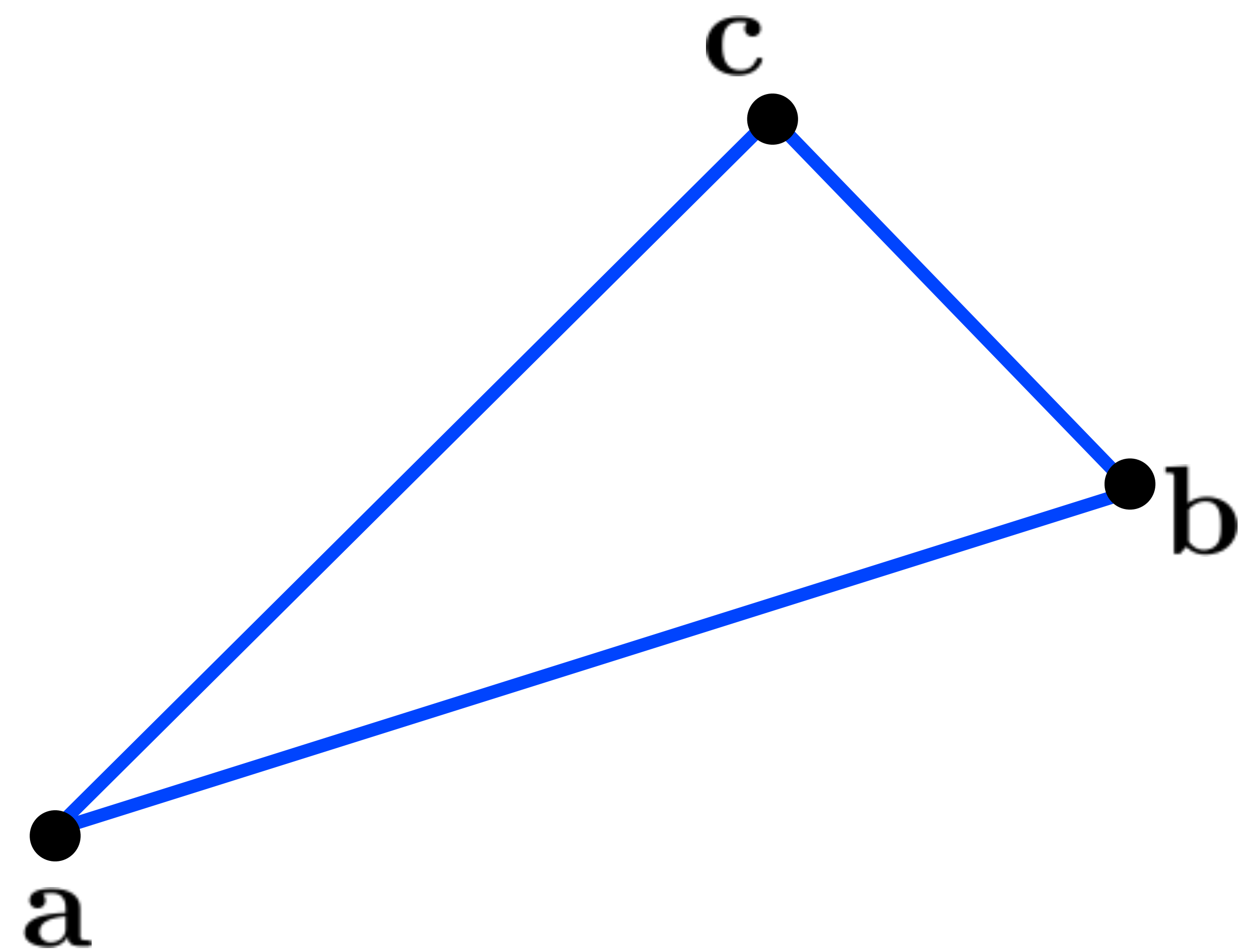
CS130 : Computer Graphics

Rasterizing Triangles and Graphics Pipeline (cont.)

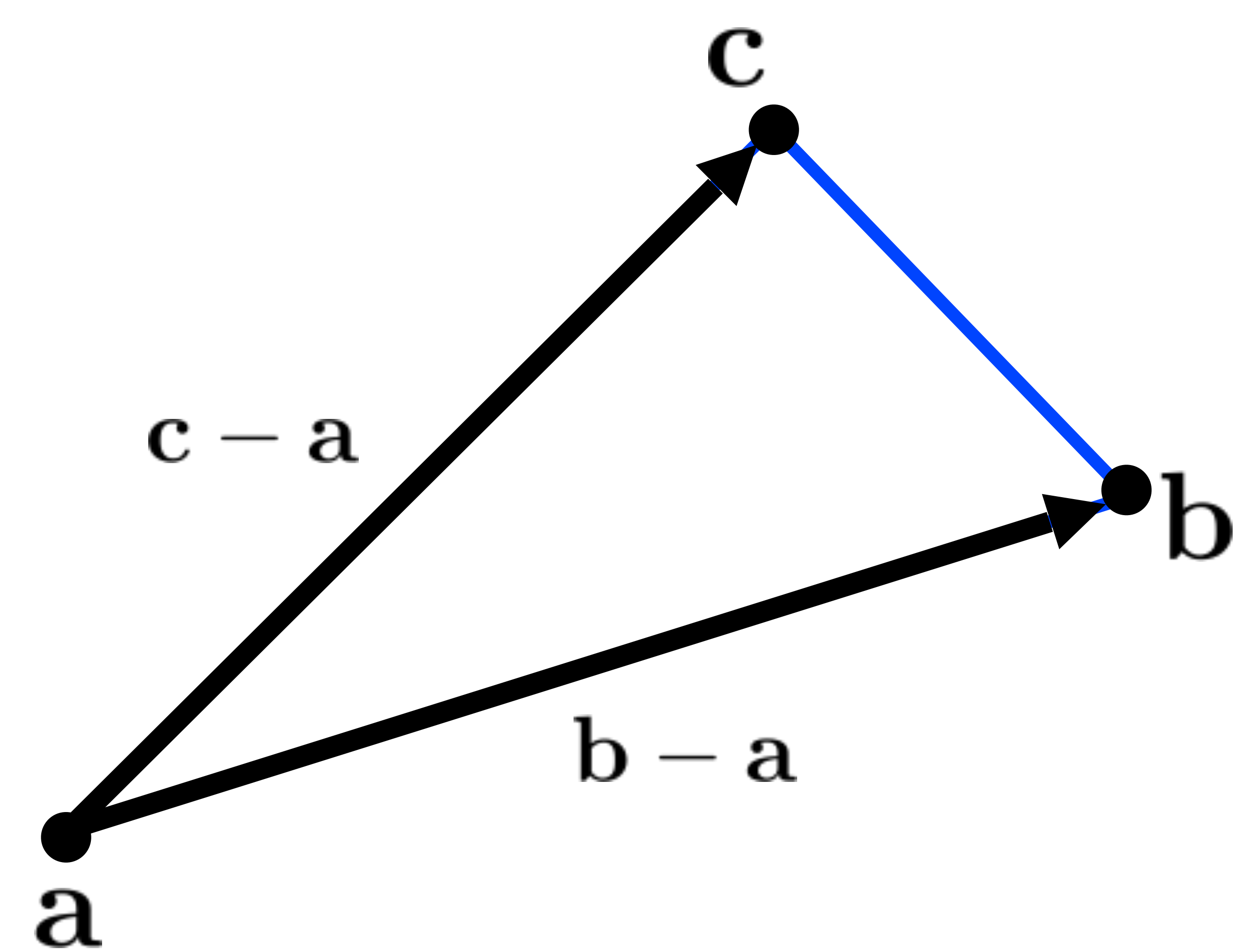
Tamar Shinar
Computer Science & Engineering
UC Riverside

Triangles

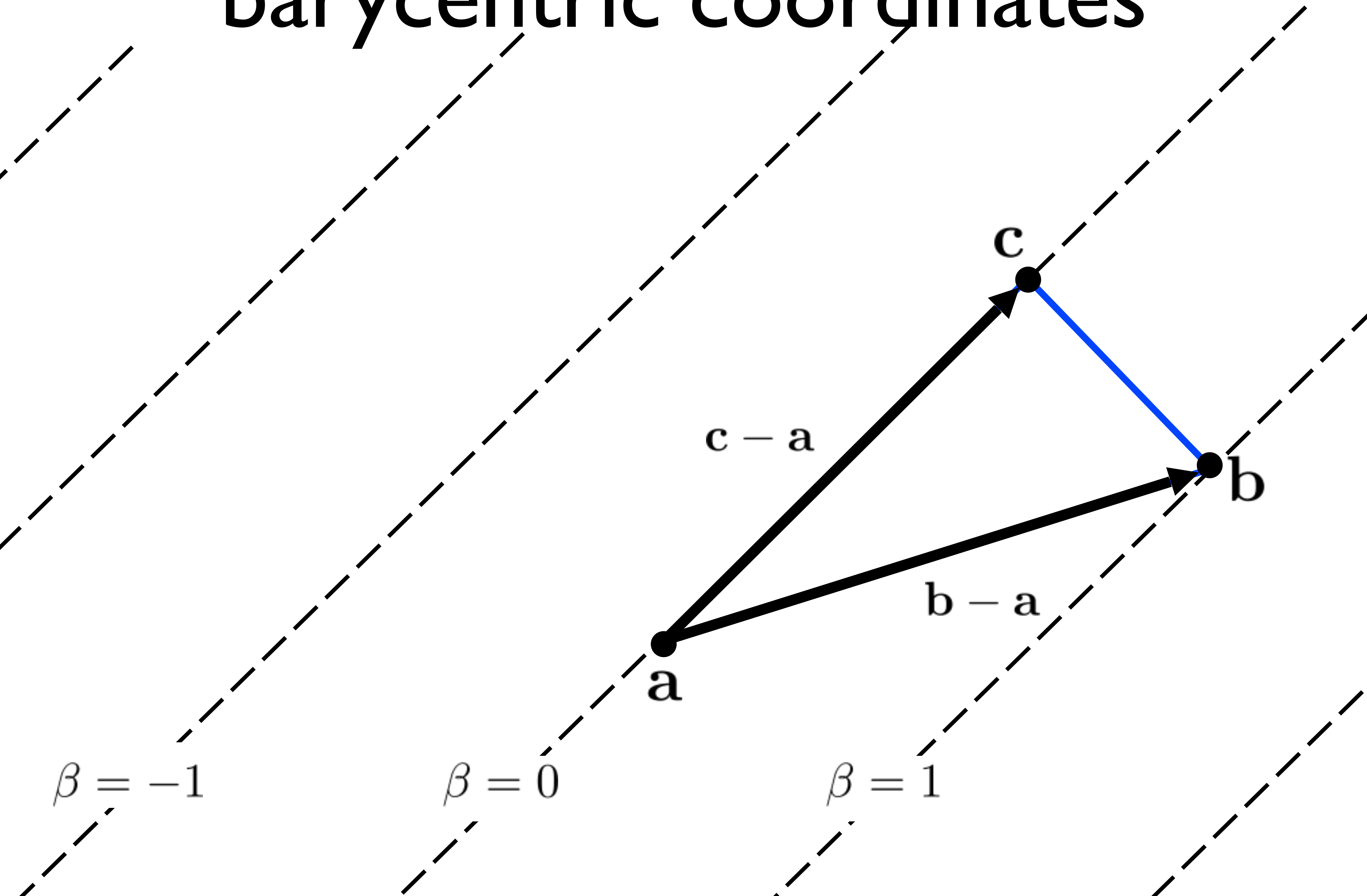
barycentric coordinates



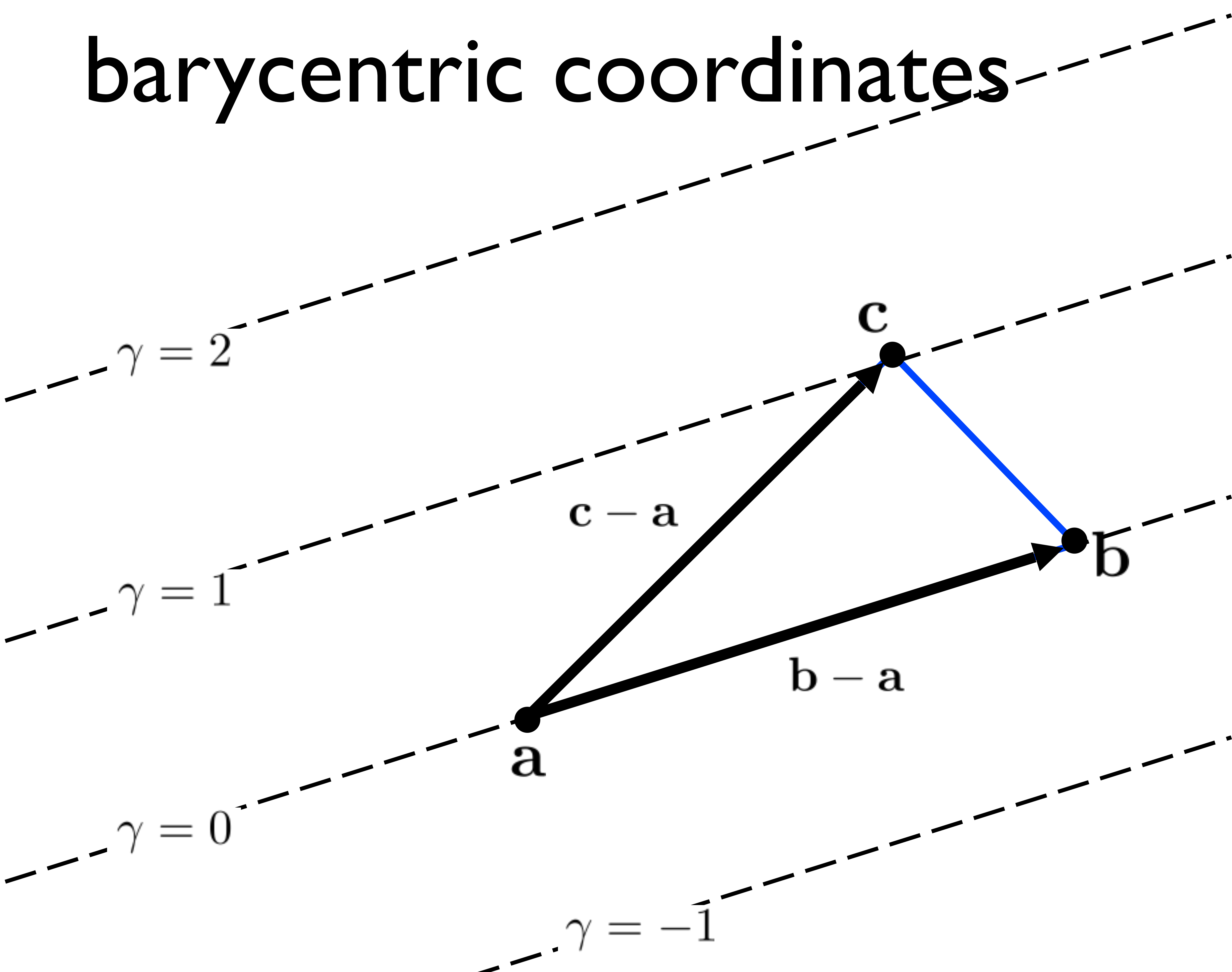
barycentric coordinates



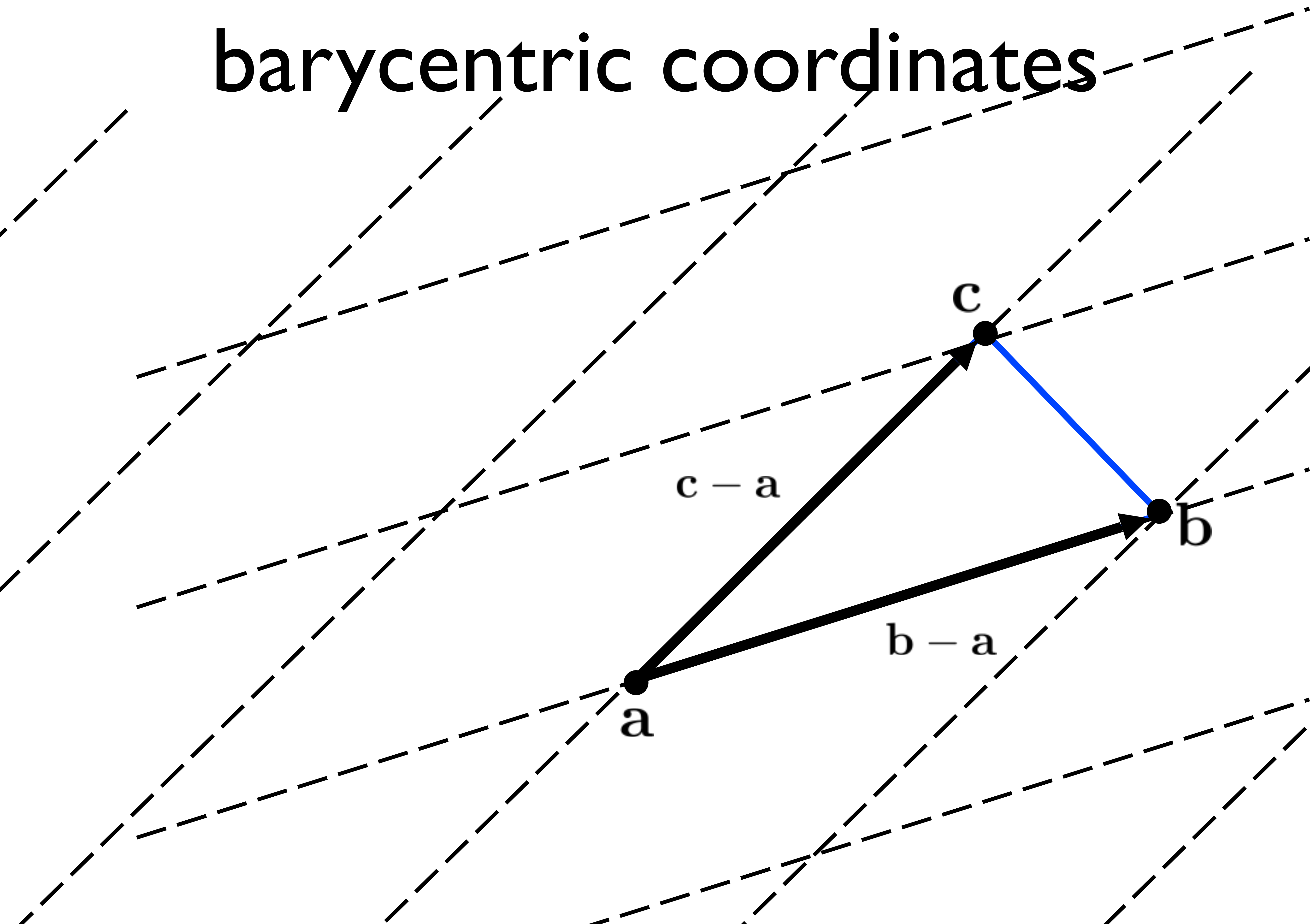
barycentric coordinates



barycentric coordinates

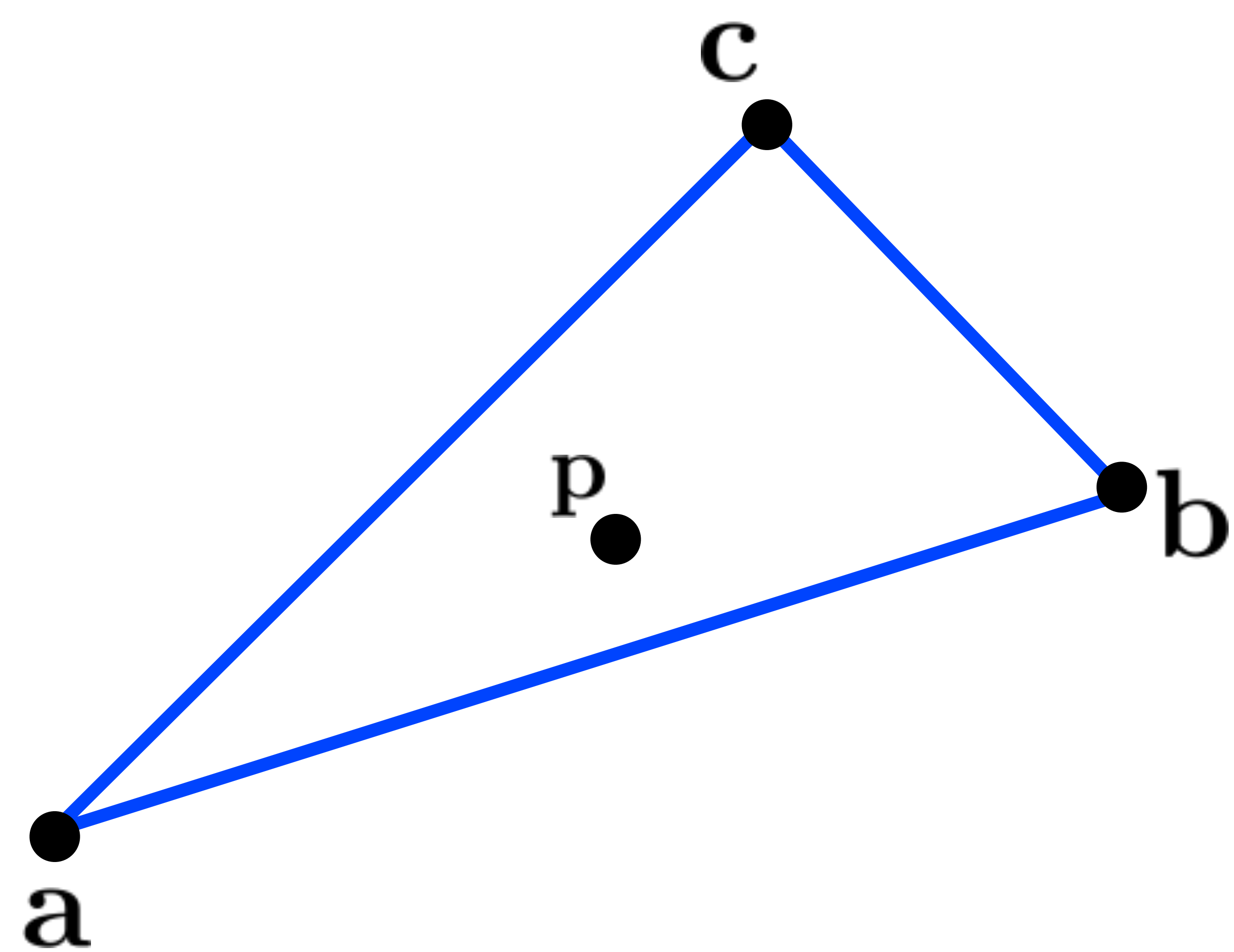


barycentric coordinates



barycentric coordinates

$$\mathbf{p} = \alpha\mathbf{a} + \beta\mathbf{b} + \gamma\mathbf{c}$$

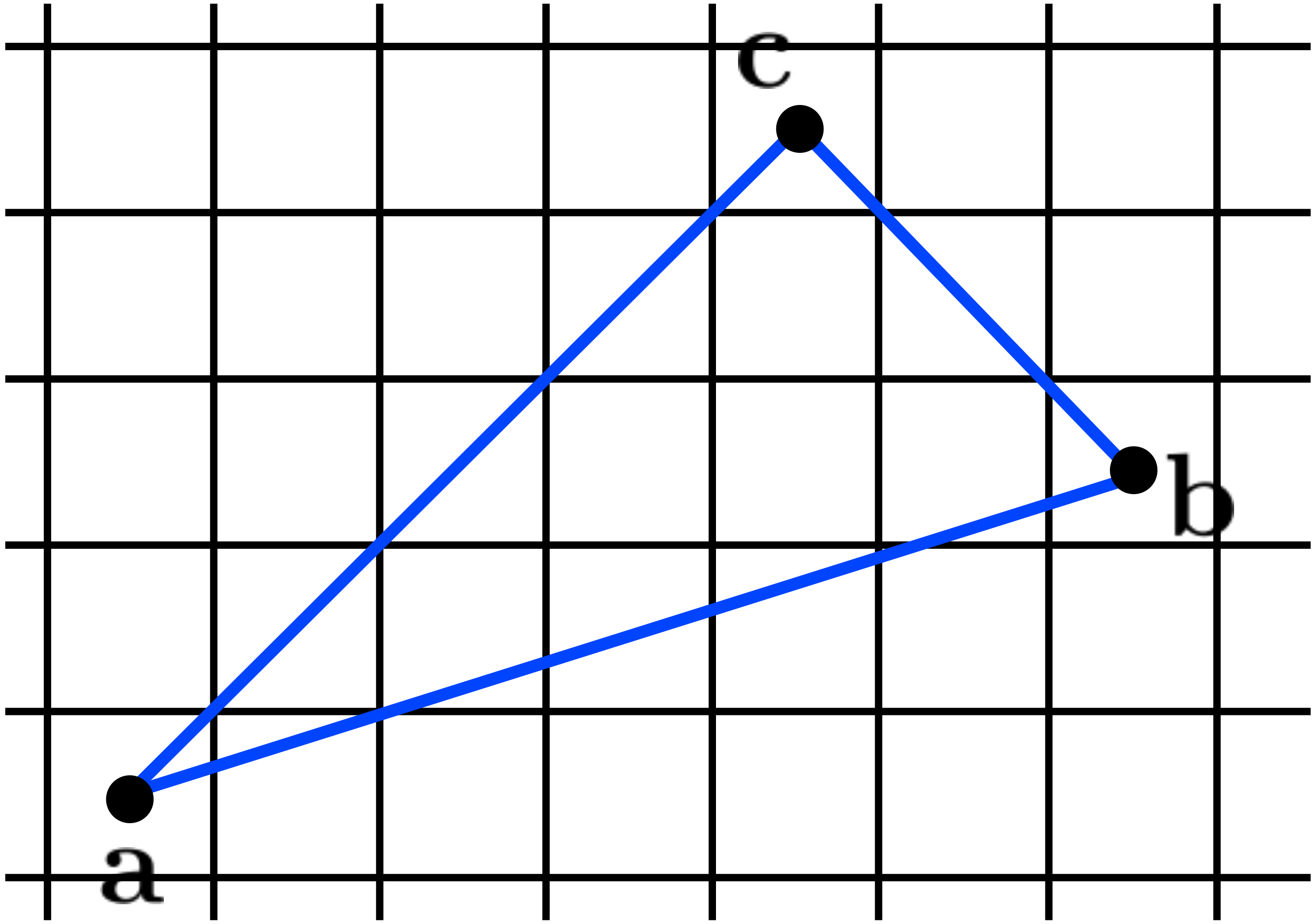


What are (α, β, γ) ?

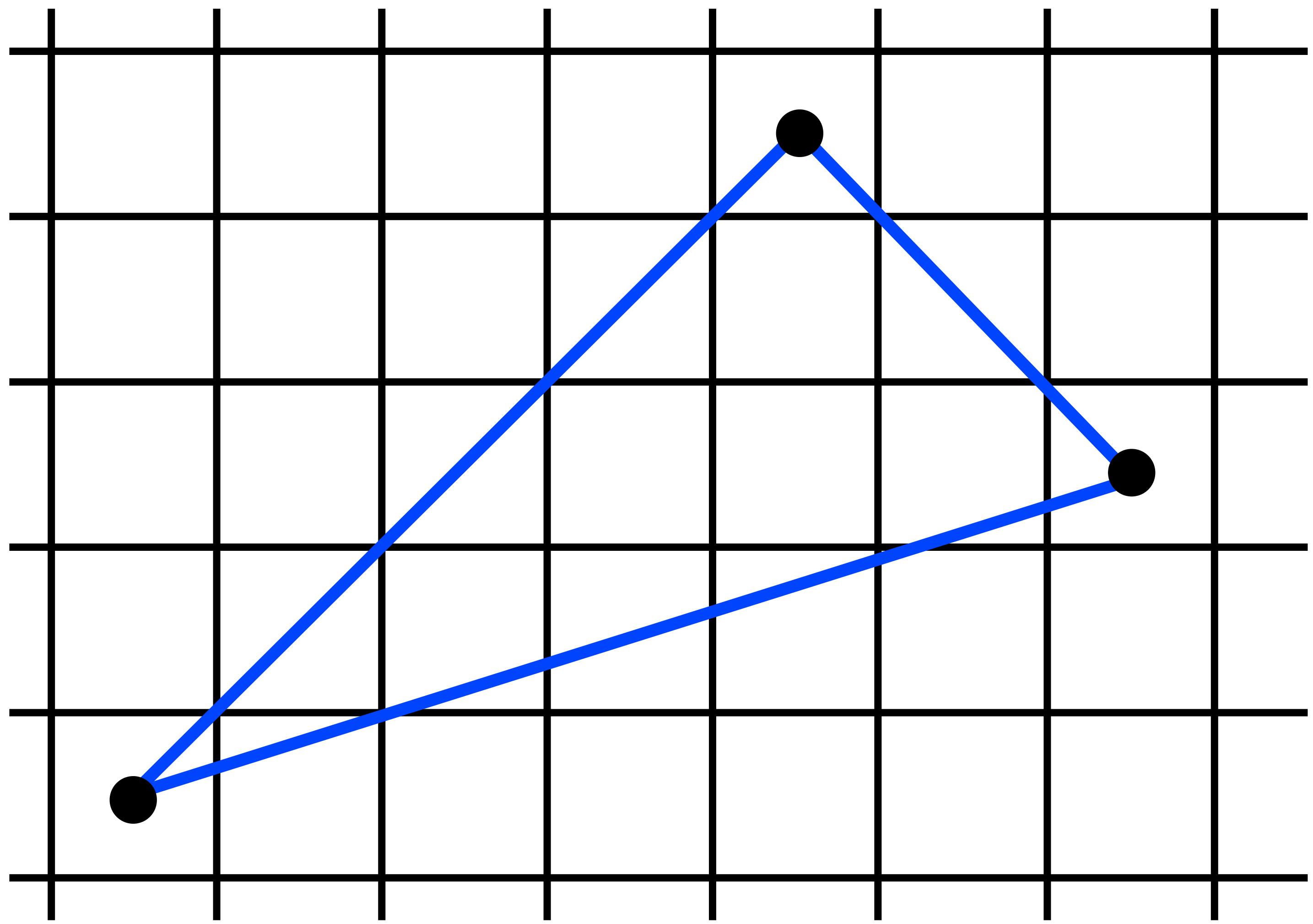
<whiteboard>

Triangle rasterization

Which pixels should be used to approximate a triangle?

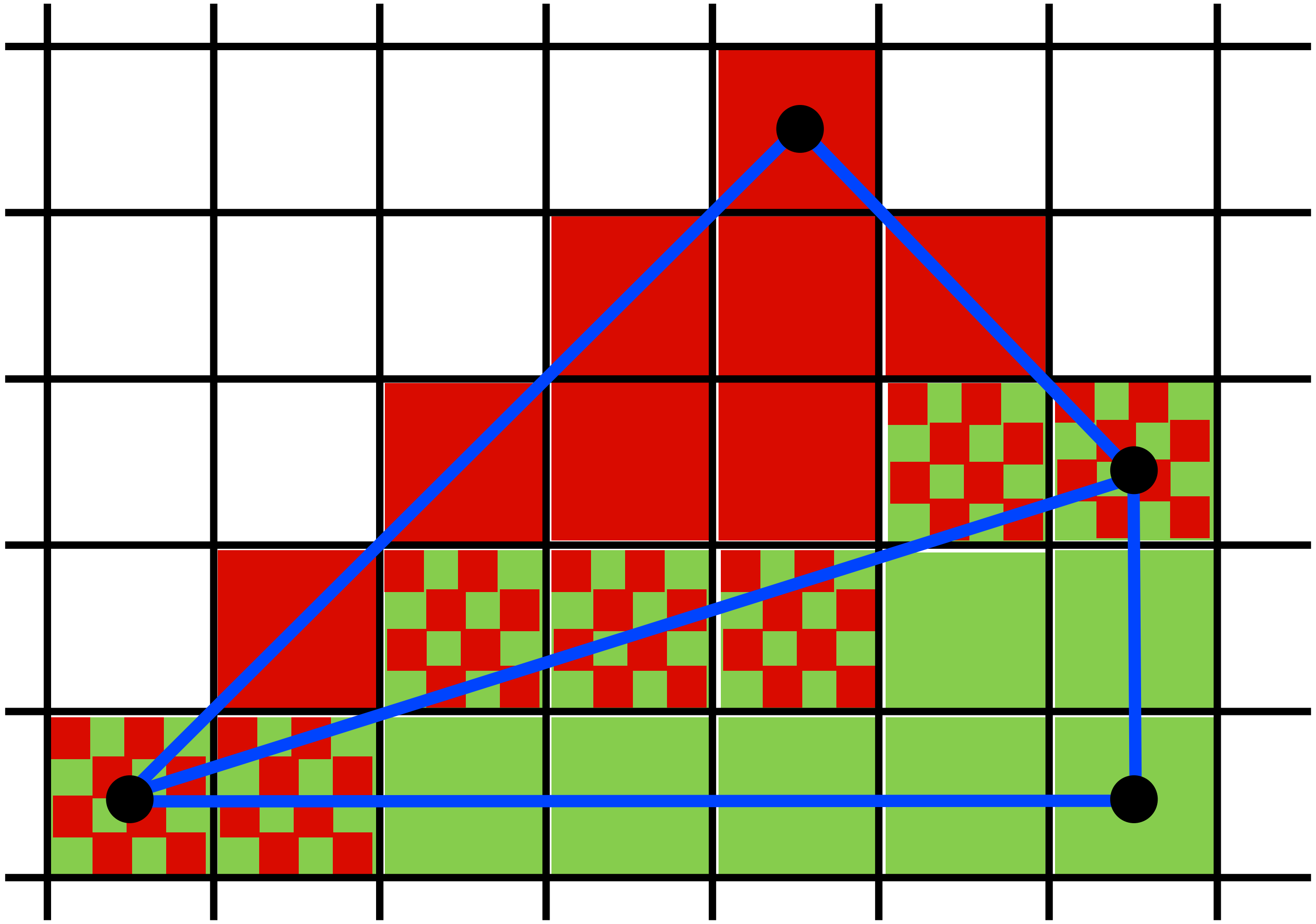


Triangle rasterization issues



Which pixels should be used to approximate a triangle?

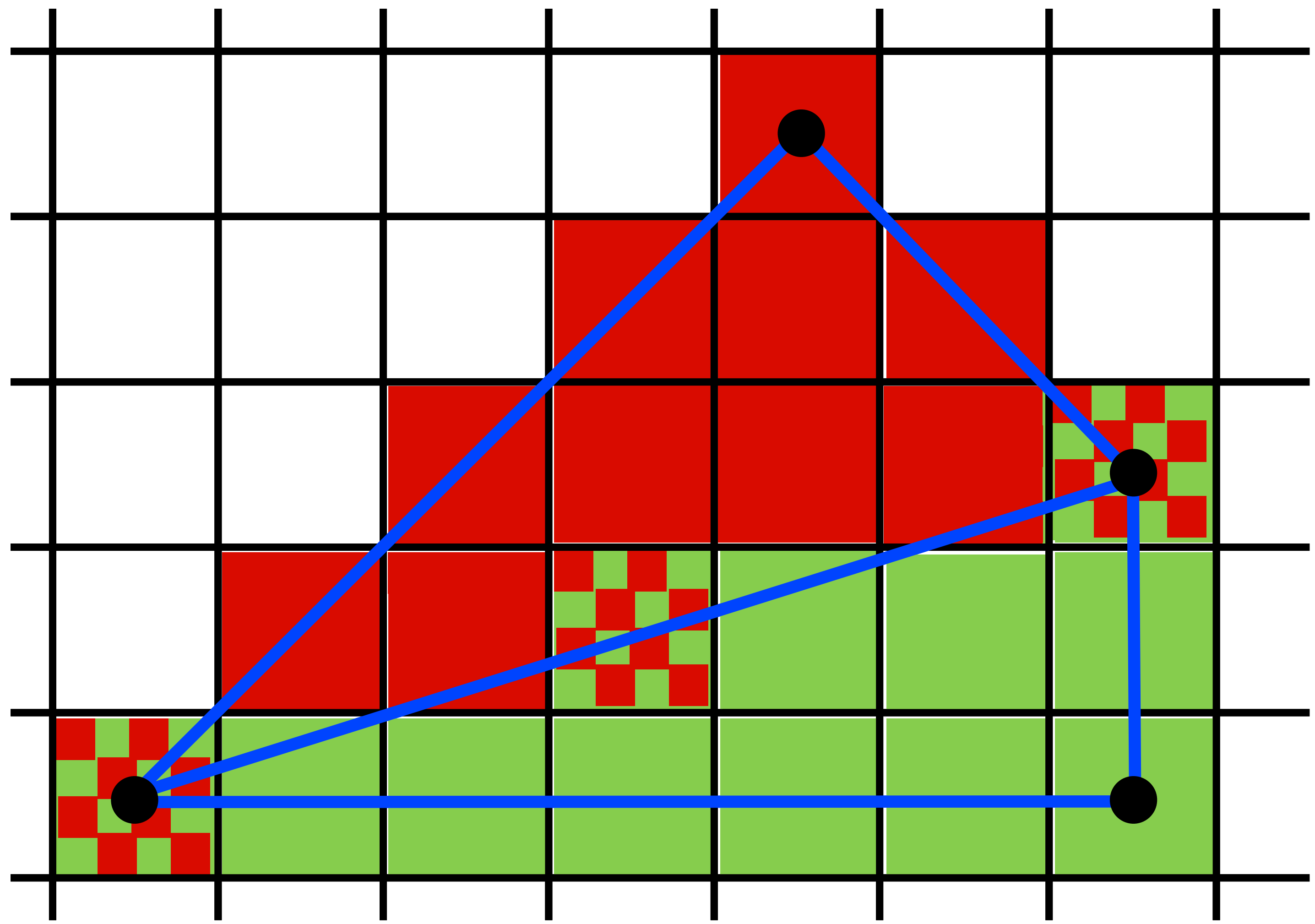
Which should fill in shared edge?



Which pixels should be used to approximate a triangle?

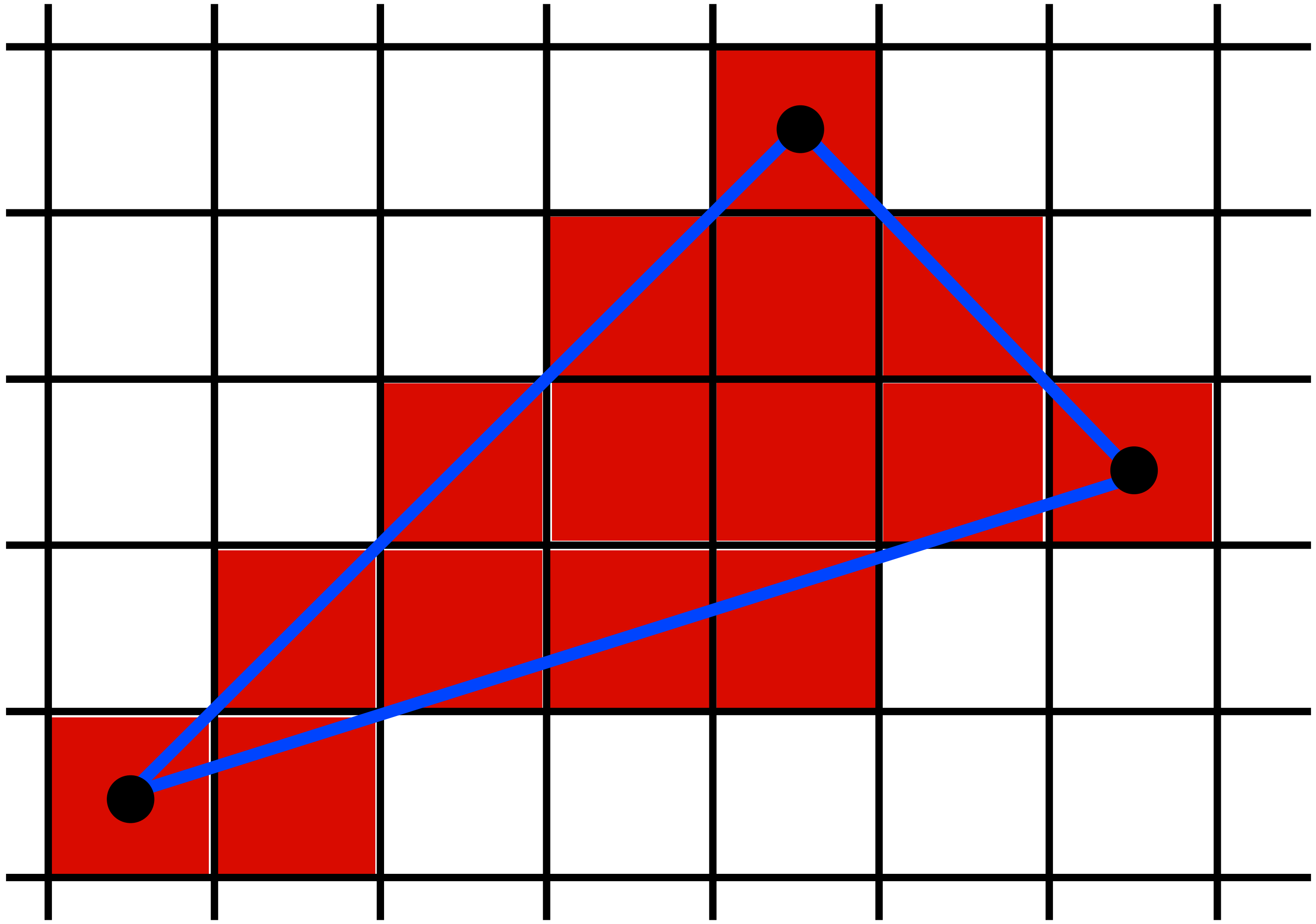
Which should fill in shared edge?

- triangle that contains pixel center
- still have some ties!
- neither? both?
- want a <u>unique</u> assignment



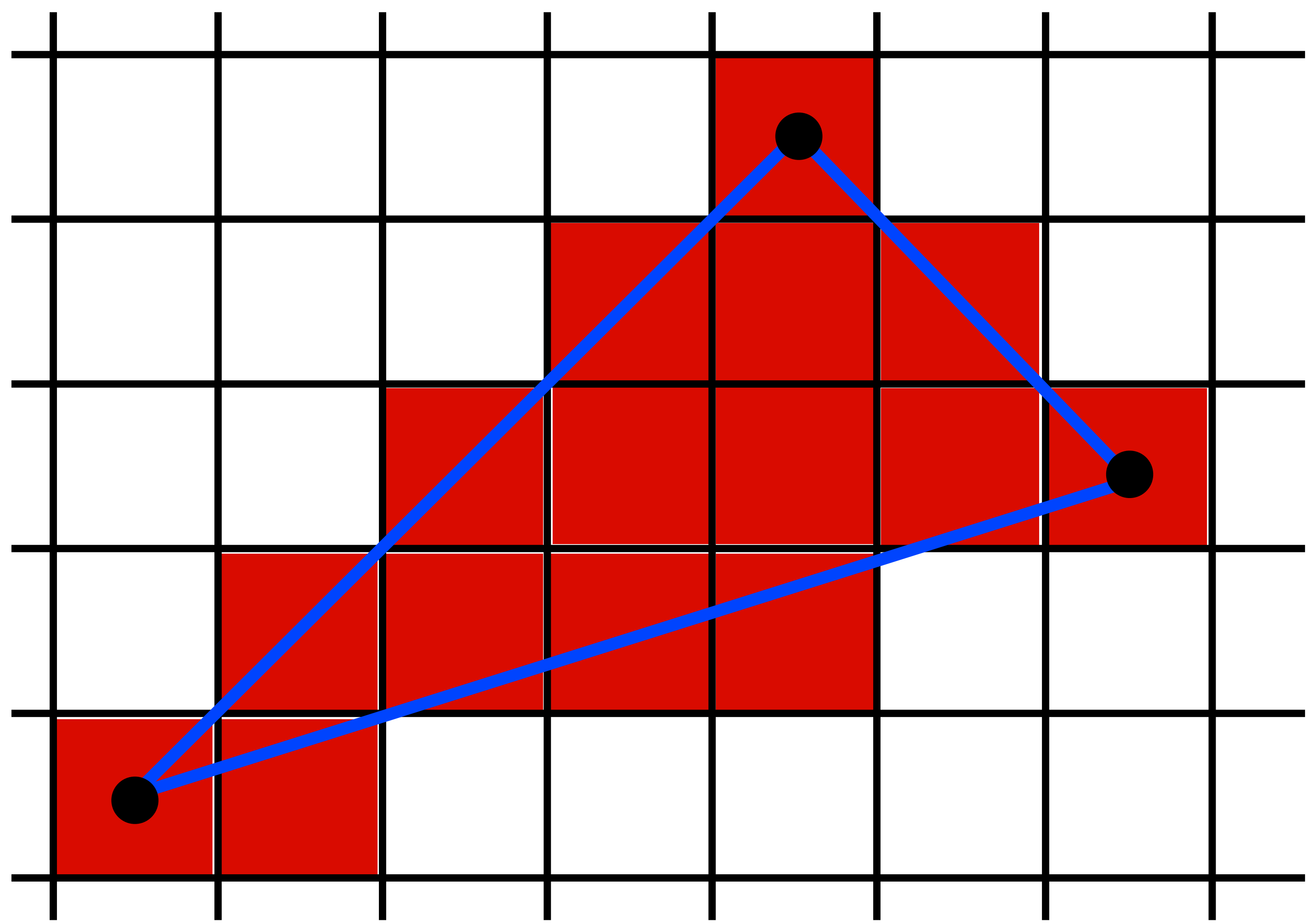
Which pixels should be used to approximate a triangle?

Use Midpoint Algorithm for edges and fill in?

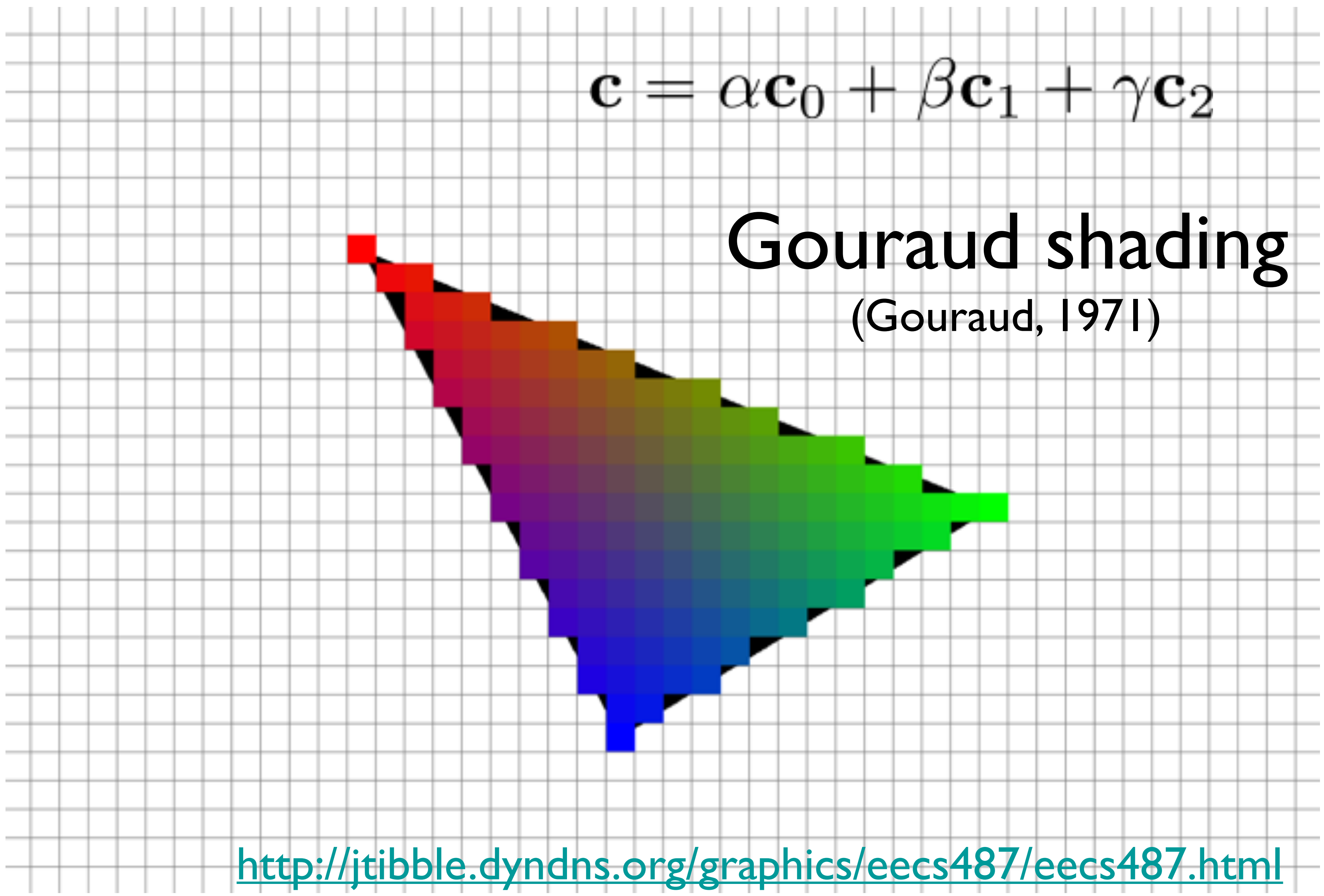


Which pixels should be used to approximate a triangle?

Use an approach based on **barycentric coordinates**

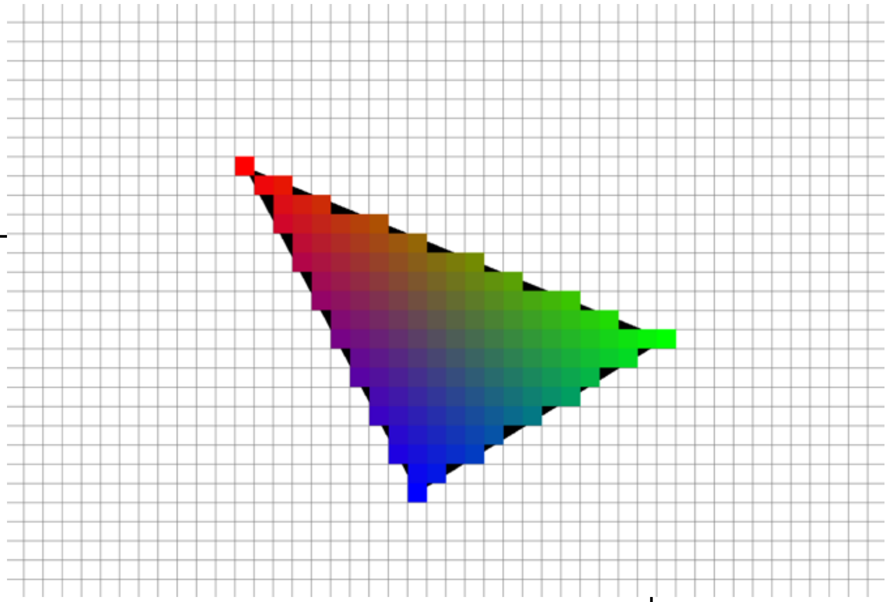


Advantage: we can easily interpolate attributes using barycentric coordinates



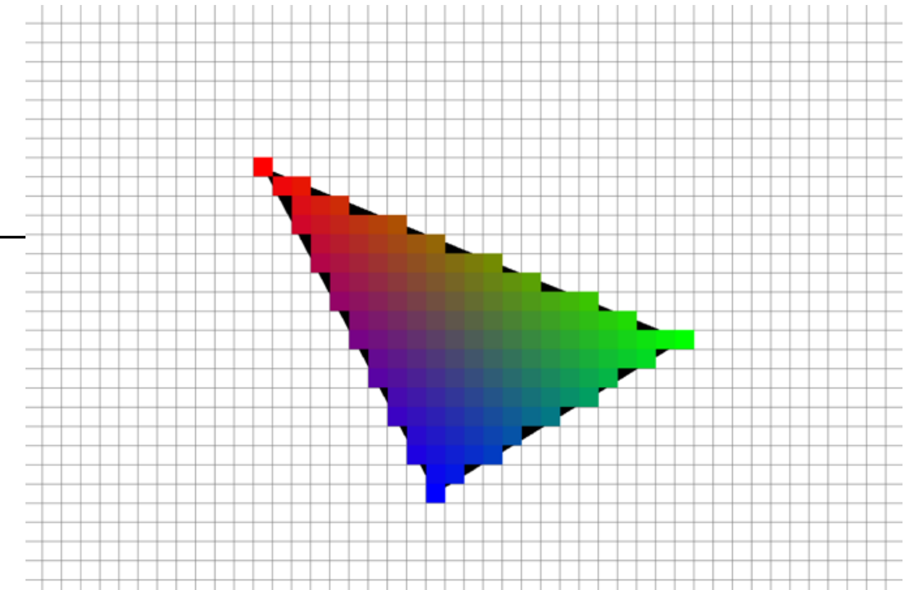
http://jtibble.dyndns.org/graphics/eecs487/eecs487.html

Triangle rasterization algorithm



for all x do
    for all y do
        compute (α, β, γ) for (x,y)
        if $(\alpha \in [0,1] \text{ and } \beta \in [0,1] \text{ and } \gamma \in [0,1])$ then
            $\mathbf{c} = \alpha\mathbf{c}_0 + \beta\mathbf{c}_1 + \gamma\mathbf{c}_2$
            drawpixel(x,y) with color c

Triangle rasterization algorithm

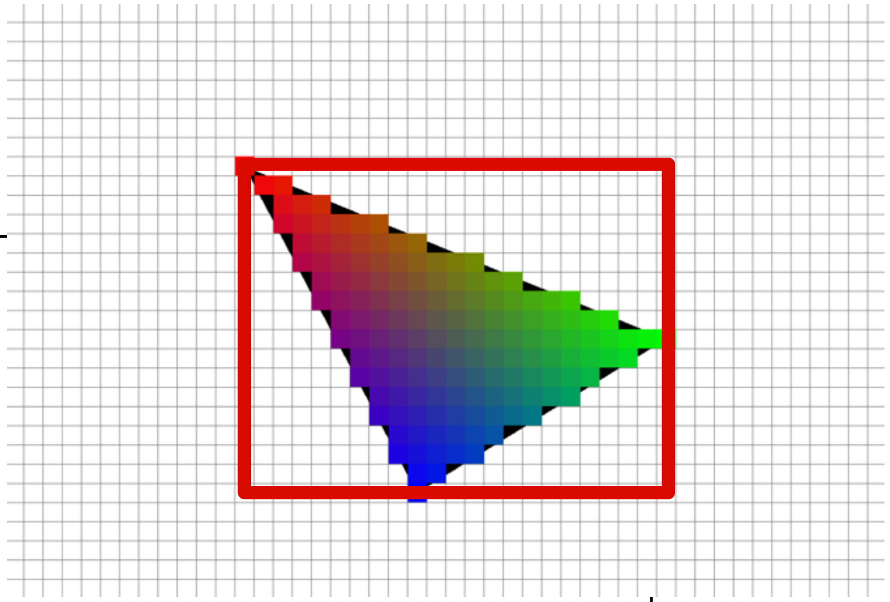


for all x do
    for all y do
        compute (α, β, γ) for (x,y)
        if $(\alpha \in [0,1]$ and $\beta \in [0,1]$ and $\gamma \in [0,1])$ then
            $\mathbf{c} = \alpha \mathbf{c}_0 + \beta \mathbf{c}_1 + \gamma \mathbf{c}_2$
            drawpixel(x,y) with color c

the rest of the algorithm is to make the steps in **red** more **efficient**

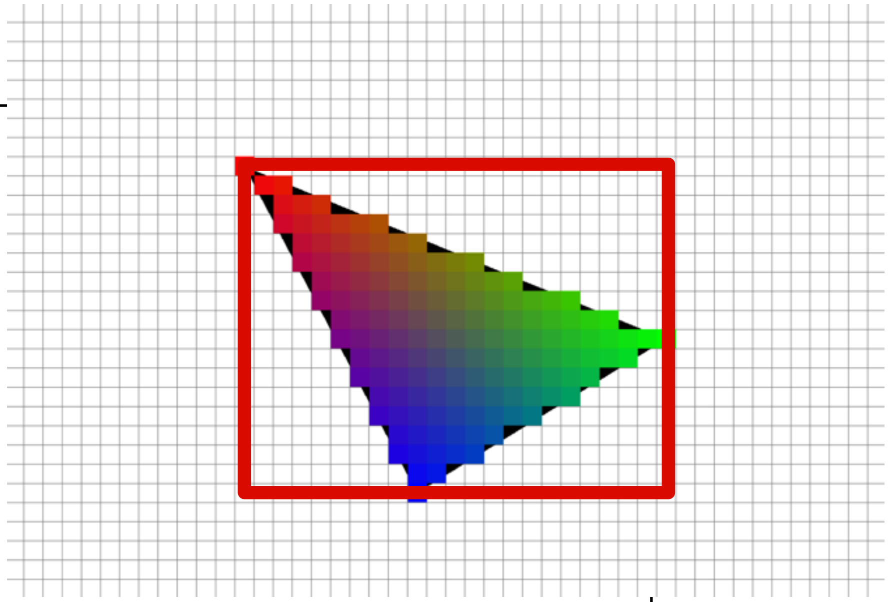
Triangle rasterization algorithm

use a bounding rectangle



```
for x in [x_min, x_max]
    for y in [y_min, y_max]
        compute (α, β, γ) for (x,y)
        if (α ∈ [0, 1] and β ∈ [0, 1] and γ ∈ [0, 1]) then
            c = αc0 + βc1 + γc2
            drawpixel(x,y) with color c
```

Triangle rasterization algorithm

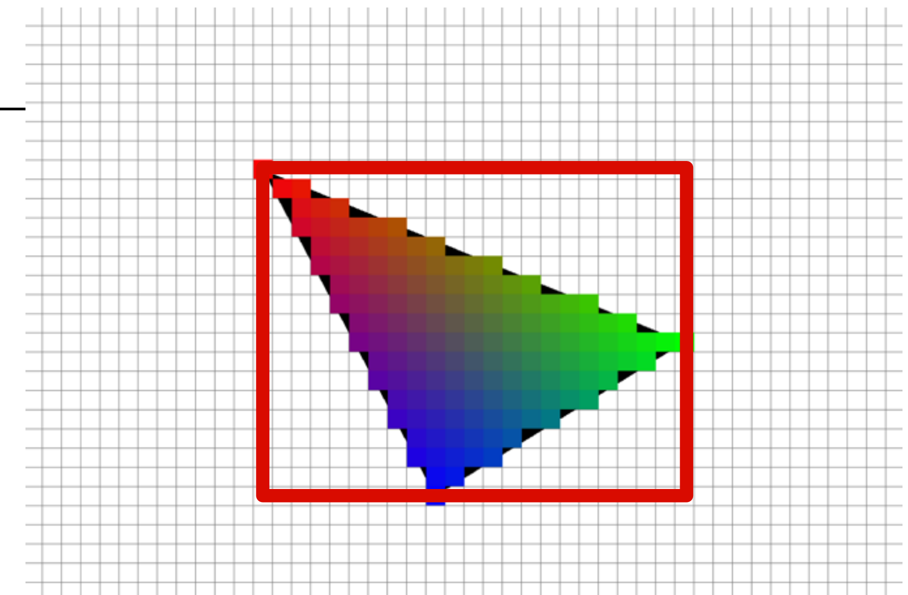


for x in [x_min, x_max]
    for y in [y_min, y_max]
        $\alpha = f_{bc}(x,y)/f_{bc}(x_a,y_a)$
        $\beta = f_{ca}(x,y)/f_{ca}(x_b,y_b)$
        $\gamma = f_{ab}(x,y)/f_{ab}(x_c,y_c)$
        if $(\alpha \in [0,1] \text{ and } \beta \in [0,1] \text{ and } \gamma \in [0,1])$ then
            $\mathbf{c} = \alpha\mathbf{c}_0 + \beta\mathbf{c}_1 + \gamma\mathbf{c}_2$
            drawpixel(x,y) with color c

<whiteboard>

Triangle rasterization algorithm

Optimizations?



for x in [x_min, x_max]

    for y in [y_min, y_max]

$$\alpha = f_{bc}(x,y)/f_{bc}(x_a,y_a)$$
$$\beta = f_{ca}(x,y)/f_{ca}(x_b,y_b)$$
$$\gamma = f_{ab}(x,y)/f_{ab}(x_c,y_c)$$

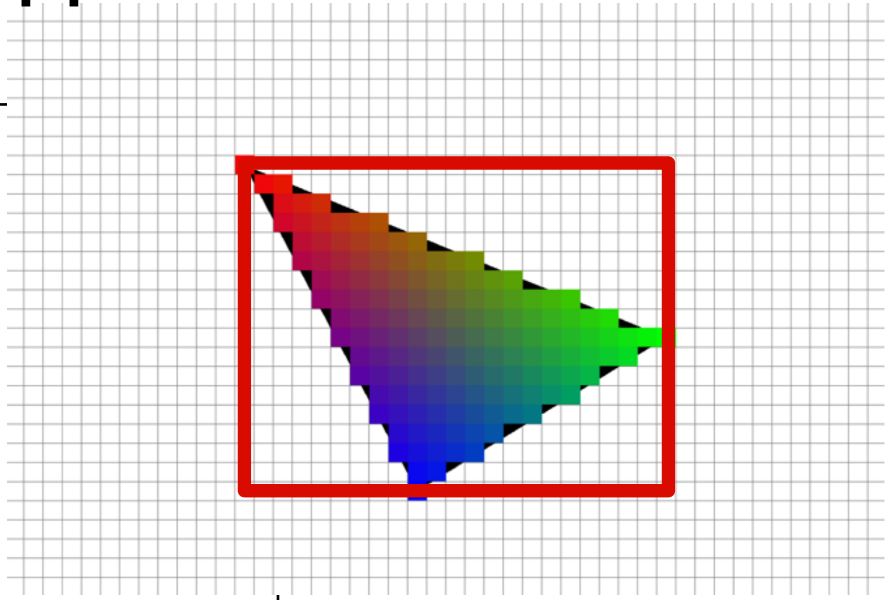
if $(\alpha \in [0,1] \text{ and } \beta \in [0,1] \text{ and } \gamma \in [0,1])$ then

$$\mathbf{c} = \alpha\mathbf{c}_0 + \beta\mathbf{c}_1 + \gamma\mathbf{c}_2$$

drawpixel(x,y) with color c

Triangle rasterization algorithm

Optimizations? don't need to check upper bound



for x in [x_min, x_max]

for y in [y_min, y_max]

$$\alpha = f_{bc}(x,y)/f_{bc}(x_a,y_a)$$

$$\beta = f_{ca}(x,y)/f_{ca}(x_b,y_b)$$

$$\gamma = f_{ab}(x,y)/f_{ab}(x_c,y_c)$$

if $(\alpha \geq 0 \text{ and } \beta \geq 0 \text{ and } \gamma \geq 0)$then

$$\mathbf{c} = \alpha\mathbf{c}_0 + \beta\mathbf{c}_1 + \gamma\mathbf{c}_2$$

drawpixel(x,y) with color c

Triangle rasterization algorithm

Optimizations? compute bary. coord. and colors incrementally

for x in [x_min, x_max]

  for y in [y_min, y_max]

$$\alpha = f_{bc}(x,y)/f_{bc}(x_a,y_a)$$

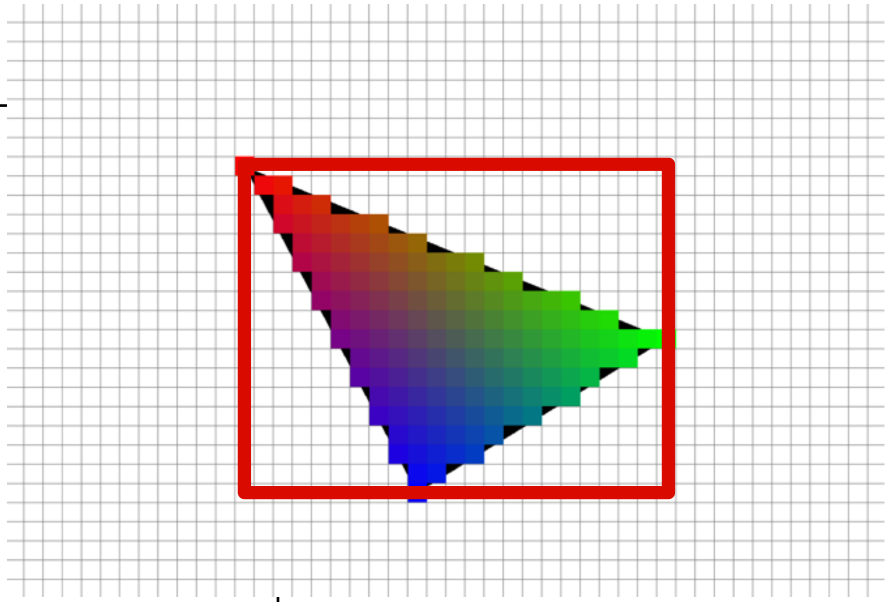
$$\beta = f_{ca}(x,y)/f_{ca}(x_b,y_b)$$

$$\gamma = f_{ab}(x,y)/f_{ab}(x_c,y_c)$$

if $(\alpha \geq 0 \text{ and } \beta \geq 0 \text{ and } \gamma \geq 0)$then

$$\mathbf{c} = \alpha\mathbf{c}_0 + \beta\mathbf{c}_1 + \gamma\mathbf{c}_2$$

drawpixel(x,y) with color c



Triangle rasterization algorithm

dealing with shared triangle edges

for x in [x_min, x_max]

for y in [y_min, y_max]

$$\alpha = f_{bc}(x,y)/f_{bc}(x_a,y_a)$$

$$\beta = f_{ac}(x,y)/f_{ac}(x_b,y_b)$$

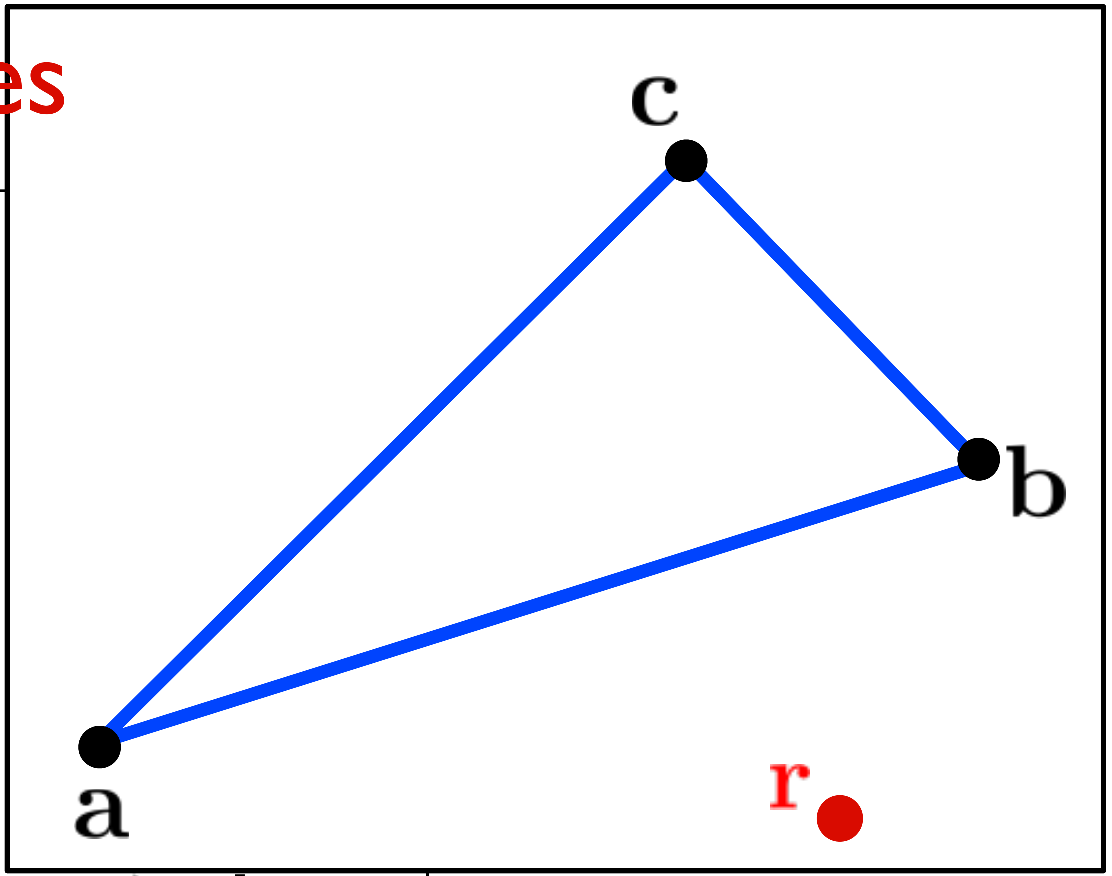
$$\gamma = f_{ab}(x,y)/f_{ab}(x_c,y_c)$$

if $(\alpha \geq 0 \text{ and } \beta \geq 0 \text{ and } \gamma \geq 0)$ then

if $(\alpha > 0 \text{ or } f_{bc}(\mathbf{a})f_{bc}(\mathbf{r}) > 0)$ and $(\beta > 0 \text{ or } f_{ca}(\mathbf{b})f_{ca}(\mathbf{r}) > 0)$ and $(\gamma > 0 \text{ or } f_{ab}(\mathbf{c})f_{ab}(\mathbf{r}) > 0)$ then

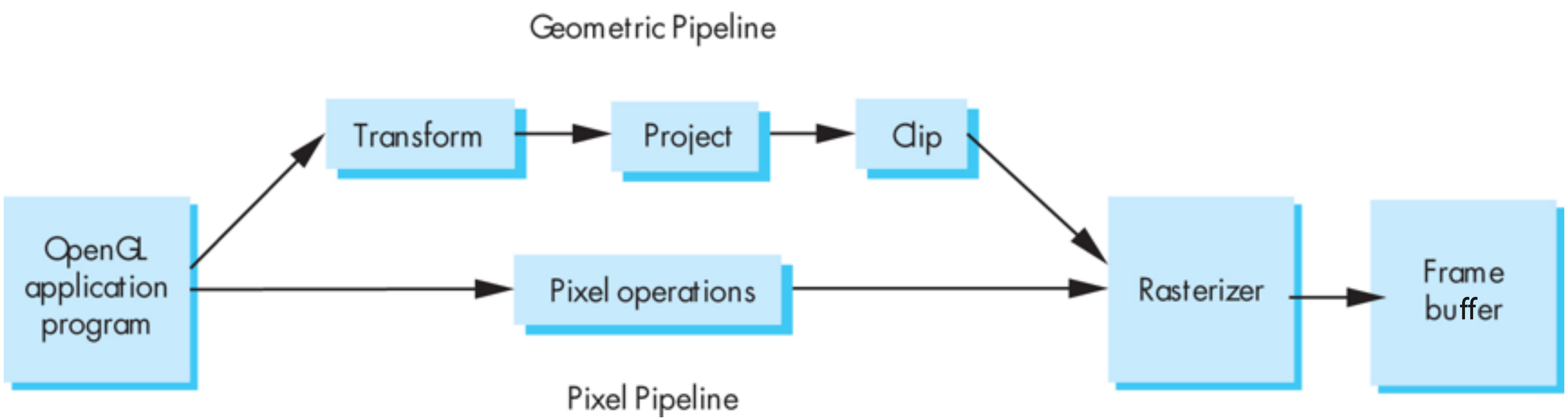
$$\mathbf{c} = \alpha\mathbf{c}_0 + \beta\mathbf{c}_1 + \gamma\mathbf{c}_2$$

drawpixel(x,y) with color c

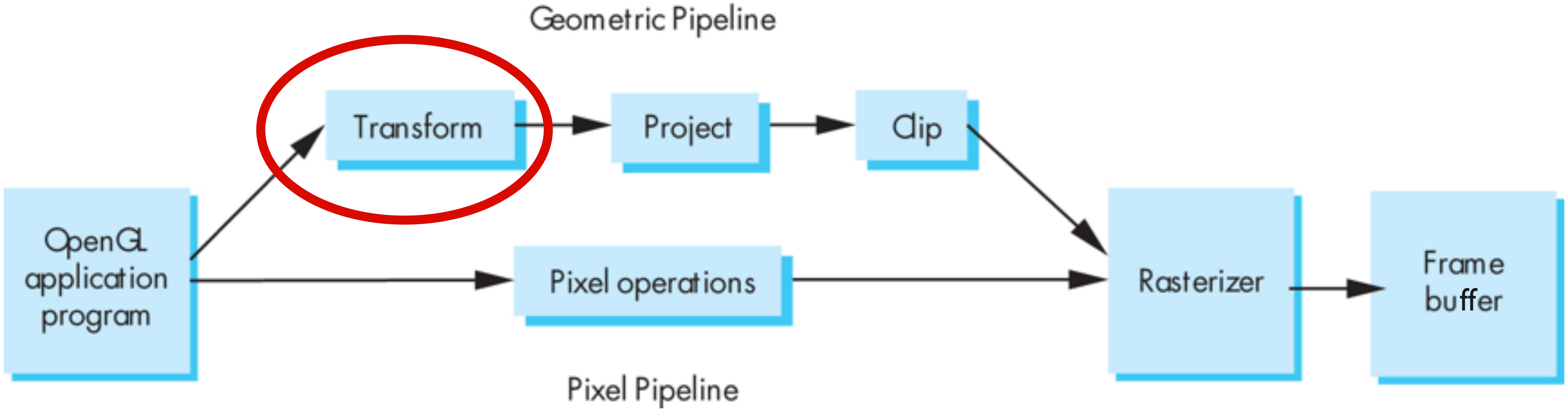


Graphics Pipeline (cont.)

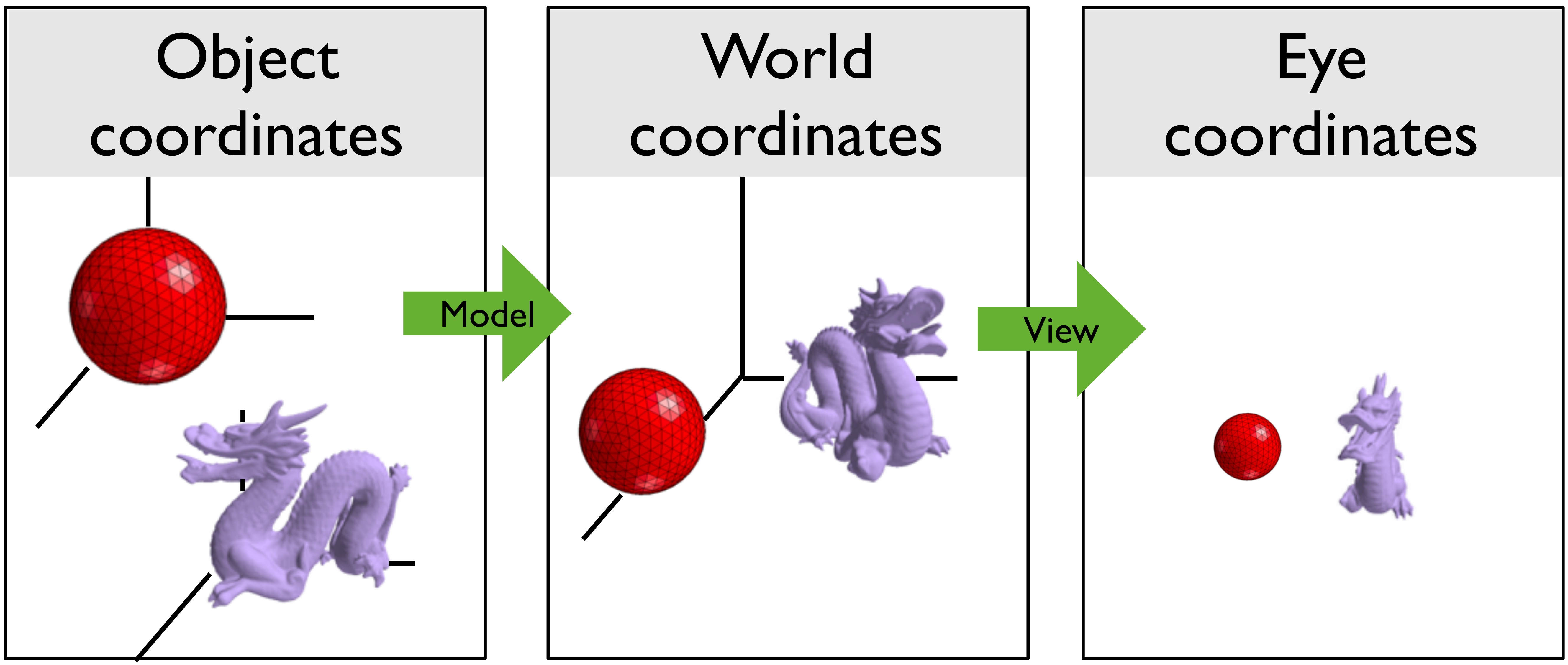
Graphics Pipeline



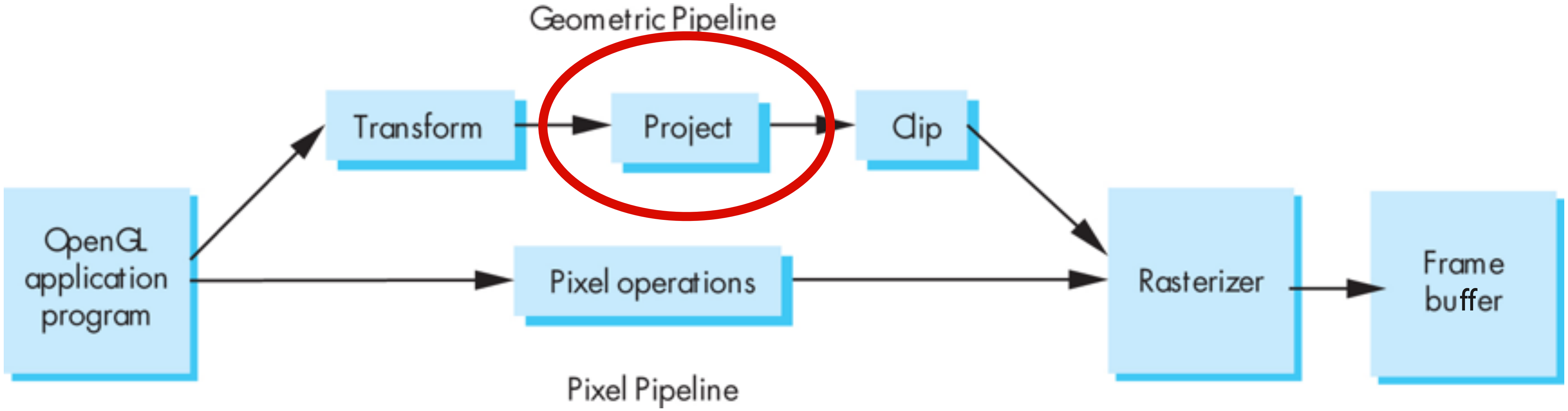
Transform


Geometric Pipeline
Transform
Project
Clip
OpenGL application program
Pixel operations
Rasterizer
Frame buffer
Pixel Pipeline

“Modelview” Transformation

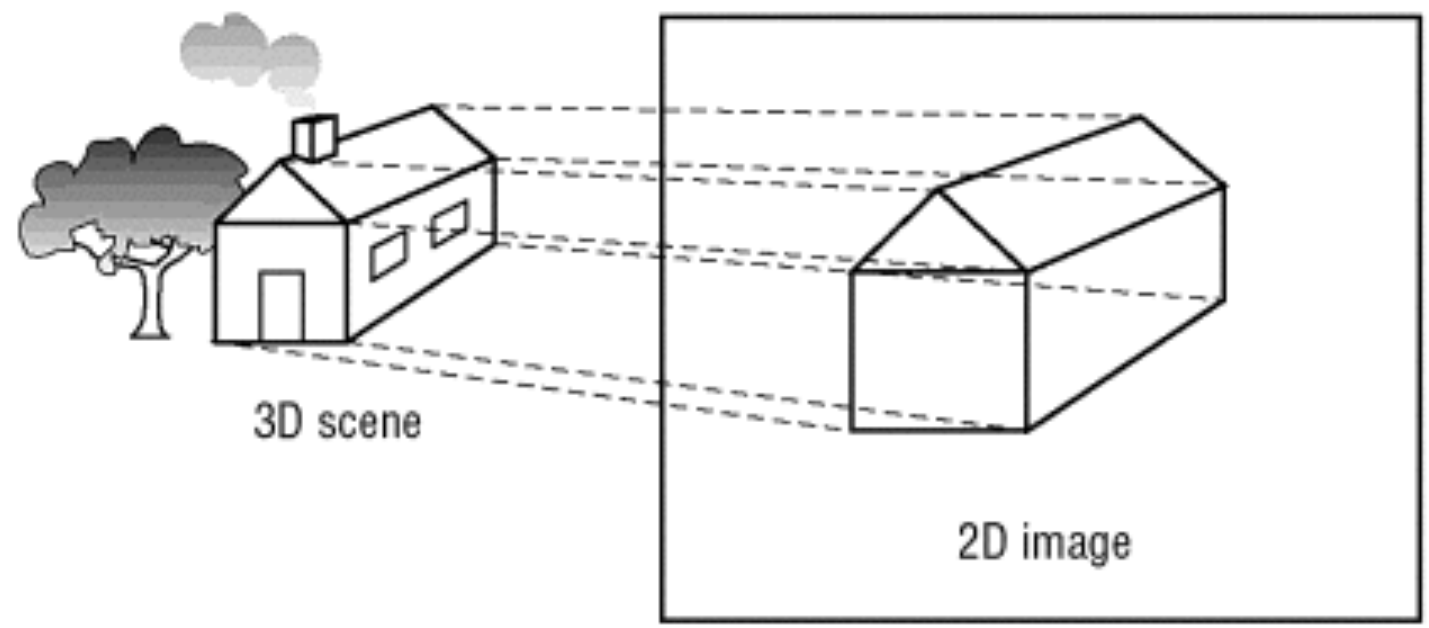


Project



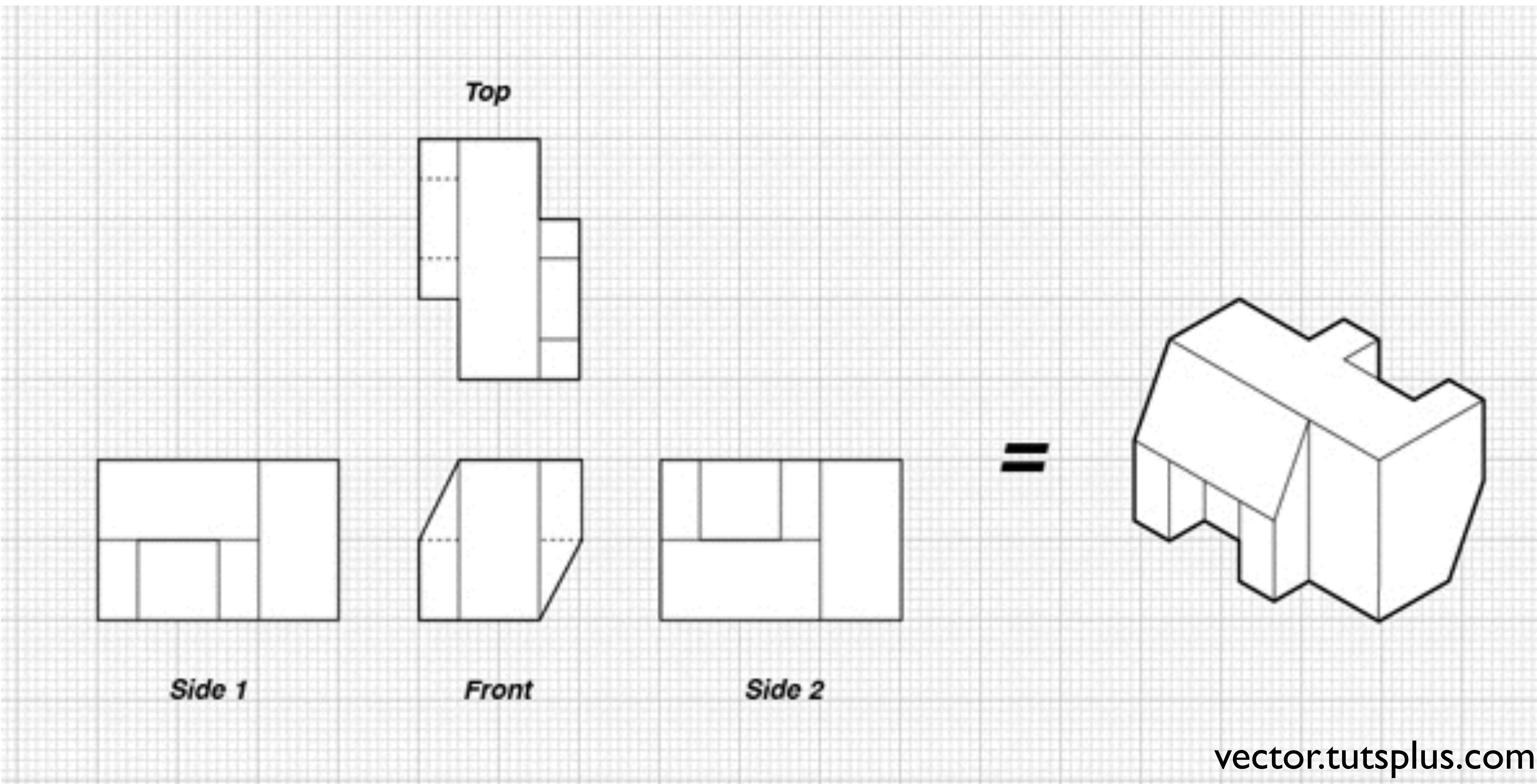
Geometric Pipeline
Transform
Project
Clip
OpenGL application program
Pixel operations
Rasterizer
Frame buffer
Pixel Pipeline

Projection: map 3D scene to 2D image



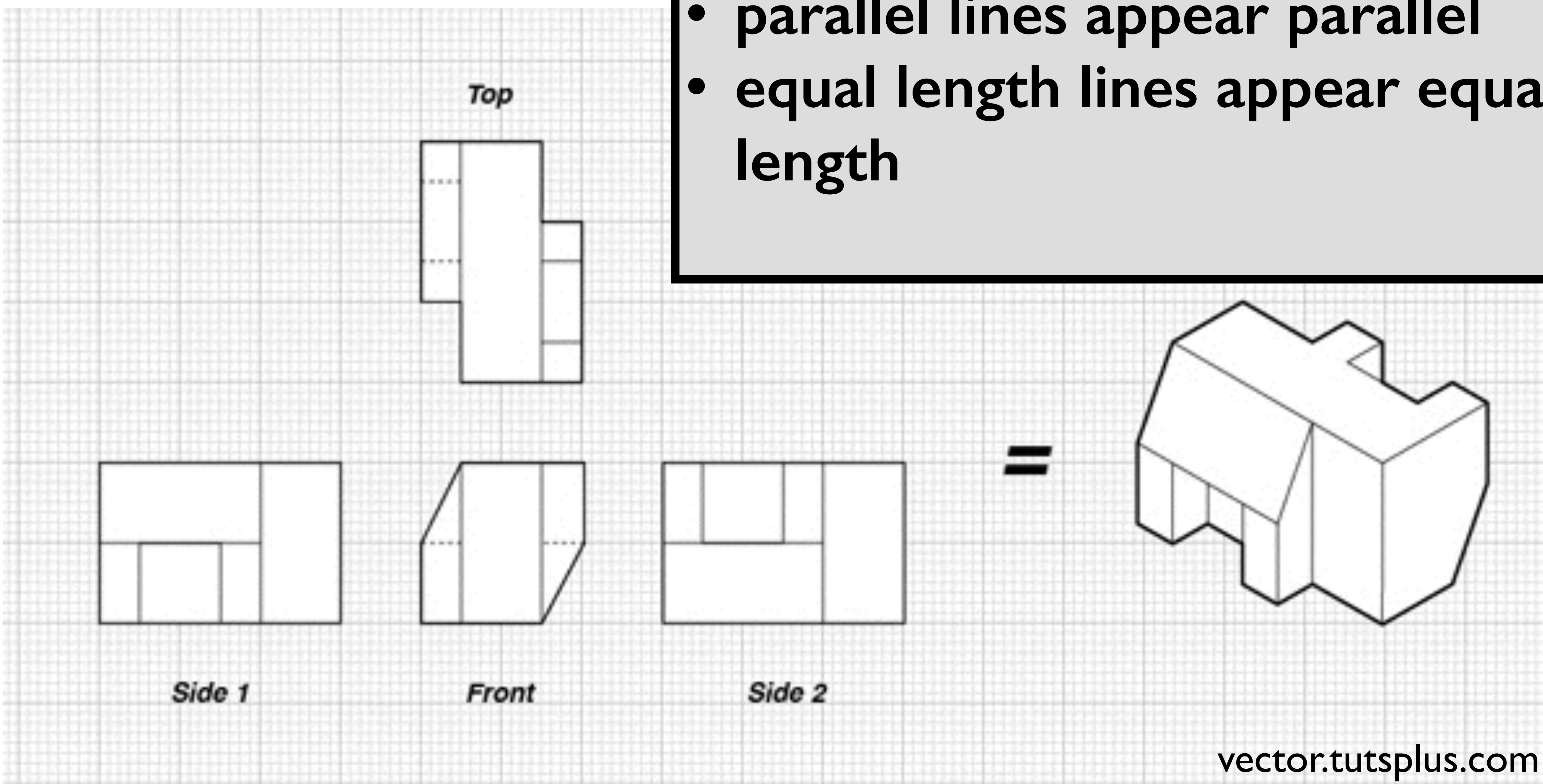
OpenGL Super Bible, 5th Ed.

Orthographic projection



Orthographic projection

- parallel lines appear parallel
- equal length lines appear equal length

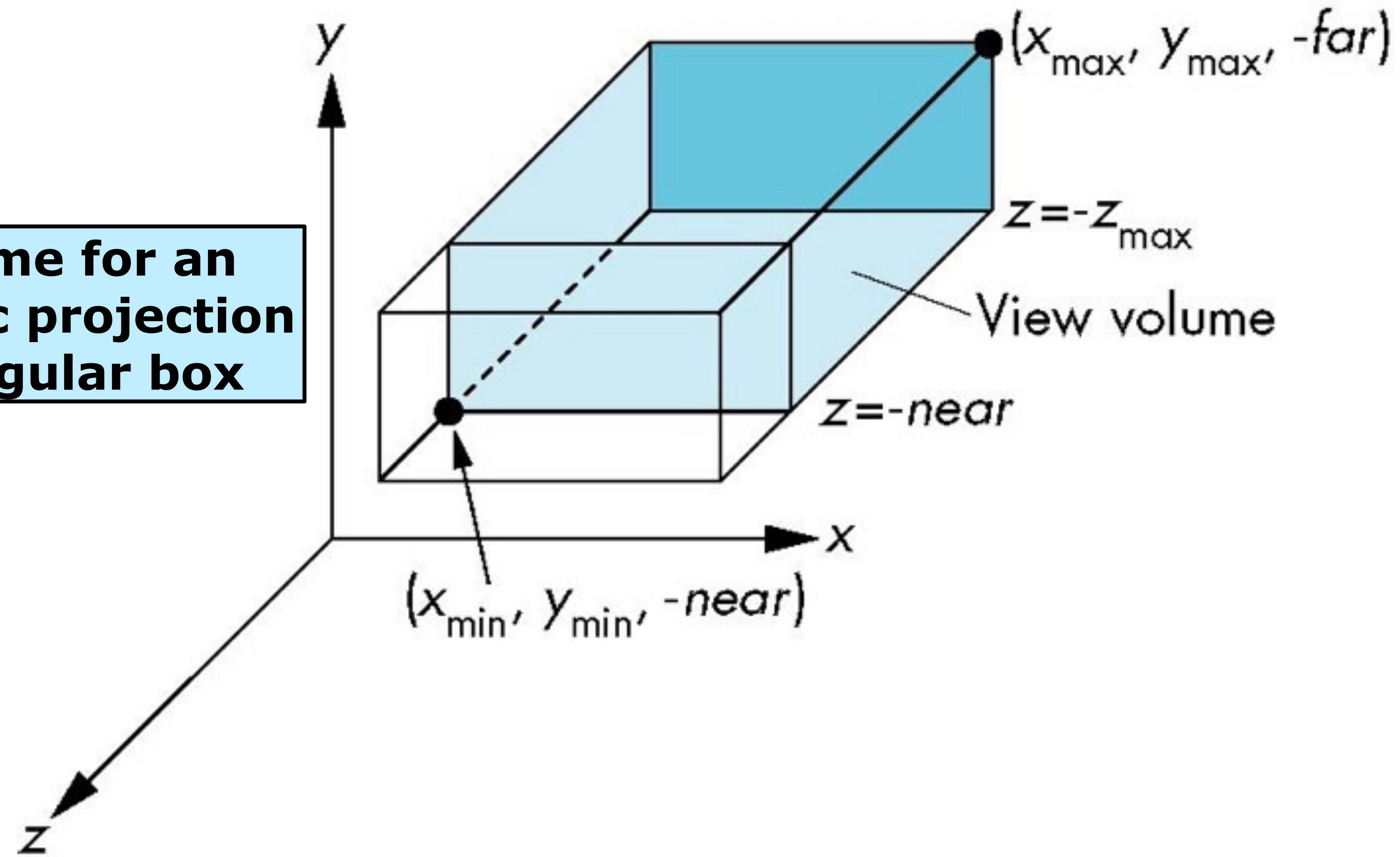


vector.tutsplus.com

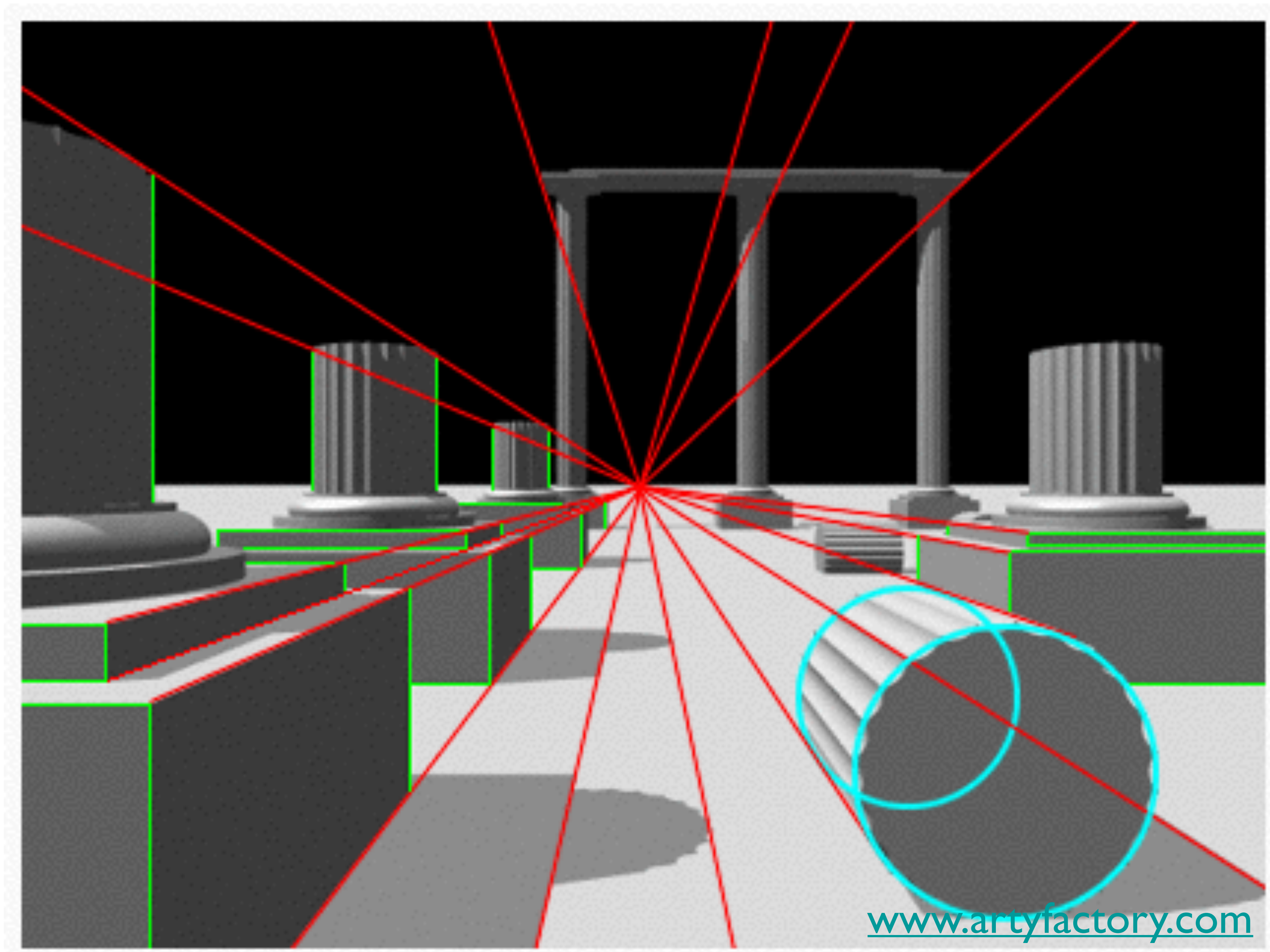
OpenGL Orthogonal Viewing

```
glOrtho(left,right,bottom,top,near,far)
```

View volume for an orthographic projection is a rectangular box



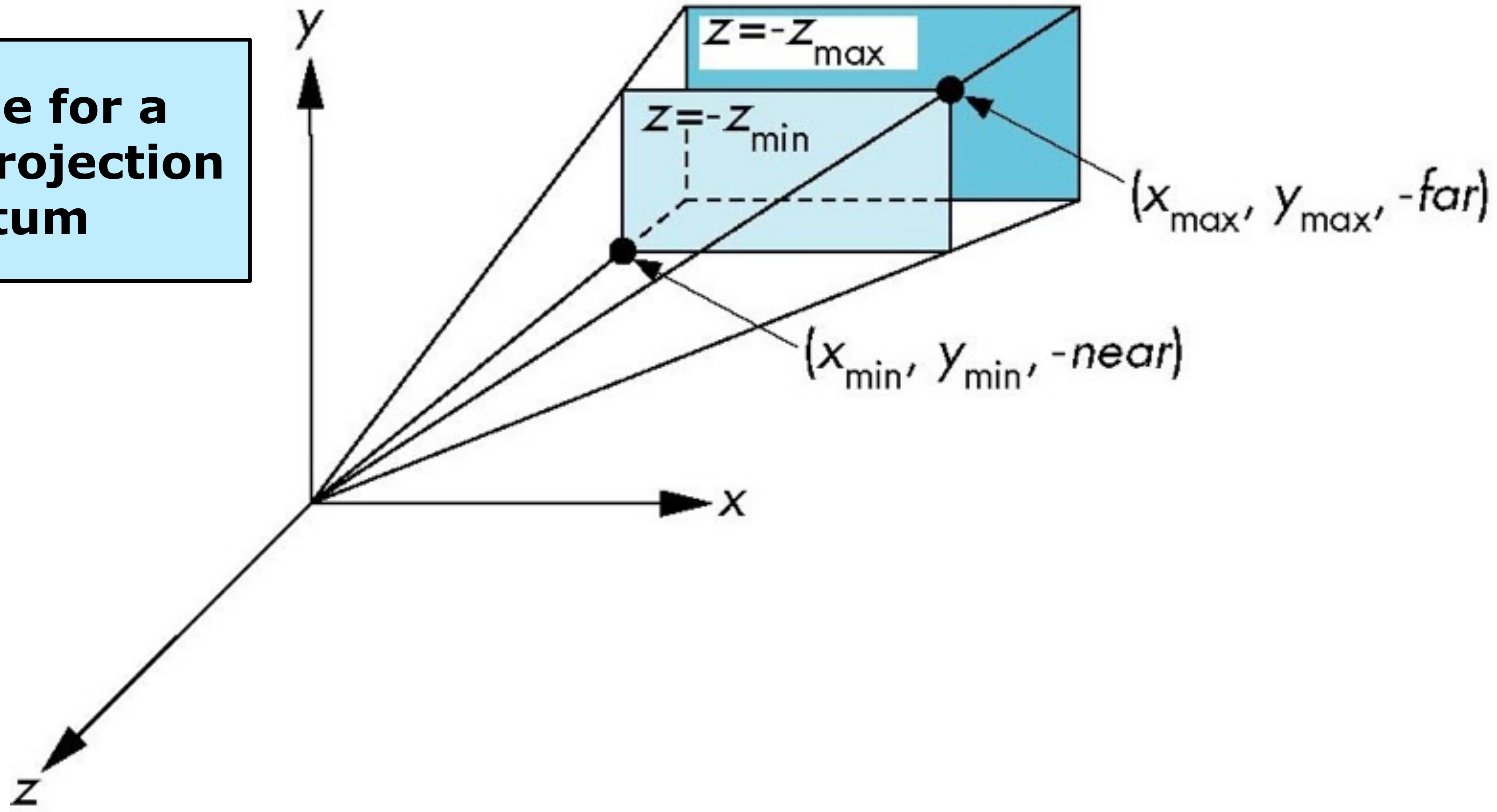
Perspective projection



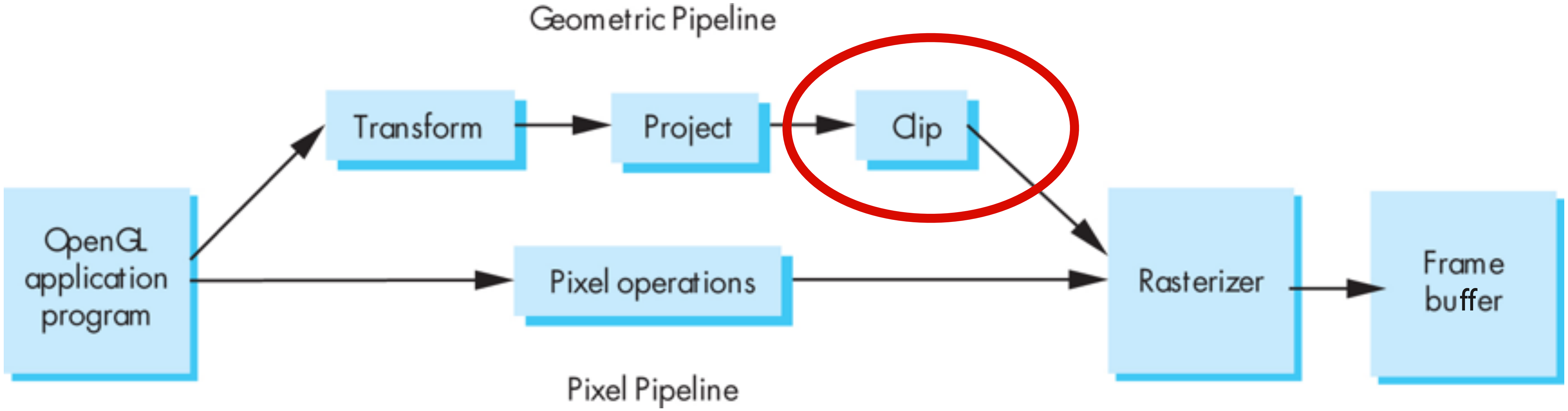
OpenGL Perspective Viewing

```
glFrustum(xmin,xmax,ymin,ymax,near,far)
```

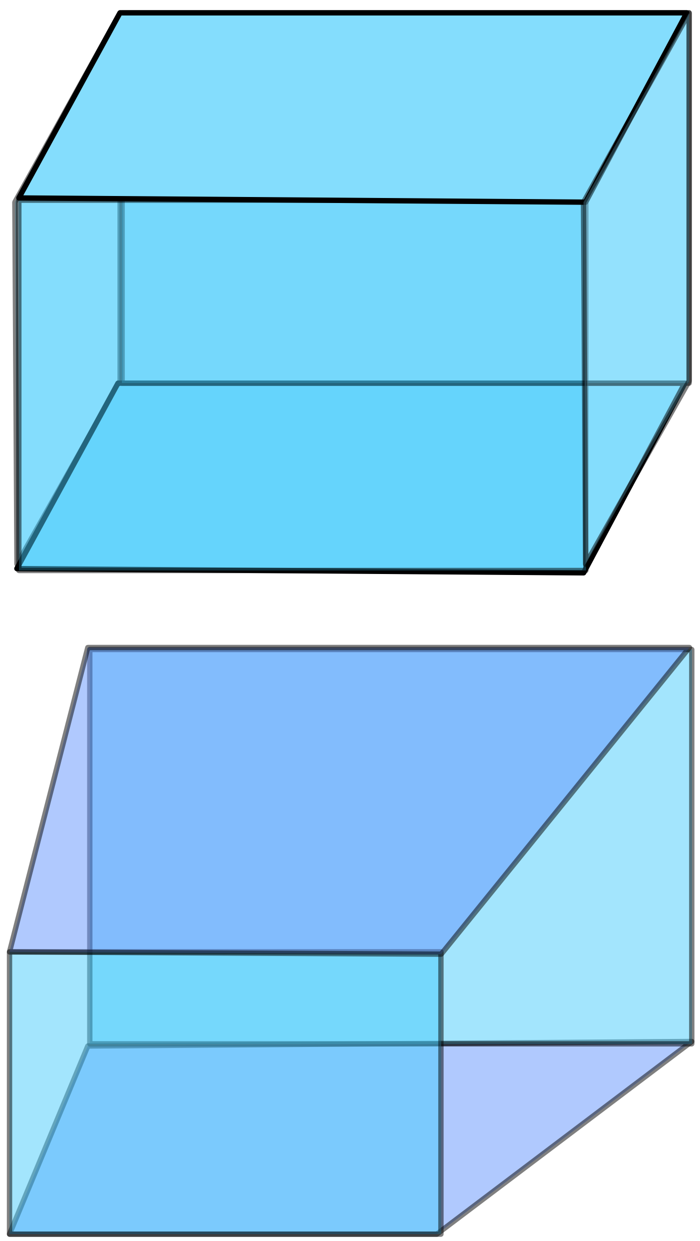
View volume for a perspective projection is a frustum

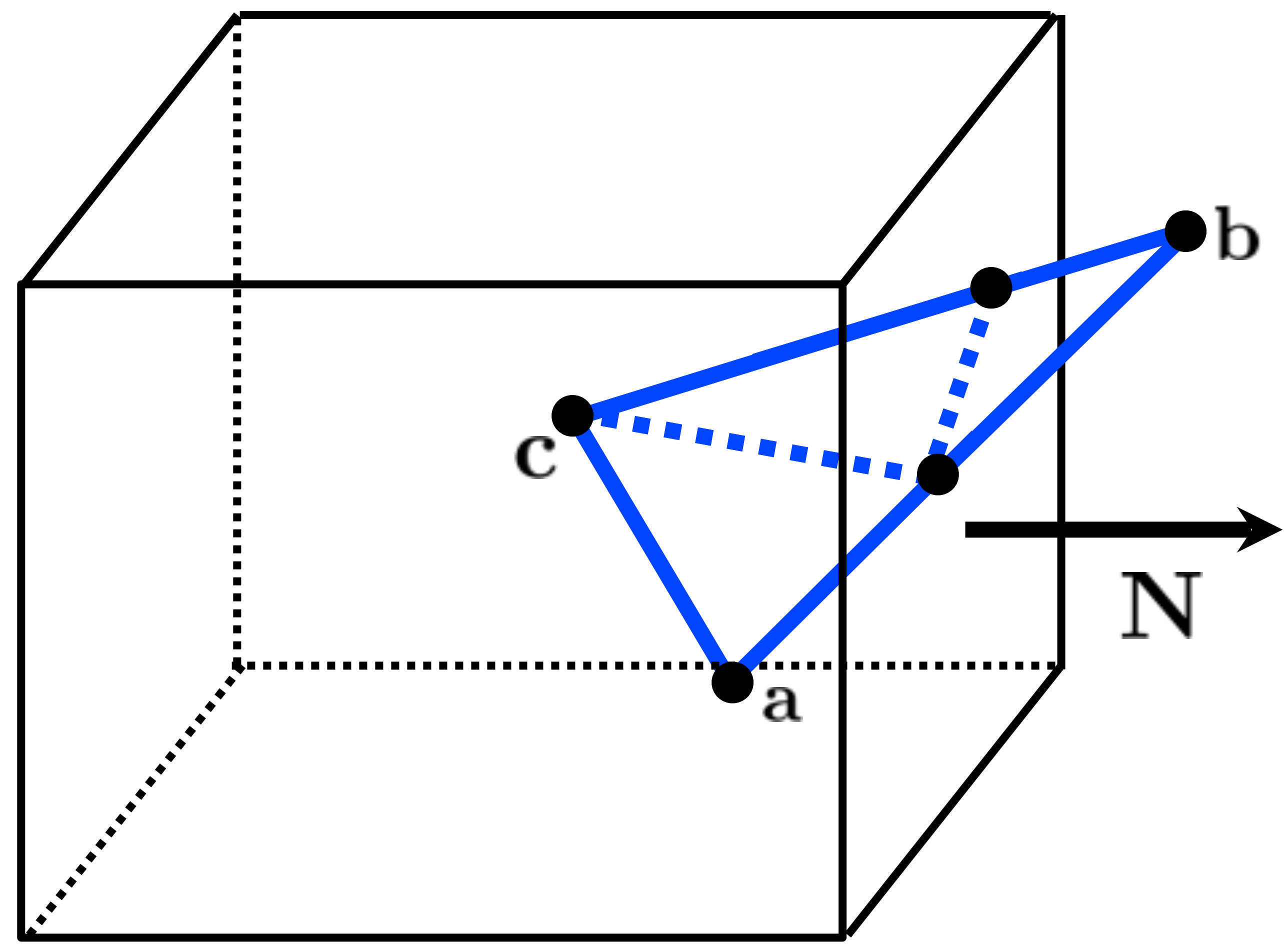


Clip


Geometric Pipeline
Transform
Project
Clip
OpenGL application program
Pixel operations
Rasterizer
Frame buffer
Pixel Pipeline

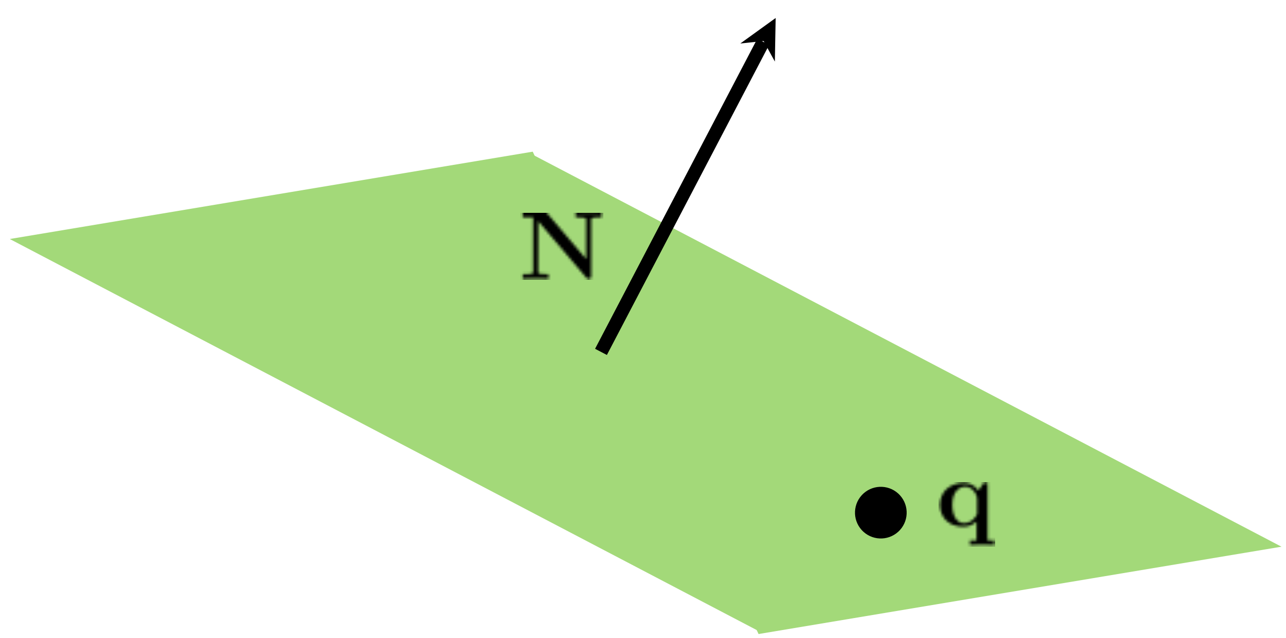
Clip against view volume

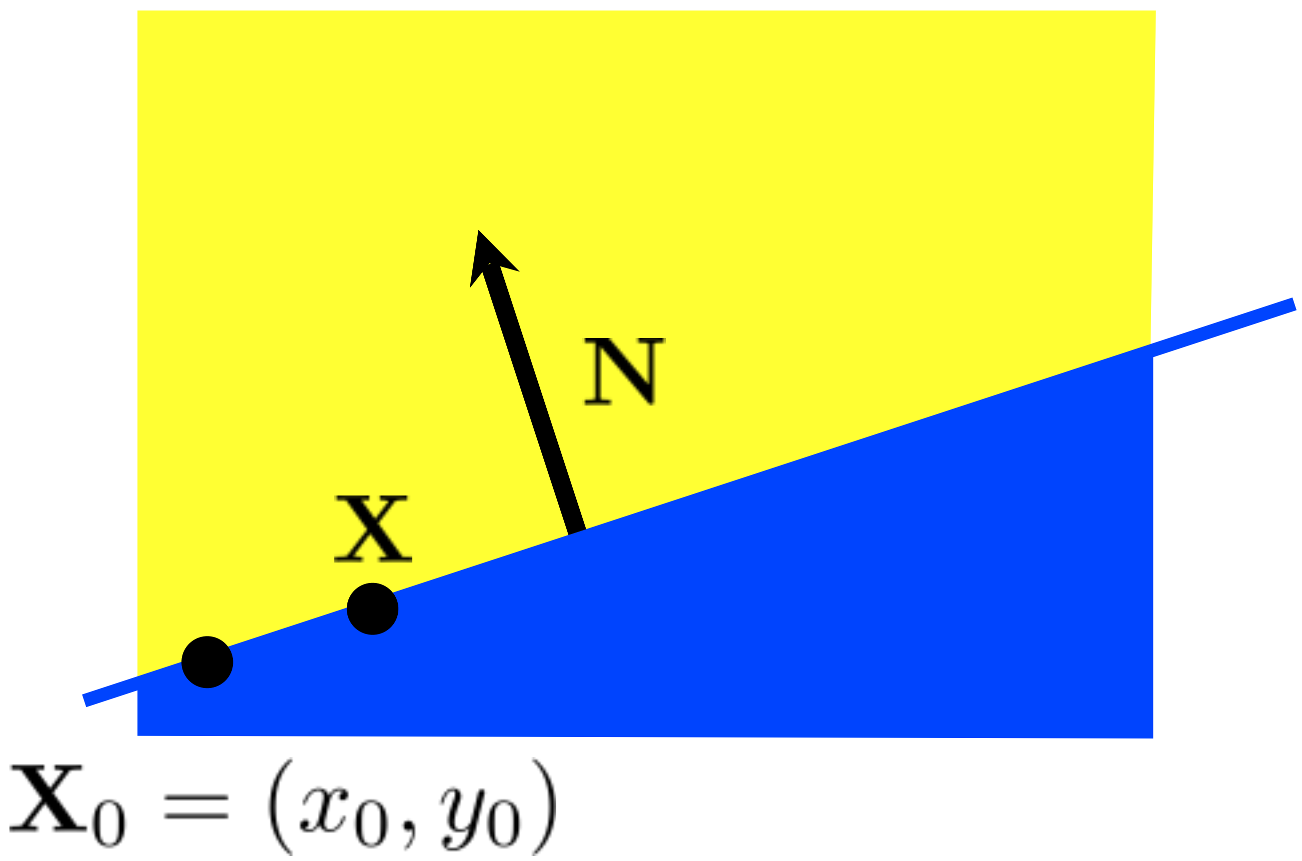




Clipping against a plane

What's the equation for the plane through **q** with normal **N**?



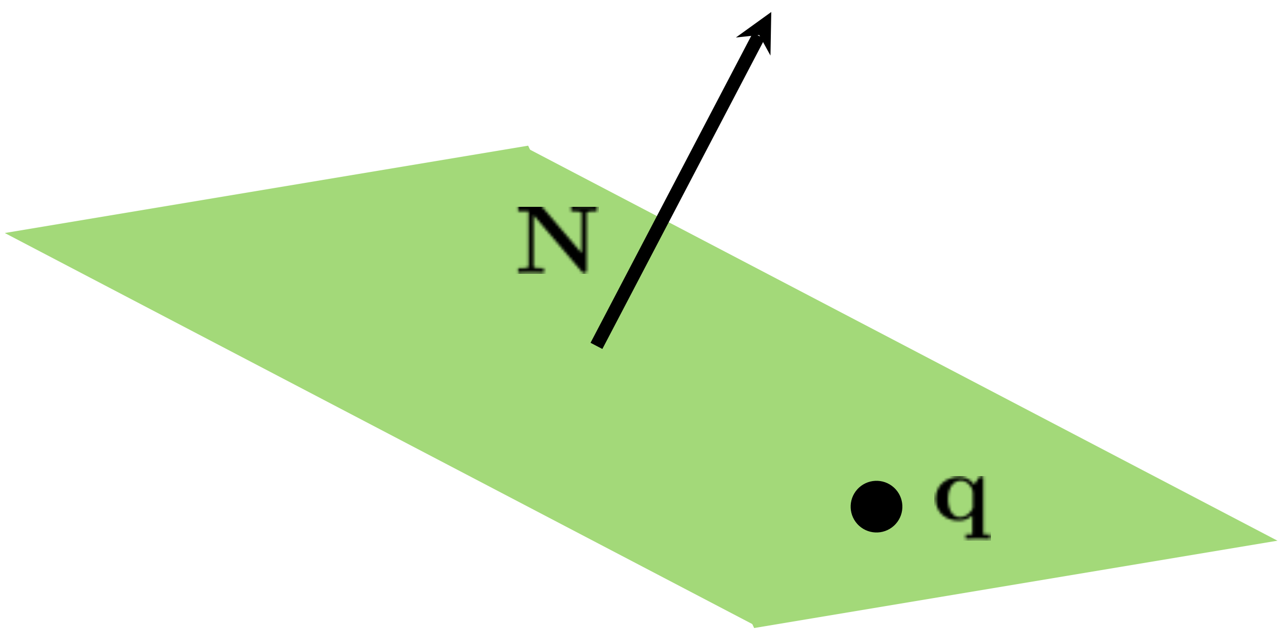


implicit line equation:

$$f(\mathbf{X}) = \mathbf{N} \cdot (\mathbf{X} - \mathbf{X}_0) = 0$$

Clipping against a plane

What's the equation for the plane through **q** with normal **N**?

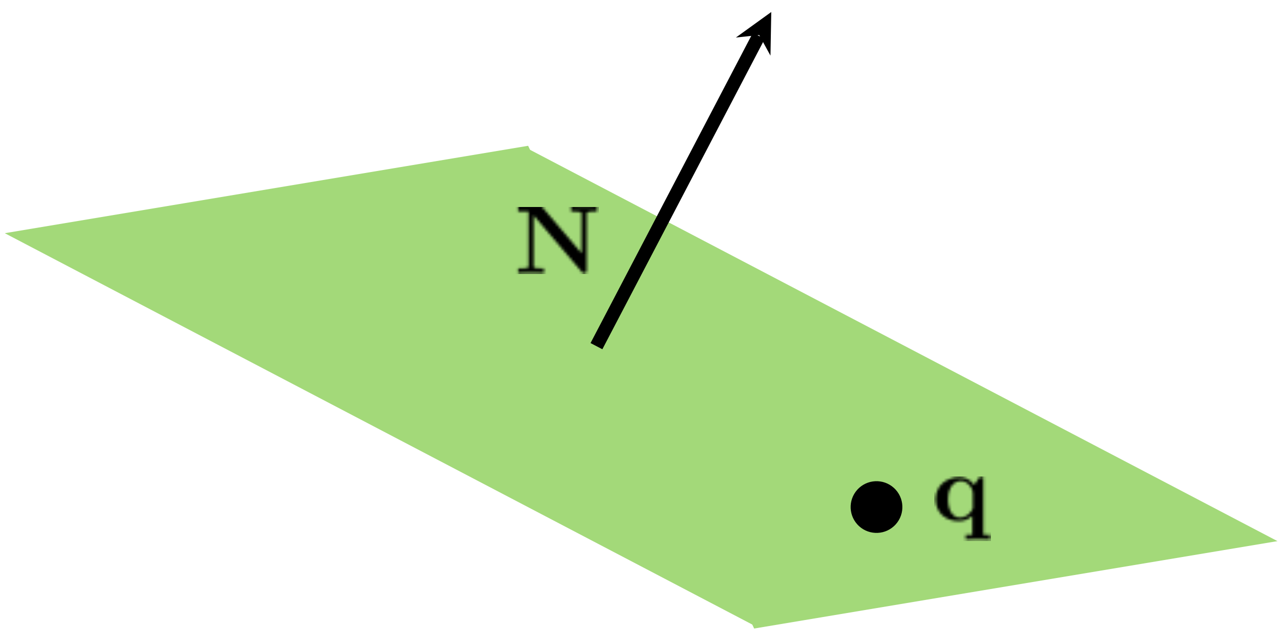


$$f(\mathbf{p}) = ? = 0$$

<whiteboard>

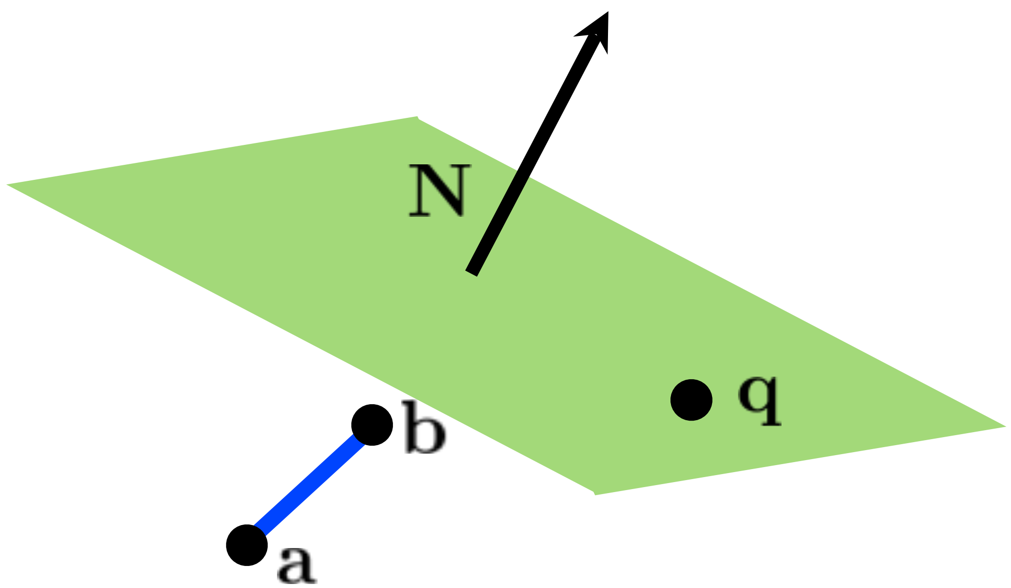
Clipping against a plane

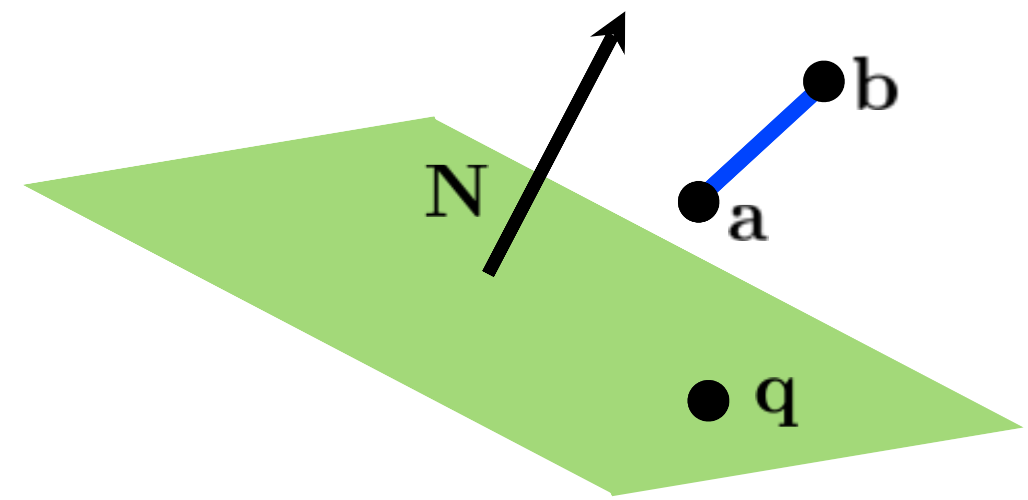
What's the equation for the plane through **q** with normal **N**?



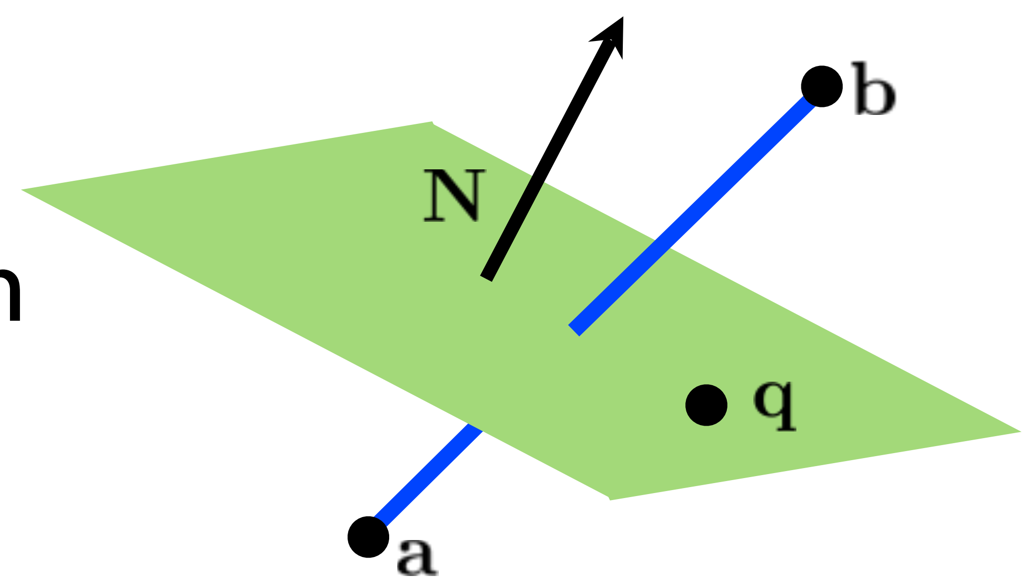
$$f(\mathbf{p}) = \mathbf{N} \cdot (\mathbf{p} - \mathbf{q}) = 0$$

Intersection of line and plane



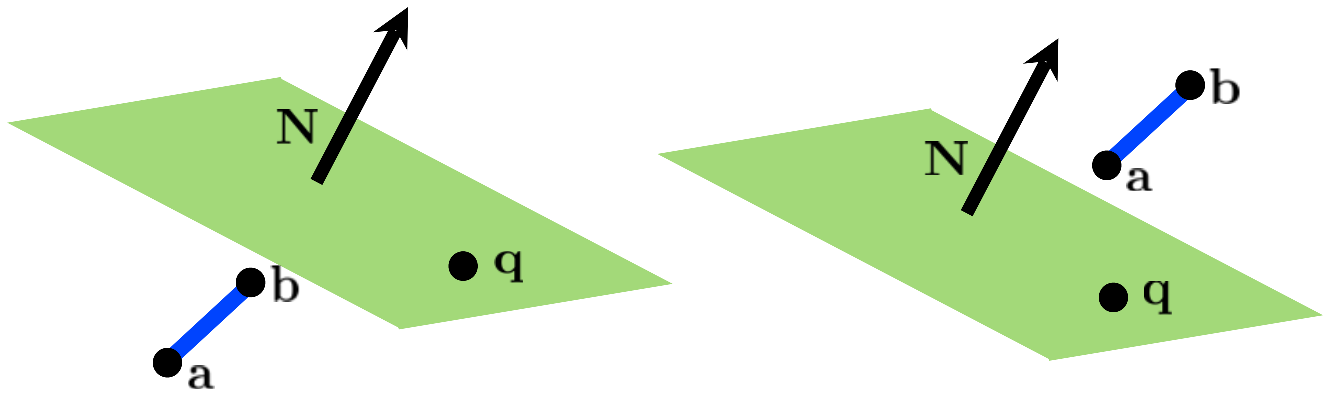


How can we distinguish between these cases?

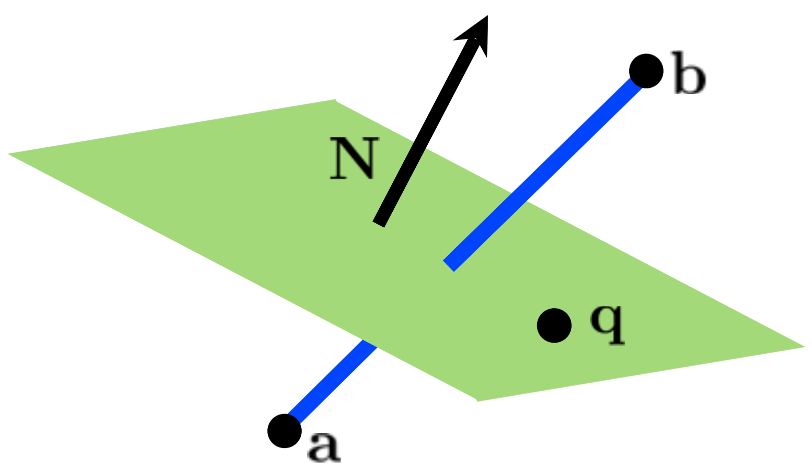


Intersection of line and plane

$$f(\mathbf{a})f(\mathbf{b}) \geq 0$$

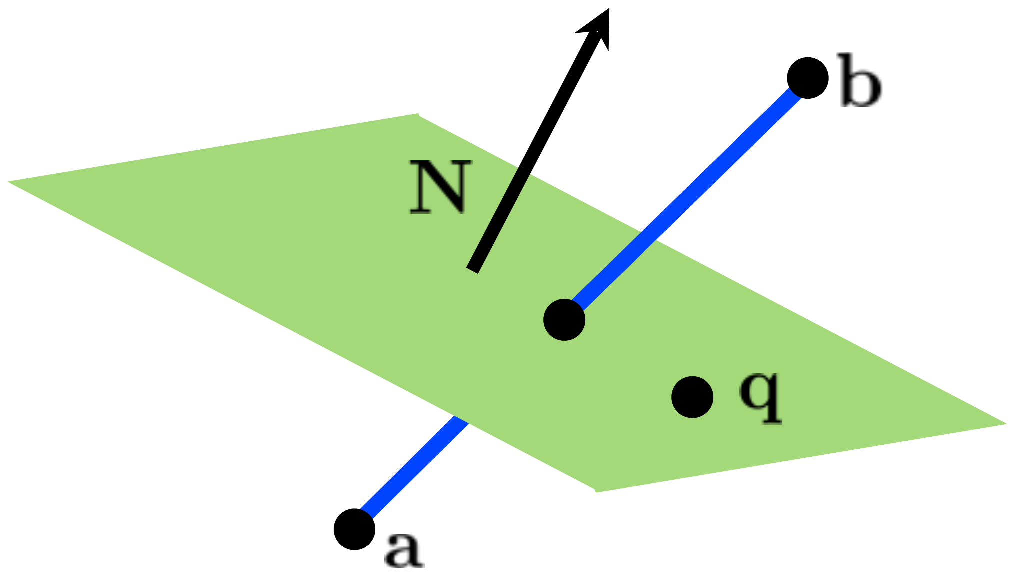


$$f(\mathbf{a})f(\mathbf{b}) < 0$$



Intersection of line and plane

How can we find the intersection point?



<whiteboard>

Clip against view volume

$$s = \frac{\mathbf{N} \cdot (\mathbf{q} - \mathbf{c})}{\mathbf{N} \cdot (\mathbf{b} - \mathbf{c})}$$

$$t = \frac{\mathbf{N} \cdot (\mathbf{q} - \mathbf{a})}{\mathbf{N} \cdot (\mathbf{b} - \mathbf{a})}$$

need to generate new triangles