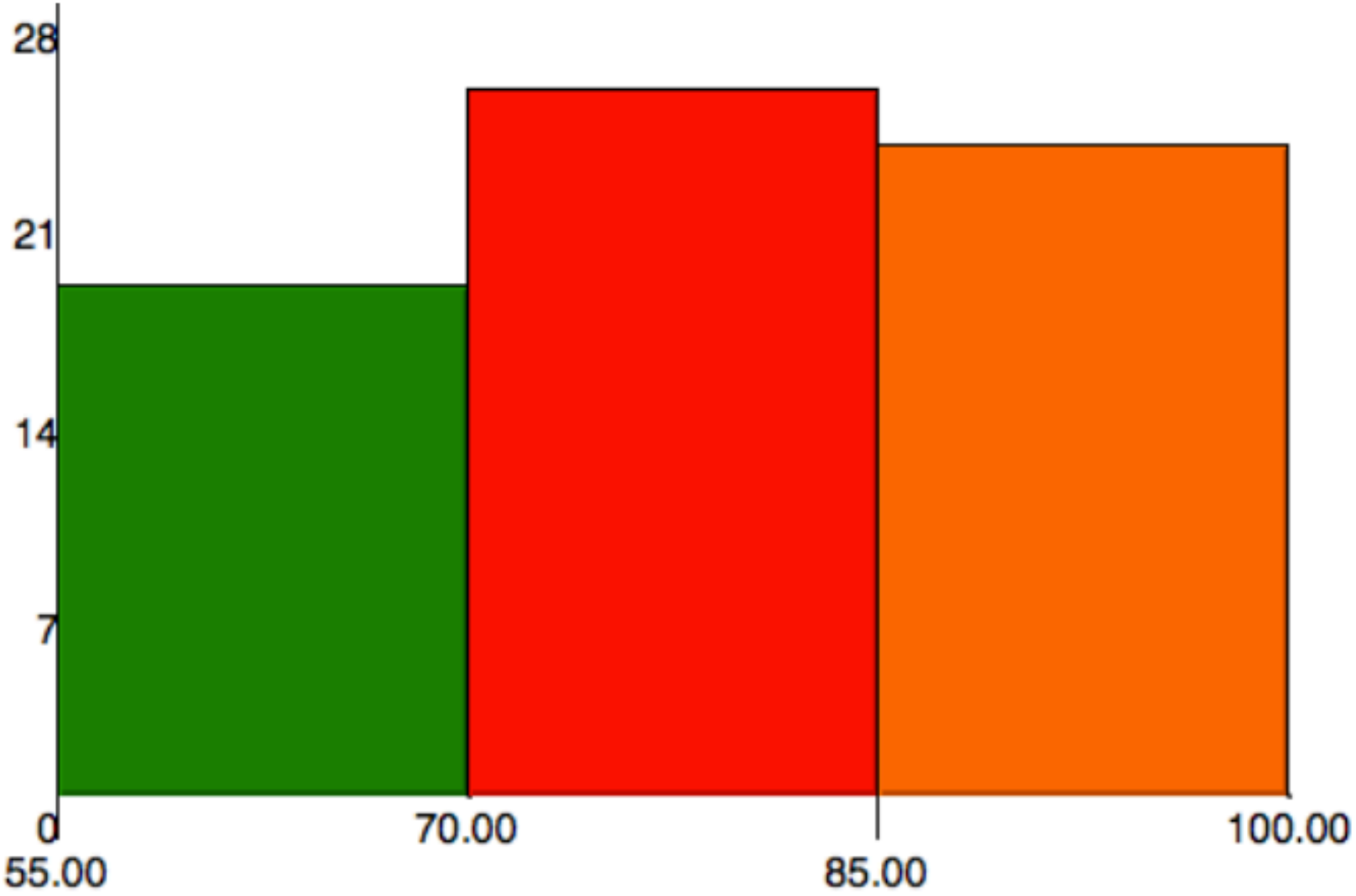
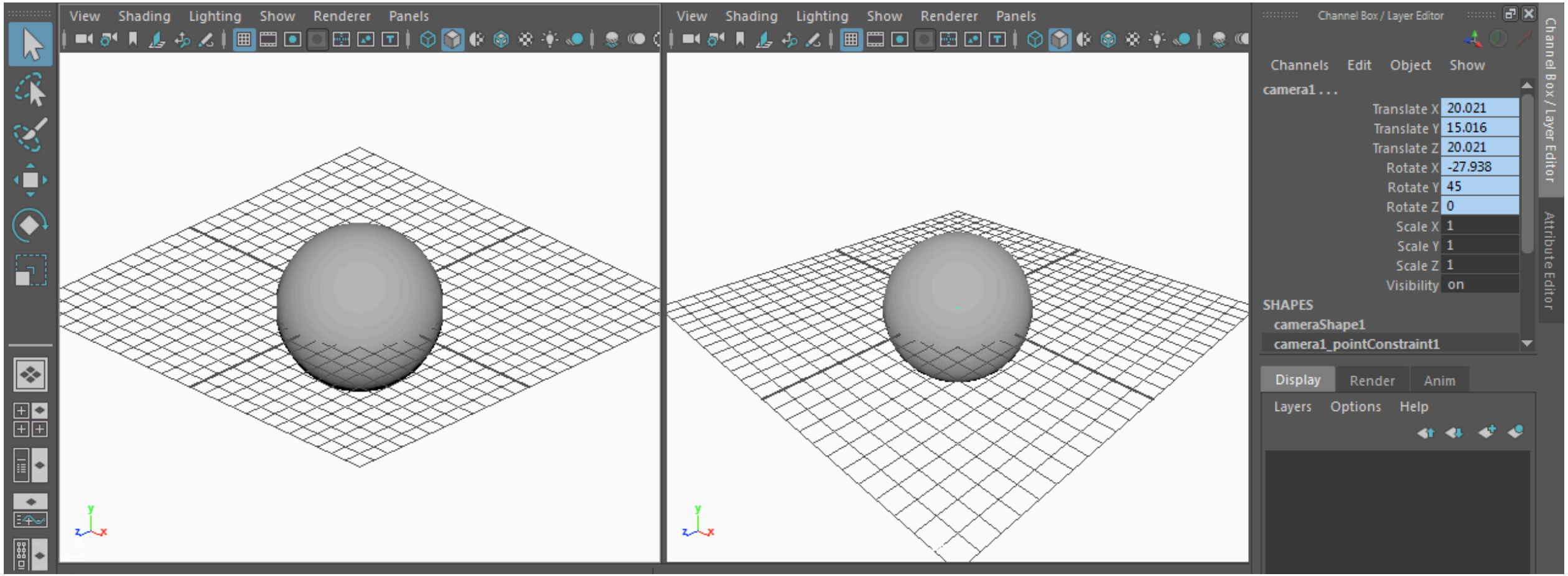
MIDTERM 1: MISSION COMPLETE

- Avg: 78%
- Median: 80%
- Max: 97%

- Have a look on Friday



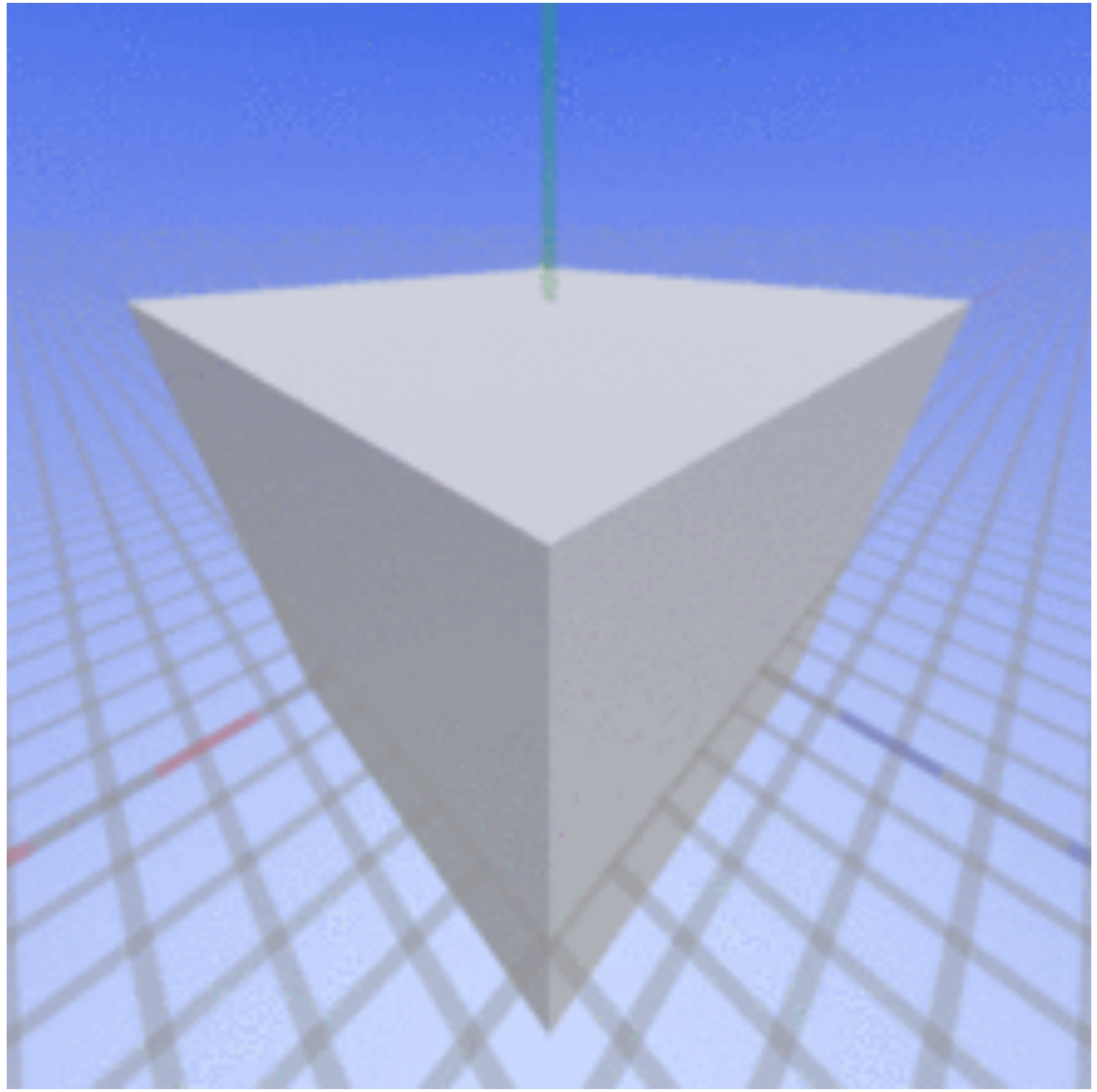
LAST BITS ON PROJECTIONS



(Switch to maya demo)

