3D Scanning & Motion Capture

Exercise - 1

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Team

Lecturers

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TAs

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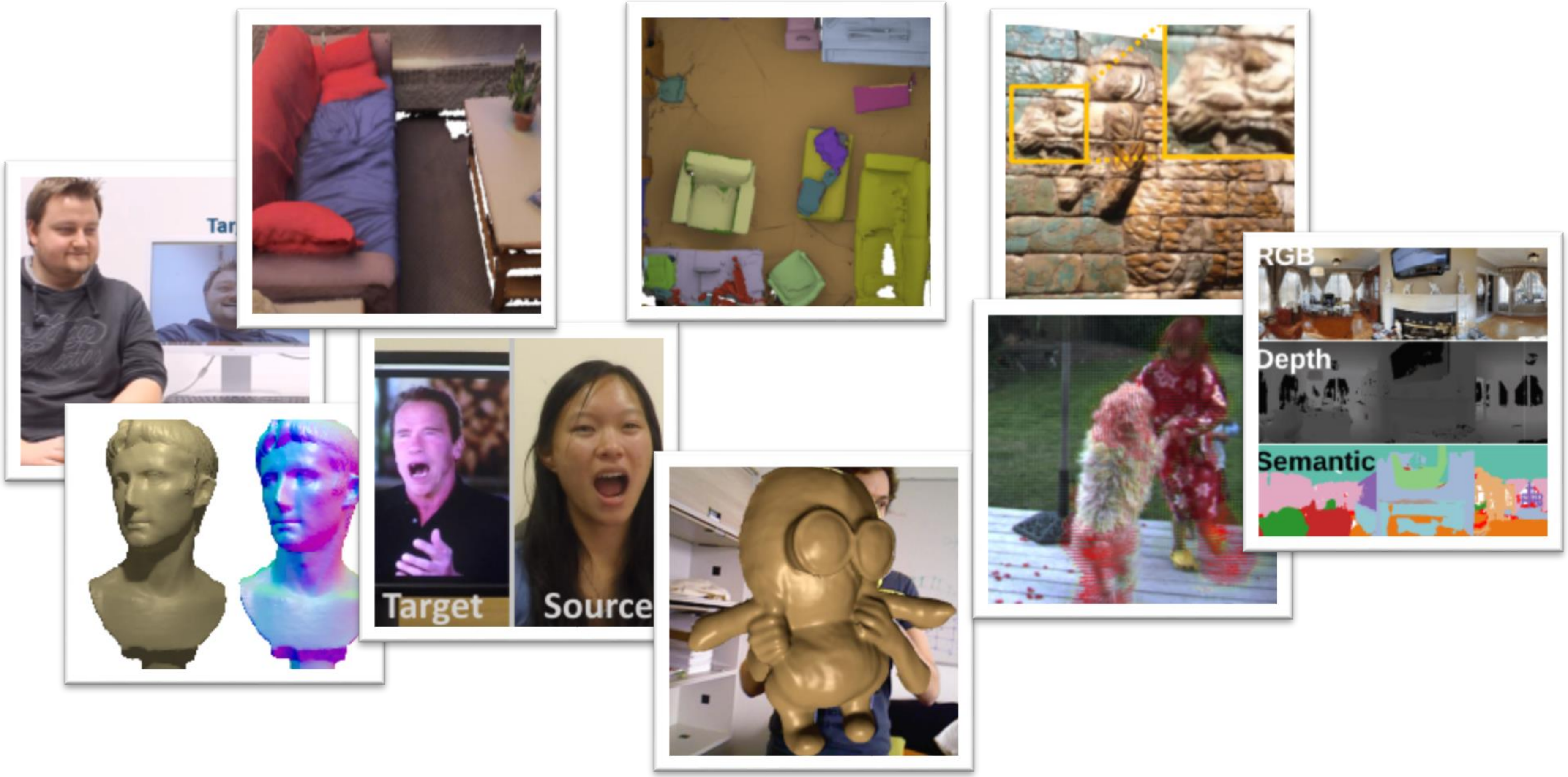
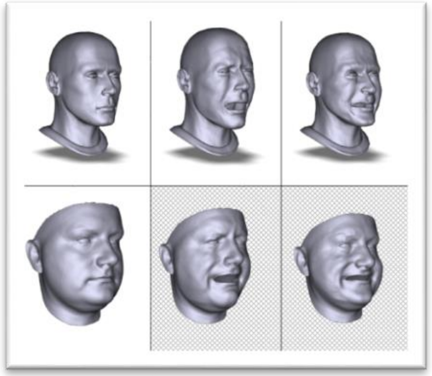
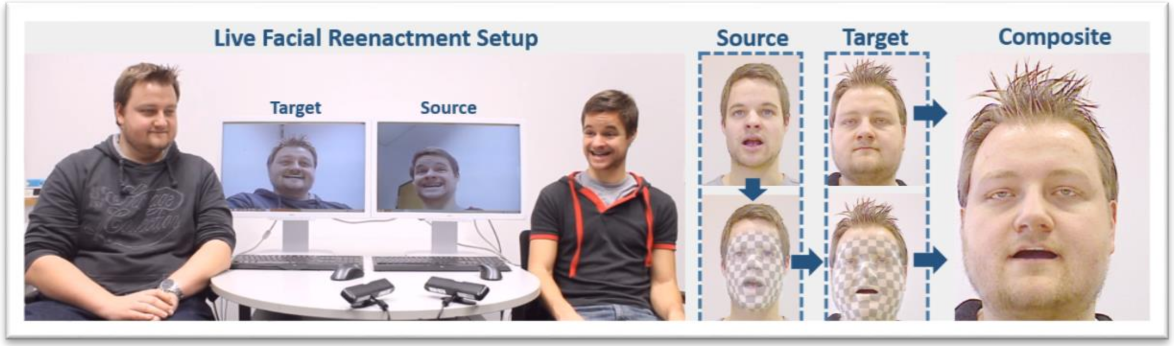
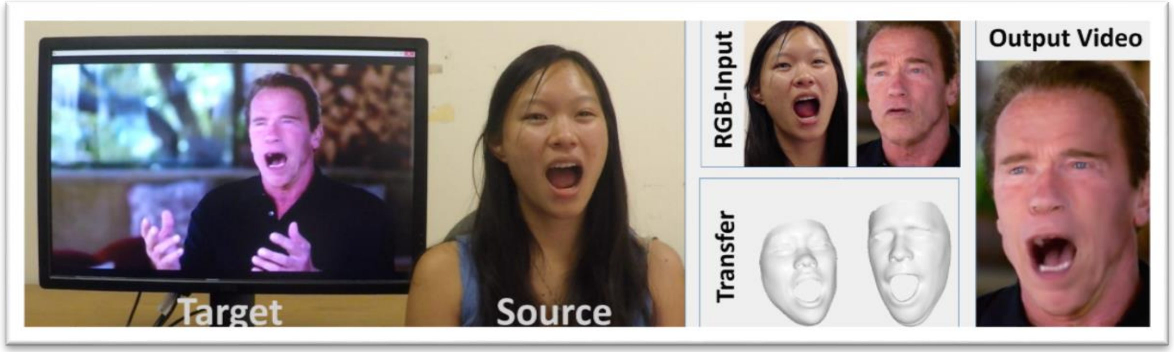
Research Projects

