

Scene Modeling for a Single View



René MAGRITTE
Portrait d'Edward James

15-463: Computational Photography
Alexei Efros, CMU, Spring 2010

*...with a lot of slides stolen from
Steve Seitz and David Brogan,*

Breaking out of 2D

...now we are ready to break out of 2D



And enter the real world!



on to 3D...

Enough of images!

We want more of the
plenoptic function

We want real 3D scene
walk-throughs:

- Camera rotation

- Camera translation

Can we do it from a single
photograph?



Camera rotations with homographies

Original image



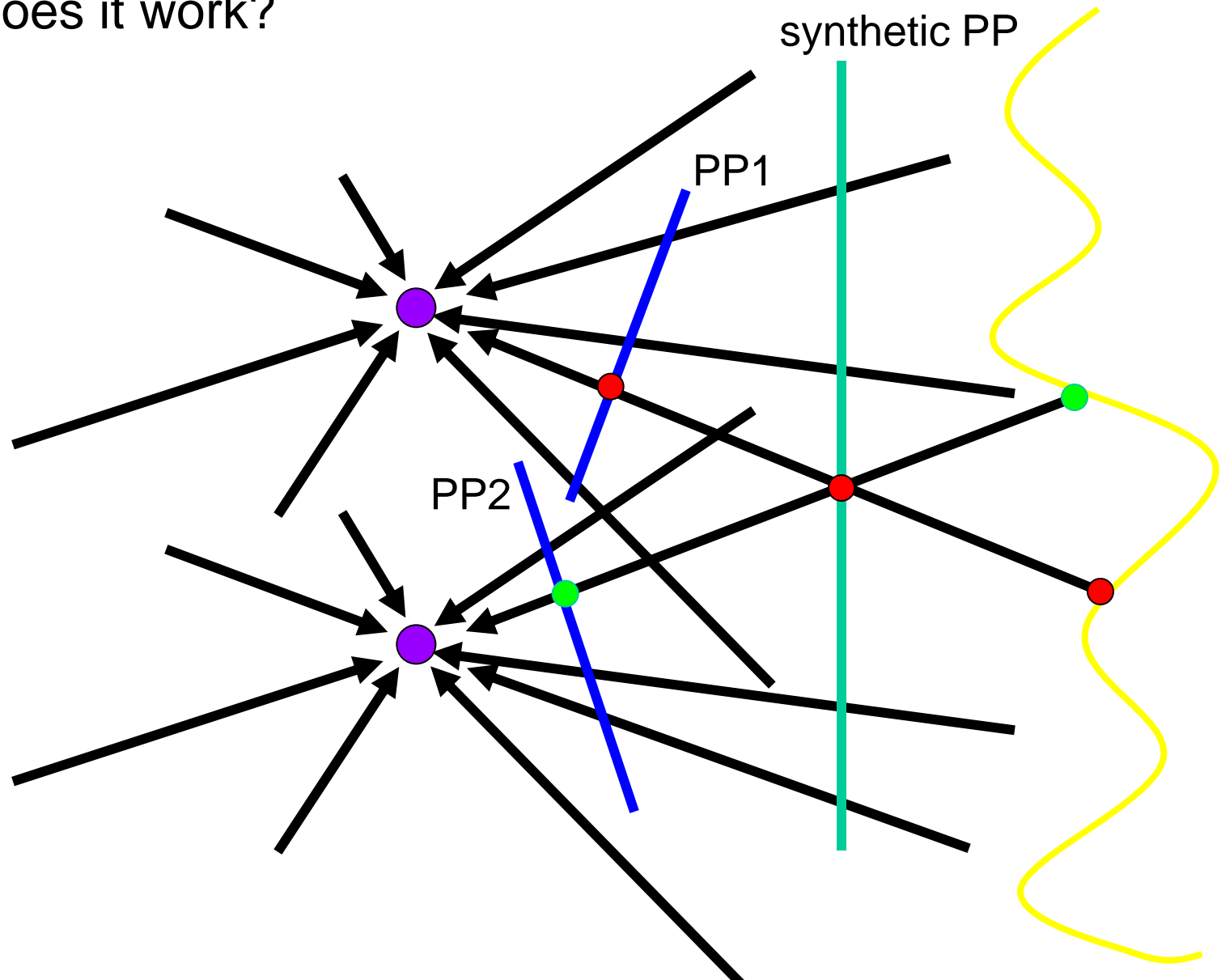
St.Petersburg
photo by A. Tikhonov

Virtual camera rotations

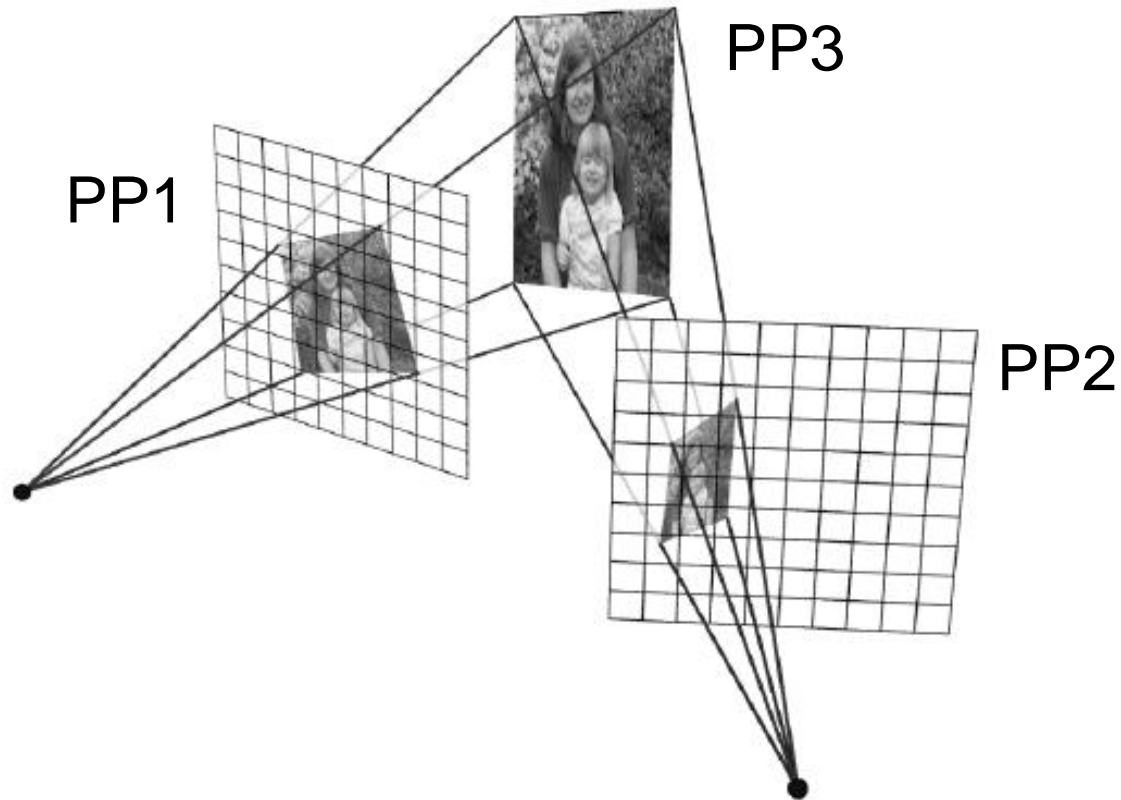


Camera translation

Does it work?



Yes, with planar scene (or far away)

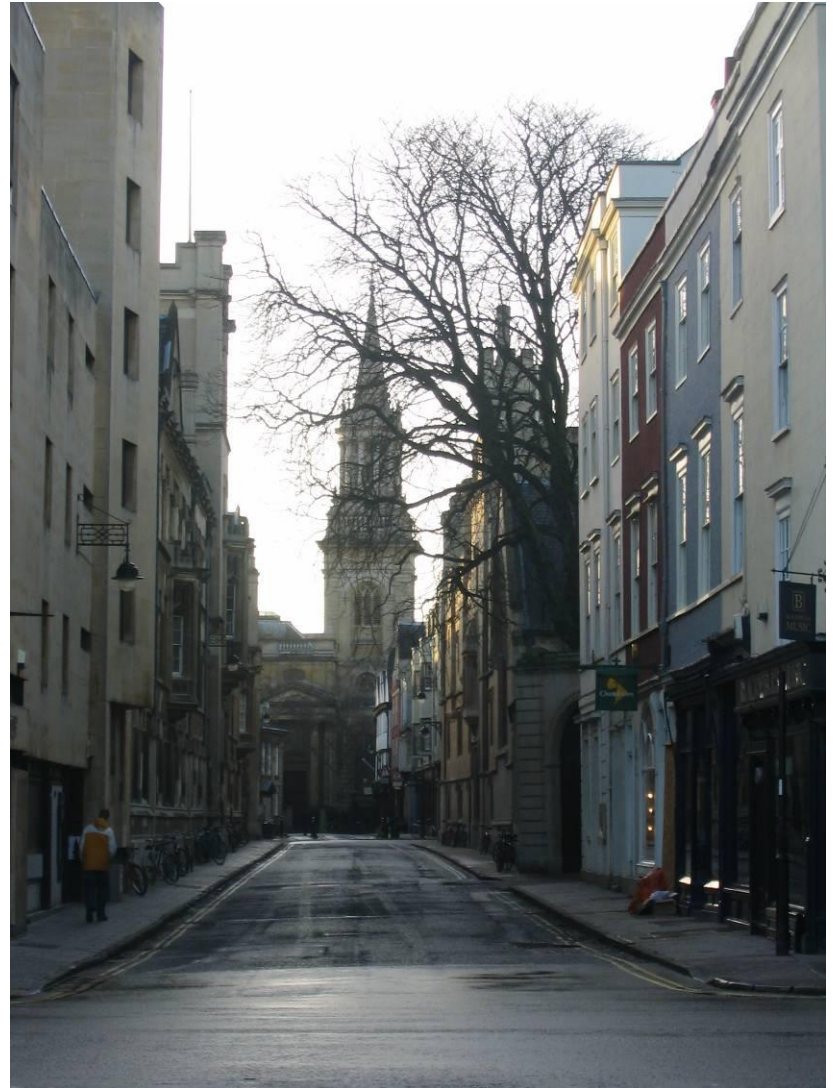


PP3 is a projection plane of both centers of projection,
so we are OK!

So, what can we do here?

Model the scene as a set of planes!

Now, just need to find the orientations of these planes.



Some preliminaries: projective geometry



[Ames Room](#)

Silly Euclid: Trix are for kids!



Parallel lines???

