Introduction to 3D vision

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Camera model

Stereo vision

Photogrammetry

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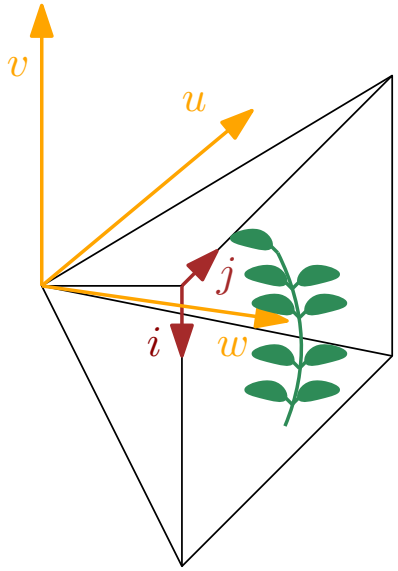
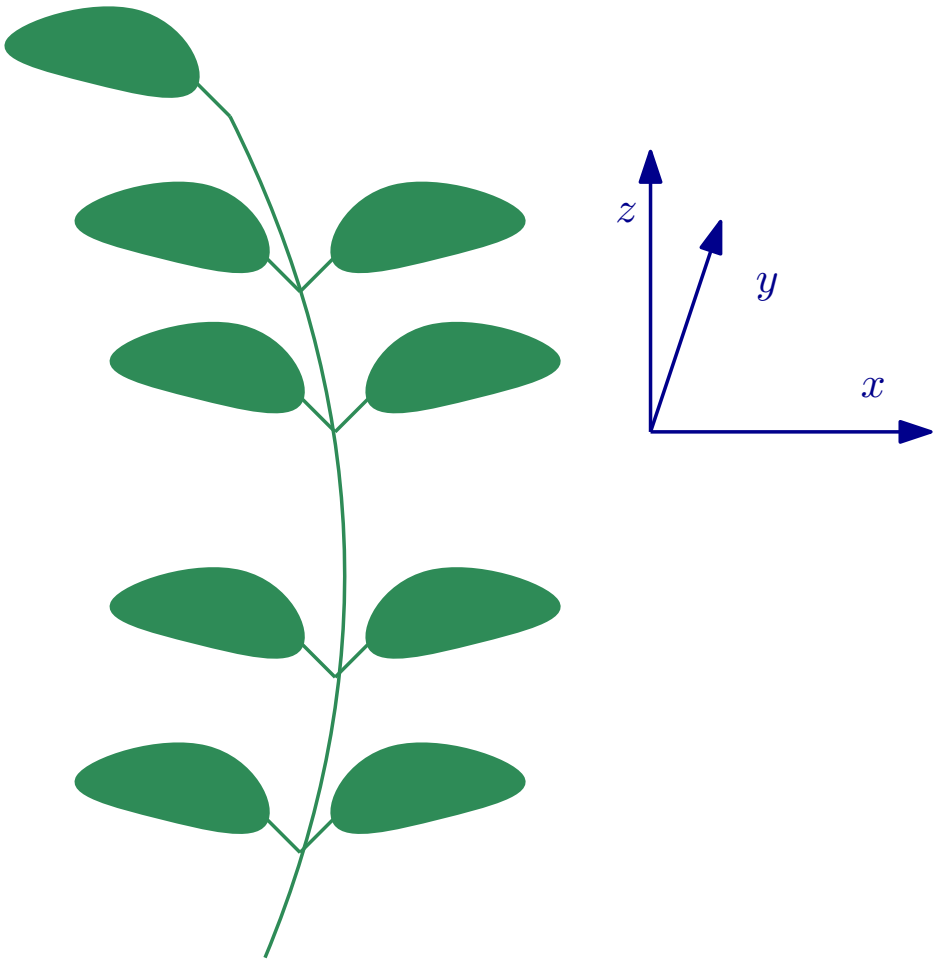
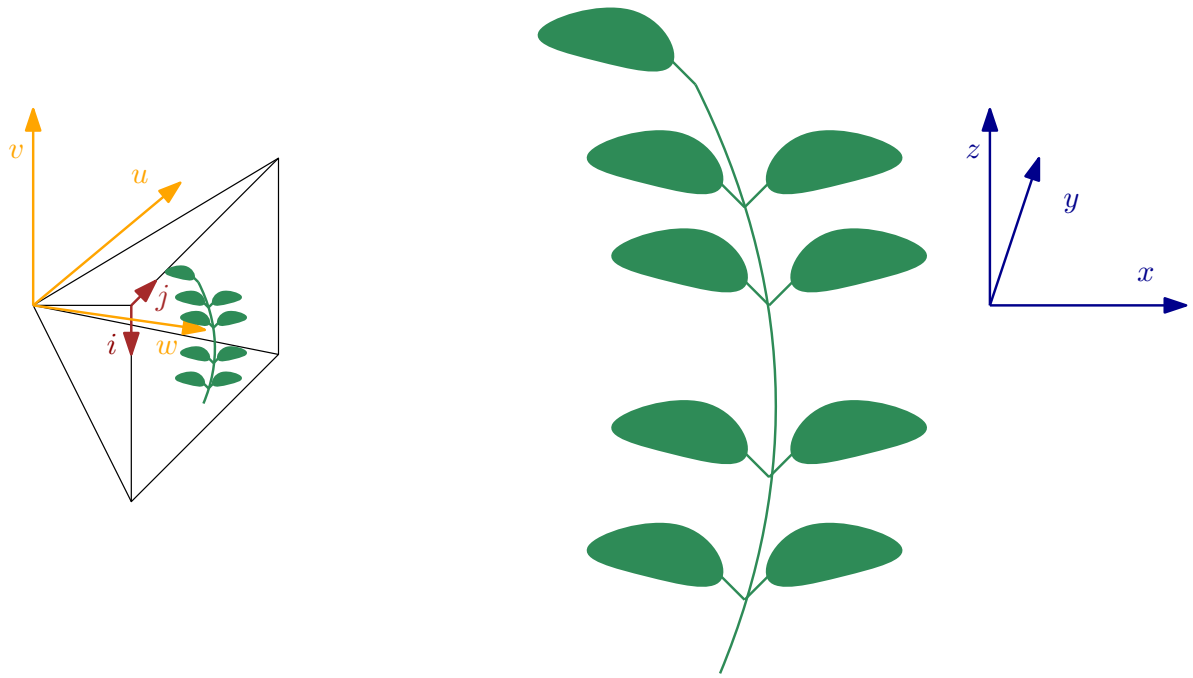
Photogrammetry

