3D Scanning & Motion Capture

Exercise - 1

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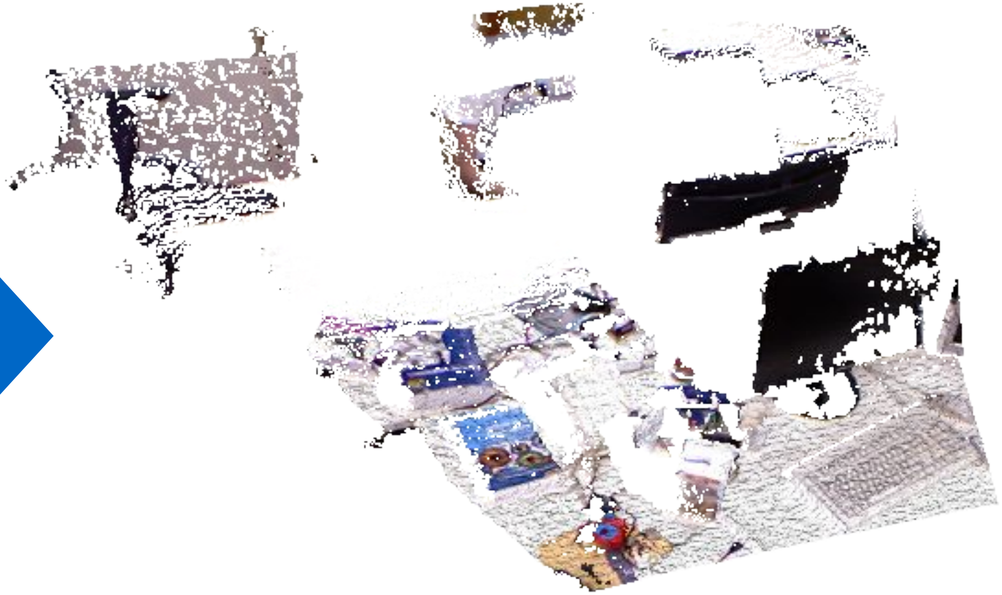
Exercises – Overview

1. **Exercise → Camera Intrinsics, Back-projection, Meshes**
2. Exercise → Surface Representations
3. Exercise → Optimization
4. Exercise → Coarse Alignment (Procrustes)
5. Exercise → Object Alignment, ICP

Exercise 1

1. **Exercise → Camera Intrinsics, Back-projection, Meshes**



TUM-RGB-D SLAM Dataset

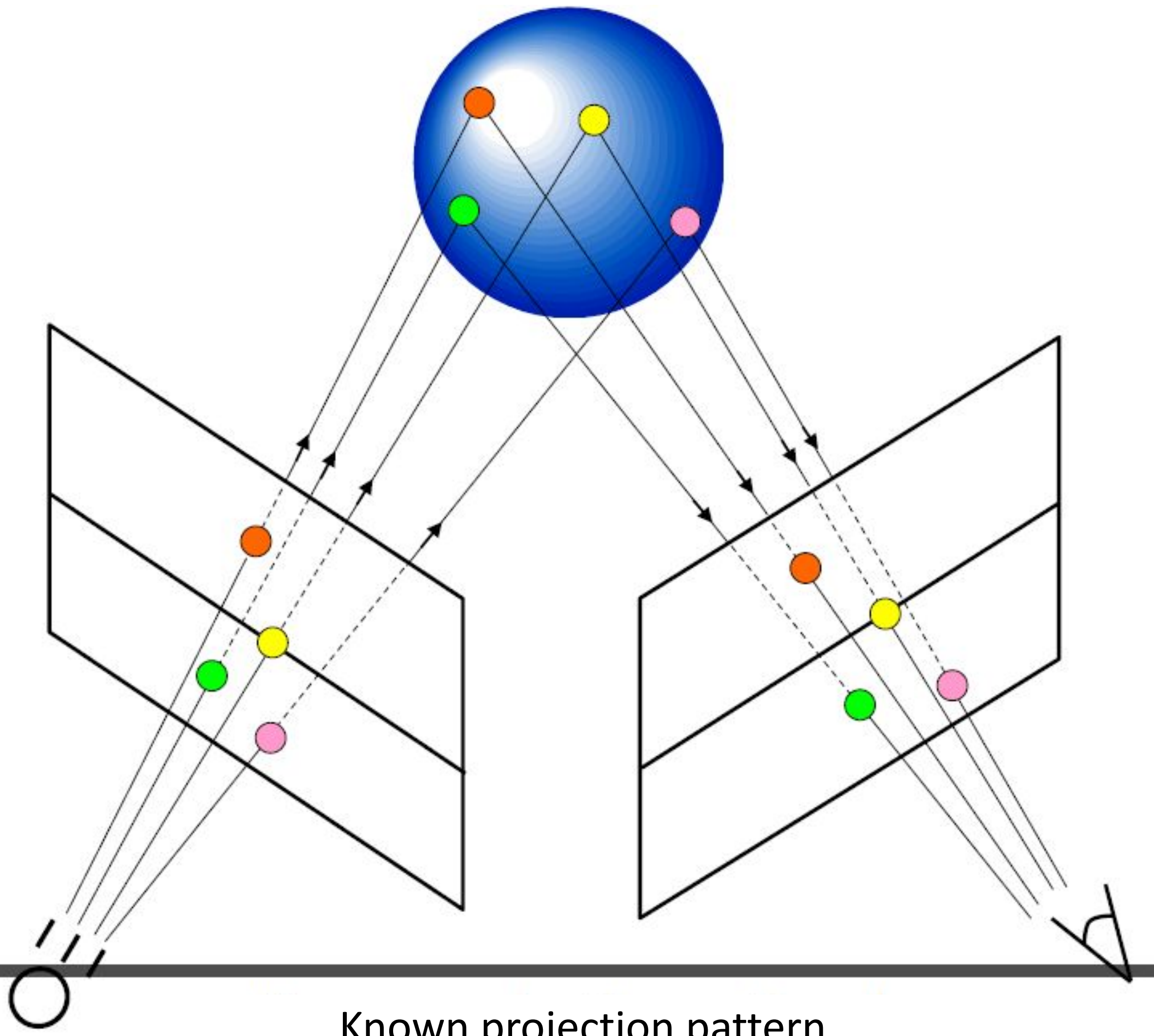
- https://vision.in.tum.de/data/datasets/rgbd-dataset
- 39 sequences
- Recorded using Kinect v.1
  - Structured light
  - Calibrated
  - Aligned depth and color maps
- Camera trajectory

TUM-RGB-D SLAM Dataset

Scene: “fr1/xyz”