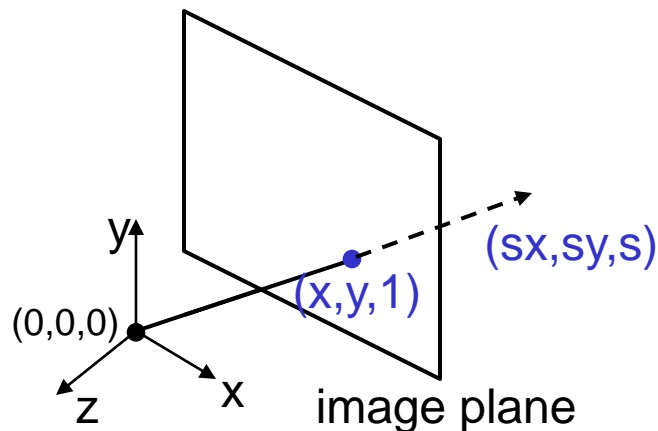
The projective plane

Why do we need homogeneous coordinates?

- represent points at infinity, homographies, perspective projection, multi-view relationships

What is the geometric intuition?

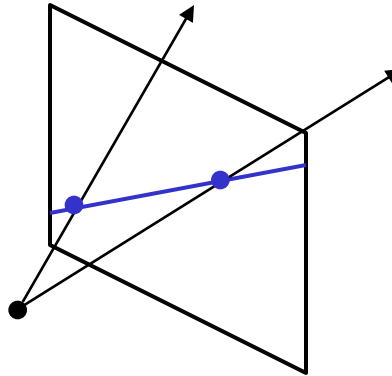
- a point in the image is a *ray* in projective space



- Each *point* (x,y) on the plane is represented by a *ray* (sx,sy,s)
 - all points on the ray are equivalent: $(x, y, 1) \cong (sx, sy, s)$

Projective lines

What does a line in the image correspond to in projective space?



- A line is a *plane* of rays through origin
 - all rays (x,y,z) satisfying: $ax + by + cz = 0$

in vector notation :

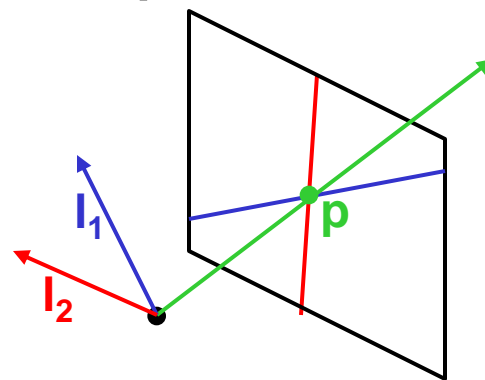
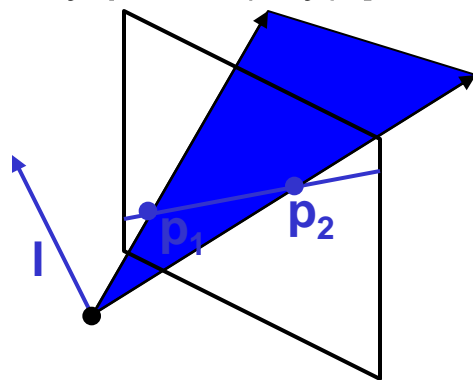
$$0 = \begin{bmatrix} a & b & c \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

l **p**

- A line is also represented as a homogeneous 3-vector **l**

Point and line duality

- A line \mathbf{l} is a homogeneous 3-vector
- It is \perp to every point (ray) \mathbf{p} on the line: $\mathbf{l} \cdot \mathbf{p} = 0$



What is the line \mathbf{l} spanned by rays \mathbf{p}_1 and \mathbf{p}_2 ?

- \mathbf{l} is \perp to \mathbf{p}_1 and $\mathbf{p}_2 \Rightarrow \mathbf{l} = \mathbf{p}_1 \times \mathbf{p}_2$
- \mathbf{l} is the plane normal

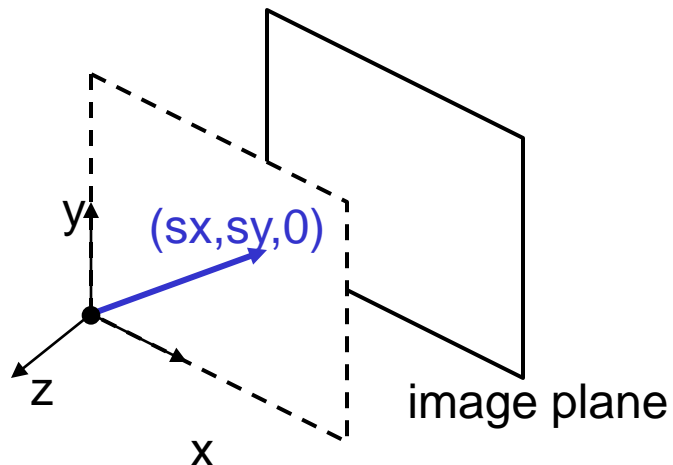
What is the intersection of two lines \mathbf{l}_1 and \mathbf{l}_2 ?

- \mathbf{p} is \perp to \mathbf{l}_1 and $\mathbf{l}_2 \Rightarrow \mathbf{p} = \mathbf{l}_1 \times \mathbf{l}_2$

Points and lines are *dual* in projective space

- given any formula, can switch the meanings of points and lines to get another formula

Ideal points and lines



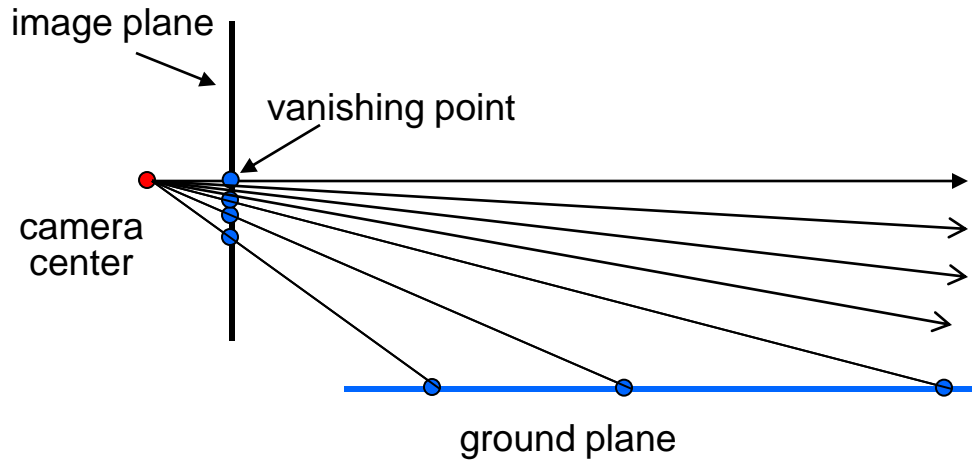
Ideal point (“point at infinity”)

- $p \cong (x, y, 0)$ – parallel to image plane
- It has infinite image coordinates

Ideal line

- $l \cong (0, 0, 1)$ – parallel to image plane

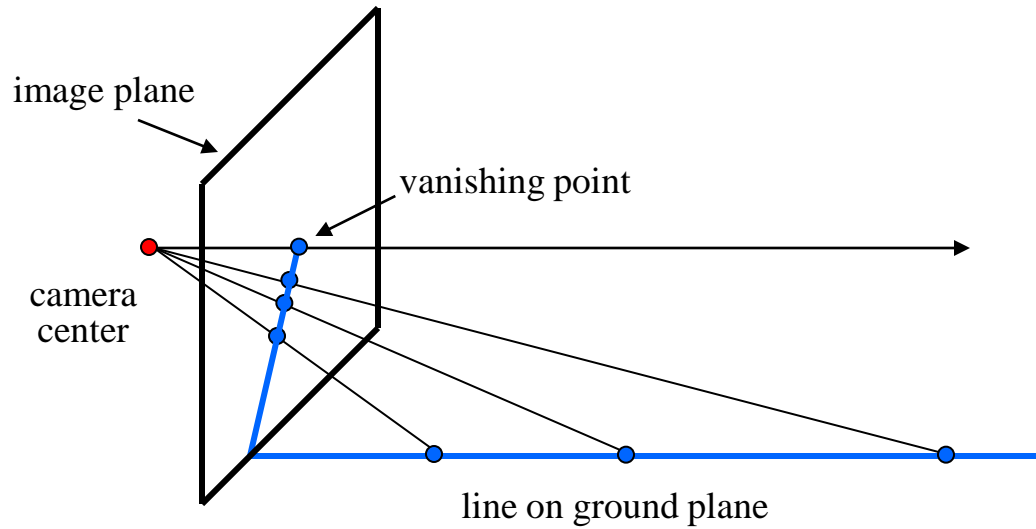
Vanishing points



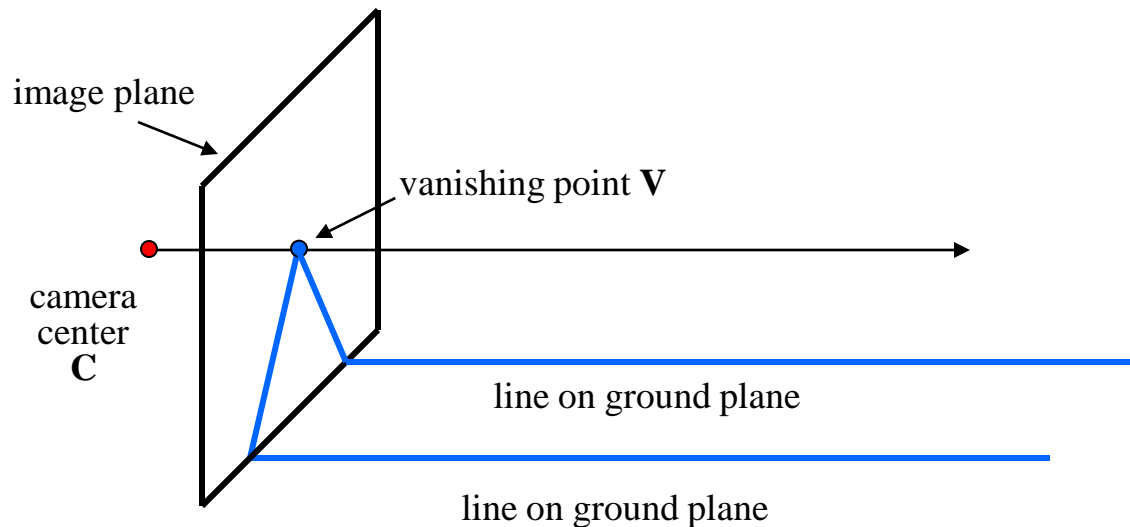
Vanishing point

- projection of a point at infinity
- Caused by ideal line

Vanishing points (2D)