Pinhole camera model





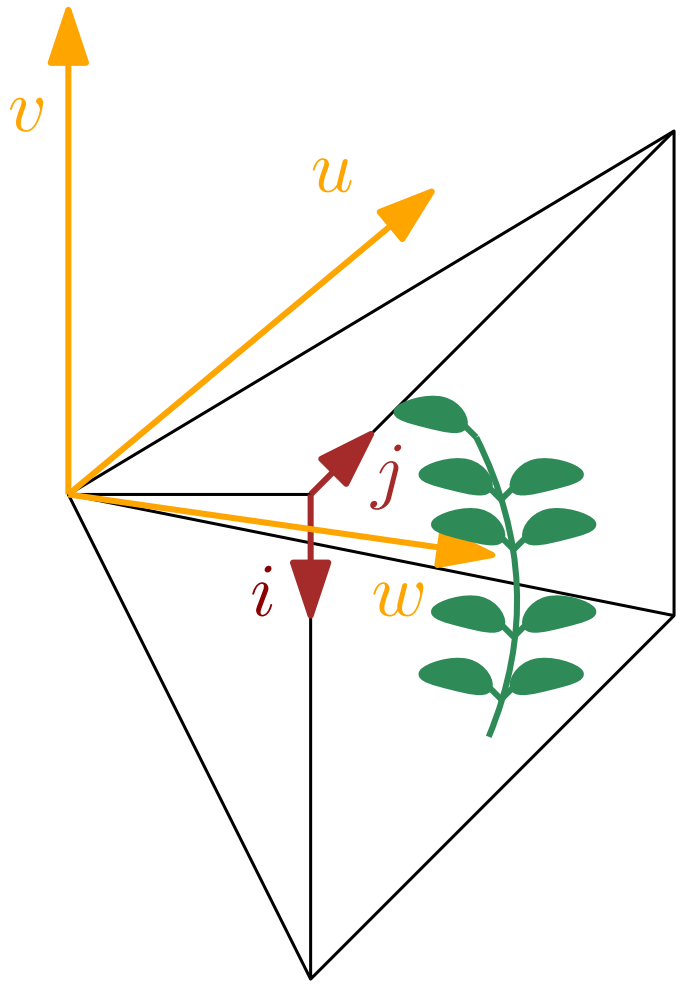
Camera pose



Extrinsics: rotation R and translation T.

