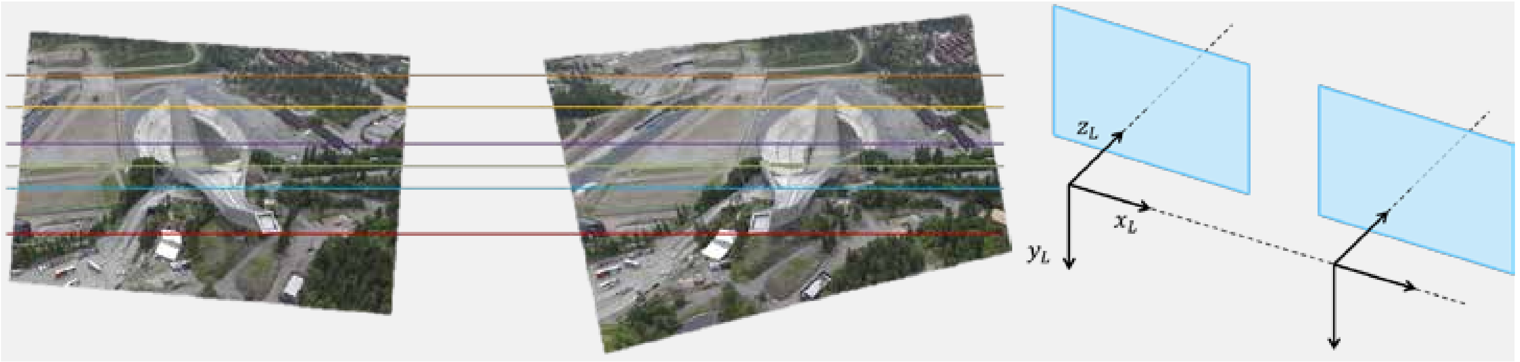


Lecture 6.2
Stereo imaging

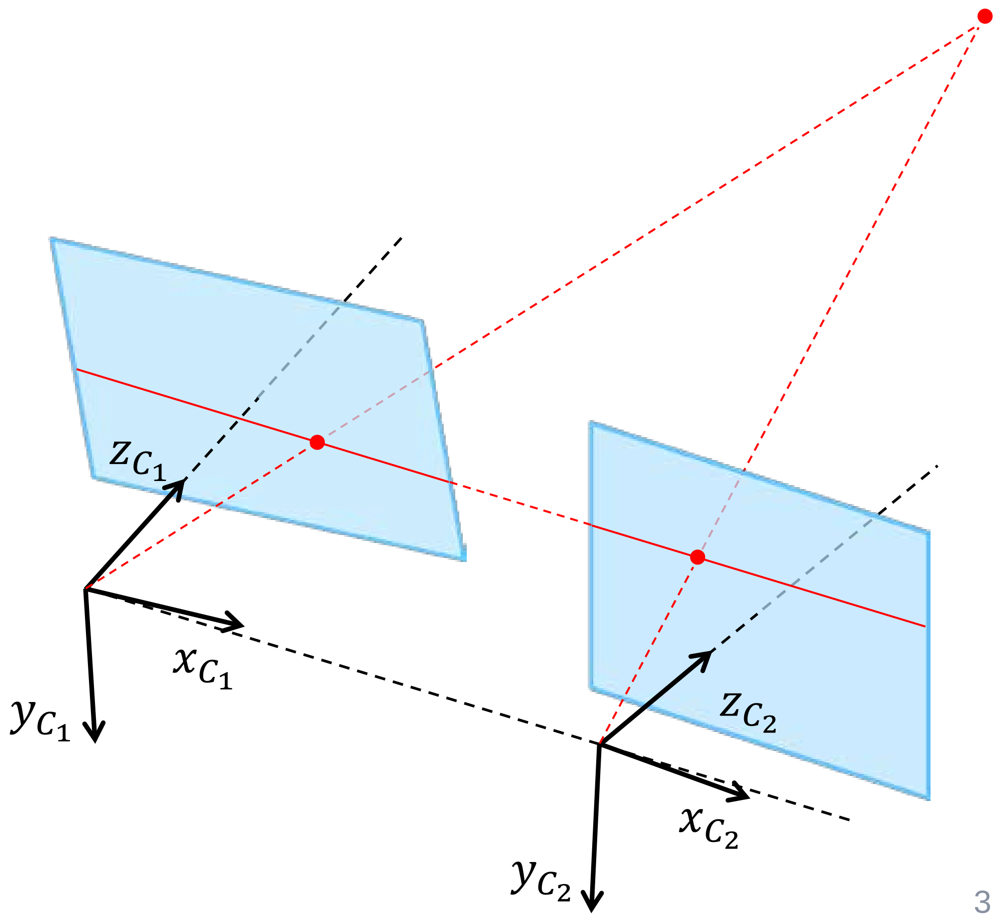
Trym Vegard Haavardsholm

World geometry from correspondences

	Structure (scene geometry)	Motion (camera geometry)	Measurements
Pose estimation	Known	Estimate	3D to 2D correspondences
Triangulation, Stereo	Estimate	Known	2D to 2D correspondences
Reconstruction, Structure from Motion	Estimate	Estimate	2D to 2D correspondences

Stereo vision

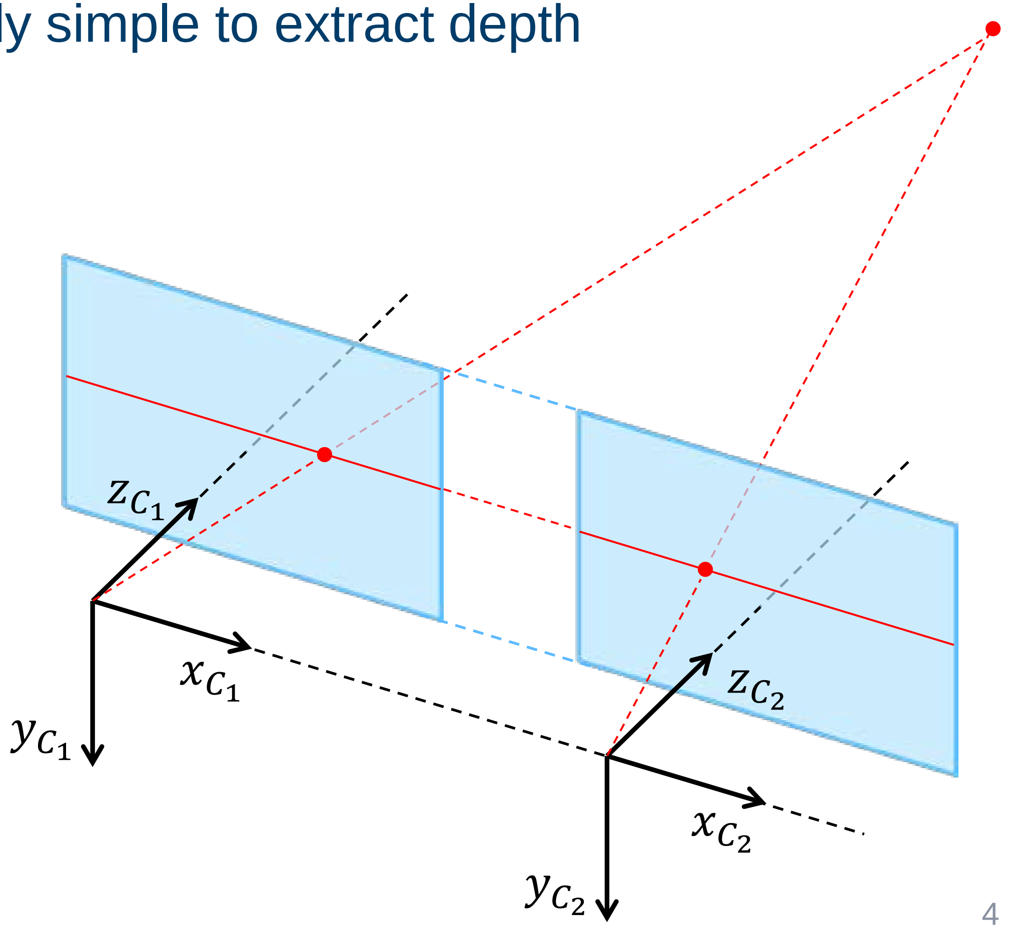
- Depth from two views with known viewpoints