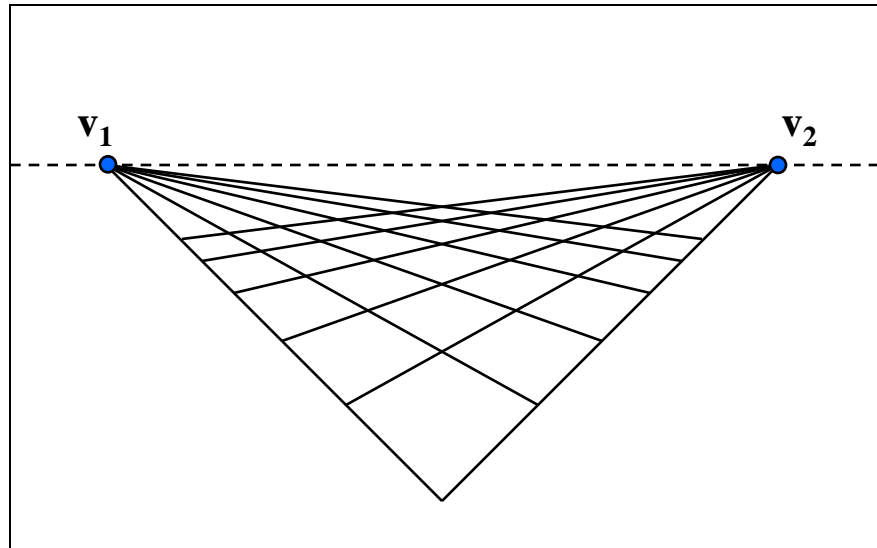
Vanishing points



Properties

- Any two parallel lines have the same vanishing point v
- The ray from C through v is parallel to the lines
- An image may have more than one vanishing point

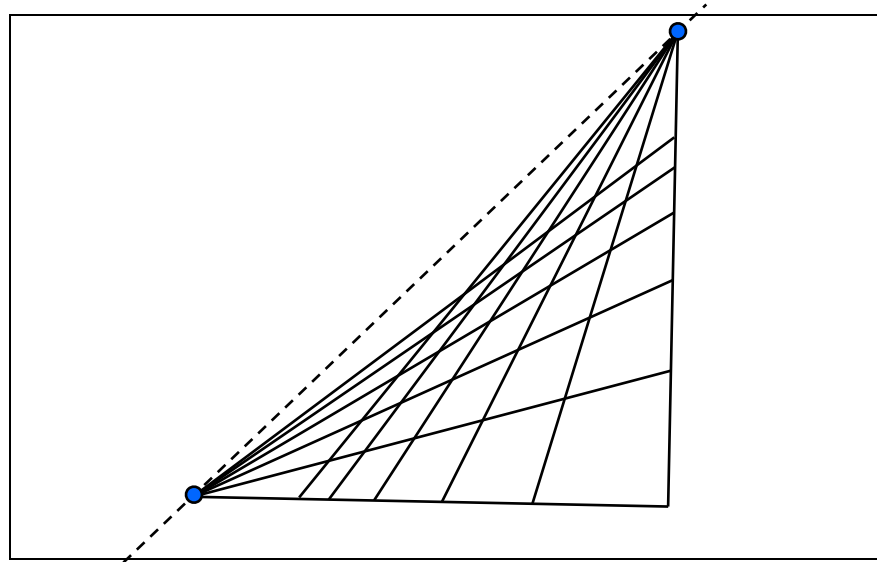
Vanishing lines



Multiple Vanishing Points

- Any set of parallel lines on the plane define a vanishing point
- The union of all of these vanishing points is the *horizon line*
 - also called *vanishing line*
- Note that different planes define different vanishing lines

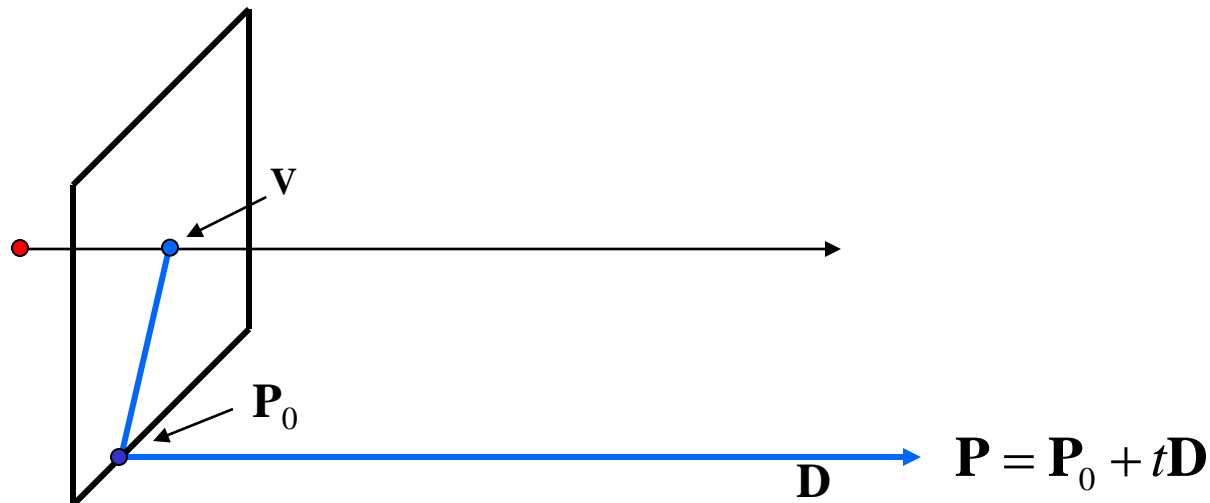
Vanishing lines



Multiple Vanishing Points

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Computing vanishing points

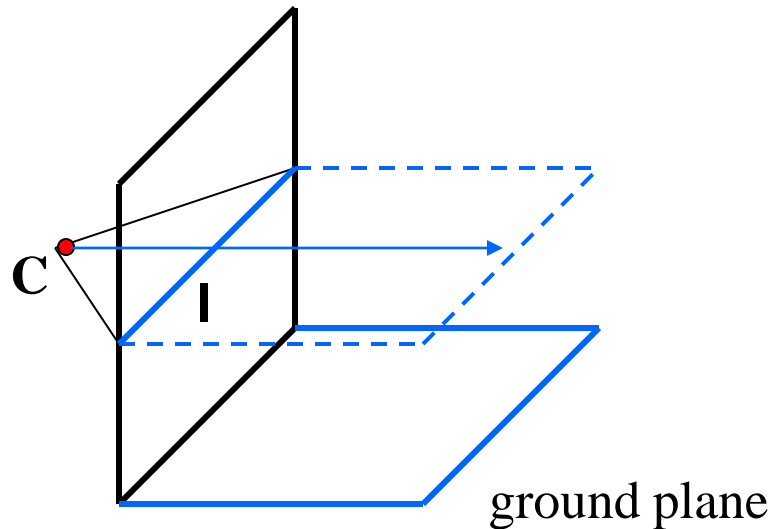


$$\mathbf{P}_t = \begin{bmatrix} P_X + tD_X \\ P_Y + tD_Y \\ P_Z + tD_Z \\ 1 \end{bmatrix} \cong \begin{bmatrix} P_X / t + D_X \\ P_Y / t + D_Y \\ P_Z / t + D_Z \\ 1/t \end{bmatrix} \quad t \rightarrow \infty \quad \mathbf{P}_\infty \cong \begin{bmatrix} D_X \\ D_Y \\ D_Z \\ 0 \end{bmatrix}$$

Properties $\mathbf{v} = \Pi \mathbf{P}_\infty$

- \mathbf{P}_∞ is a point at *infinity*, \mathbf{v} is its projection
- They depend only on line *direction*
- Parallel lines $\mathbf{P}_0 + t\mathbf{D}$, $\mathbf{P}_1 + t\mathbf{D}$ intersect at \mathbf{P}_∞

Computing vanishing lines

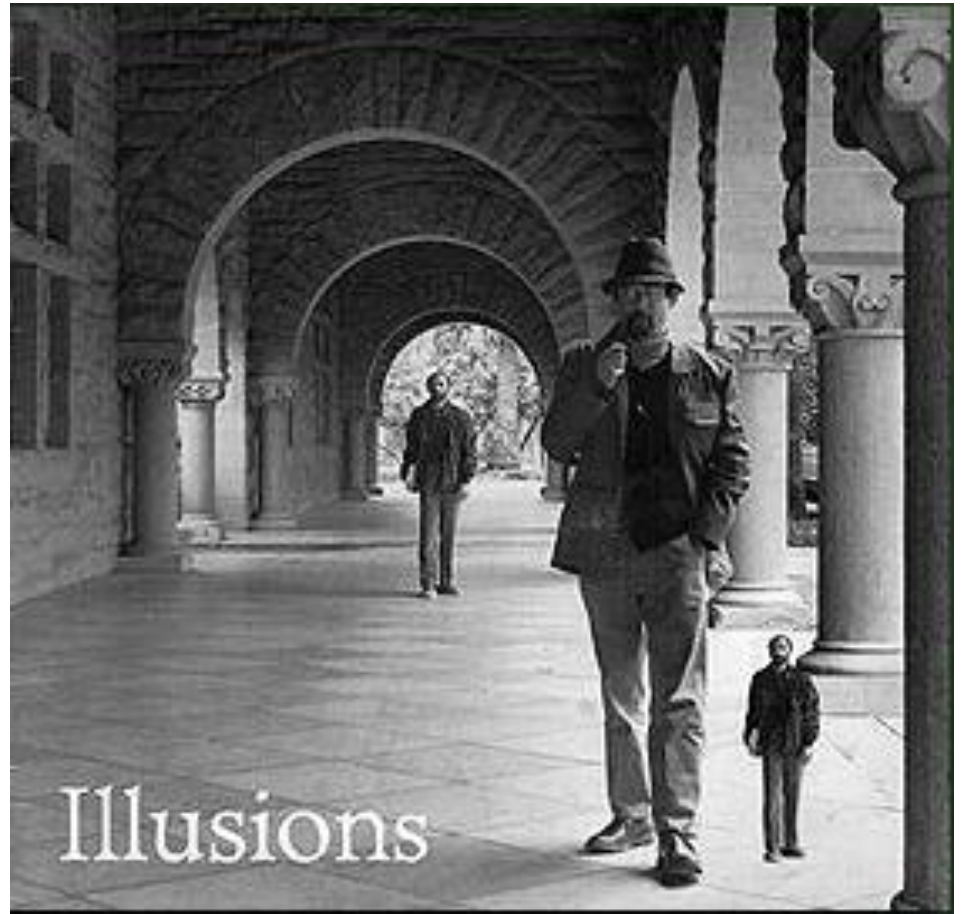
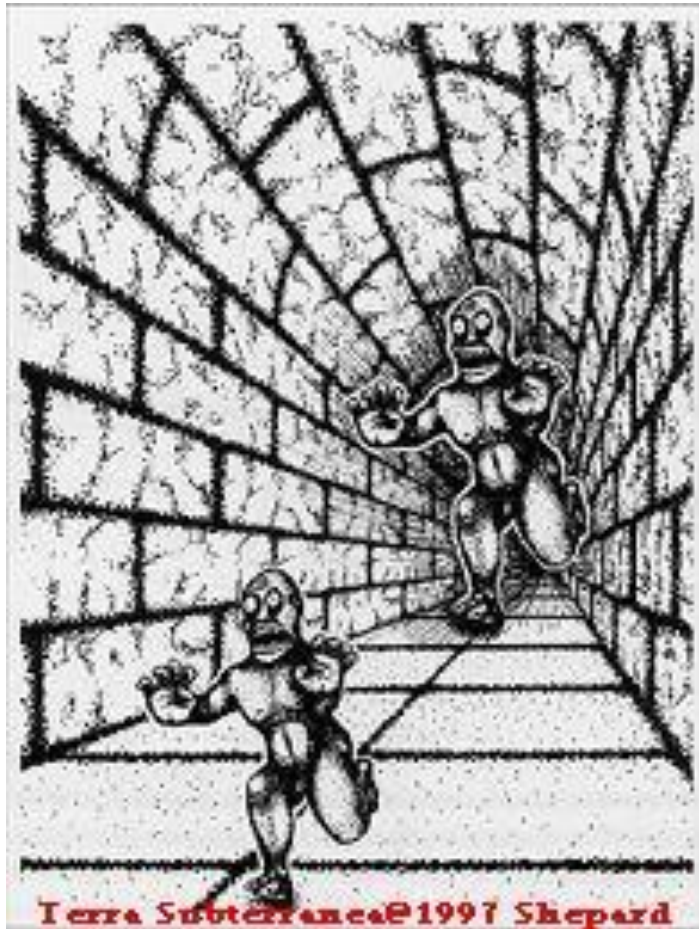


