Computer Graphics

Lecture 7

General Perspective Cameras

Orthographic Cameras

Announcements

- Tentatively: back in person tomorrow; watch for a Canvas announcement around 7am to confirm.
- Grading turnaround target: 1 week
    - It's not realistic to grade HW[i] before A[i] deadline.
    - But you can check your math with classmates (esp. after the HW[i] deadline)
    - And, this is graphics: if you did the math wrong, the results will probably look wrong!

Goals

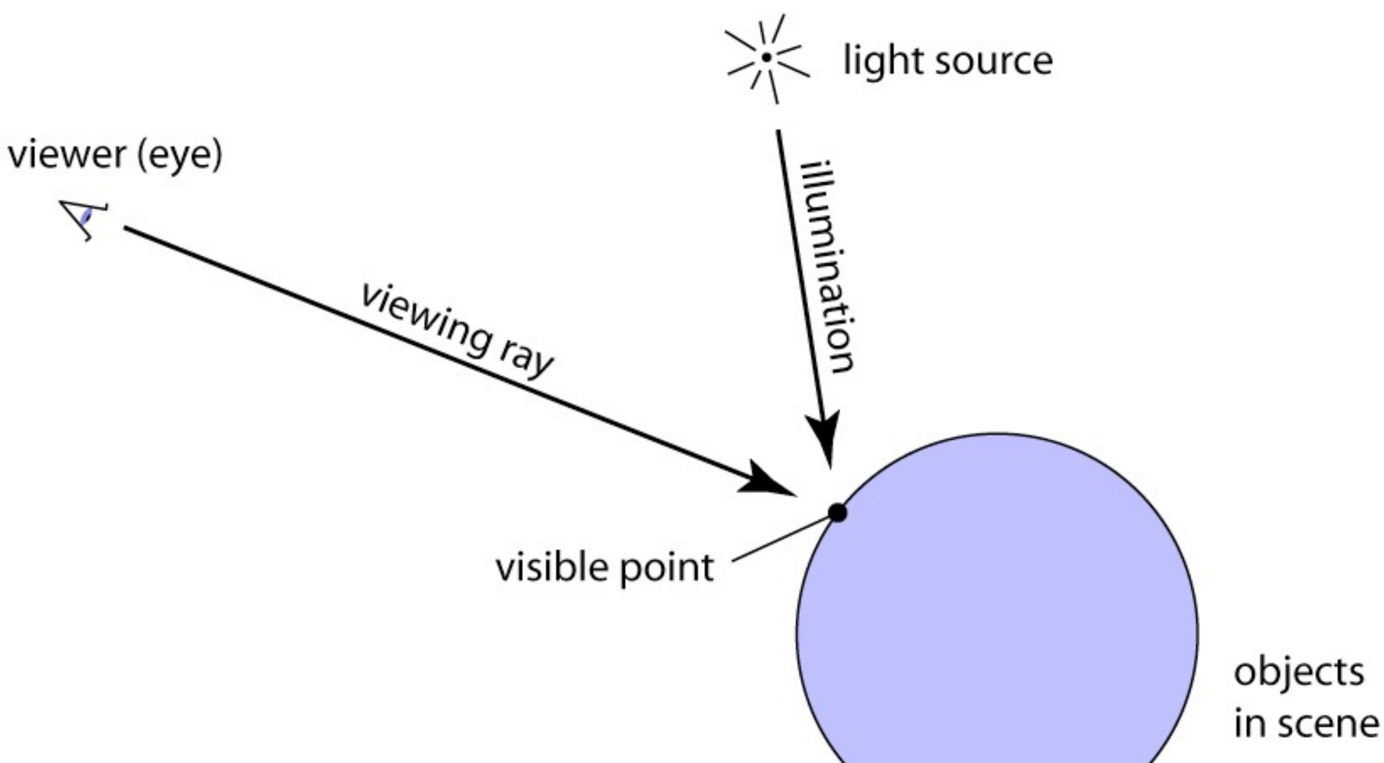
Know how to generate rays for <u>general</u> perspective cameras.
(and orthographic)

Know how to construct a camera basis given eye, view, and up vectors.

(Be aware of some variations on perspective and orthographic projections)

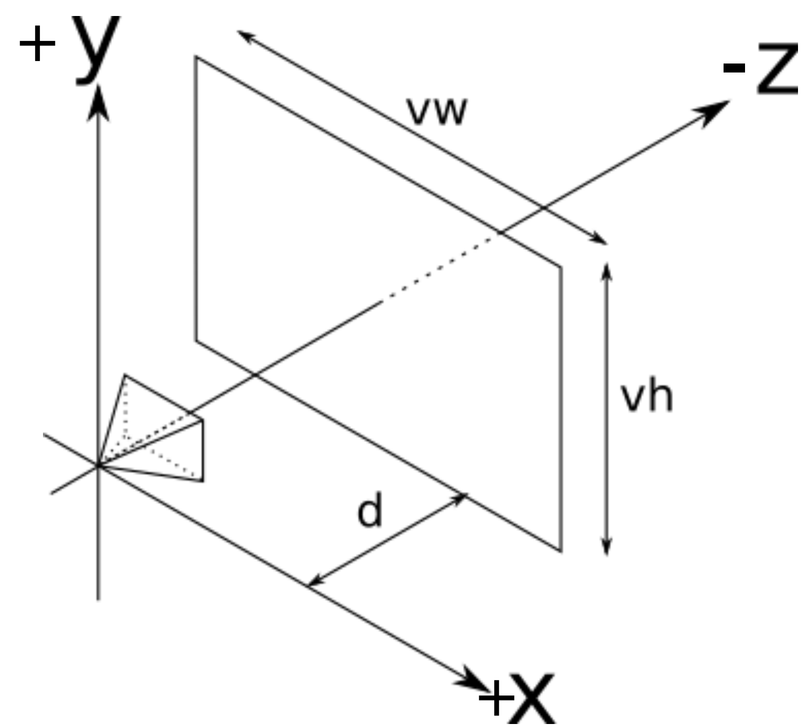
Ray Tracing: Pseudocode

```
for each pixel:
    generate a viewing ray for the pixel
    find the closest object it intersects
    determine the color of the object
```



A "canonical" camera

- Eye is at the origin (0, 0, 0)
- Looking down the **negative** z axis
- Viewport is aligned with the xy plane
- vh = vw = 1
- d = 1



Canonical Perspective Camera: Viewing Rays

$$u = \frac{j - \frac{1}{2}}{W} - \frac{1}{2}$$

$$v = -\left(\frac{i - \frac{1}{2}}{H} - \frac{1}{2}\right)$$

Origin (**p**): (0, 0, 0)
Direction (**d**): (*u*, *v*, -1)

- Eye is at the origin (0, 0, 0)
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- Viewport is aligned with the xy plane
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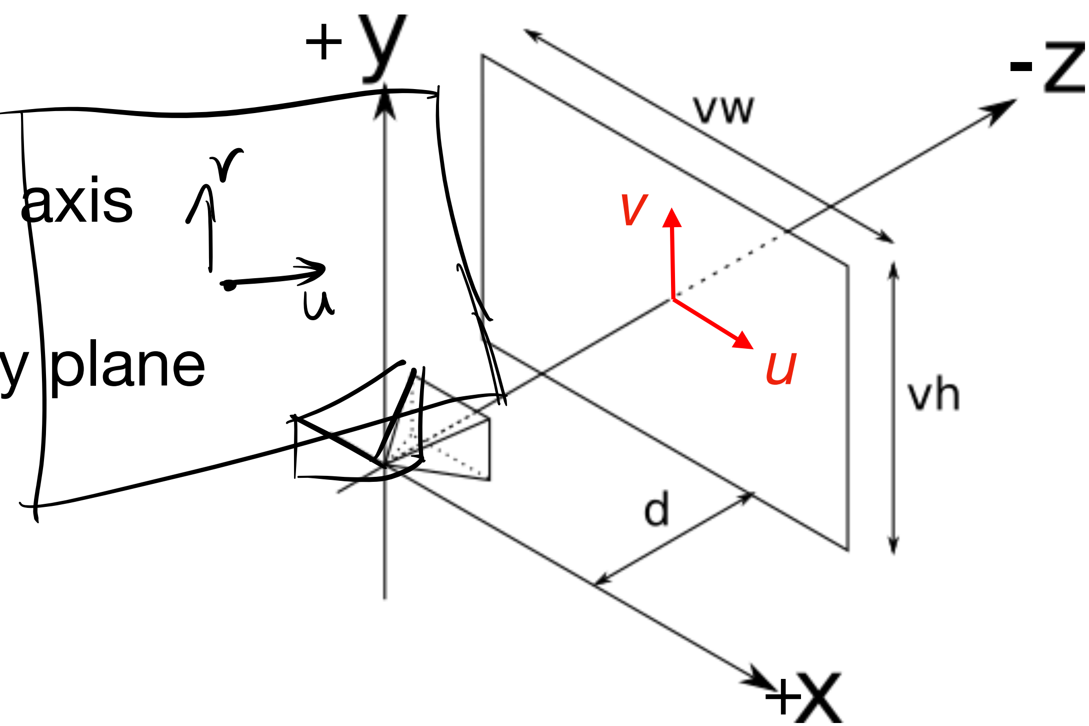