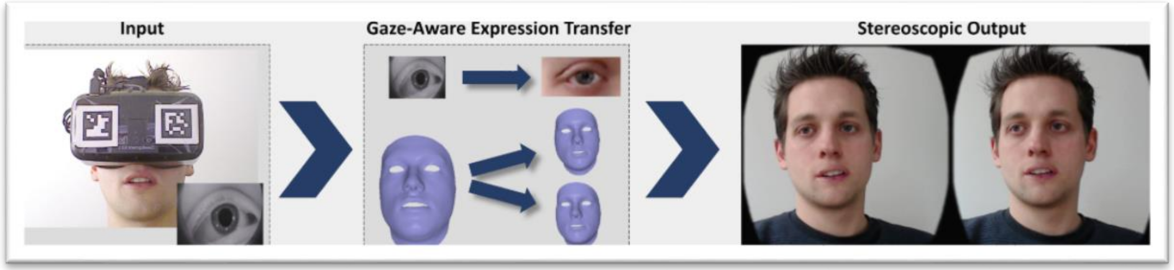


Research Projects









Lecture+Tutorials

- Requirements
  - C++ is a must
  - Profound knowledge of linear algebra
  - Basic concepts of 3D graphics

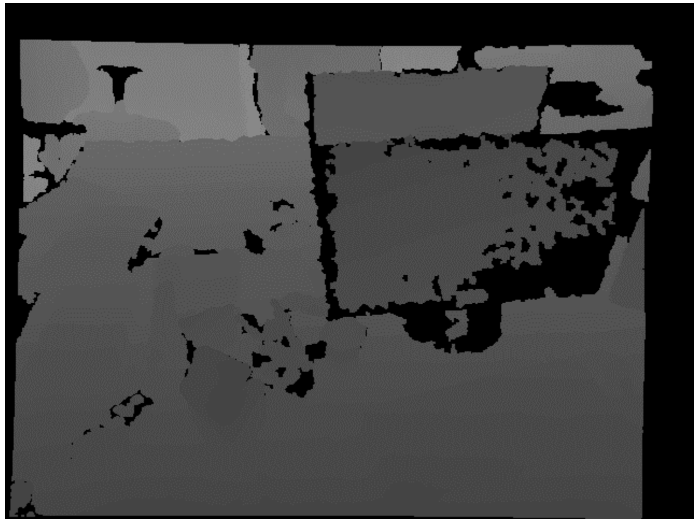
Tutorials

- Basic 3D reconstruction algorithms
  1. Exercise (Camera Intrinsics, Back-projection, Meshes)
  2. Exercise (Surface Representations, Volumetric Fusion, SDF)
  3. Exercise (Object Alignment, ICP)
  4. Exercise (Feature Matching)
- 1 week of working time
- **Groups of two** are allowed
- Need to pass at least three exercise submissions, with the fourth being at least borderline accepted for 0.3 bonus

Project

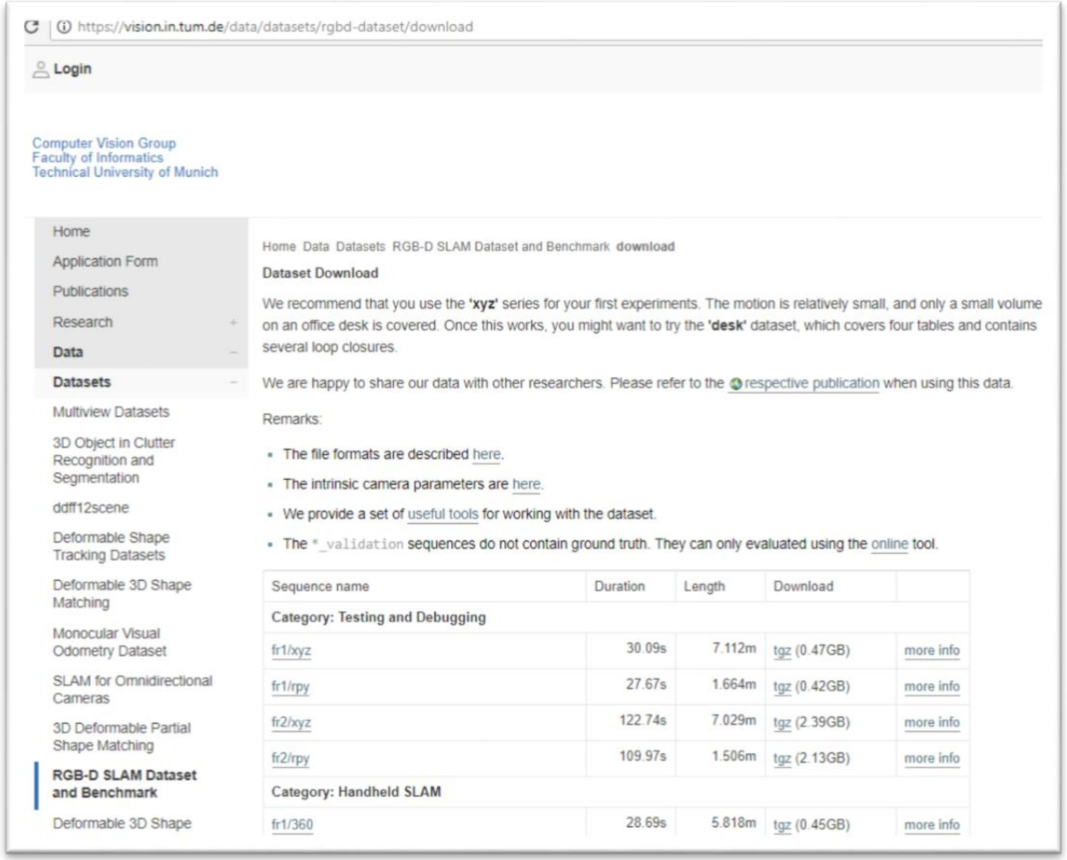
- 3D reconstruction / tracking project
  - KinectFusion, Face Fitting, Bundling etc. …
- 6 weeks
- Groups of 4
- Proposal (abstract 1-2 pages)
- Presentation of the project (poster) + abstract (2 pages with results)
- 40% of the exam

