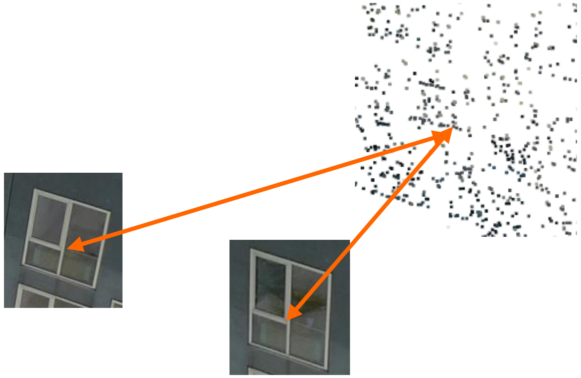
Orthophoto

Structure-from-Motion (SfM) concept

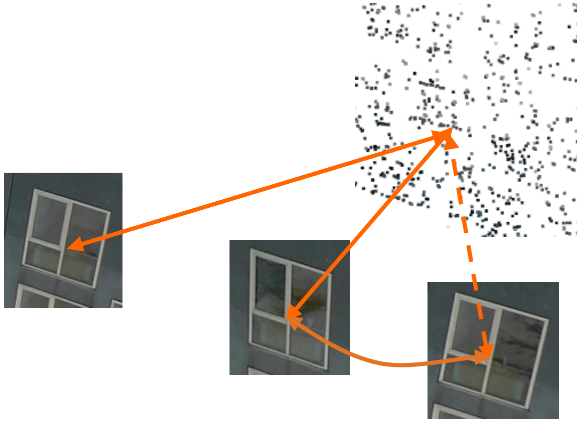


Structure-from-Motion (SfM) concept

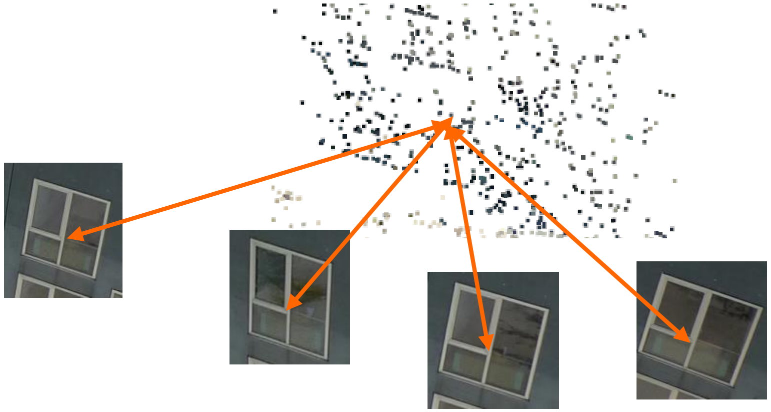
Initialize Motion
(P_1,P_2 compatible with F)



Initialize Structure
(minimize reprojection error)

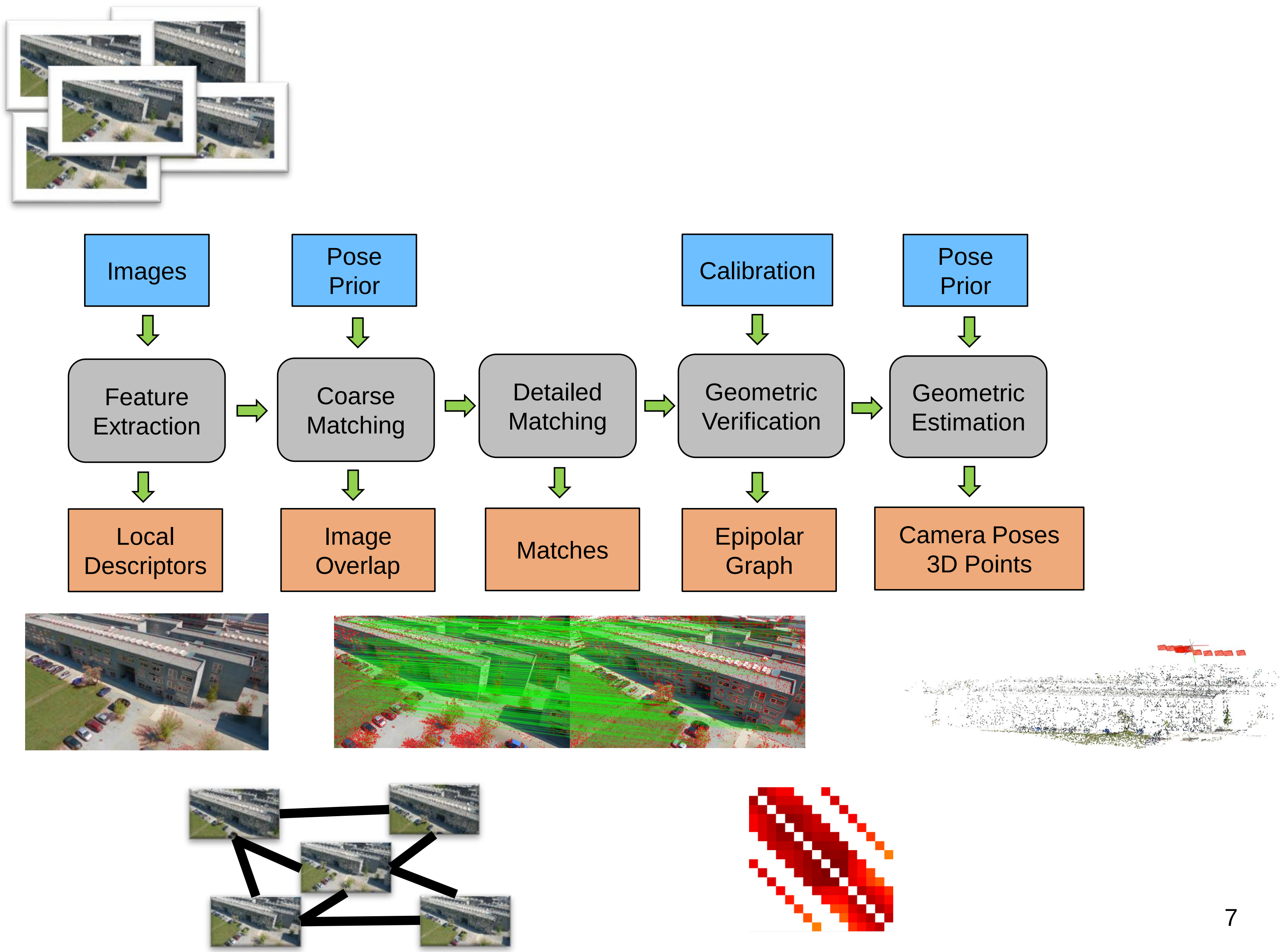


Extend motion
(compute pose through matches
seen in 2 or more previous views)

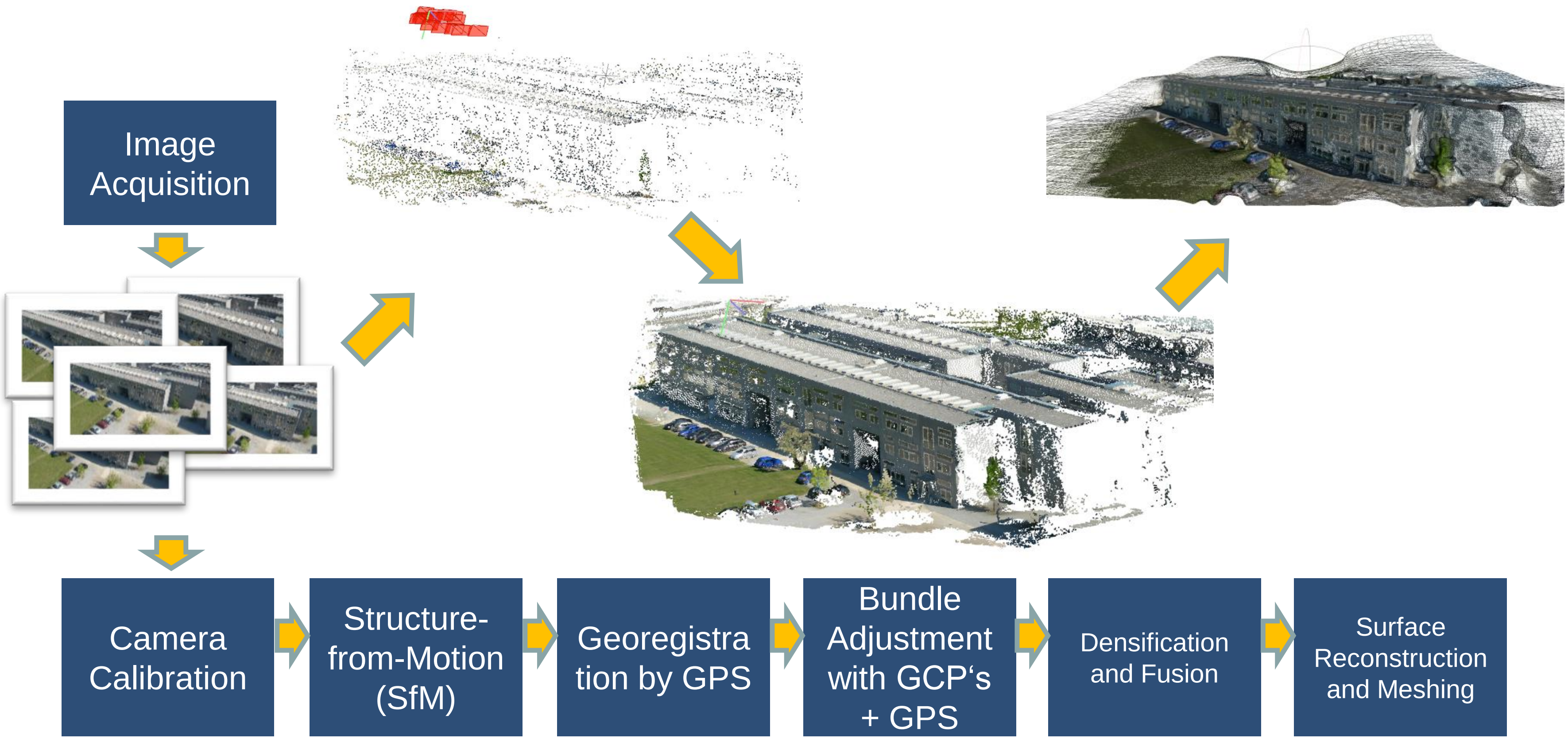


Extend structure
(Initialize new structure,
refine existing structure)

