Virtual Cameras and The Transformation Pipeline

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with content from

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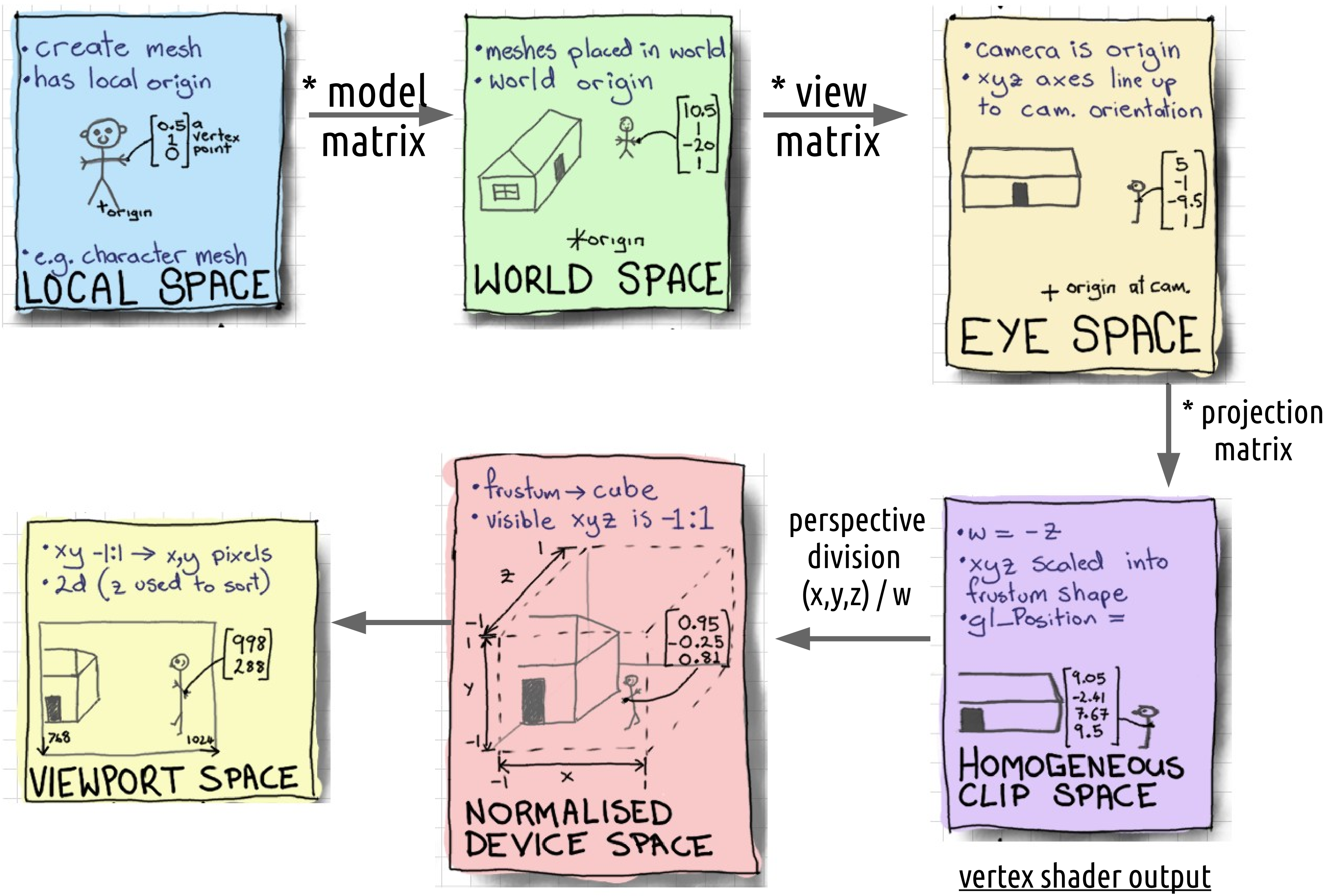
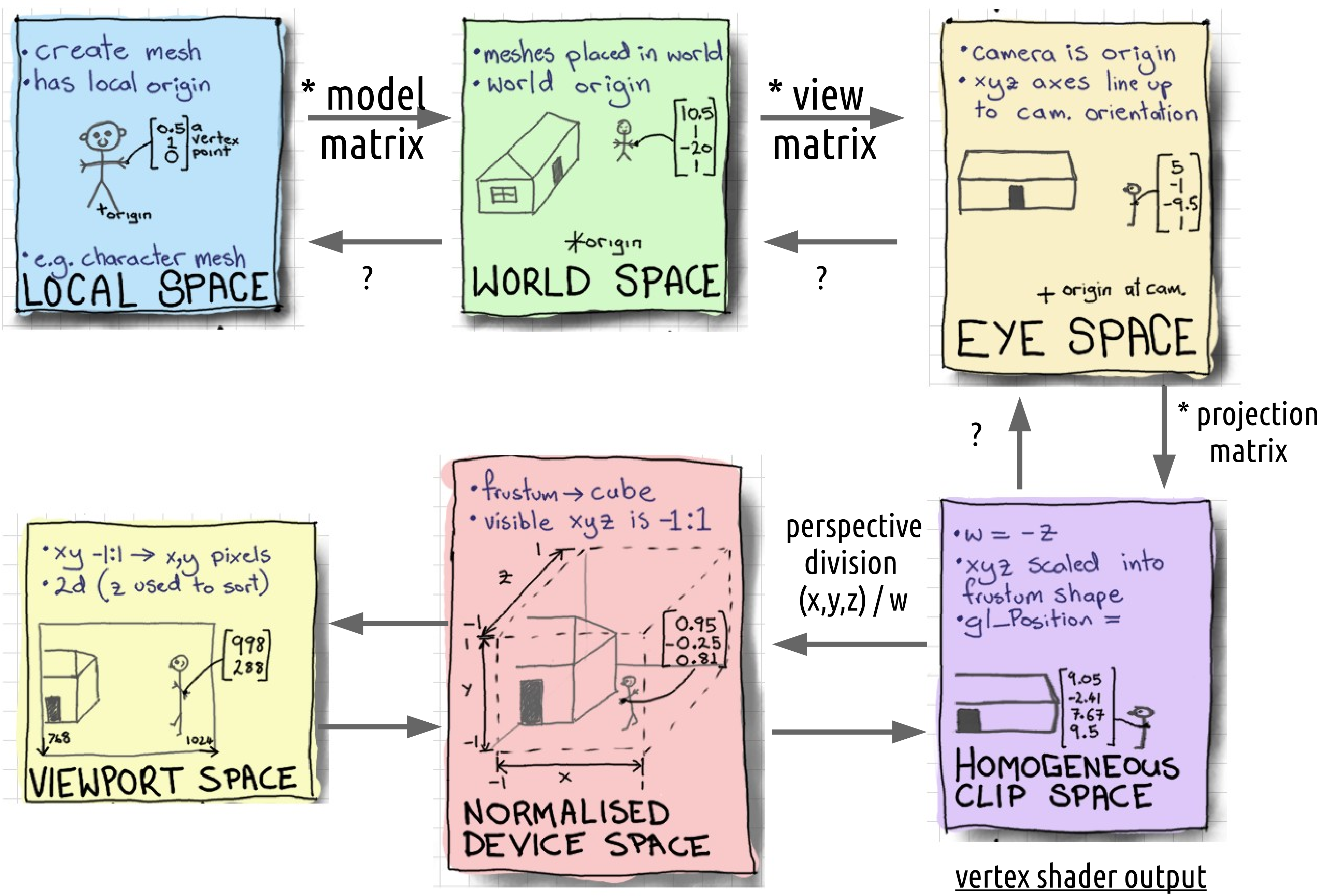
Virtual Camera

- We want to navigate through our scene in 3d
- Solution = create a **transformation pipeline**
- Move all points relative to some arbitrary **view point**, such that the view point is the <u>new (0,0,0) origin</u>
- Also project our scene with a **perspective** rather than orthogonal view

Transformation Pipeline – Coordinate Spaces



Transformation Pipeline – Coordinate Spaces



Local Space

- When you create a triangle or
- Load a mesh from a file
- Has some (0,0,0) origin, <u>local</u> to that particular mesh
- Translate, rotate, scale to position in a virtual world
  - Multiply points with a **model matrix** aka "world matrix"
  - `mat4 M = T * R * S;`

```
vec4 pos_wor = M * vec4 (pos_loc, 1.0);
```