Kinect



Kinect – RGB-D Dataset

- https://vision.in.tum.de/data/datasets/rgbd-dataset



https://vision.in.tum.de/data/datasets/rgbd-dataset/download

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Dataset Download

We recommend that you use the **'xyz'** series for your first experiments. The motion is relatively small, and only a small volume on an office desk is covered. Once this works, you might want to try the **'desk'** dataset, which covers four tables and contains several loop closures.

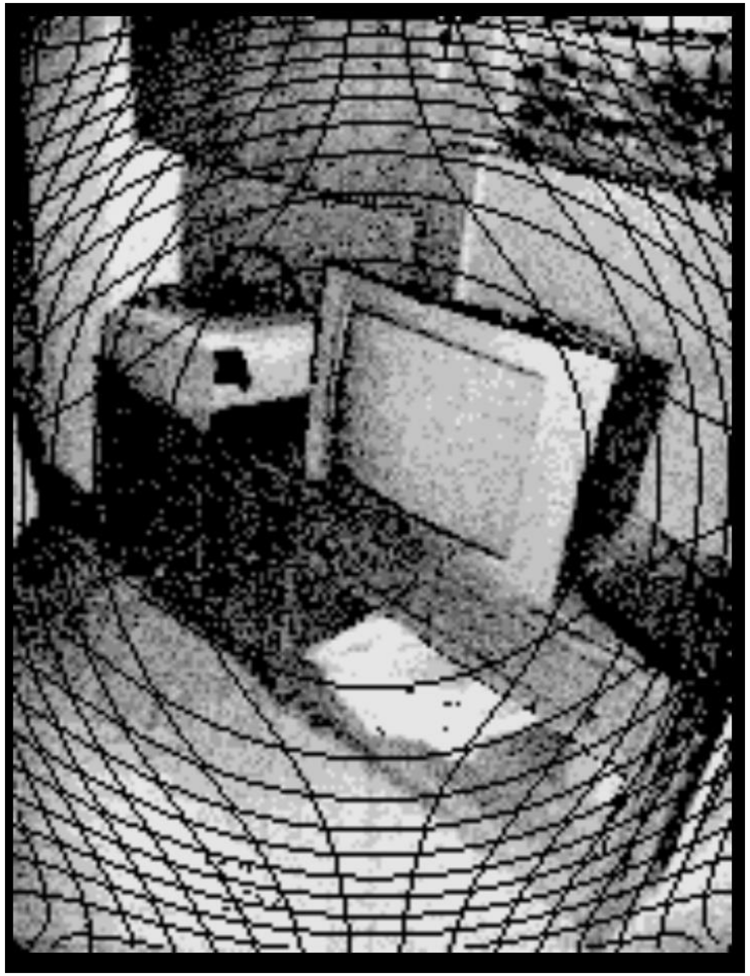
We are happy to share our data with other researchers. Please refer to the respective publication when using this data.

Remarks:

- The file formats are described here.
- The intrinsic camera parameters are here.
- We provide a set of useful tools for working with the dataset.
- The `*_validation` sequences do not contain ground truth. They can only evaluated using the online tool.

Sequence name	Duration	Length	Download	
Category: Testing and Debugging				
fr1/xyz	30.09s	7.112m	tgz (0.47GB)	more info
fr1/rpy	27.67s	1.664m	tgz (0.42GB)	more info
fr2/xyz	122.74s	7.029m	tgz (2.39GB)	more info
fr2/rpy	109.97s	1.506m	tgz (2.13GB)	more info
Category: Handheld SLAM				
fr1/360	28.69s	5.818m	tgz (0.45GB)	more info

Example: RGB and Depth Pair from Google Tango



Tasks

- Back-Projection
  - Use the given intrinsics, extrinsics and the camera trajectory to project the camera observation back to world space
  - Assign the color to the back-projected points
- Write a 3D mesh
  - Write an OFF file containing the back-projected position and color information
  - Make use of the grid structure of the observation to perform the triangulation

Projection Pipeline (from World to Pixels)

$$p_{world} := \text{arbitary point} \in \mathbb{R}^4 = \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}^T$$

$$M_{camera} := \text{camera pose} \in \mathbb{R}^{4\times4}$$

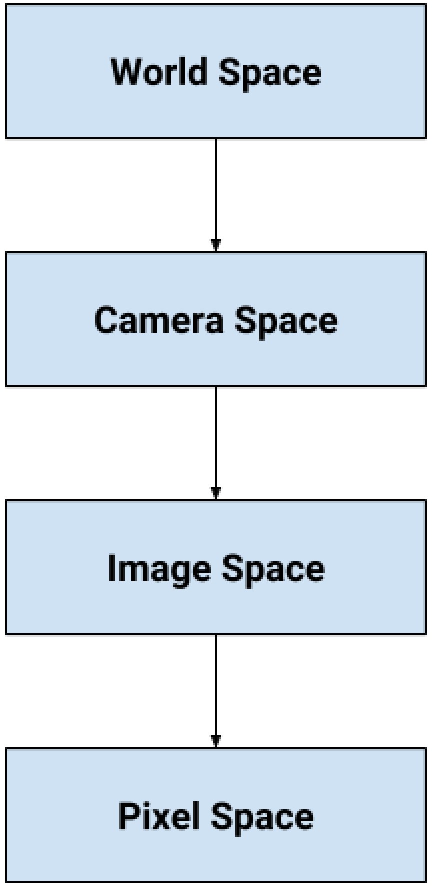
$$K := \text{intrinsic matrix} \in \mathbb{R}^{3\times3} = \begin{bmatrix} \frac{f\cdot w}{W} & 0 & c_x \\ 0 & \frac{f\cdot h}{H} & c_y \\ 0 & 0 & 1 \end{bmatrix}$$