More General Cameras

$$u = \frac{j - \frac{1}{2}}{W} - \frac{1}{2}$$

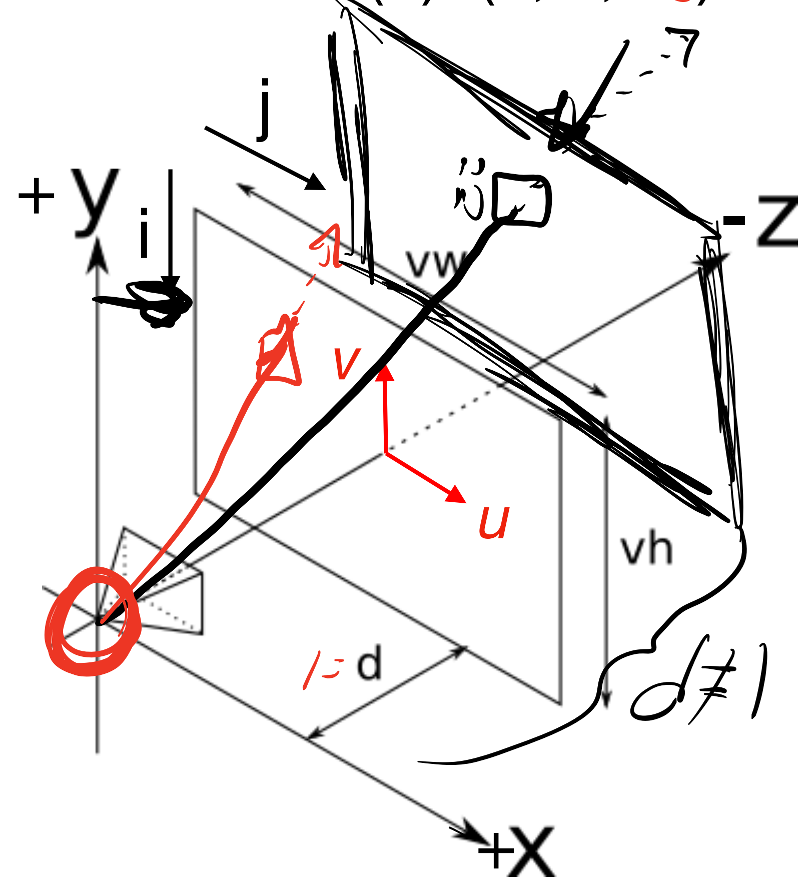
$$v = -\left(\frac{i - \frac{1}{2}}{H} - \frac{1}{2}\right)$$

Origin (**p**): (0, 0, 0)

Direction (**d**): (*u*, *v*, -1)

Let's break some assumptions!

- **d = 1**
- vh = vw = 1
- Eye is at the origin (0, 0, 0)
- Looking down the **negative** z axis



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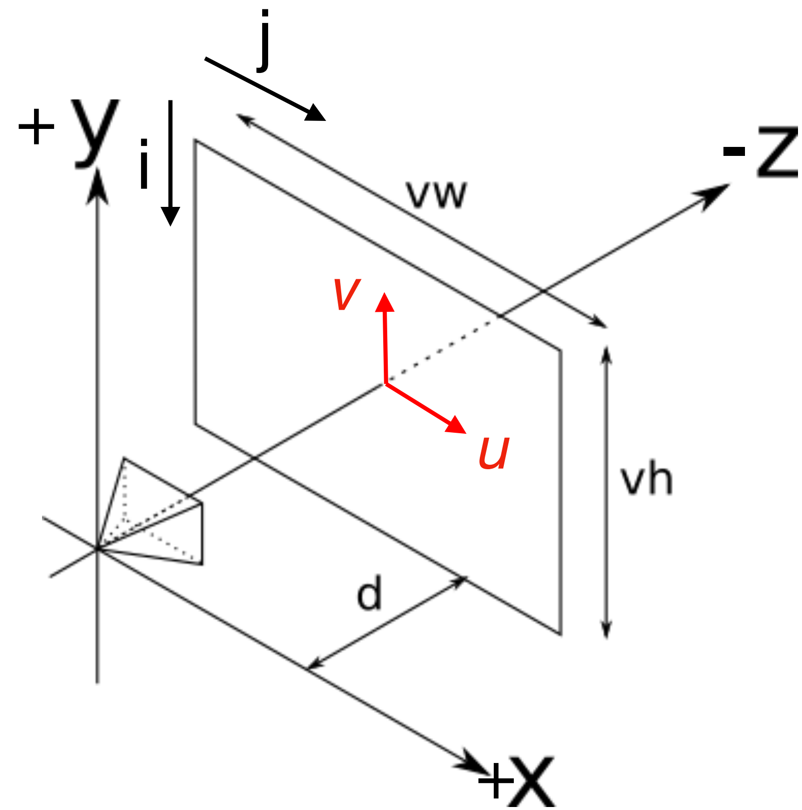

More General Cameras

$$u = \left(\frac{j - \frac{1}{2}}{W} - \frac{1}{2}\right)$$

$$v = -\left(\frac{i - \frac{1}{2}}{H} - \frac{1}{2}\right)$$

Origin (**p**): (0, 0, 0)

Direction (**d**): (*u*, *v*, -1)

Let's break some assumptions!

- d = 1
- **vh = vw = 1**
- Eye is at the origin (0, 0, 0)
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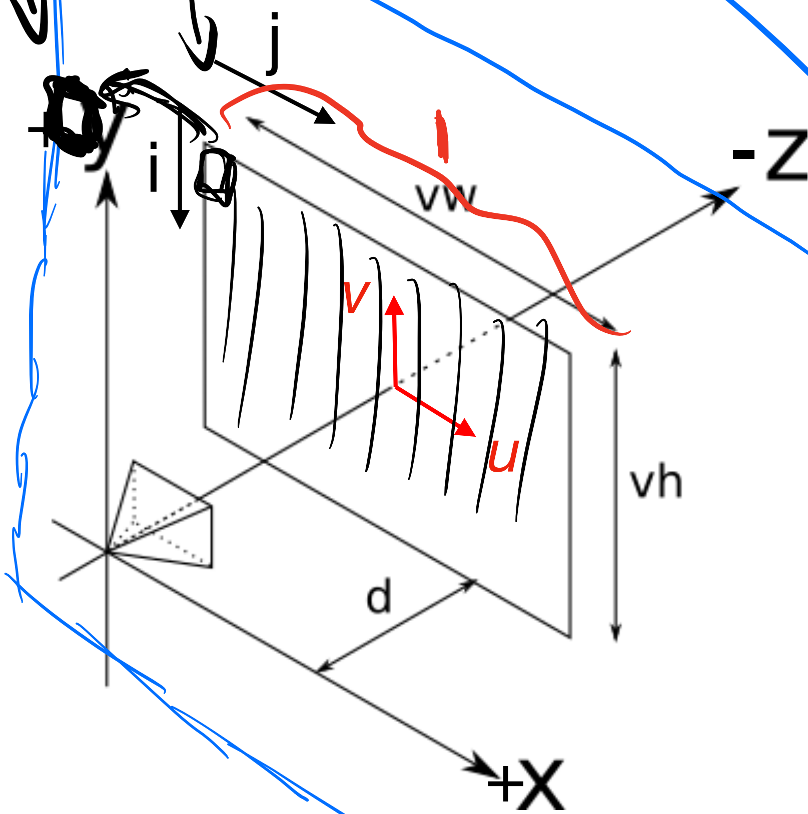

More General Cameras

$$u = \frac{j - \frac{1}{2}}{W} - \frac{1}{2} \quad * \text{ vw}$$

$$v = -\left(\frac{i - \frac{1}{2}}{H} - \frac{1}{2}\right) \quad * \text{ vh}$$

Origin (**p**): (0, 0, 0)
Direction (**d**): (*u*, *v*, -1)