Structure-from-Motion (SfM) core pipeline

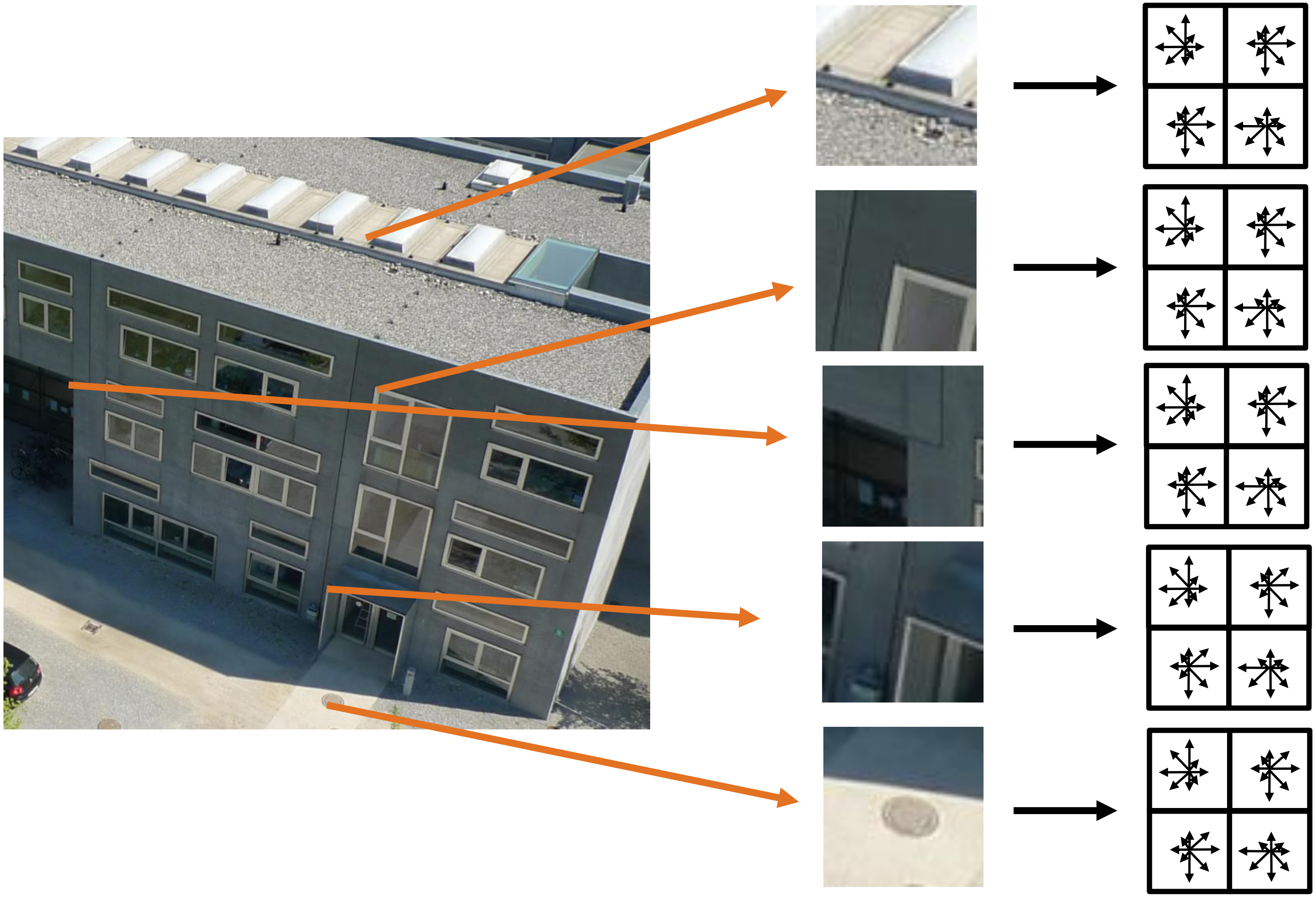


3D data generation overall pipeline



Feature extraction

- SIFT features (best working features for matching right now)
- Each descriptor is a vector of length 128 (gradient histogram)



Coarse matching

- Cluster similar images by similarity using visual words
- Will be used for speeding up exhaustive (nxn) matching

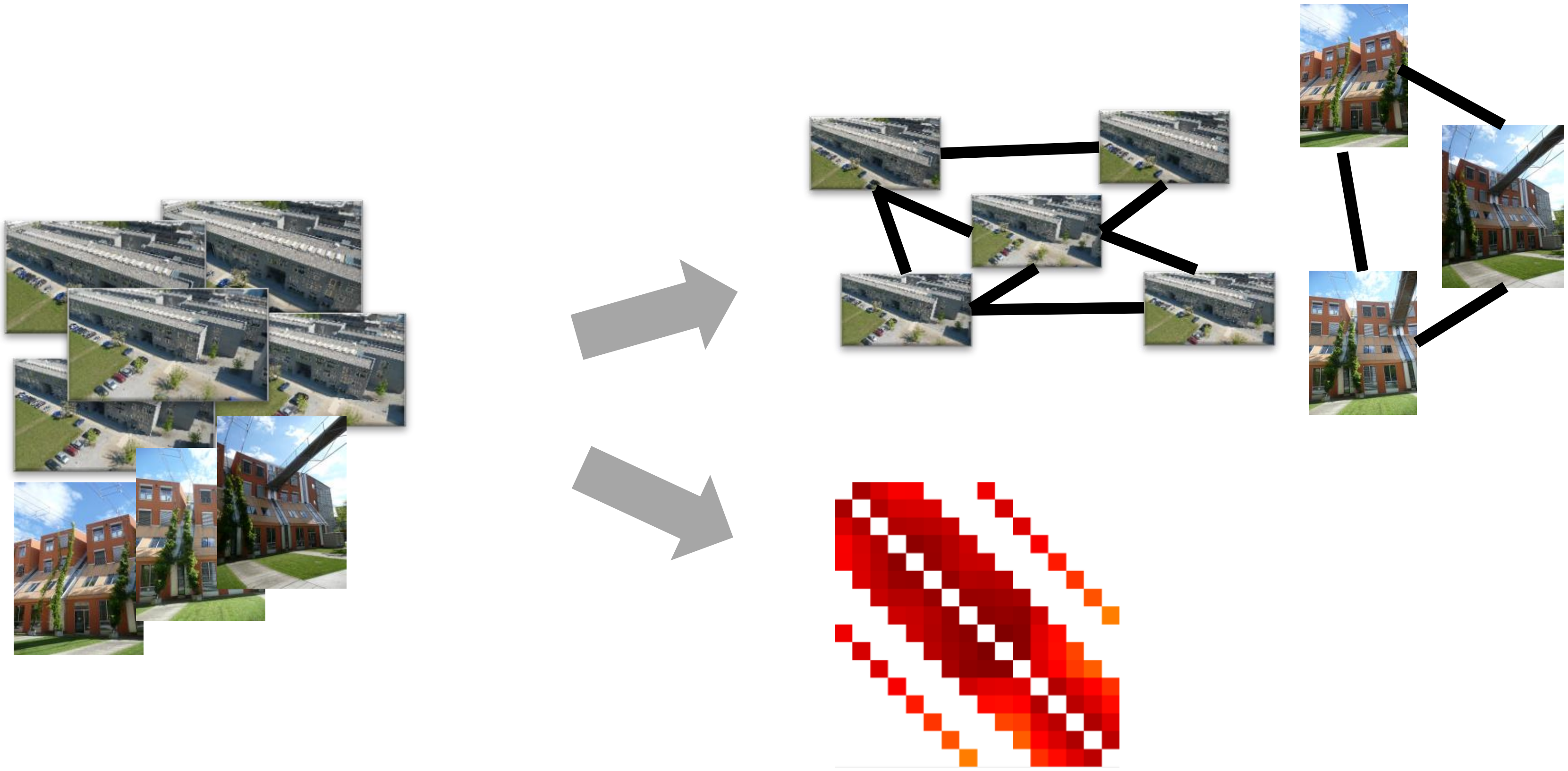
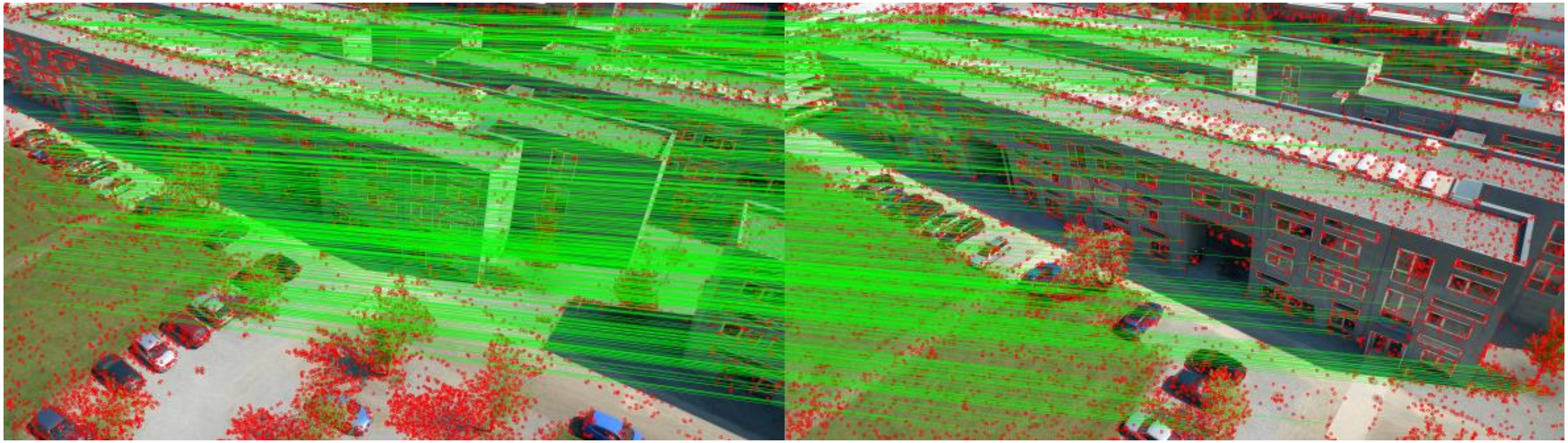
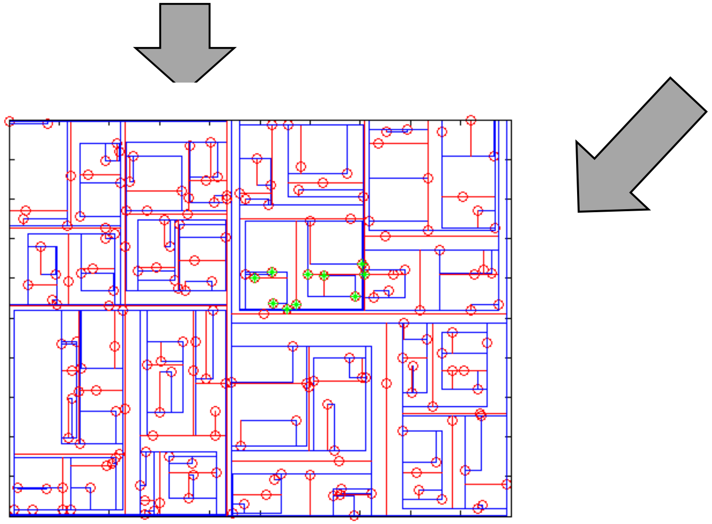