$$E := \text{extrinsic matrix} \in \mathbb{R}^{4\times4} = \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix}$$

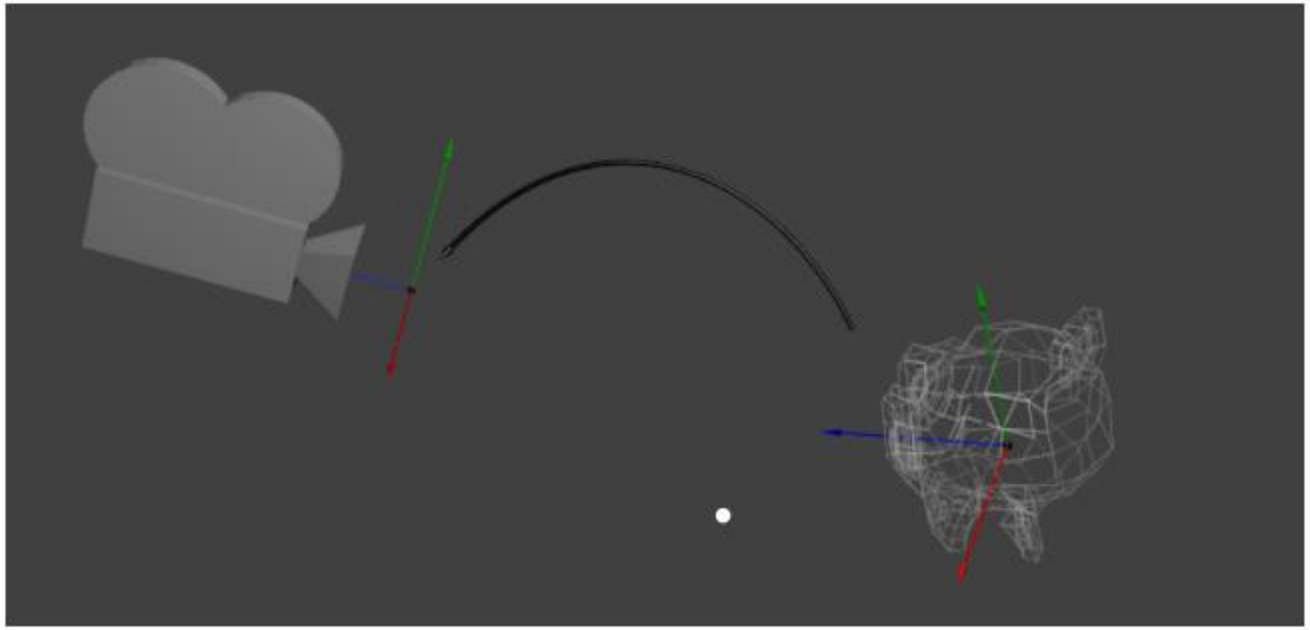
$$p_{camera} = E \cdot M_{camera} \cdot p_{world} \in \mathbb{R}^4$$

$$p_{image} = K \cdot \begin{bmatrix} I_3 & 0 \end{bmatrix} \cdot p_{camera} \in \mathbb{R}^3$$

$$p_{pixel} = \frac{1}{p_{image,z}} \begin{bmatrix} p_{image,x} \\ p_{image,y} \end{bmatrix} \in \mathbb{R}^2$$

