CS130 : Computer Graphics

Rasterizing Triangles and Graphics Pipeline (cont.)

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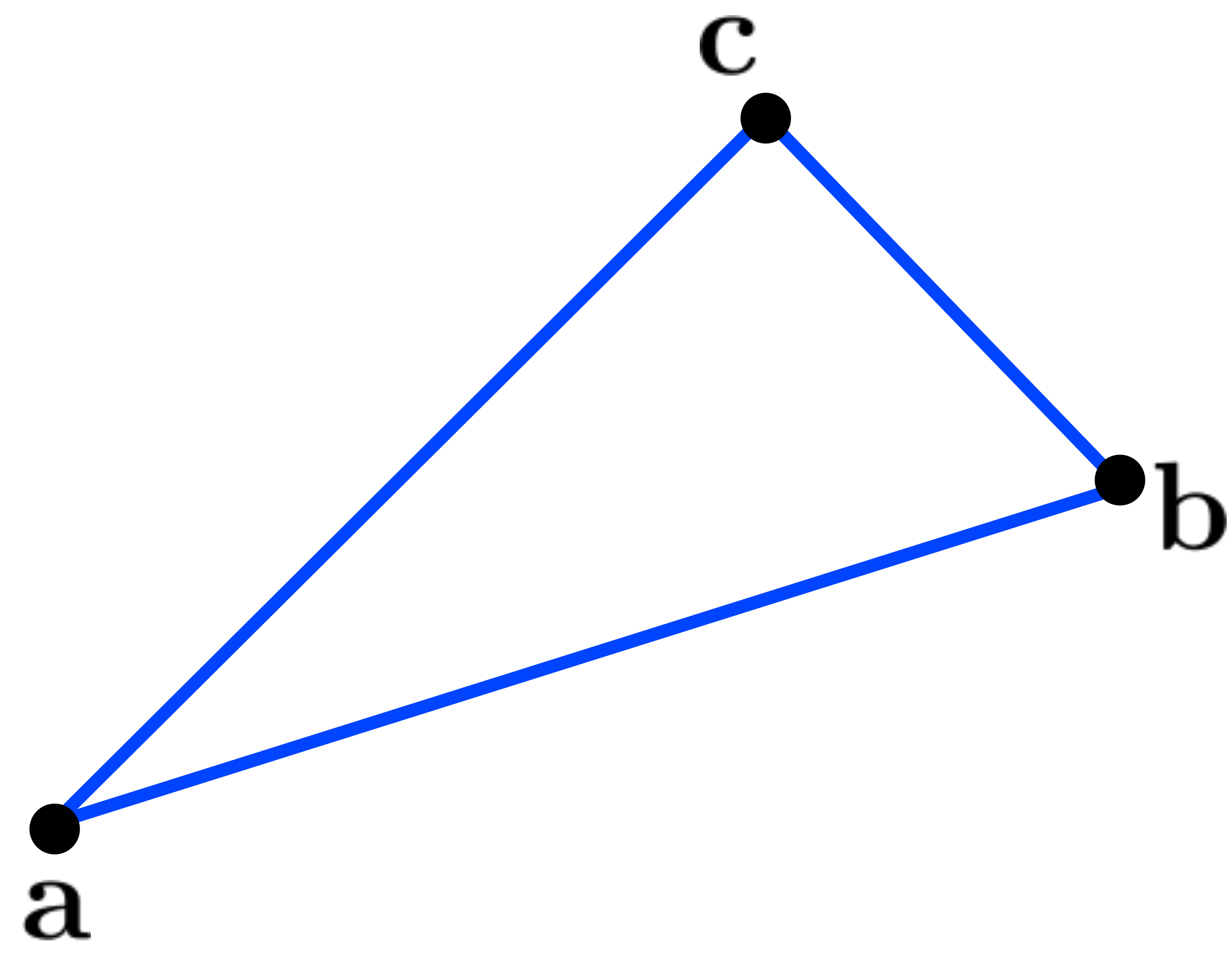
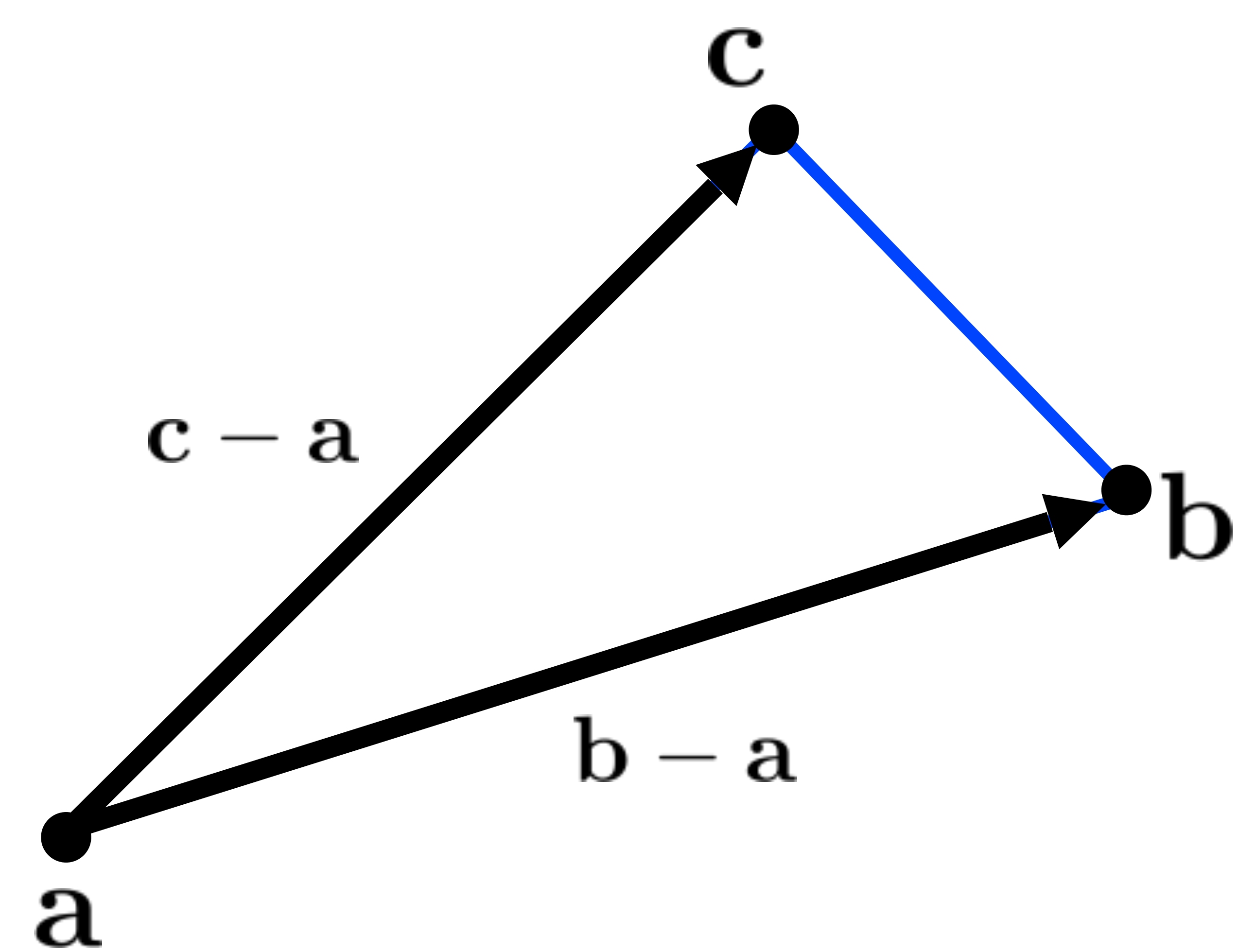
Triangles