Properties

- **I** is intersection of horizontal plane through **C** with image plane
- Compute **I** from two sets of parallel lines on ground plane
- All points at same height as **C** project to **I**
 - points higher than **C** project above **I**
- Provides way of comparing height of objects in the scene



Fun with vanishing points



“Tour into the Picture” (SIGGRAPH '97)

Create a 3D “theatre stage” of five billboards



Specify foreground objects through bounding polygons



Use camera transformations to navigate through the scene



The idea

Many scenes (especially paintings), can be represented as an axis-aligned box volume (i.e. a stage)

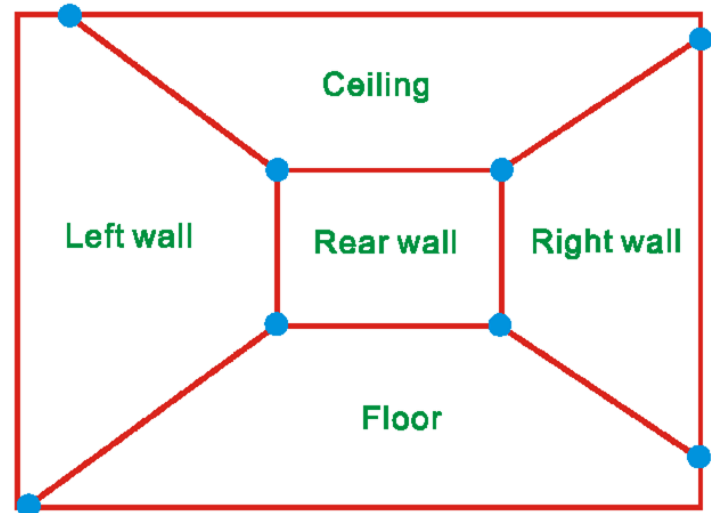
Key assumptions:

- All walls of volume are orthogonal
- Camera view plane is parallel to back of volume
- Camera up is normal to volume bottom

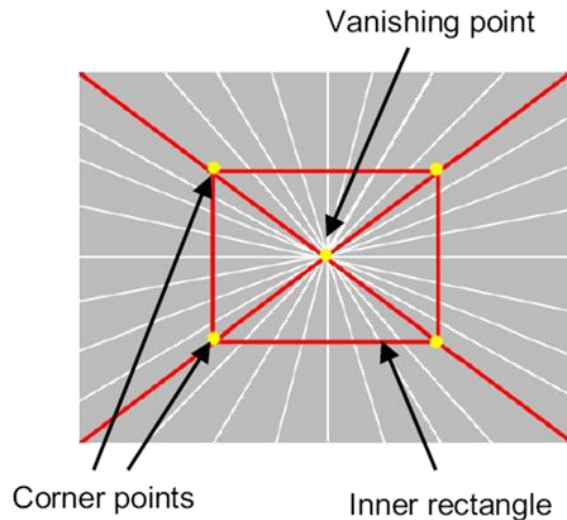
How many vanishing points does the box have?

- Three, but two at infinity
- Single-point perspective

Can use the vanishing point to fit the box to the particular Scene!



Fitting the box volume

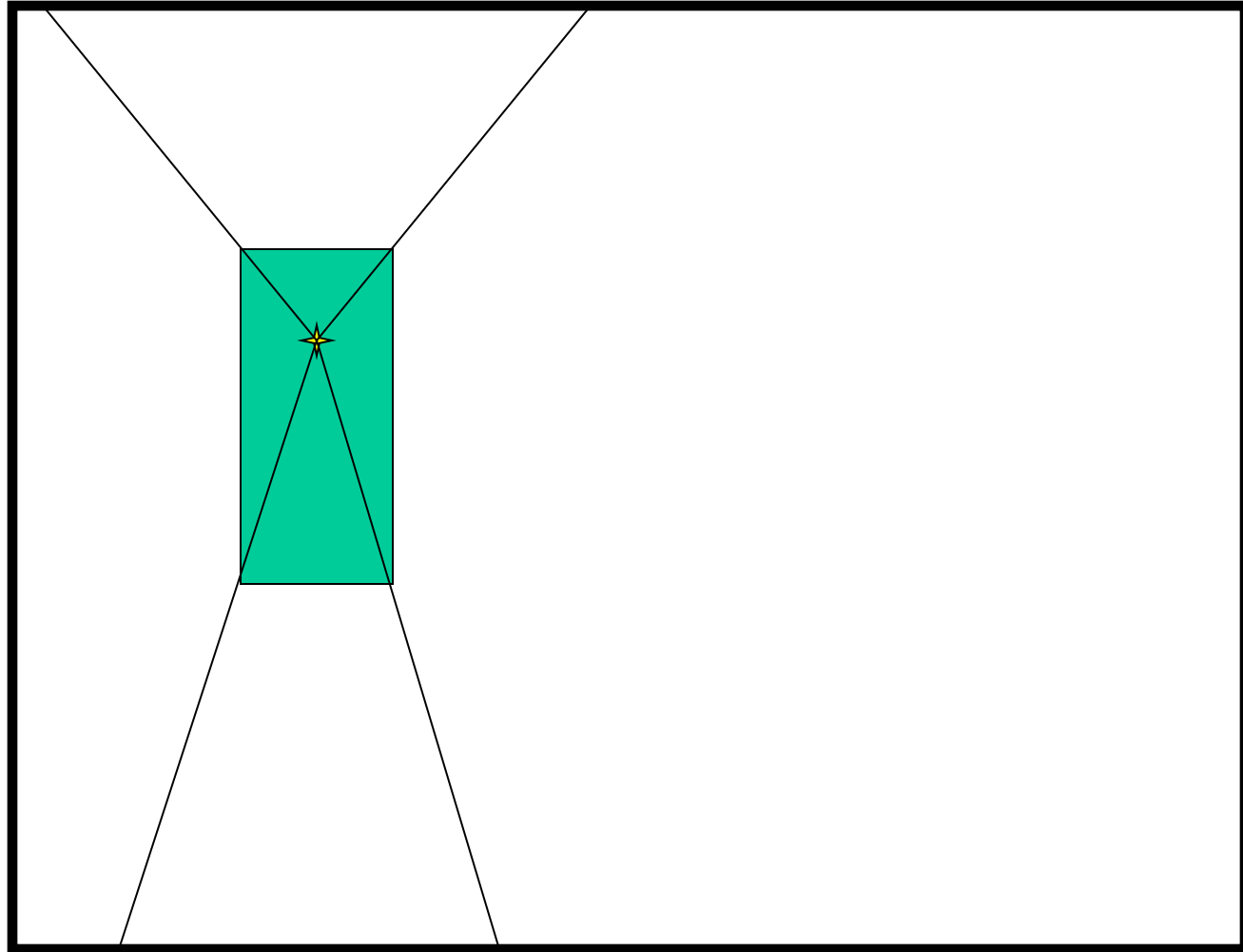


User controls the inner box and the vanishing point placement (# of DOF???)

Q: What's the significance of the vanishing point location?

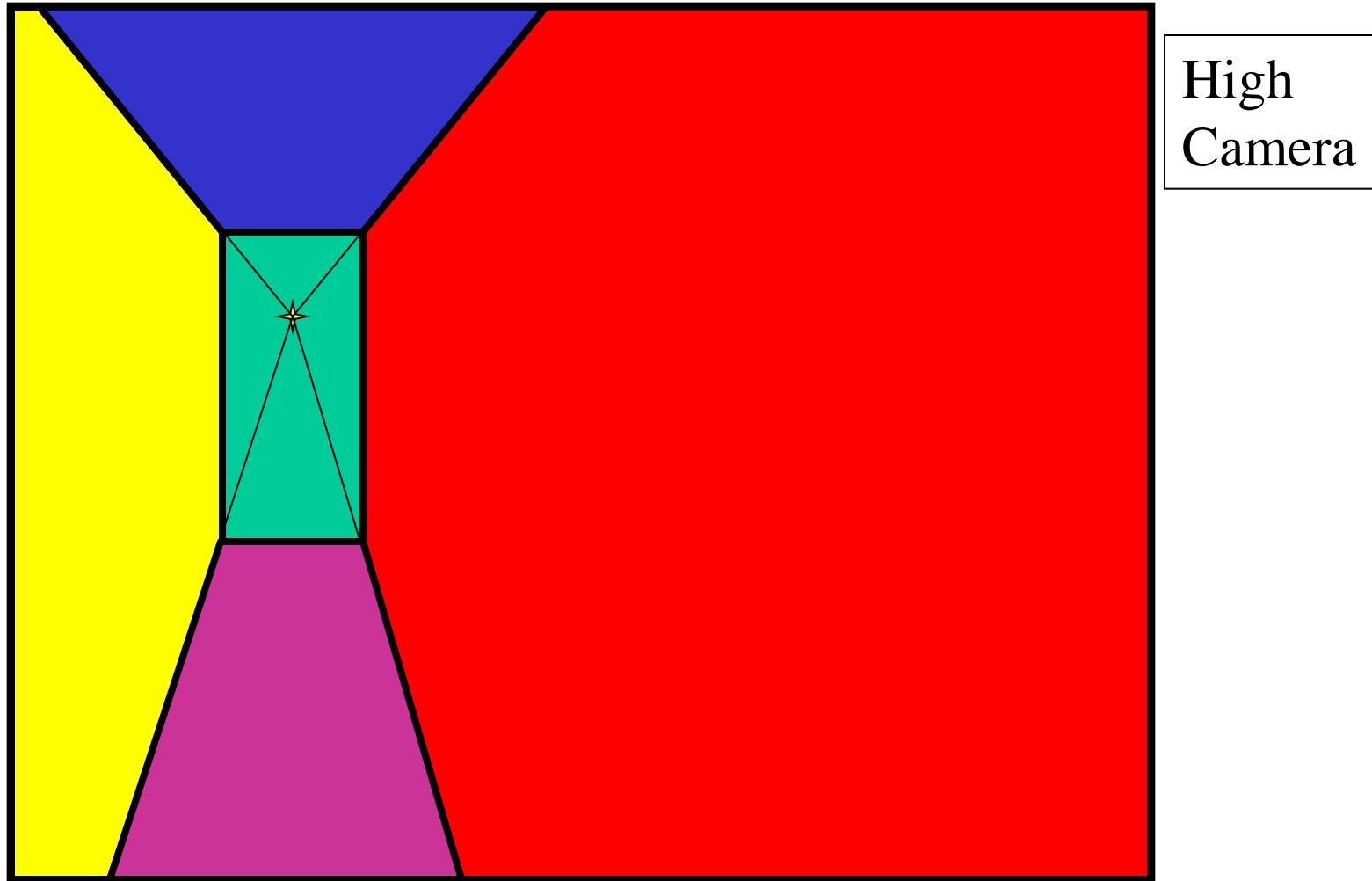
A: It's at eye level: ray from COP to VP is perpendicular to image plane.