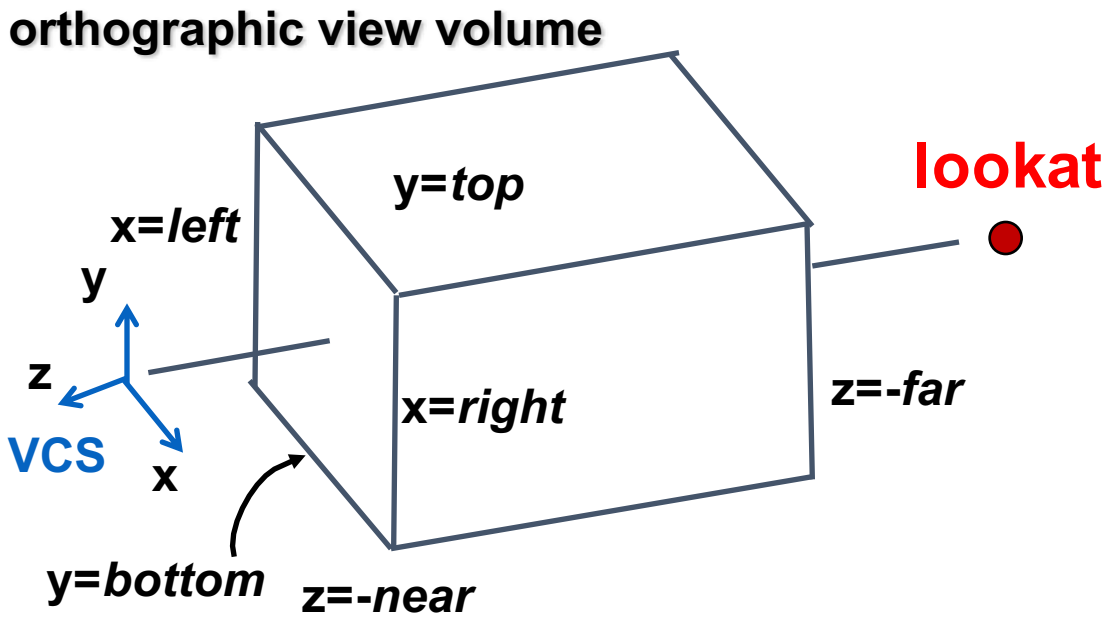
ORTHOGRAPHIC =

VERY FAR PERSPECTIVE (WITH VERY GOOD ZOOM)



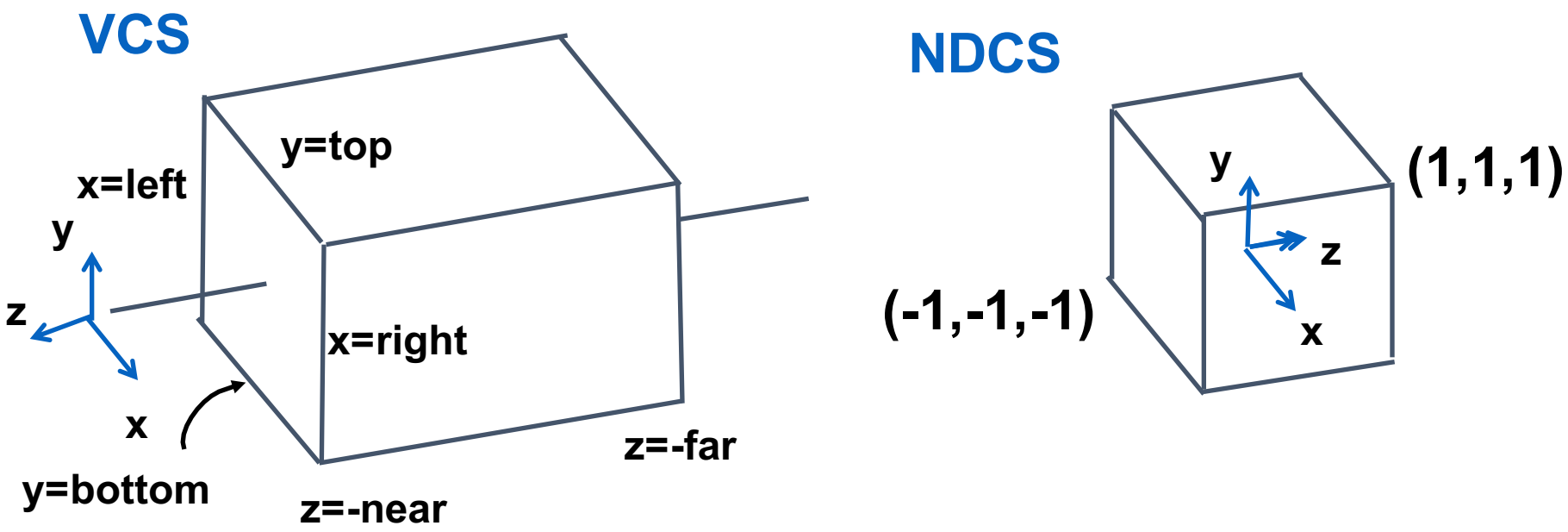
VIEW VOLUME
ORTHOGRAPHIC PROJECTION

- specifies field-of-view, used for clipping
- restricts domain of z stored for visibility test



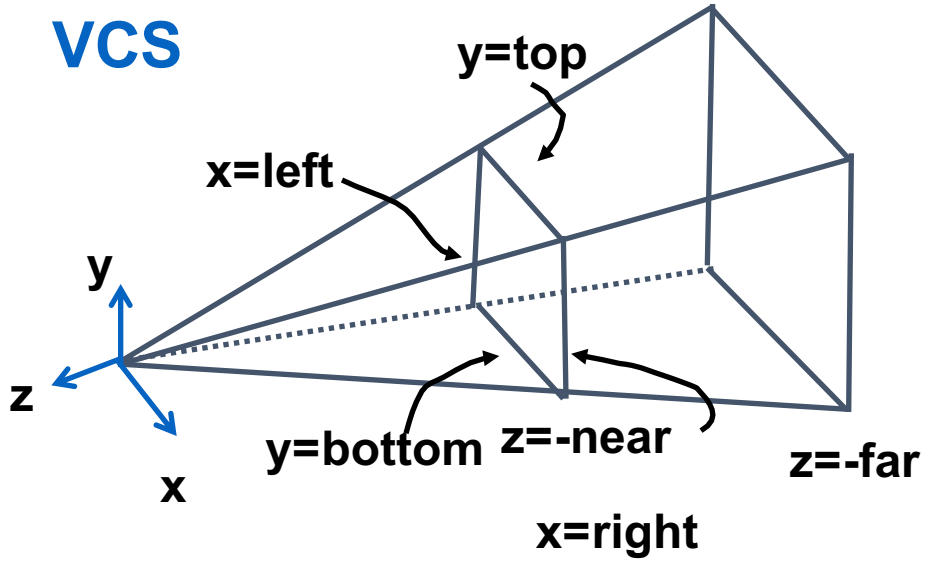
UNDERSTANDING Z

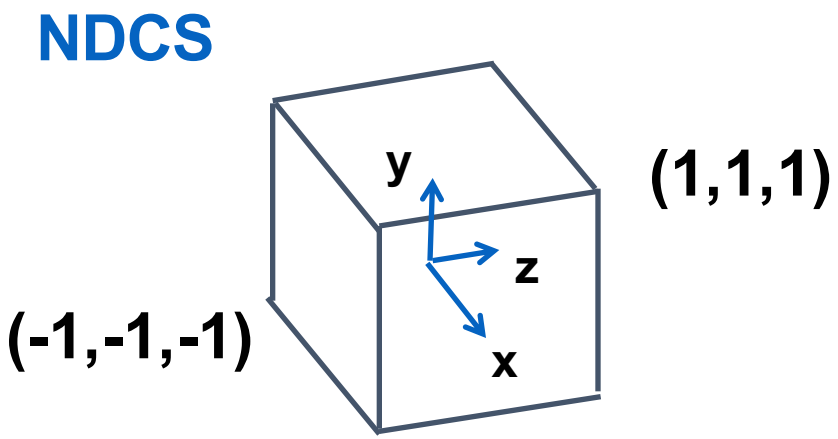
- z axis flip changes coord system handedness
  - RHS before projection (eye/view coords)
  - LHS after projection (clip, norm device coords)



OPENGL PERSPECTIVE DERIVATION

Map FRUSTUM to the NDCS cube. Later z will be ignored.
Now we need to scale/translate/shear -> generic transform