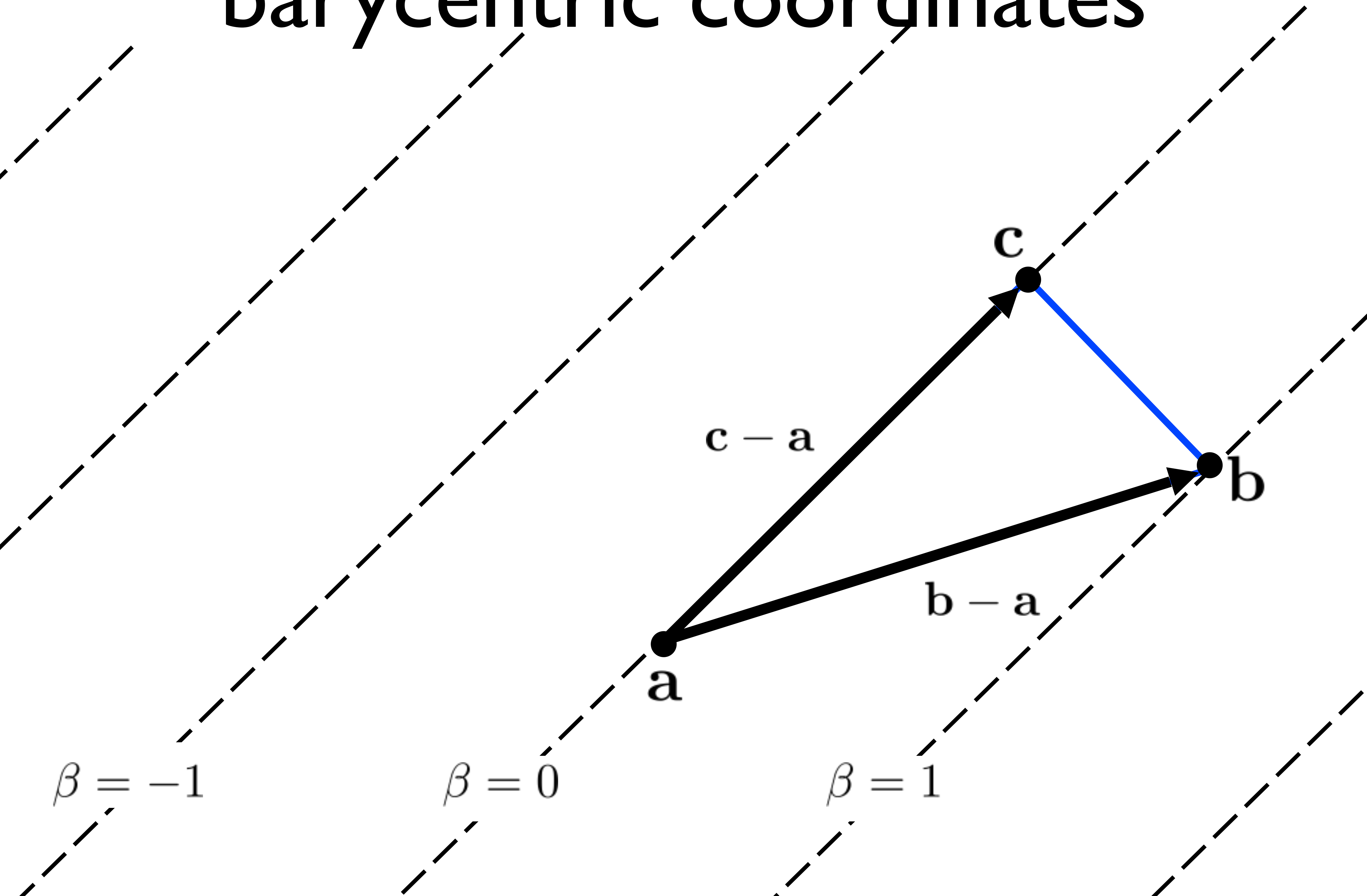
barycentric coordinates



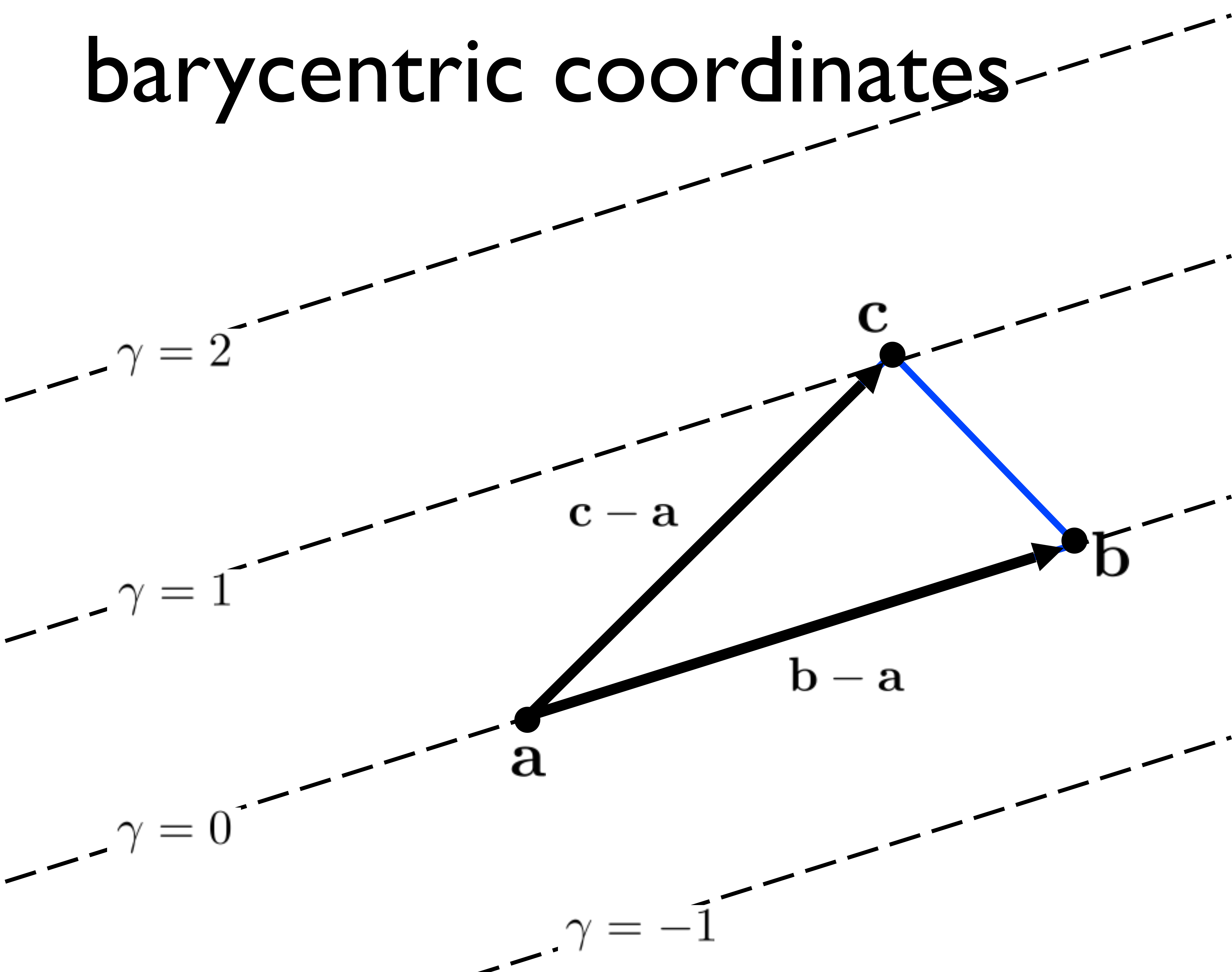
barycentric coordinates