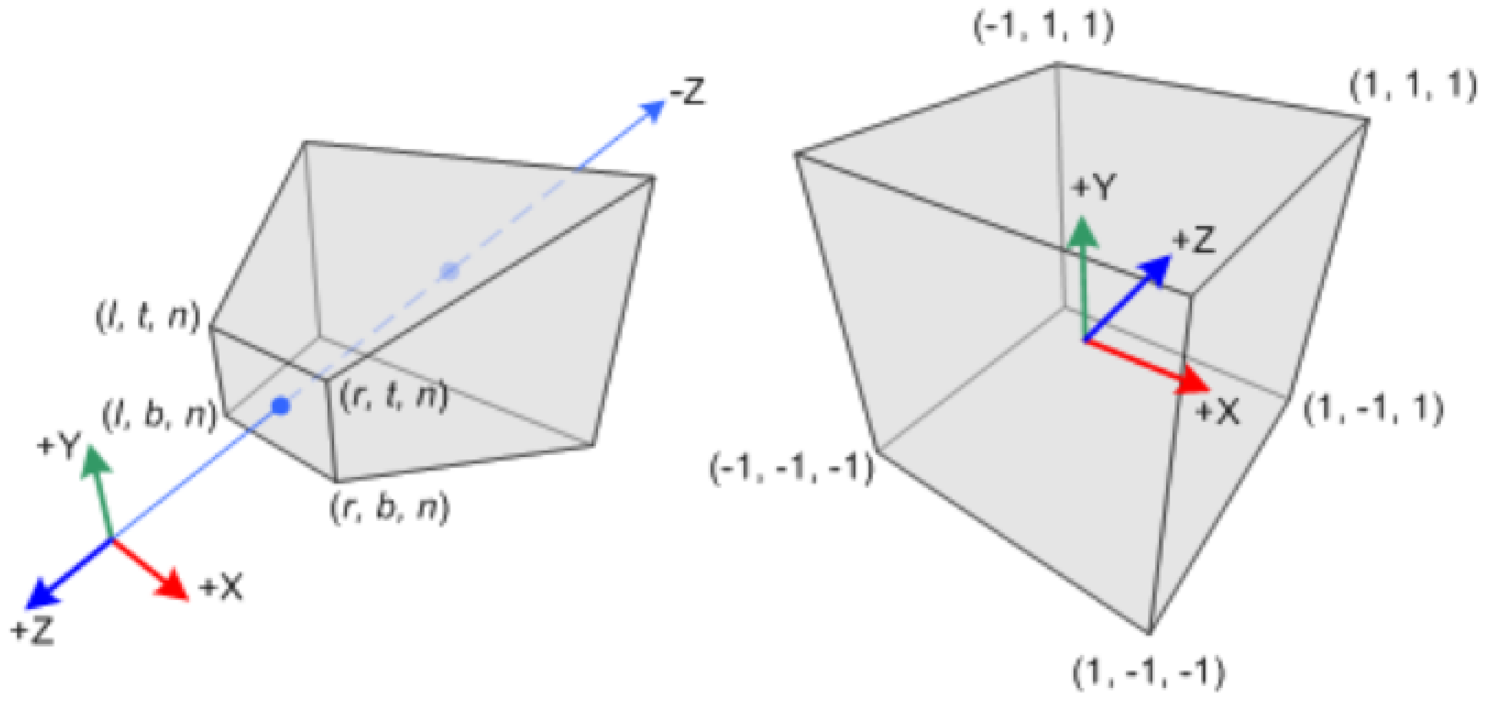


Projection Pipeline



Arbitrary point in the world E.g. point on the monkey	$p_{world} \in \mathbb{R}^3$
Camera pose Somewhere in the world with some look-at direction	$M_{camera} \in \mathbb{R}^{4\times4}$

Perspective Projection in CG



Perspective Frustum and Normalized Device Coordinates (NDC)

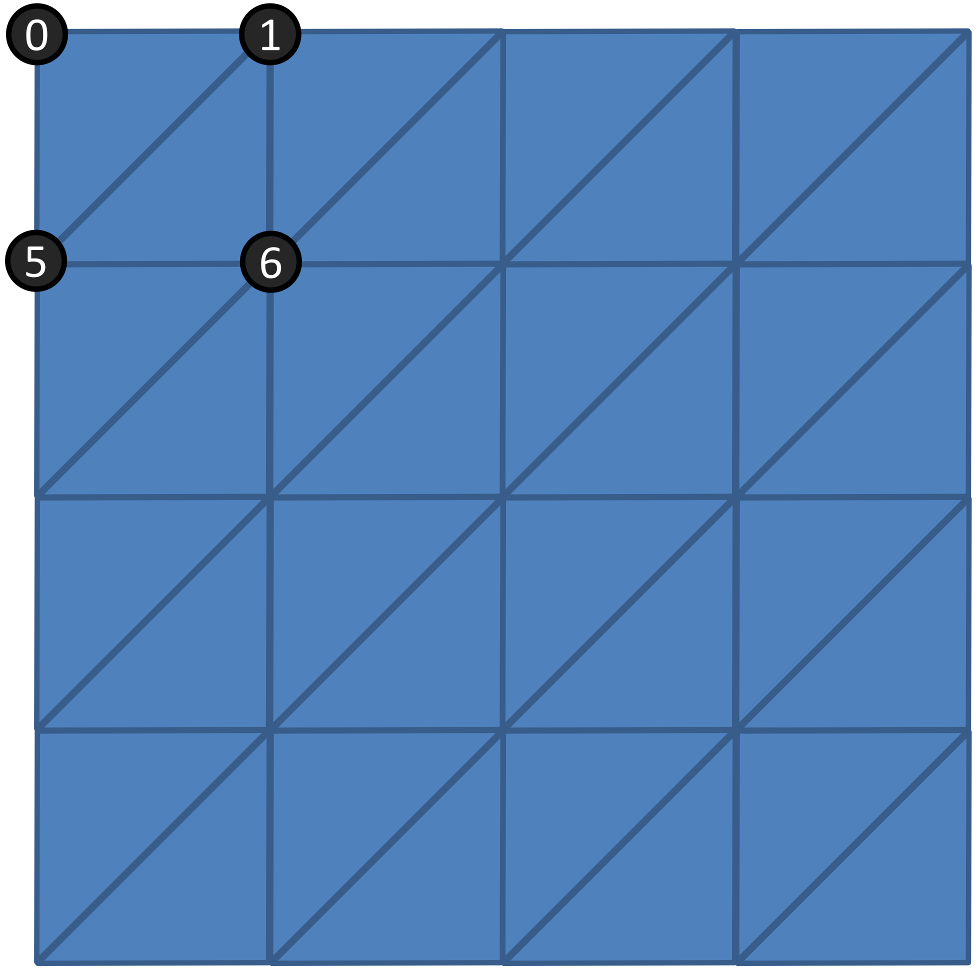
- http://www.songho.ca/opengl/gl_projectionmatrix.html
- https://www.scratchapixel.com/lessons/3d-basic-rendering/perspective-and-orthographic-projection-matrix/opengl-perspective-projection-matrix

Perspective Projection in CV

$$\begin{pmatrix} fov_X & 0 & c_x \\ 0 & fov_Y & c_y \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ \boldsymbol{z} \end{pmatrix} = \begin{pmatrix} u' \\ v' \\ w' \end{pmatrix} \xrightarrow[\textbf{Dehomogenization}]{} \begin{pmatrix} \boldsymbol{u} \\ \boldsymbol{v} \end{pmatrix} = \begin{pmatrix} u'/_{w'} \\ v'/_{w'} \end{pmatrix}$$

- Keep track of the unmapped z values!
- For backprojection, perform the transformations in reverse order

Mesh Structure



Ensure consistent orientation of the triangles!