Example of user input: vanishing point and back face of view volume are defined

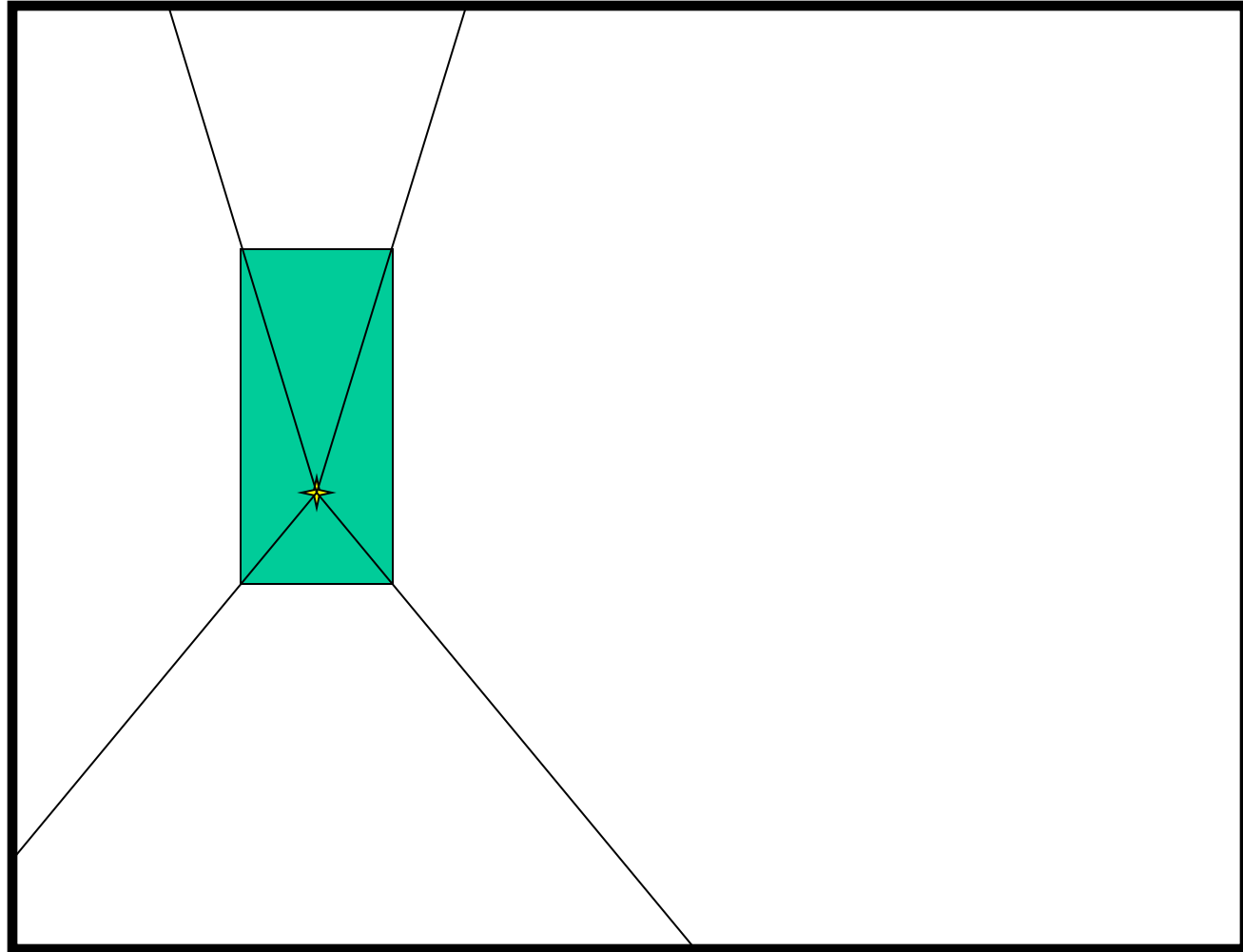


High
Camera

Example of user input: vanishing point and back face of view volume are defined

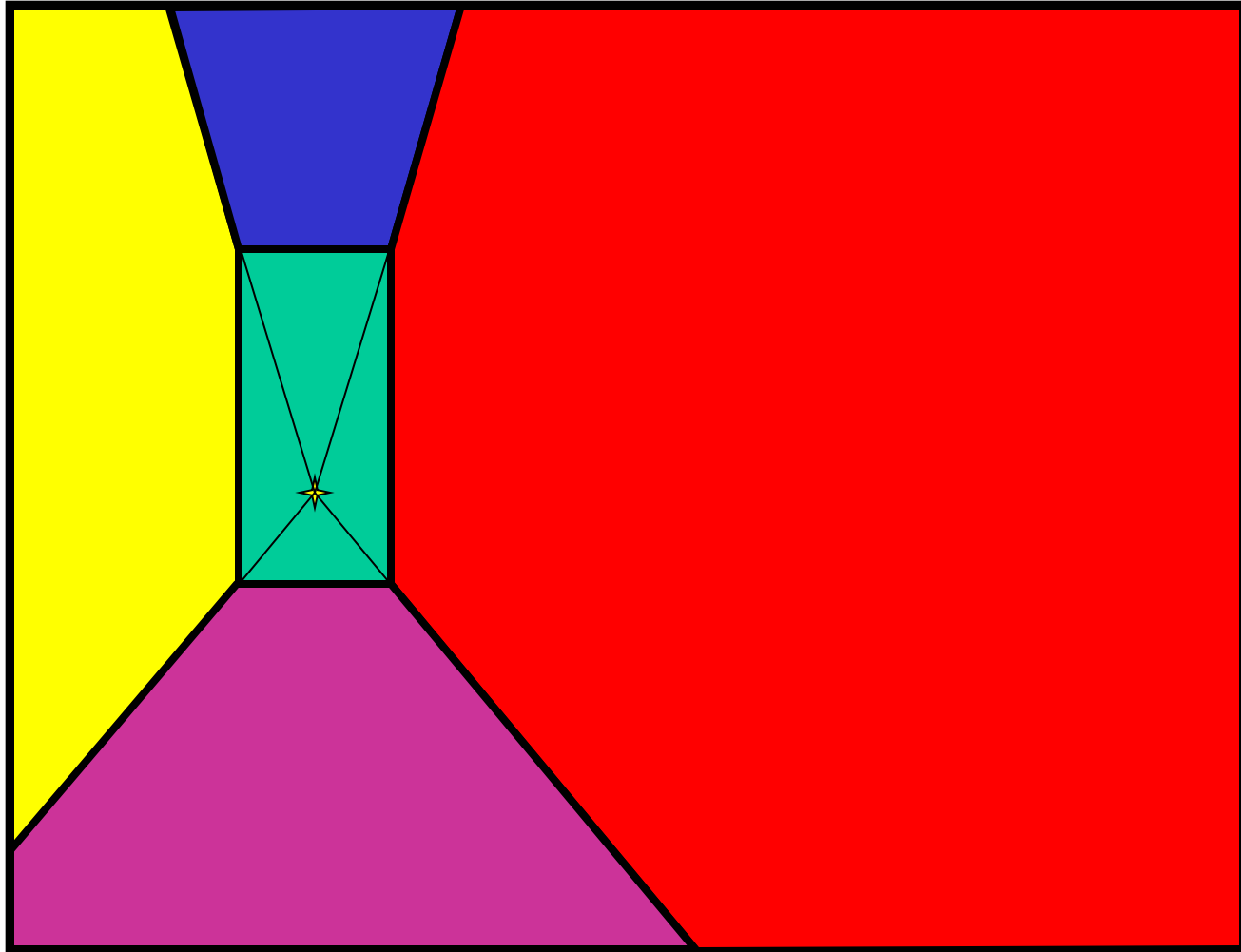


Example of user input: vanishing point and back face of view volume are defined



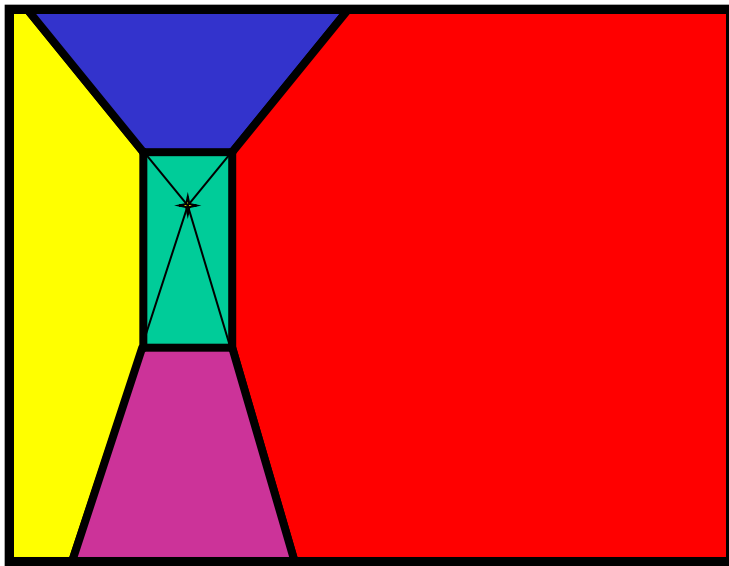
Low
Camera

Example of user input: vanishing point and back face of view volume are defined