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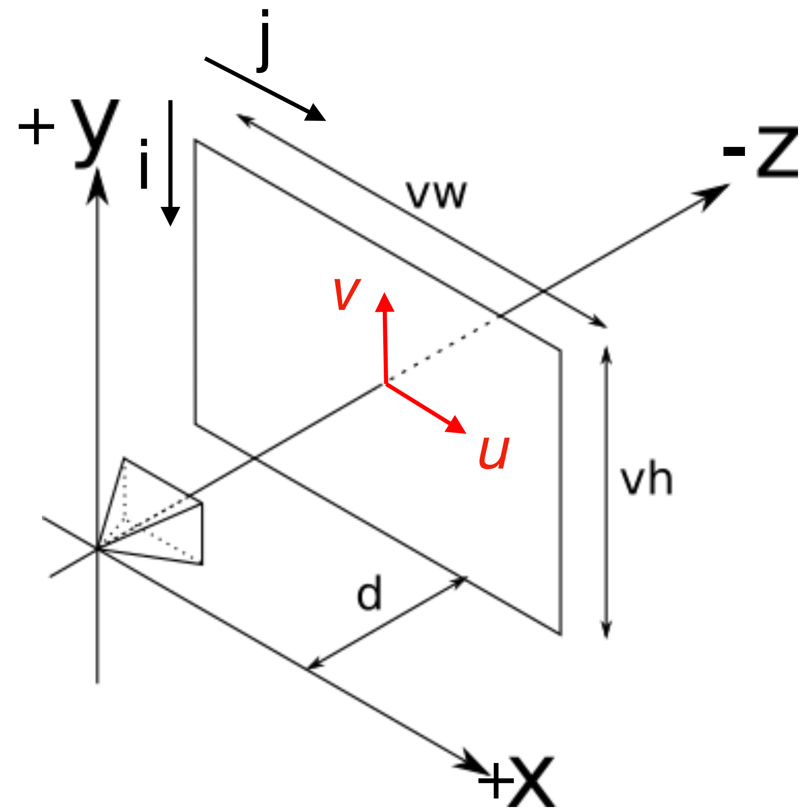

More General Cameras

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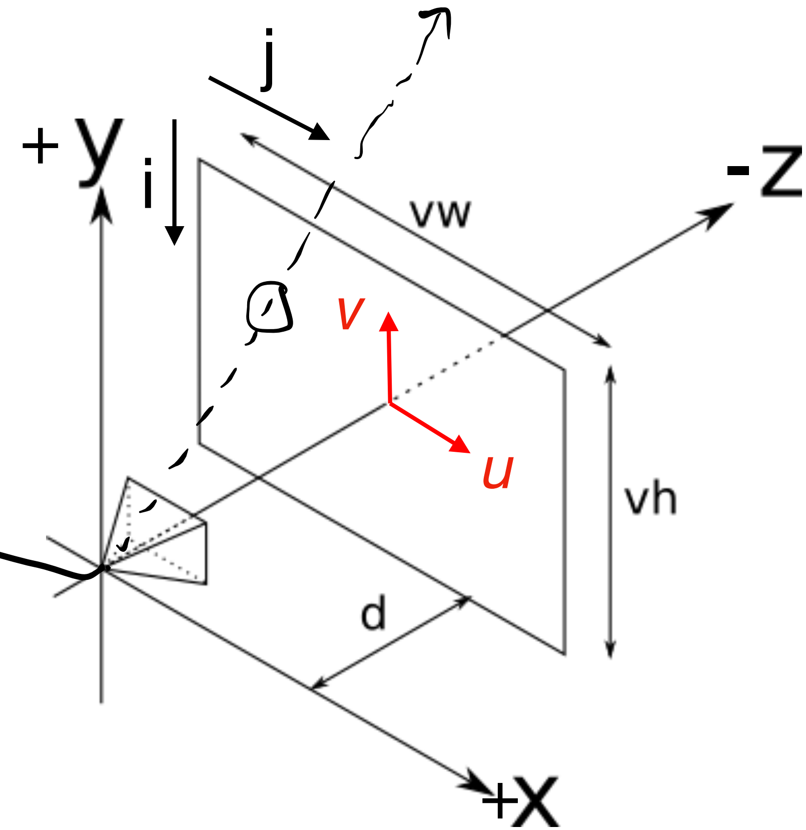

More General Cameras

$$u = \frac{j - \frac{1}{2}}{W} - \frac{1}{2}$$

$$v = -\left(\frac{i - \frac{1}{2}}{H} - \frac{1}{2}\right)$$

Origin (**p**): (e_x, e_y, e_z)

Direction (**d**): (*u*, *v*, -1)

Let's break some assumptions!

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- vh = vw = 1
- **Eye is at the origin (0, 0, 0)**
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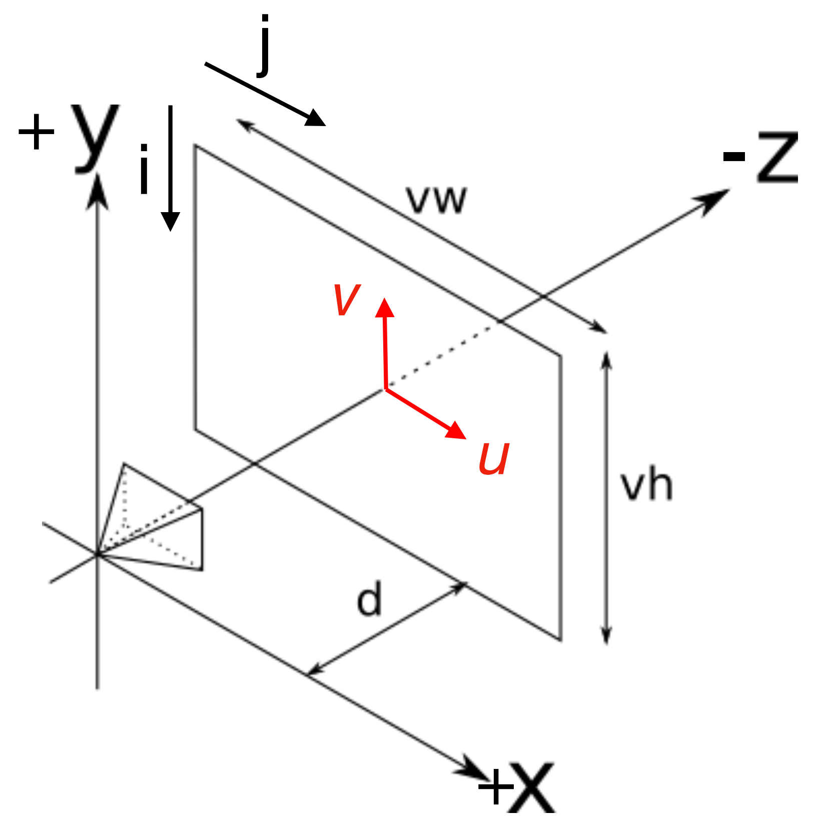