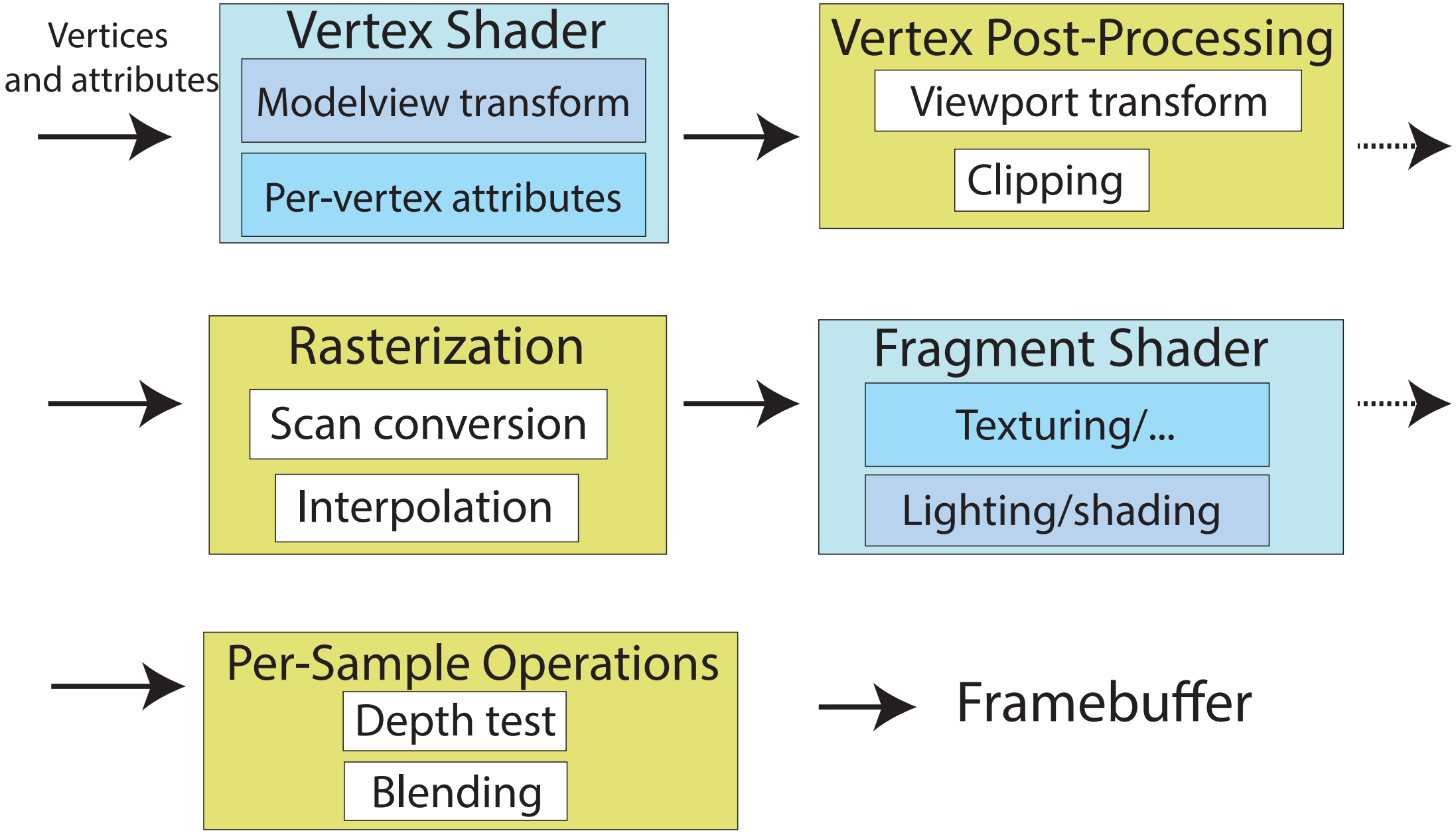


CPSC 314
14 – CLIPPING & RASTERIZATION

UGRAD.CS.UBC.CA/~CS314

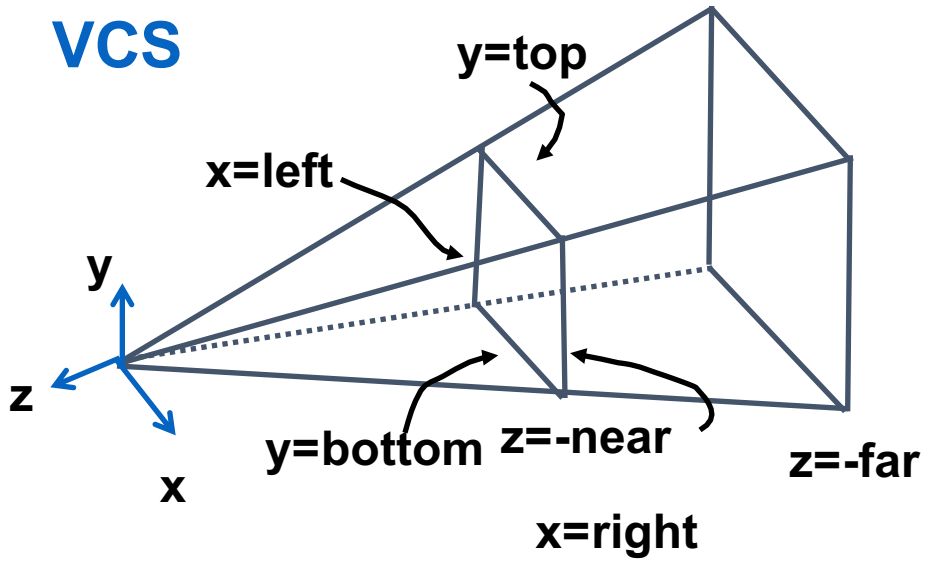
Mikhail Bessmeltsev

THE RENDERING PIPELINE



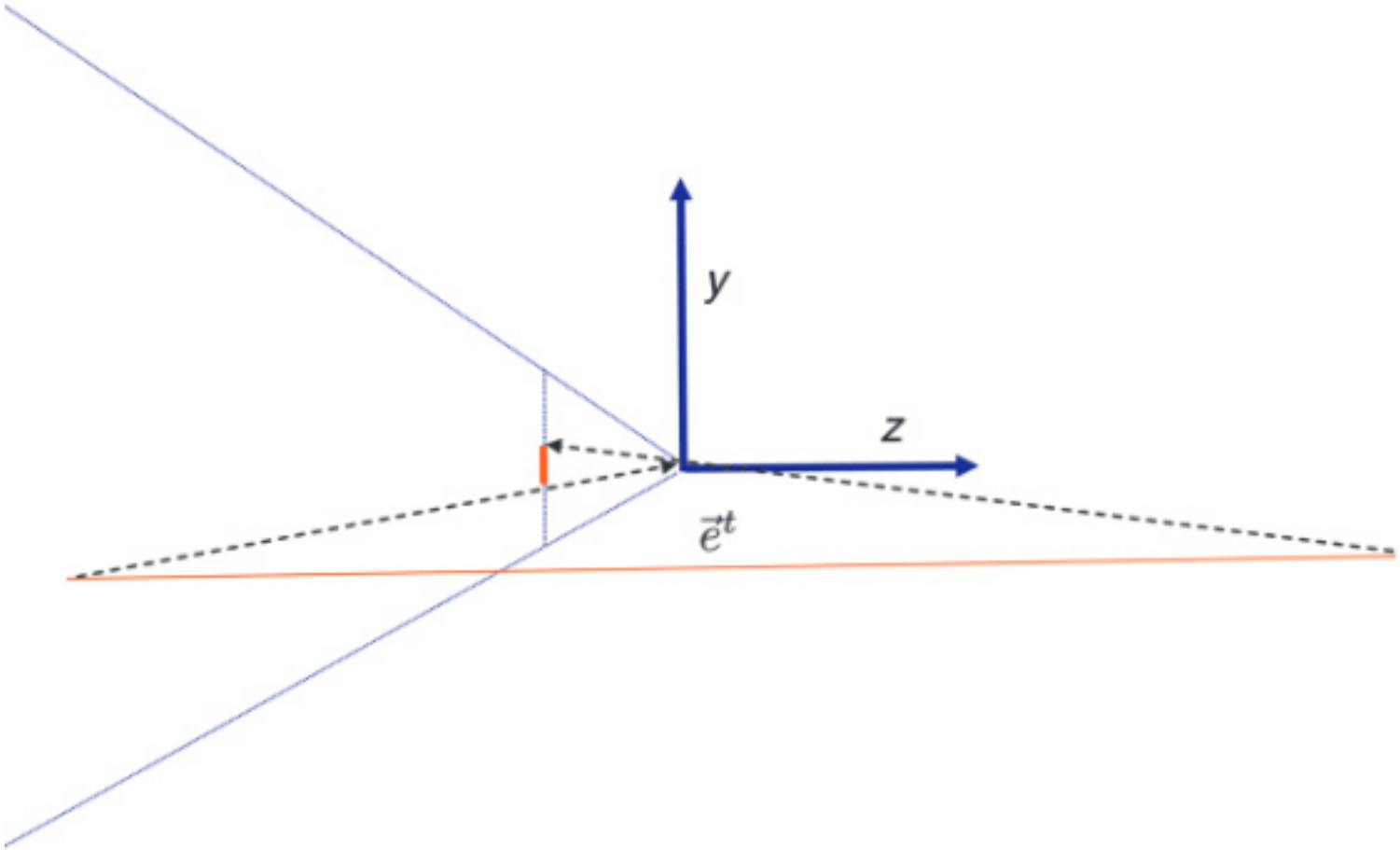
CLIPPING

- We have to clip what's outside our view volume
- Outside to the left/right, top/bottom
- More importantly, front/near:



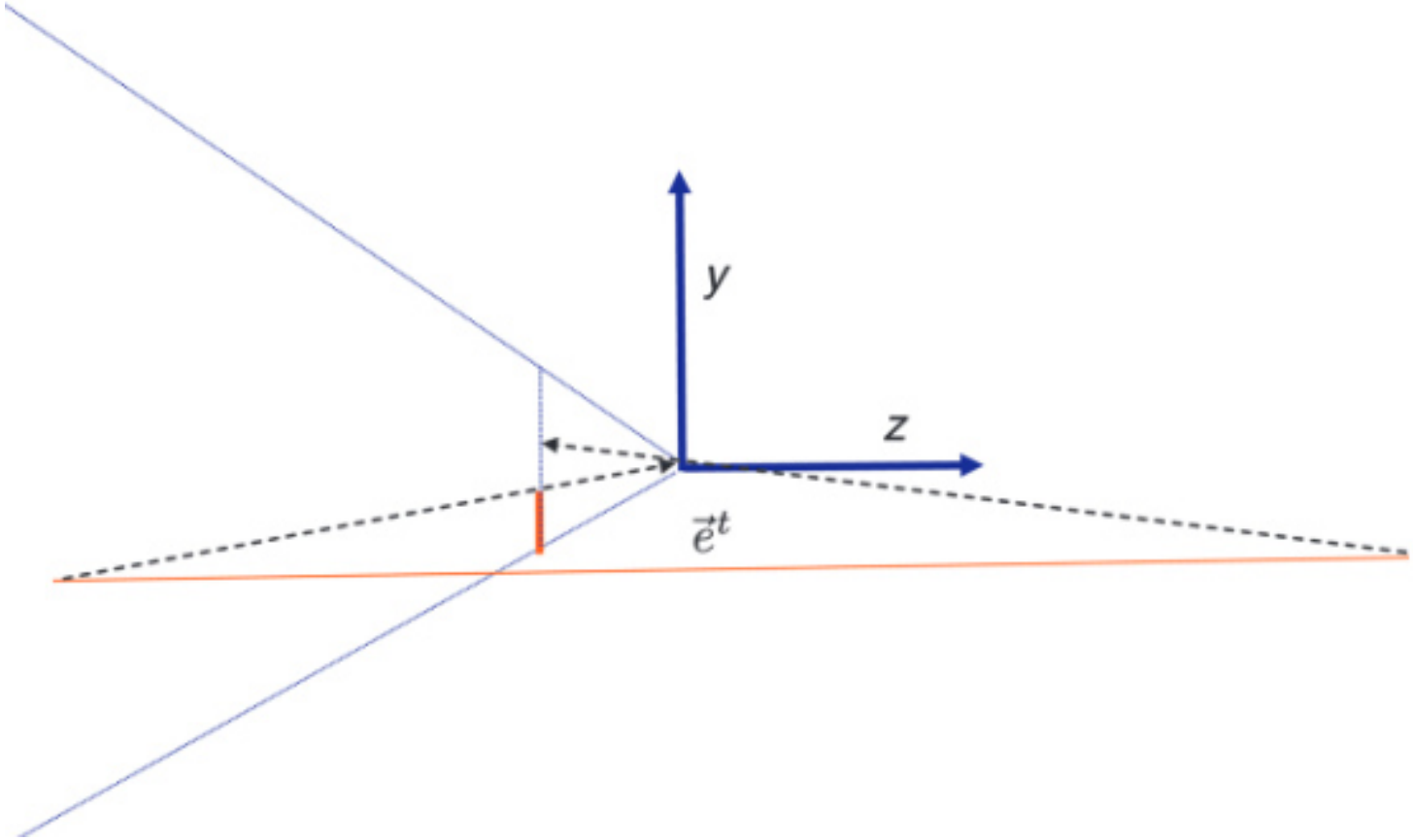
CLIPPING

- More importantly, front/near:



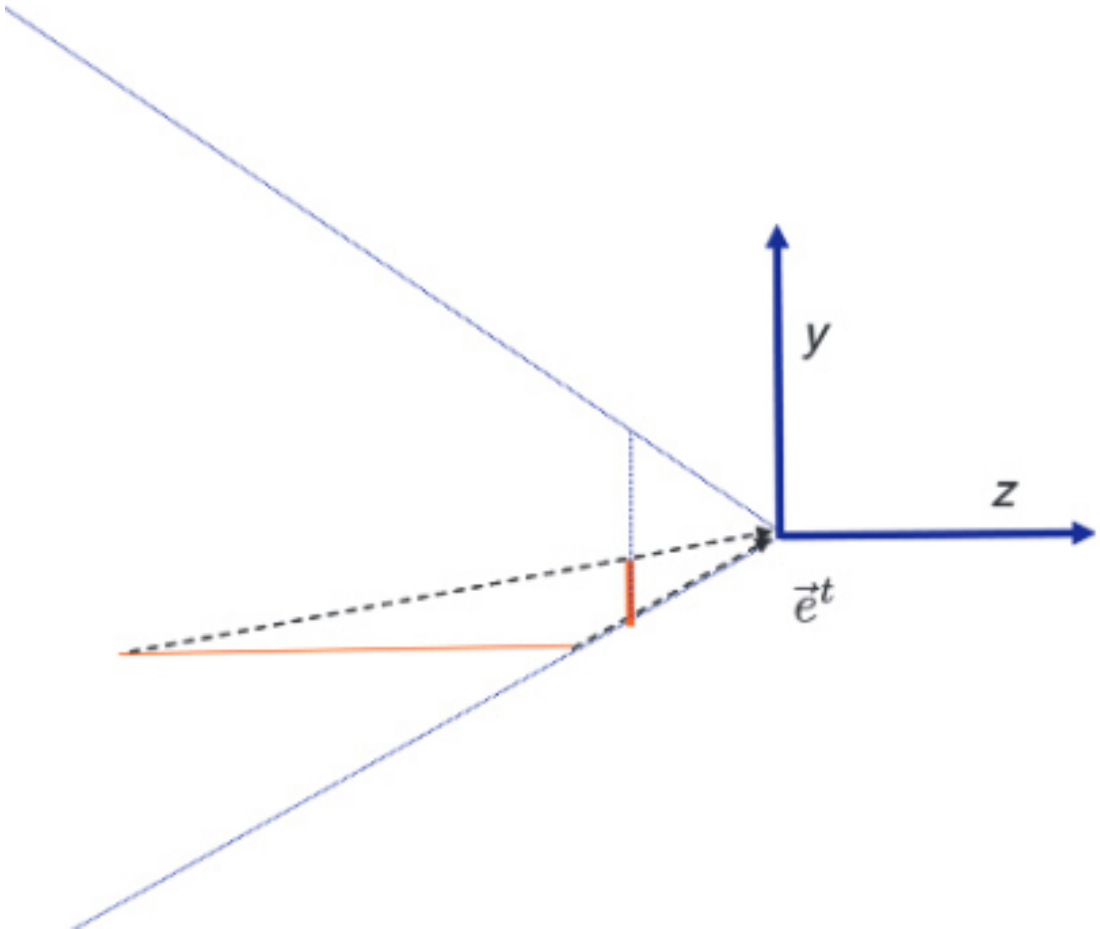
CLIPPING

- More importantly, front/near:



CLIPPING

- More importantly, front/near:



CLIPPING

- Where to do it in pipeline?

CLIPPING

- Option 1: Before projection
- Option 2: After NDCS
- Option 3: In between?

CLIPPING

- ~~Option 1: Before projection~~
  - Then it would have to know all the camera info
- Option 2: After NDCS
- Option 3: In between?

CLIPPING

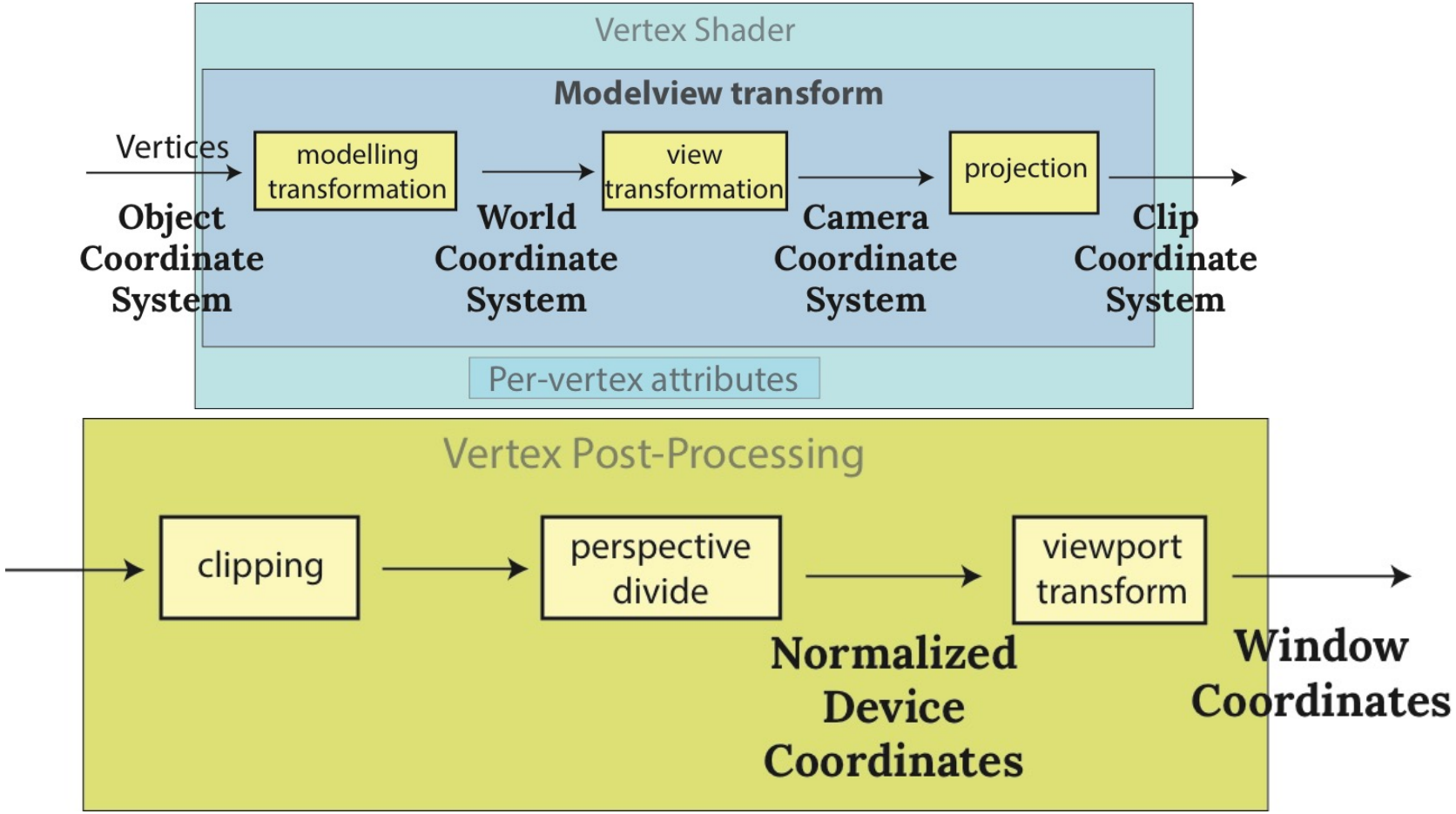
- ~~Option 1: Before projection~~
  - Then it would have to know all the camera info
- ~~Option 2: After NDCS~~
  - Flip already occurred
  - Too many calculations
- Option 3: In between?