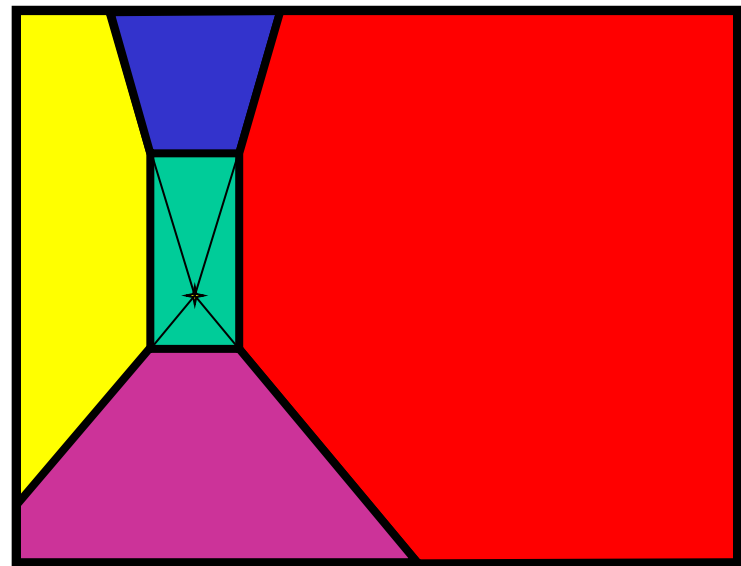


Low
Camera

Comparison of how image is subdivided based on two different camera positions. You should see how moving the vanishing point corresponds to moving the eyepoint in the 3D world.

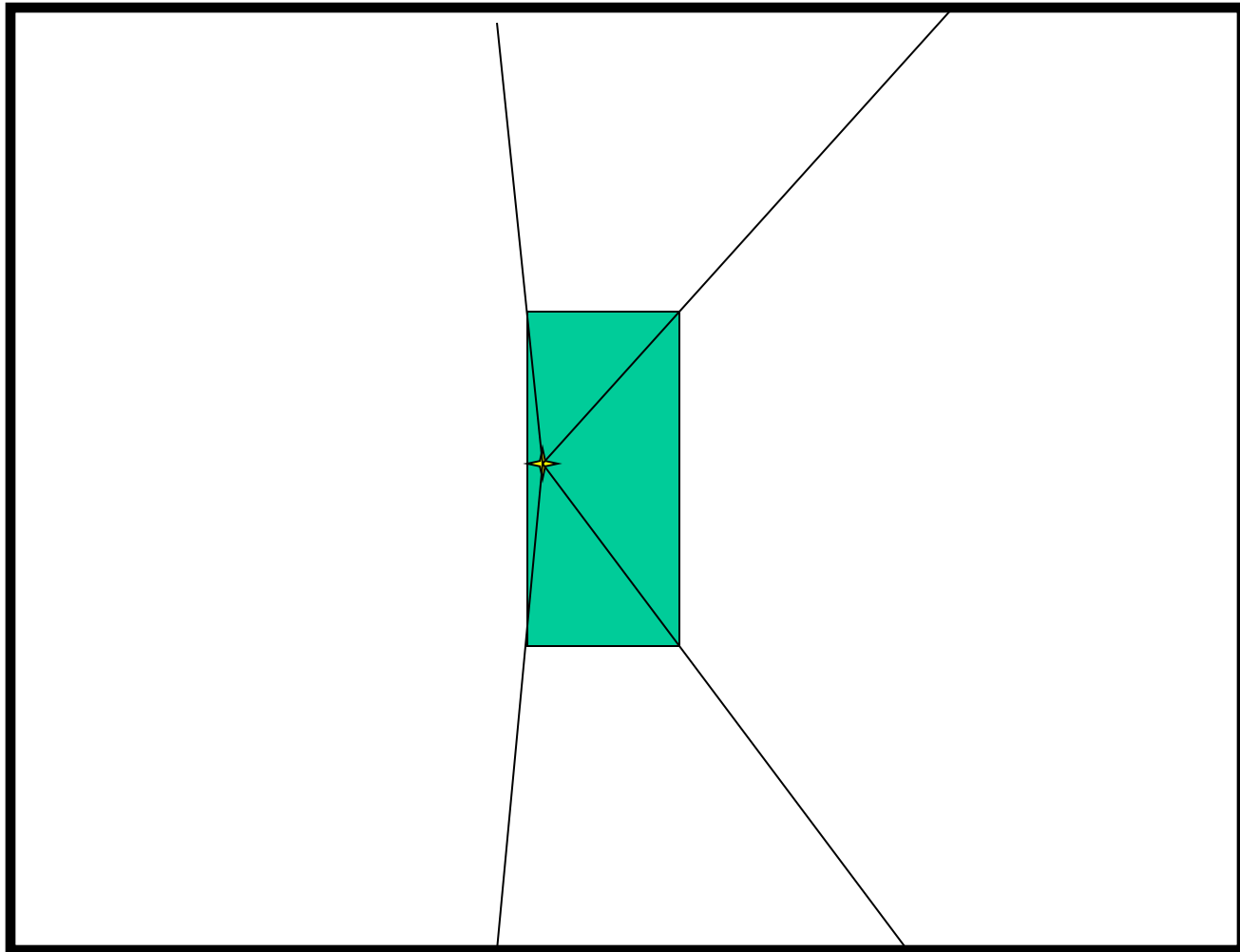


High Camera



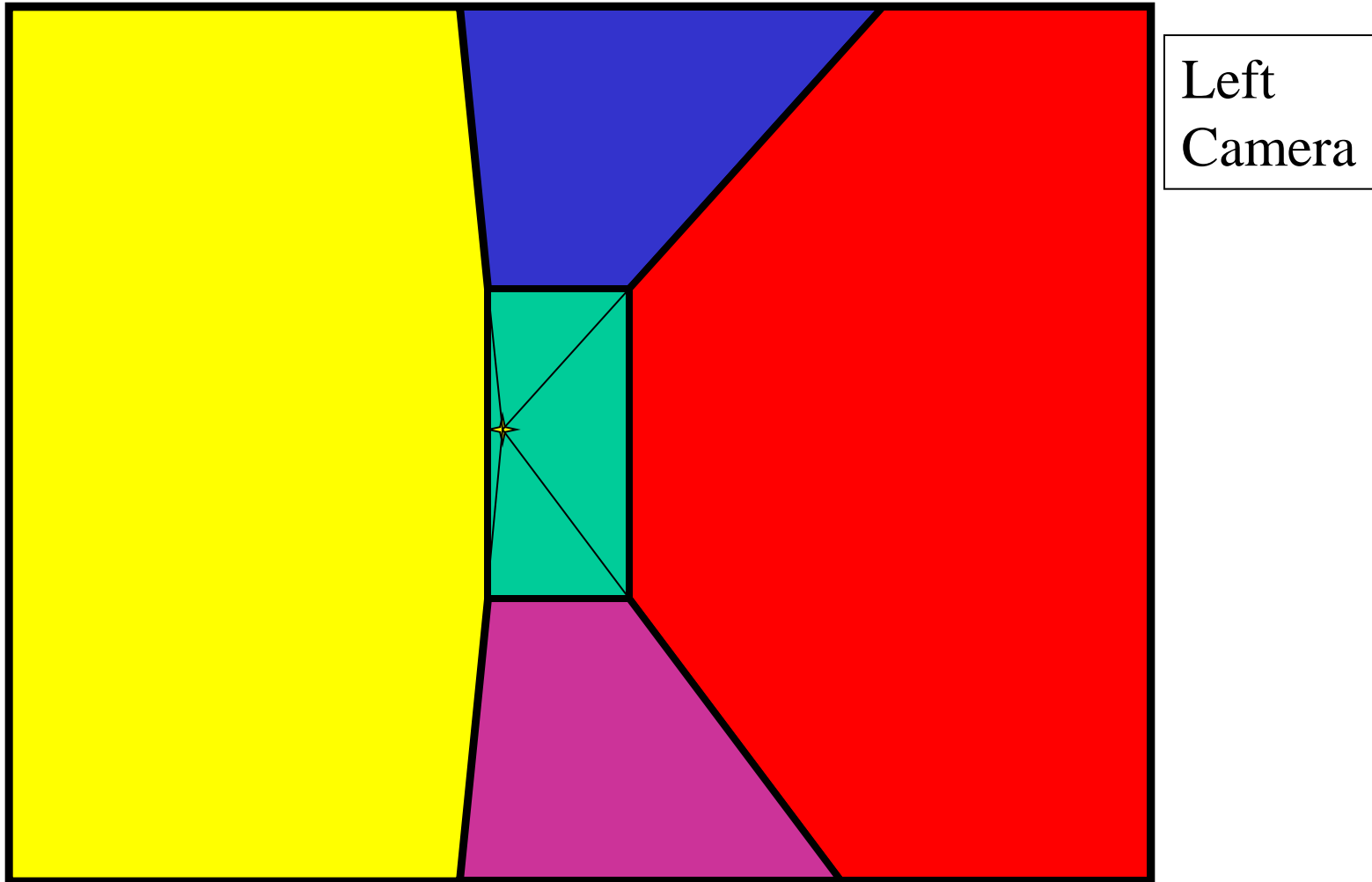
Low Camera

Another example of user input: vanishing point and back face of view volume are defined