More General Cameras

$$u = \frac{j - \frac{1}{2}}{W} - \frac{1}{2}$$

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Origin (**p**): (0, 0, 0)
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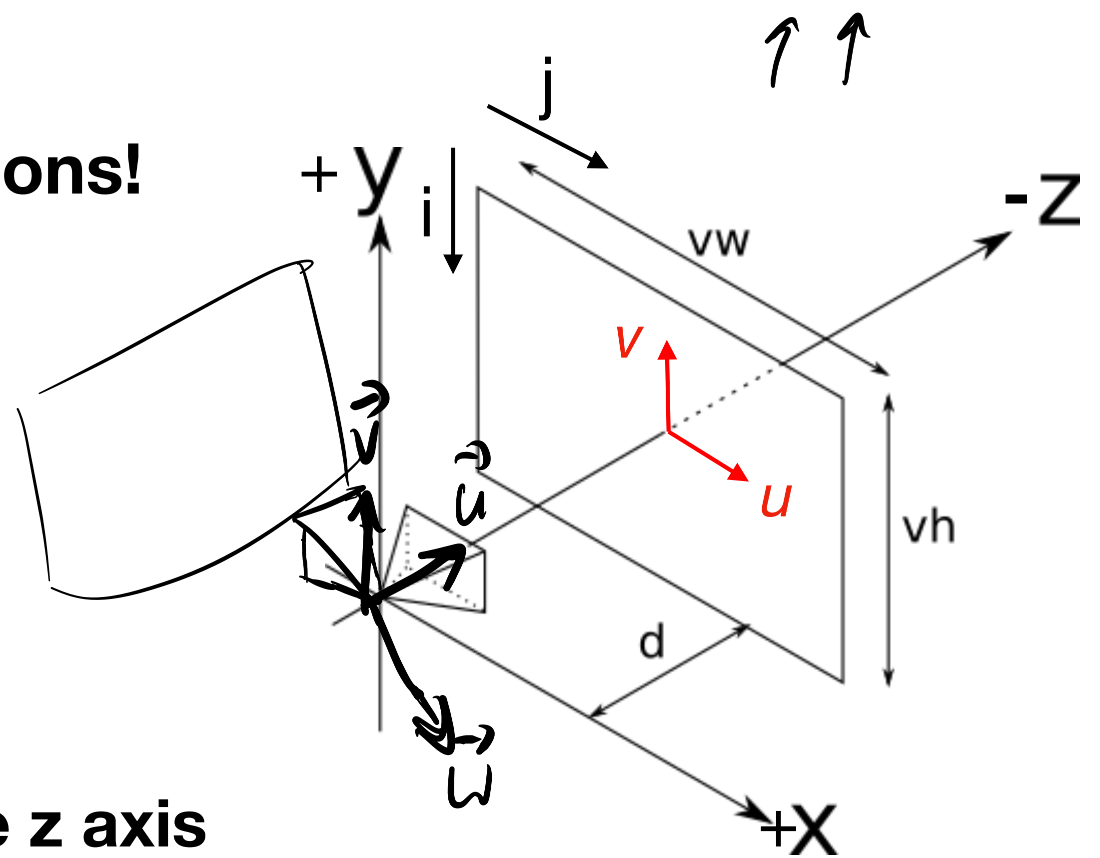
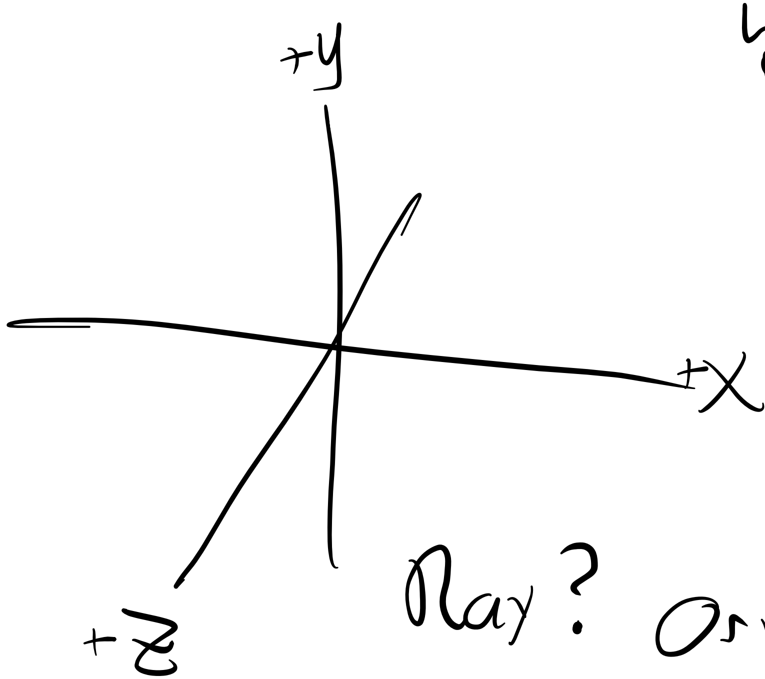
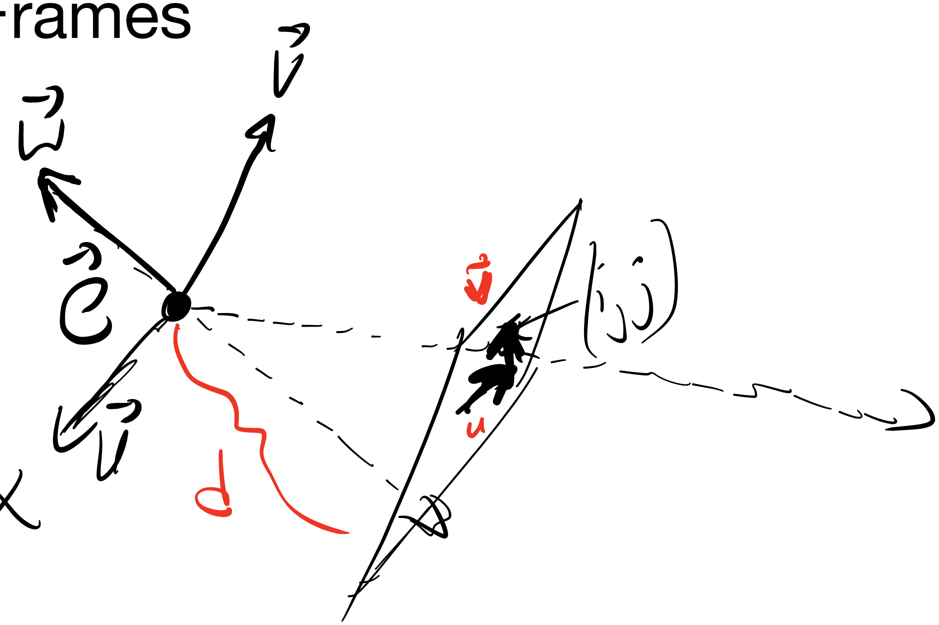


Change of Basis

Reminder: 3B1B video, and Section 2.4.5 - Orthonormal Bases and Coordinate Frames





Ray? Origin: (e_x, e_y, e_z)

Direction: $u \cdot \vec{u} + v \cdot \vec{v} + -d\,\vec{w}$

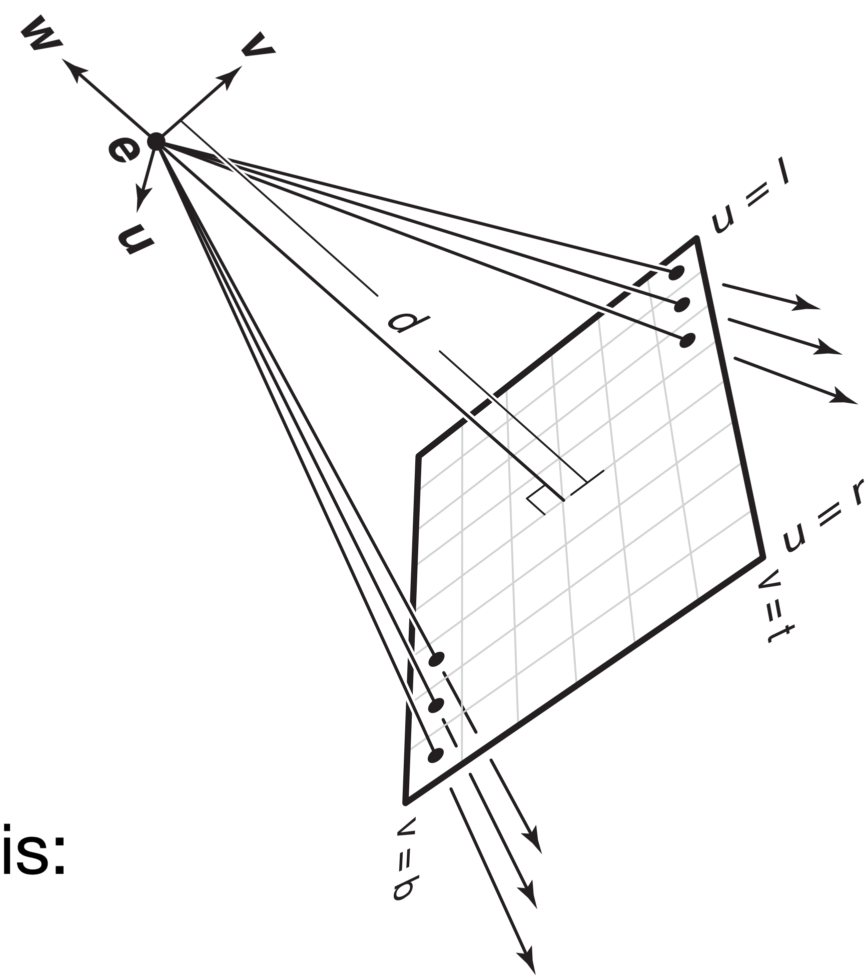
If I want to put the camera somewhere else?