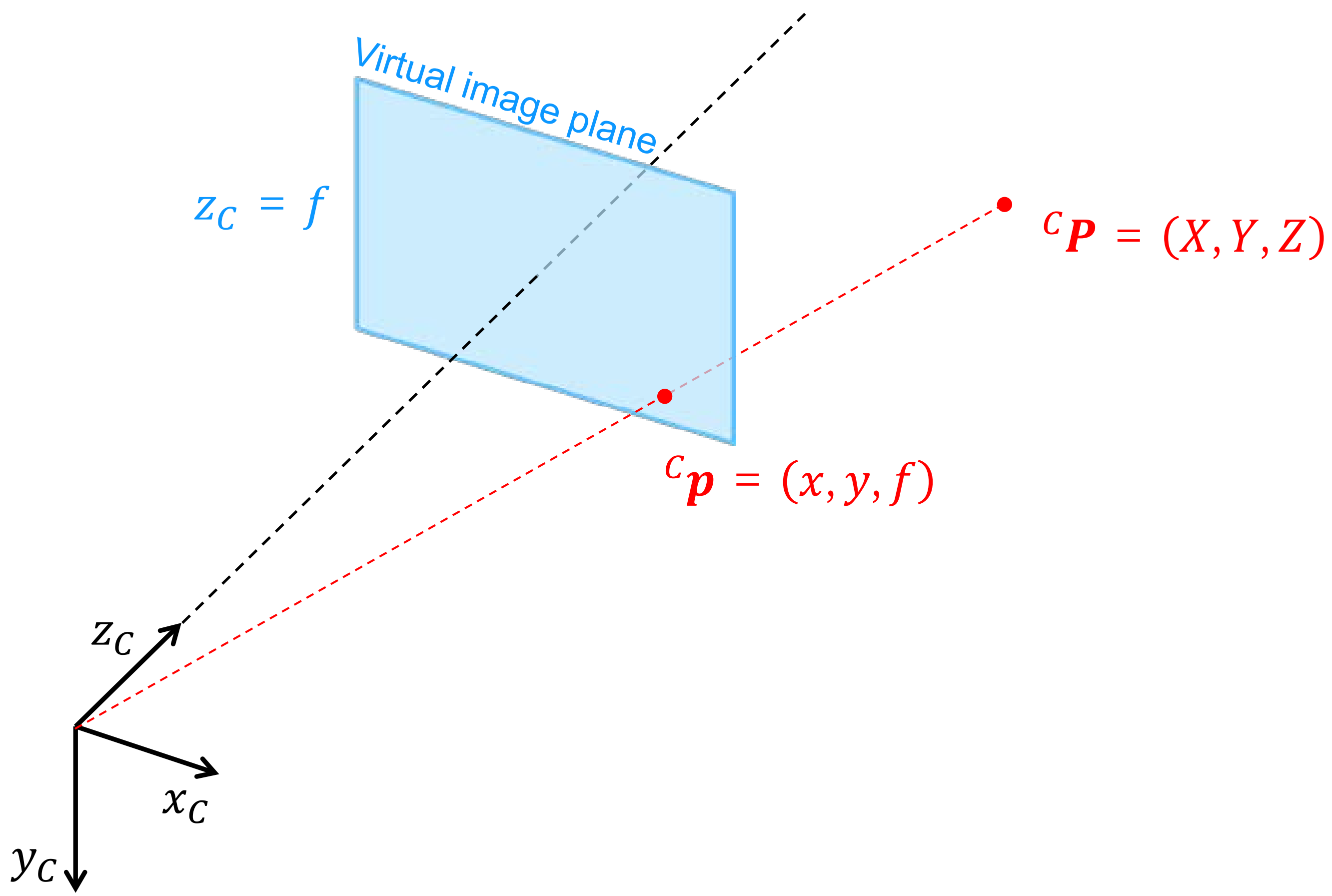
Stereo vision

- Depth from two views with known viewpoints

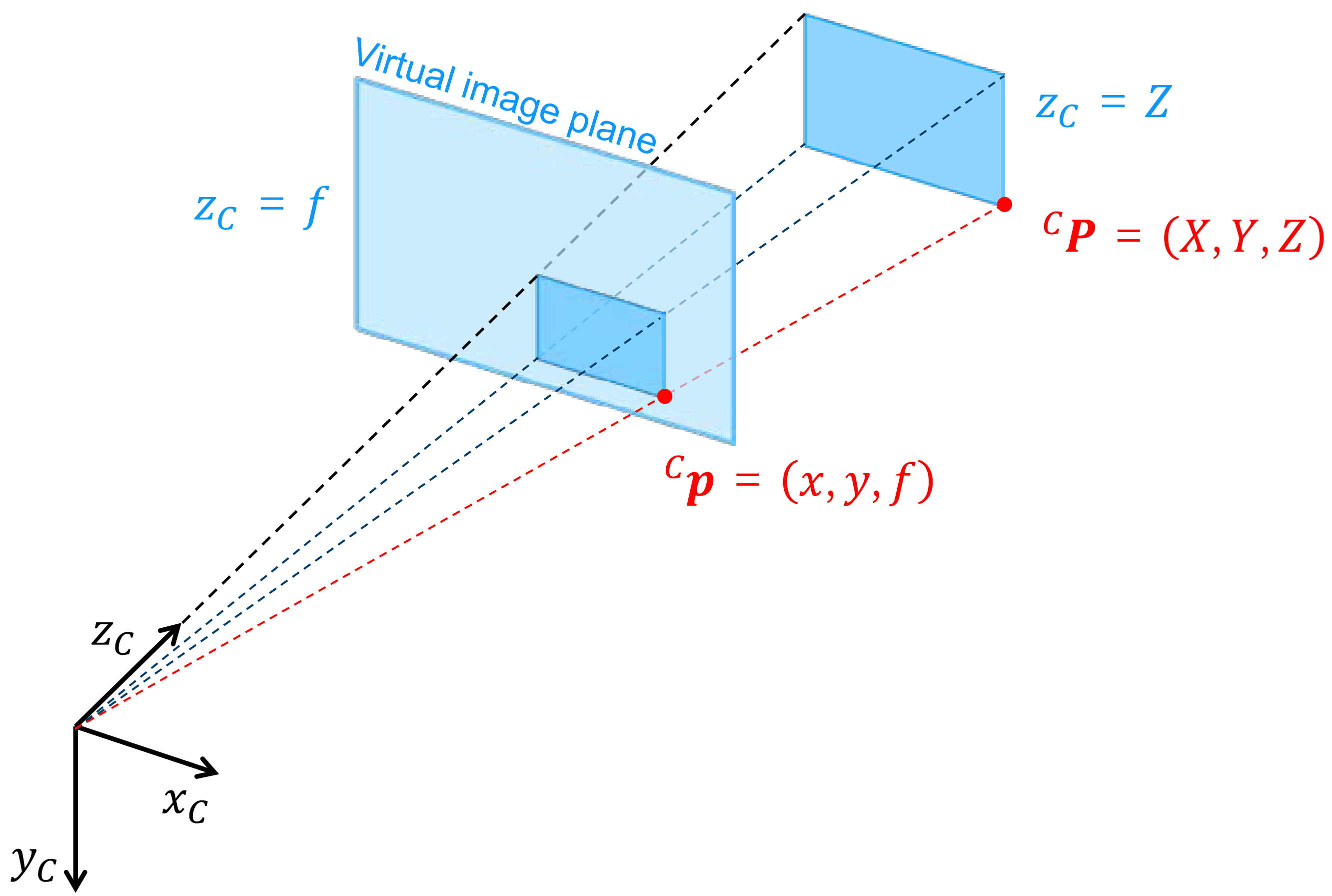
  …with an imaging geometry that makes it especially simple to extract depth