Kinect v.1 – Depth and Color Information

Kinect v.1 – Structured Light



Known projection pattern

Tasks

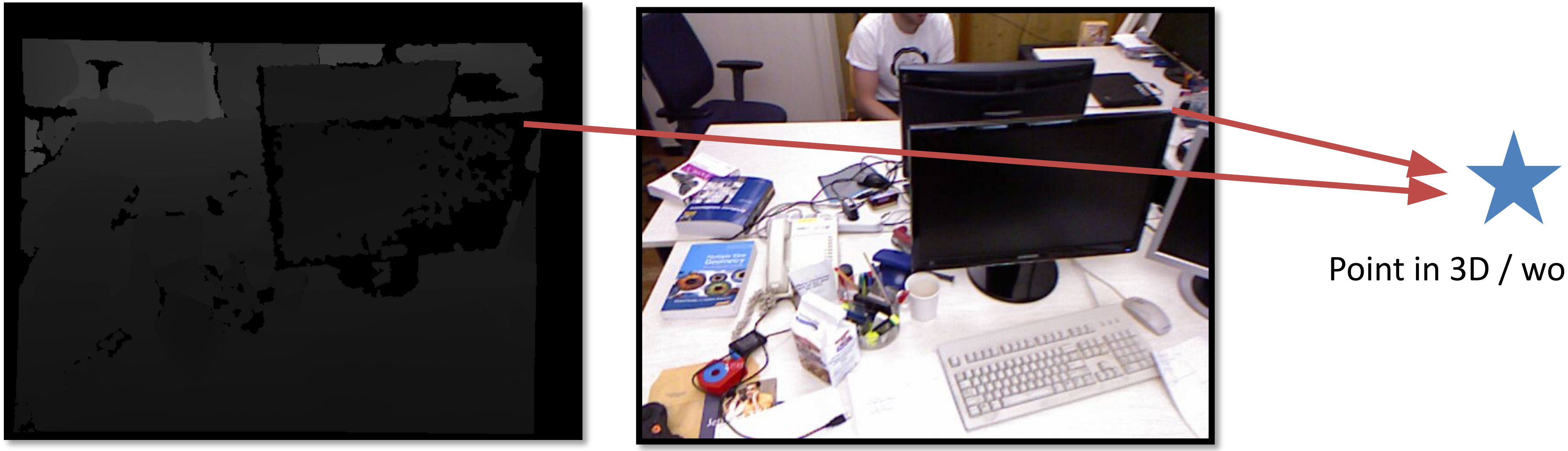
1. Project dependencies & CMake configuration
2. Back-Projection
   – Use the given intrinsics, extrinsics and the camera trajectory to project the camera observation back to world space
   – Assign the color to the back-projected points
3. Write a 3D mesh
   – Write an OFF file containing the back-projected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

Task 1) Project dependencies

- Eigen http://eigen.tuxfamily.org
  - Headers-only
  - Linear Algebra library
  - Matrix, Vector, Solvers, …
  - TIP: Do not use C++'s `auto`
- FreeImage http://freeimage.sourceforge.net/
  - Support for many image formats
  - Windows: We provide a pre-compiled binary
  - Linux: `$ sudo apt-get install libfreeimage3 libfreeimage-dev`

Task 2) Back-Projection

- Use depth map, camera intrinsics and trajectory to project points from 2D $\rightarrow$ 3D.

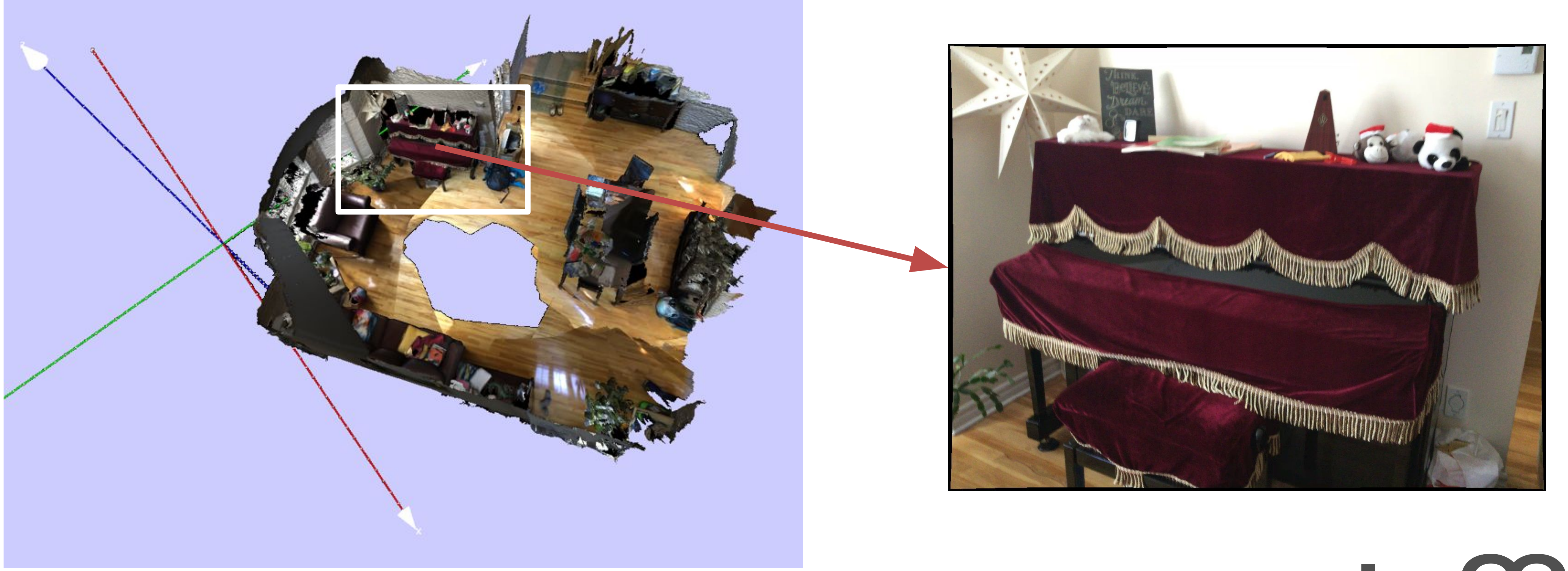


1 float / pixel (z)

4 chars / pixel (R, G, B, A)