$$\begin{pmatrix} u \\ v \\ w \end{pmatrix} = R \begin{pmatrix} x \\ y \\ z \end{pmatrix} + T$$

Fundamental matrix



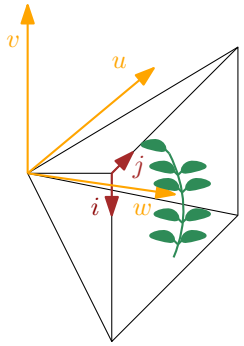
$$j = f_x \frac{u}{w} + c_x, i = f_y \frac{v}{w} + c_y$$

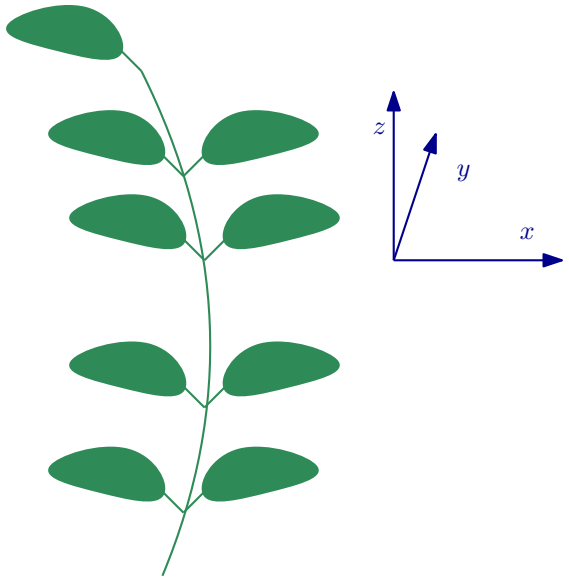
$$\begin{pmatrix} j \\ i \\ 1 \end{pmatrix} = F \begin{pmatrix} u/w \\ v/w \\ 1 \end{pmatrix}$$

where

$$F = \begin{pmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{pmatrix}$$

Pinhole camera model

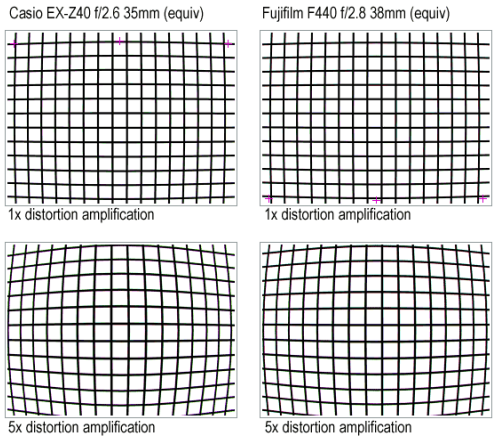




$$\text{Extrinsics: } \begin{pmatrix} u \\ v \\ w \end{pmatrix} = R \begin{pmatrix} x \\ y \\ z \end{pmatrix} + T$$

$$\text{Intrinsics: } \begin{pmatrix} u \\ v \\ w \end{pmatrix}$$

Camera distortion



OpenCV model

$$r = \sqrt{x^2 + y^2}$$

$$x_{\text{corrected}} = x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$$

$$y_{\text{corrected}} = x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6)$$

Simplified radial: $k_2 = k_3 = 0$.

Summary

Camera parameters

5 to 7 parameters: $f_x, f_y, c_x, c_y, k_1, (k_2, k_3)$.

Pose parameters

6 parameters: 3 for R, 3 for T.