The camera's pose is defined by a **coordinate frame:**

- **u** points right from the **eye**
- **v** points up from the eye
- **w** points back from the eye

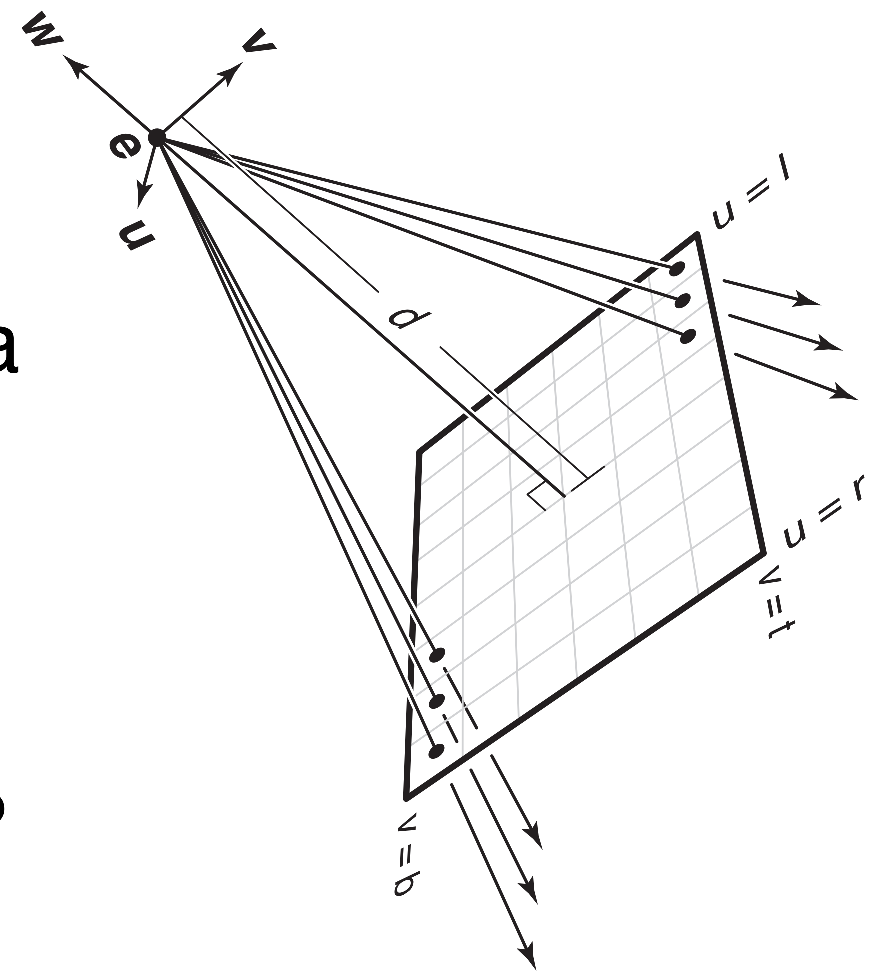
Given this, we can generate a viewing ray as follows:

1. Turn (i,j) into *u, v* as before
2. Viewing ray in (x, y, z) world is:
   origin = **eye**
   direction = u * **u** + v * **v** + $-d$ * **w**



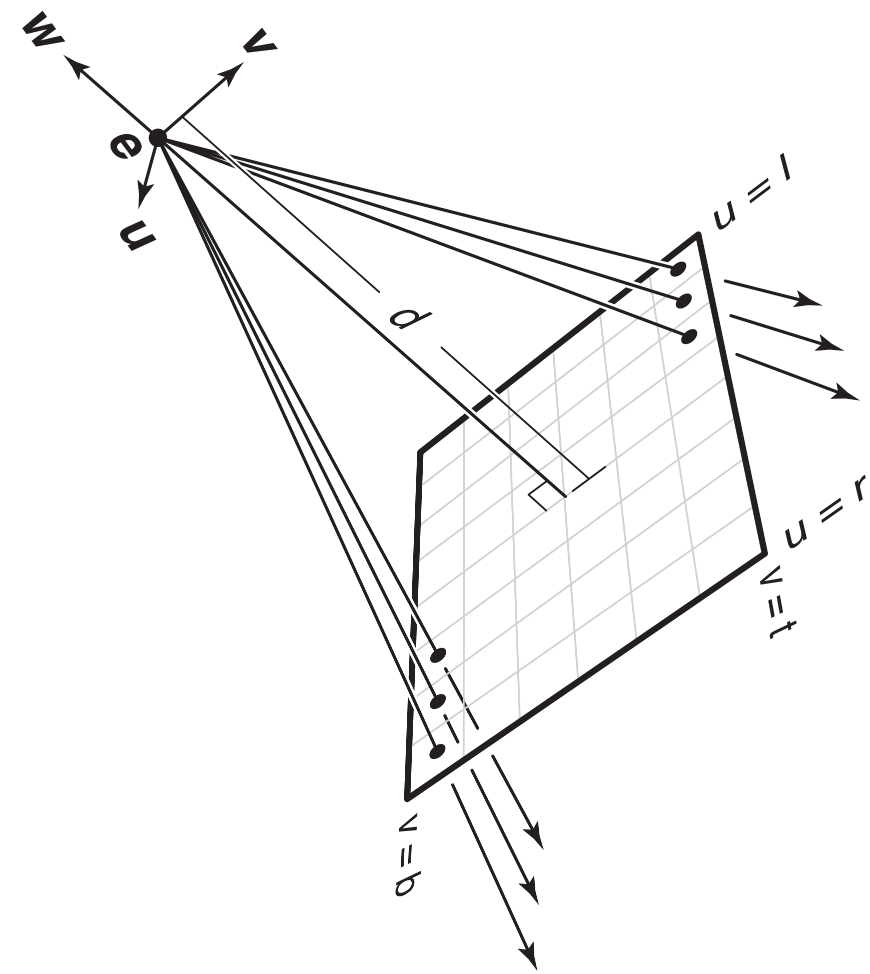
Creating A Camera Basis

- **e, u, v, w** : simple math, but not very intuitive
- Can we position a camera based on:
  - eye
  - view direction or point?



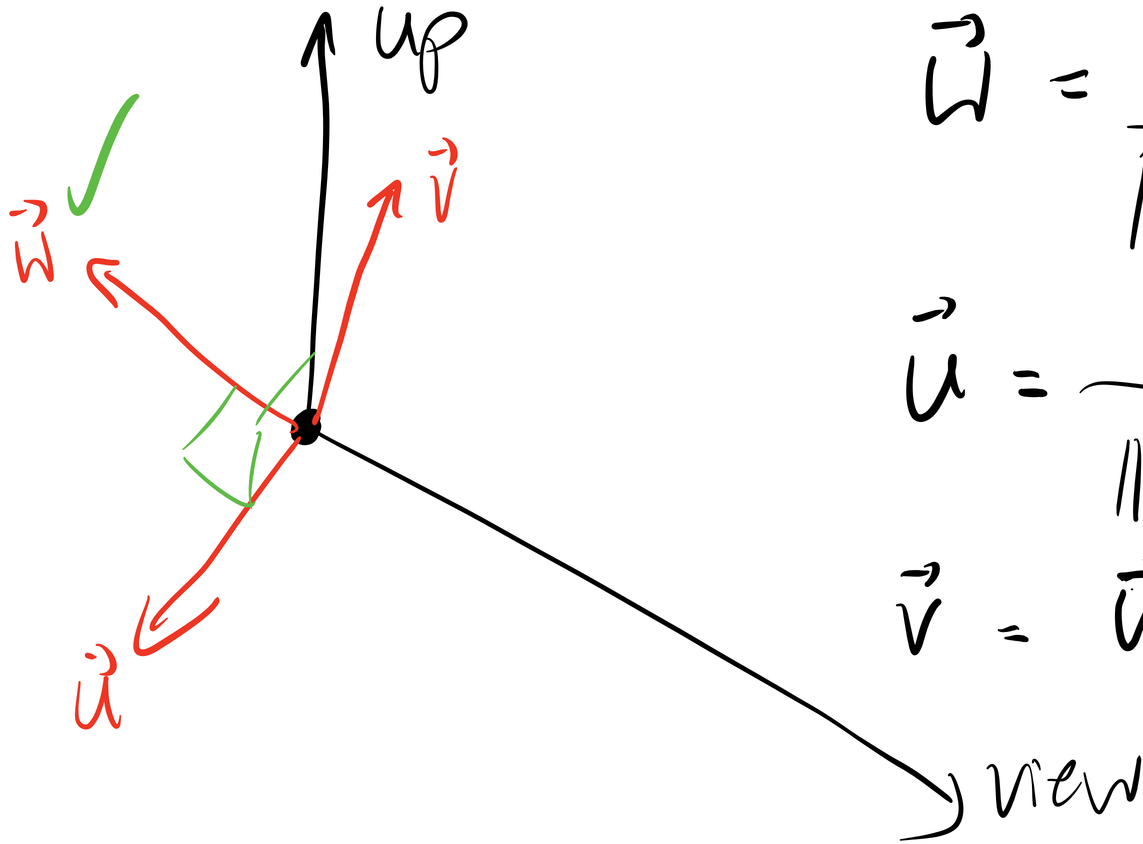
Creating A Camera Basis

- **eye** - position of eye
- **view** direction - direction camera is looking
- **up** vector - points "up" in the scene, but not necessarily in image space.