Image similarity

Detailed matching

- Typically using NN-search with a Kd-tree





Epipolar graph

- Defines the sequential order for geometry processing
- Is a plot of the number of geometrically verified feature matches

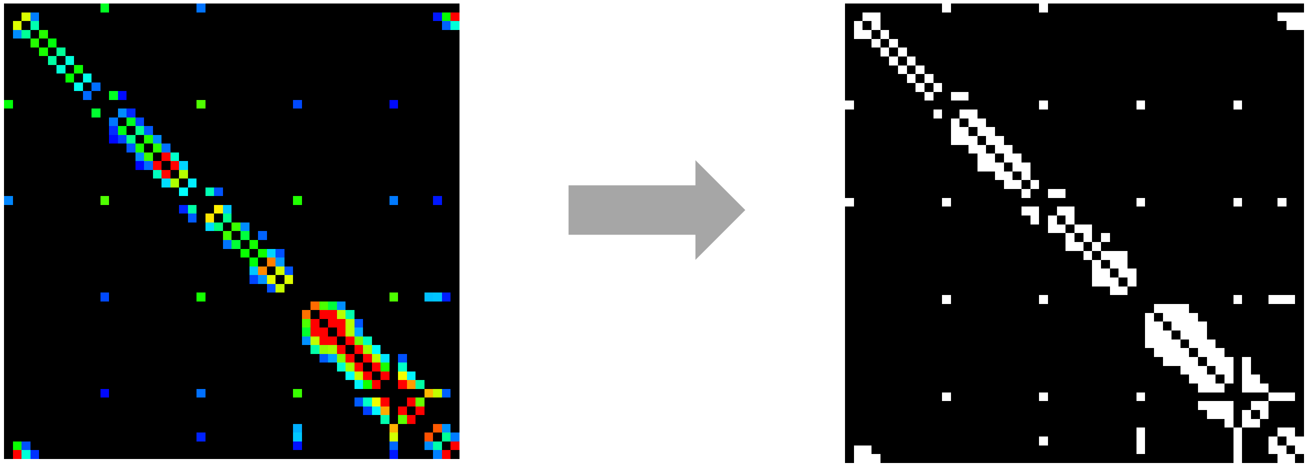


Image similarity

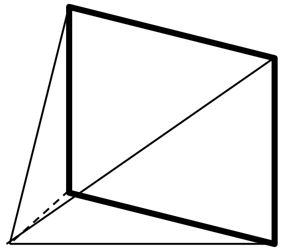
Epipolar graph

Geometry estimation

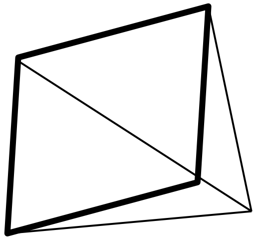
- Following the sequence ordering from the epipolar graph geometry is estimated for all images
- Geometry estimation is an alternating scheme:
  - Estimate camera pose of new images (position, rotation)
  - Triangulate new 3D data points seen in new image
  - Refinement by non-linear optimization (Bundle adjustment)

Geometry estimation steps

- Compute camera poses of the first two images from feature matches



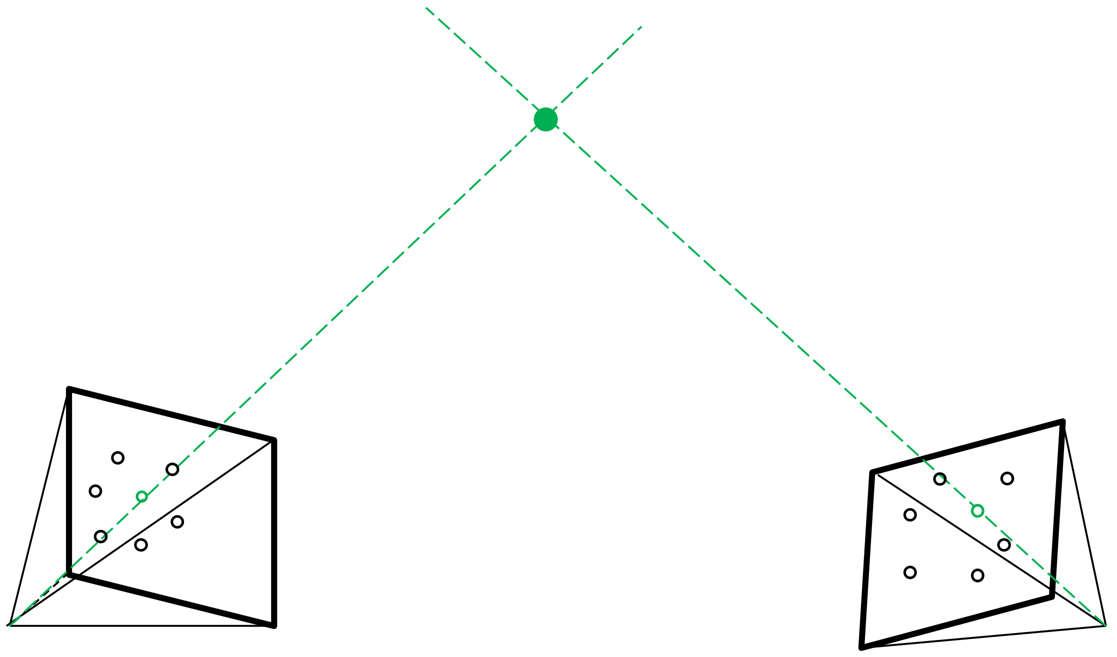
$$P = K[I|0]$$



$$P' = K'[R'|t']$$

Geometry estimation steps

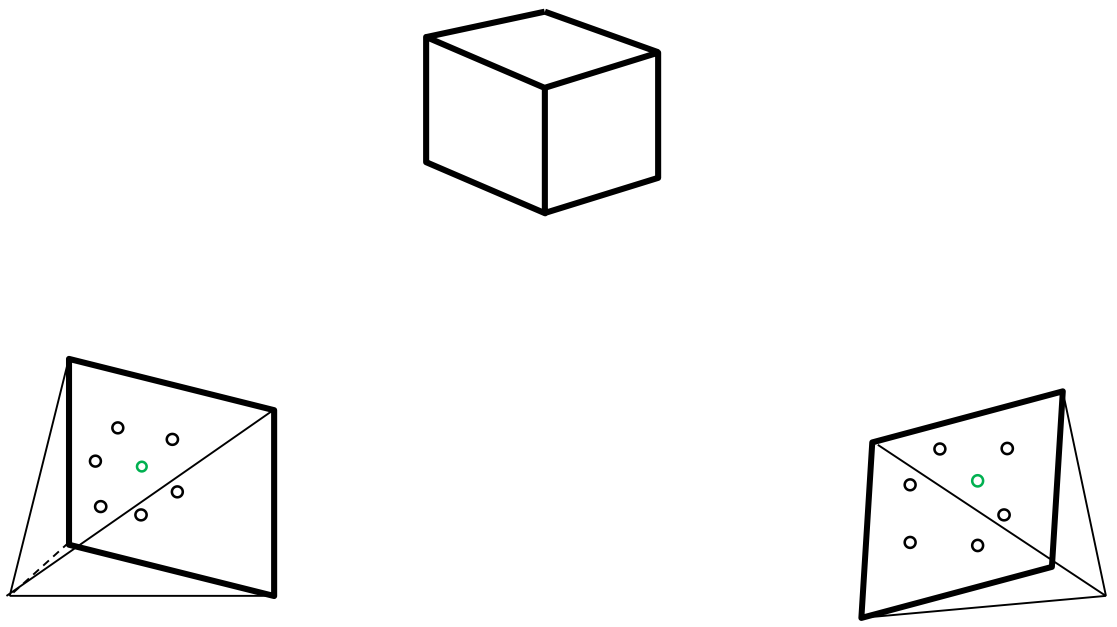
- Computation of first 3D points by triangulation