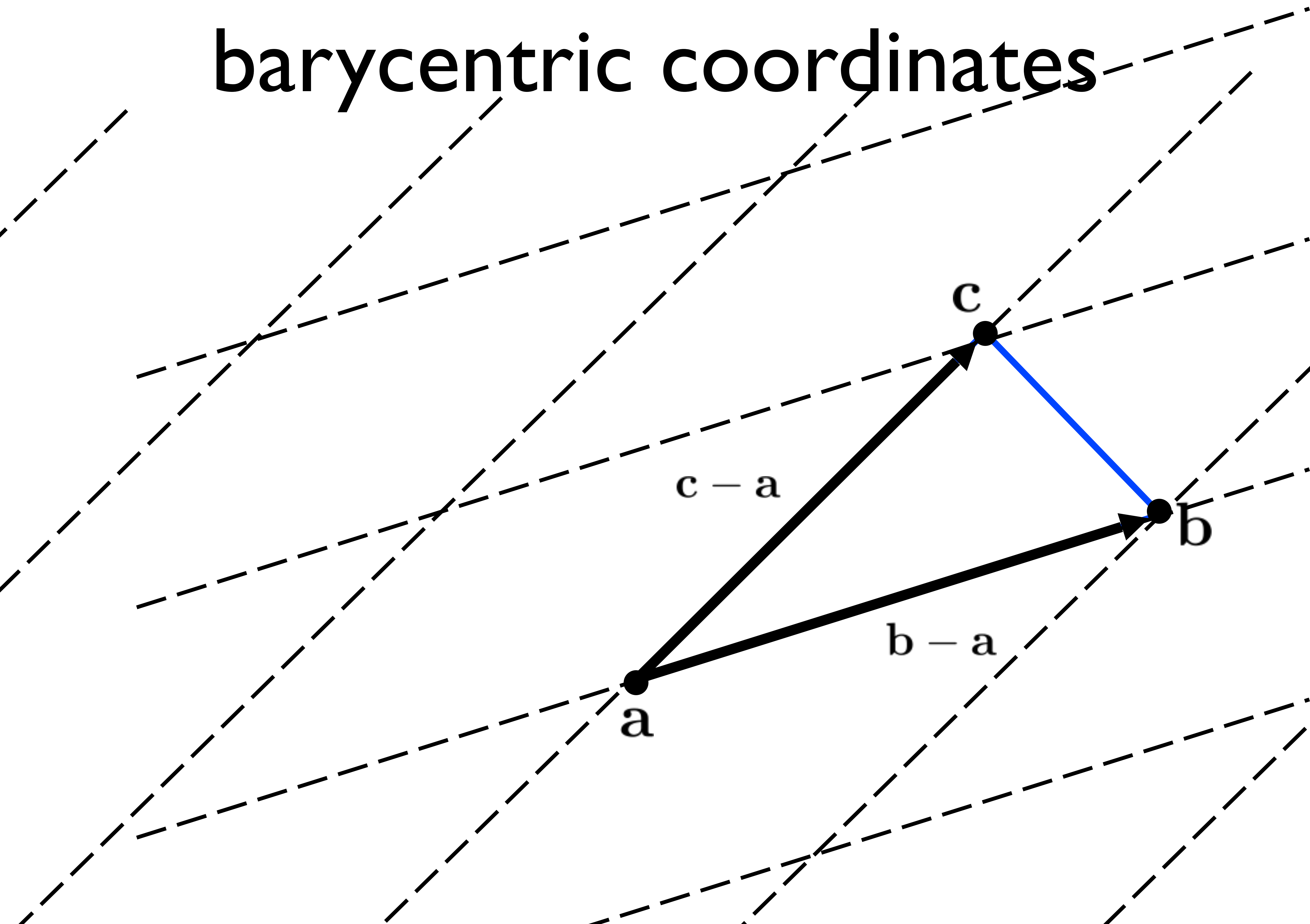
barycentric coordinates



barycentric coordinates

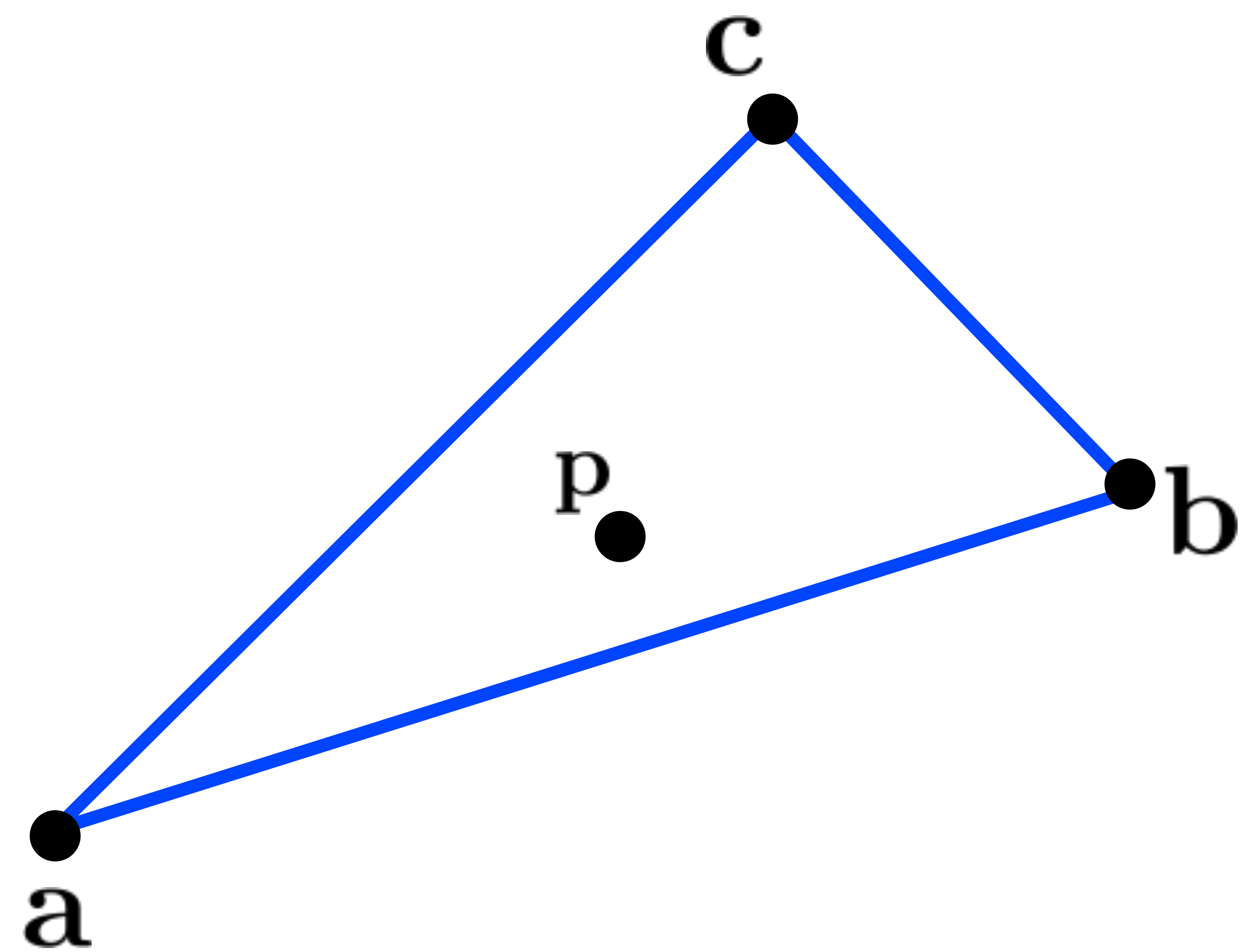


barycentric coordinates



barycentric coordinates

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



What are (α, β, γ) ?