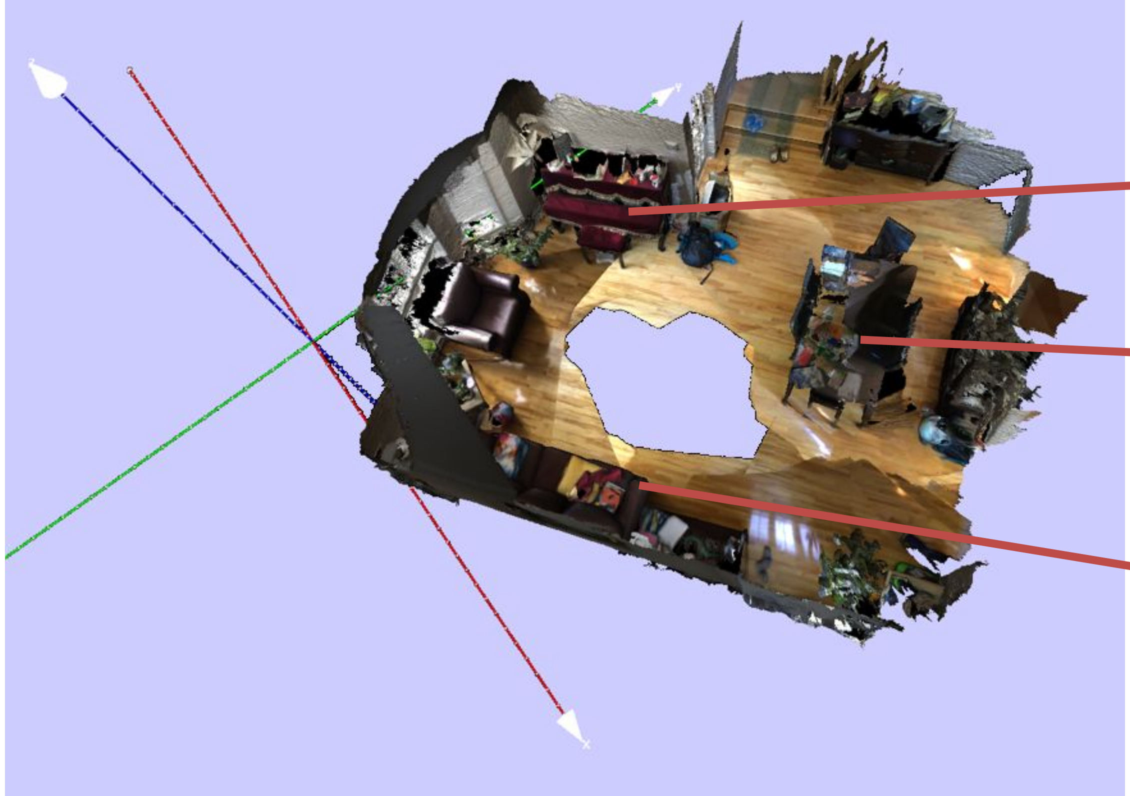
How are images synthesized?

- Given a real-world/CG scene and a camera, we want to project the 3D points in the scene to 2D pixel positions in the image



World Space

- Every point in the scene has its (X, Y, Z) coordinates



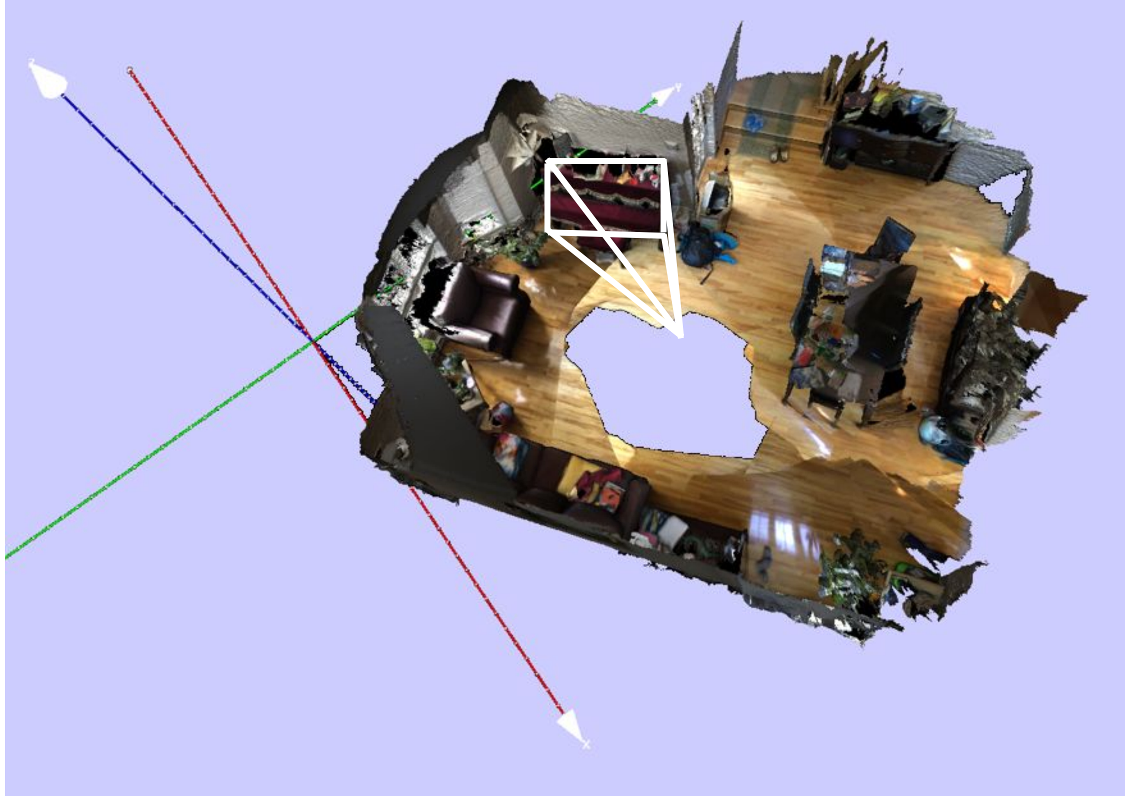
(X, Y, Z) = (0.78, 2.31, 0.57)

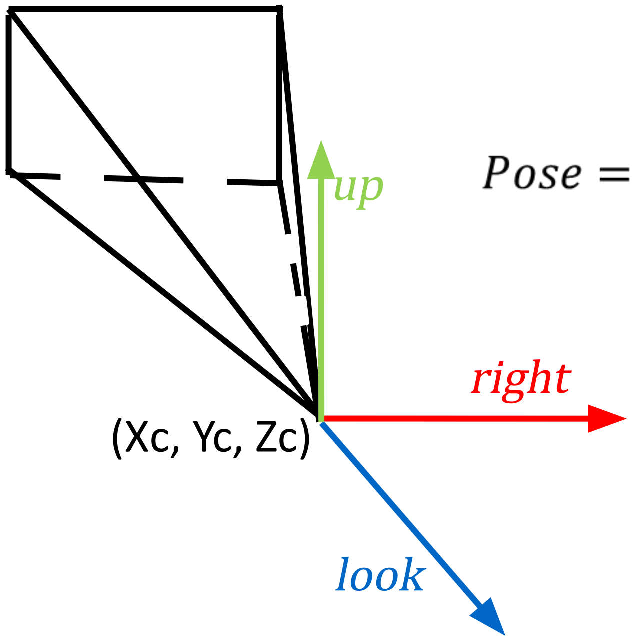
(X, Y, Z) = (3.13, 3.41, 0.65)