$P = K[I|0]$ $\qquad$ $P' = K'[R'|t']$

Geometry estimation steps

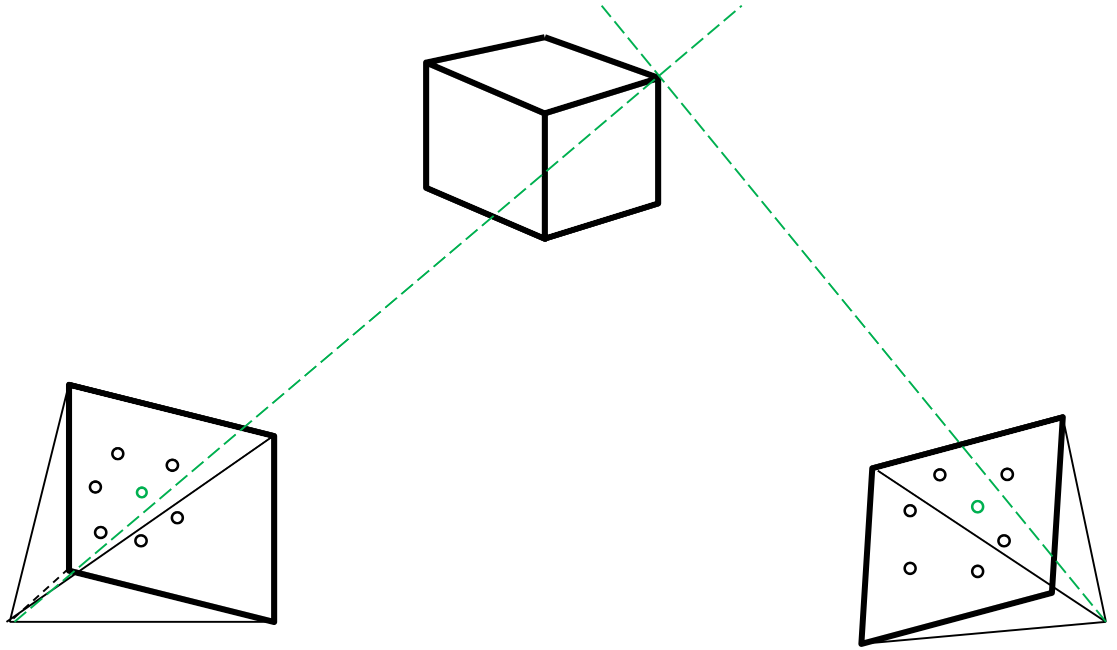
- Triangulate all feature matches of the first images



$P = K[I|0]$ $\qquad$ $P' = K'[R'|t']$

Geometry estimation steps

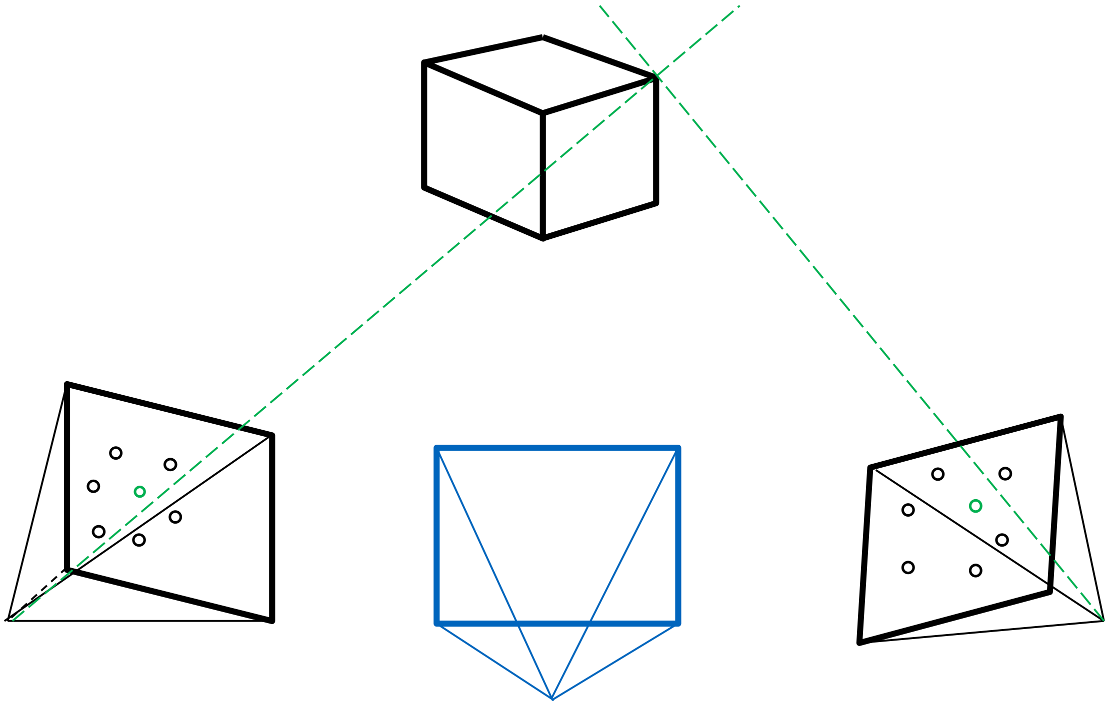
- First refinement of camera poses and 3D points by non-linear estimation of the re-projection error through bundle adjustment



$P = K[I|0]$ $\qquad$ $P' = K'[R'|t']$

Geometry estimation steps

- Start processing the next image



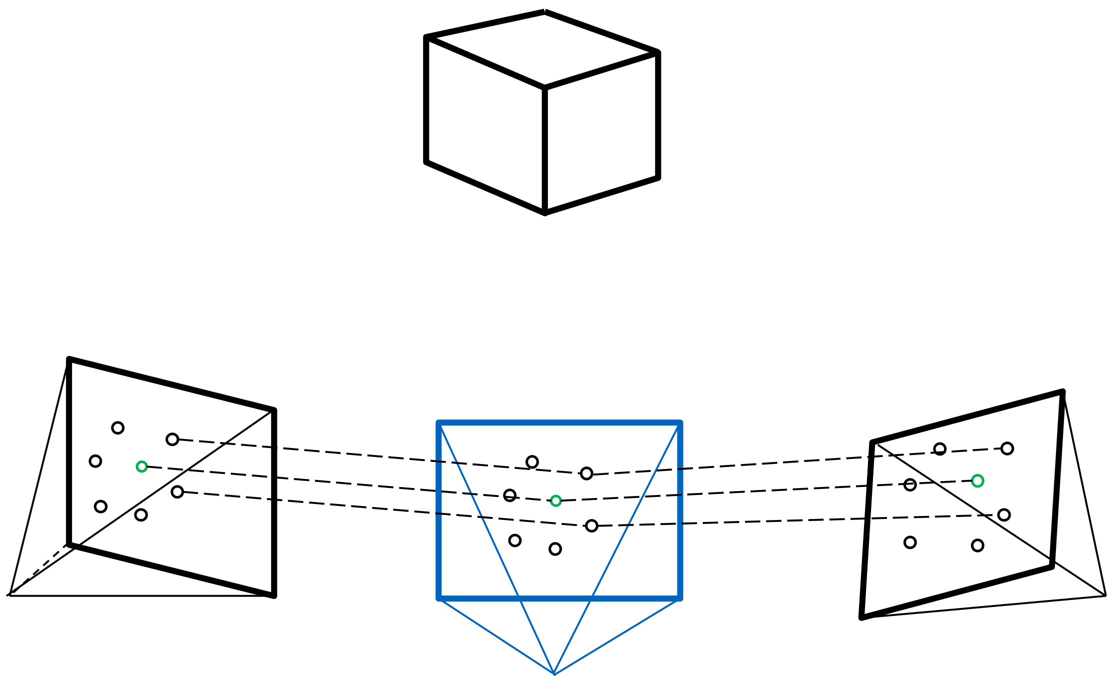
$P = K[I|0]$

$P' = K'[R'|t']$

$P'' = ?$

Geometry estimation steps

- First, create feature matches to all the previous, neighboring images



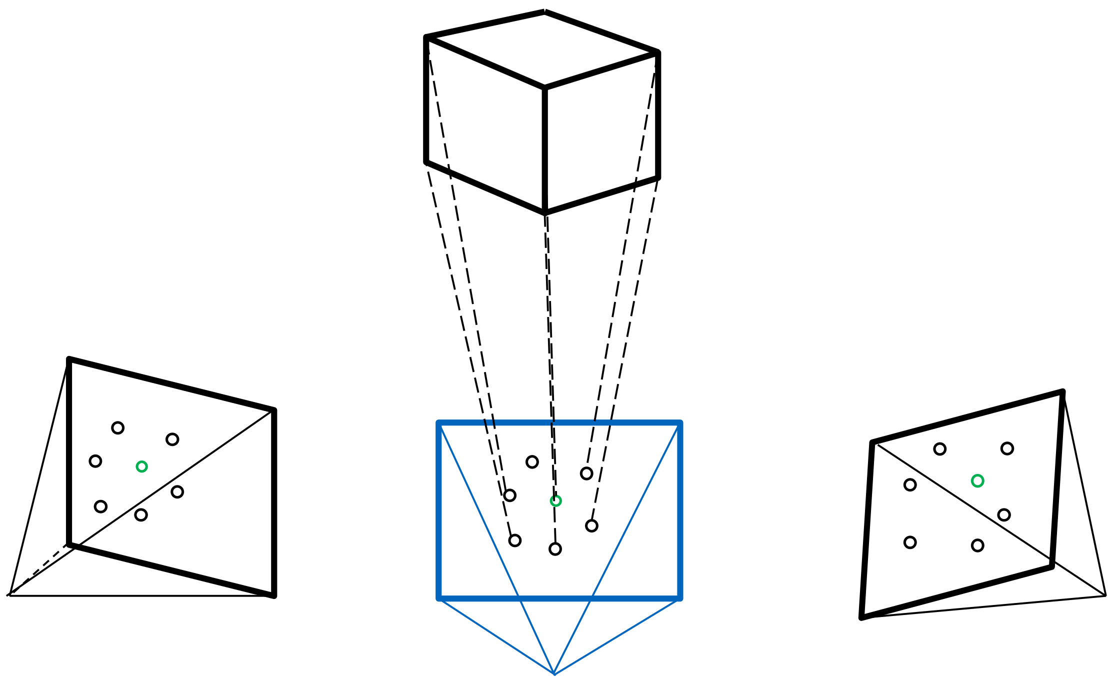
$P = K[I|0]$

$P'' = ?$

$P' = K'[R'|t']$

Geometry estimation steps

- Feature matches give correspondences to already computed 3D points
- From corresponding 2D and 3D points the pose of the new camera can be computed using the PnP-Algorithm