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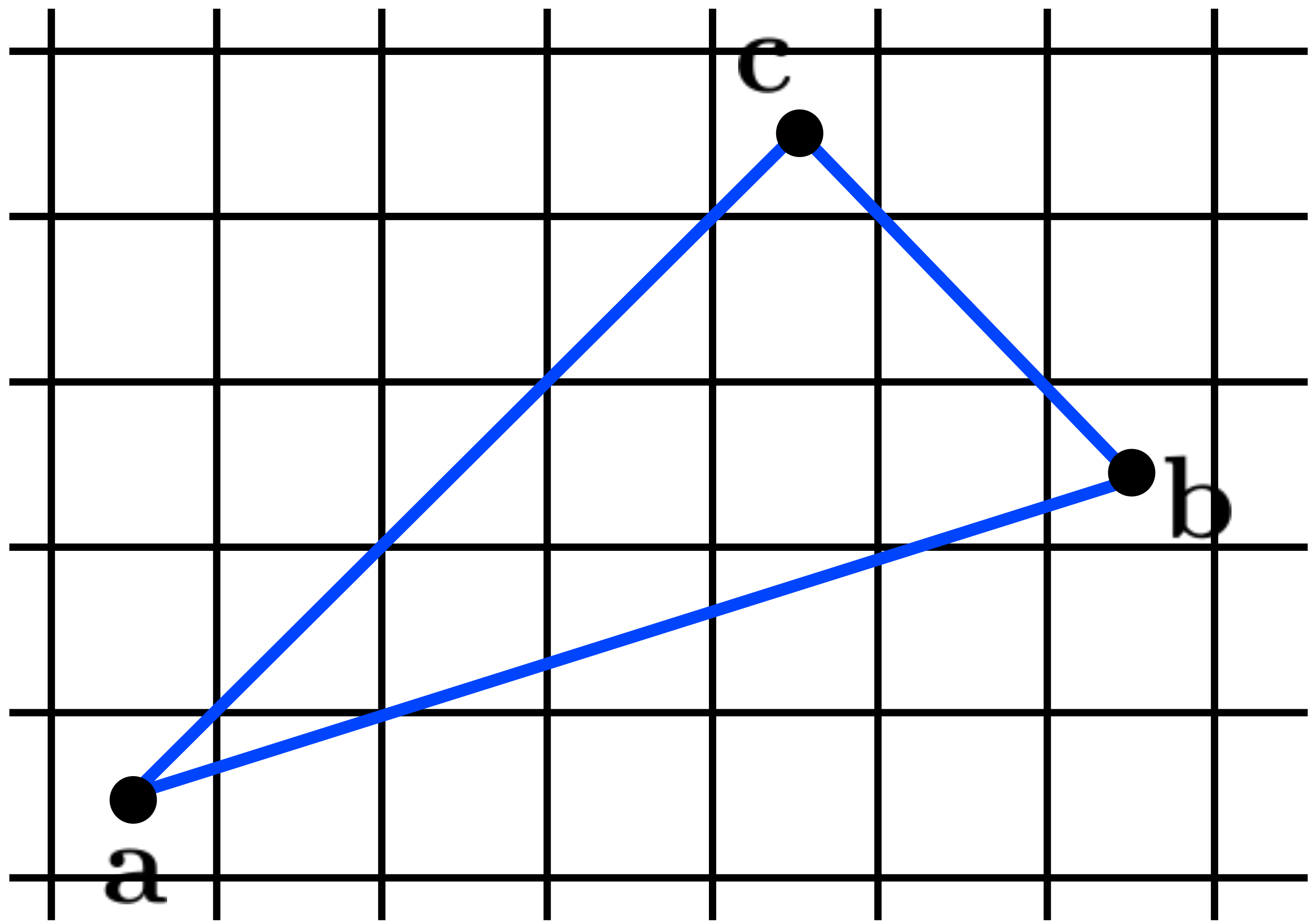
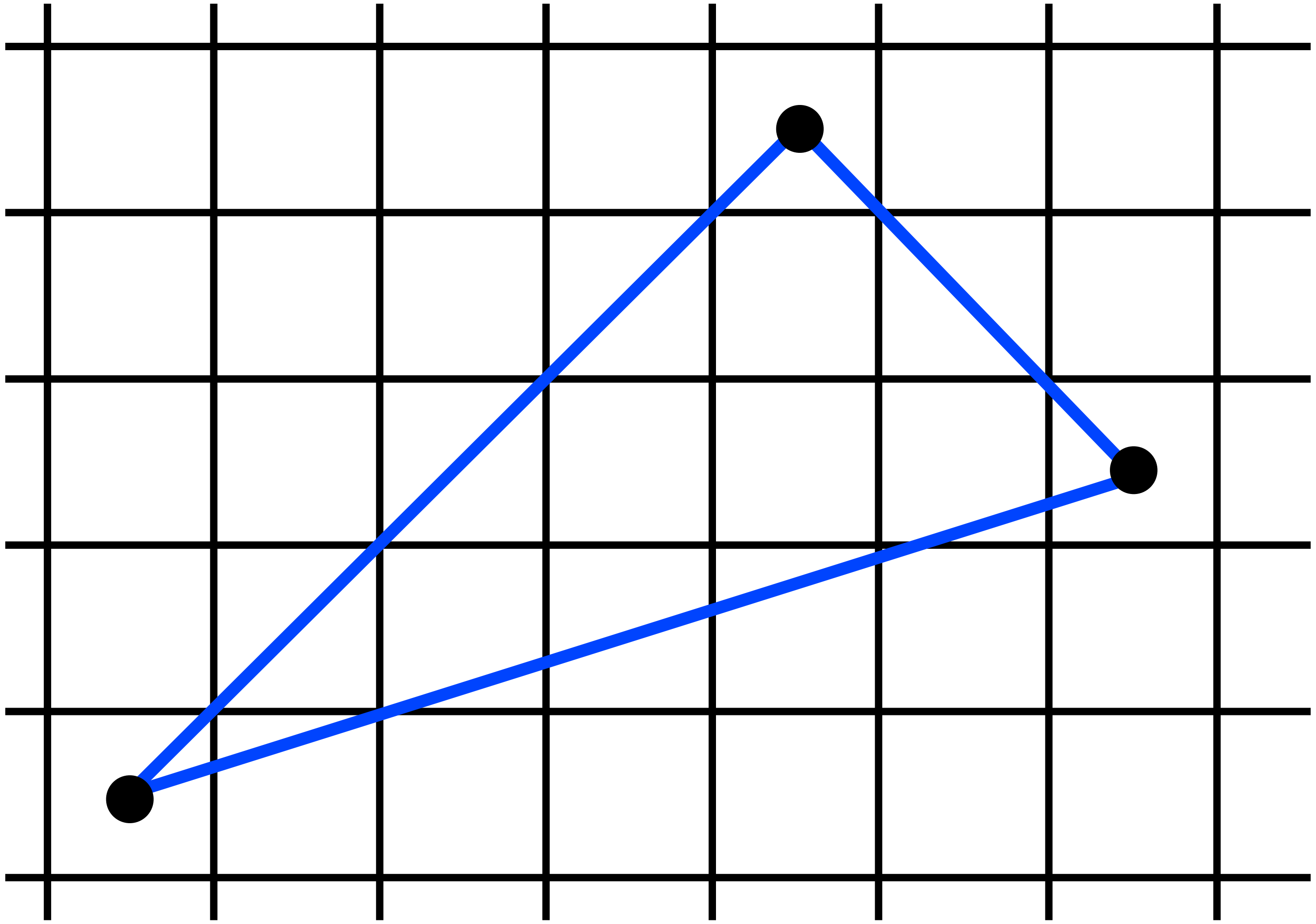
Triangle rasterization

Which pixels should be used to approximate a triangle?