Creating a Camera Basis

Given **eye**, **view**, and **up**:



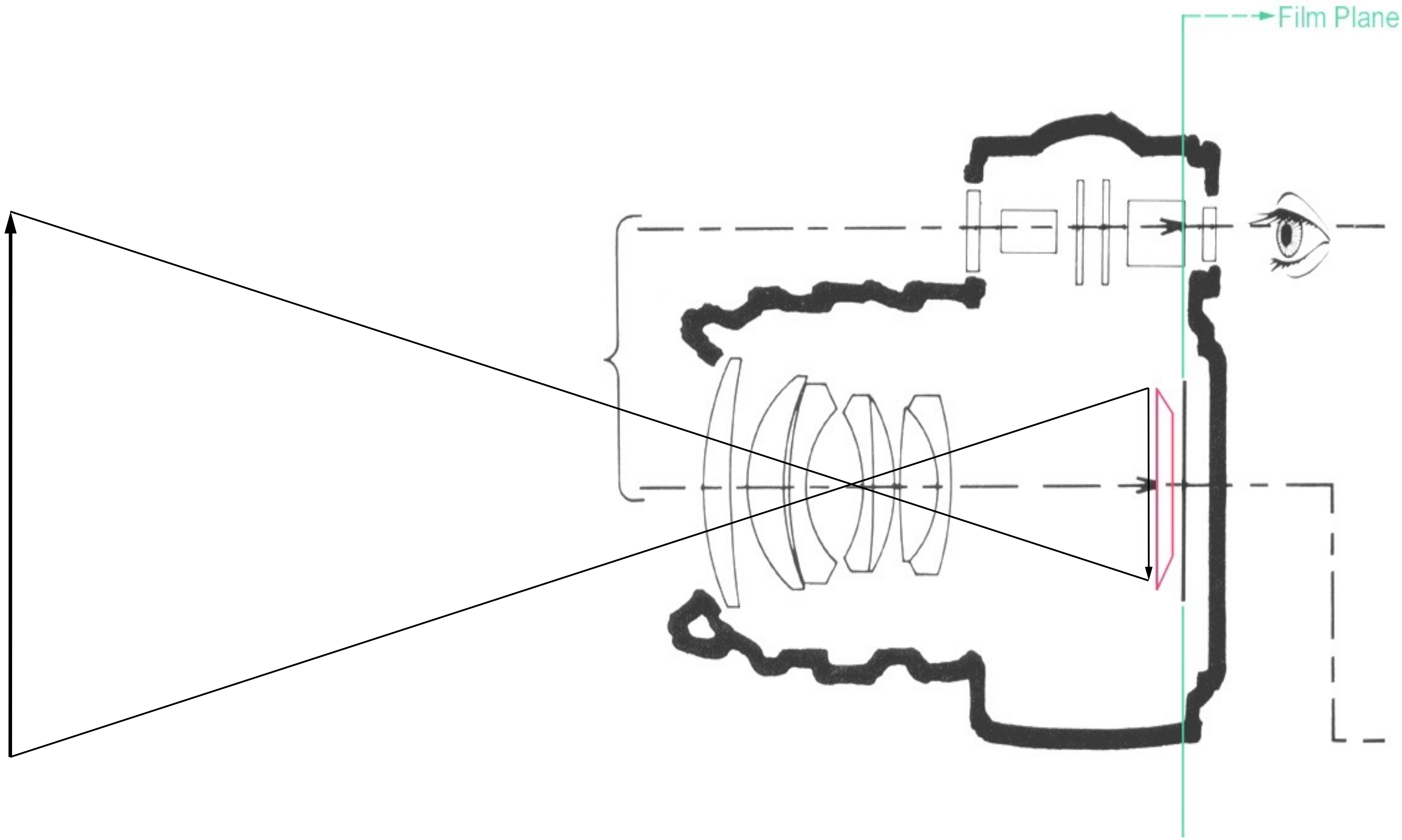
$$\vec{w} = \frac{-\vec{view}}{\|view\|}$$

$$\vec{u} = \frac{up \times \vec{w}}{\|up \times \vec{w}\|}$$

$$\vec{v} = \vec{w} \times \vec{u}$$

Time check: Problems?