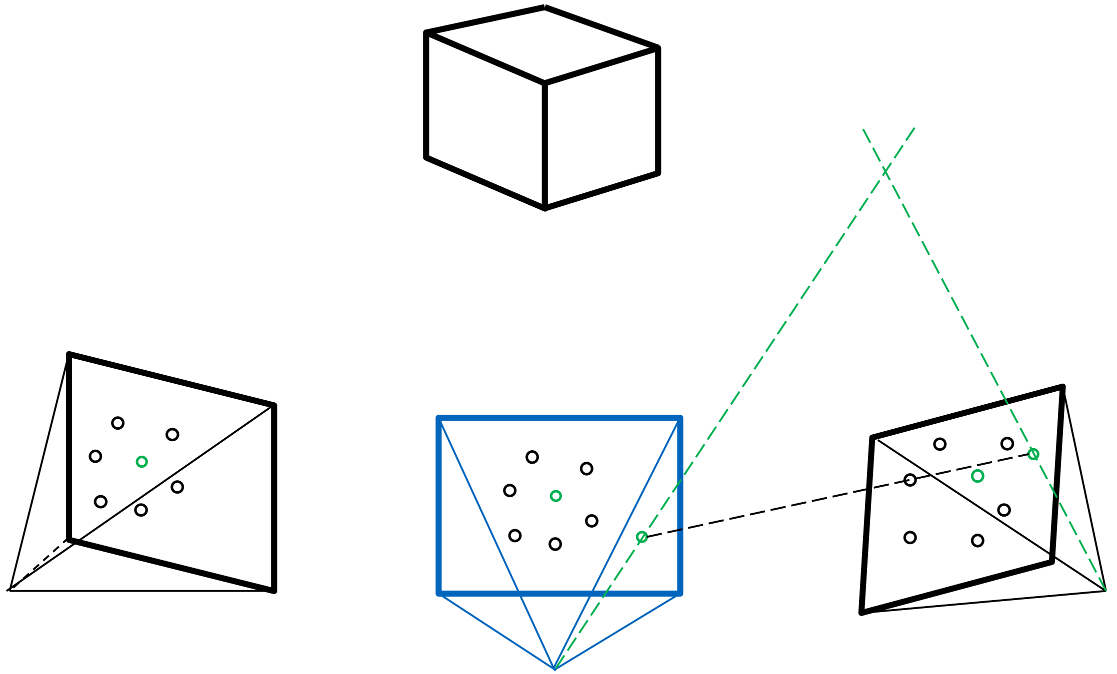
$P = K[I|0]$

$P'' = ?$

$P' = K'[R'|t']$

Geometry estimation steps

- Repeat the process starting again from triangulation of new features



$P = K[I|0]$

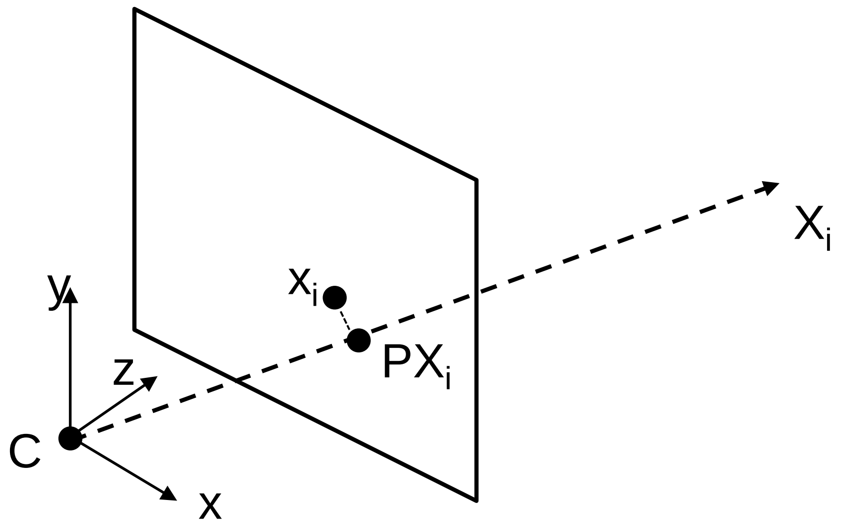
$P' = K'[R'|t']$

$P'' = K''[R''|t'']$

Bundle adjustment

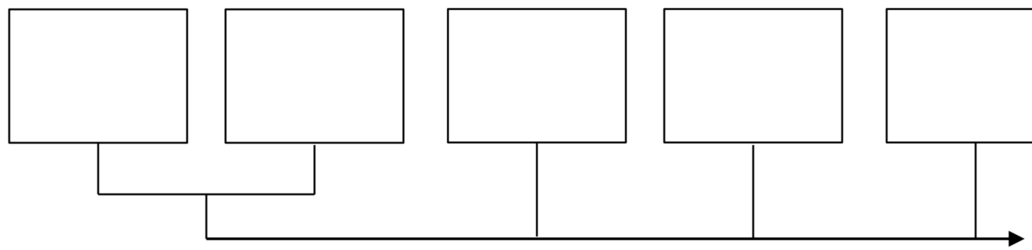
- Levenberg-Marquard optimization of re-projection error
- Parameters are camera poses and all 3D points (millions of parameters to optimize!)

$$\min_{P_j, X_i} \left(\sum_i \sum_j \left\| x_{i,j} - P_j X_i \right\| \right)$$

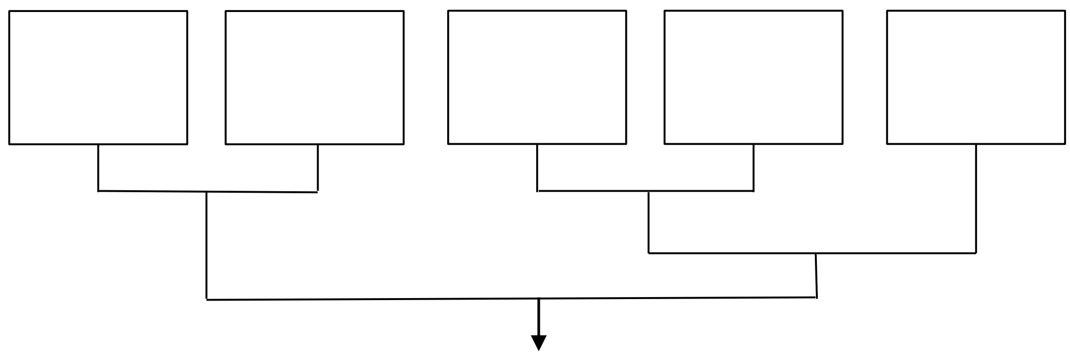


3 paradigms

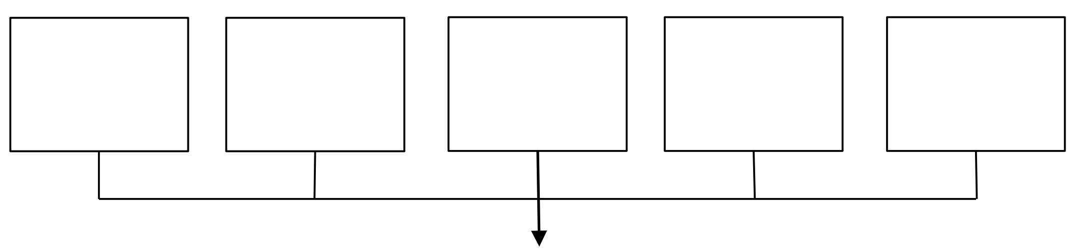
sequential



hierarchical



global

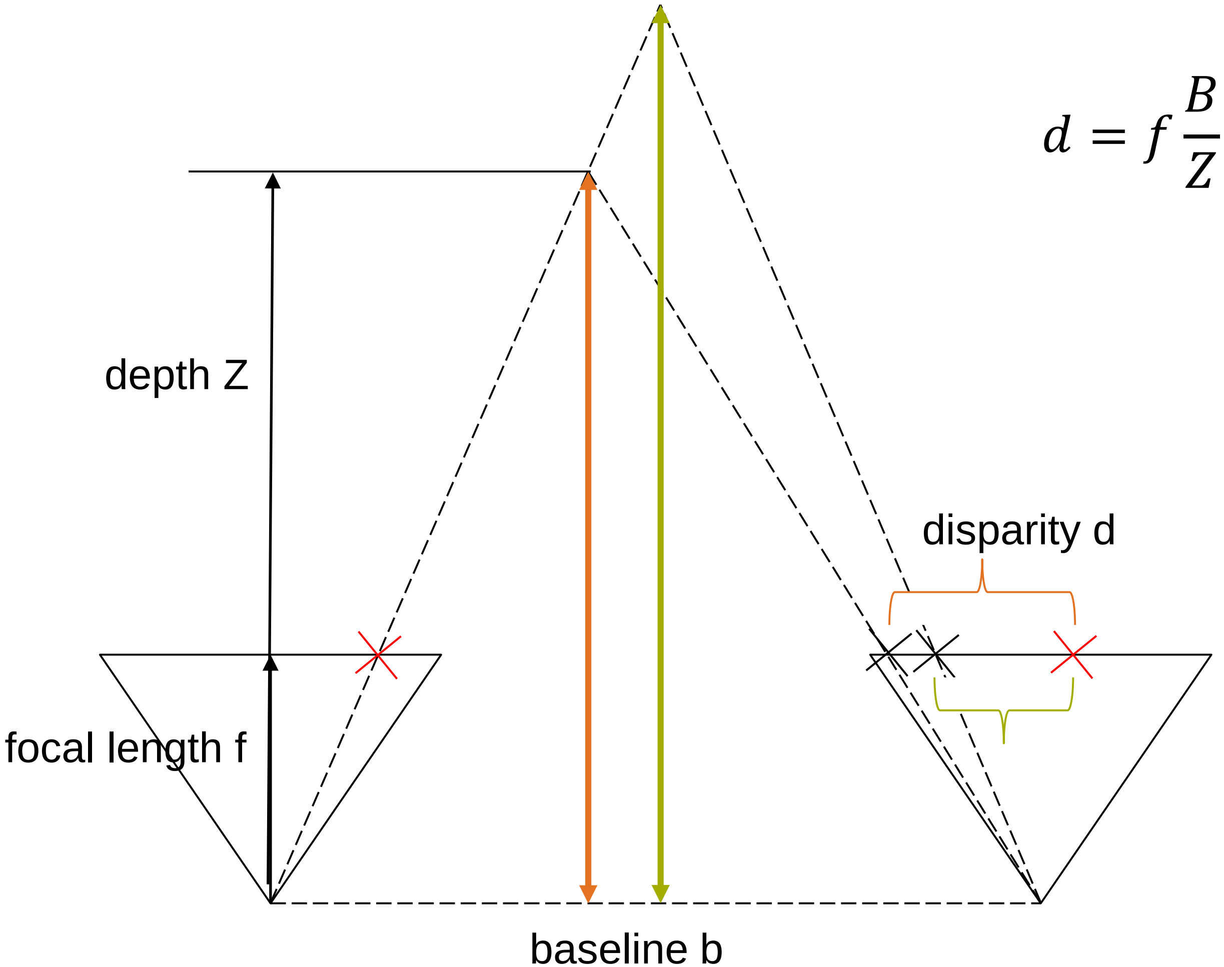


Dense matching

- SfM only gives sparse 3D data
- Only SIFT feature points 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