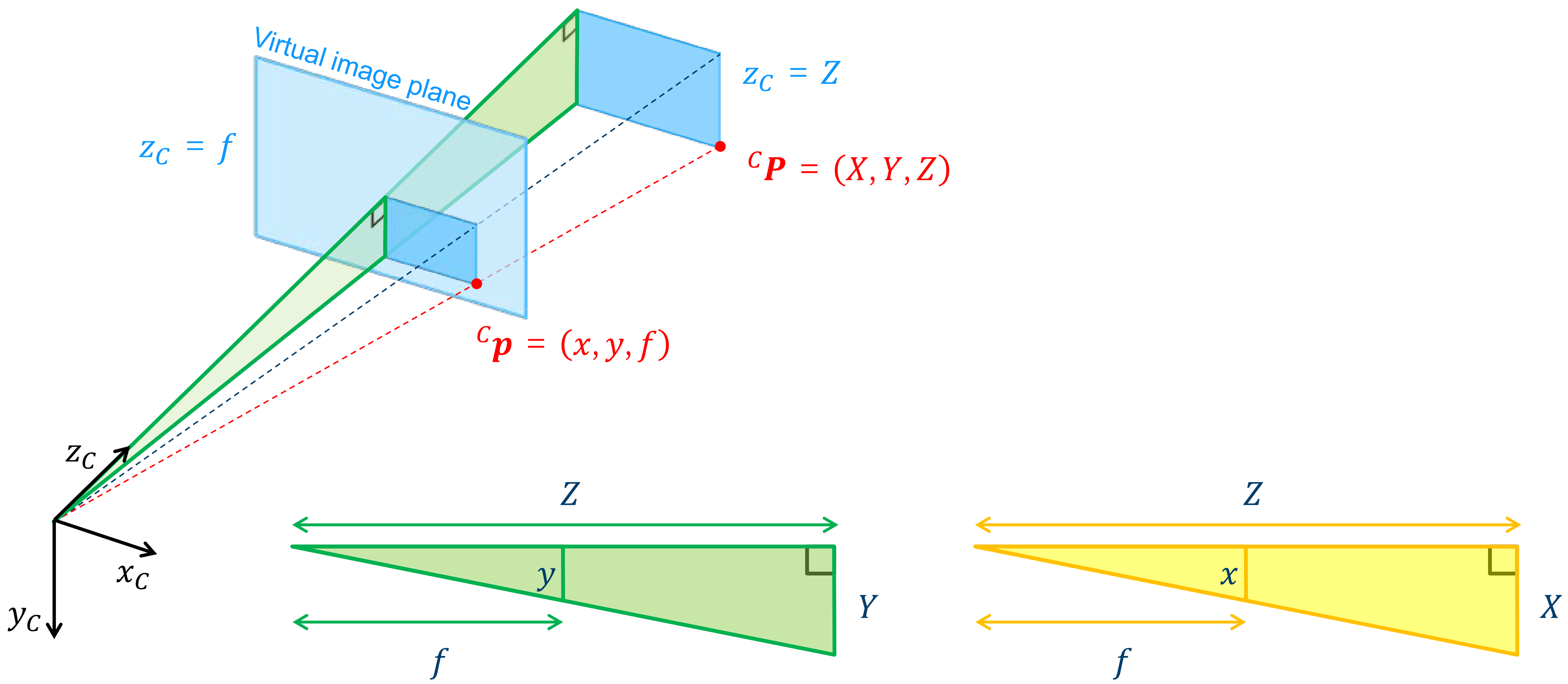
Depth from images



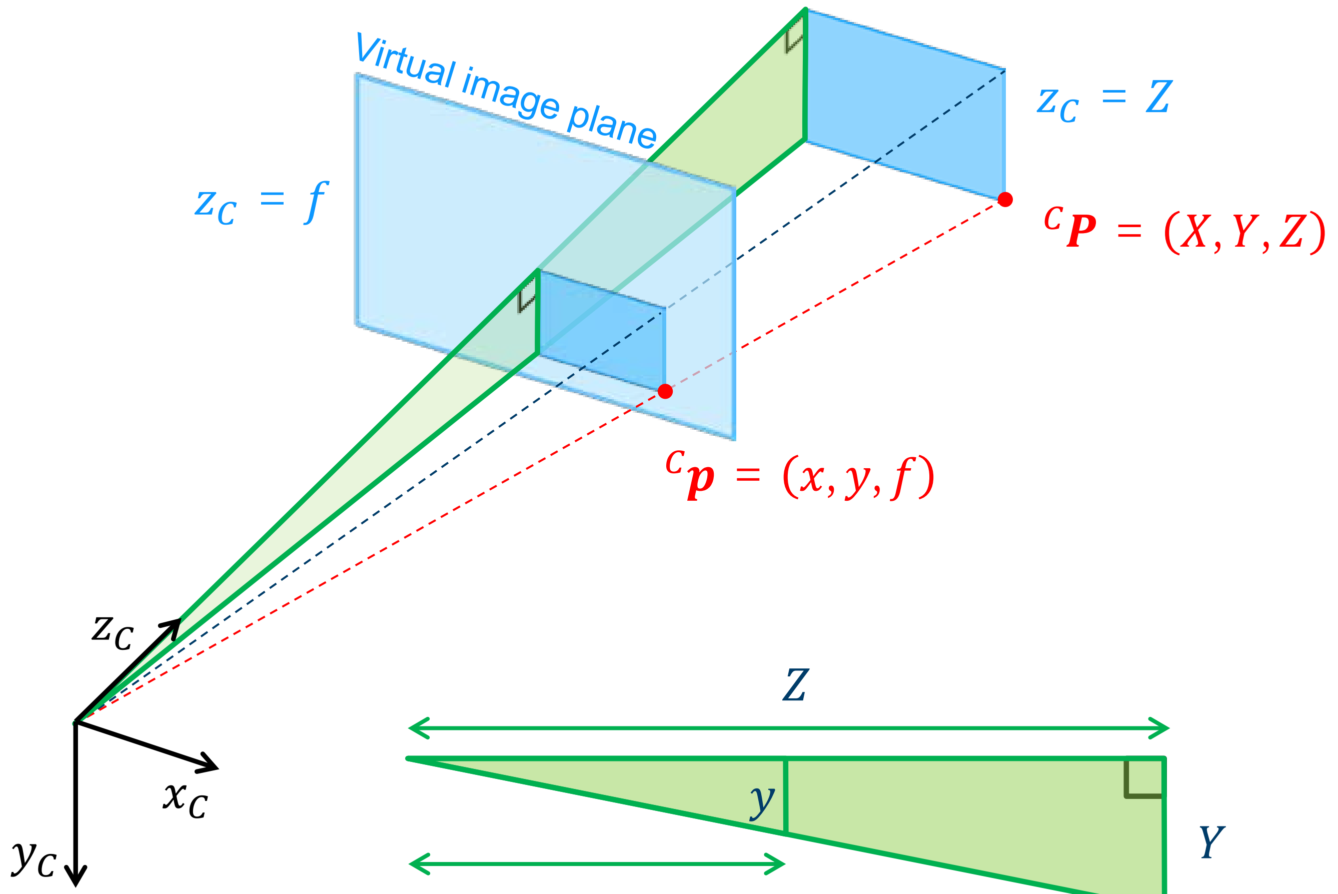
Depth from images



Depth from images

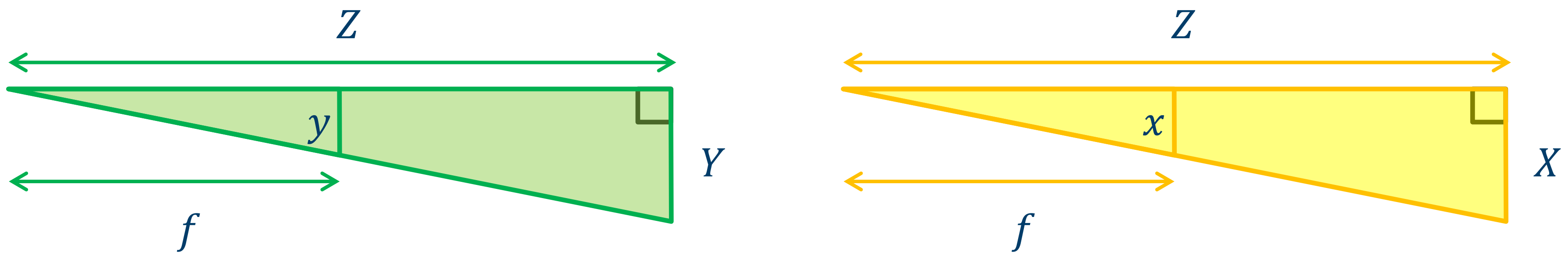


Depth from images

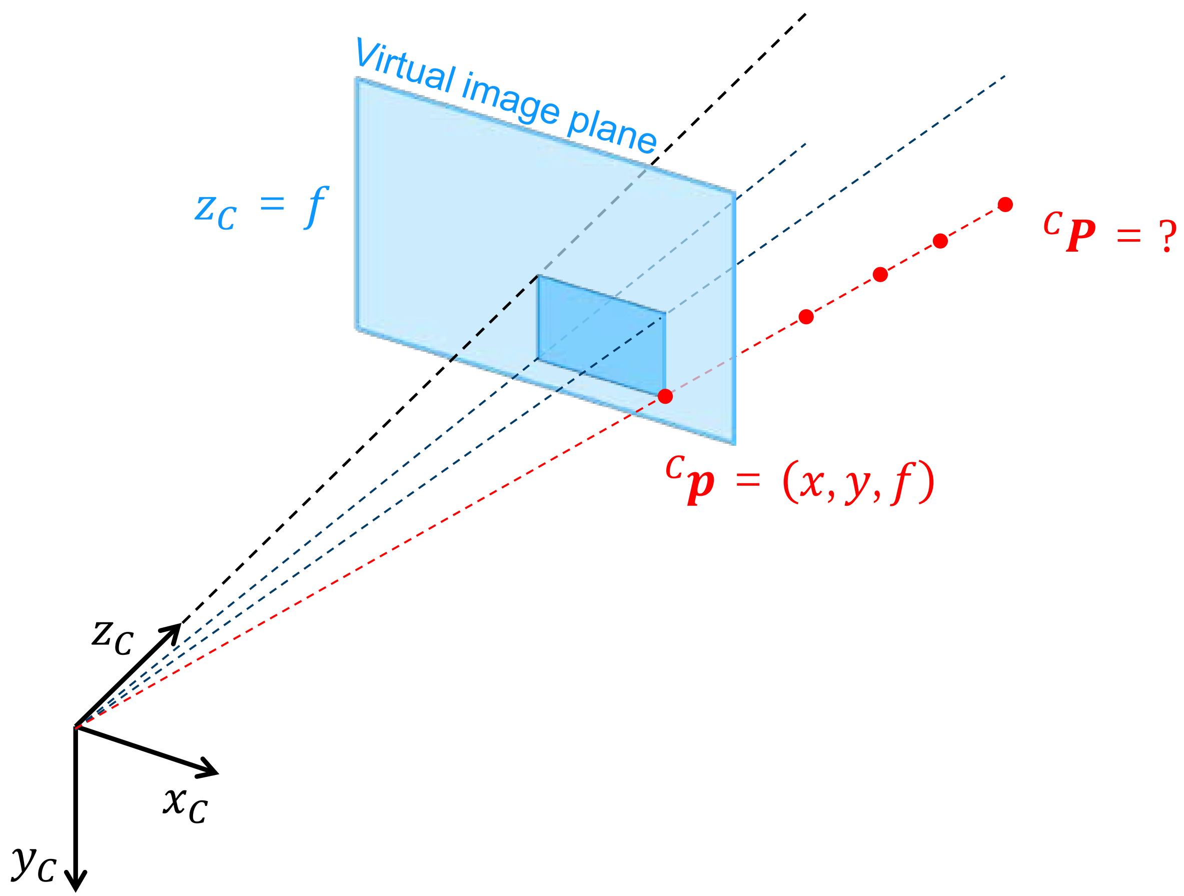


$$x = f\,\frac{X}{Z}$$

$$y = f\,\frac{Y}{Z}$$



Depth from images

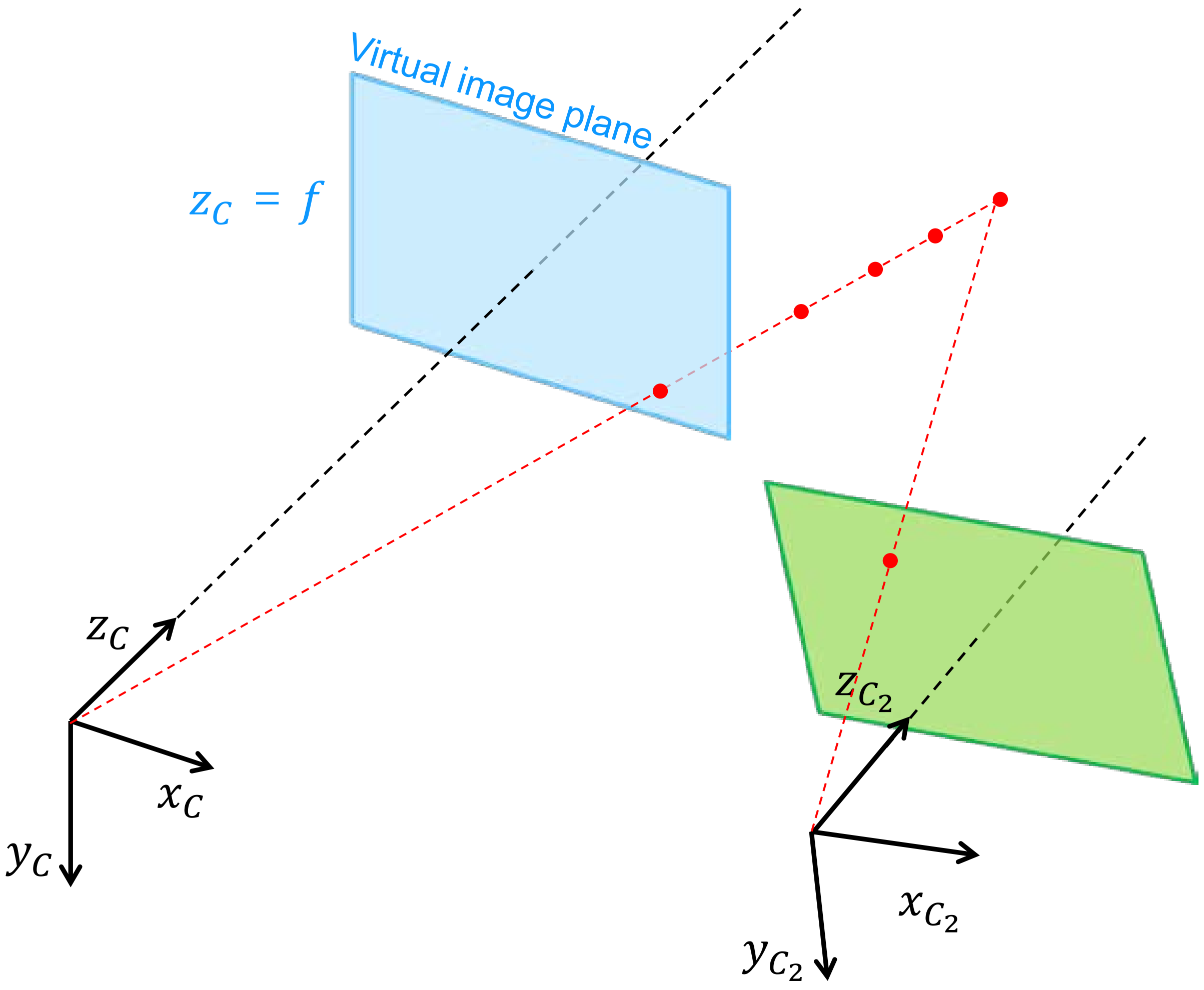


$$x = f\,\frac{X}{Z} = f\,\frac{kX}{kZ}$$

$$y = f\,\frac{Y}{Z} = f\,\frac{kY}{kZ}$$

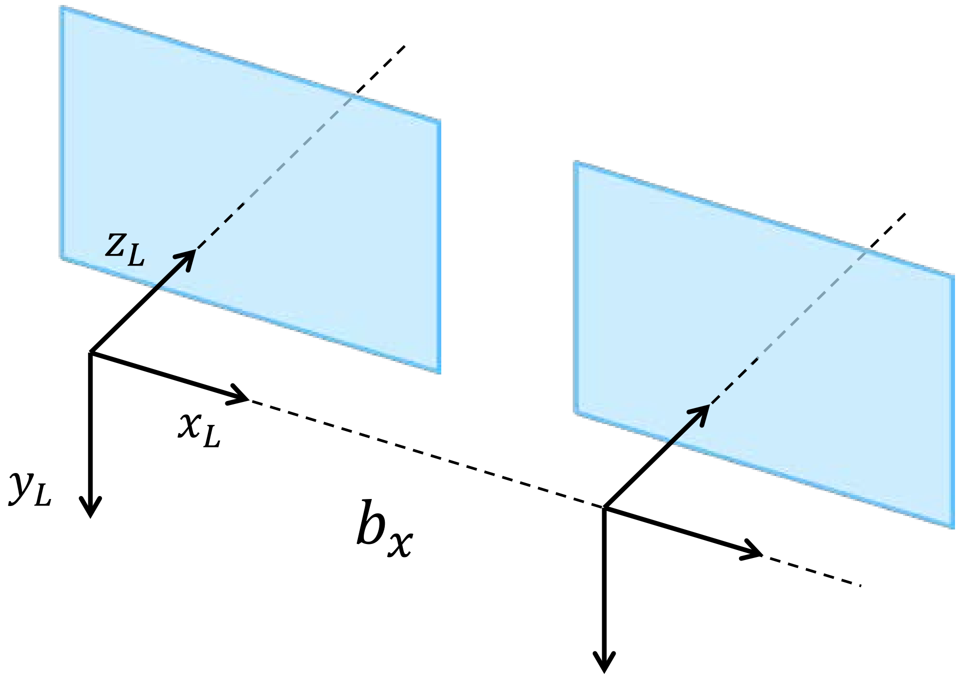
Any point on the ray has image ${}^{C}\mathbf{p}$