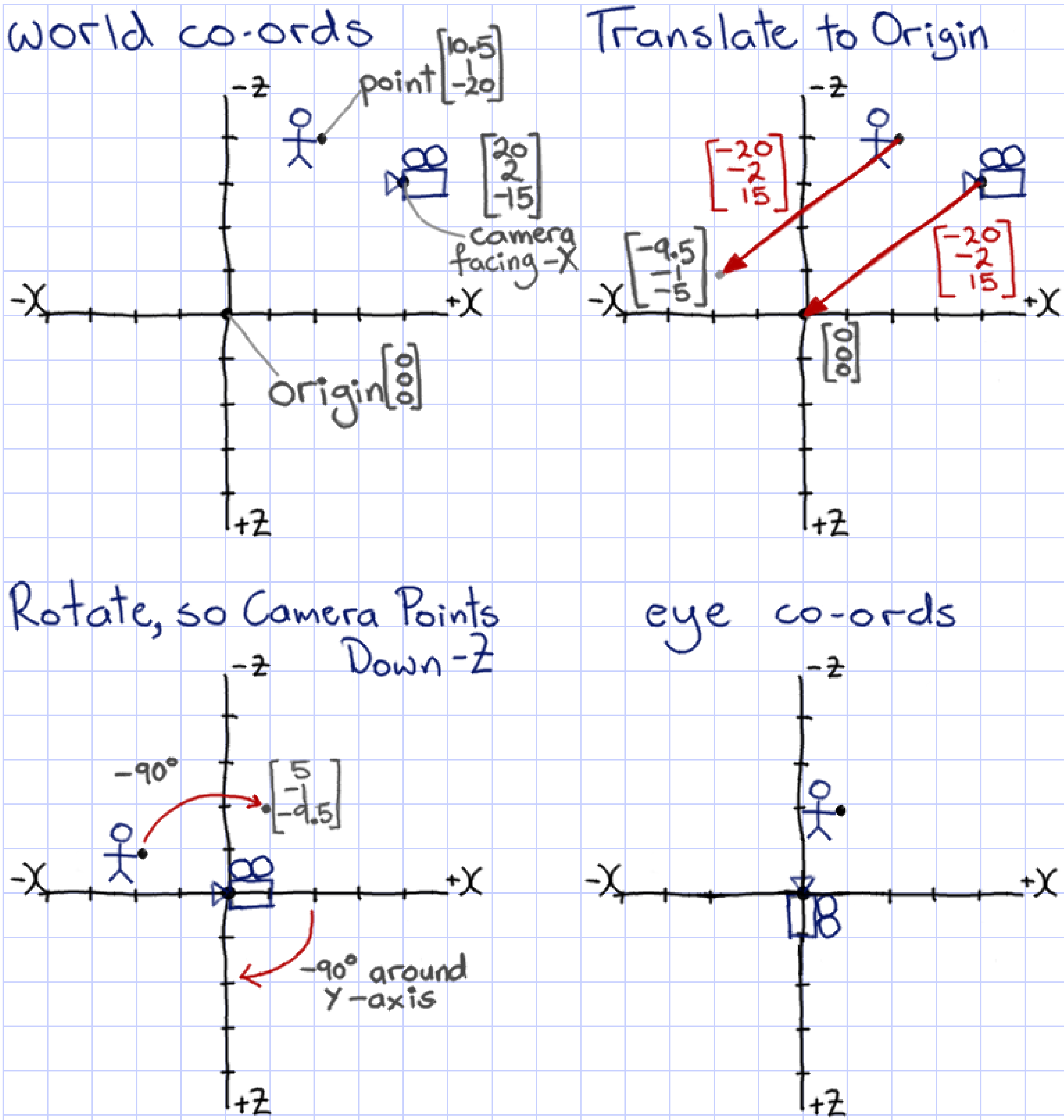
World Space

- Objects positioned in scene or “virtual world”
- Has a world (0,0,0) origin
- Can get distances between objects
- Now we want to show the view from a camera, moving through the virtual world
- Multiply <u>world space</u> points by a **view matrix** to get to <u>eye space</u>

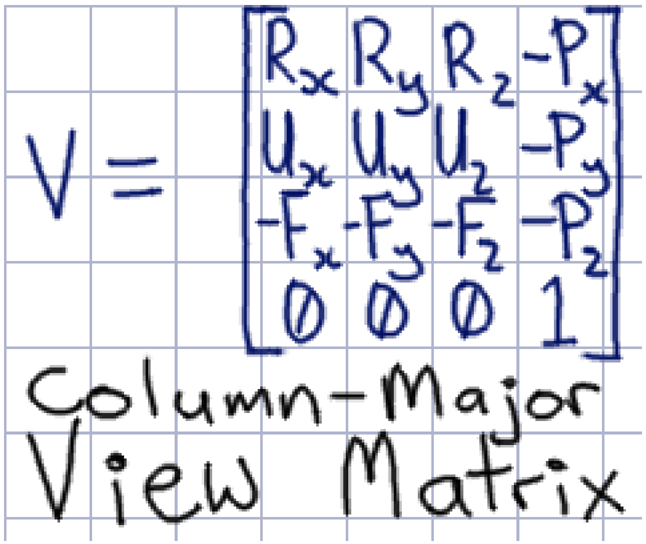
```
mat4 V = R * T; // inverse of cam pos & angle
mat4 V = lookAt (vec3 pos, vec3 target, vec3 up);
```

```
vec4 pos_eye = M * pos_wor;
```

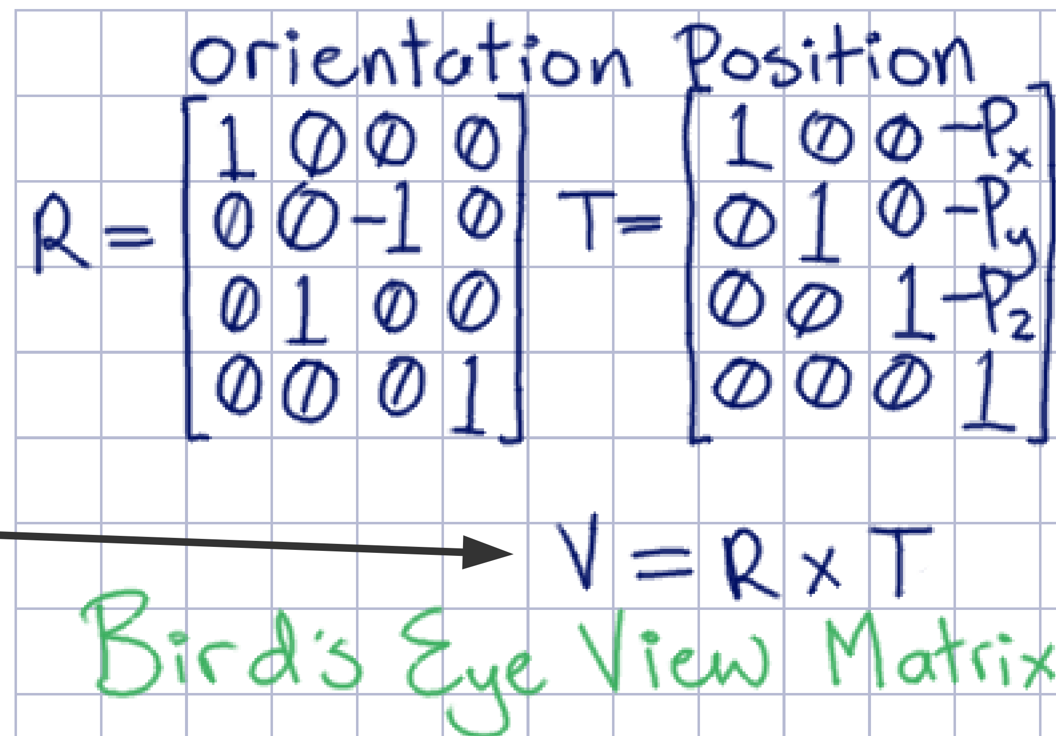
What the View Matrix Does



View Matrix



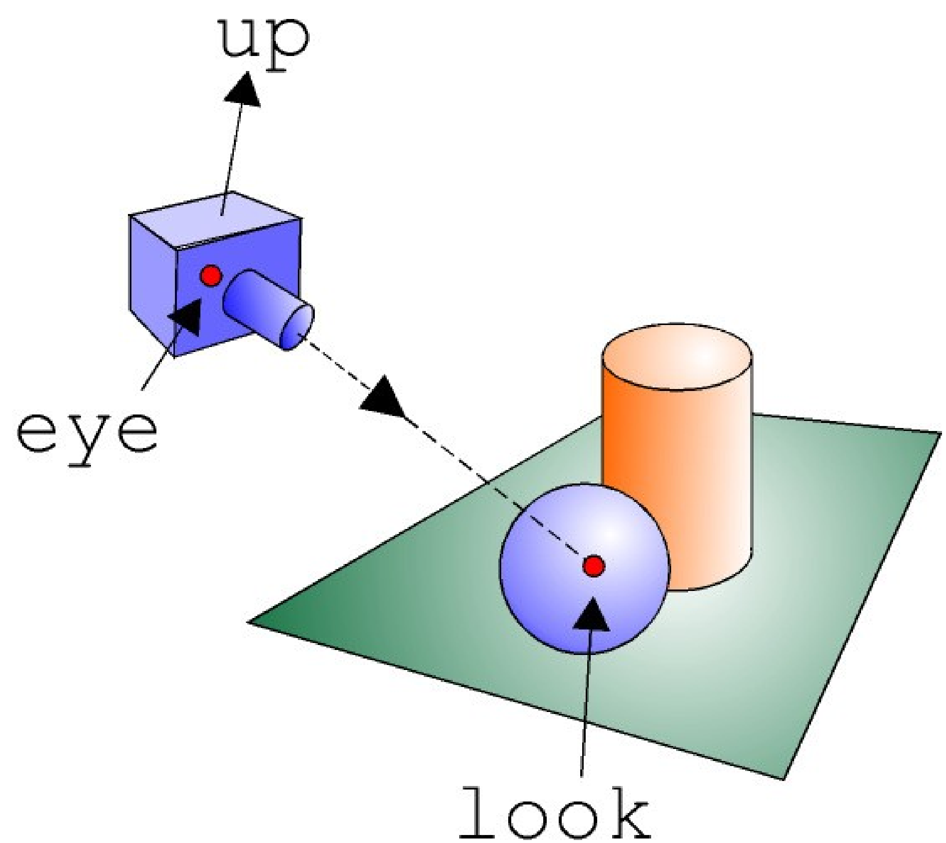
Right xyz
Up xyz
-Forward xyz
-Position xyz



Careful now!