(X, Y, Z) = (2.74, 1.55, 0.52)

World -> Camera Space

- We place a camera at the (X, Y, Z) position in world space
- The pose/orientation is given by the right/up/look vectors

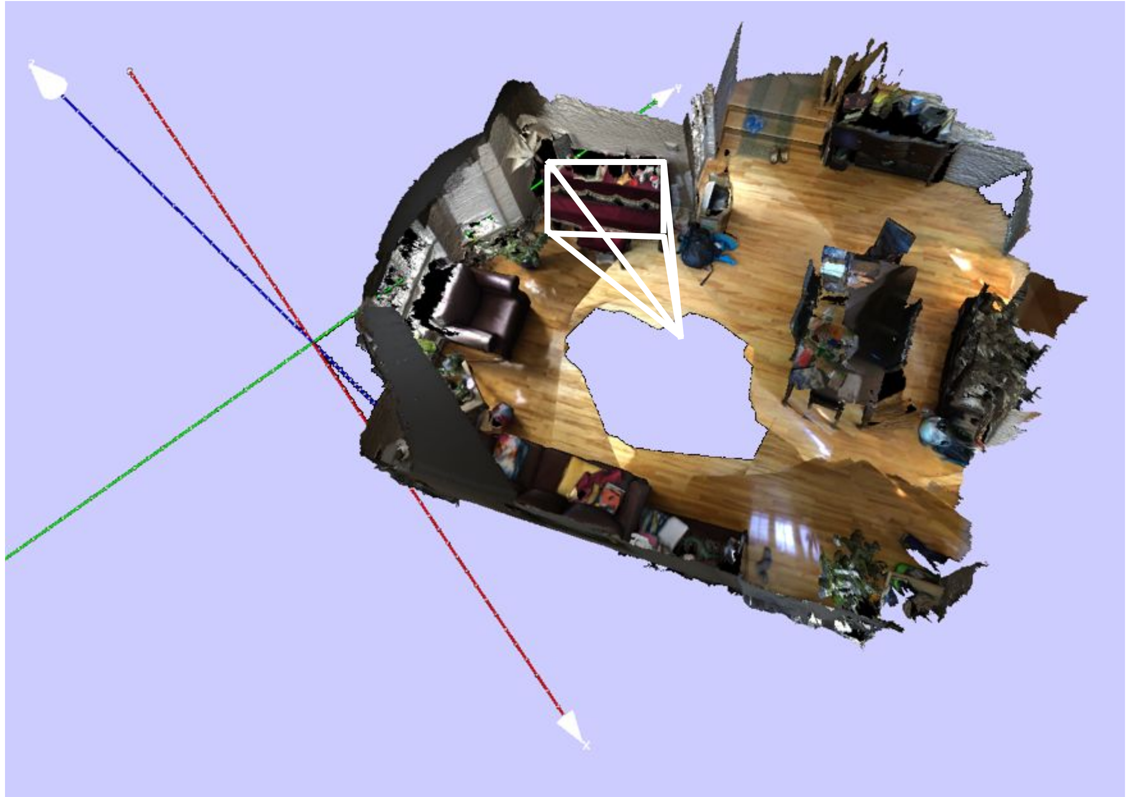




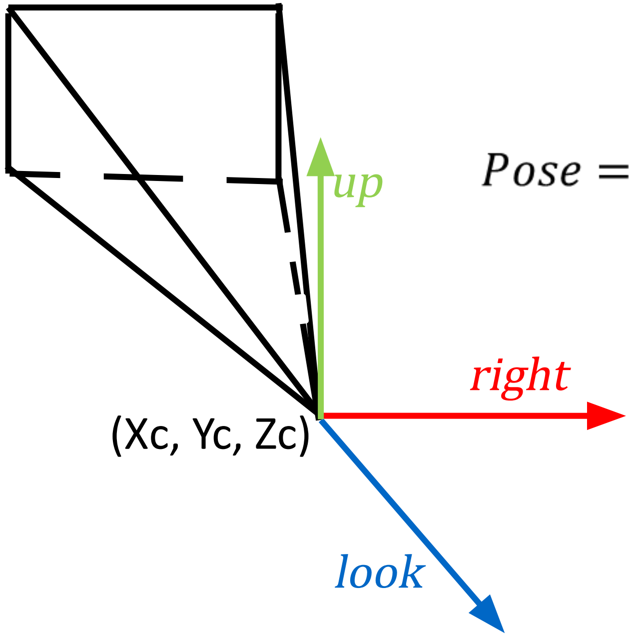
$$Pose = \begin{pmatrix} R_x & U_x & L_x & X_c \\ R_y & U_y & L_y & Y_c \\ R_z & U_z & L_z & Z_c \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

World -> Camera Space

- To transform points from world space to camera space, we need to multiply them by the camera extrinsic matrix

