# Introduction to 3D vision

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Sony CSL Paris

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Context

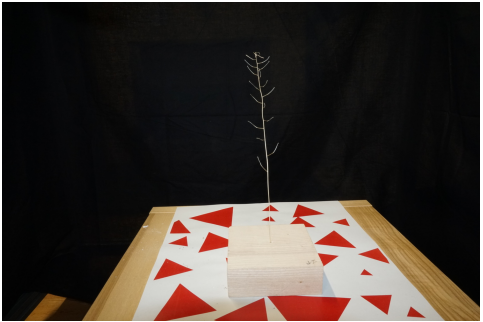
Camera model

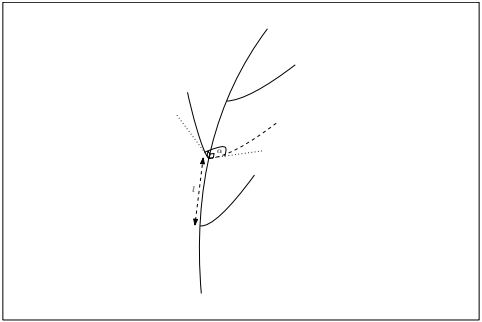
Stereo vision

Photogrammetry

# Context

Extract phyllotaxic parameters of plants:





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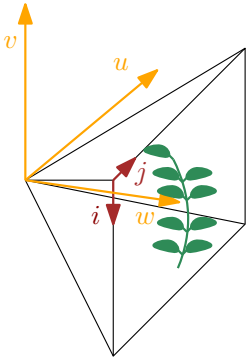
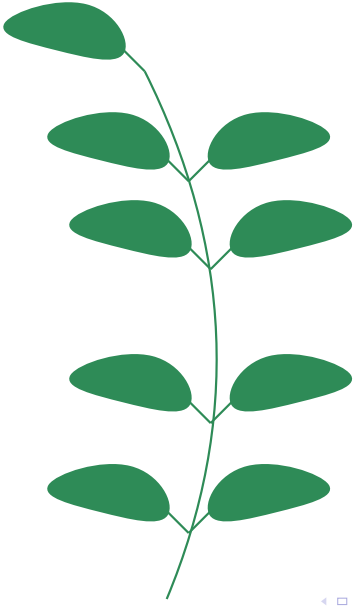
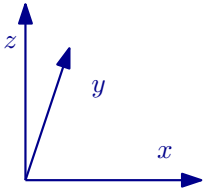
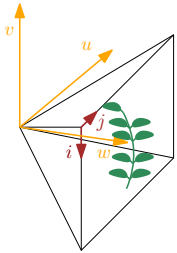
# Pinhole camera model

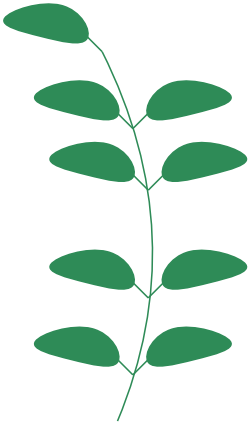


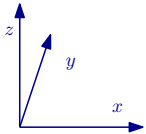





# Camera pose



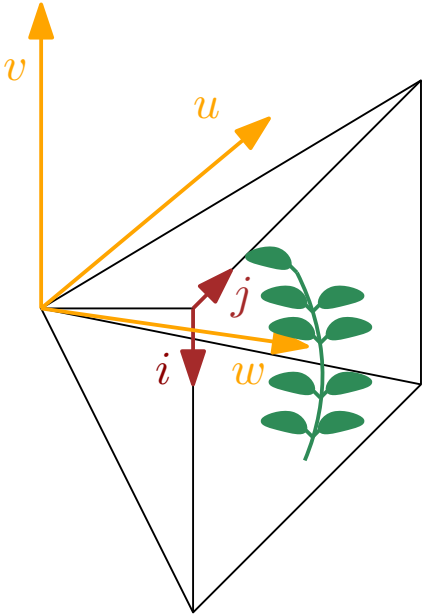






Extrinsics: rotation $R$ and translation $T$.

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

# Fundamental matrix



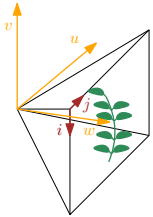

$$j = f_x \frac{u}{w} + c_x, i = f_y \frac{v}{w} + c_y$$

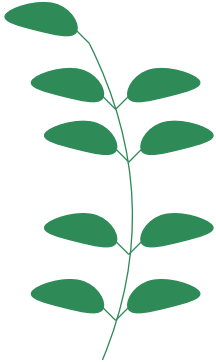
$$\begin{pmatrix} j \\ i \\ 1 \end{pmatrix} = F \begin{pmatrix} u/w \\ v/w \\ 1 \end{pmatrix}$$

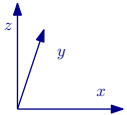
where

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

# Pinhole camera model



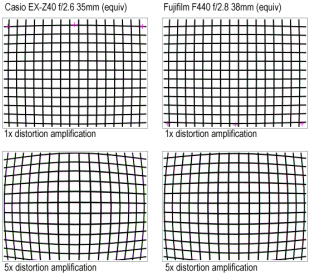






$$\text{Extrinsics: } \begin{pmatrix} u \\ v \\ w \end{pmatrix} = R \begin{pmatrix} x \\ y \\ z \end{pmatrix} + T$$