Depth from images



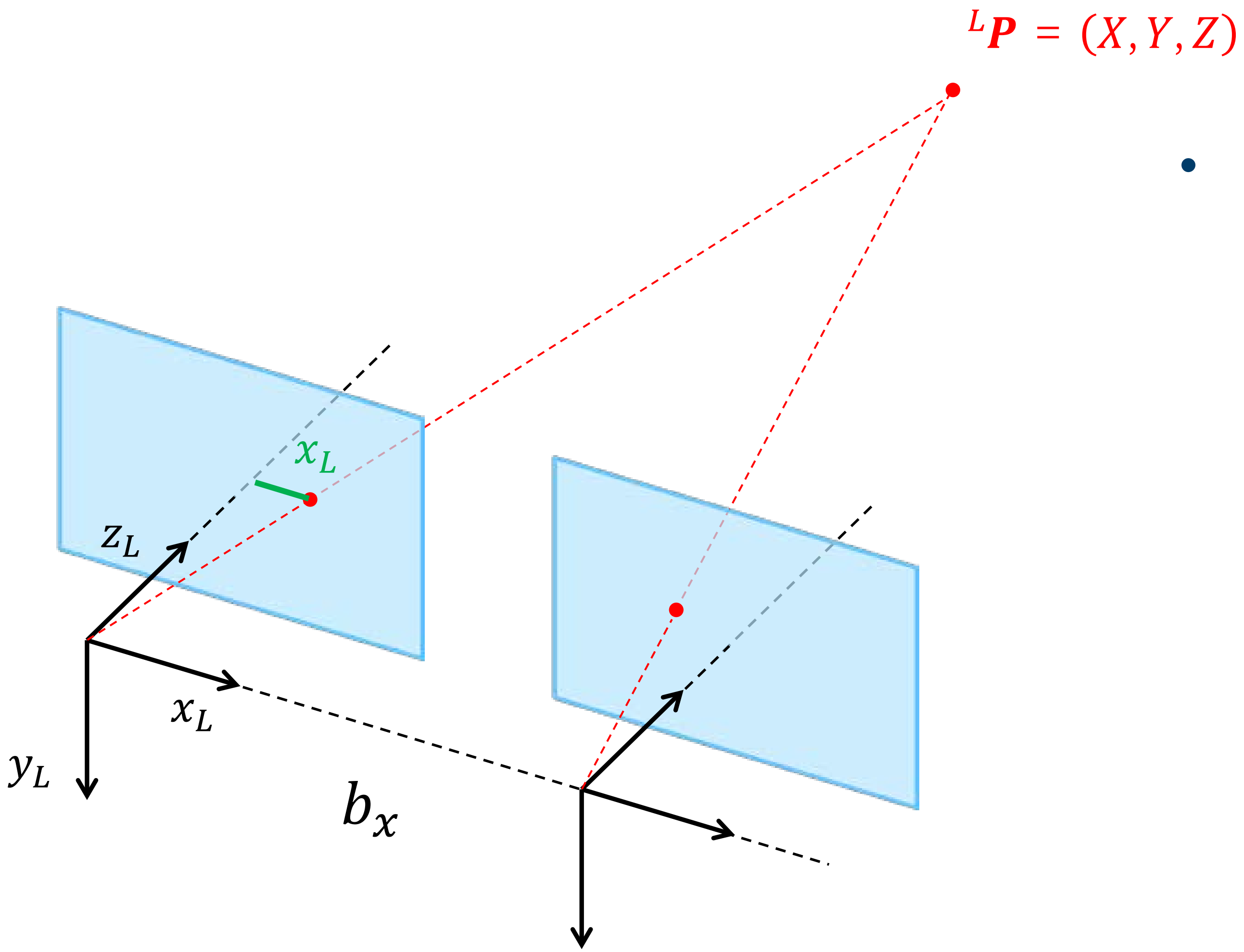
Add a second view!

An ideal stereo system



- Left camera defines common coordinate system
- Right camera shifted b_x units along the *x*-axis
  - Baseline
- Otherwise identical
  - Orientation
  - Focal lengths

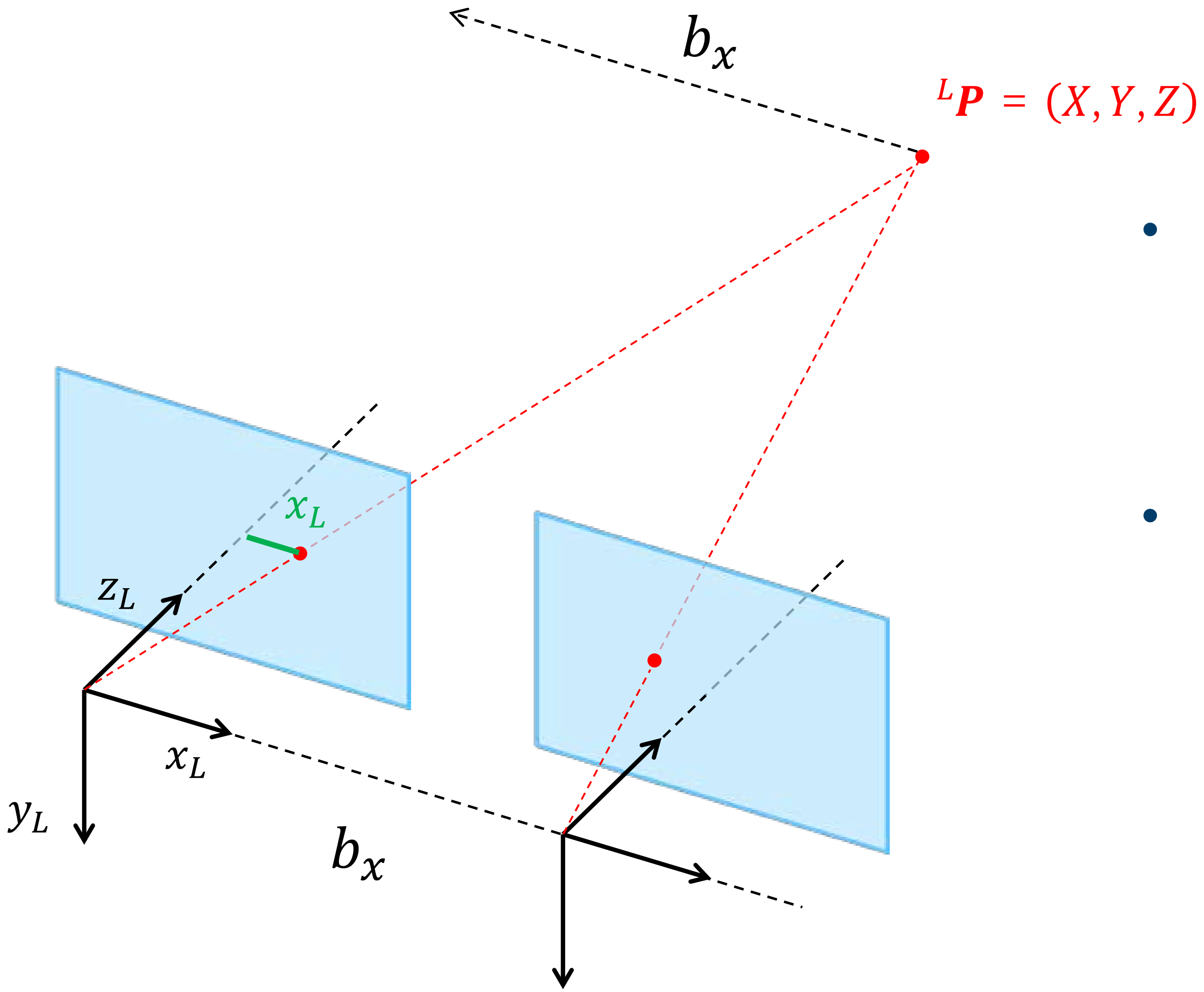
An ideal stereo system



- Image of $\boldsymbol{P}$ in left camera:

$$x_L = f\,\frac{X}{Z}\,, \qquad y_L = f\,\frac{Y}{Z}$$

An ideal stereo system



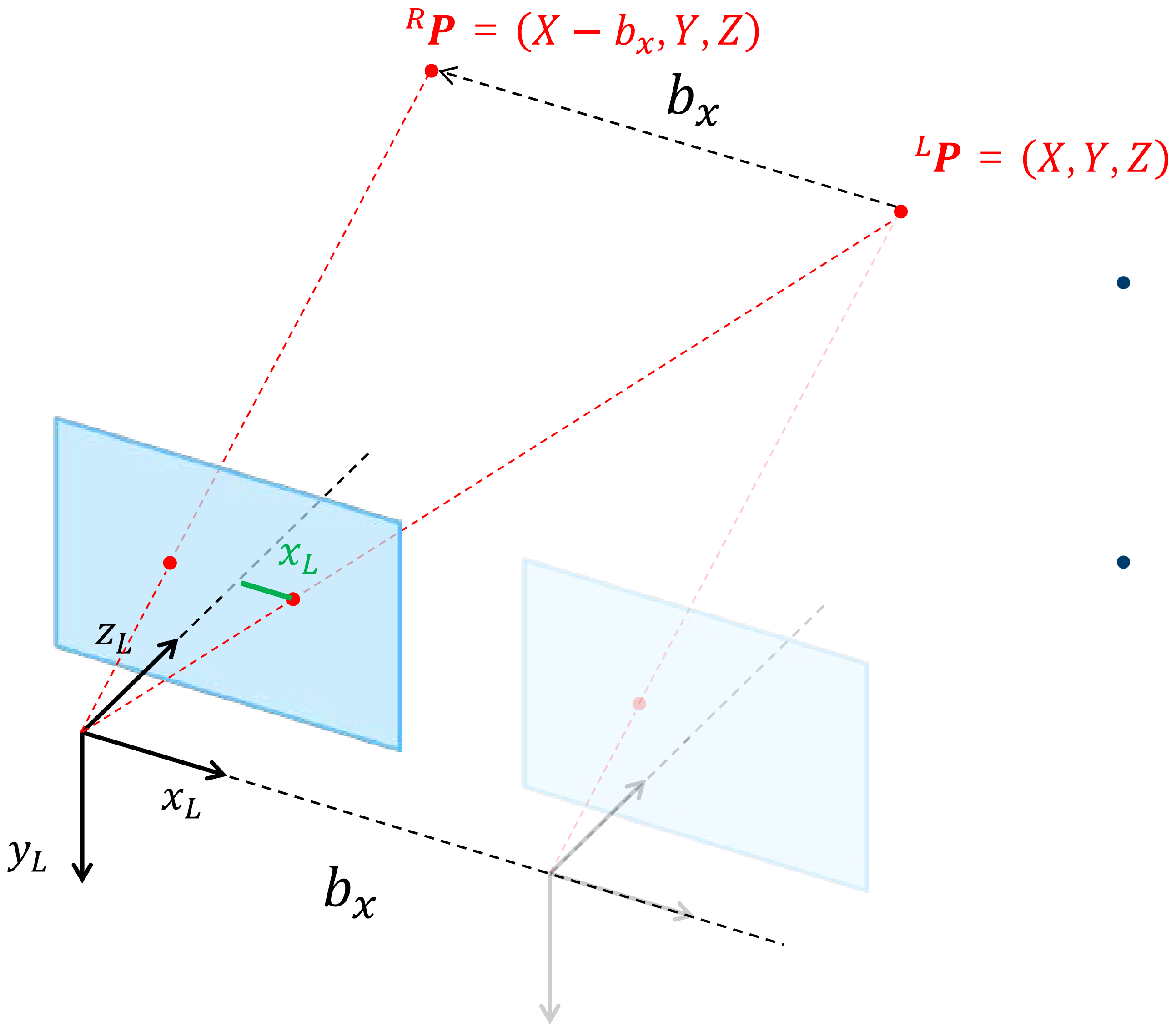
- Image of $\boldsymbol{P}$ in left camera:

$$x_L = f\,\frac{X}{Z}\,, \qquad y_L = f\,\frac{Y}{Z}$$

- Image of $\boldsymbol{P}$ in right camera:

(translating the camera to the right is equivalent to translating the world to the left)

An ideal stereo system



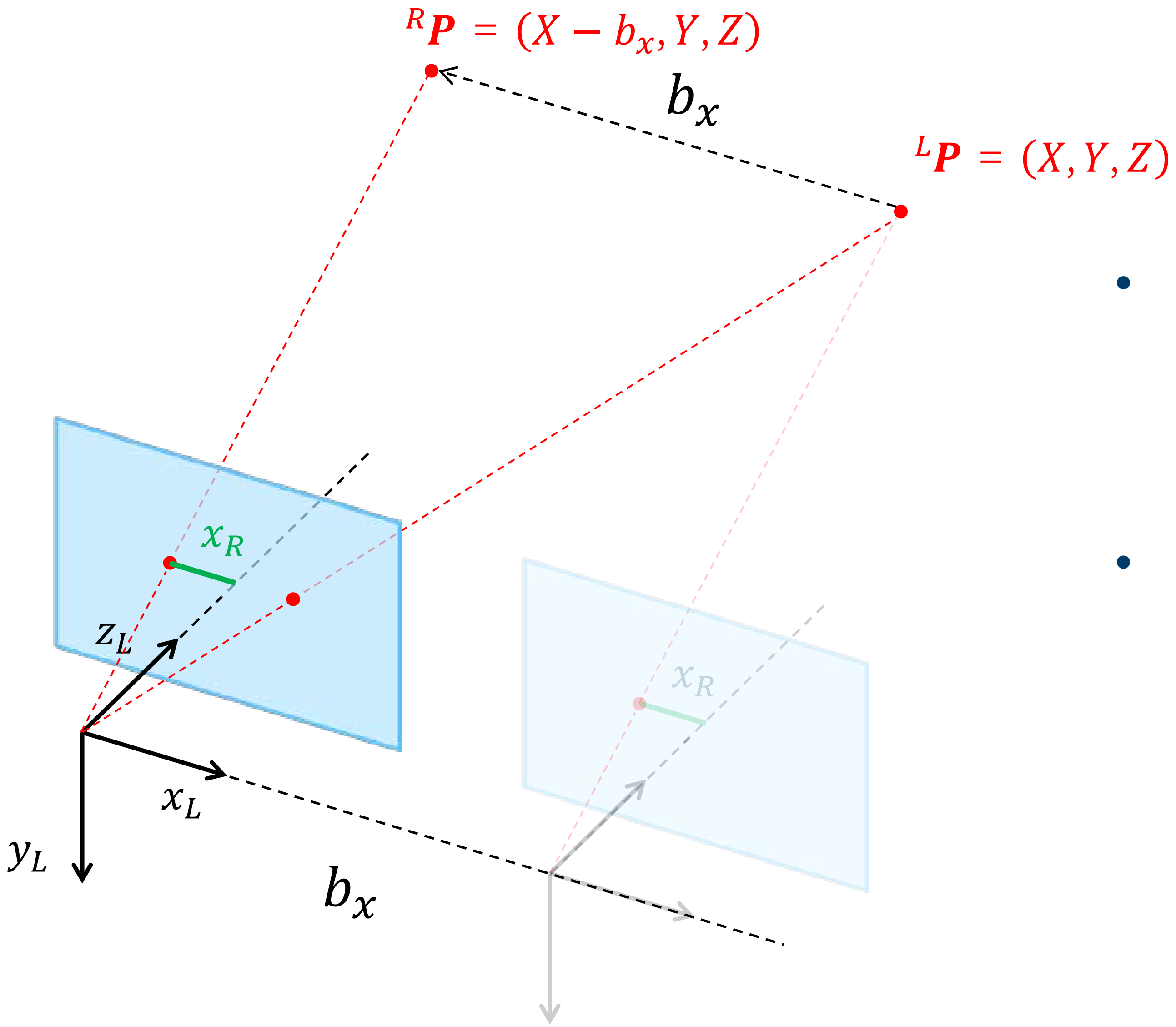
- Image of $\boldsymbol{P}$ in left camera:

$$x_L = f\frac{X}{Z}, \qquad y_L = f\frac{Y}{Z}$$

- Image of $\boldsymbol{P}$ in right camera:

(translating the camera to the right is equivalent to translating the world to the left)

An ideal stereo system



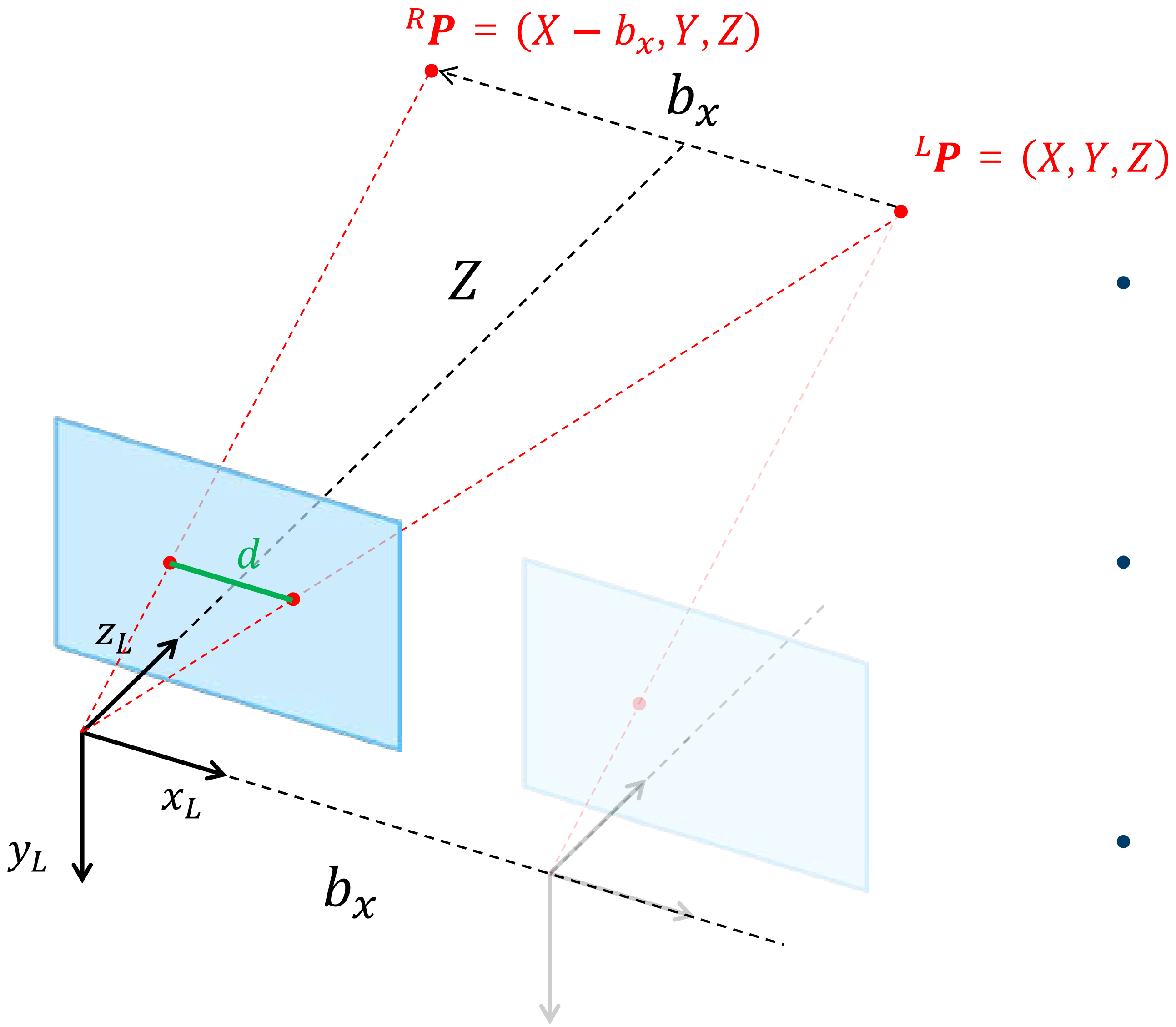
- Image of $\boldsymbol{P}$ in left camera:

$$x_L = f\frac{X}{Z}, \qquad y_L = f\frac{Y}{Z}$$

- Image of $\boldsymbol{P}$ in right camera:

$$x_R = f\frac{X - b_x}{Z}, \qquad y_R = f\frac{Y}{Z}$$

An ideal stereo system



- Image of $\boldsymbol{P}$ in left camera:

$$x_L = f\frac{X}{Z}, \qquad y_L = f\frac{Y}{Z}$$

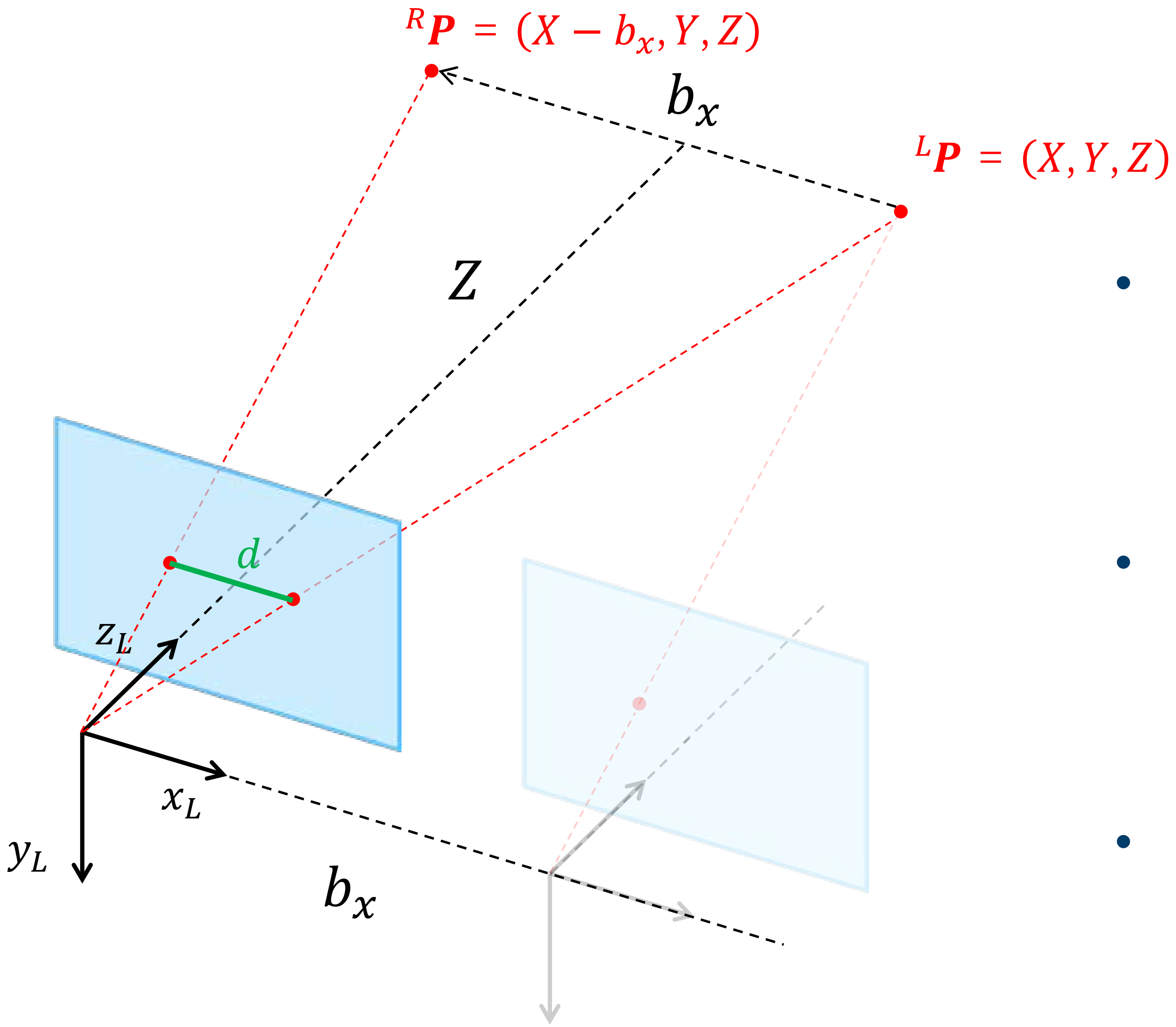
- Image of $\boldsymbol{P}$ in right camera:

$$x_R = f\frac{X - b_x}{Z}, \qquad y_R = f\frac{Y}{Z}$$

- Stereo disparity

$$d = x_L - x_R$$

An ideal stereo system



- Image of $\boldsymbol{P}$ in left camera:

$$x_L = f\frac{X}{Z}, \qquad y_L = f\frac{Y}{Z}$$

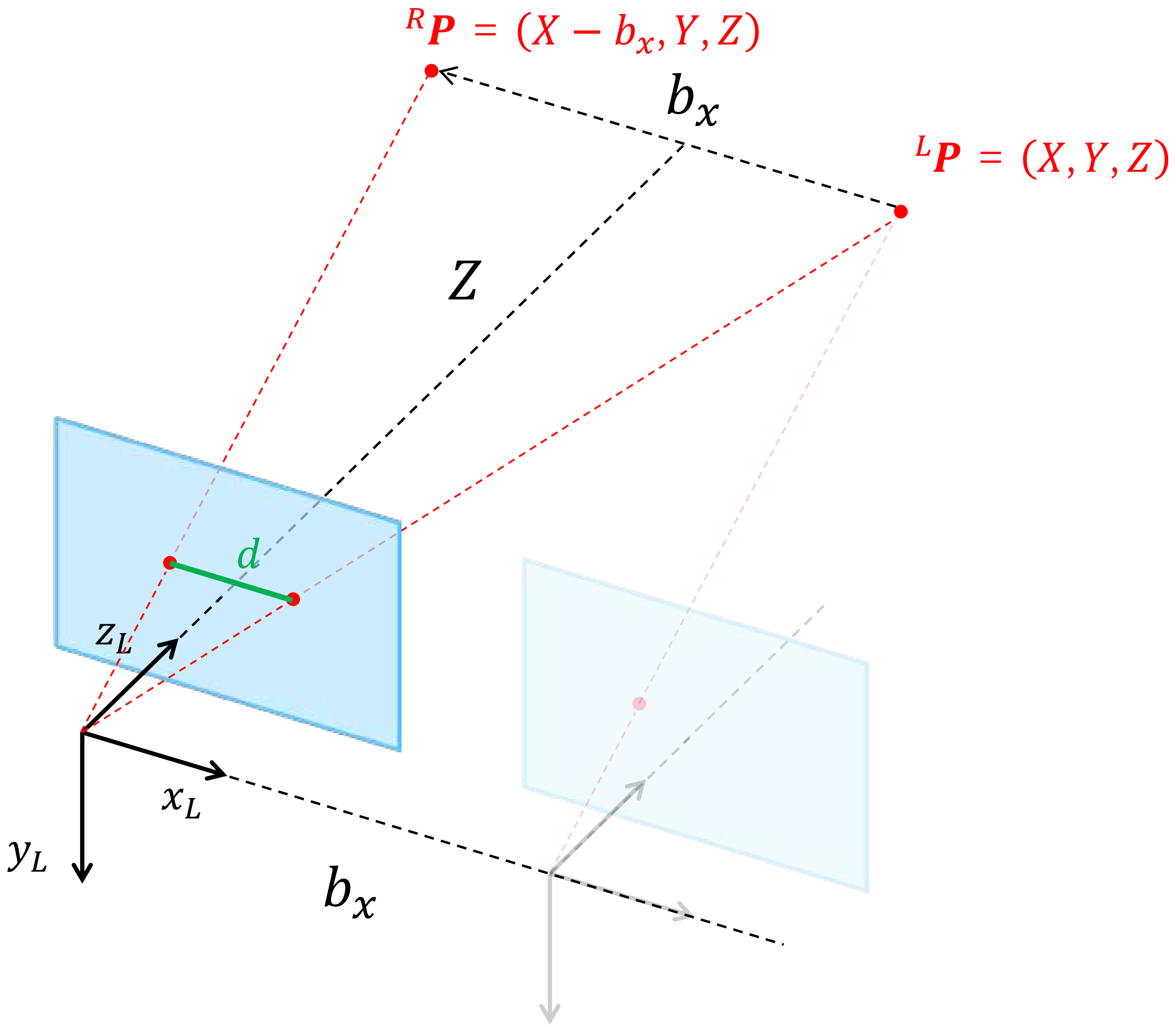
- Image of $\boldsymbol{P}$ in right camera:

$$x_R = f\frac{X-b_x}{Z}, \qquad y_R = f\frac{Y}{Z}$$

- Stereo disparity

$$d = x_L - x_R = f\frac{X}{Z} - \left(f\frac{X}{Z} - f\frac{b_x}{Z}\right)$$

Stereo disparity



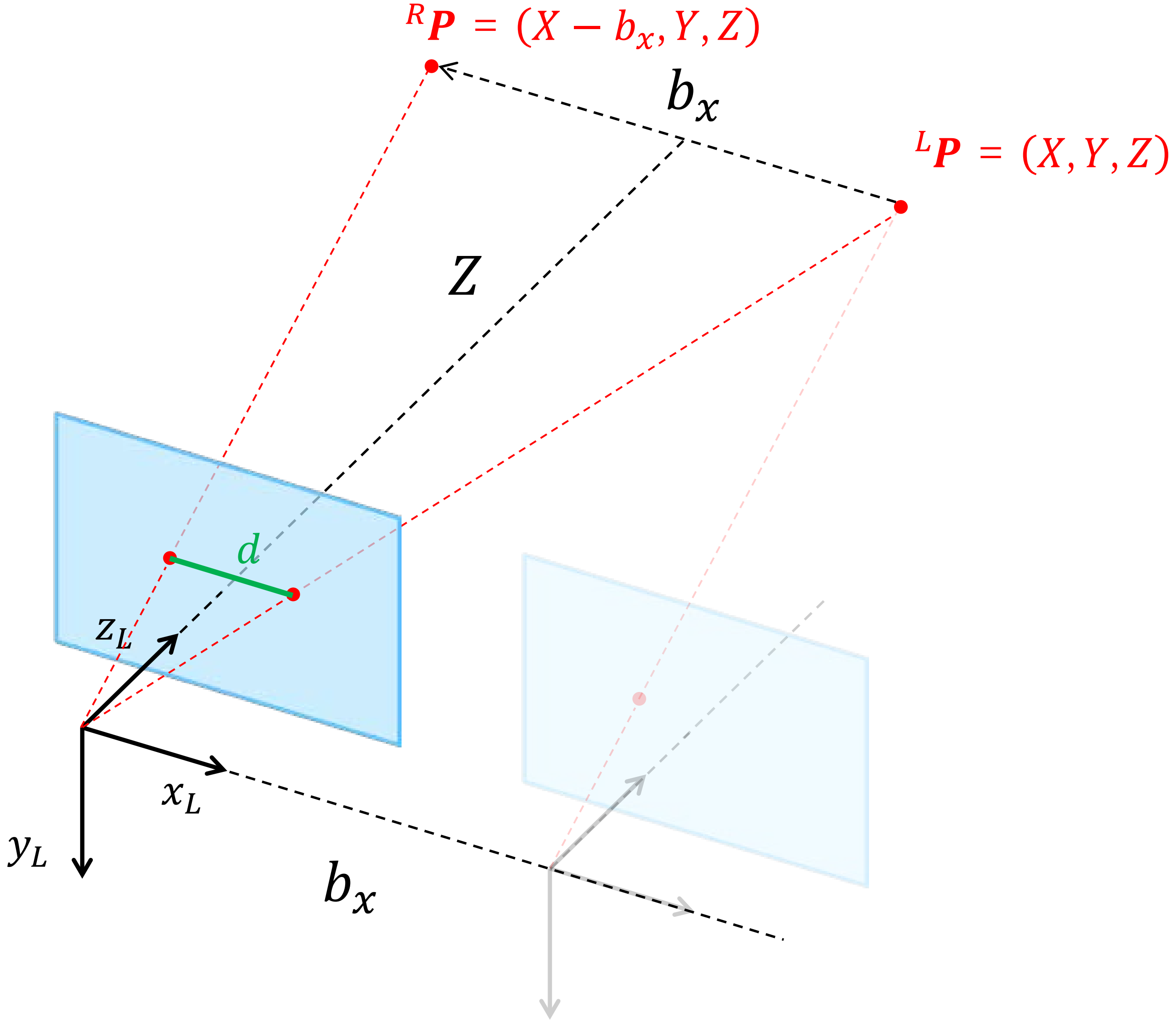
Baseline

Disparity

$$d = f\,\frac{b_x}{Z}$$

Depth

Stereo disparity



Baseline

Depth

$$Z = f\,\frac{b_x}{d}$$

Disparity

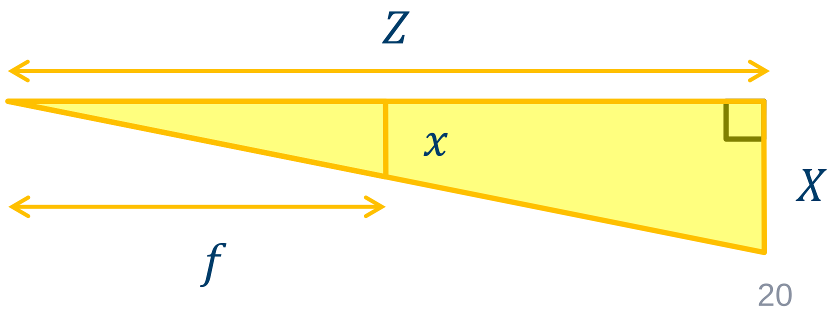
3D from stereo images

- From normalized coordinates

$$Z = f\frac{b_x}{d}$$

$$X = x_L\frac{Z}{f}$$

$$Y = y_L\frac{Z}{f}$$



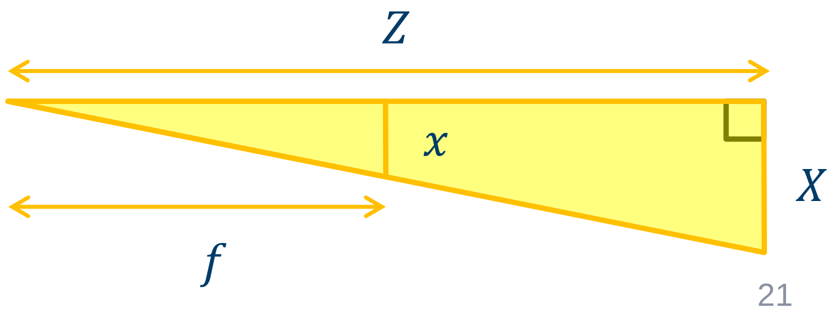
3D from stereo images

- From normalized coordinates

$$Z = f\frac{b_x}{d}$$

$$X = x_L\frac{b_x}{d}$$

$$Y = y_L\frac{b_x}{d}$$



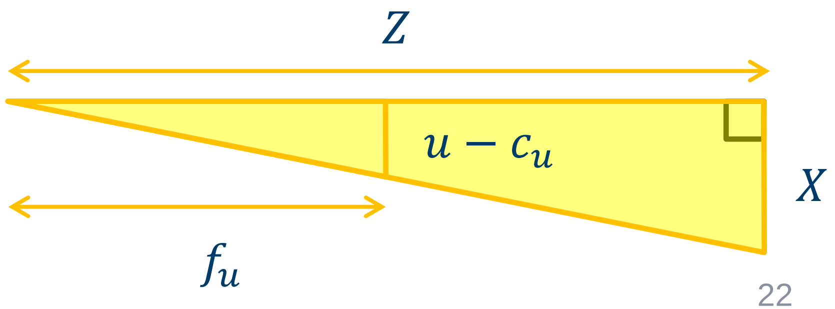
3D from stereo images

- From pixel coordinates

$$Z = f_u \frac{b_x}{d_u}$$

$$X = (u_L - {}^L c_u)\frac{b_x}{d_u}$$

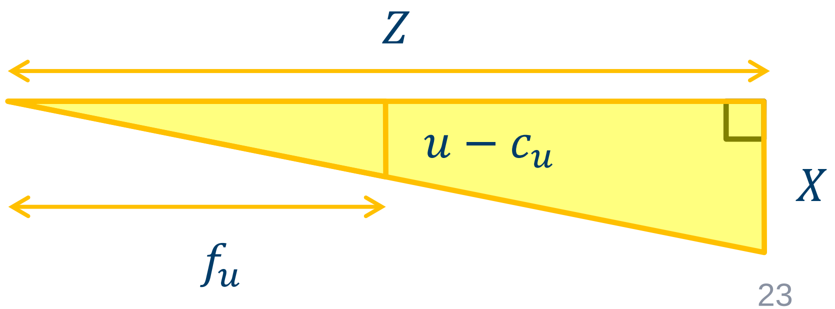
$$Y = (v_L - {}^L c_v)\frac{b_x}{d_u}$$



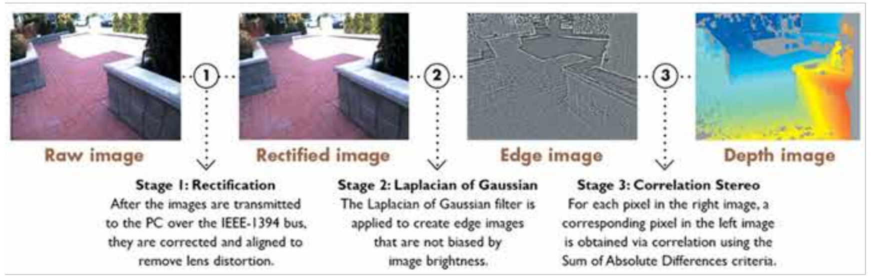
3D from stereo images

- From pixel coordinates

$$Q\tilde{u}_L = \begin{bmatrix} 1 & 0 & 0 & -{}^{L}c_u \\ 0 & 1 & 0 & -{}^{L}c_v \\ 0 & 0 & 0 & f_u \\ 0 & 0 & \frac{1}{b_x} & \frac{{}^{R}c_u - {}^{L}c_u}{b_x} \end{bmatrix} \begin{bmatrix} u_L \\ v_L \\ d \\ 1 \end{bmatrix} = \begin{bmatrix} X' \\ Y' \\ Z' \\ W' \end{bmatrix} = \begin{bmatrix} X'/W' \\ Y'/W' \\ Z'/W' \\ 1 \end{bmatrix} = \tilde{X}$$



Stereo cameras



http://www.ptgrey.com

"Kinect2-ir-image" by User:Kolossos
http://commons.wikimedia.org/wiki/File:Kinect2-ir-image.png

Stereo cameras

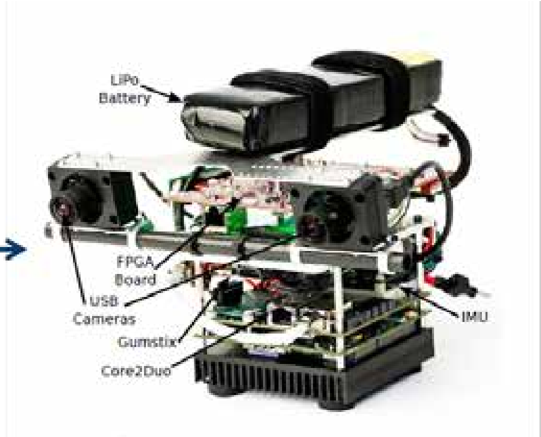
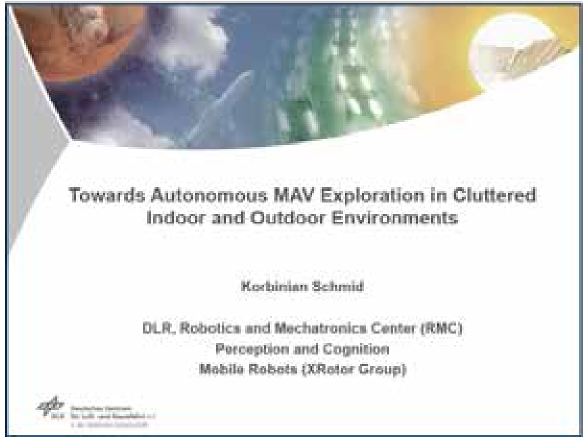
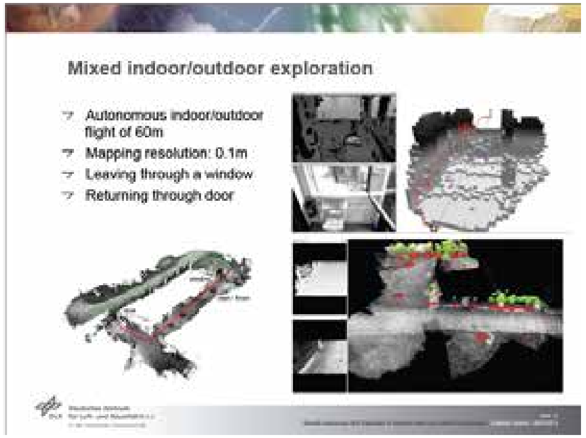
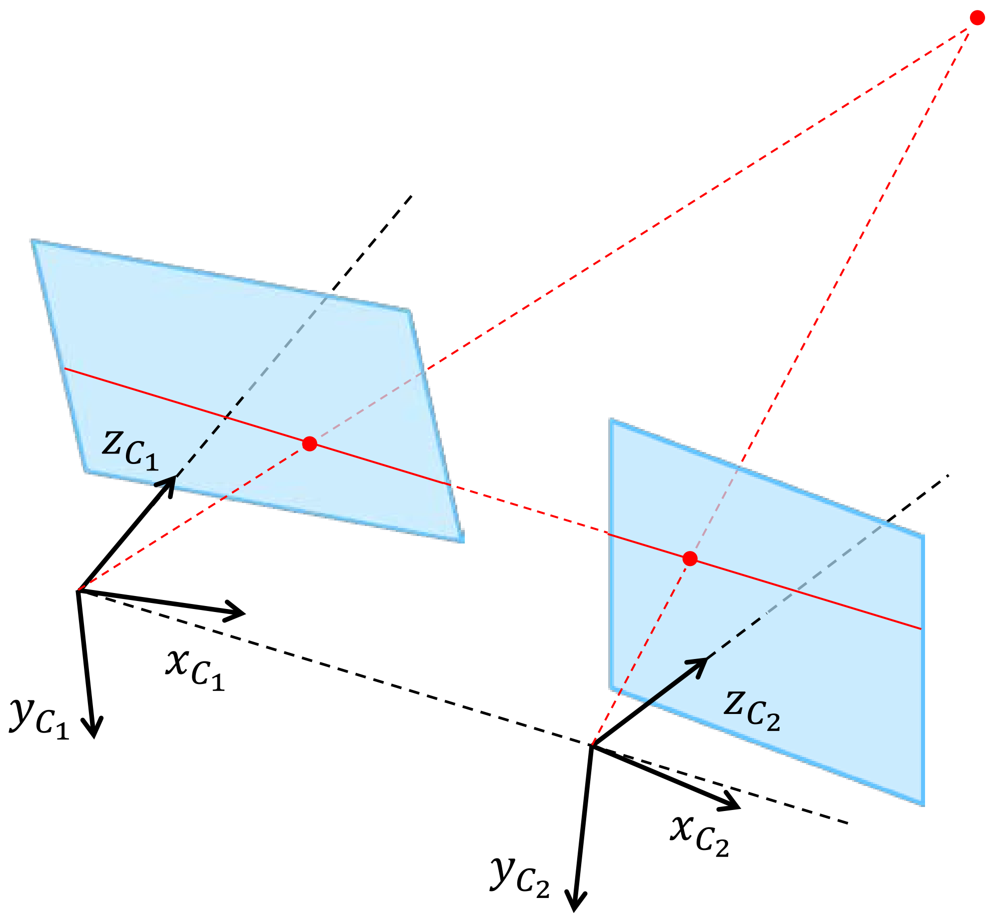