CLIPPING

- ~~Option 1: Before projection~~
  - Then it would have to know all the camera info
- ~~Option 2: After NDCS~~
  - Flip already occurred
  - Too many calculations
- Option 3: In between?

CLIPPING

- Perform clipping in clip-coordinates!
  - After projection and before dividing by w



CLIPPING

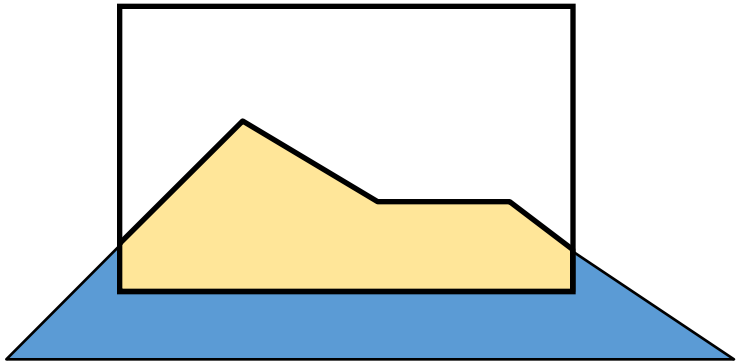
- Perform clipping in clip-coordinates!
  - After projection and before dividing by w

$$-w_c < x_c < w_c$$
$$-w_c < y_c < w_c$$
$$-w_c < z_c < w_c$$

We have not performed any divisions =>
no flip; efficiency

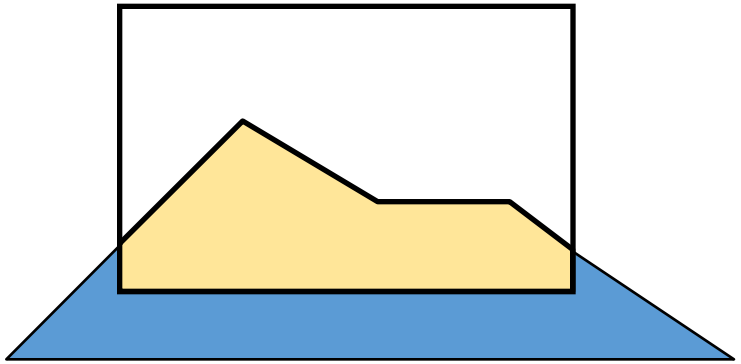
CLIPPING: UNDER THE HOOD

- Creates new vertices
- Done automatically, we won't study the actual algorithm



CLIPPING: UNDER THE HOOD

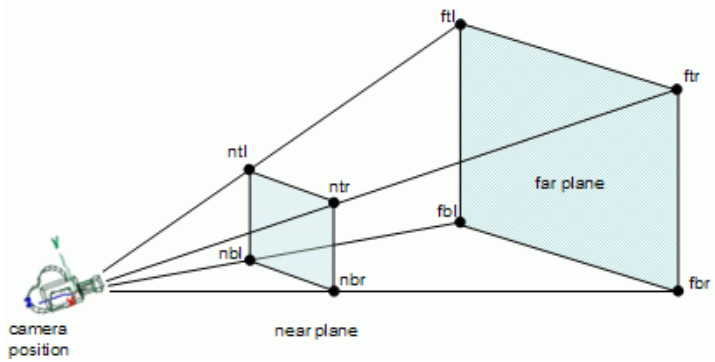
- Creates new vertices
- Done automatically, we won't study the actual algorithm
- Clip:
  - Points -> discard
  - Triangles -> clip



CLIPPING COORDINATES

- Eye coordinates (projected) → clip coordinates → normalized device coordinates (NDCs)
- Dividing clip coordinates (x_c, y_c, z_c, w_c) by the $w_c (w_c = w_n)$ component (the fourth component in the homogeneous coordinates) yields normalized device coordinates (NDCs).

$$\begin{bmatrix} x_n w_n \\ y_n w_n \\ z_n w_n \\ w_n \end{bmatrix} = \begin{bmatrix} x_c \\ y_c \\ z_c \\ w_c \end{bmatrix} = \begin{bmatrix} s_x & 0 & -c_x & 0 \\ 0 & s_y & -c_y & 0 \\ 0 & 0 & \frac{f+n}{f-n} & -\frac{2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x_e \\ y_e \\ z_e \\ 1 \end{bmatrix}$$



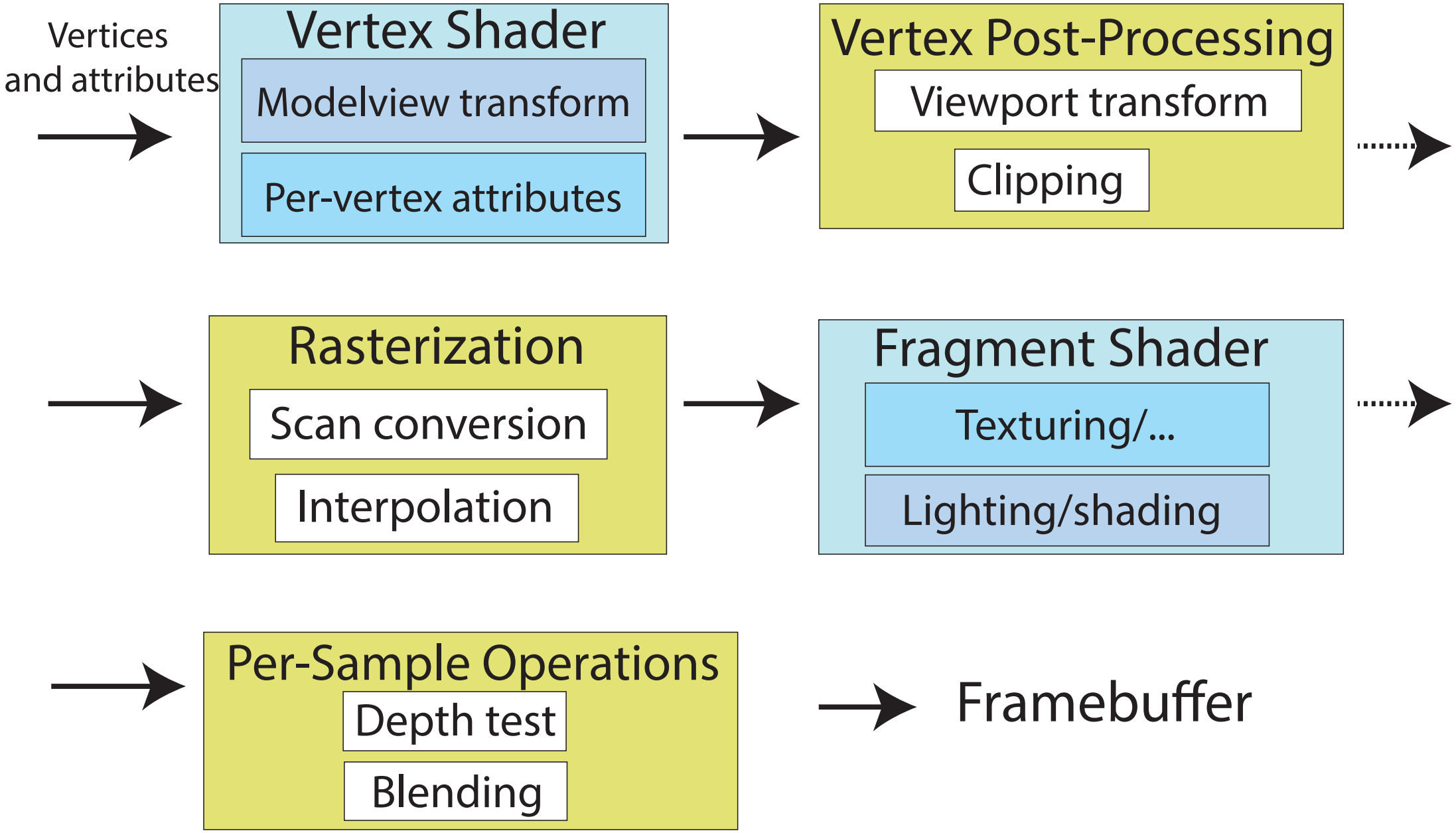
VIEWPORT MATRIX

- We need a transform that maps the lower left corner to $[-0.5,-0.5]^t$ and upper right corner to $[W-0.5, H-0.5]^t$

- The appropriate scale and shift can be done using the viewport matrix:

$$\begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} = \begin{bmatrix} W/2 & 0 & 0 & (W-1)/2 \\ 0 & H/2 & 0 & (H-1)/2 \\ 0 & 0 & 1/2 & 1/2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_n \\ y_n \\ z_n \\ 1 \end{bmatrix}$$