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

# 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 $T$.

# OpenCV

Camera calibration:

- https://docs.opencv.org/3.1.0/dc/dbb/tutorial_py_calibration.html

```
ret, mtx, dist, rvecs, tvecs =
cv2.calibrateCamera(objpoints, imgpoints,
gray.shape[::-1],None,None)
```

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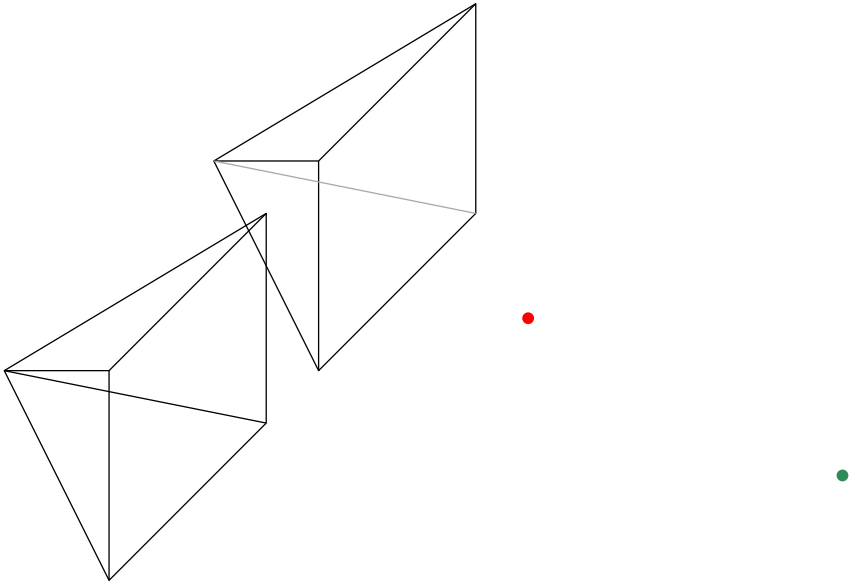
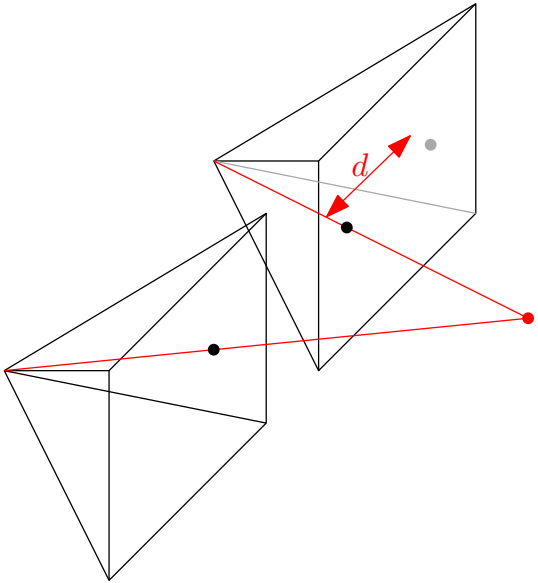
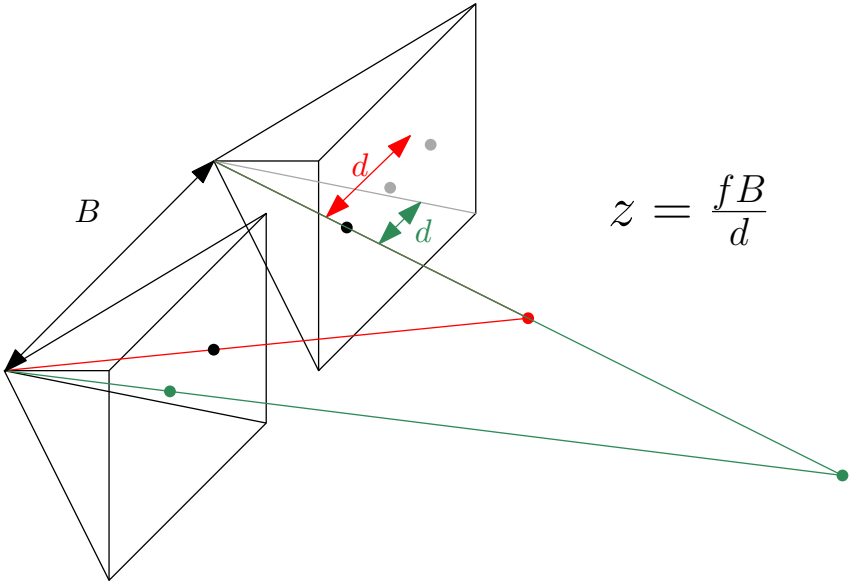
# Basic principle



# Basic principle



# Basic principle




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

# Disparity map

## Goal

Compute depth at every point in the image.