Camera model

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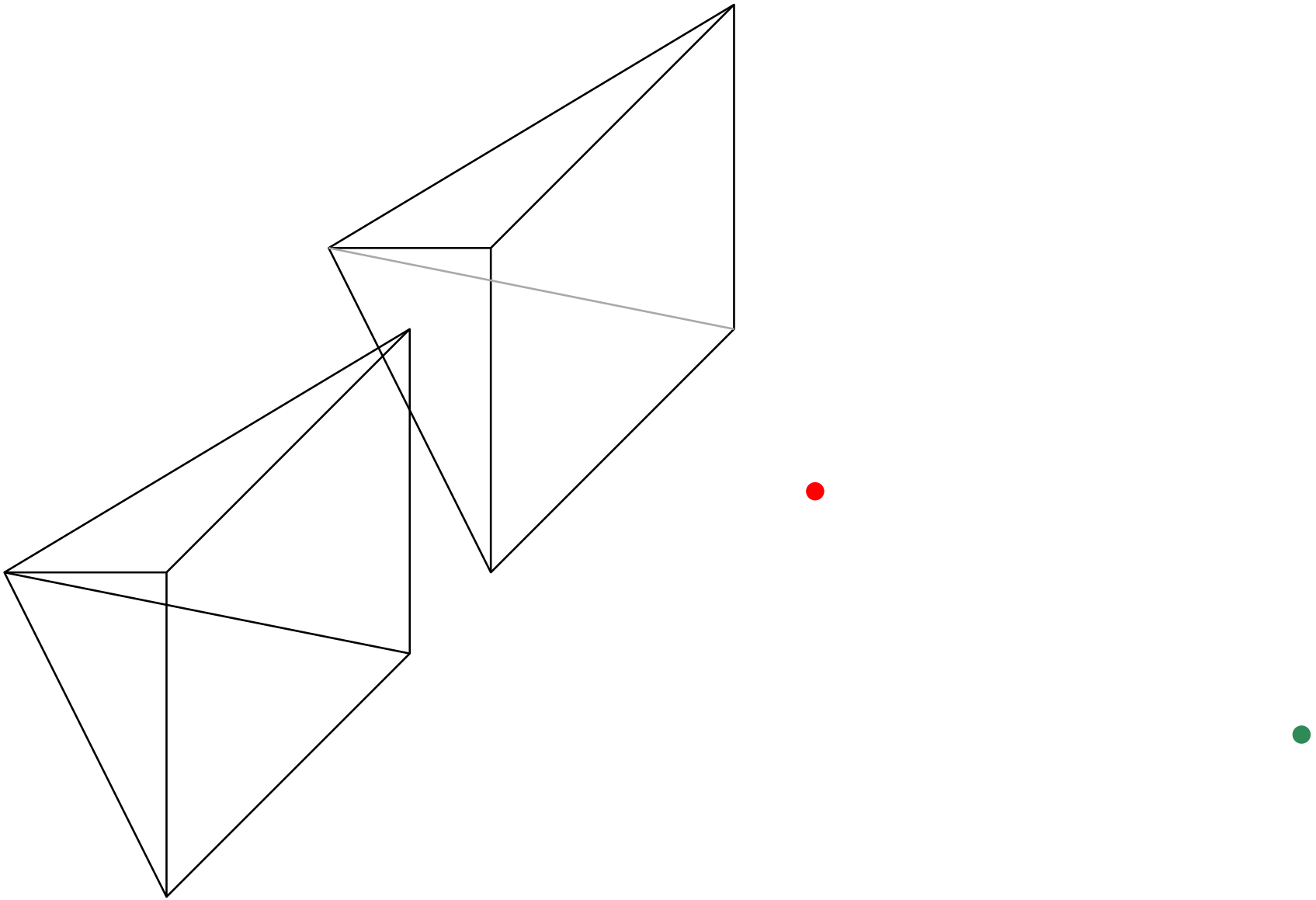
