Computer Graphics

Lecture 5

Introduction to Ray-Tracing

Cameras and Ray Generation

Announcements

- A1 is out!
- HW1 is forthcoming
- Getting help:
  - #q-and-a channel on Discord
  - email me

Where were we?

Pseudocode for 3D graphics:

```
Create a model of a scene
Render an image of the model
```

Triangle(**a**, **b**, **c)**
Sphere(**c**, r)
meshgen.jl (A1)

Where were we?

Pseudocode for 3D graphics:

```
Create a model of a scene
Render an image of the model
```

```
For each pixel:
  if inside triangle:
   color pixel
```

Two Rendering Algorithms

```
for each object in the scene {
  for each pixel in the image {
    if (object affects pixel) {
      do something
    }
  }
}
```

object order
or
rasterization

```
for each pixel in the image {
  for each object in the scene {
    if (object affects pixel) {
      do something
    }
  }
}
```

image order
or
ray tracing

Two Rendering Algorithms

```
for each object in the scene {
  for each pixel in the image {
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object order
or
rasterization

```
for each pixel in the image {
  for each object in the scene {
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    }
  }
}
```

image order
or
ray tracing

Q: Which of these did we do in A0?

Today

`Render` `an` **`image`** `of the model`

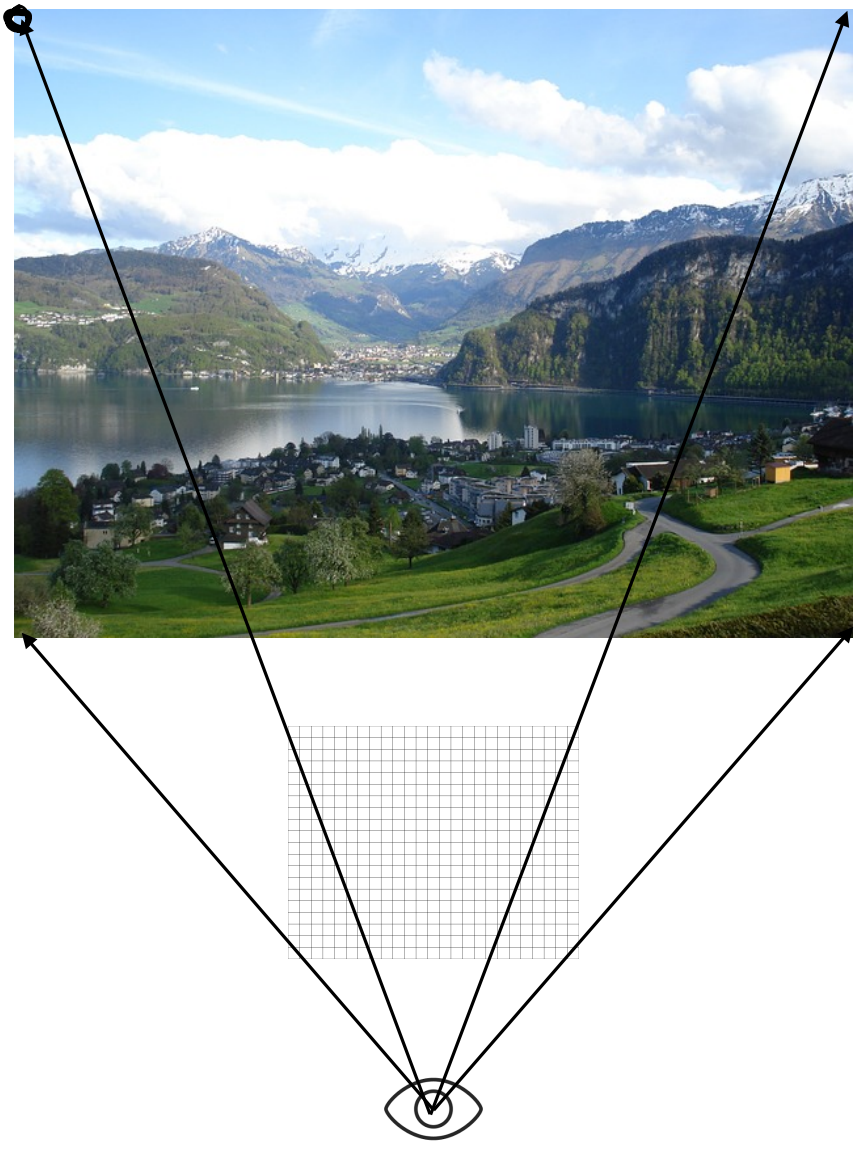
- What does image mean? ✓
- What does render mean?
- Beginnings of **image-order** rendering (i.e., ray tracing)
  - Where do rays come from?

How do we make images?

- camera?
- canvas(i,j) = color
- draw_tri, etc
- MS Paint
  - Paint brushes

How do we make images?

- IRL:
  - pencils, paintbrushes, watercolors, etc
  - eyes
  - **cameras**
- On computers:
  - MS paint
  - manually writing pixel values into Julia arrays
  - **virtual cameras**



The Camera Conundrum:

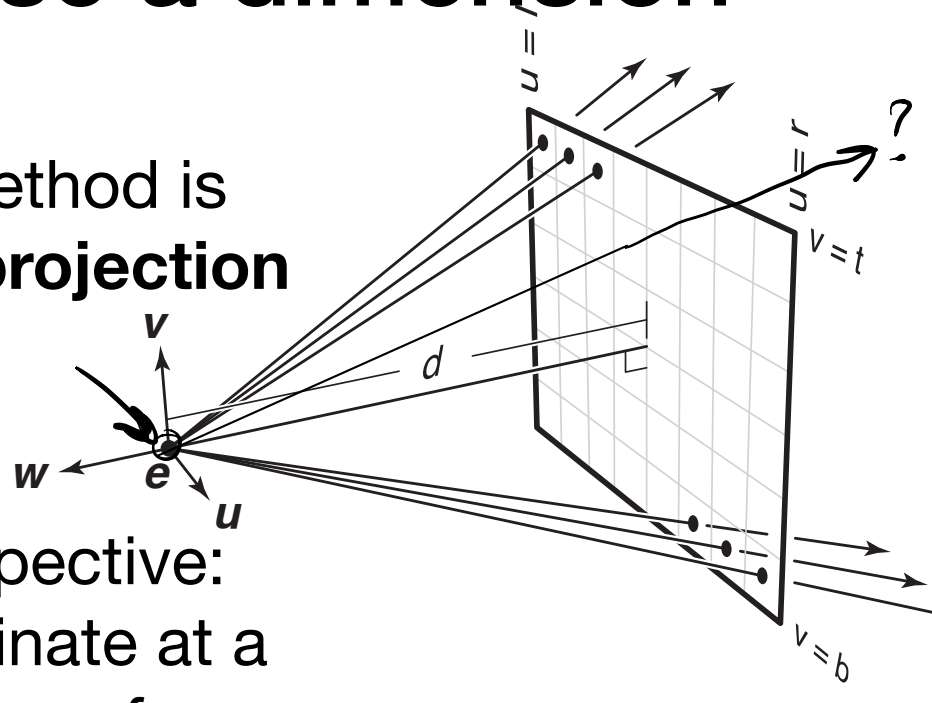
The world is 3D

Images are 2D

we gotta lose a dimension somehow

Projections: ways to lose a dimension

- The picture-frame method is called **perspective projection**

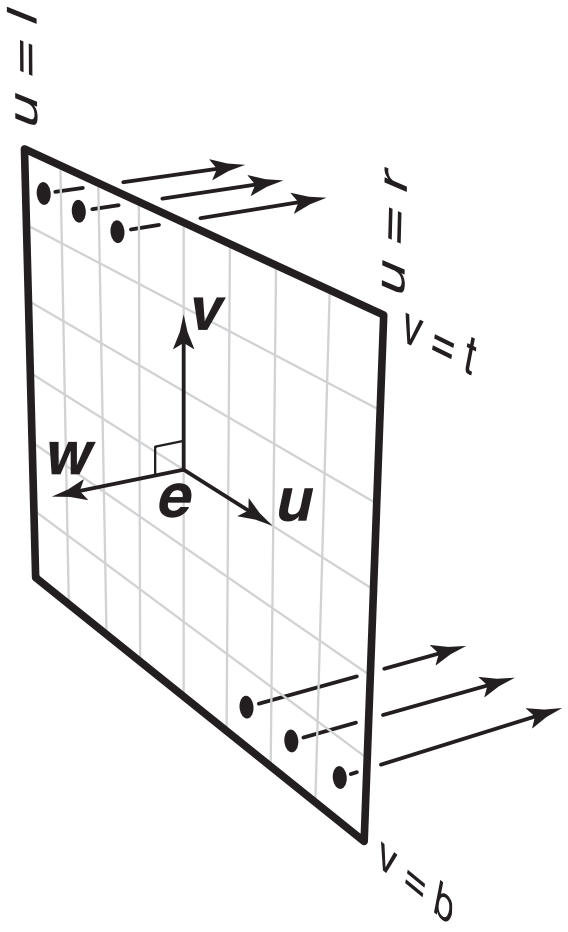


- Key property of perspective: all **viewing rays** originate at a single point, the *center of projection*, or *eye*.

Projections: ways to lose a dimension

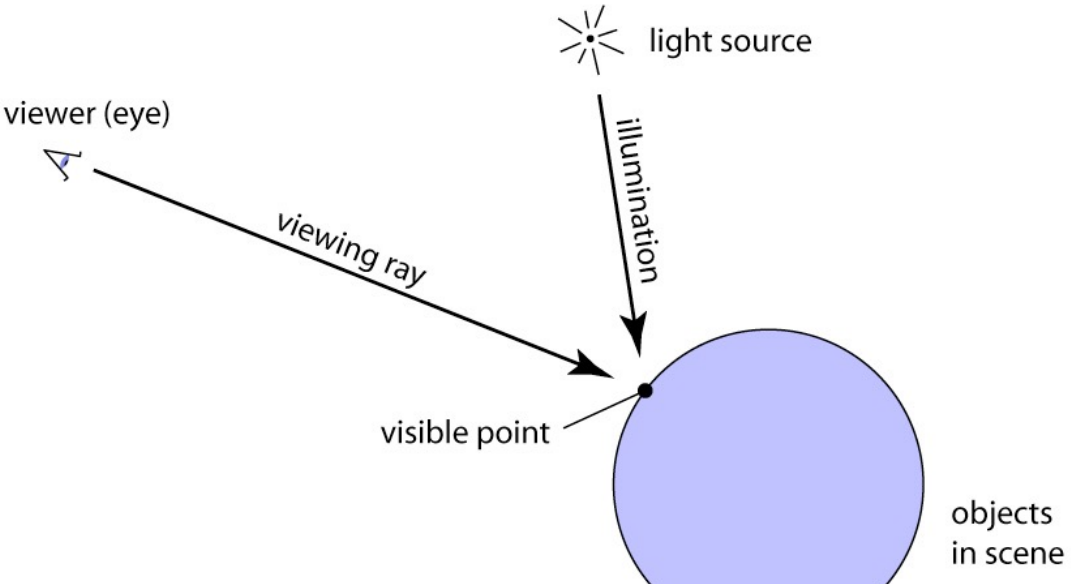
- Another common one is **parallel projection**

- Key property of parallel projections:
  all **viewing rays** are parallel



Ray Tracing: Pseudocode

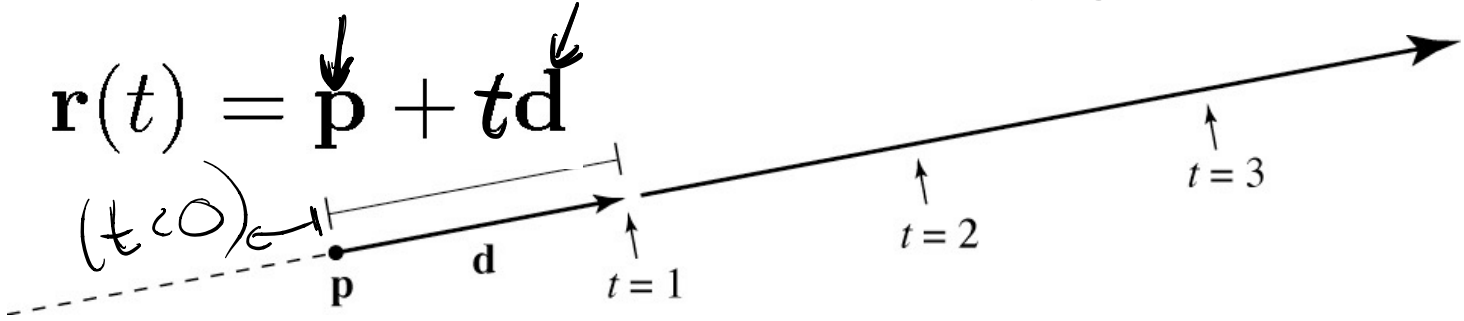
```
for each pixel:
    generate a viewing ray for the pixel
    find the closest object it intersects
    determine the color of the object
```



A ray is half a line.

We'll describe rays using:

- An *origin* (**p**) where the ray begins
- A *direction* (**d**) in which the ray goes



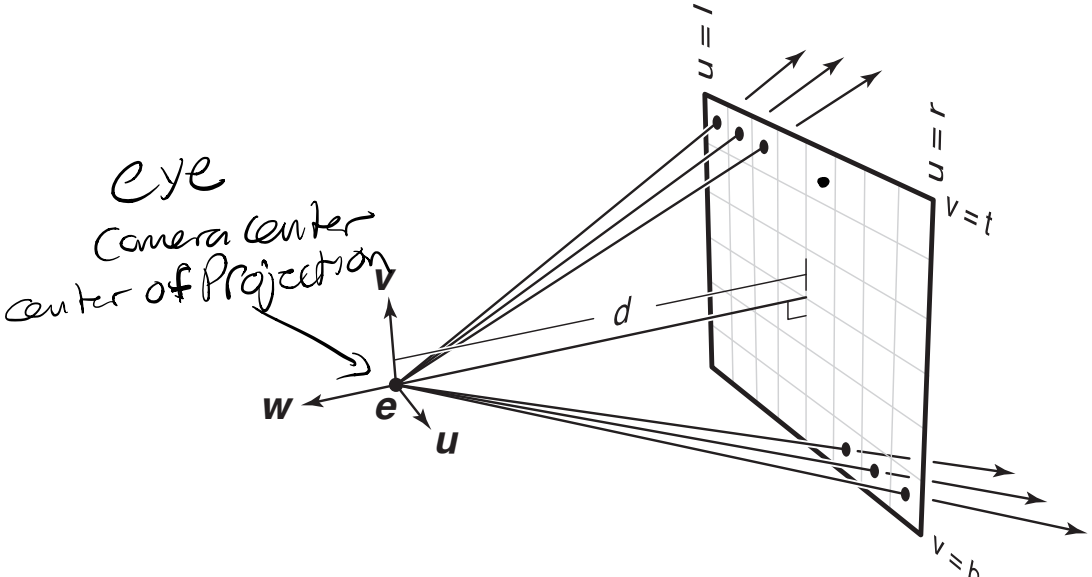
- This is a *parametric equation*: it **generates** points on the line
- The set of points with $t > 0$ gives all points on the ray

Viewing Rays

are determined by the **position** and **orientation** of the camera

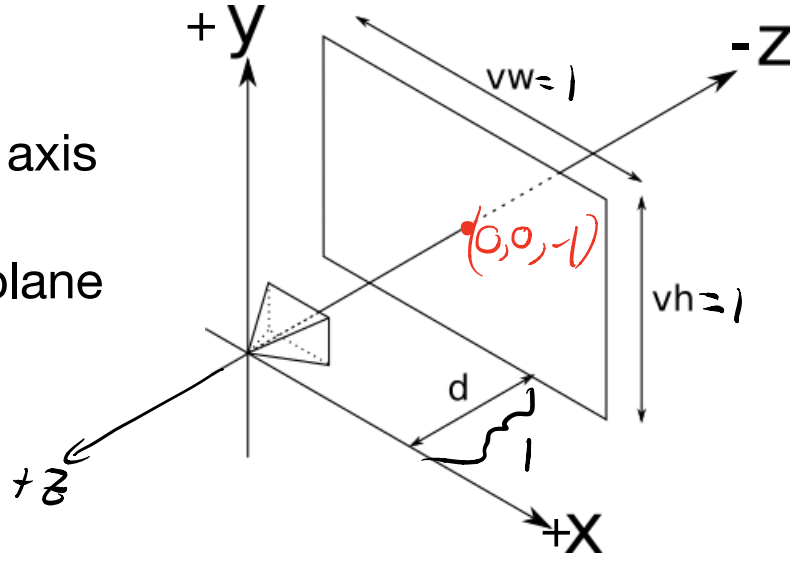
- For perspective projection, viewing rays originate at the **eye**.

- The direction varies depending on the pixel.



Let's start with a simple camera

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



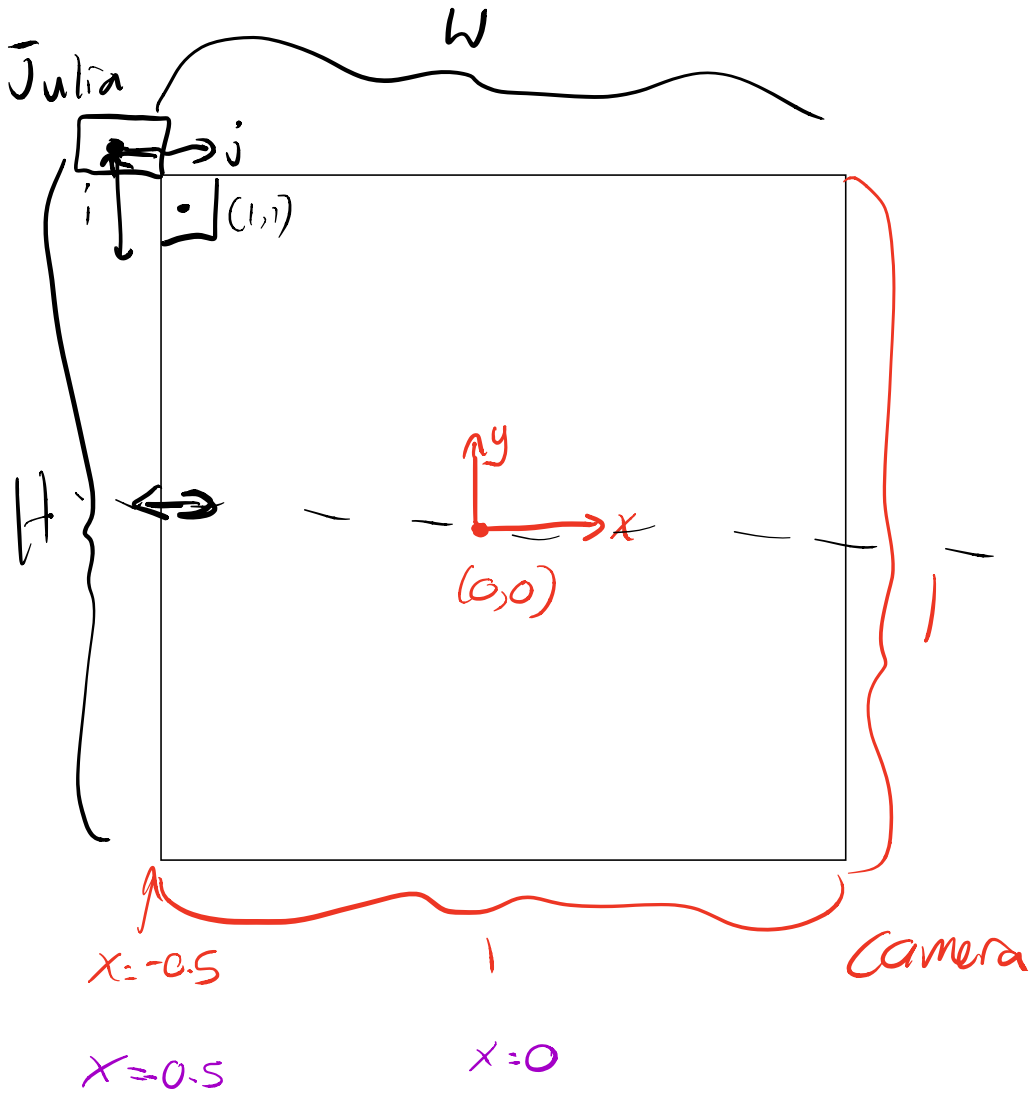
origin: (0,0,0)

direction:

What is the 3D viewing ray for pixel (i, j)?

$$x(j) = \frac{(j-\frac{1}{2})}{W} - \frac{1}{2}$$

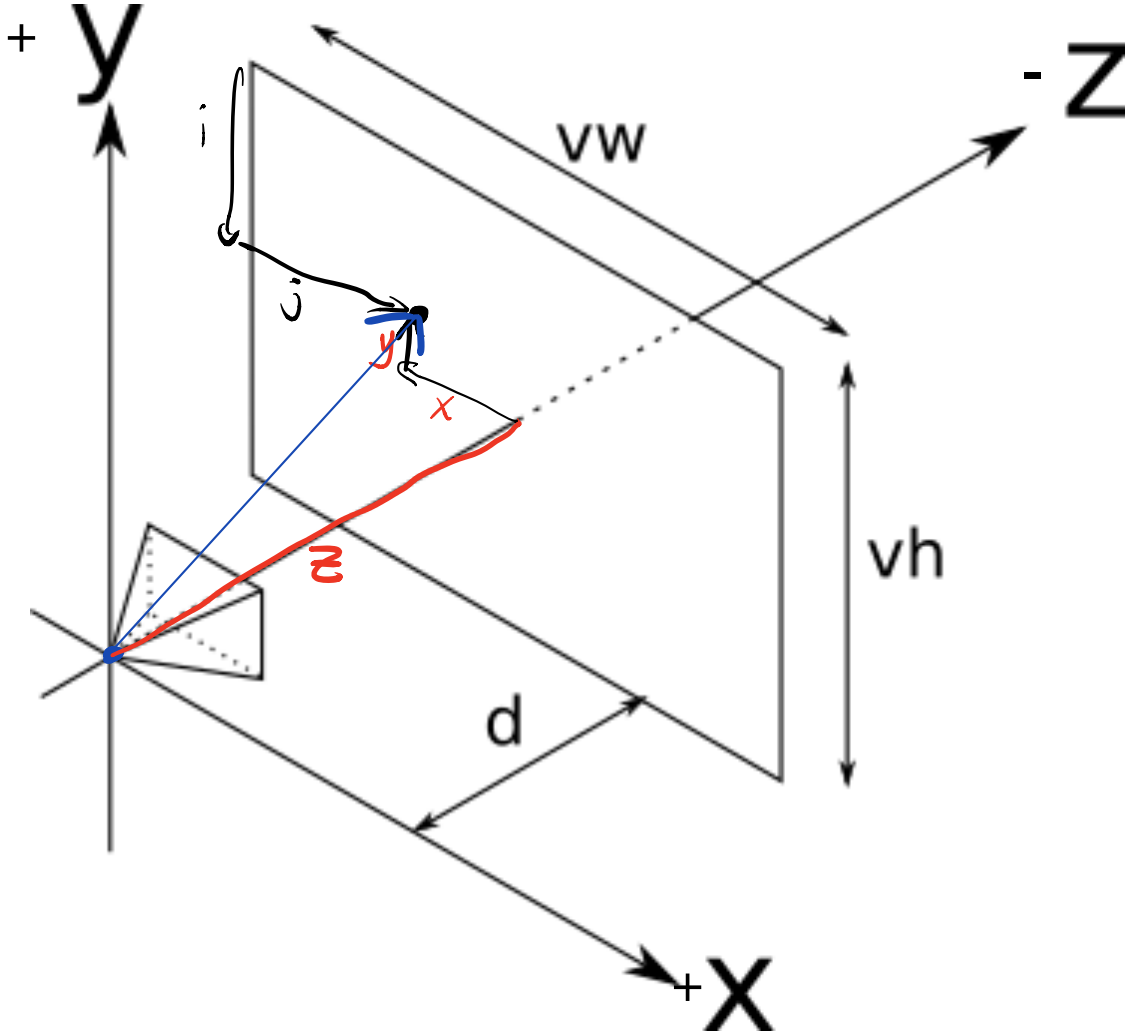
$$y(i) = -\left(\frac{i-\frac{1}{2}}{H} - \frac{1}{2}\right)$$



$$p = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$d = \begin{bmatrix} x \\ y \\ -1 \end{bmatrix}$$

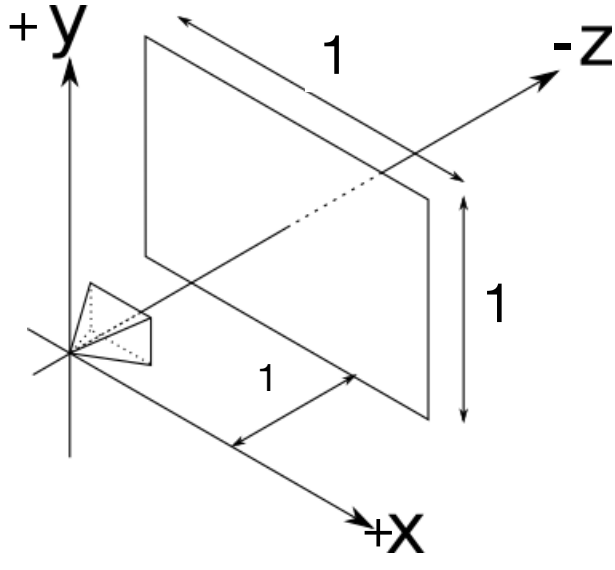
$$p + t\,d$$



Viewing rays for the canonical camera

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

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



Origin (**p**): (0, 0, 0)
Direction (**d**): (*x*, *y*, -1)

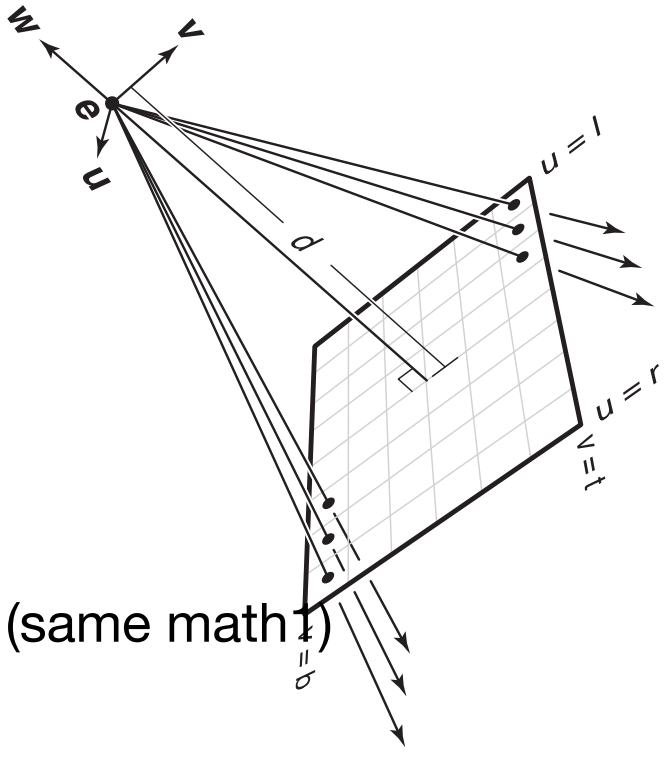
Problems - in groups

1. Generate an example viewing ray
2. Intersect the ray with a plane in the scene
3. Generalize camera model by removing assumptions:
   - Eye is **not** at the origin (0, 0, 0)
   - vh **!=** vw **!=** 1
   - d **!=** 1

What if I want to point 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* instead of x, y (same math!)
2. Viewing ray in (x, y, z) world is:
   origin = eye
   direction = u * **u** + v * **v** + -d * **w**