First, we need to *rectify* images. I.e. align images such that points in 3D space are on the same line in both images.

Then for any pixel location $i, j$ in the left image we have to find the corresponding point $i, j - d(i, j)$ in the right image. To do this, we minimize:

$$d(i,j) = \mathrm{argmin}_d(C(i,j,d)),$$

$$C(i,j,d) := \sum_{i',j' \in W(i,j)} \left| D_1(i',j') - D_2(i',j'-d) \right| .$$

# Disparity map

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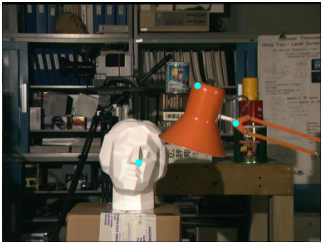

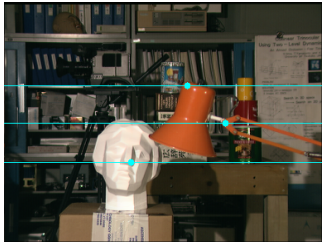

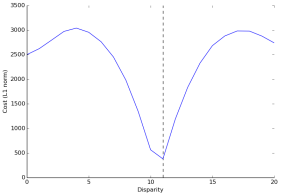


https://sourishghosh.com/2016/dense-disparity-maps-orb-descriptors/

# Disparity map

# OpenCV

Stereo depth:

https://docs.opencv.org/3.1.0/dc/dbb/tutorial_py_calibration.html

```
import numpy as np
import cv2
from matplotlib import pyplot as plt

imgL = cv2.imread('tsukuba_l.png',0)
imgR = cv2.imread('tsukuba_r.png',0)

stereo = cv2.StereoBM_create(numDisparities=16, blockSize=15)
disparity = stereo.compute(imgL,imgR)
plt.imshow(disparity,'gray')
plt.show()
```

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# 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

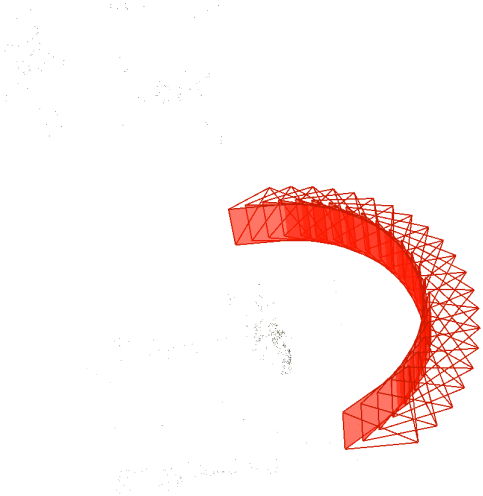
Refine the pose of all cameras and the position of all points simultaneously:

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

where:

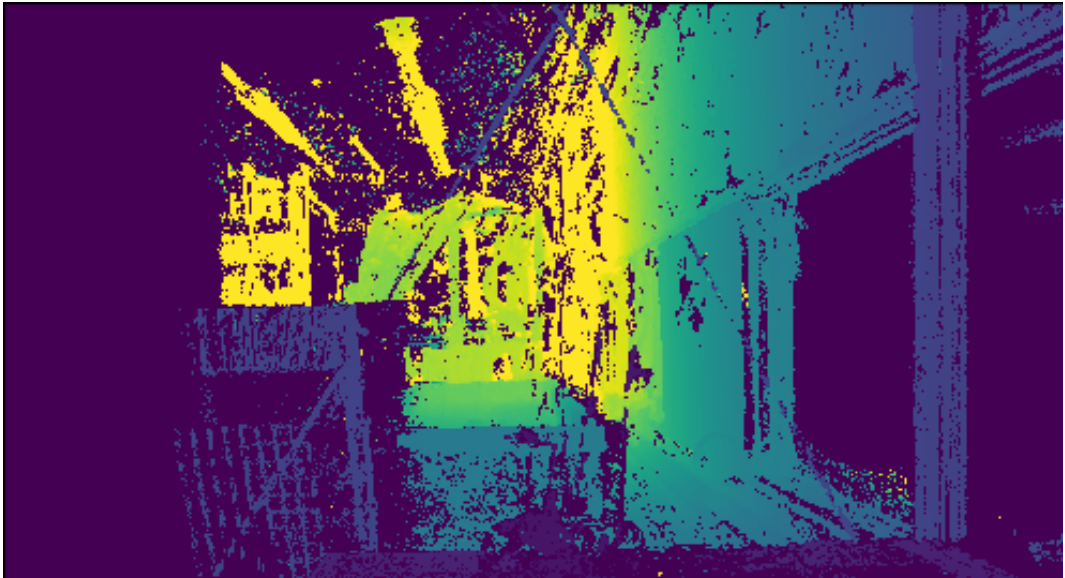
- $R_i$, $T_i$, $F$: camera parameters,
- $x_i$: 3D points,
- $d$: euclidian distance.

# Result (colmap)



# Dense point cloud

We compute stereo disparity maps in each pair of images:



# Colmap documentation

https://colmap.github.io/