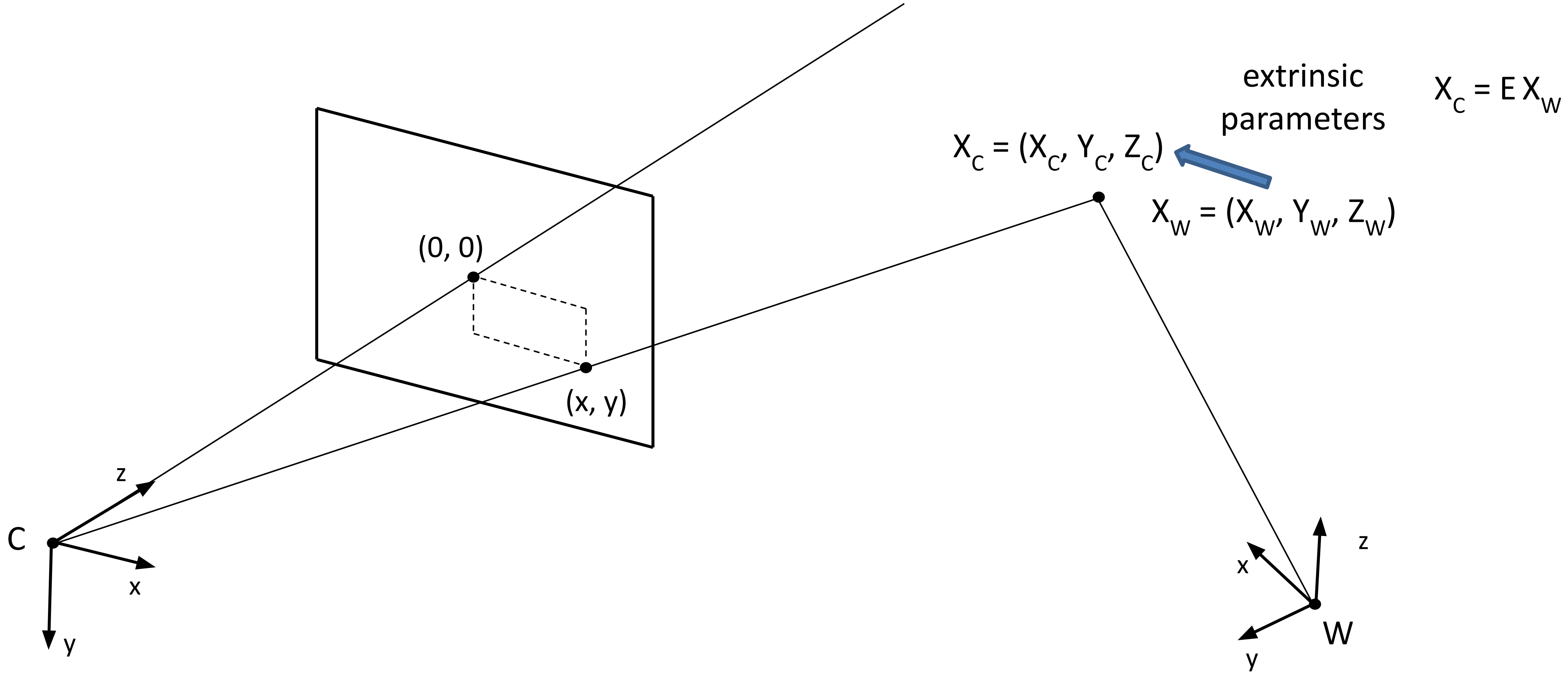


$$\boxed{Extrinsic = Pose^{-1}}$$

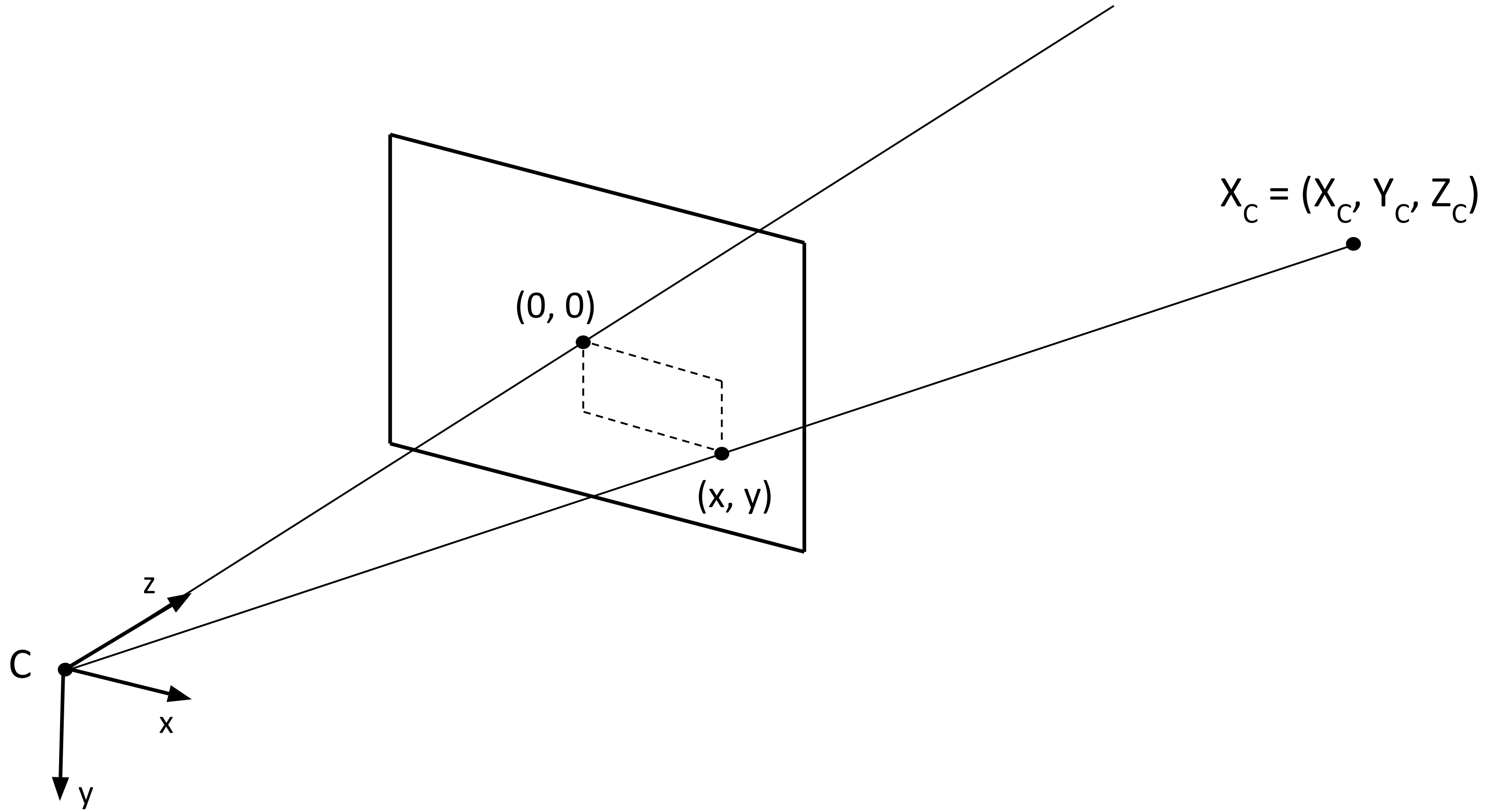


$$Pose = \begin{pmatrix} R_x & U_x & L_x & X_c \\ R_y & U_y & L_y & Y_c \\ R_z & U_z & L_z & Z_c \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