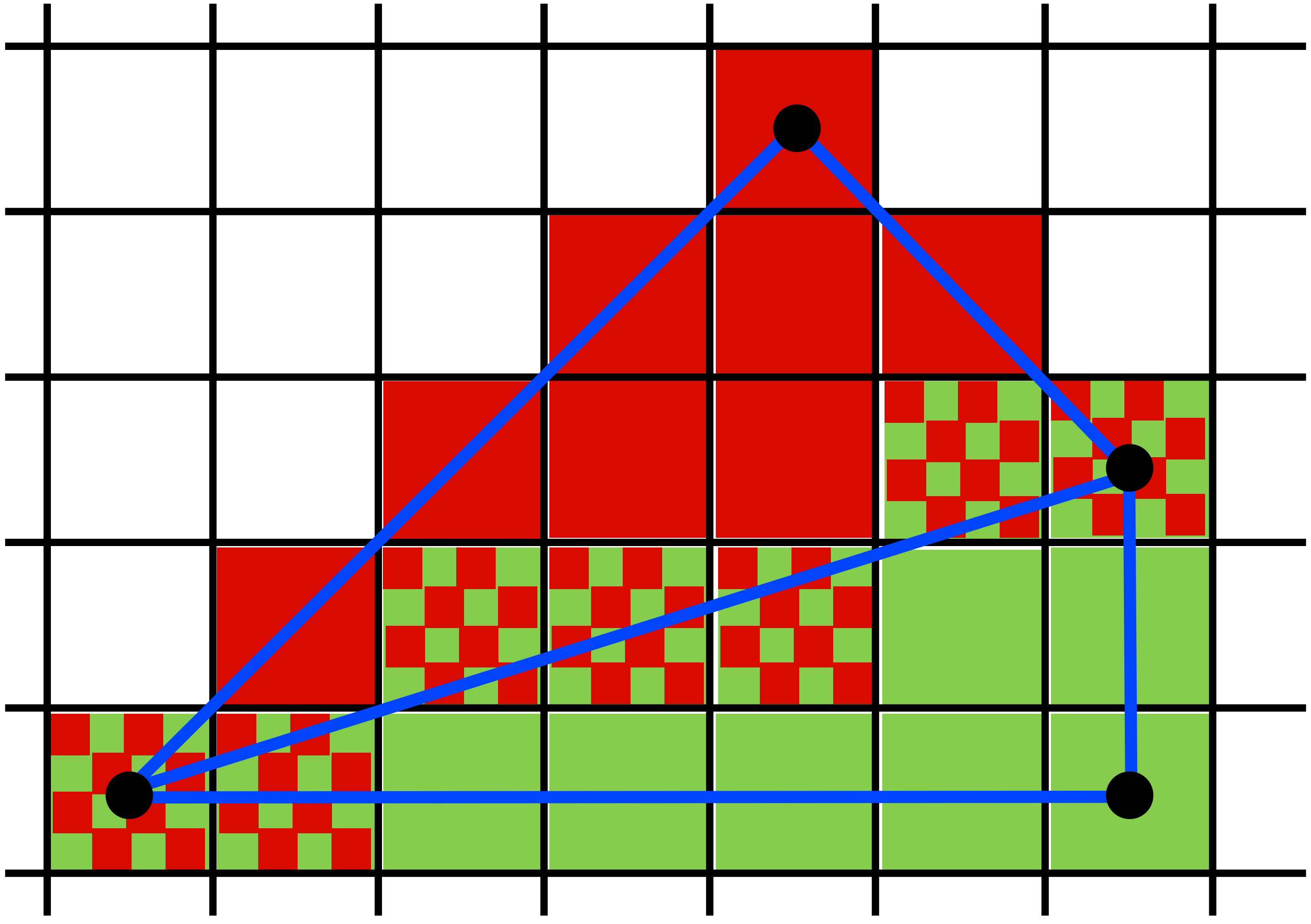


Triangle rasterization issues



Which pixels should be used to approximate a triangle?

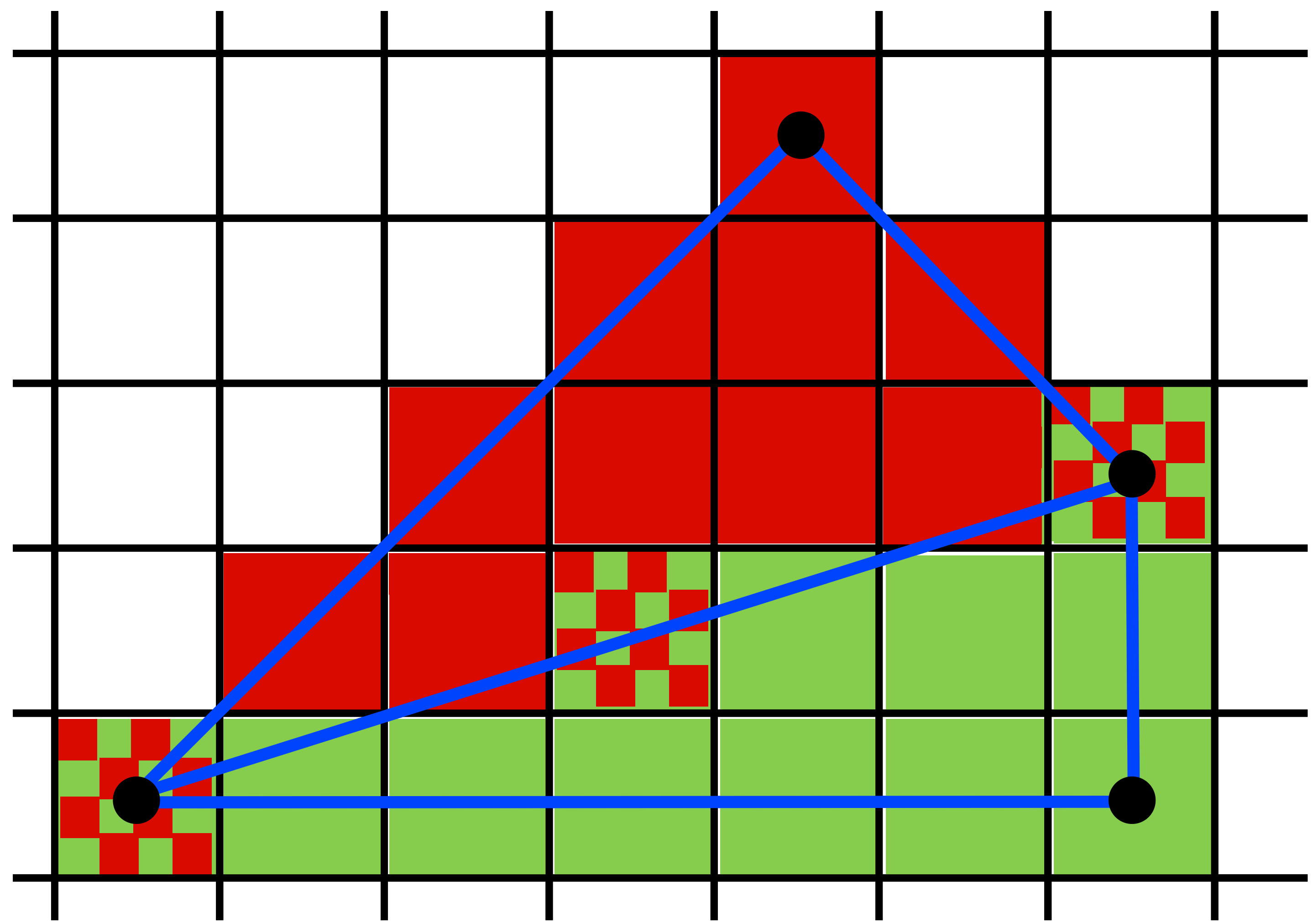
Which should fill in shared edge?