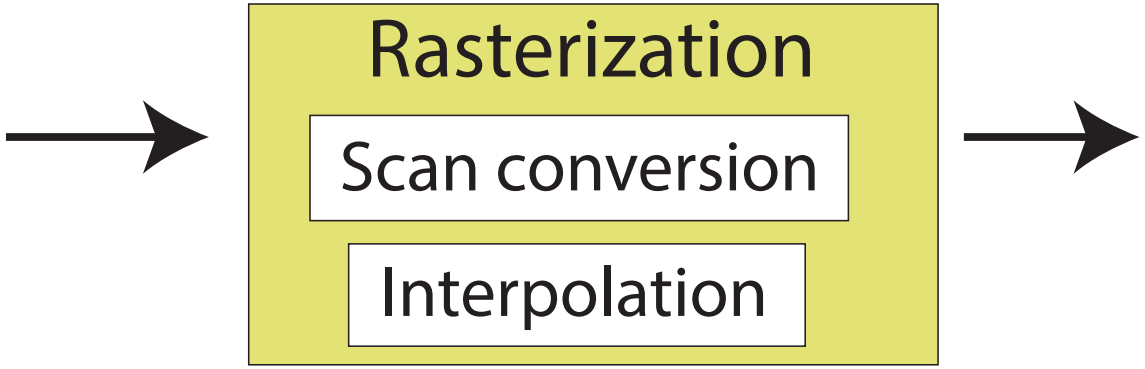
THE RENDERING PIPELINE



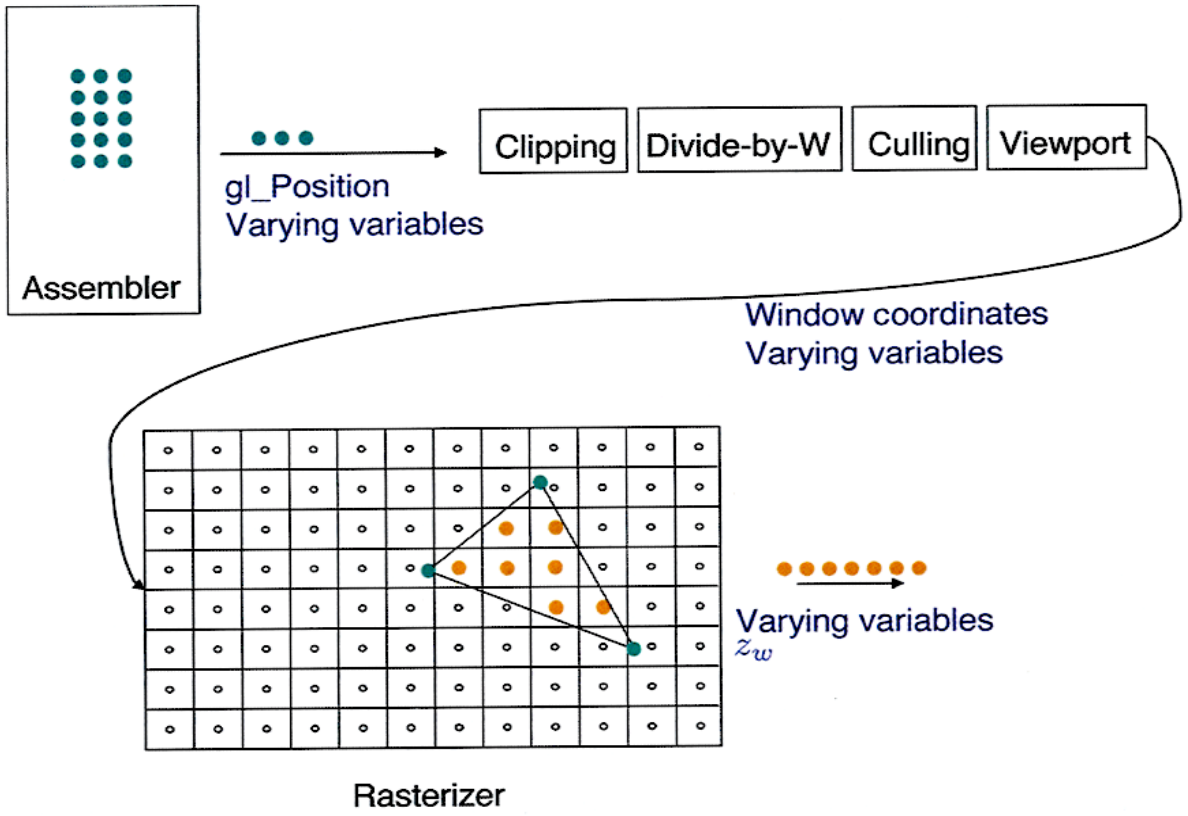
RASTERIZATION

- This is part of the fixed function pipeline

- Input: all polygons are clipped
- Output: fragments (with **varying variables** interpolated)



PATH FROM VERTEX TO PIXEL



SHAPES - CURVES/SURFACES

- Mathematical representations:
  - Explicit functions
  - Parametric functions
  - Implicit functions

SHAPES: EXPLICIT FUNCTIONS

- Curves:
  - y is a function of x:
  - Only works in 2D

$$y := \sin(x)$$

- Surfaces:
  - z is a function of x and y:
  - Cannot define arbitrary shapes in 3D

$$z := \sin(x) + \cos(y)$$

SHAPES: PARAMETRIC FUNCTIONS

- Curves:
  - 2D: x and y are functions of a parameter value t
  - 3D: x, y, and z are functions of a parameter value t

$$C(t) := \begin{pmatrix} \cos(t) \\ \sin(t) \\ t \end{pmatrix}$$

SHAPES: PARAMETRIC FUNCTIONS

- Surfaces:
  - Surface S is defined as a function of parameter values s, t
  - Names of parameters can be different to match intuition:

$$S(\phi,\theta) := \begin{pmatrix} \cos(\phi)\cos(\theta) \\ \sin(\phi)\cos(\theta) \\ \sin(\theta) \end{pmatrix}$$

SHAPES: IMPLICIT

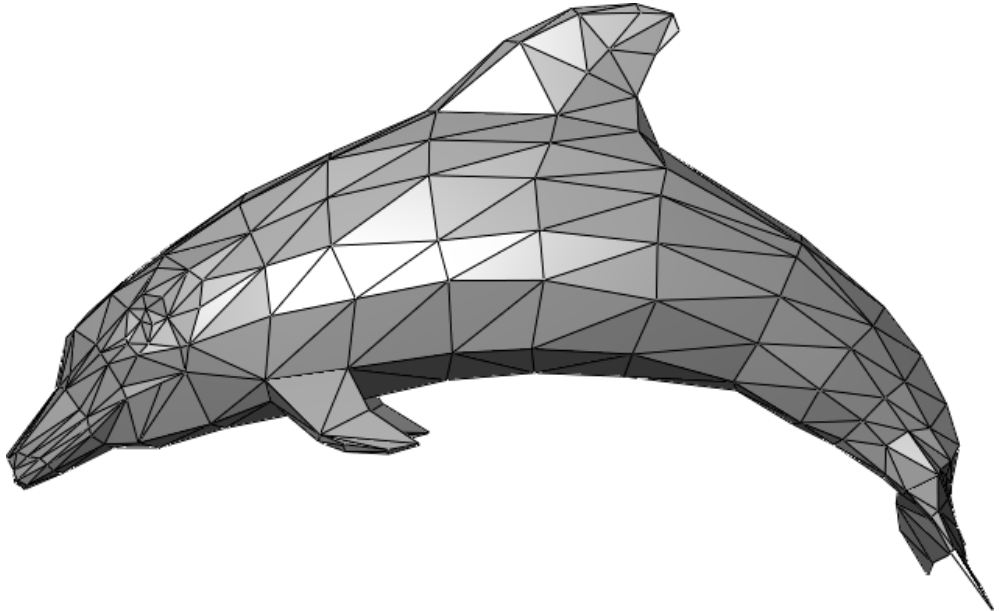
- Surface (3D) or Curve (2D) defined by zero set (roots) of function
  - E.g:

$$S(x, y, z) : x^2 + y^2 + z^2 - 1 = 0$$

POLYGONS

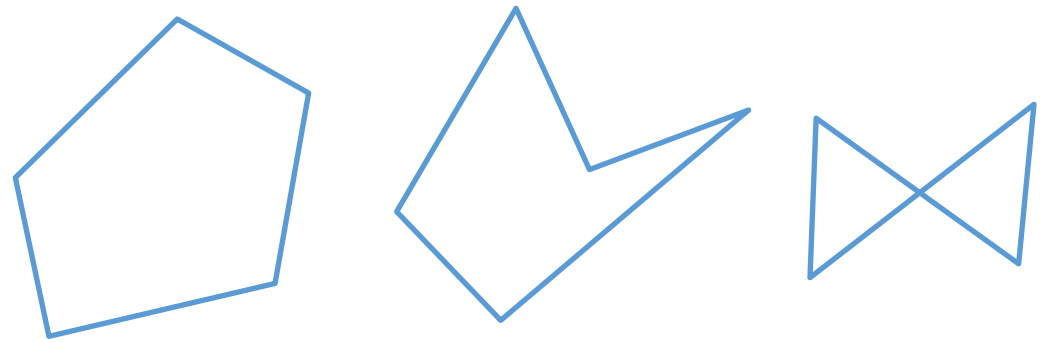
Interactive graphics uses Polygons

- Can represent any surface *with arbitrary accuracy*
  - *Splines, mathematical functions, ...*
- simple, regular rendering algorithms
  - *embed well in hardware*



POLYGONS

- Basic Types

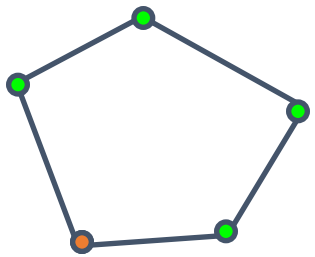


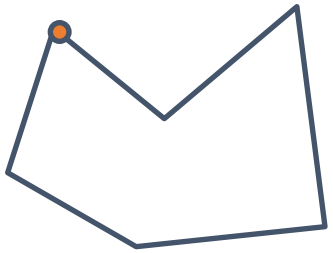
simple convex | **simple concave** | **non-simple (self-intersection)**