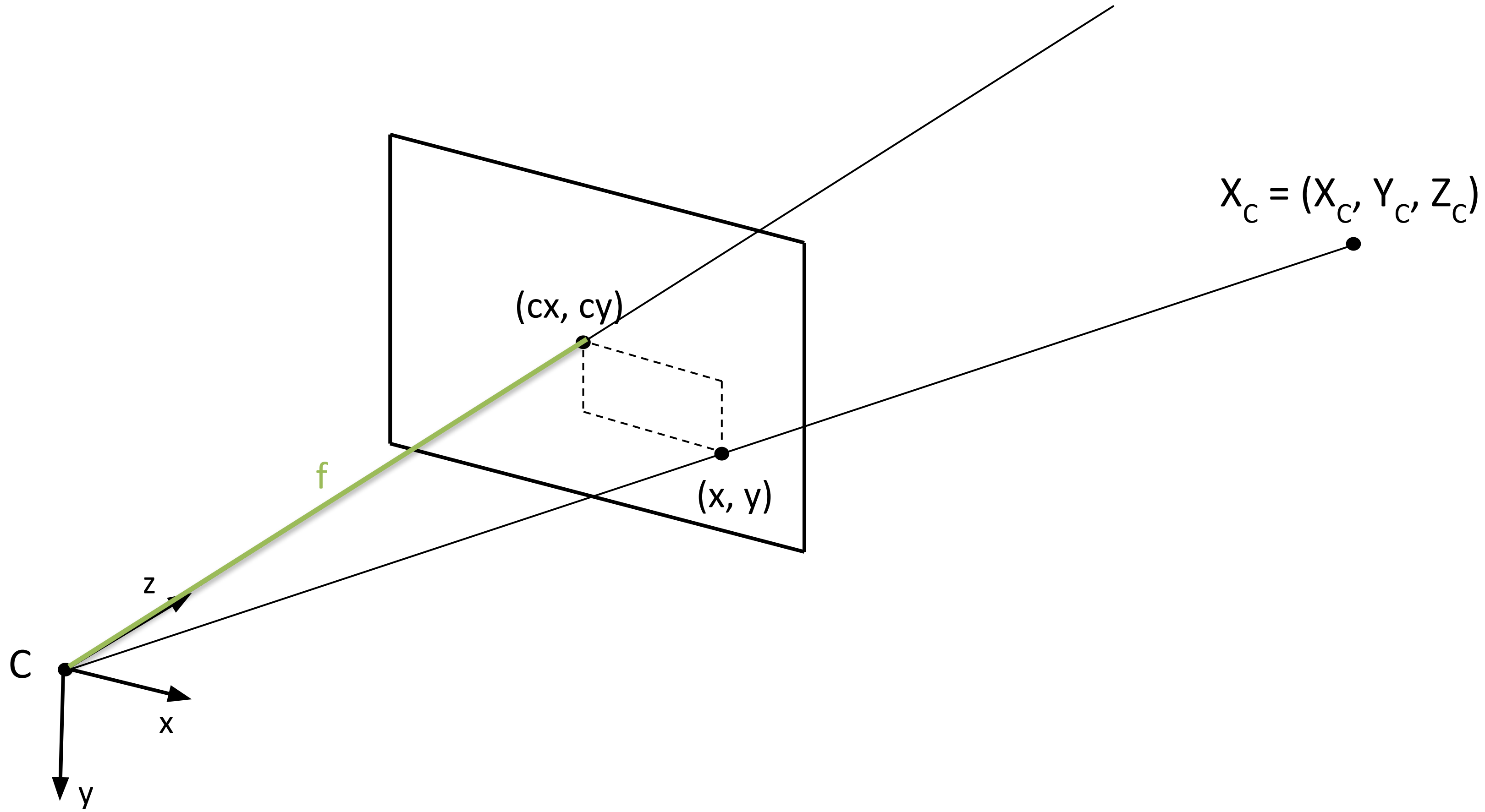
Camera Extrinsic matrix



Pinhole camera model



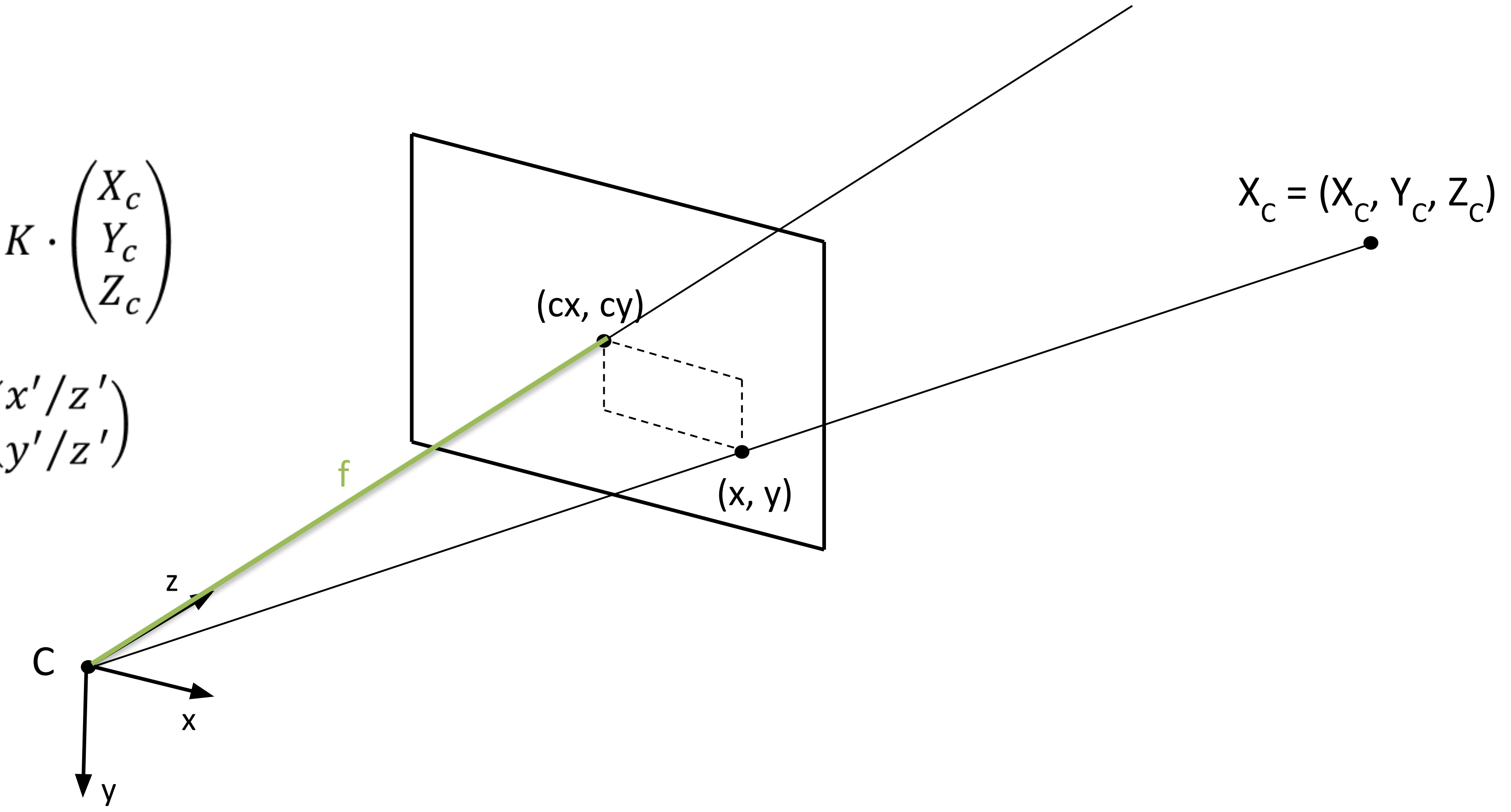
Pinhole camera model



Camera Intrinsic Matrix

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = K \cdot \begin{pmatrix} X_c \\ Y_c \\ Z_c \end{pmatrix}$$

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} x'/z' \\ y'/z' \end{pmatrix}$$



Intrinsic matrix

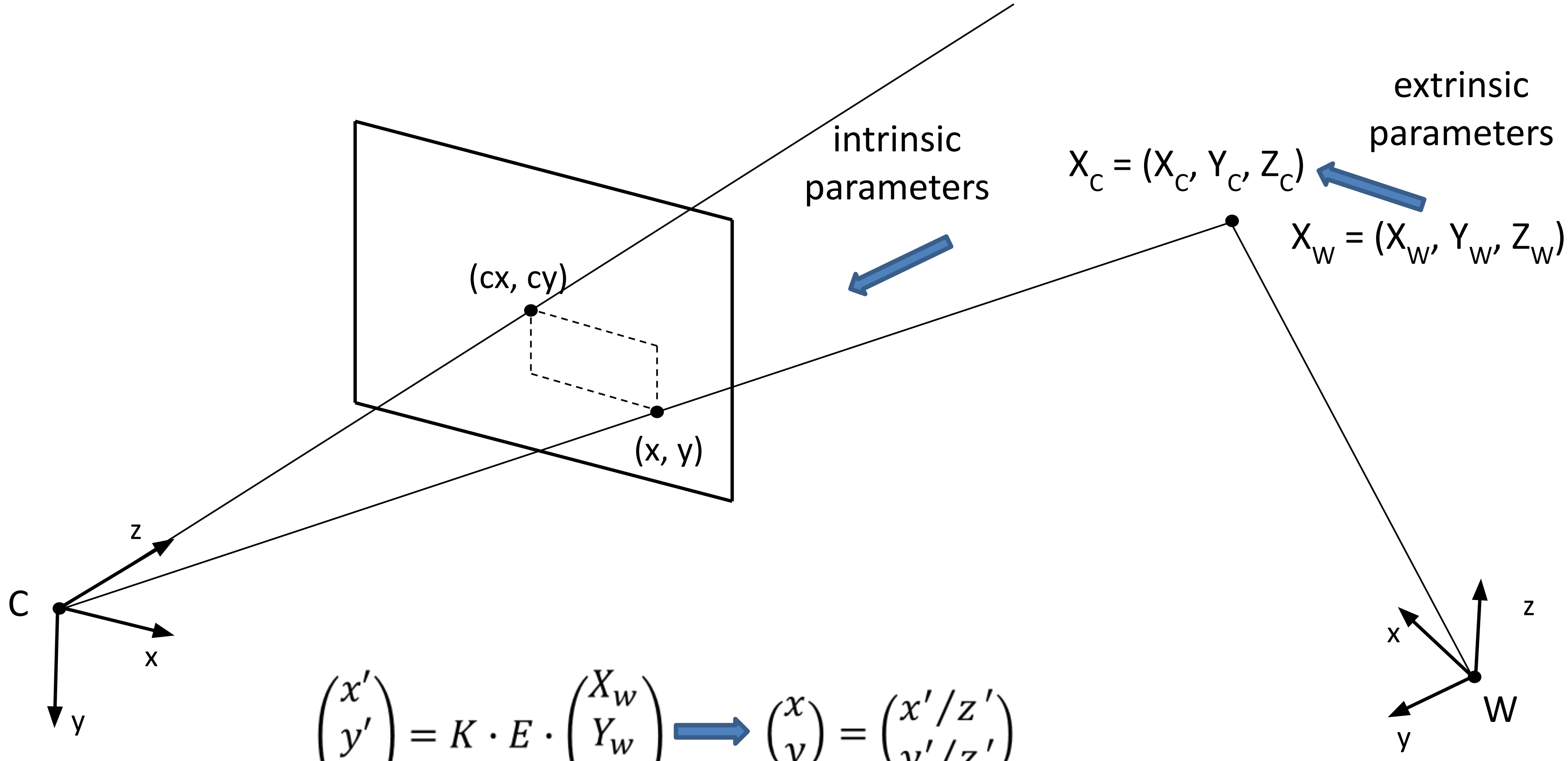
$$f := \text{focal length} = 4.1mm$$
$$W := \text{sensor width} = 4.54mm$$
$$H := \text{sensor height} = 3.42mm$$
$$w := \text{image width} = 640$$
$$h := \text{image width} = 480$$
$$c_x := \text{image center x} = 320$$
$$c_y := \text{image center y} = 240$$

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

Perspective Projection

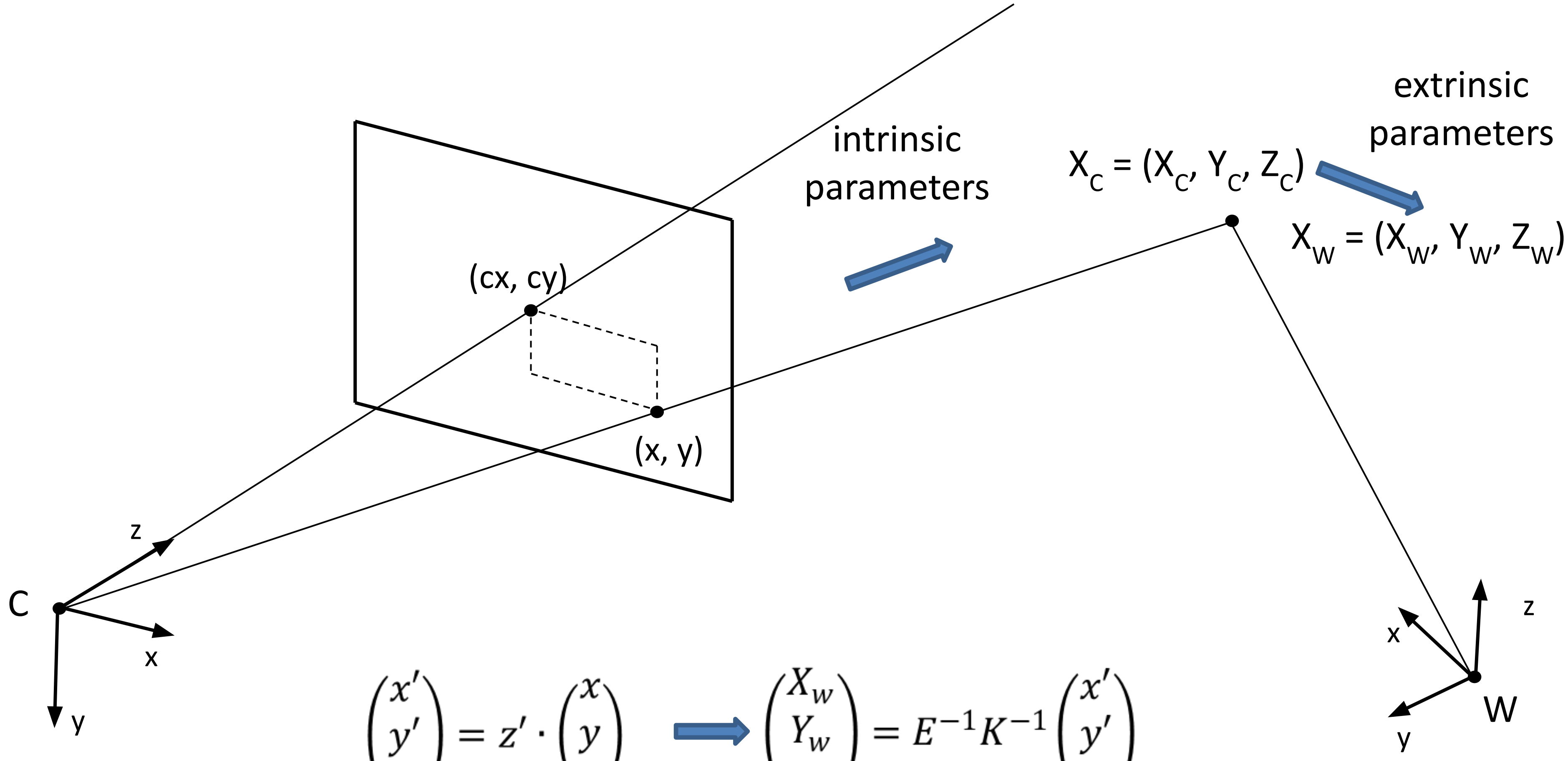
$$\begin{pmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} X_c \\ Y_c \\ Z_c \end{pmatrix} = \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} \xrightarrow[\textbf{Dehomogenization}]{} \begin{pmatrix} \boldsymbol{x} \\ \boldsymbol{y} \end{pmatrix} = \begin{pmatrix} x'/z' \\ y'/z' \end{pmatrix}$$

Projection Pipeline



$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = K \cdot E \cdot \begin{pmatrix} X_W \\ Y_W \\ Z_W \end{pmatrix} \Rightarrow \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} x'/z' \\ y'/z' \end{pmatrix}$$

Projection Pipeline



$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = z' \cdot \begin{pmatrix} x \\ y \\ 1 \end{pmatrix} \Rightarrow \begin{pmatrix} X_W \\ Y_W \\ Z_W \end{pmatrix} = E^{-1} K^{-1} \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix}$$

More Than One Camera

- RGB-D Sensor like the Kinect (or your phone) have multiple cameras
- This raises the question: Which camera does the extrinsic matrix correspond to?

More Than One Camera

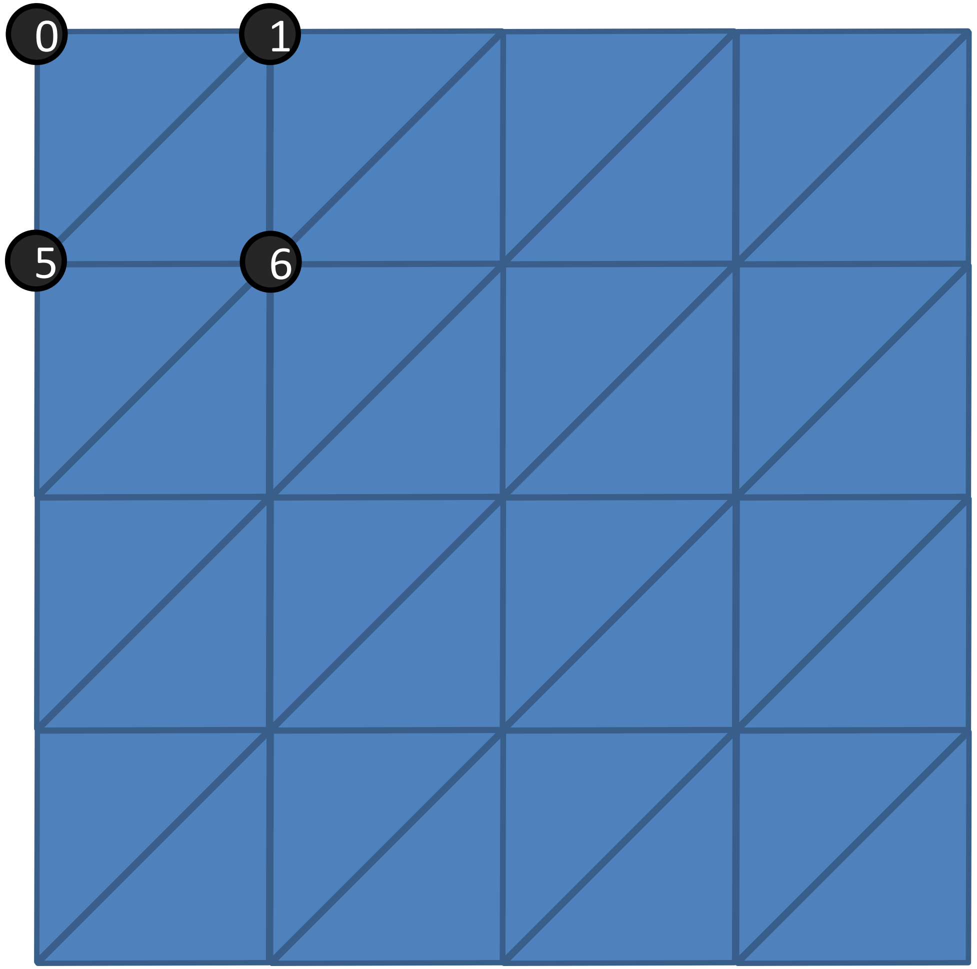
- Pick a point on the camera as the reference
- Each camera gets an extrinsic matrix that describes its pose relative to the reference point

Task 3) Mesh Output

- Write OFF file
  - Simple text-based format
  - Vertices/Points:
    - Position
    - Color
  - Faces
    - Indices of vertices

```
COFF
# numVertices numFaces numEdges
4 2 0
# list of vertices
# X Y Z R G B A
0.0 1.0 0.0 255 255 255 255
0.0 0.0 0.0 255 255 255 255
1.0 0.0 0.0 255 255 255 255
1.0 1.0 0.0 255 255 255 255
# list of faces
# nVerticesPerFace idx0 idx1 idx2 ...
3 0 1 2
3 0 2 3
```

Task 3) Mesh Structure



Ensure consistent orientation of the triangles! (Usually counter-clockwise)

Example:

First triangle: 0-5-1

Second triangle: 5-6-1

Submit your solution to Moodle

- Upload your main.cpp and a snapshot from MeshLab to Moodle
- If you worked in a group
  - **Both team members** of the group should upload the solution
  - List all team members **names** and **matriculation numbers** in a separate **team_members.txt** file and upload it with your solution

See you next time!