Example:

First triangle: 0-5-1

Second triangle: 5-6-1

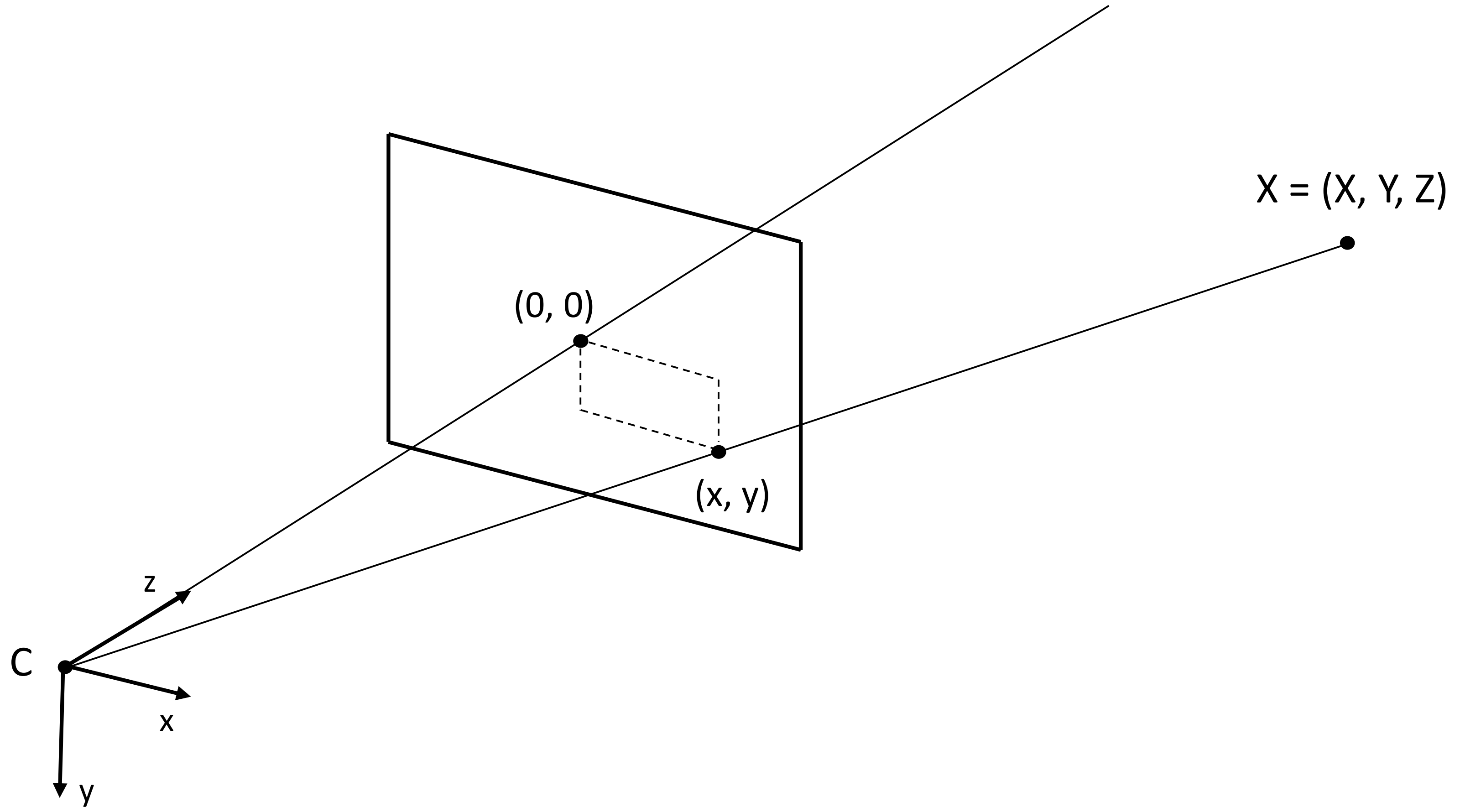
Visual Studio 2017 Community

- https://www.visualstudio.com/de/downloads/

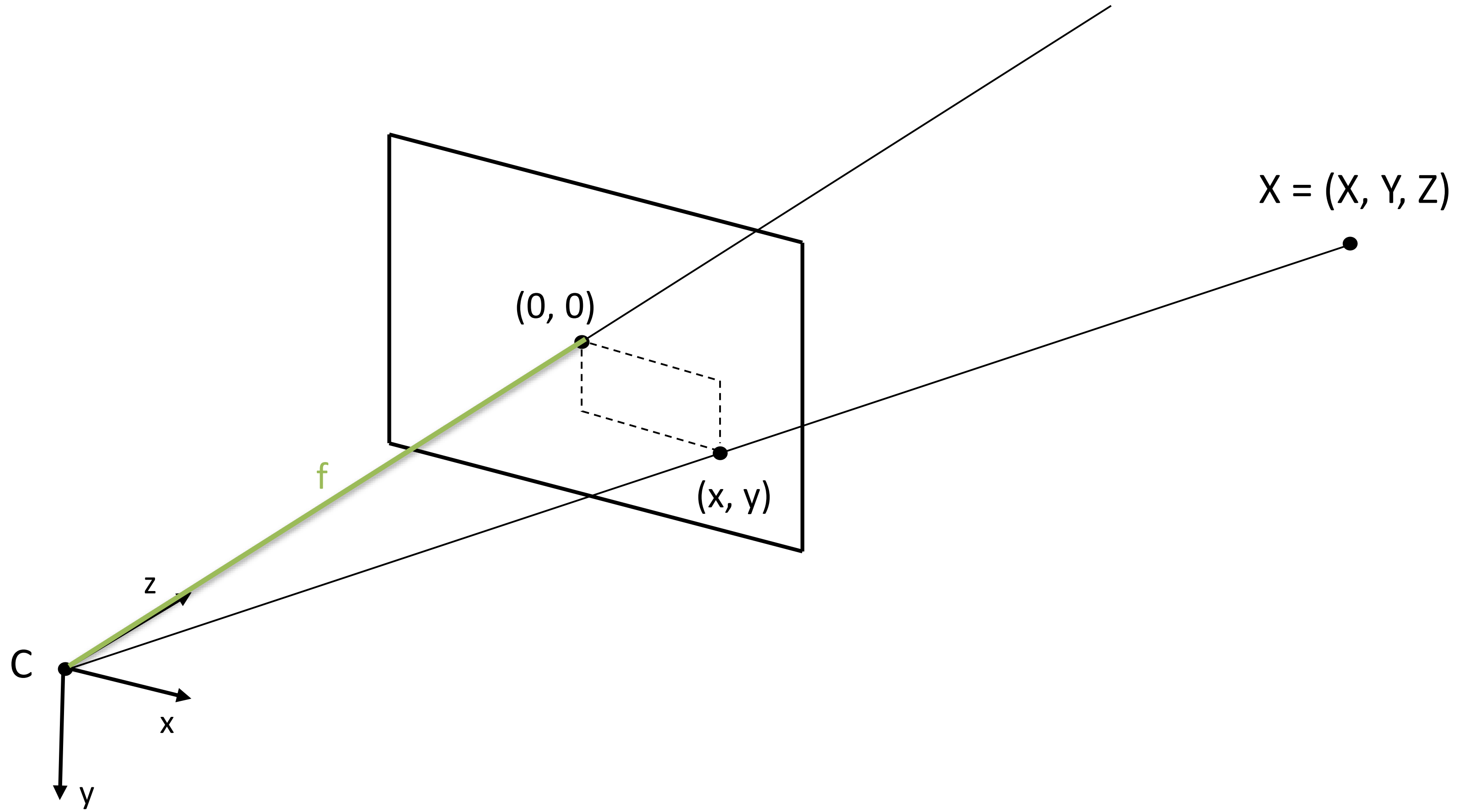
- Known issues:
  - fatal error LNK1104: cannot open file ‘gdi32.lib‘
    - https://stackoverflow.com/questions/33599723/fatal-error-lnk1104-cannot-open-file-gdi32-lib