Which pixels should be used to approximate a triangle?

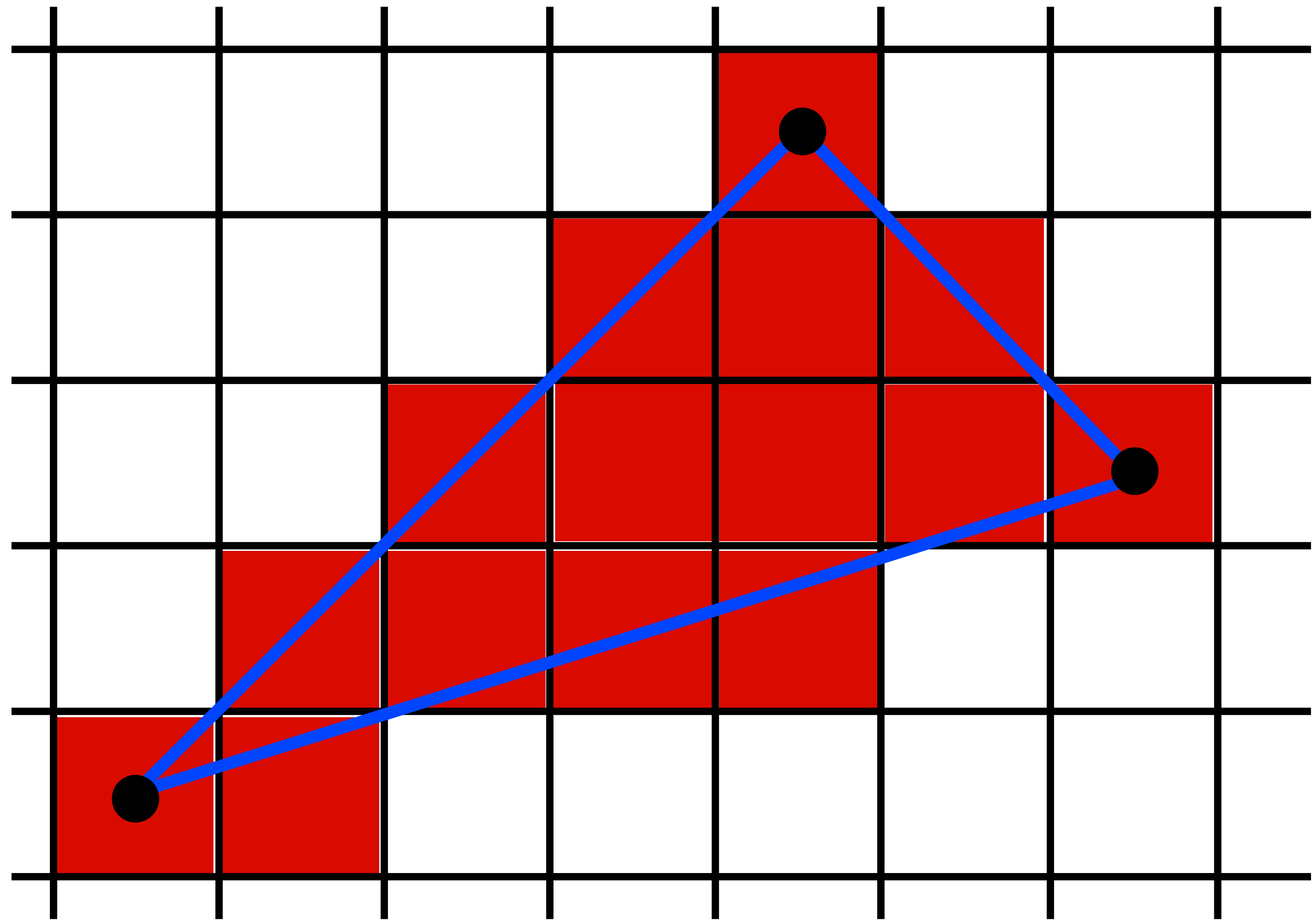
Which should fill in shared edge?