FROM POLYGONS TO TRIANGLES

- why? triangles are always planar, always convex

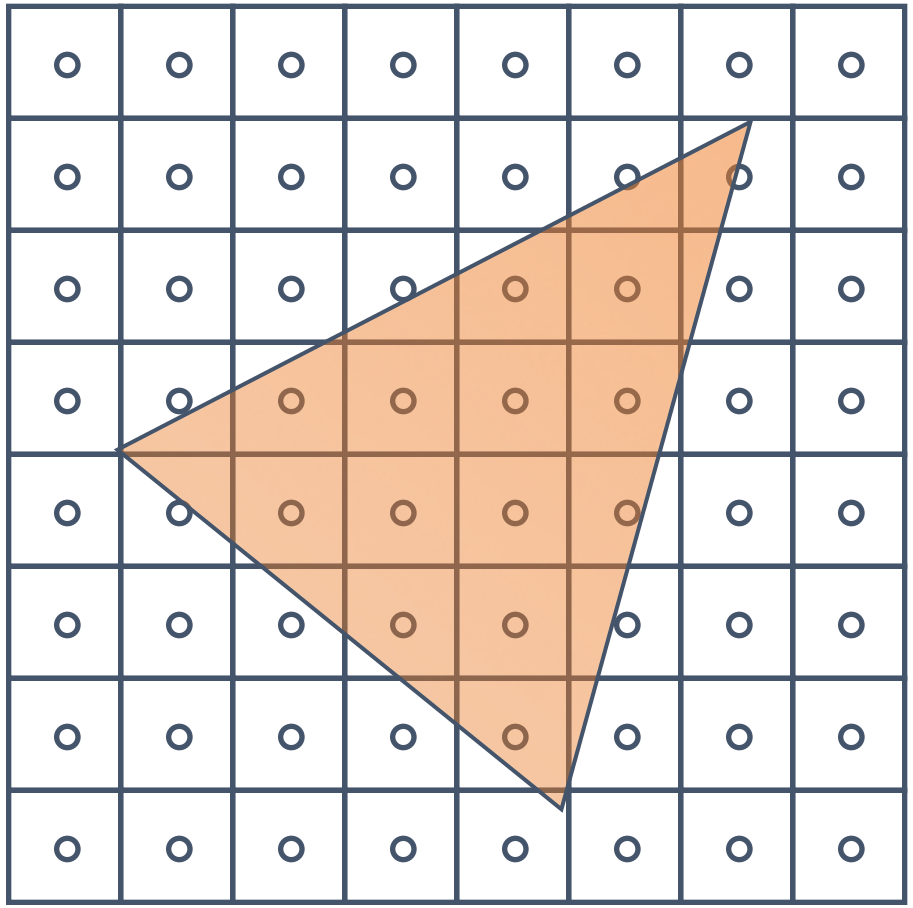
- simple convex polygons
  - trivial to break into triangles
- concave or non-simple polygons
  - more effort to break into triangles



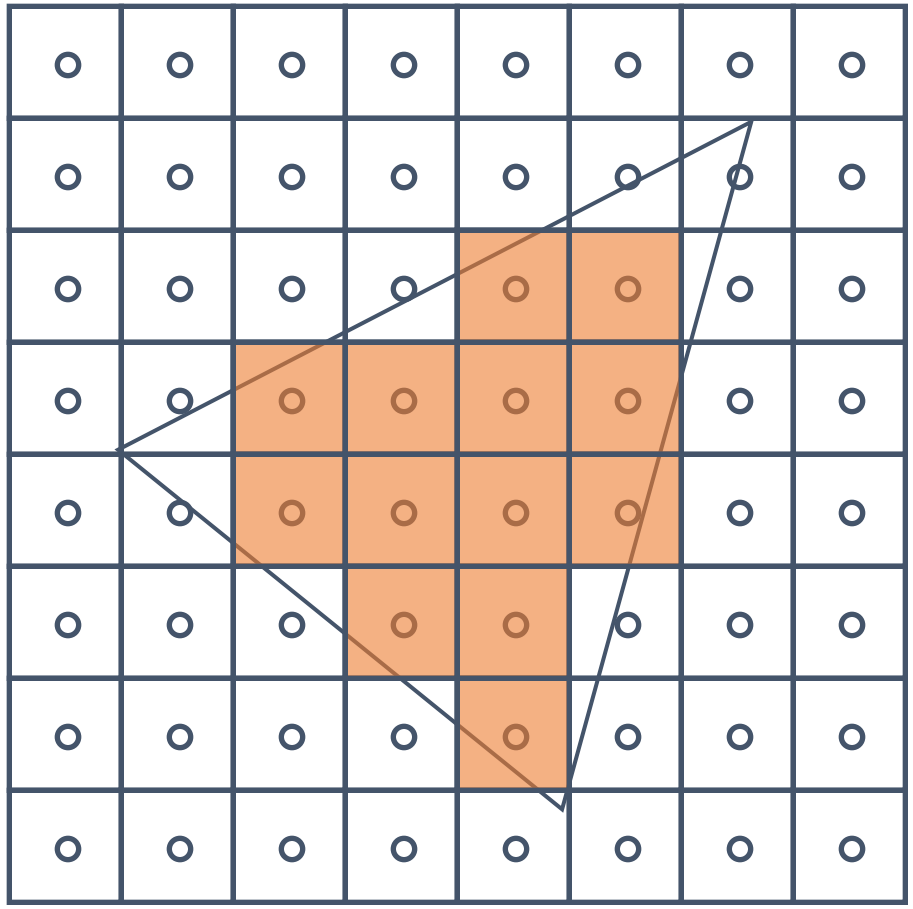


WHAT IS SCAN CONVERSION? (A.K.A. RASTERIZATION)

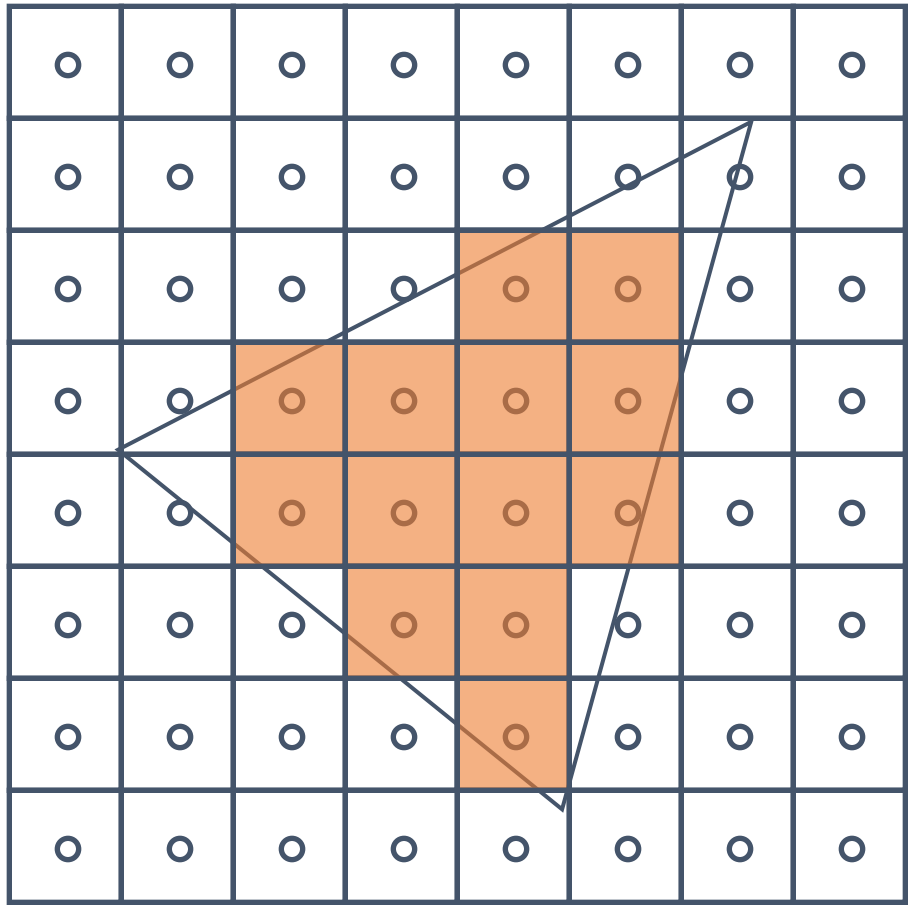
- screen is discrete



•one possible scan conversion

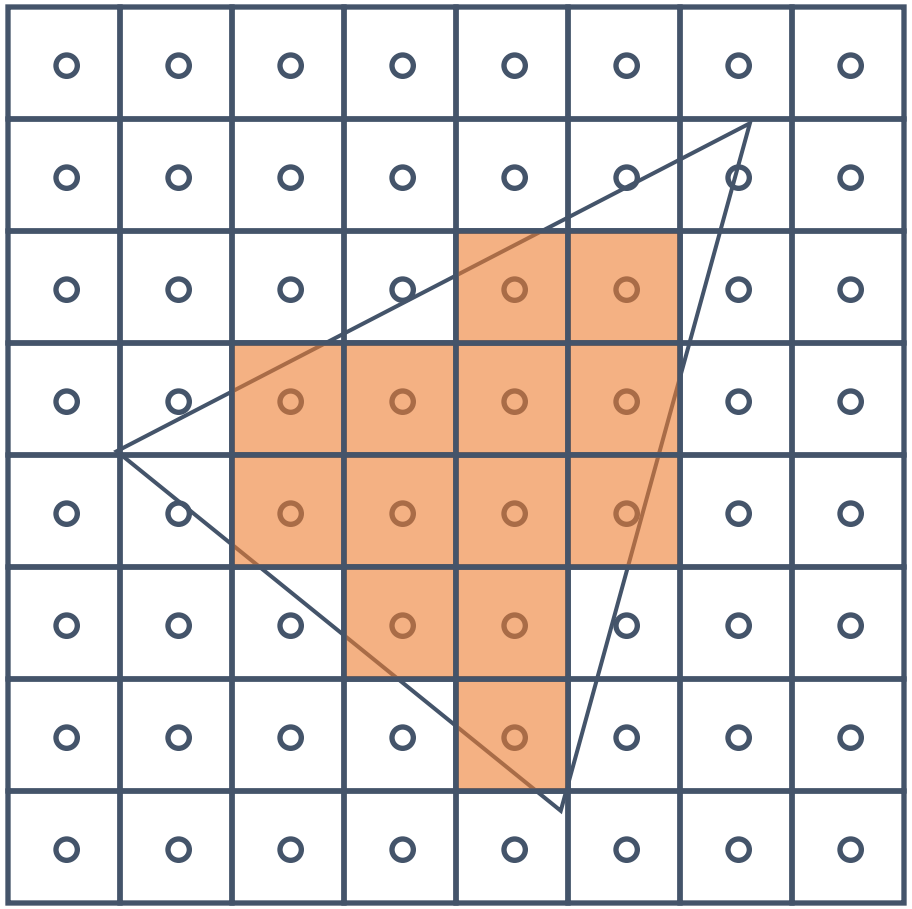


HOW TO CHECK IF A PIXEL IS INSIDE?



HOW TO CHECK IF A PIXEL IS INSIDE?