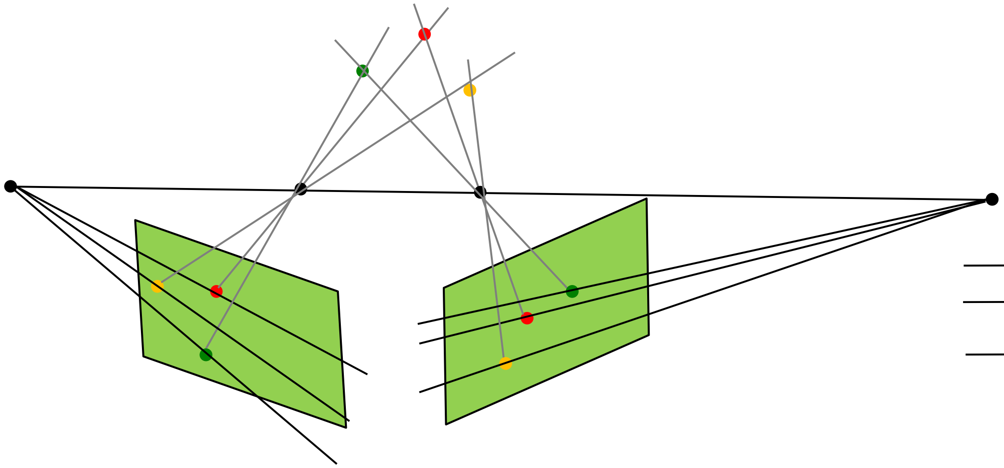
- Stereo normal case
- Depth Z [m] can be computed from disparity d [pixel]



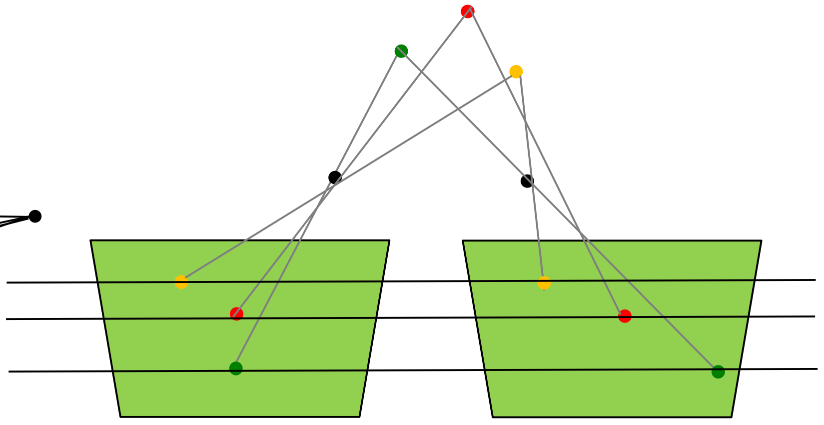
$$d = f\,\frac{B}{Z}$$

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“

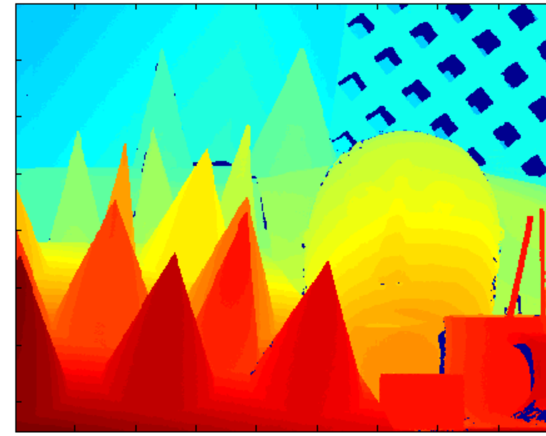
Dense matching process

Left View

I_l

Right View

*



Disparity image

D

- Estimate disparity (depth) 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 correspondent pixel *q* in the right image.

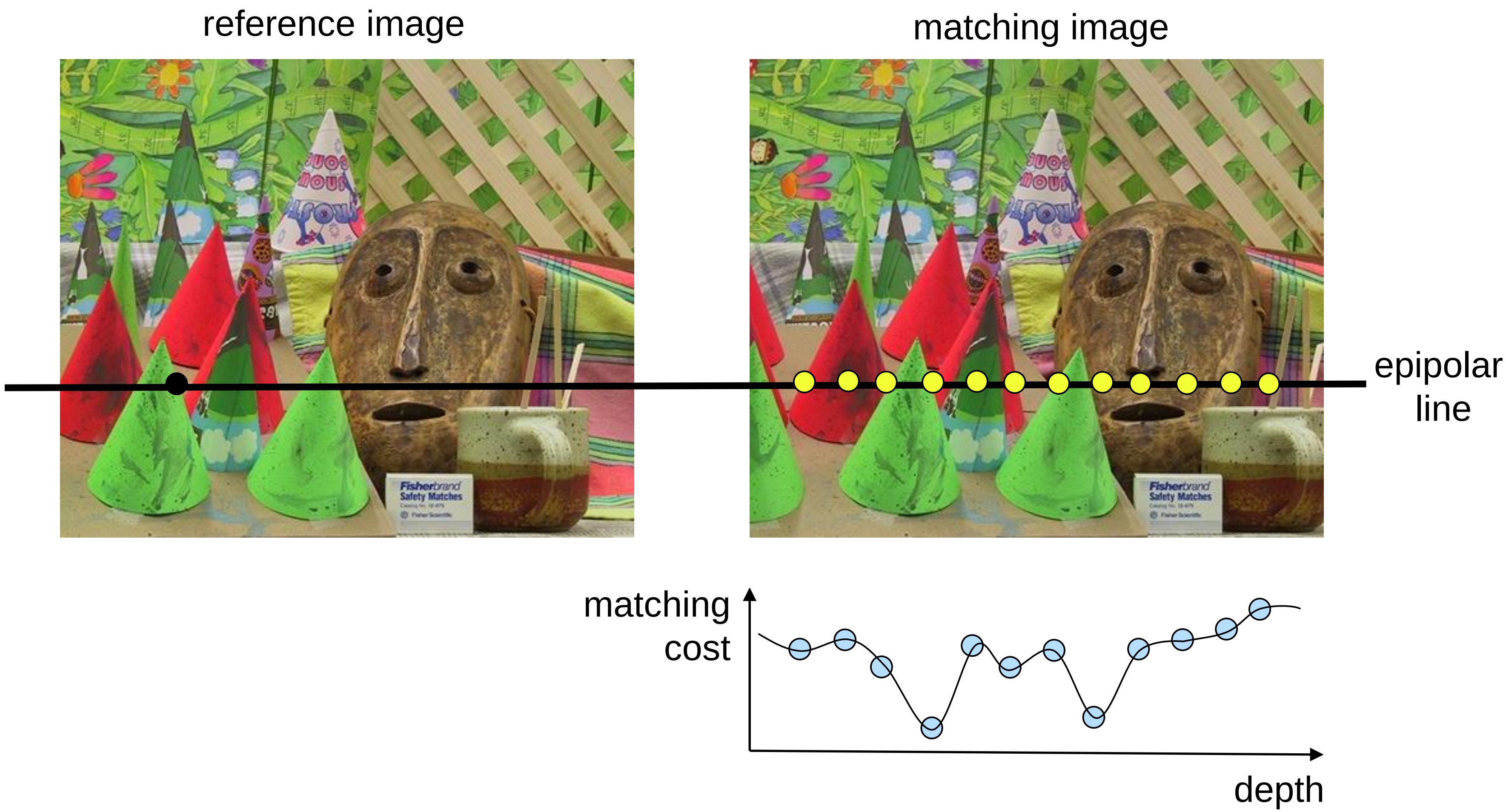
Census Transform

- 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 lesser than the central pixel (0 .. if center pixel is smaller, 1 .. if center pixel is larger)