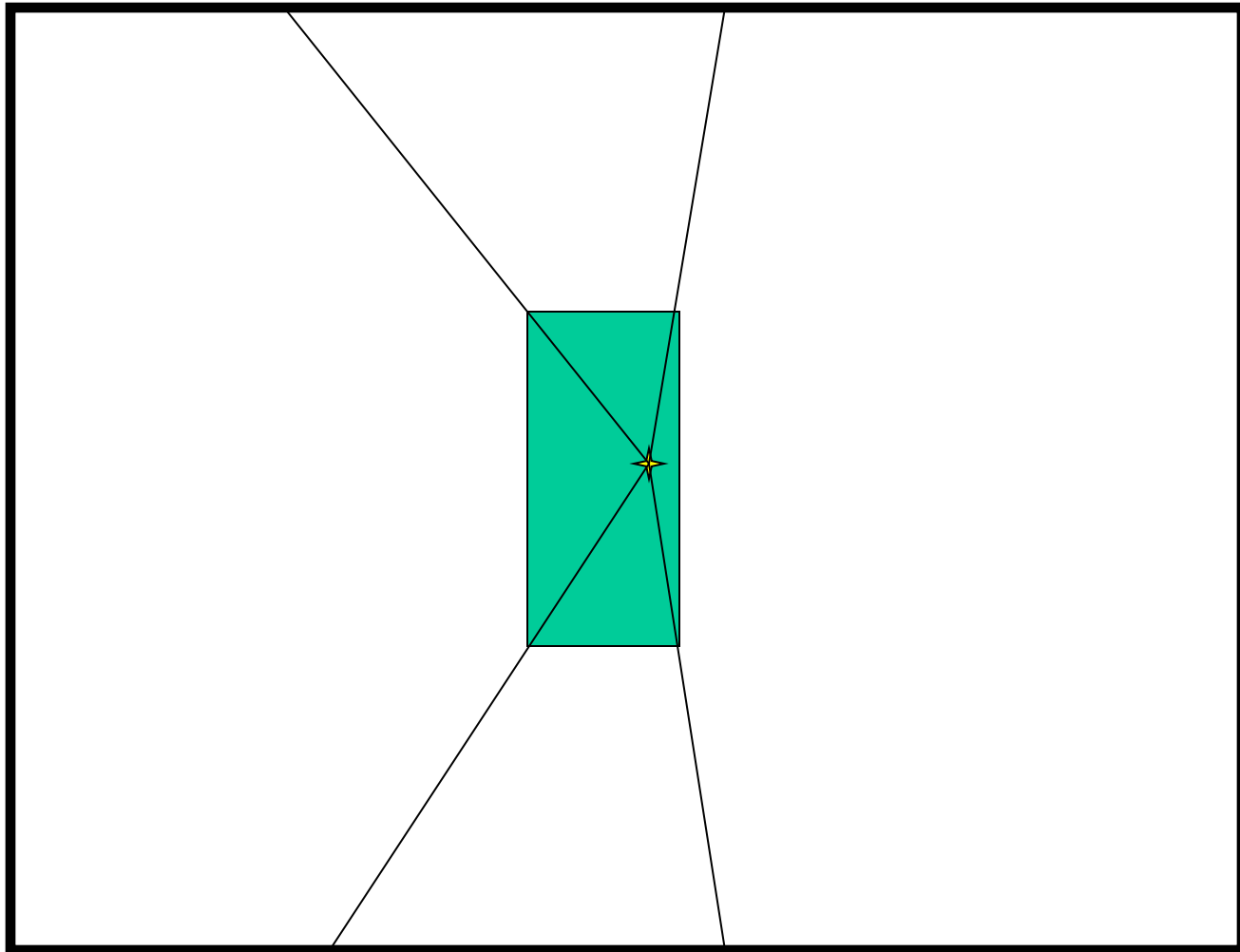


Left
Camera

Another example of user input: vanishing point and back face of view volume are defined

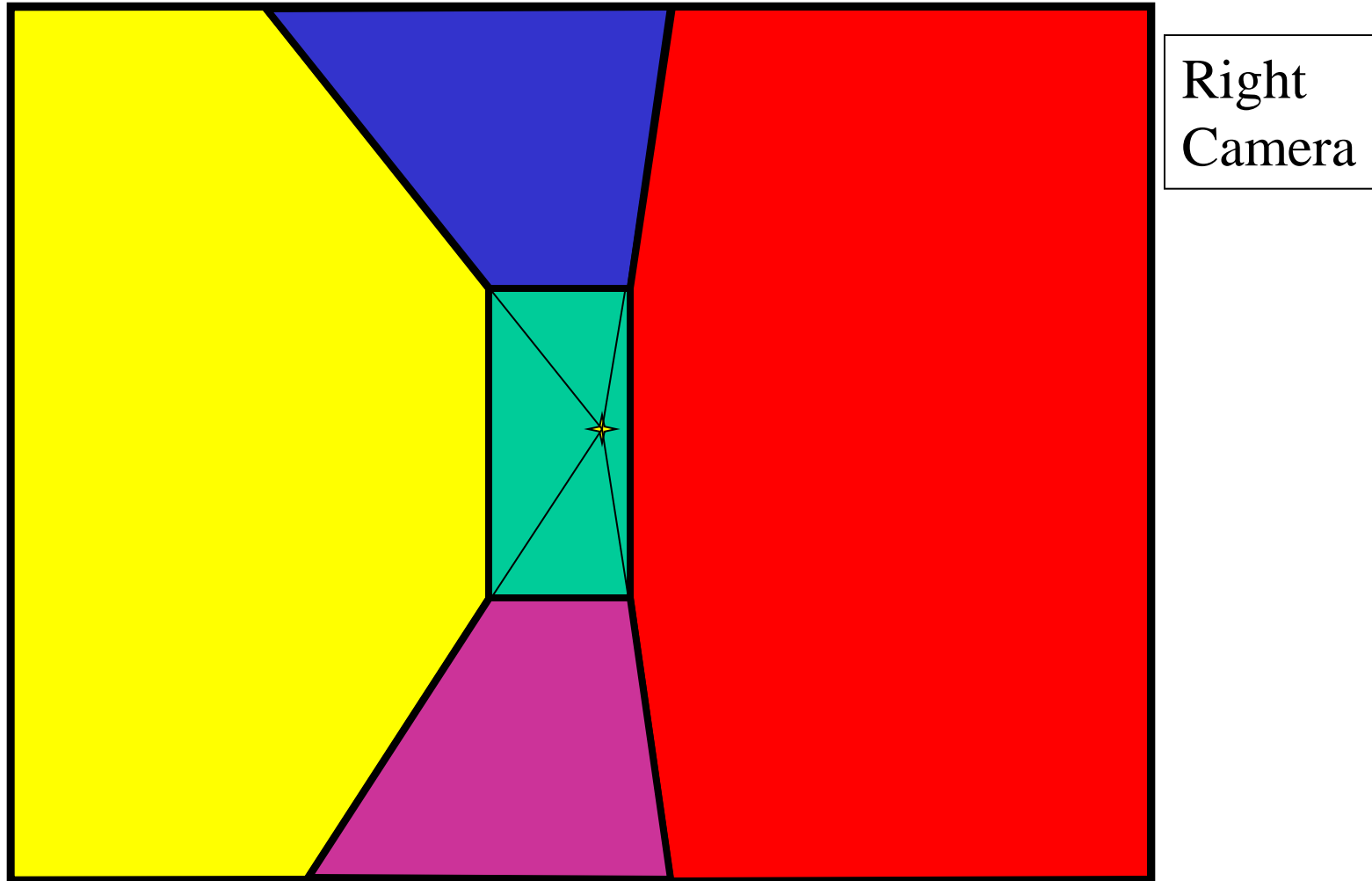


Another example of user input: vanishing point
and back face of view volume are defined

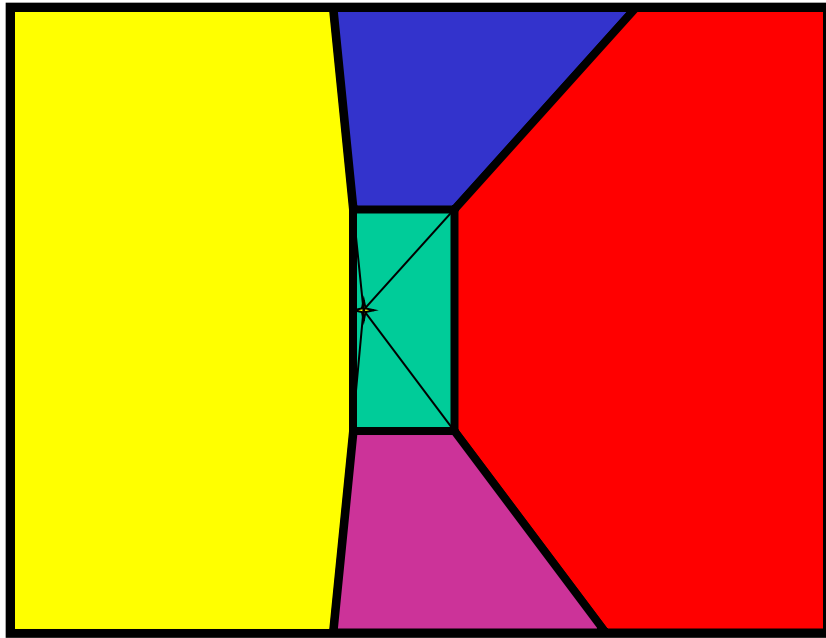


Right
Camera

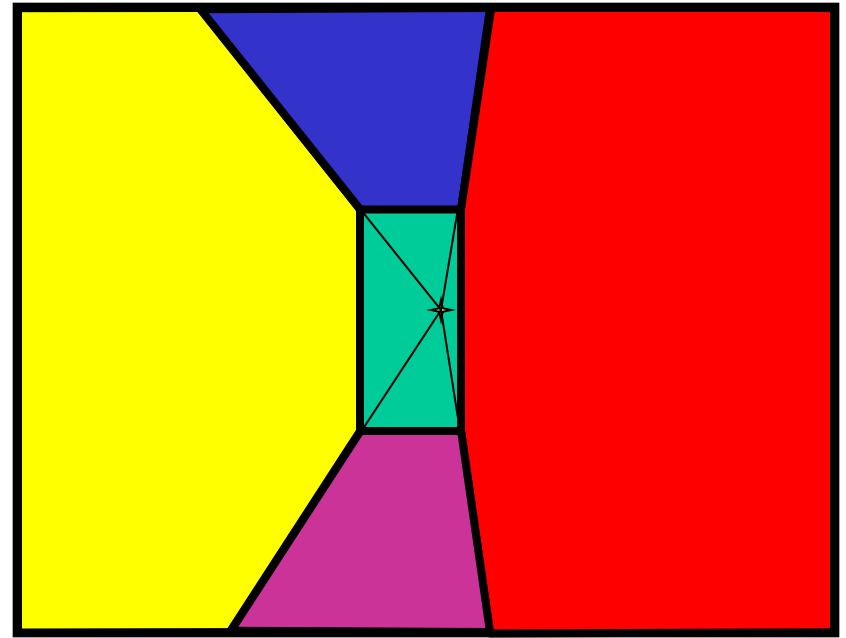
Another example of user input: vanishing point and back face of view volume are defined



Comparison of two camera placements – left and right. Corresponding subdivisions match view you would see if you looked down a hallway.