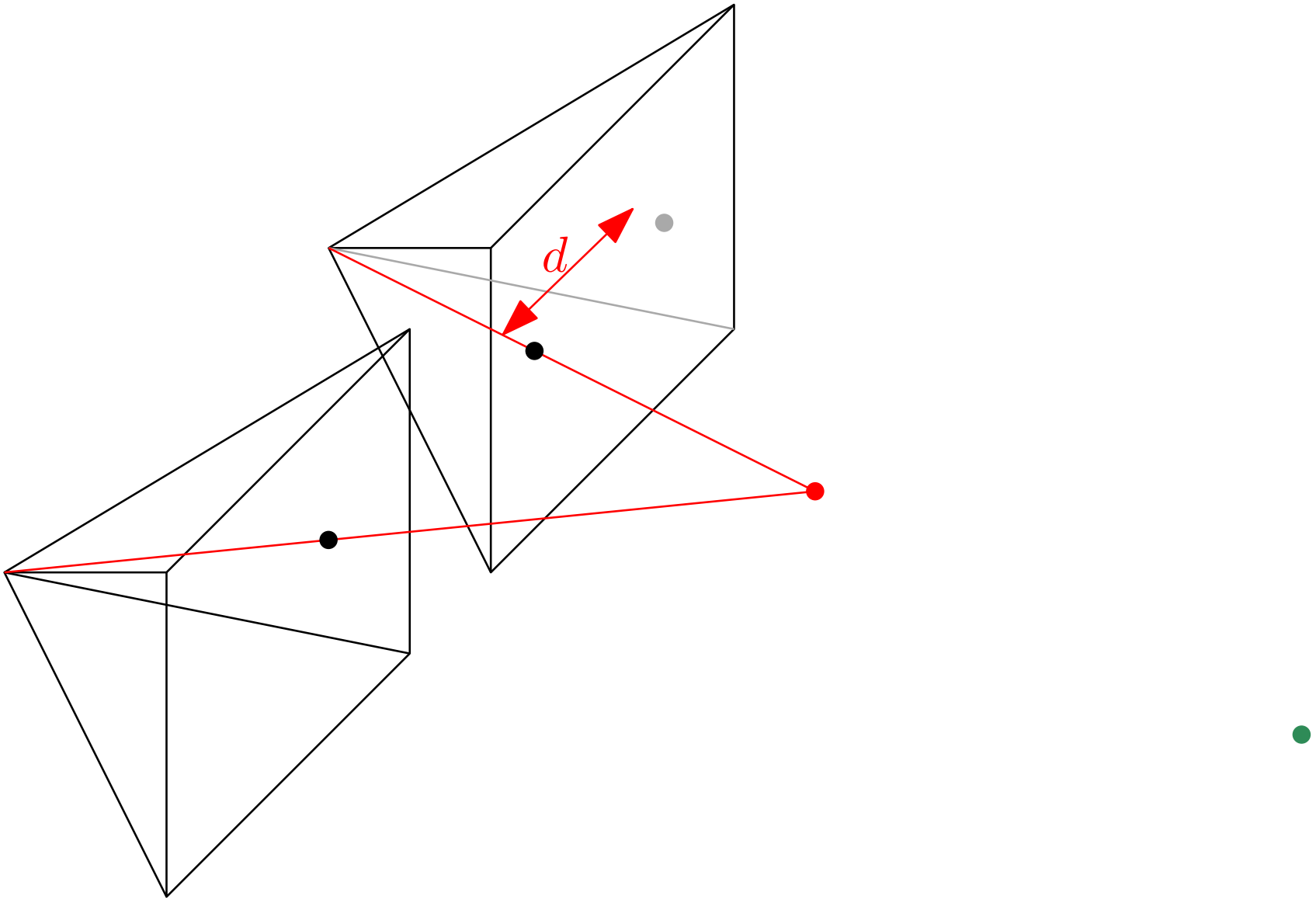
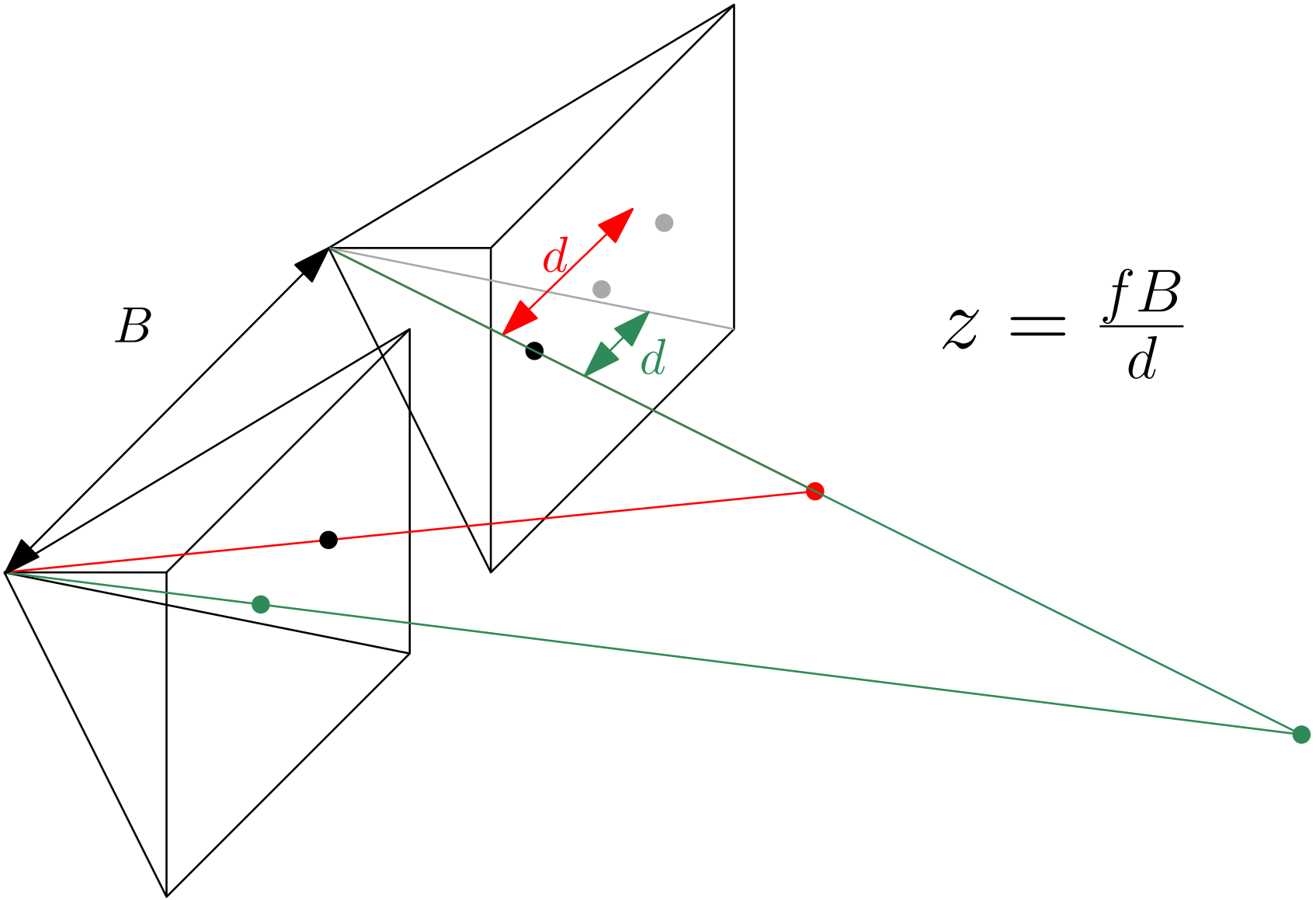
Basic principle