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

00000011

Dense matching process



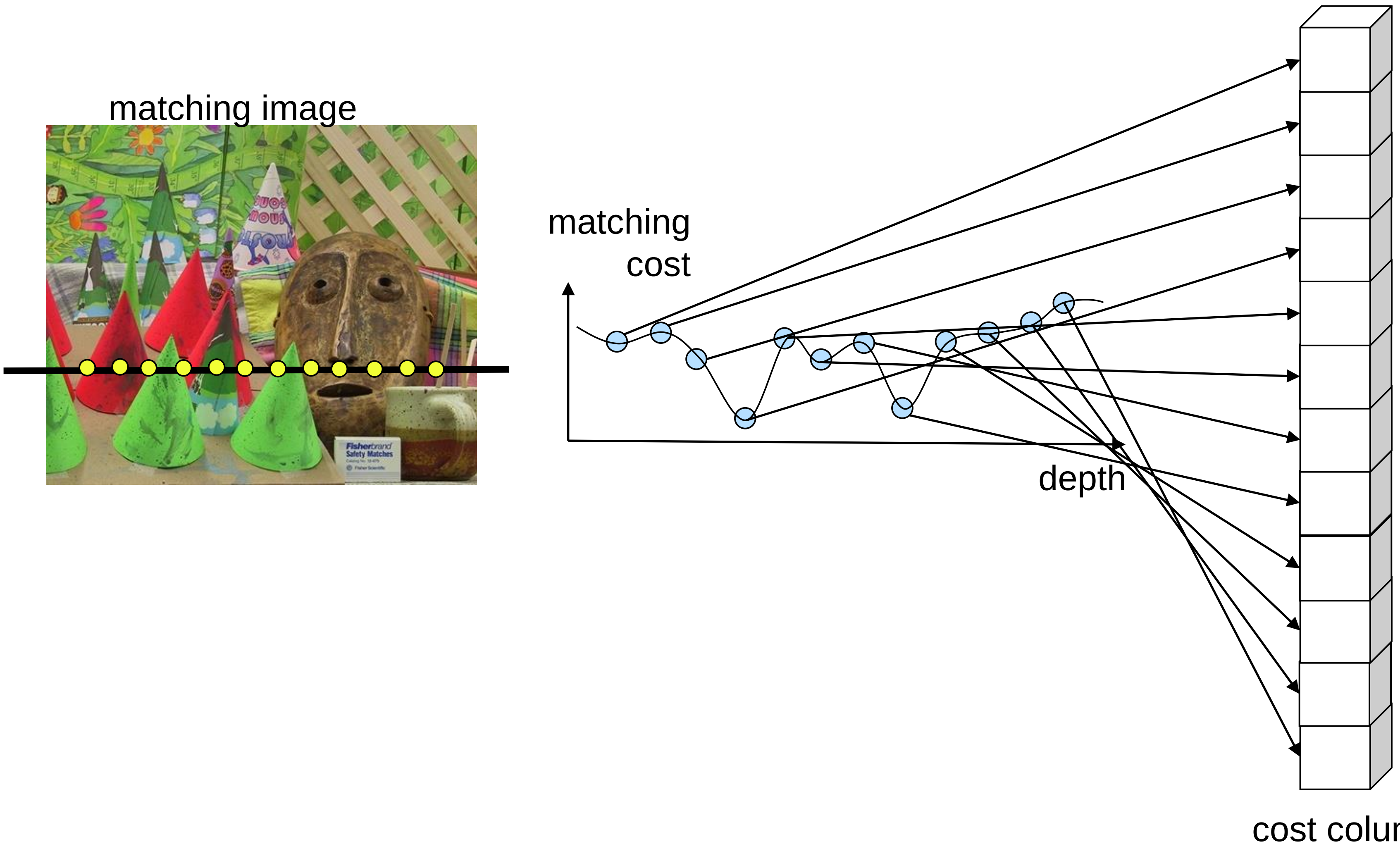
Disparity selection

- Single scanline based
  - Winner takes all (WTA)
    Select the disparity with the lowest cost (i.e. the highest similarity)

  - Scanline optimization (Dynamic programming)
    Select the disparities of the whole scanline such that the total (added up) costs for a scanline is minimal

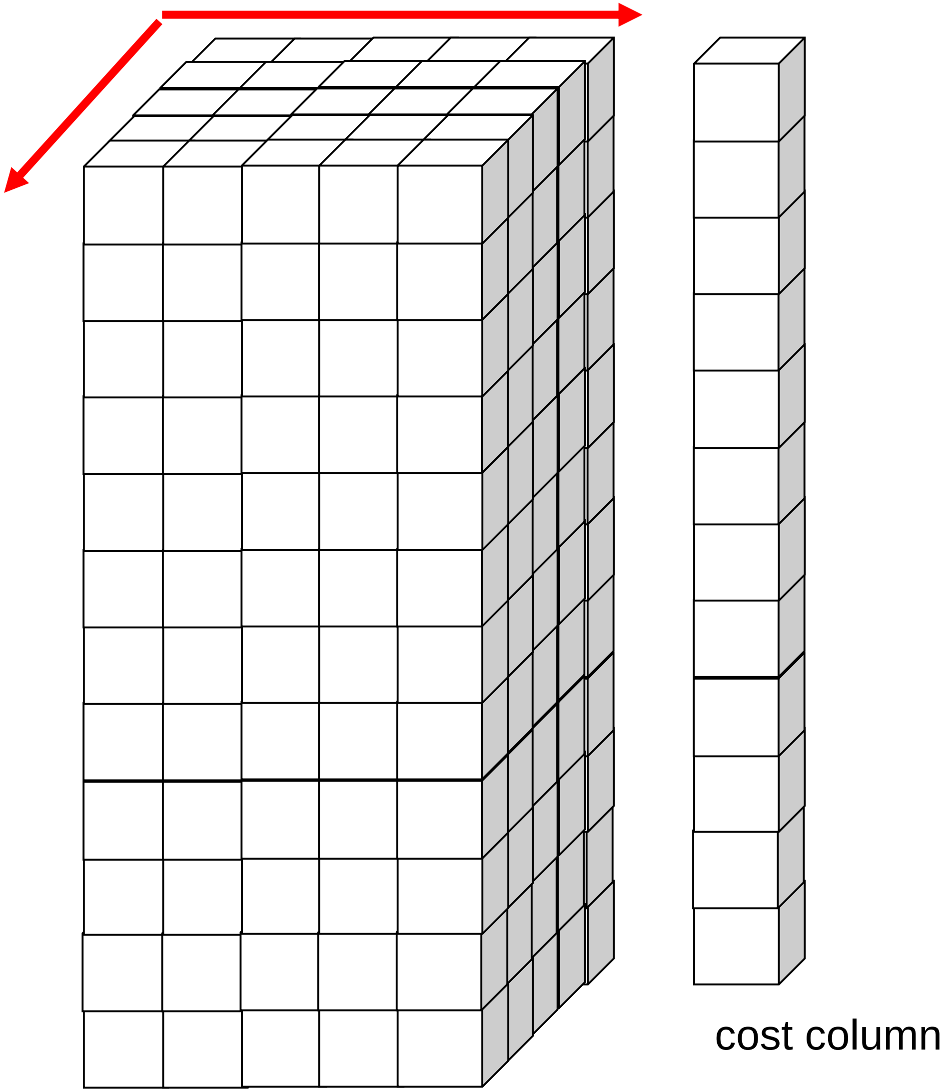
- Global methods (Cost volume optimization)
  - Belief propagation
    Selects the disparities such that the total cost for the whole image is minimal
  - Semi-global Matching
    Approximates the optimization of the whole disparity image