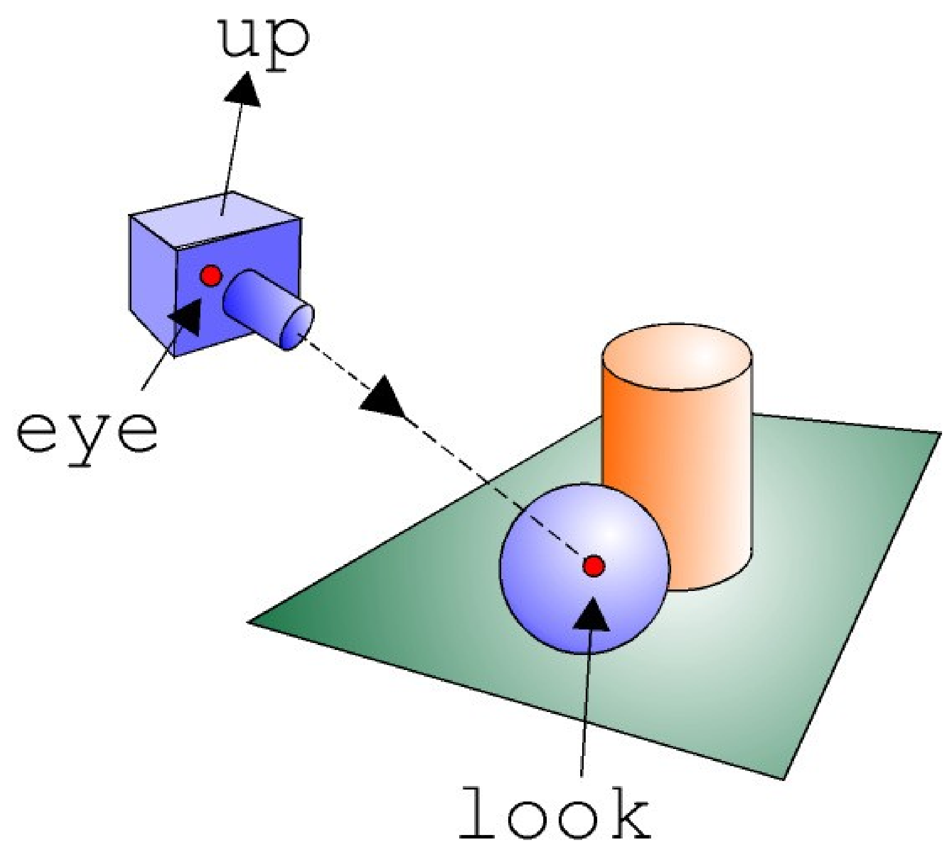
lookAt(vec3 eye, vec3 look, vec3 up)

- Typical maths library function
- Returns `mat4`
- Sets camera position
- Point at target
- Careful with "up" unit vector
- Not ideal for full 3d rotation



lookAt(vec3 eye, vec3 look, vec3 up)

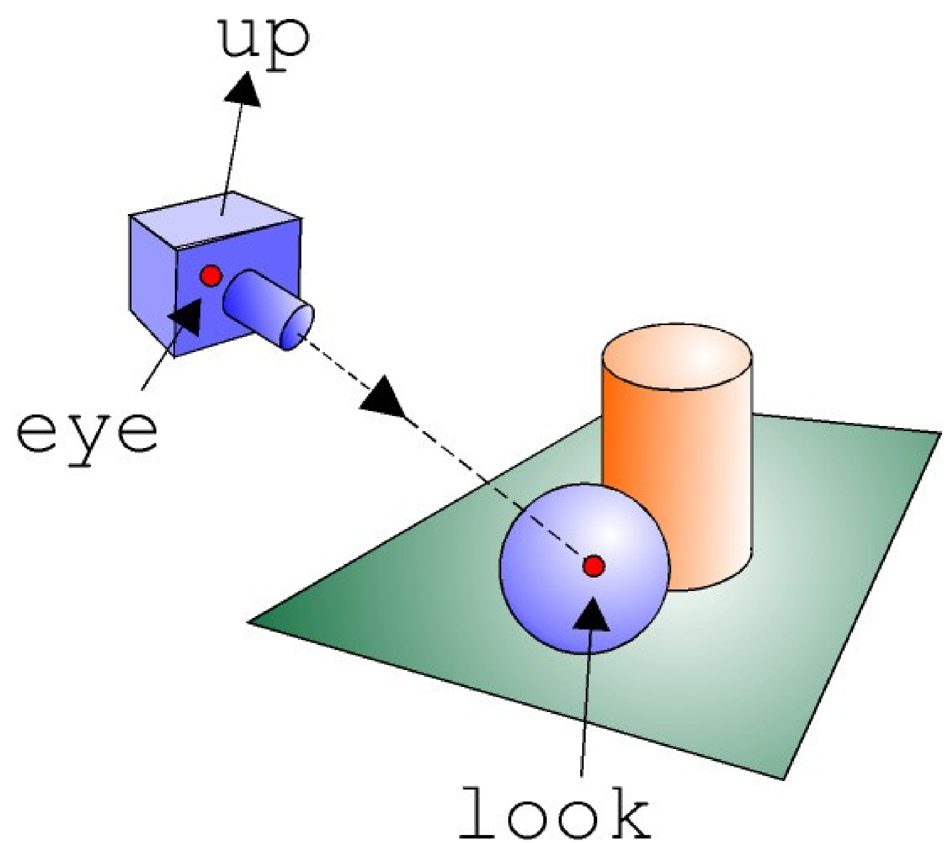
- Rem: view matrix needs
  - Right
  - Forward
  - Up
  - Position
- (set of 3d vectors)
- **Q1: How can we work out "forward"?**



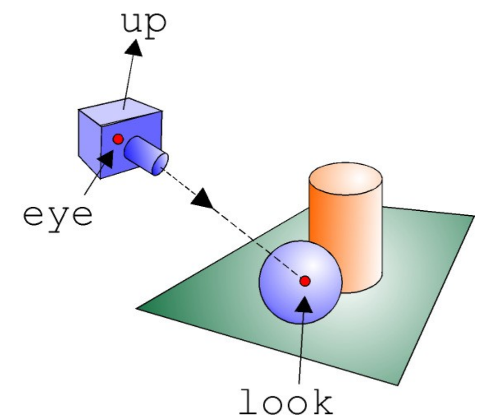
lookAt(vec3 eye, vec3 look, vec3 up)

```
vec3 f = normalise(look
- eye);
```

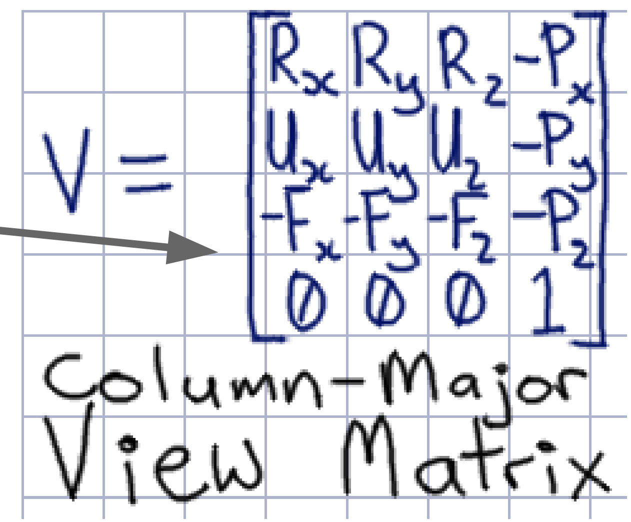
- **Q2. How can we work out “right” from “up” and “forward” ?**



lookAt()



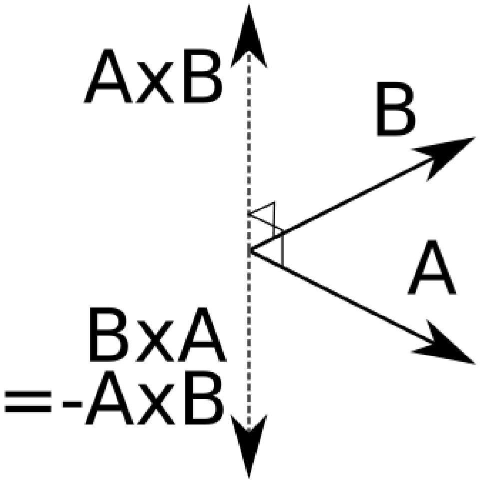

```
vec3 r = cross(f, up);
// recalc up to be sure
vec3 u = normalise (cross (r, f));

mat4 T = translate (-eye);
mat4 R = plug-in r,u,-f
return R * T;
```



- **Q3. Why did I re-calculate "up"?**
- **Q4. What would happen if I did cross(up, f) instead?**
- **Q5. What must you do if camera pitches up/down?**

Cross Product of 2 Vectors

Produces a vector perpendicular to the plane containing the 2 vectors.



$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} \times \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} a_2b_3 - a_3b_2 \\ a_3b_1 - a_1b_3 \\ a_1b_2 - a_2b_1 \end{bmatrix}$$

To compute **surface normals** from 2 edges:

```
N = normalize (cross (A, B));
```

Q1. What is the cross product of these vectors?