Basic principle



Basic principle



$$z = \frac{fB}{d}$$

Disparity map

Goal

Compute d at every point in the image.

Camera model

Stereo vision

Photogrammetry

Principle

RGB Images

$\Rightarrow$

Point Cloud

Solutions

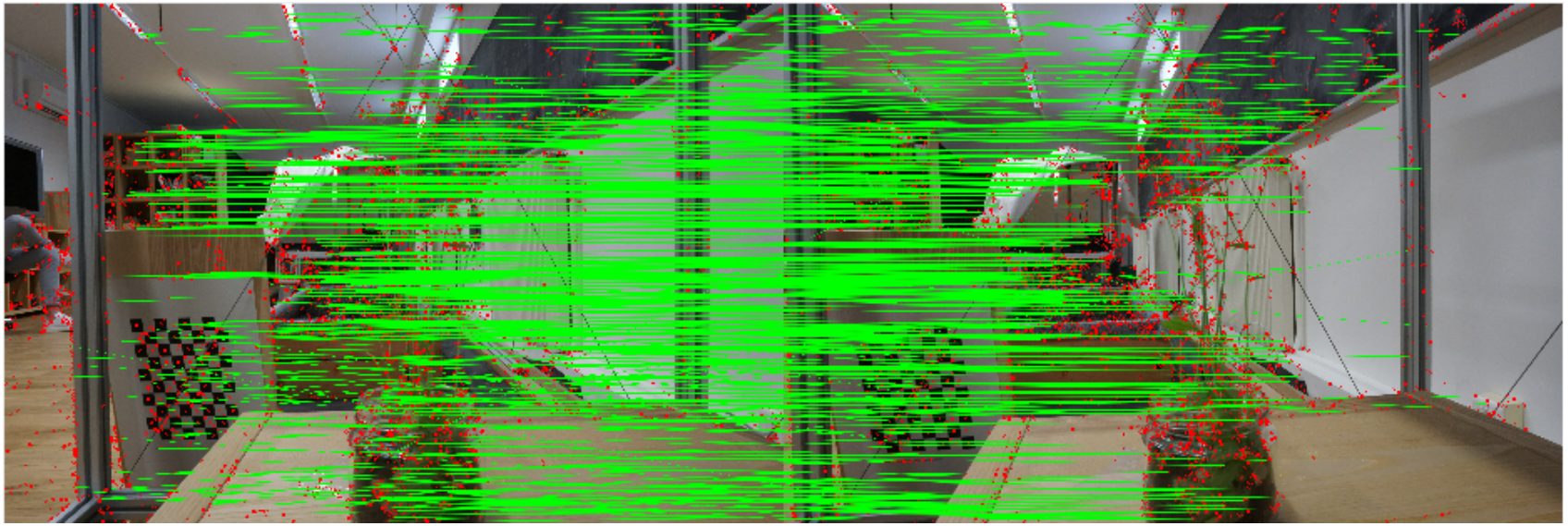
Free and open source: colmap, openMVG+openMVS, ...