Dense matching process



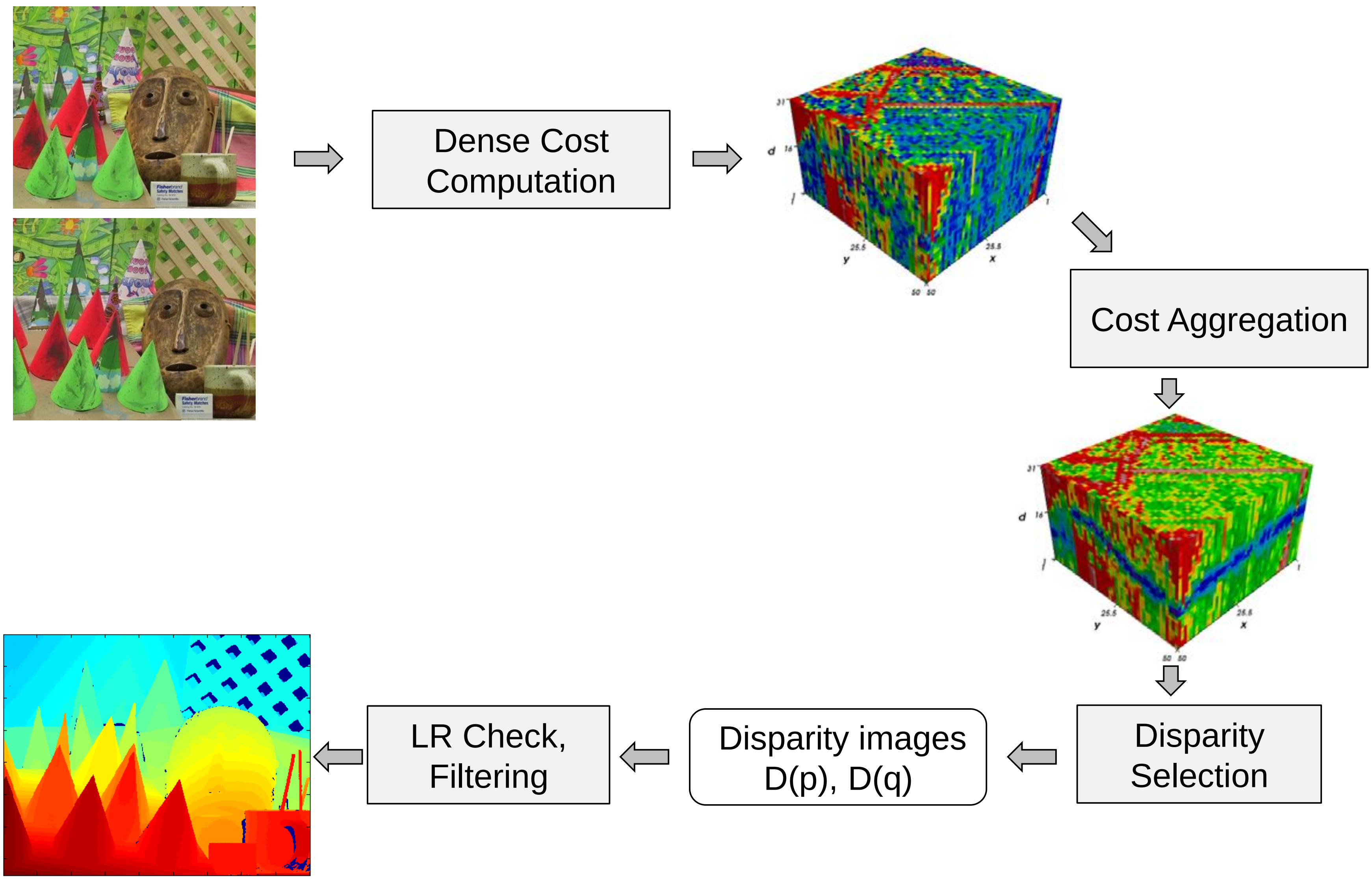
Dense matching process

matching image



cost volume

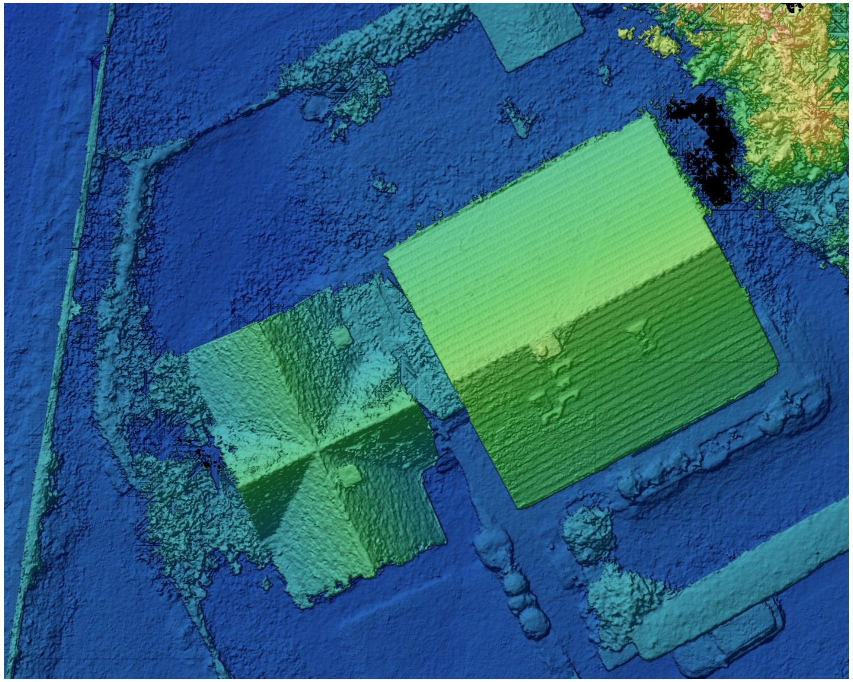
Semiglobal matching



Digital Surface Model (DSM)

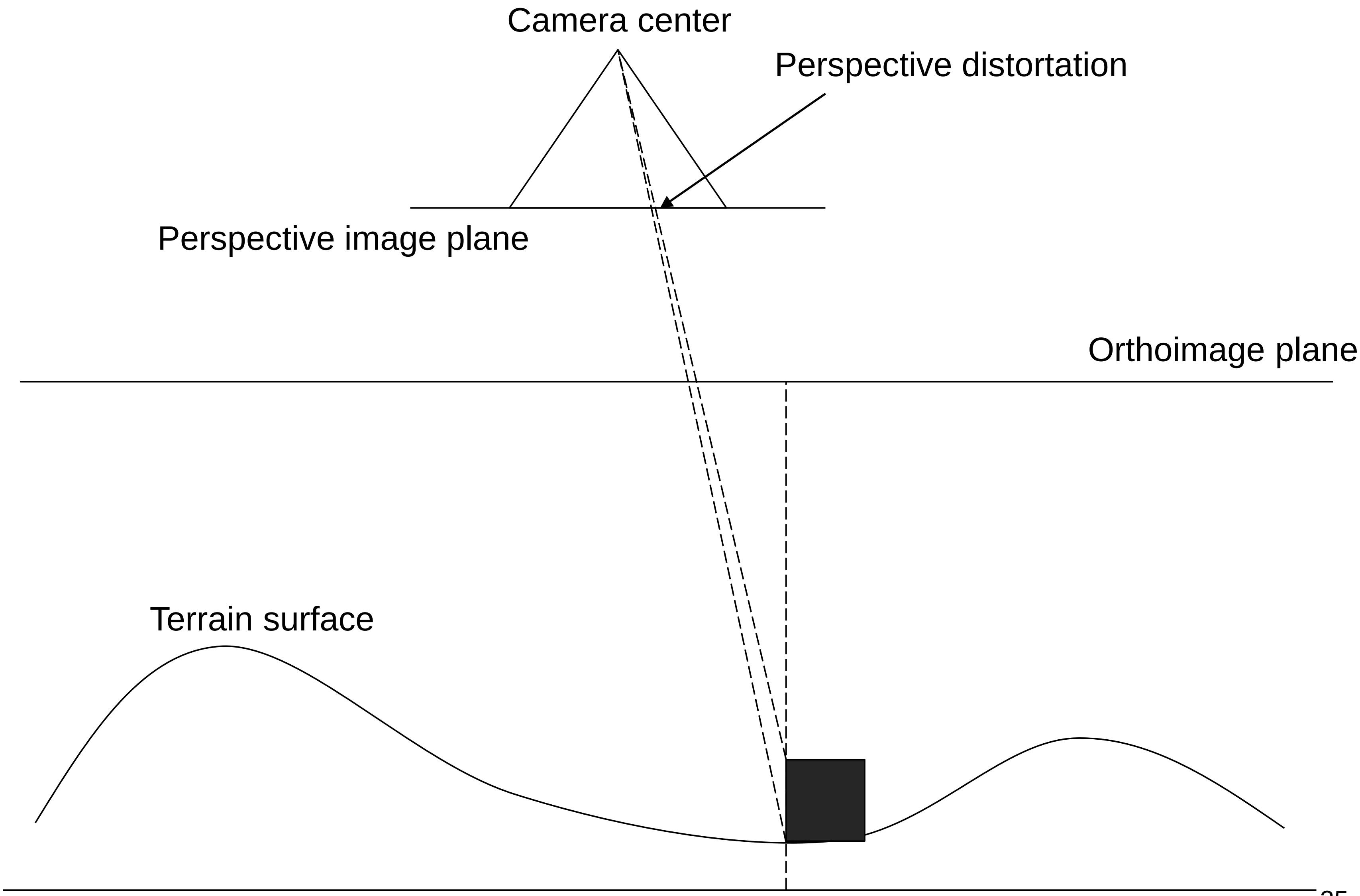
- 1 height value per ground location

original image

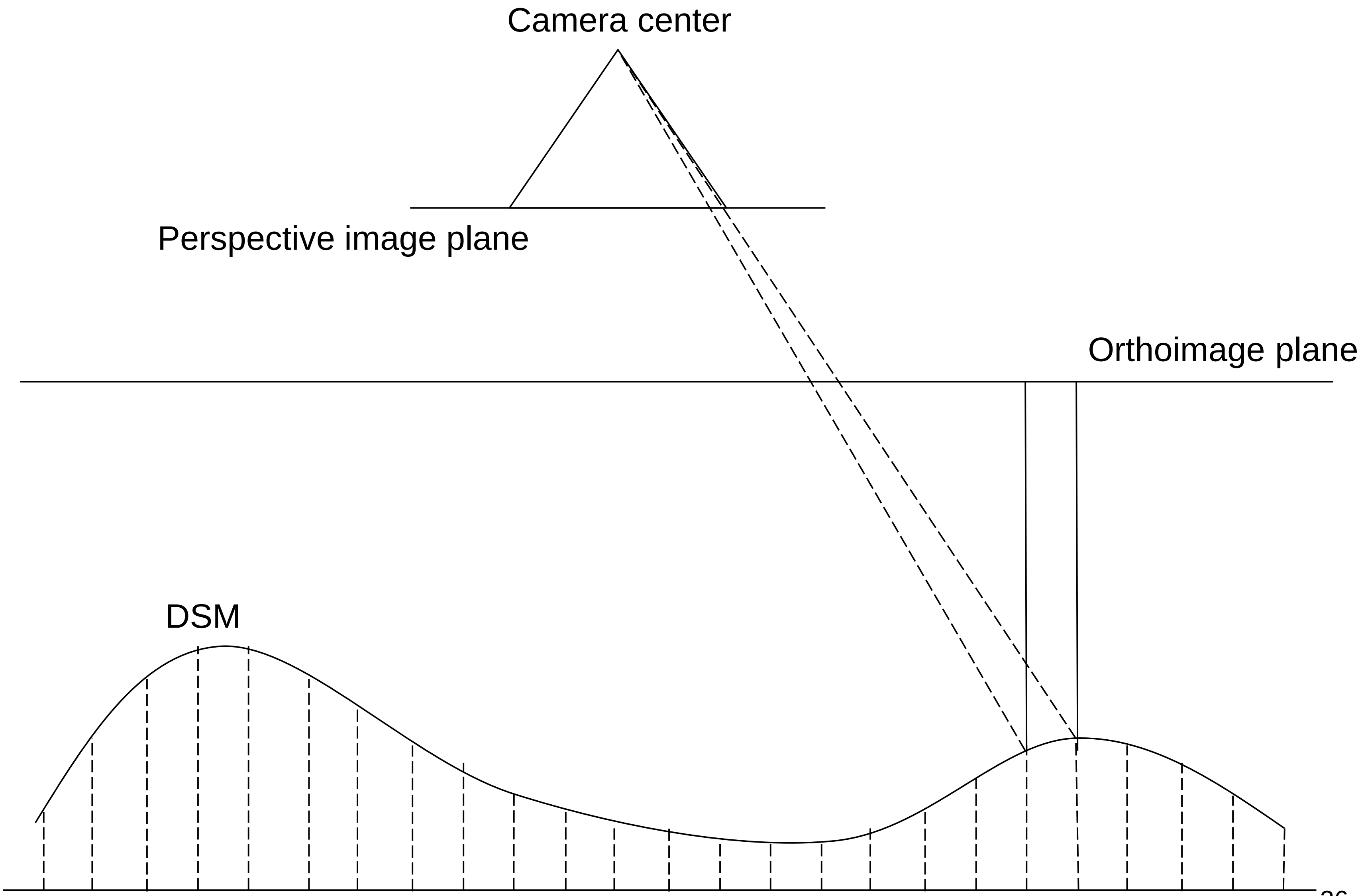


digital surface model
(color represents height)

Orthographic image projection



Orthophoto generation



Orthophoto example

- A true orthophoto has all perspective effects removed

original image

true orthophoto