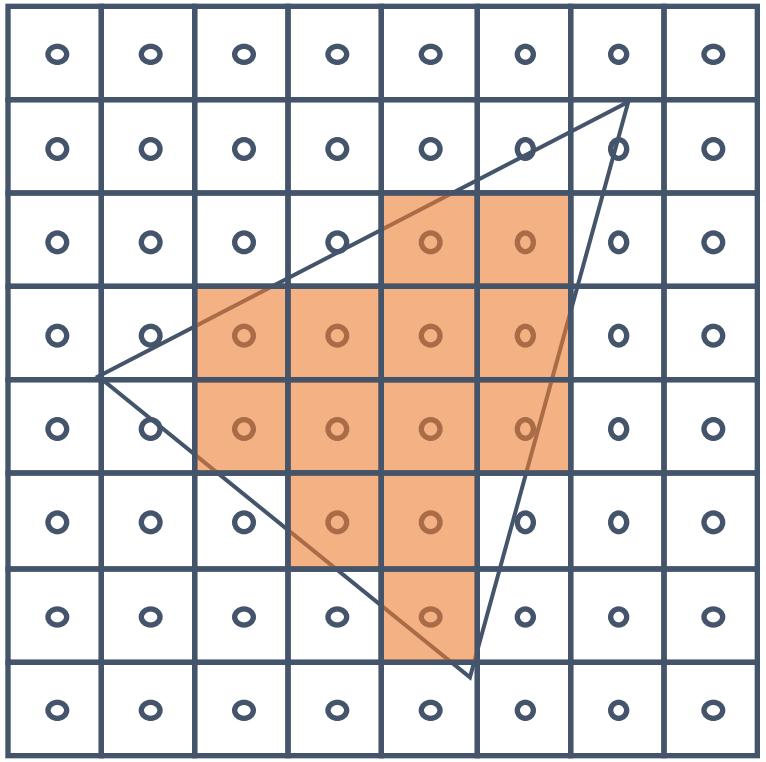
- Use implicit line equation:
  - $Ax + By + C = 0$
- How to find A,B,C?
- Orientation?



HOW TO CHECK IF A PIXEL IS INSIDE?

A point is inside ⇔

$$A_i x + B_i y + C > 0, i = 1, \dots, 3$$



HOW TO TREAT BOUNDARY?

HOW TO TREAT BOUNDARY?

- If two triangles share an edge, scan conversion should be consistent
  - No pixel drawn twice
  - No gaps

- Strategy ideas?

BONUS 2

- With the algorithm above, what's the minimum number of pixels that will be drawn for the following triangle:

$$P_1 = (0.5, 0.5)$$
$$P_2 = (99.5, 100.5)$$
$$P_3 = (-98.5, 100.5)$$

- Proof!
- 5 first solutions accepted; +5% to final grade

NAÏVE SCAN CONVERSION

- Testing every pixel is suboptimal
- Better ideas?

SCANLINE IDEA

- Basic structure of code:
  - Setup: compute edge equations, bounding box
  - (Outer loop) For each scanline in bounding box…
  - (Inner loop) …check each pixel on scanline, evaluating edge equations and drawing the pixel if all three are positive

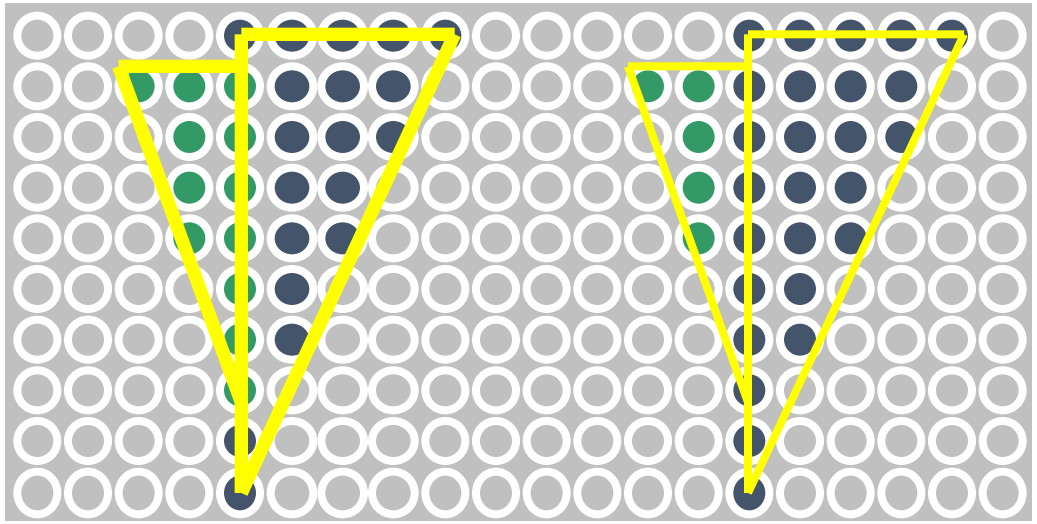
SCANLINE: CODE

```
findBoundingBox(xmin, xmax, ymin, ymax);
setupEdges (a0,b0,c0,a1,b1,c1,a2,b2,c2);

for (int y = yMin; y <= yMax; y++) {
  for (int x = xMin; x <= xMax; x++) {
    float e0 = a0*x + b0*y + c0;
    float e1 = a1*x + b1*y + c1;
    float e2 = a2*x + b2*y + c2;
    if (e0 > 0 && e1 > 0 && e2 > 0)
        Image[x][y] = TriangleColor;
  }
}
```

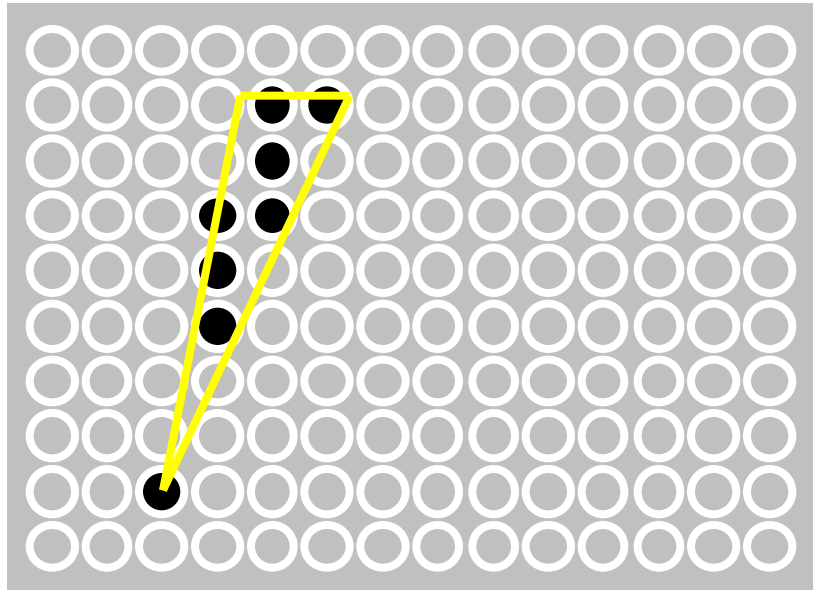
TRIANGLE RASTERIZATION ISSUES

- Exactly which pixels should be lit?
- A: Those pixels inside the triangle edges
- What about pixels exactly on the edge?

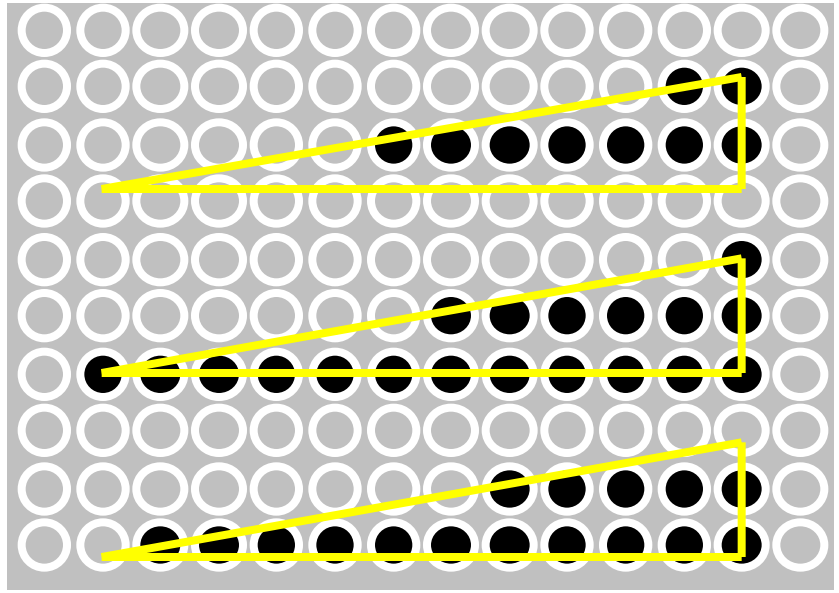


TRIANGLE RASTERIZATION ISSUES

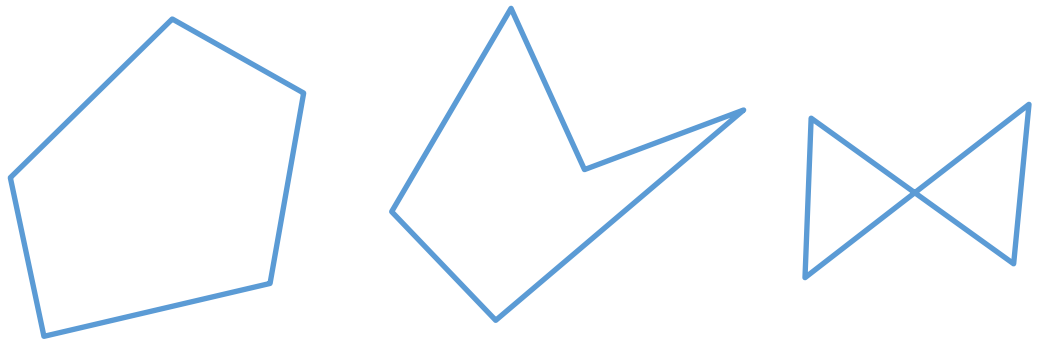
Sliver



- Moving Slivers



HOW TO TEST IF A POINT IS IN A POLYGON?



simple
convex

simple
concave

non-simple
(self-intersection)