Supplemental material for perspective projection

Pinhole camera model

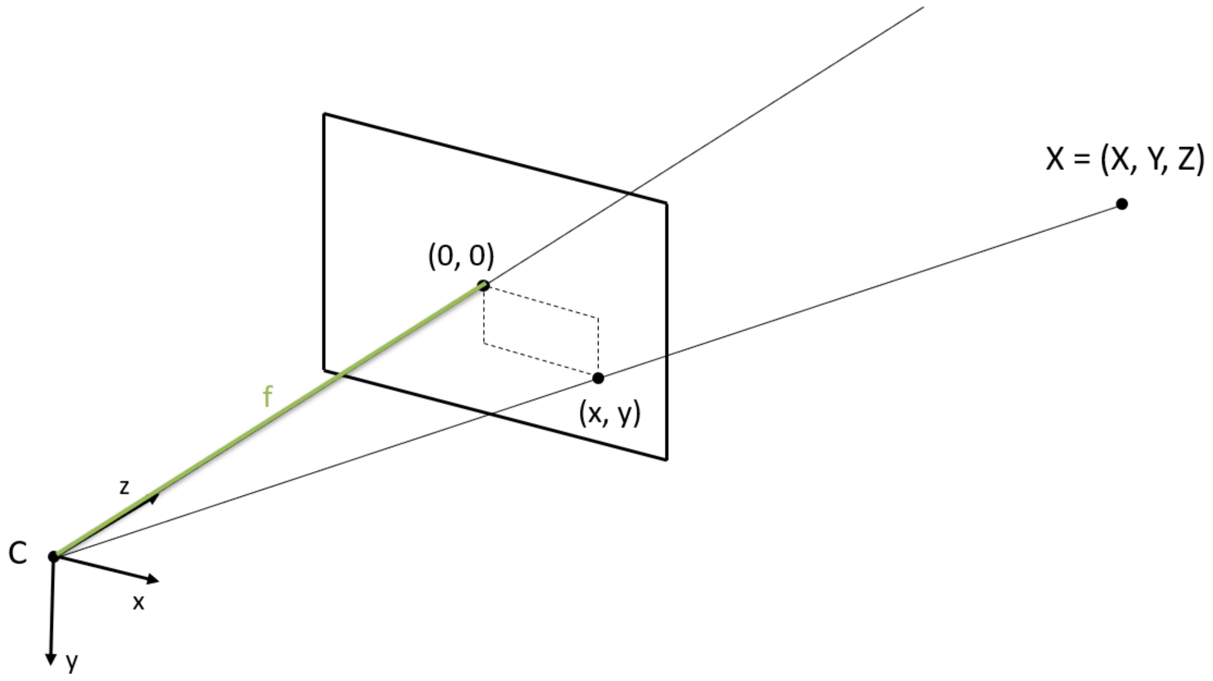


Pinhole camera model

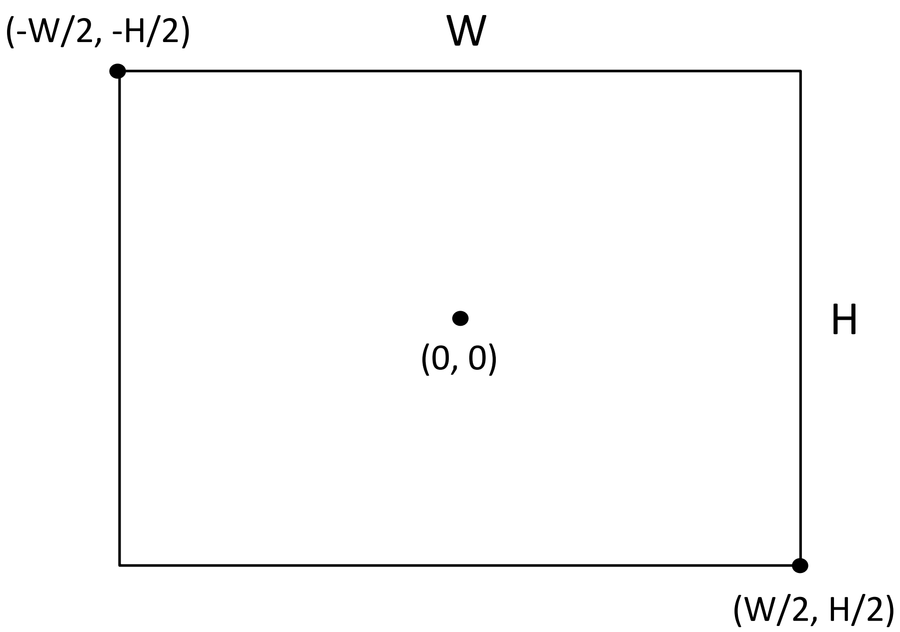


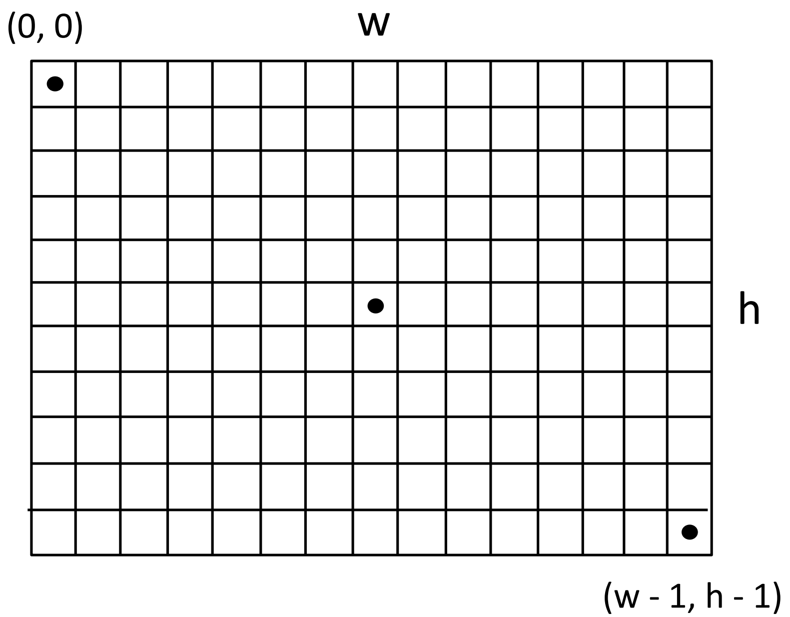
Pinhole camera model

$$\begin{pmatrix} x \\ y \end{pmatrix} = f \cdot \begin{pmatrix} X/Z \\ Y/Z \end{pmatrix}$$

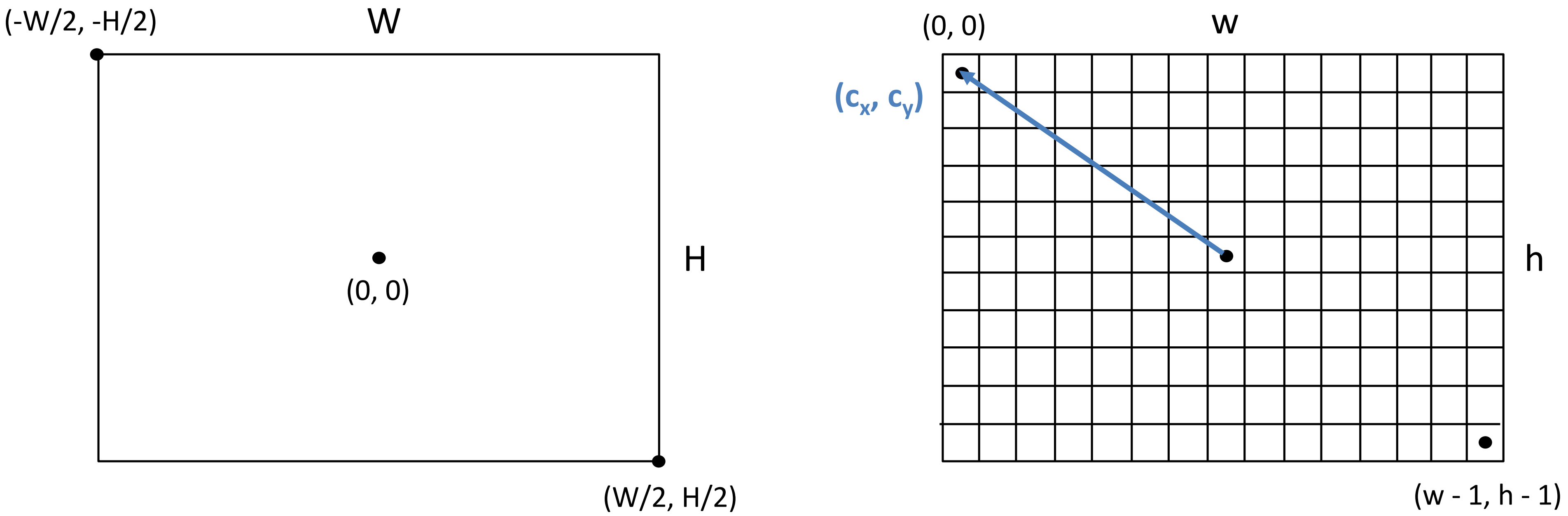


From sensor to pixels





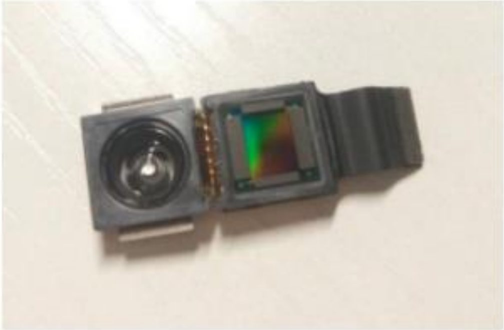
From sensor to pixels



Intrinsic parameters

Camera sensor

- Sensor width = 4.54 mm
- Sensor height = 3.42 mm
- focal length = 4.1 mm



Compare: Professional cameras have 35mm sensor!

Intrinsic matrix

$$
\begin{aligned}
f &:= \text{focal length} = 4.1mm \\
W &:= \text{sensor width} = 4.54mm \\
H &:= \text{sensor height} = 3.42mm \\
w &:= \text{image width} = 640 \\
h &:= \text{image width} = 480 \\
c_x &:= \text{image center x} = 320 \\
c_y &:= \text{image center y} = 240
\end{aligned}
$$

$$
\text{Resulting intrisic matrix}: \begin{bmatrix} \frac{f \cdot w}{W} & 0 & c_x \\ 0 & \frac{f \cdot h}{H} & c_y \\ 0 & 0 & 1 \end{bmatrix}
$$