Fig. 1. Mobile robot perception device



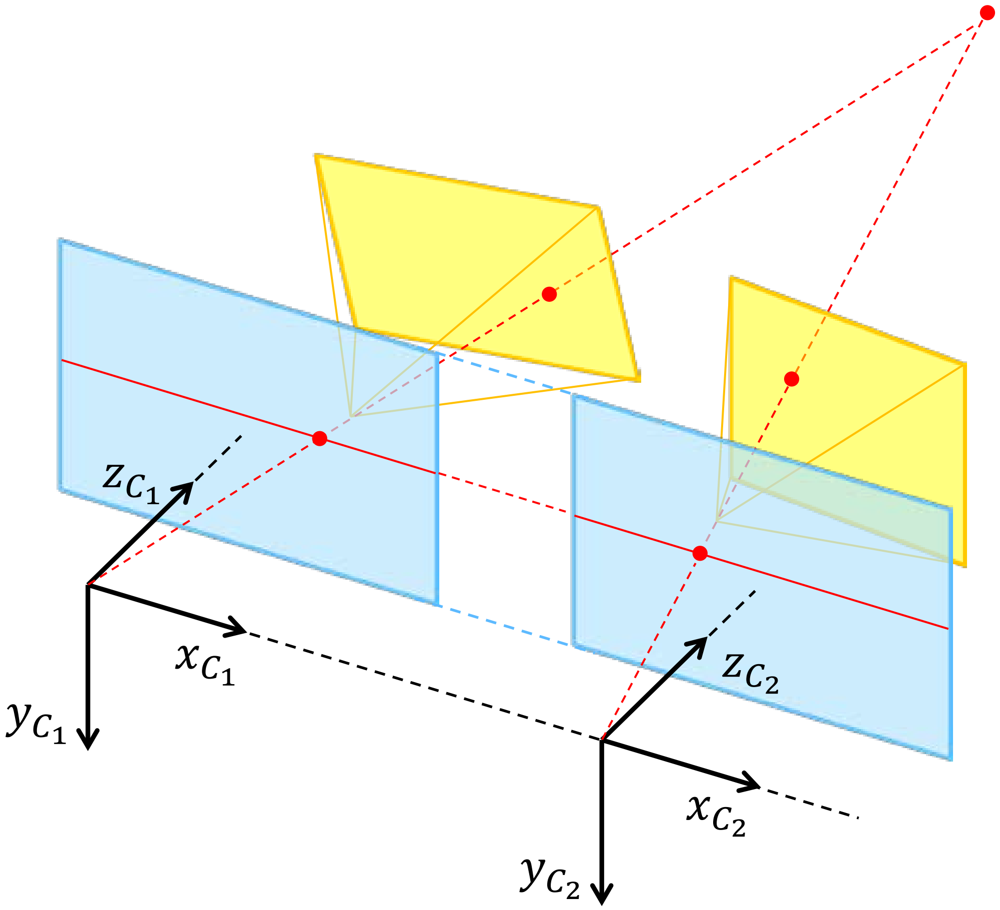


What if we do not have parallel cameras?



- Epipolar lines no longer horizontal
- What does disparity mean now?
- How to reproject to 3D points?

Stereo rectification

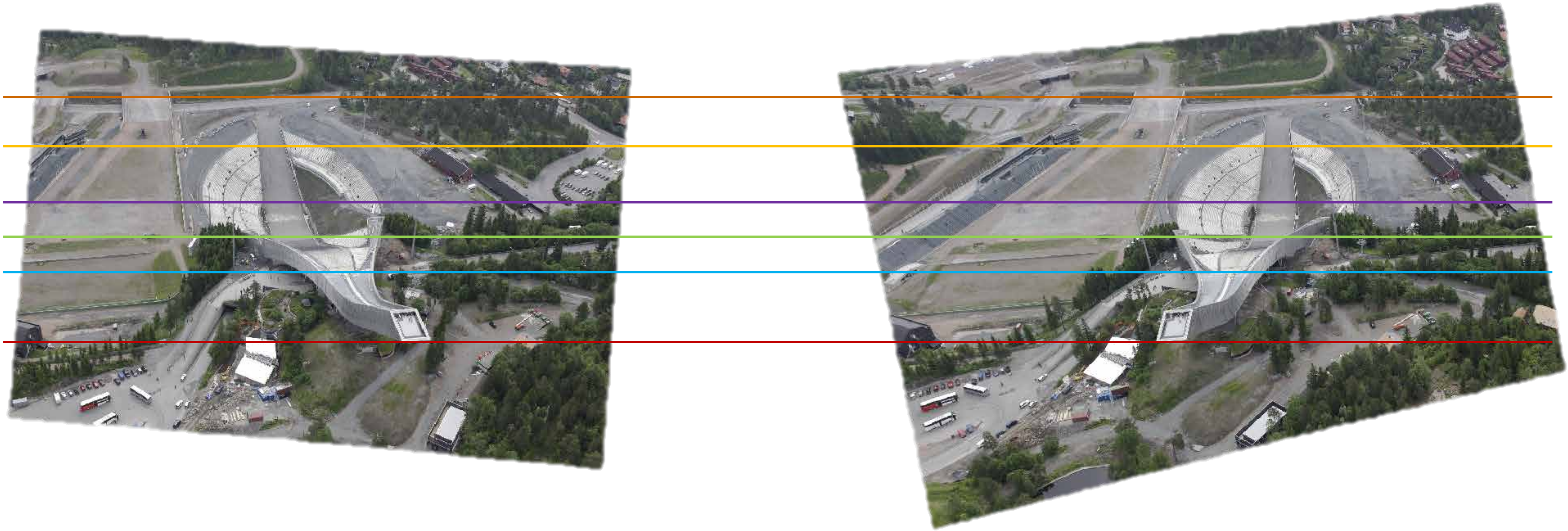


- Reproject image planes onto a common plane parallel to the line between the camera centers
- The epipolar lines are horizontal after this transformation
- Two homographies
- C. Loop and Z. Zhang. Computing Rectifying Homographies for Stereo Vision. IEEE Conf. Computer Vision and Pattern Recognition, 1999.

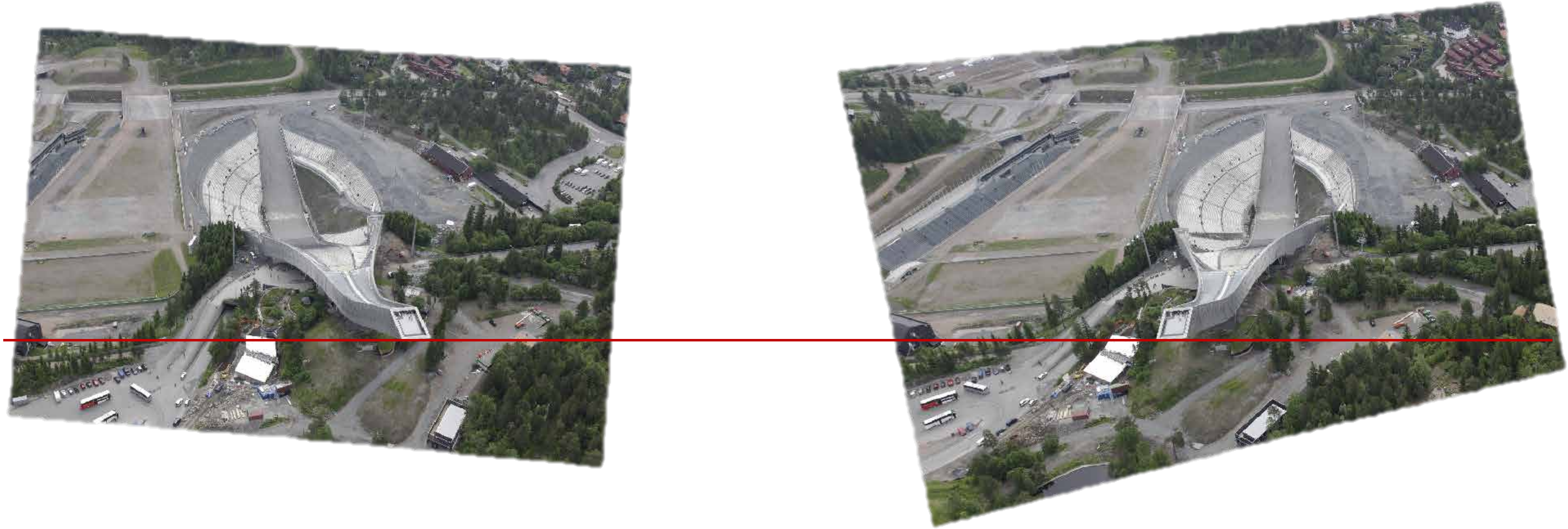
Stereo rectification example

Stereo rectification example

Stereo rectification example



Stereo rectification example



Summary

- Stereo imaging
  - Horizontal epipolar lines
  - Disparity
  - 3D from disparity
  - Stereo rectification

- Next: Stereo processing