Commercial: agisoft, ...

Pipeline

- Feature detection and computation
- Feature matching
- Pose estimation
- Bundle adjustment
- Dense point cloud generation

Feature detection and matching



Pose estimation

For every match of a real world point $\mathbf{x} = (x, y, z)$, between a camera pair k_1, k_2. Let $x_1 = (i_1, j_1)$ be the pixel in view k_1, and $x_2 = (i_2, j_2)$ be the corresponding pixel in view k_2. We get the equations:

$$F(R_1\mathbf{x} + T_1) = \mathbf{x}_1$$

$$F(R_2\mathbf{x} + T_2) = \mathbf{x}_2$$

For every match, we add 4 equations and 3 unknowns. With enough matches, we can recover the relative pose of the two views up to a homotopy of the whole space.

Pose estimation

Iterating this over all pairs of images we obtain:

- The relative pose of all cameras.
- A sparse set of 3D points corresponding to the matches.

Bundle adjustment

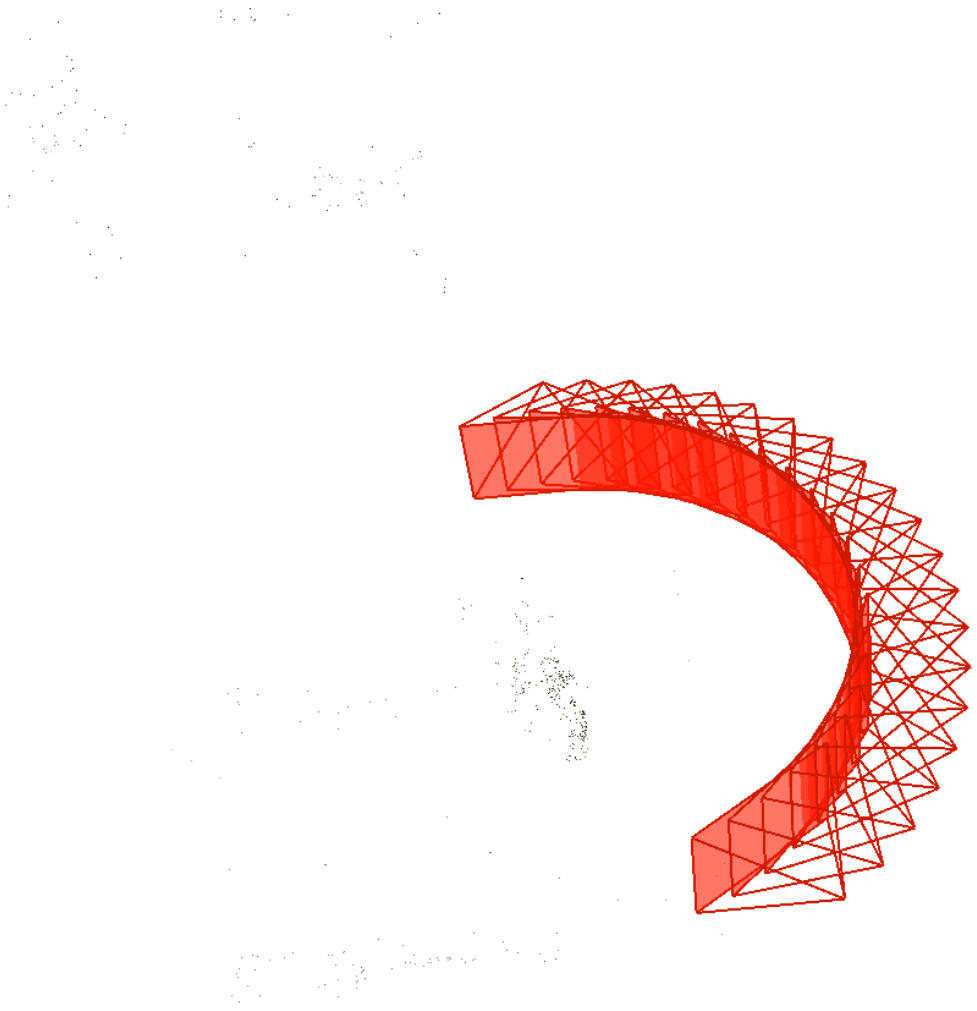
Refine the pose of all cameras and the position of all points simultaneously:

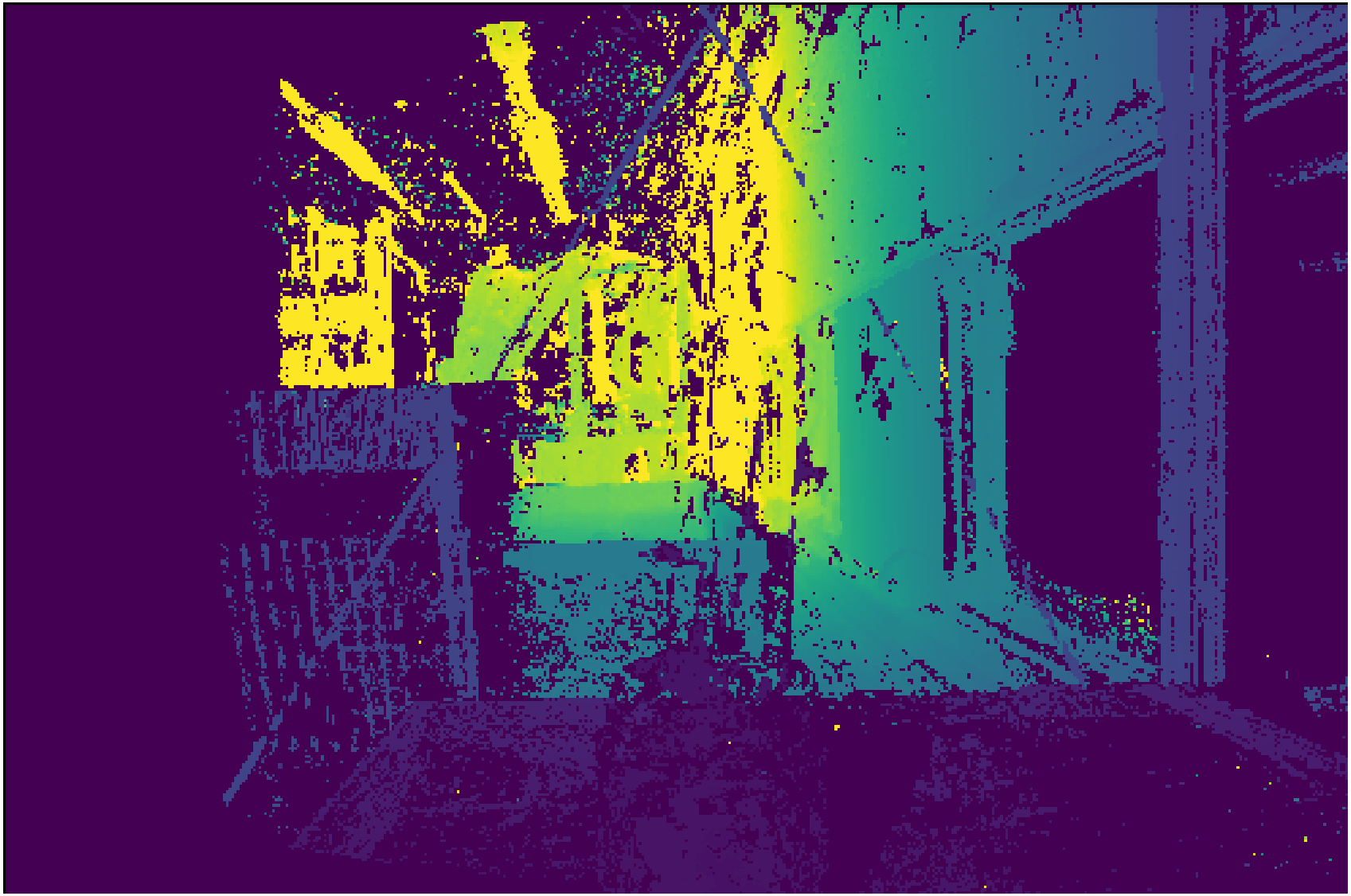
$$\min_{R_i, T_i, F, x_i} \sum_i \sum_j v_{i,j} d(F(R_i x_i + T_i), y_i)^2,$$

where:

- R_i, T_i, F: camera parameters,
- x_i: 3D points,
- d: euclidian distance.

Result (colmap)



Dense point cloud

We compute stereo disparity maps in each pair of images: