3D Point Cloud Processing

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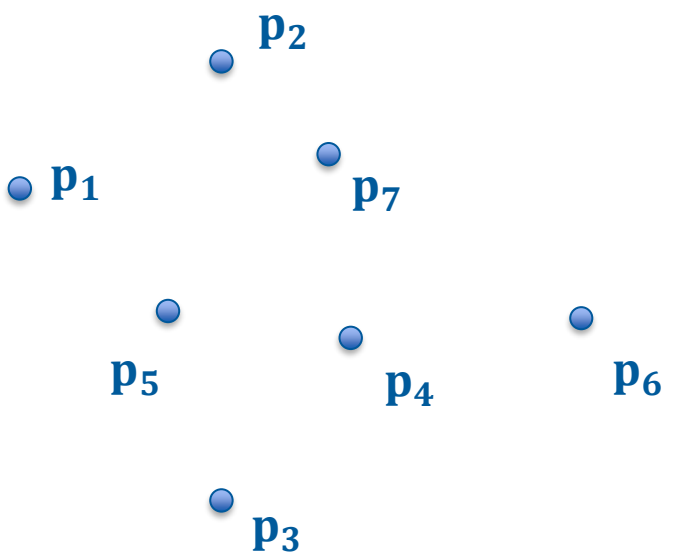
Point Cloud

A 3D point cloud is a set of points with the following properties:

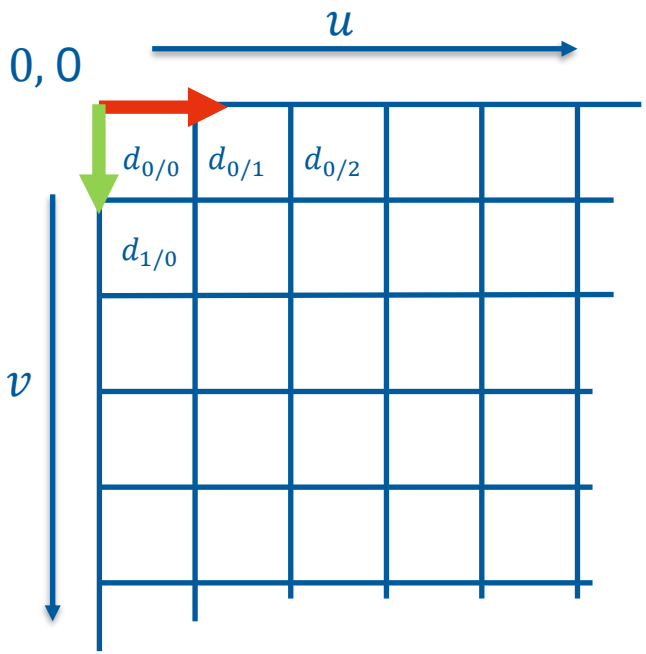
- single point $\mathbf{p}$ contains **three components** for x, y, and z
- the value of the components is **metric**
- the **number of points** in a cloud is arbitrary – here we have n points
- common formats:
  - pcd -> point cloud library
  - ply
- common convention:
  - z values increase in depth
  - values are in meters

$$\mathbf{p}_1 = (x_1, y_1, z_1)^T$$
$$\mathbf{p}_2 = (x_2, y_2, z_2)^T$$
$$\mathbf{p}_3 = (x_3, y_3, z_3)^T$$
$$\vdots$$
$$\mathbf{p}_n = (x_n, y_n, z_n)^T$$



Depth Image

- A depth map or depth image can be seen as a matrix:
- Cells are ordered in a **grid structure**
- A cell is called **pixel q**
- Each pixel is accessed by **two coordinates** u and v
- A pixel has a single value containing the **metric depth information**
- The **number of points** in a depth images is given by the rows and cols, or **width** and **height** of the image
- common formats:
    - npy -> numpy matrix
    - png for visualization



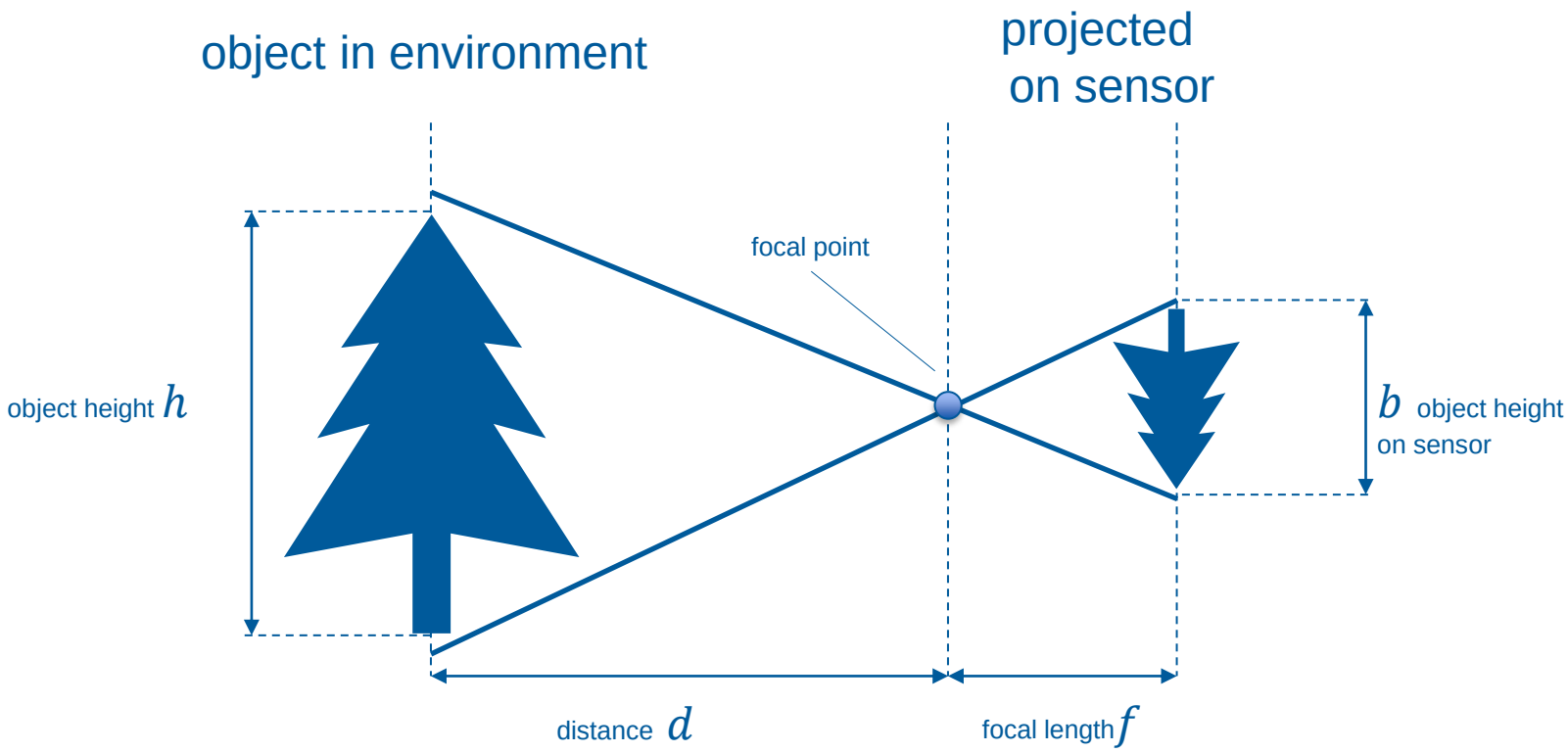
$$u_1, v_1, d_{1/1}$$
$$u_1, v_2, d_{1/2}$$
$$\vdots$$
$$u_2, v_1, d_{1/1}$$
$$u_2, v_2, d_{1/1}$$
$$\vdots$$
$$u_n, v_m, d_{n/m}$$

Pin Hole Camera Model

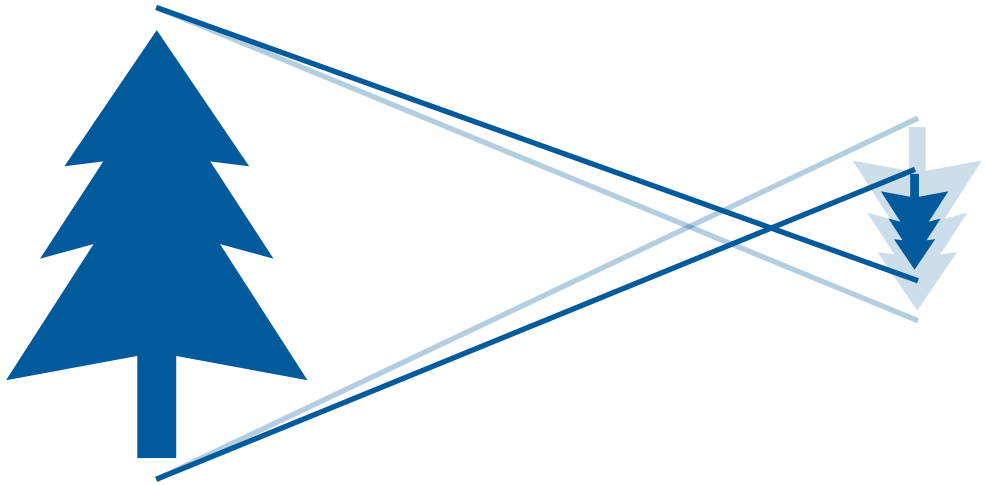
Projecting environment on a image plane

The relation between the object in the environment and the projection on the sensor can be defined by

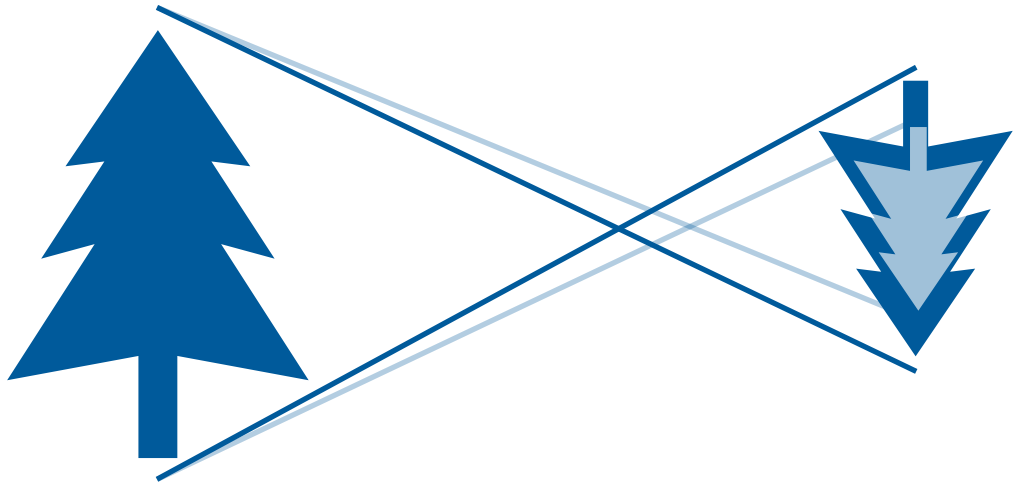
$$\frac{h}{d} = \frac{b}{f}$$



Field of View



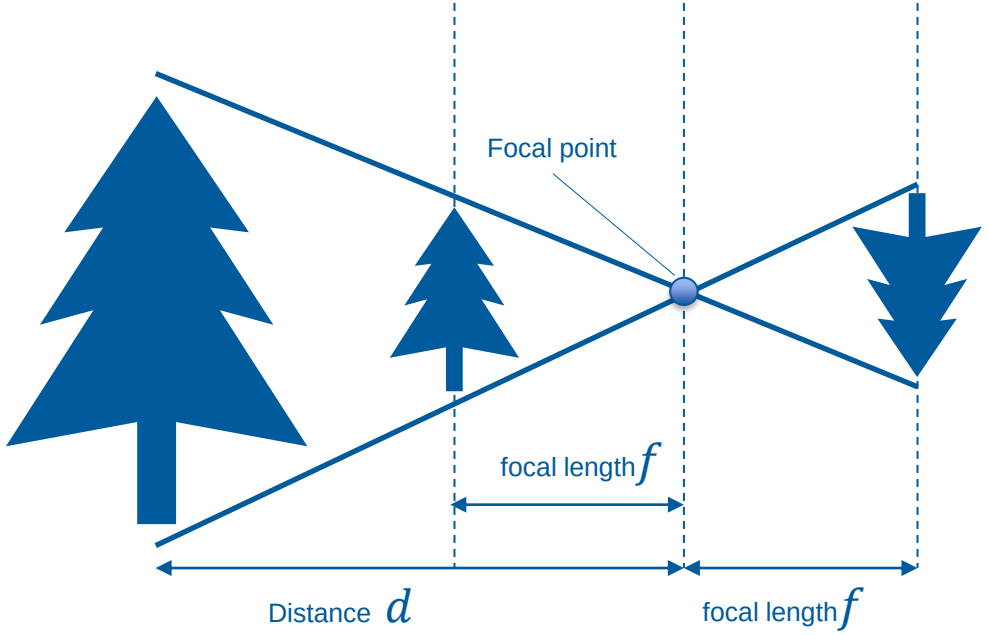
A **lower focal length** creats a smaller projection on the sensor‘s plane. This has the same effect as the object is more far away from the camera.



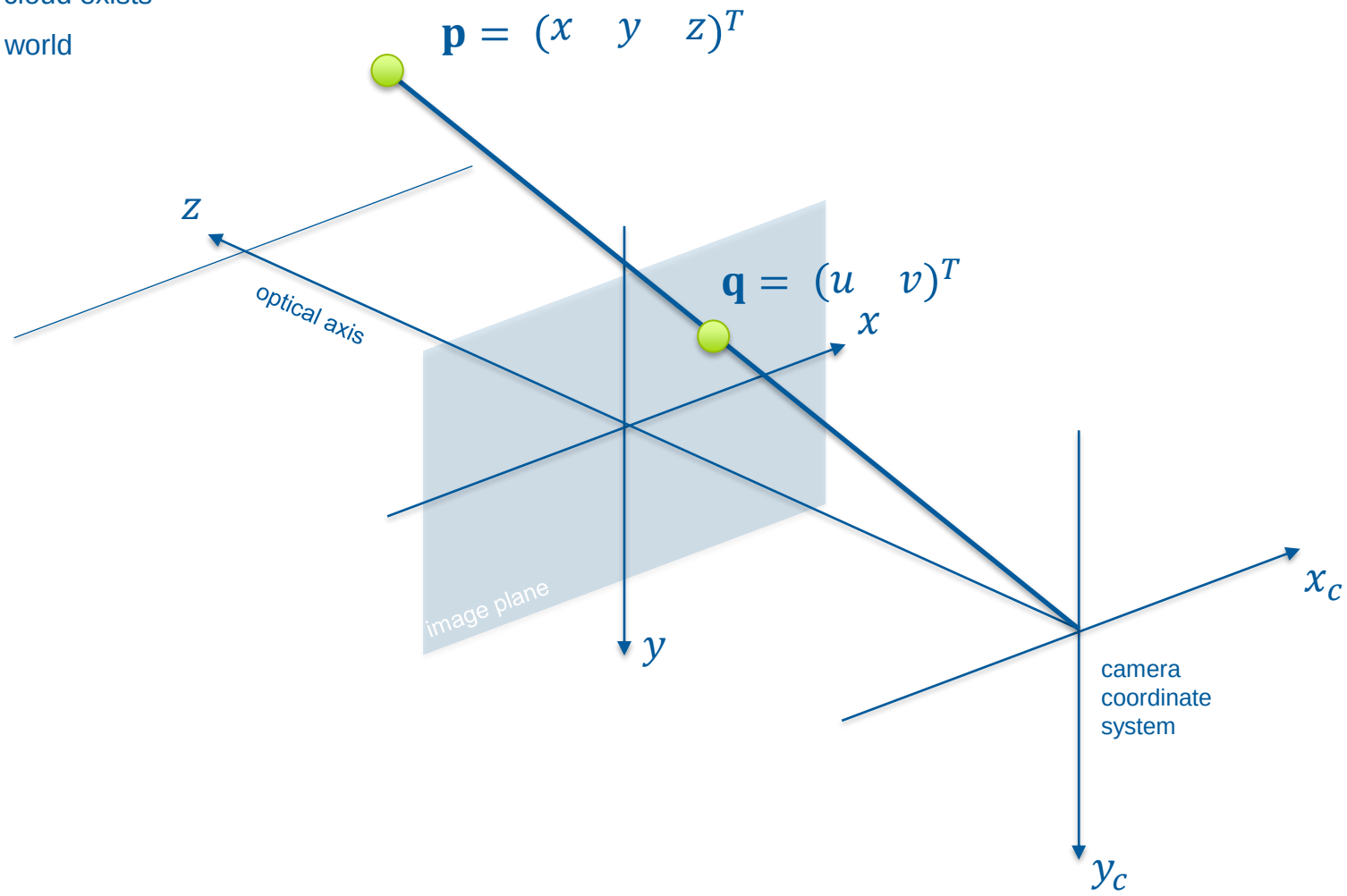
A **higher focal length** creats a bigger projection on the sensor‘s plane. This is the same effect as the camera gets closer to the object.

A small change of perspective

Currently, the object on the sensor is flipped. To ease upcomming computation, we move the image plane towards the object, so the distance between the image plane and the focal point is still the focal length.



- For every pixel in the depth image, a point in the point cloud exists
- The point on the image plane is a projection of the real world



Projection Matrix

The parameters in the projection matrix depend on the camera (sensor size and focal length).

Rules of thumb:

- ✓ The focal length for x and y direction have mostly equally values $f_x \approx f_y$
- ✓ The offset for the center of image c_x in x direction is close to half of the width of the sensor
- ✓ The offset for the center of image c_y in y direction is close to half of the height of the sensor

$$d \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \begin{pmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

$\mathbf{q}$ pixel in the depth image

$\mathbf{P}$ projection matrix

$\mathbf{p}$ point in the point cloud

f_x Focal length of x axis

f_y Focal length of y axis

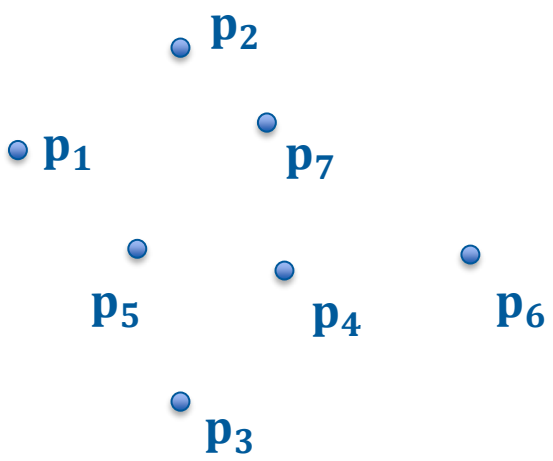
c_x Offset to center of image in x direction

c_y Offset to center of image in y direction

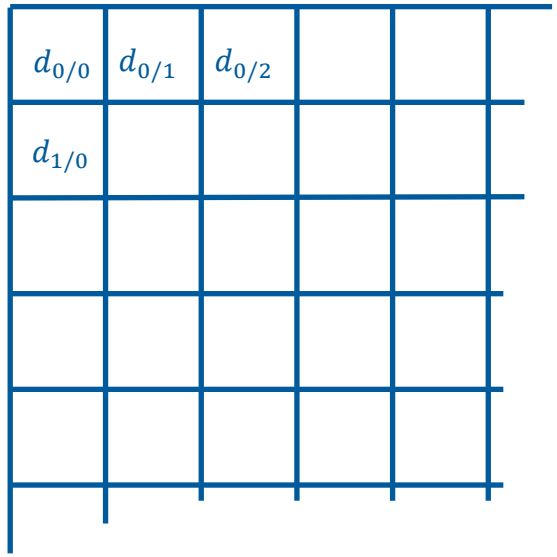
Projecting a point cloud or a Depth Map

Data conversion

$$\mathbf{q} = \mathbf{P} \cdot \mathbf{p}$$



point cloud



depth image

$$\mathbf{p} = \mathbf{P}^{-1} \cdot \mathbf{q}$$

Upcomming

- Sensor Fusion
- Camera calibration