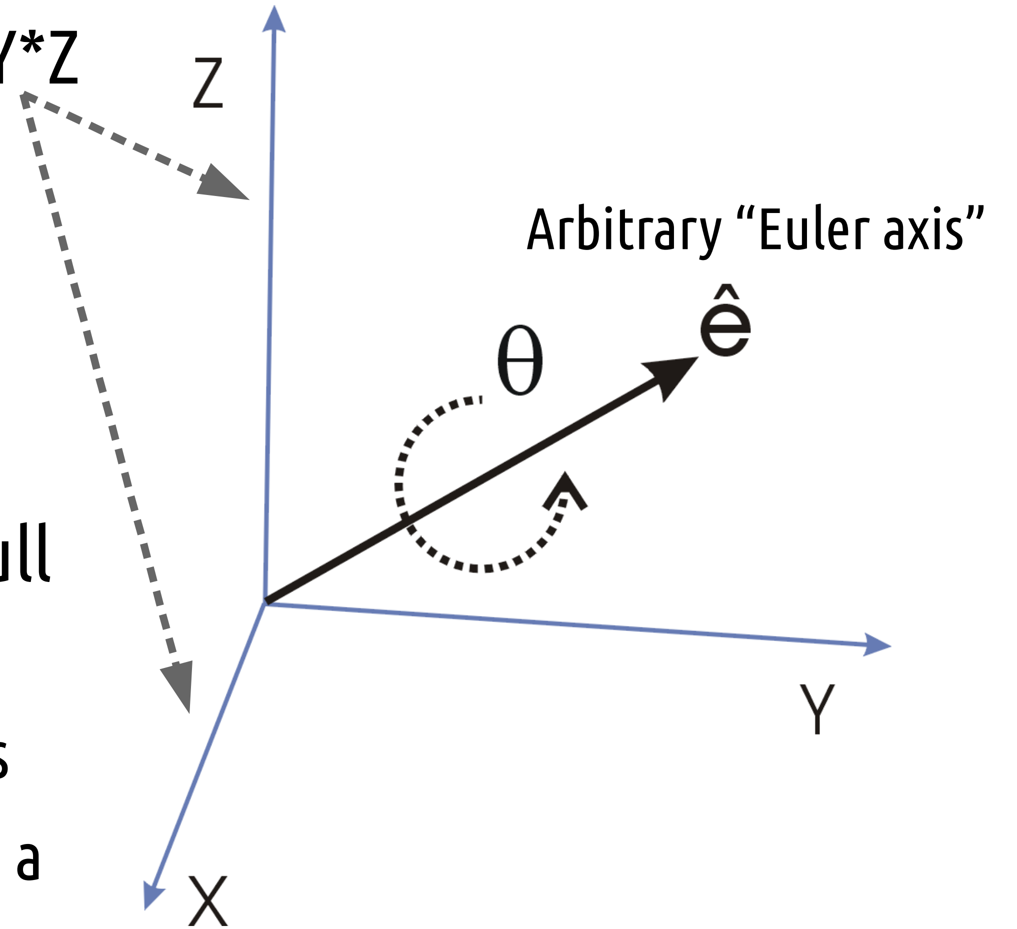
[0.0, 0.0, 1.0] X [1.0, 0.0, 0.0]

Q2. How do you normalise a 4d vector?

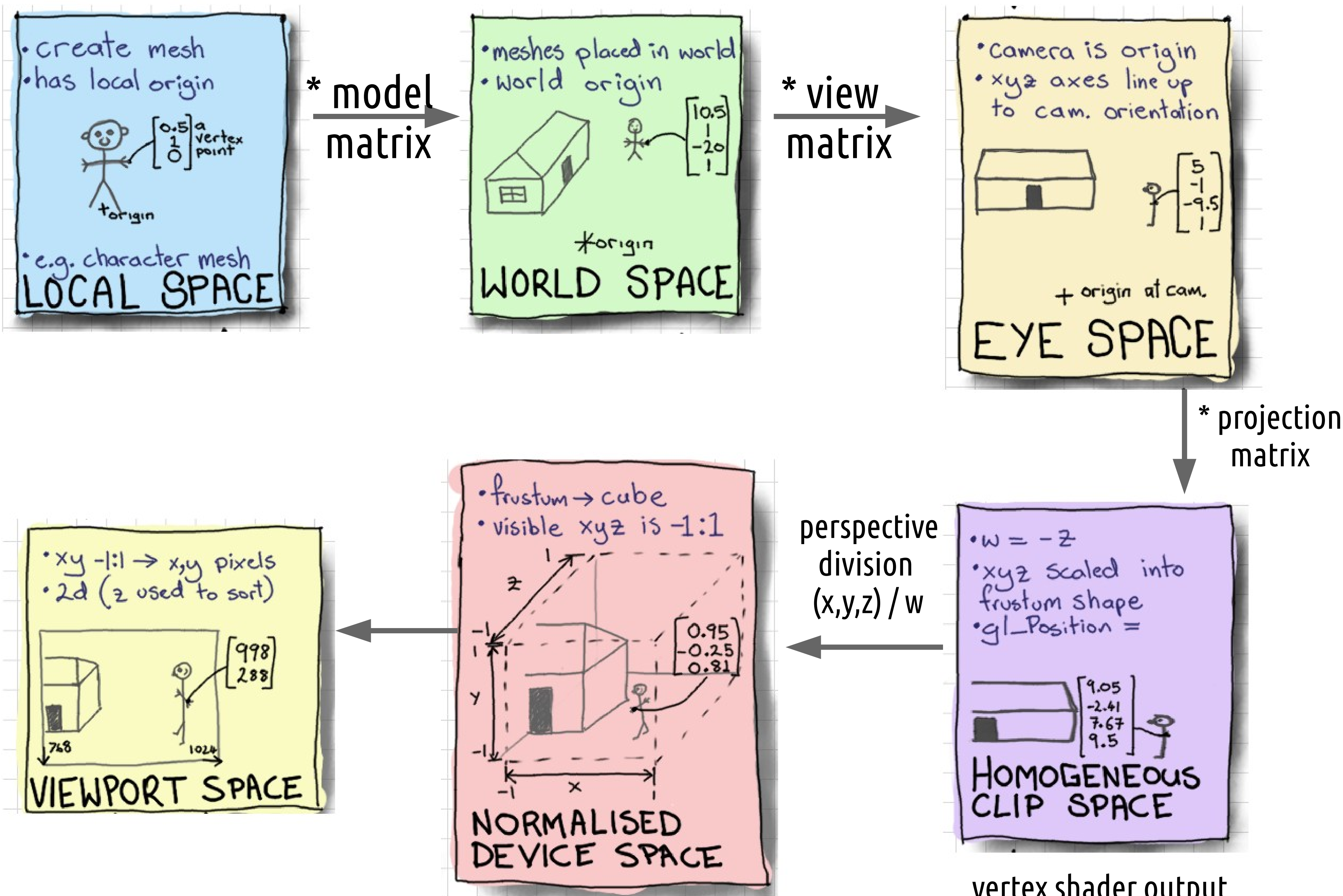
[10.0, 0.0, 0.0, 0.0]

Rotation Method Limitations

- Calculating from **fixed-axis** X*Y*Z rotation matrices
- LookAt() is good for panning, not great for flight sims
- **quaternions** better suited to creating rotation matrix with full 3d rotation
  - **Euler axis** & **angle** in 4 numbers
  - then some multiplications to get a 4X4 rotation matrix
  - Good for local pitch/yaw/roll



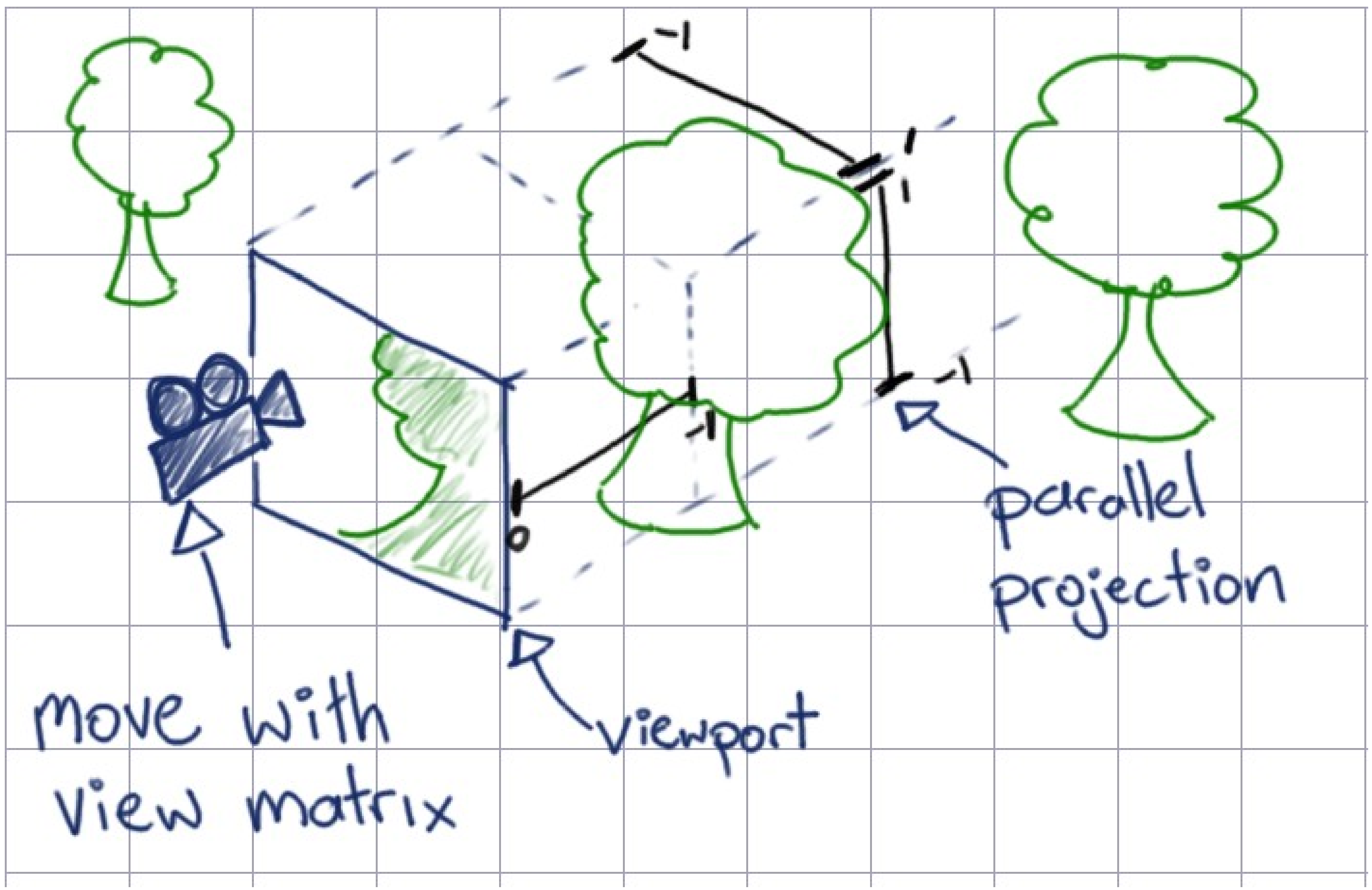
Transformation Pipeline – Coordinate Spaces



Eye Space

- Objects positioned relative to view point and direction
- Has an eye origin (0, 0, 0)
- Our view area is still -1 to 1 on XYZ.
- Our view is still a parallel (orthogonal/orthographic) projection.
- **Q. How can we manipulate the projection?**

What We Have Now



Q. How can we make our view cover more of the scene?

Orthographic Projection Matrix

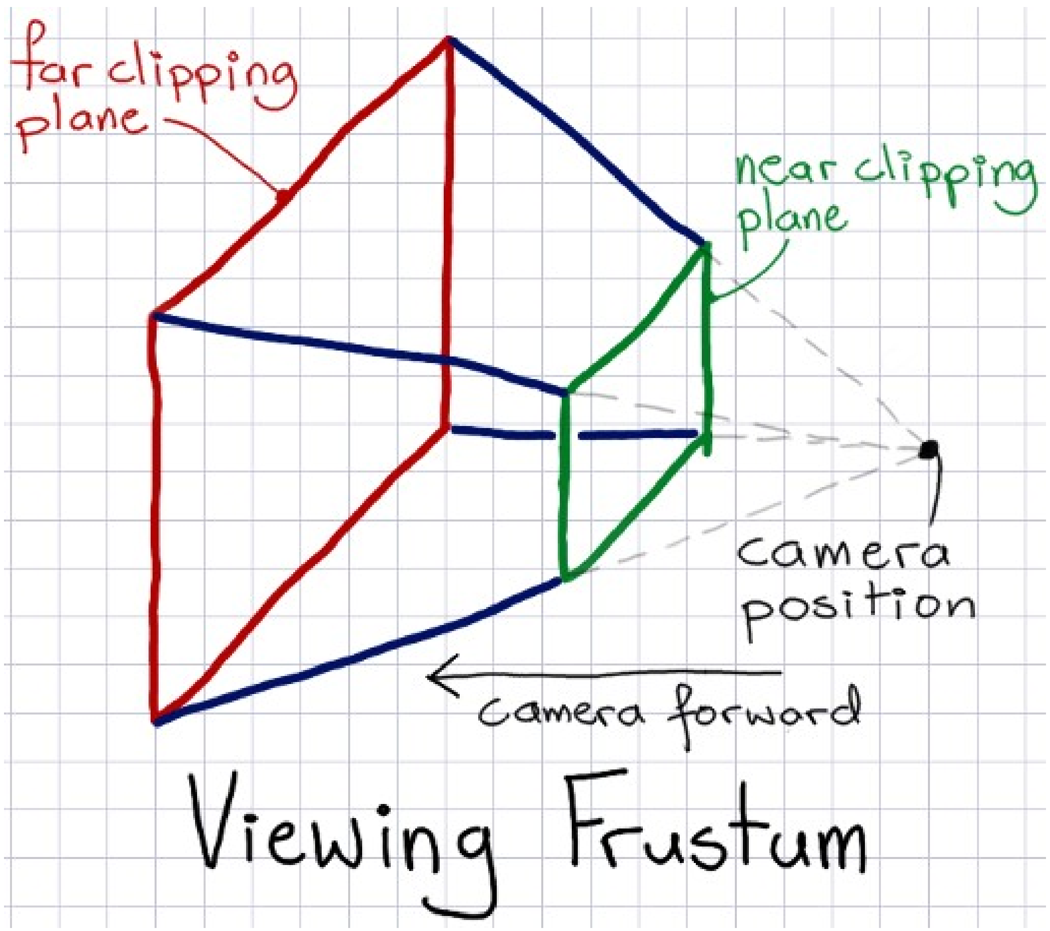
$$
\begin{bmatrix}
\frac{2}{x_f - x_i} & 0 & 0 & \frac{-(x_f + x_i)}{x_f - x_i} \\
0 & \frac{2}{y_f - y_i} & 0 & \frac{-(y_f + y_i)}{y_f - y_i} \\
0 & 0 & \frac{2}{Z_i - z_f} & \frac{Z_i + Z_f}{Z_f - Z_i} \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

Q. What affine matrices does this look similar to?

How can we approximate a cone of view?

- Has to map to a 2d **rectangular** view, not a circle (well…we could do a circle)
- Has to have minimum and maximum **cut-off** distances
- Some sort of **angle** of view
- We had a cuboid before for orthographic
- **Q. What 3d geometric shape is this?**

Perspective Projection



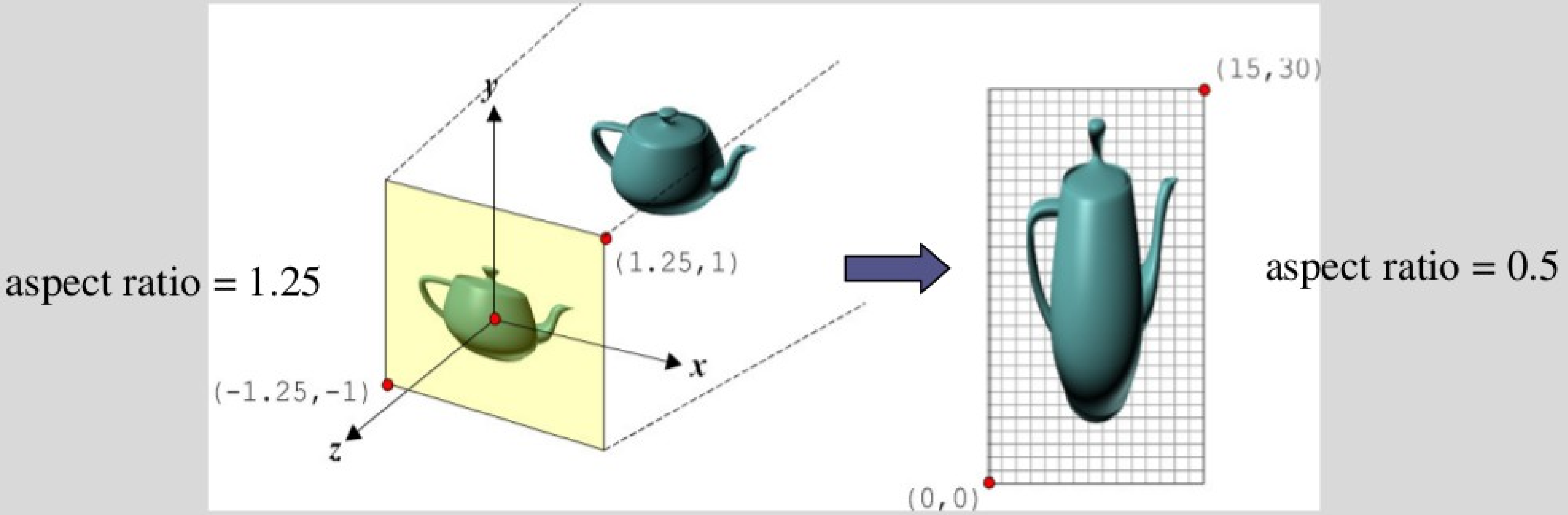
Typical Perspective Function

```
mat4 perspective (
  float fovy,
  float aspect,
  float zNear,
  float zFar
);
```

- Fovy is "**field of view** y-axis"
  - angle from horizon to top
  - convert to radians
- **Aspect ratio** is `(float)width / (float)height` of viewport
- Near and far are "**clip planes**"
  - 0.1 and 1000.0 are typical

Aspect Ratio

- The *aspect ratio* defines the relationship between the width and height of an image.
- Using `Perspective` matrix, a viewport aspect ratio may be explicitly provided, otherwise the aspect ratio is a function of the supplied viewport width and height.
- The aspect ratio of the window (defined by the user) must match the viewport aspect ratio to prevent unwanted *affine* distortion:



A Symmetric Perspective Matrix

$$\begin{pmatrix} \frac{f}{aspect} & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & \frac{zFar + zNear}{zNear - zFar} & \frac{2 \times zFar \times zNear}{zNear - zFar} \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

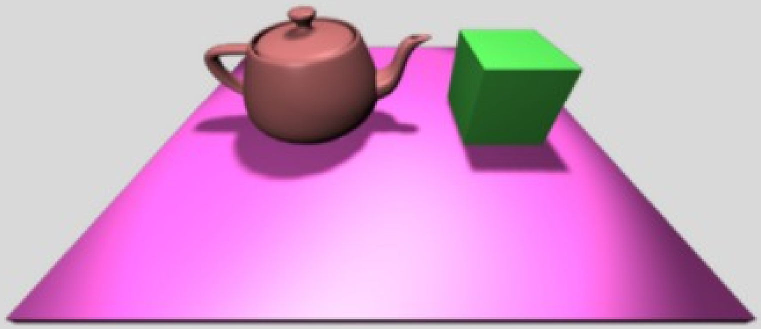
$$f = cotangent\left(\frac{fovy}{2}\right)$$

???

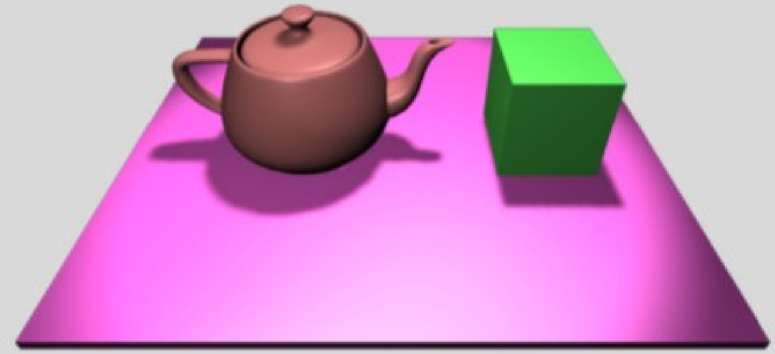
1.0 / tan (fovy * 0.5);

- Q. An aspect of 2.0 means?
- Wrong aspect = distortion
- Depth buffer precision (ranges of z) has only so many bits per pixel.
- Smaller zFar / zNear ratio = more precision
- As zNear -> 0, zFar -> infinity
  - Do not make zNear = 0.0

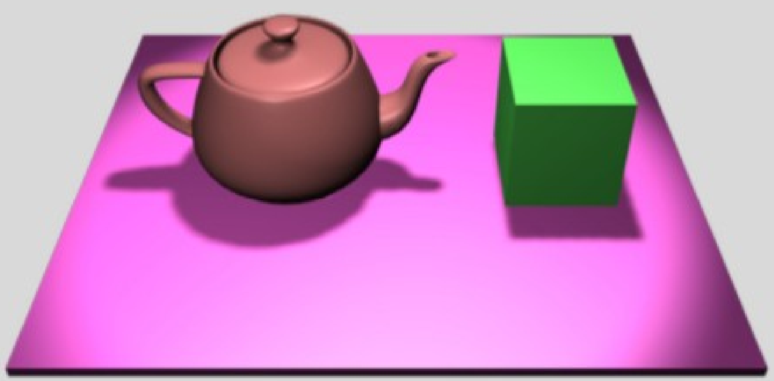
Lens Configurations



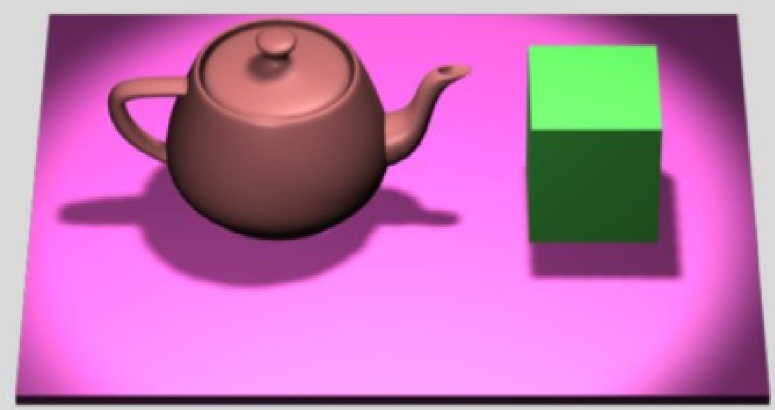
10mm Lens (fov = 122°)



20mm Lens (fov = 84°)



35mm Lens (fov = 54°)



200mm Lens (fov = 10°)

FOV

- Beware comparisons of angle of view
- Older games etc. used horizontal angles of view ~90 degrees
- These also had fixed-aspect displays:
  - 320x200 (2.5:4)
  - 320x240, 640x480, etc. -> (3:4) = 1.3333…
- LookAt() etc. Use vertical angles
  - 90 degrees horiz. / 1.333333 = 67.5 degrees vert.

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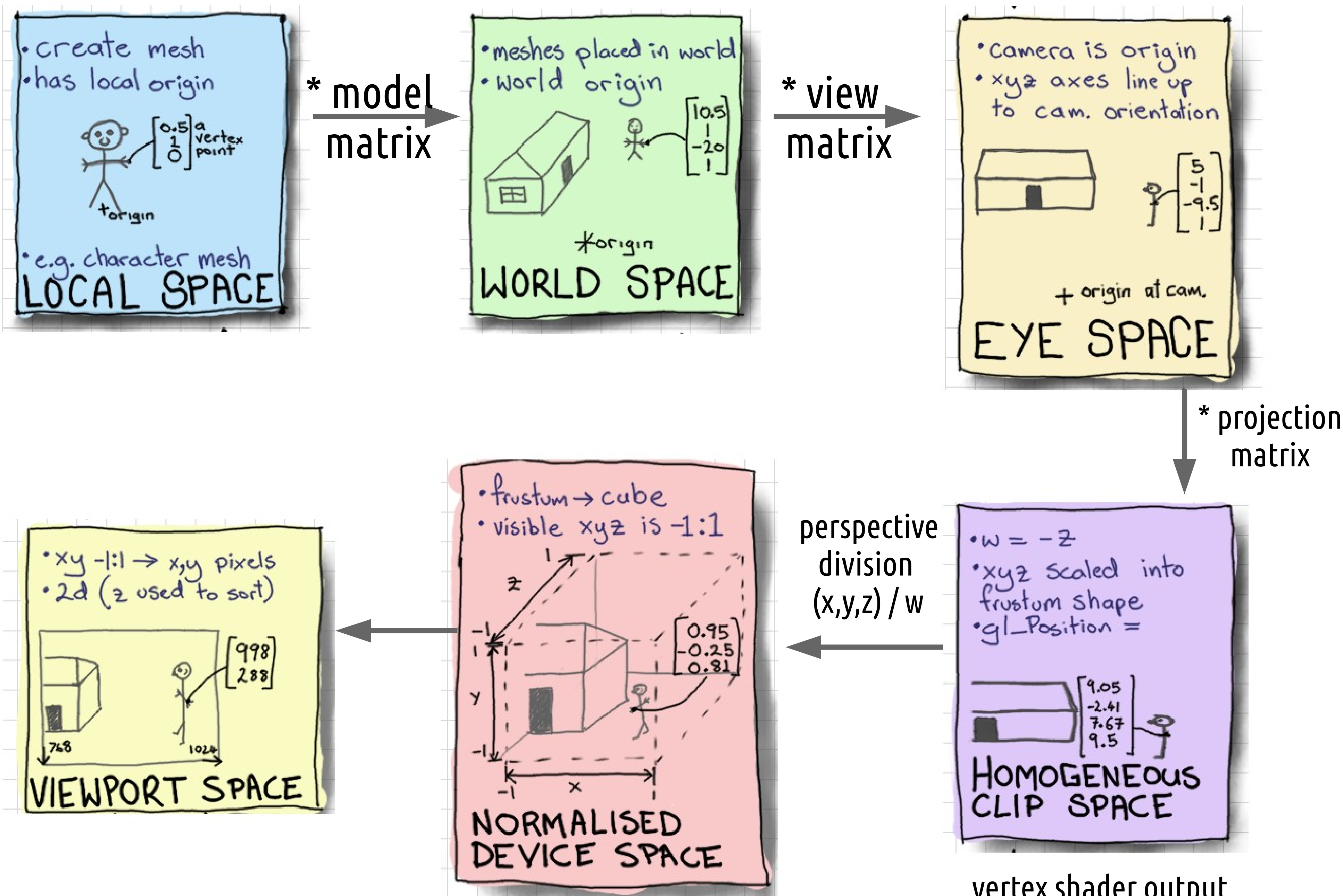
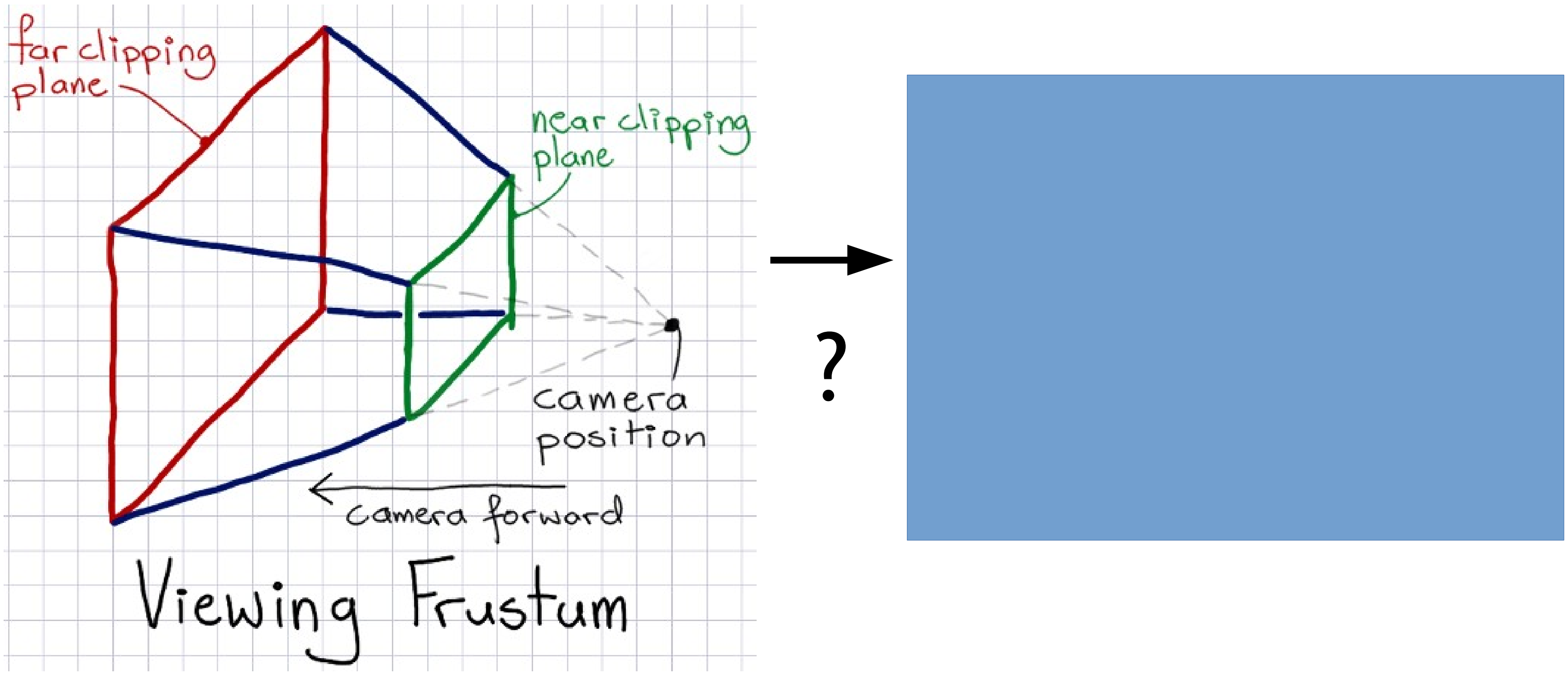
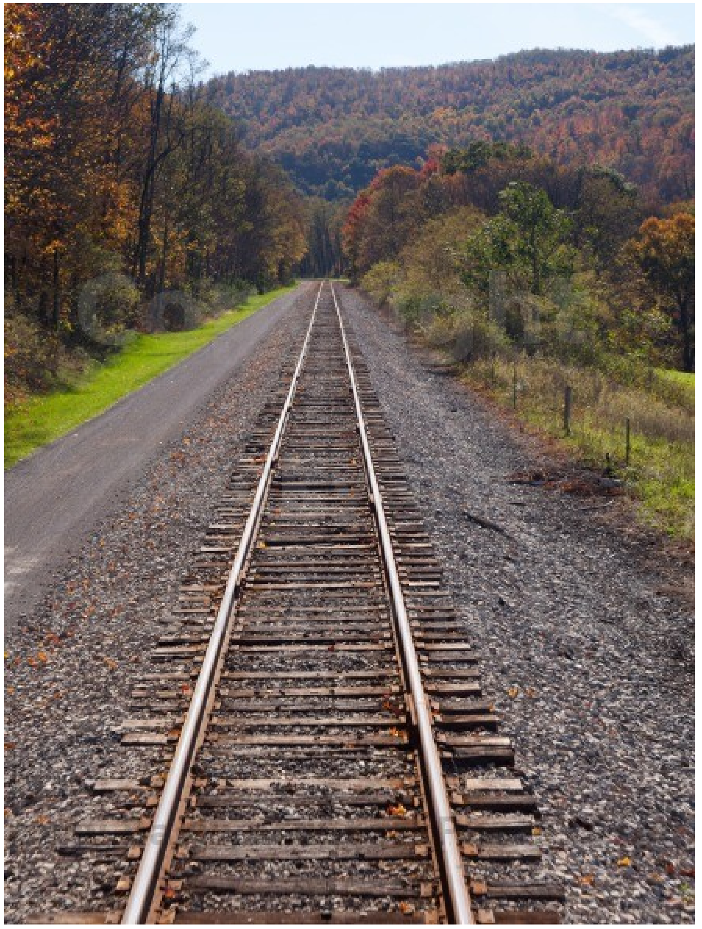


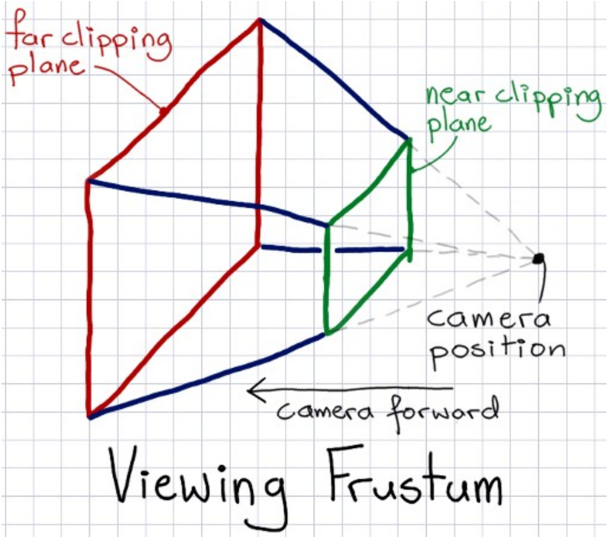
Homogenous Clip Space

- Geometry outside near/far xyz clip planes is “clipped” after the VS
- **Q. How will we map our frustum area onto a 2d drawing surface?**
  Hint: The orthographic cuboid was easy.



Perspective Division





A. We will squish in the large back end until it is a -1 to 1 XYZ box.

Q. How? Hint: Some of you did this in Assignment 0

Perspective Division

- Vertex shader output is a 4d variable

```
gl_Position = P * V * M * vec4 (vp, 1.0);

gl_Position = vec4 (x, y, z, w);
```

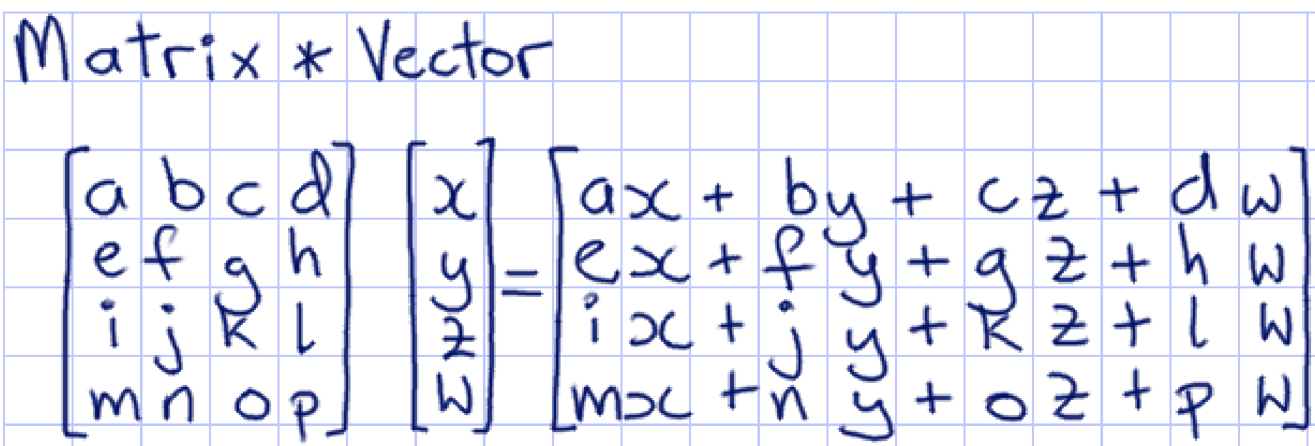
- After the VS, a built-in mechanism does

```
position = vec3 (gl_Position.xyz / gl_Position.w);
```

- **Q. What does the perspective matrix do to w?**

Perspective Division

$$\begin{pmatrix} \frac{f}{aspect} & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & \frac{zFar + zNear}{zNear - zFar} & \frac{2 \times zFar \times zNear}{zNear - zFar} \\ 0 & 0 & -1 & 0 \end{pmatrix}$$



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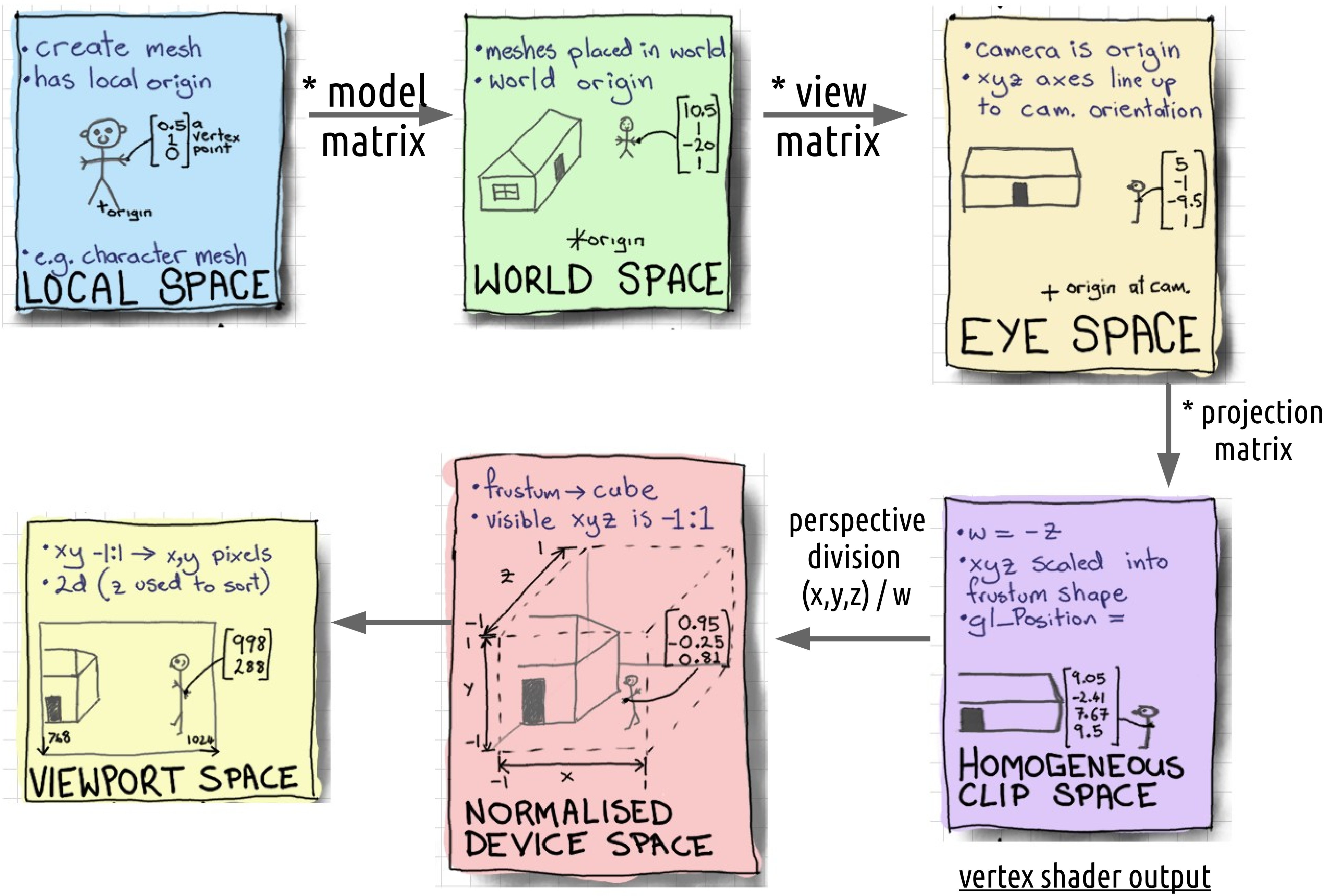

Normalised Device Space

- All coordinates are between -1 and 1 – the **unit cube**
- This is very easy to scale by # pixels wide and high
- Project to 2d
- Front/back face select and **cull** if enabled
- **Rasterise** to pixels/fragments

Typical Vertex Shader w/ Camera

```
#version 400
in vec3 vertex_point, vertex_normal;
uniform mat4 P, V, M;
out vec3 p_eye, n_eye;

void main () {
  gl_Position = P * V * M * vec4 (vertex_point, 1.0);

  p_eye = V * M * vec4 (vertex_point, 1.0);
  n_eye = V * M * vec4 (vertex_normal, 0.0);
}
```

useful for lighting

- Order of multiplication is fundamentally important
- Never compare variables from different coordinate spaces
- Use a postfix or prefix naming convention for variables

Normalised Device Space

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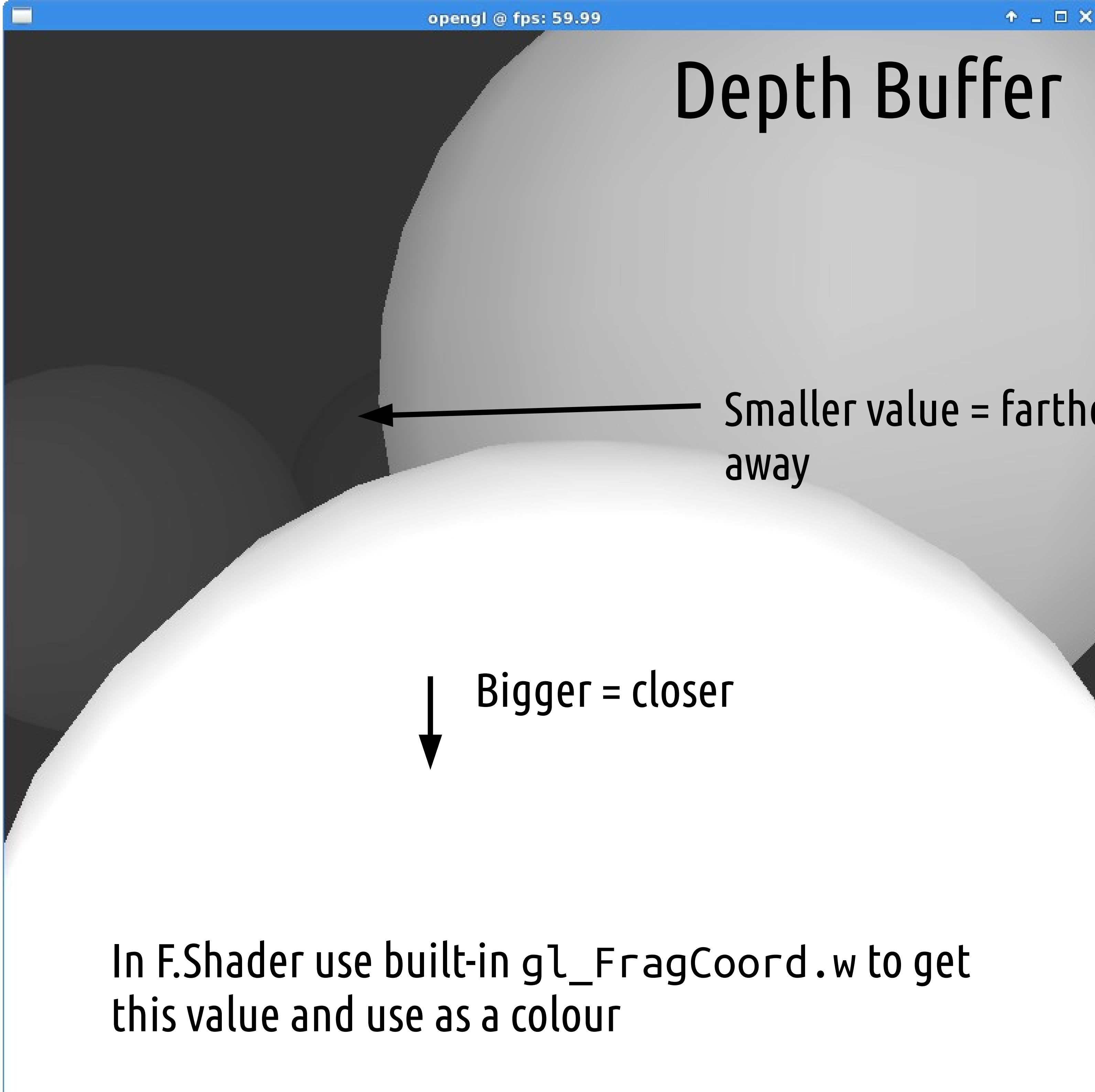
Depth Testing (automatic step) and The Depth Buffer

- **Edwin Catmull** again – PhD thesis 1974, U. Utah.
- Whenever we write a fragment it writes the colour to the framebuffer's **colour buffer** (a big 2d image)
- But first...if **depth testing** is enabled
- It checks another 2d image called the **depth buffer**
- If its own depth is smaller/closer it **overwrites** both the depth and colour buffer pixels
- **Q. What does this do?**
- Can we disable the depth testing and try?

Depth Buffer



In F.Shader use built-in `gl_FragCoord.w` to get this value and use as a colour

Reading List and Practical Tasks

- Shirley & Marschner – “Fundamentals” Ch. 7 “Viewing”
- Akenine Moeller *et. al* “Real-Time Rendering” Ch. 2 and 4.6 “Projections” (very good)

- Know how to work out the pipeline <u>by hand</u> on paper for 1 vertex & M, V, and P
- Hint: add a “print_matrix(m)” function to check contents

3rd Assignment - Viewing

- Due next week!
- Start **way ahead of time**
(easy to get into a transformations mess)
- If you finish early, get a head start on game project skills:
  - Play
  - Upgrade – Load a mesh? Full 3d camera controls?
  - make all the mistakes
  - ask for advice now (discussion boards)