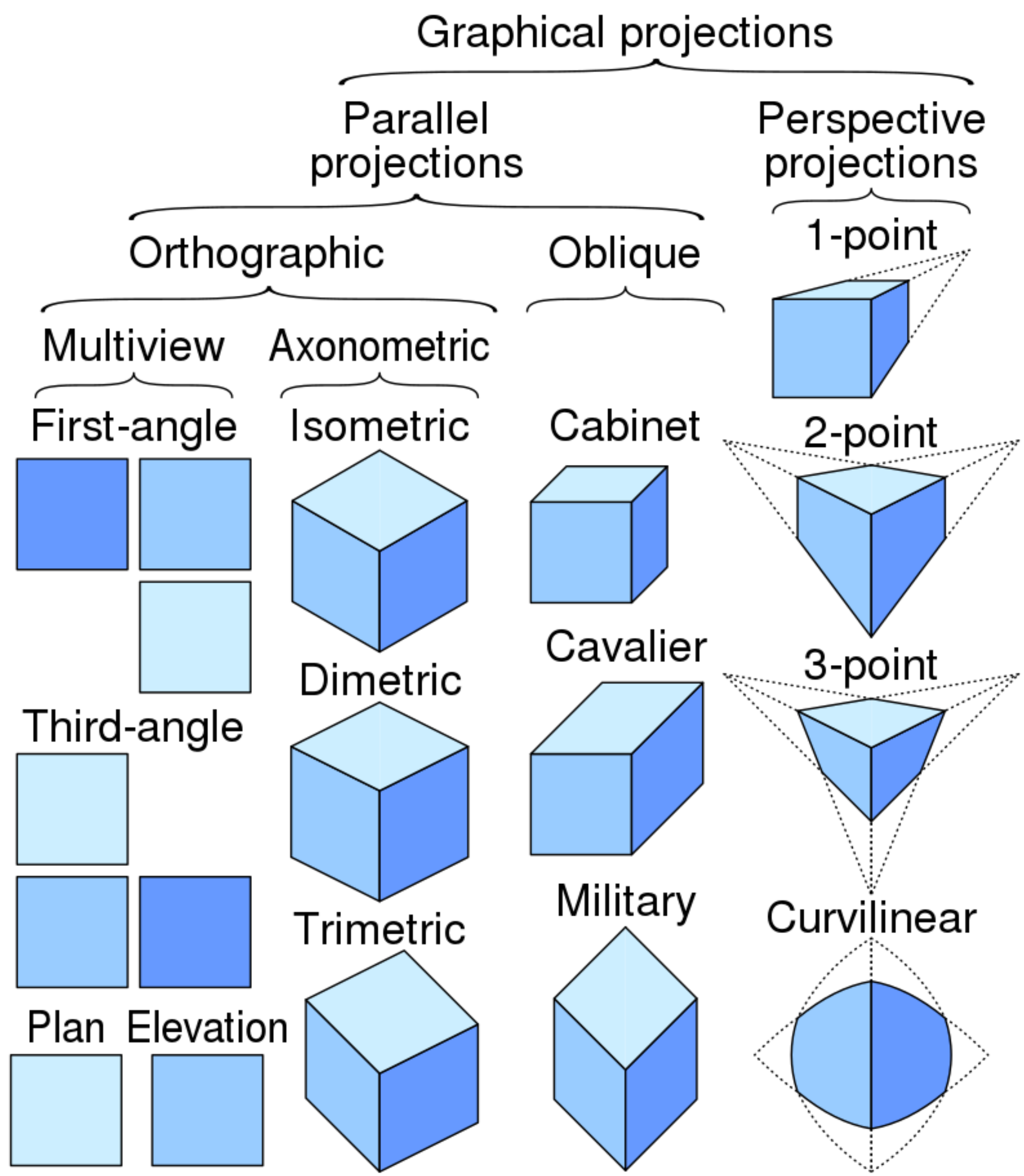
Perspective Cameras: IRL



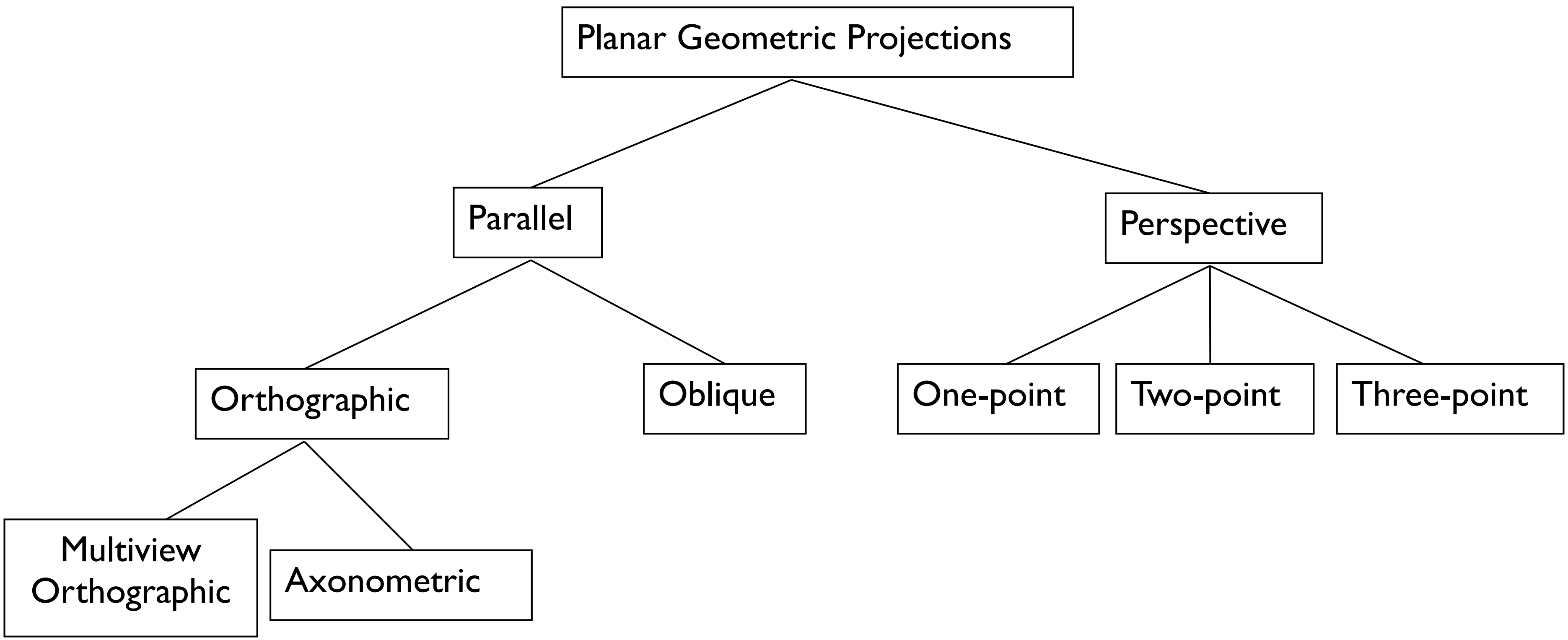
Perspective Cameras: IR(ish)L

- Thin lens model

Classical Projections: Taxonomy

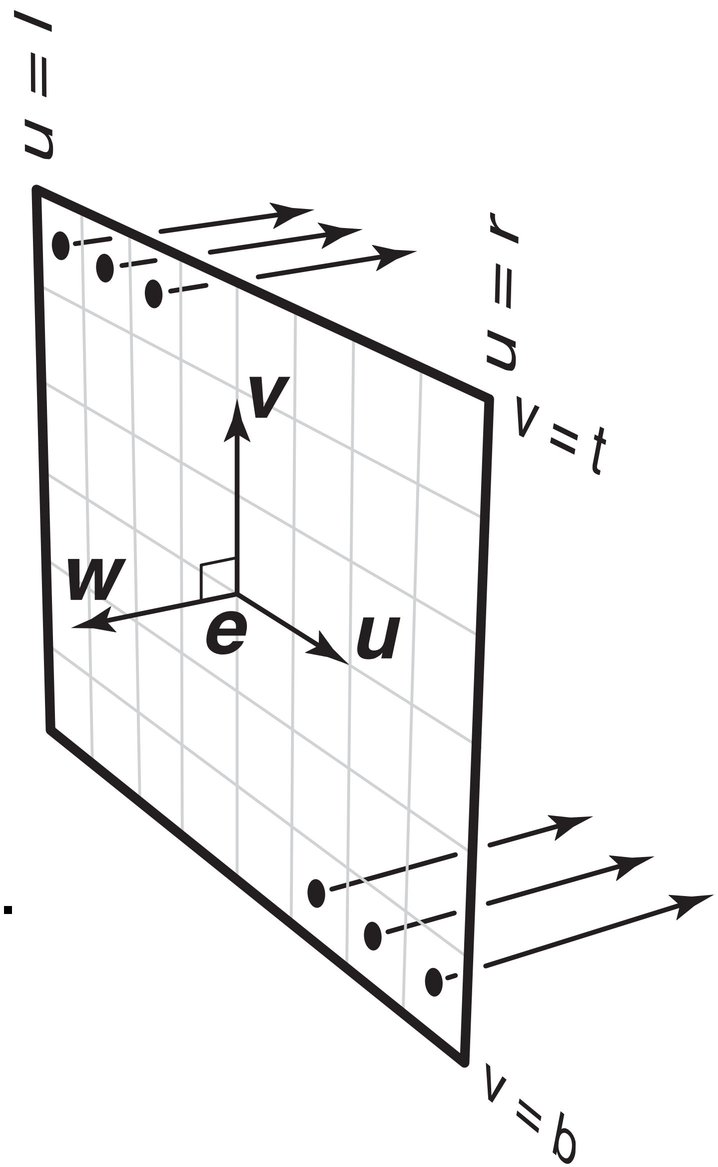


Classical Projections: Taxonomy



Parallel Projections

- Parallel viewing rays
- Ray origins from pixels
- Camera origin (eye) is on the image plane

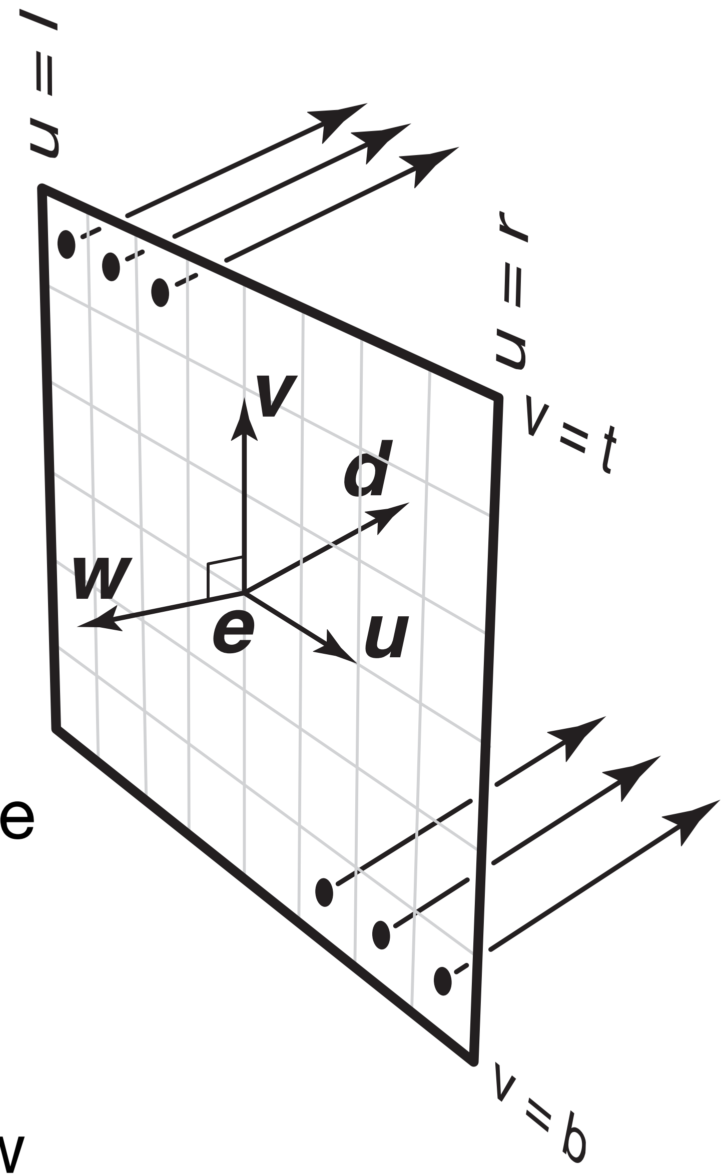


Orthographic: viewing rays are perpendicular to projection plane.

i.e., ray direction **d** = -w

Funky Parallel Projections

- Parallel viewing rays
- Ray origins from pixels
- Camera origin (eye) is on the image plane

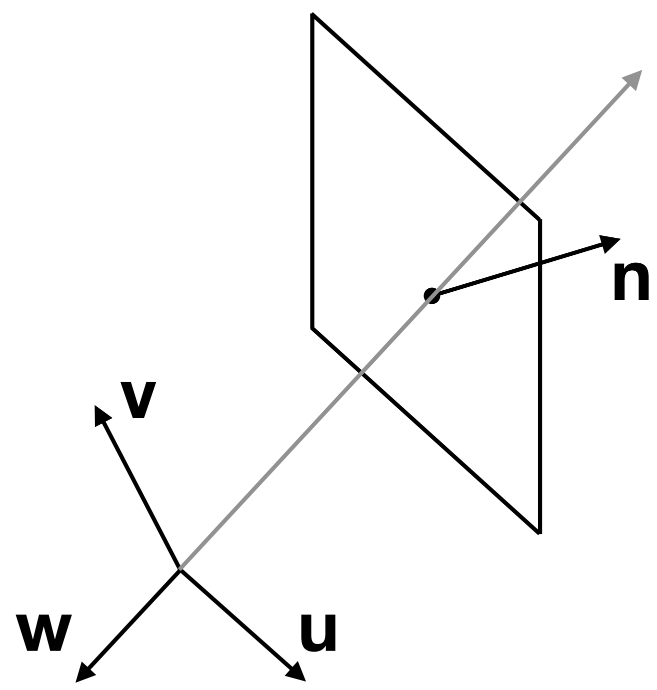


Oblique parallel: viewing rays are *not* perpendicular to projection plane.

i.e., ray direction **d** differs from -w

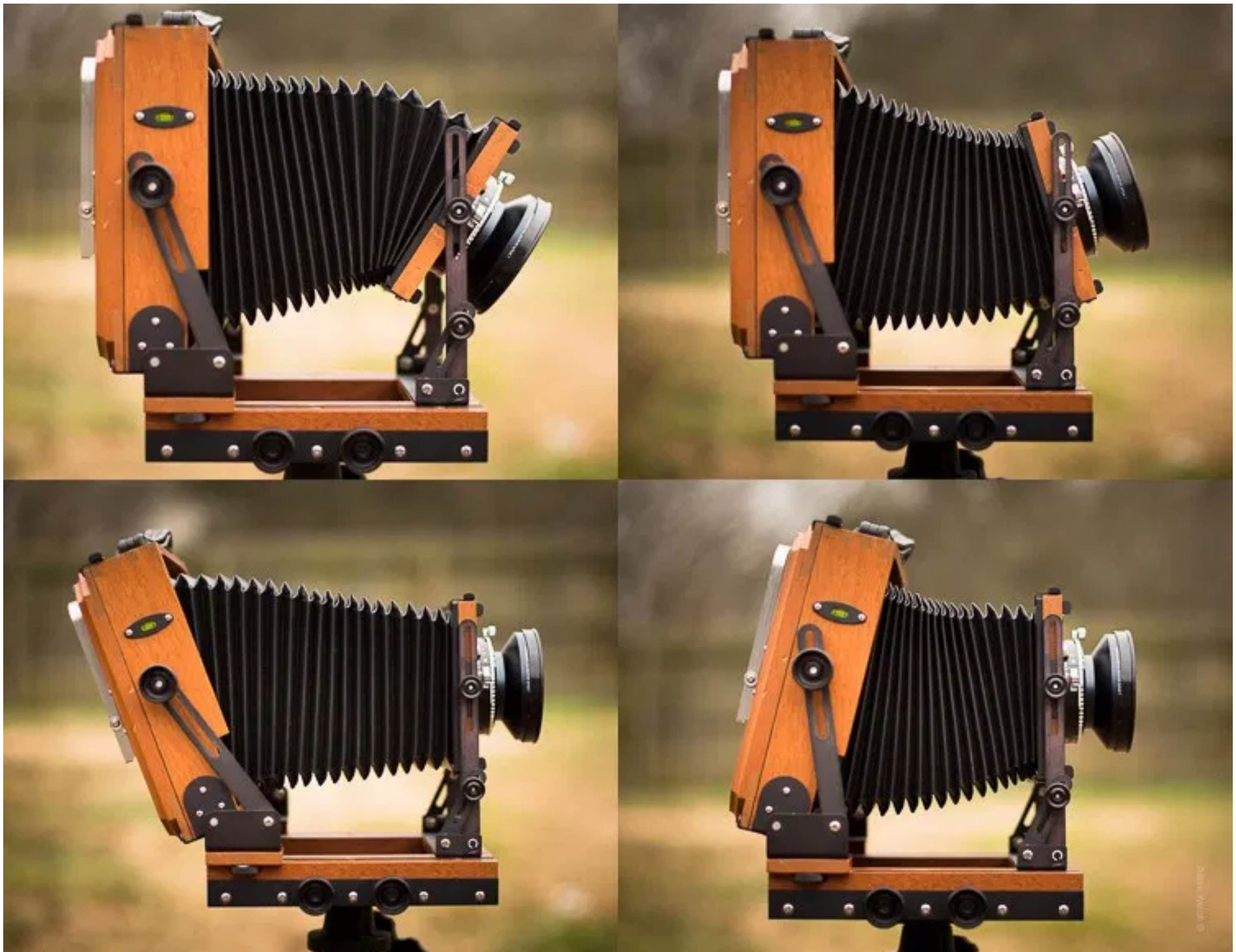
Funky Perspective Projections

Shifted perspective: view direction **not** the same as the projection plane normal



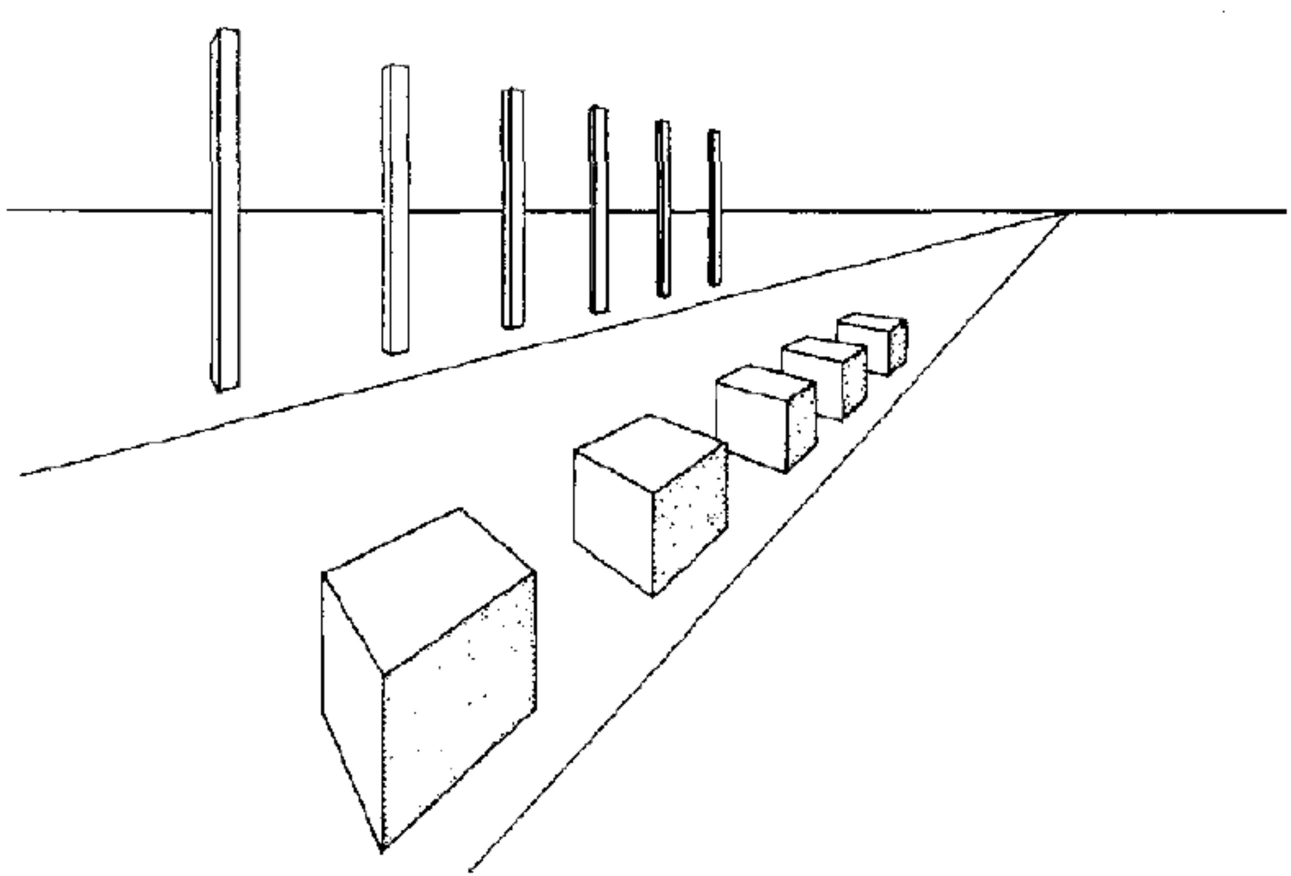
...why do we want this?

Funky Perspective Projections: IRL



Perspective distortions

- Lengths, length ratios



[Carlbom & Paciorek 78]

"foreshortening": object size is inversely related to depth

[Philip Greenspun]

camera tilted up: converging vertical lines

[Philip Greenspun]

lens shifted up: parallel vertical lines