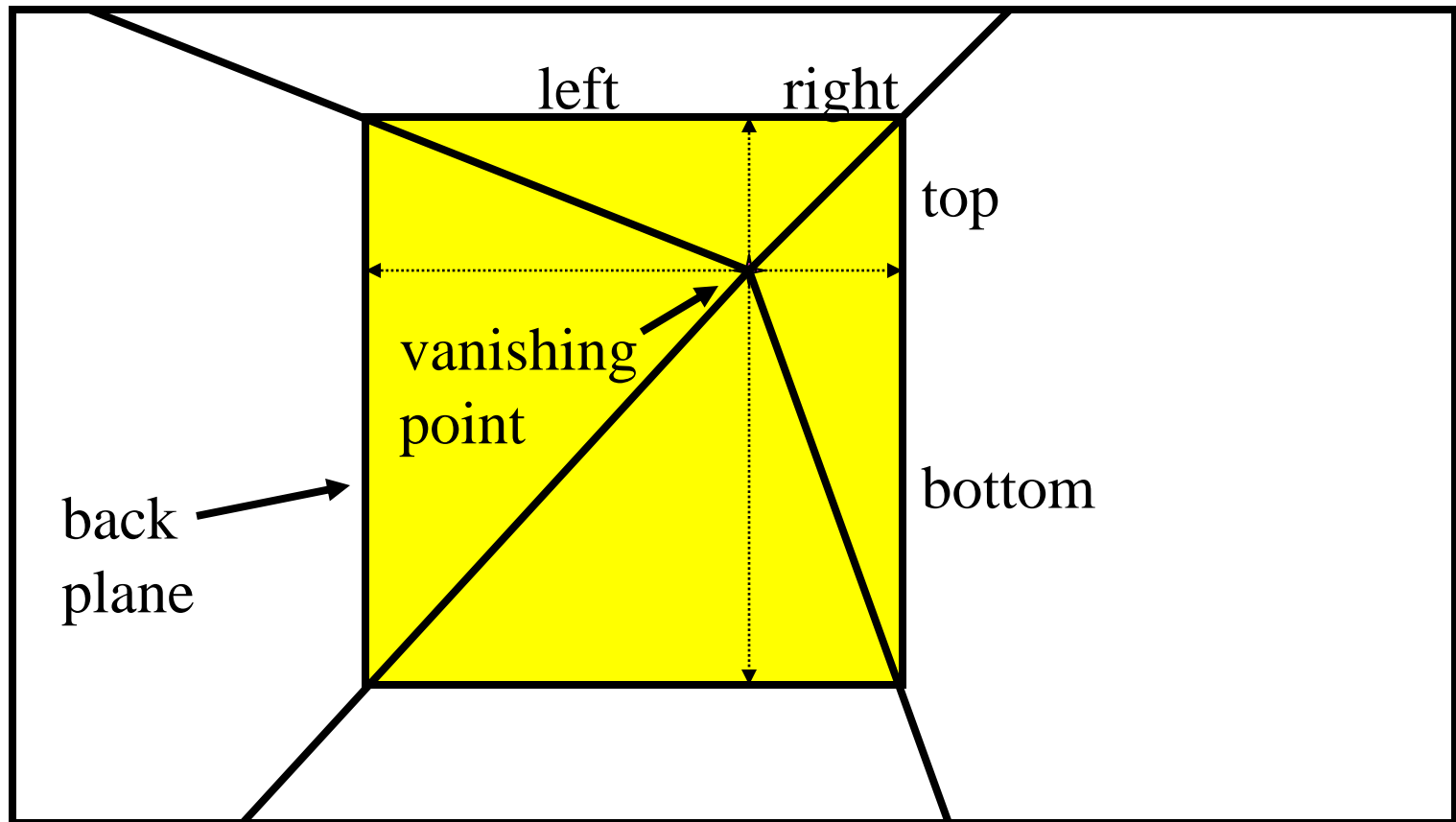
Left Camera



Right Camera

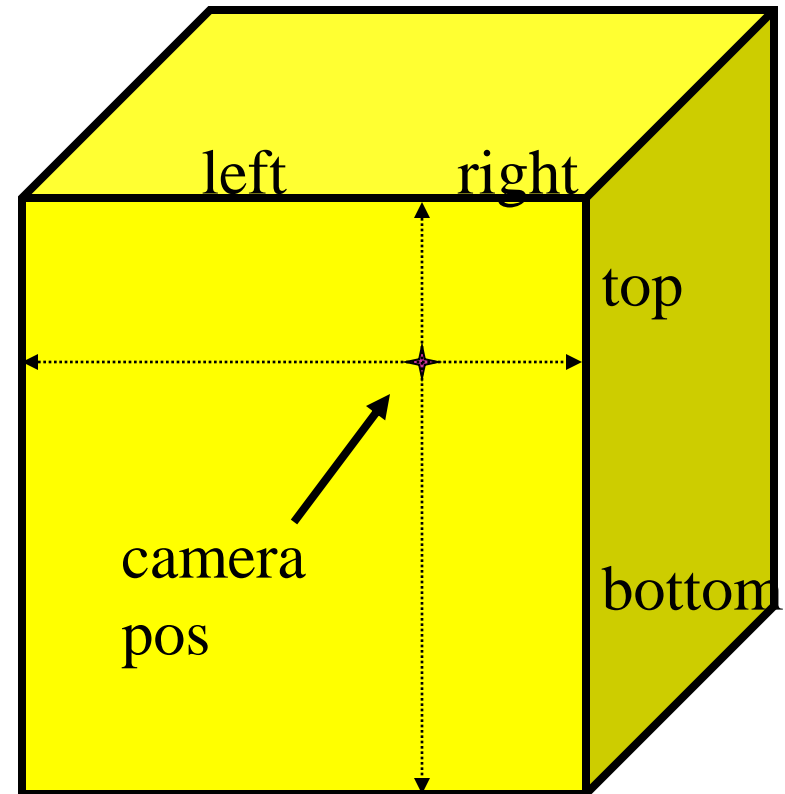
2D to 3D conversion

First, we can get ratios

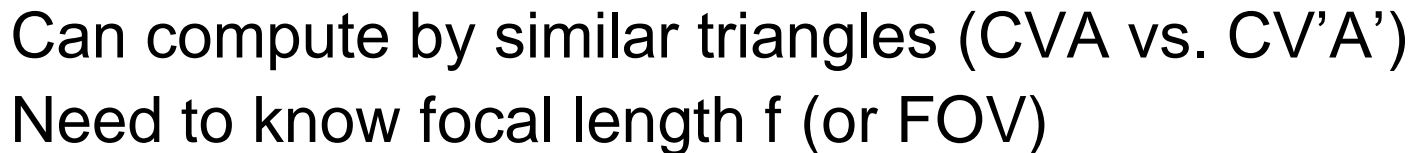


2D to 3D conversion

- Size of user-defined back plane must equal size of camera plane (orthogonal sides)
- Use top versus side ratio to determine relative height and width dimensions of box
- Left/right and top/bot ratios determine part of 3D camera placement



A diagram of a hyperbolic paraboloid, or saddle shape, which is a surface of negative Gaussian curvature. The surface is shown in perspective, with a central point labeled 'V' and two points labeled 'A' and 'B' on the surface. The surface is colored with a gradient from light blue to dark blue.

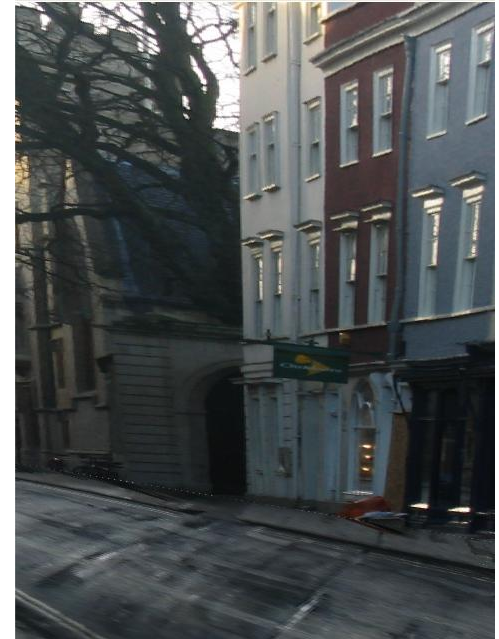
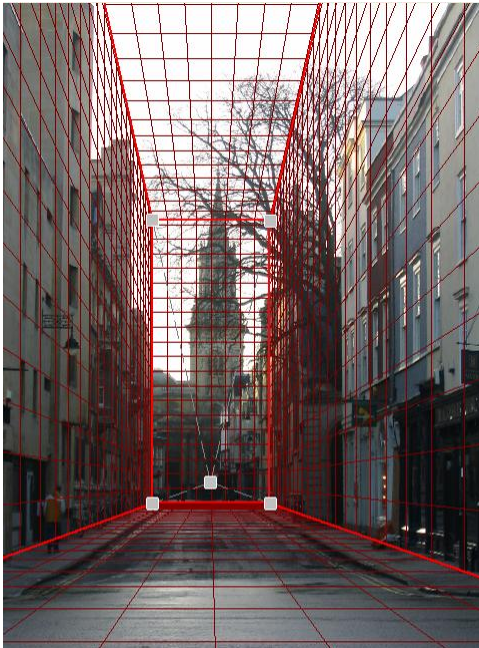


- Simple unprojection
- What about things off the ground?

DEMO

Now, we know the 3D geometry of the box

We can texture-map the box walls with texture from the image

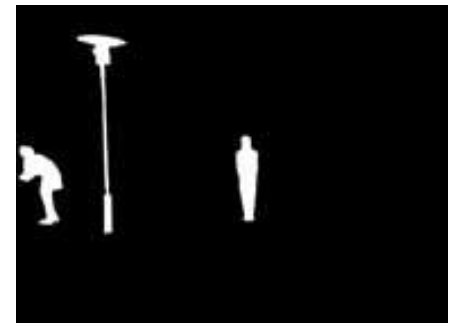


Foreground Objects

Use separate billboard for each

For this to work, three separate images used:

- Original image.
- Mask to isolate desired foreground images.
- Background with objects removed



Foreground Objects

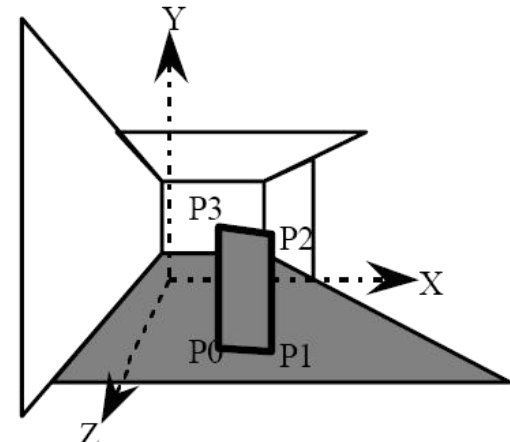
Add vertical rectangles for each foreground object

Can compute 3D coordinates P_0 , P_1 since they are on known plane.

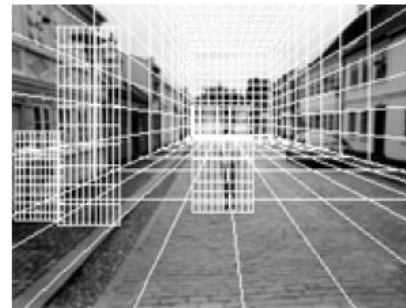
P_2 , P_3 can be computed as before (similar triangles)



(a) Specifying of a foreground object



(b) Estimating the vertices of the foreground object model



(c) Three foreground object models

Foreground DEMO