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



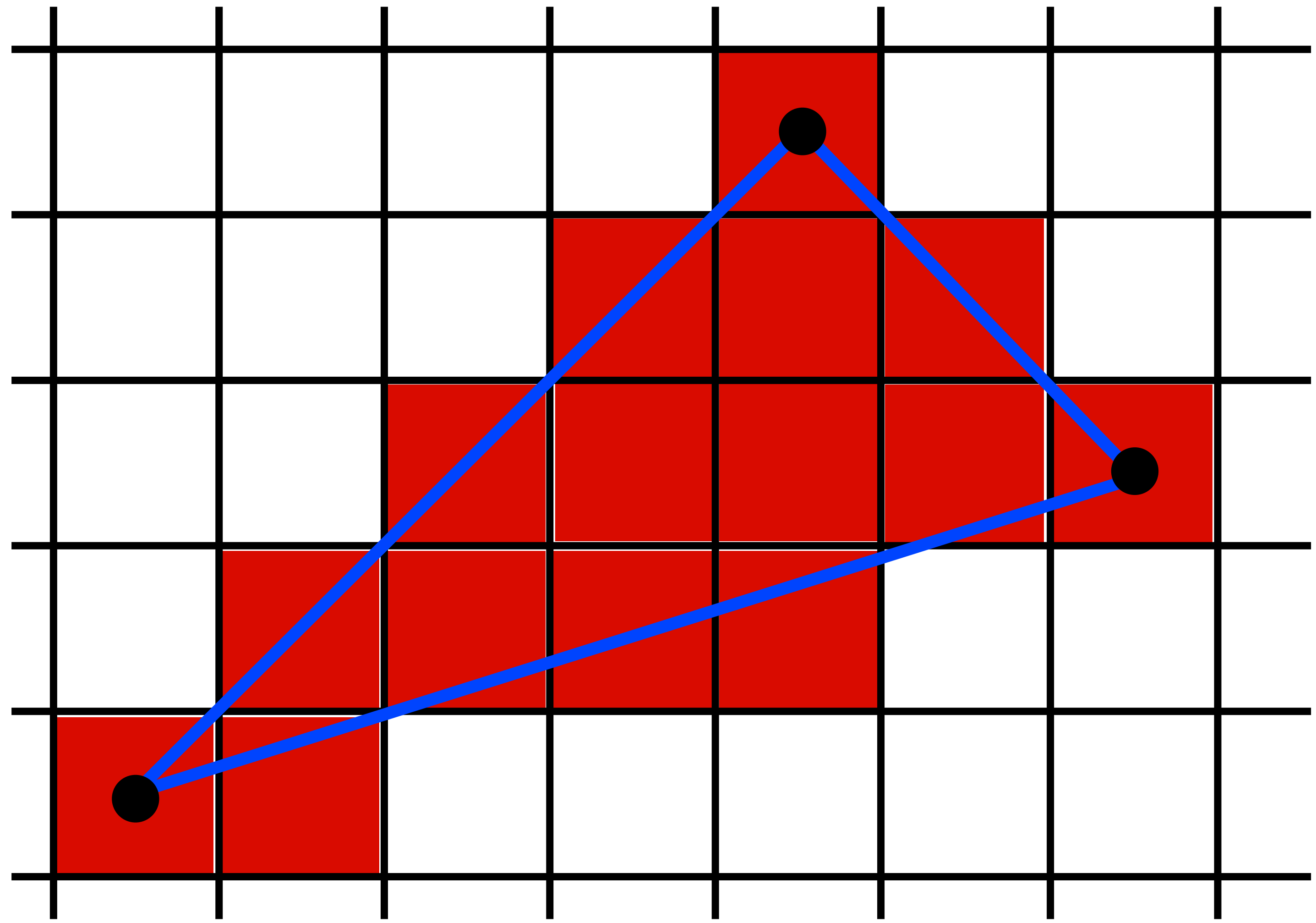
Which pixels should be used to approximate a triangle?

Use Midpoint Algorithm for edges and fill in?

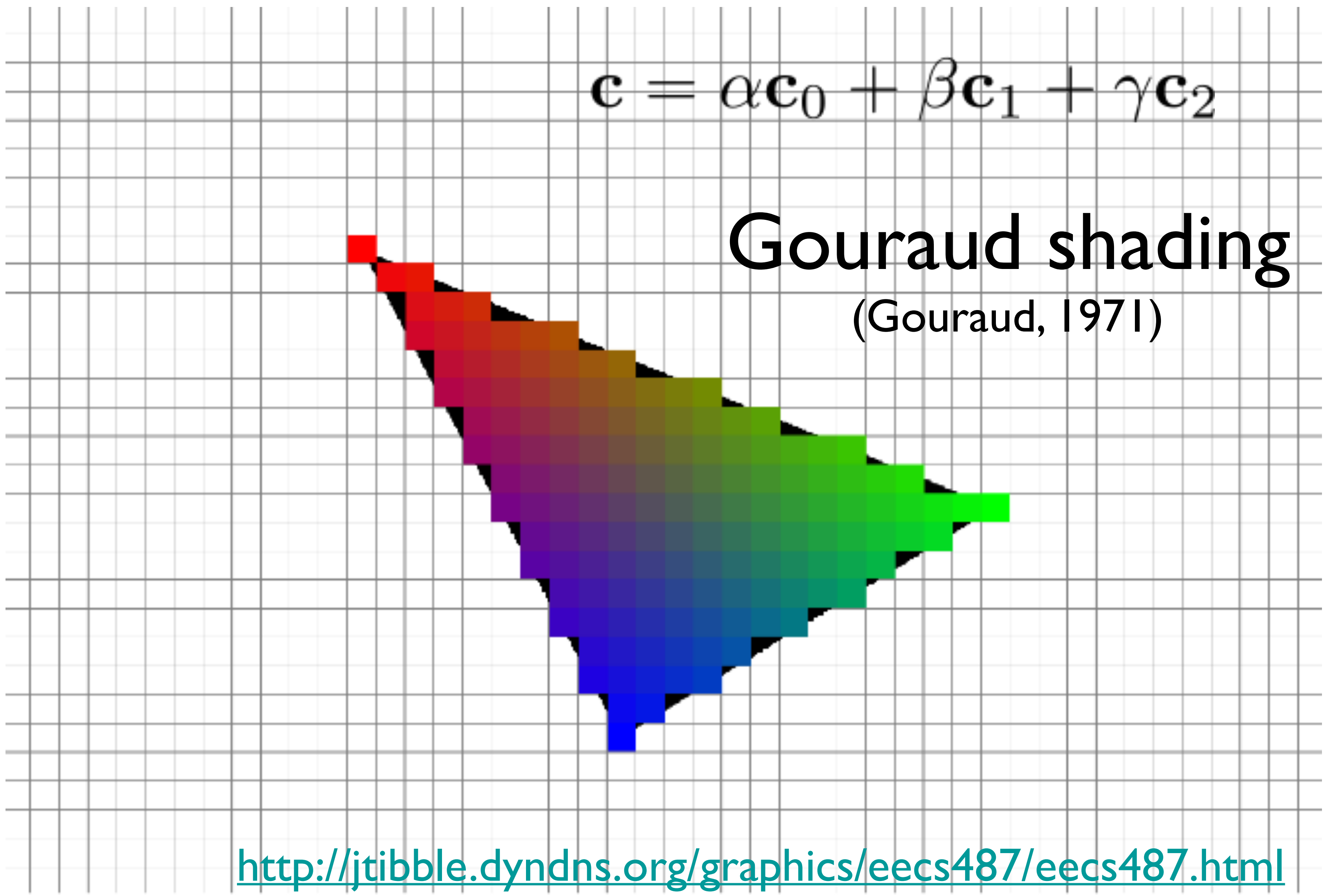


Which pixels should be used to approximate a triangle?

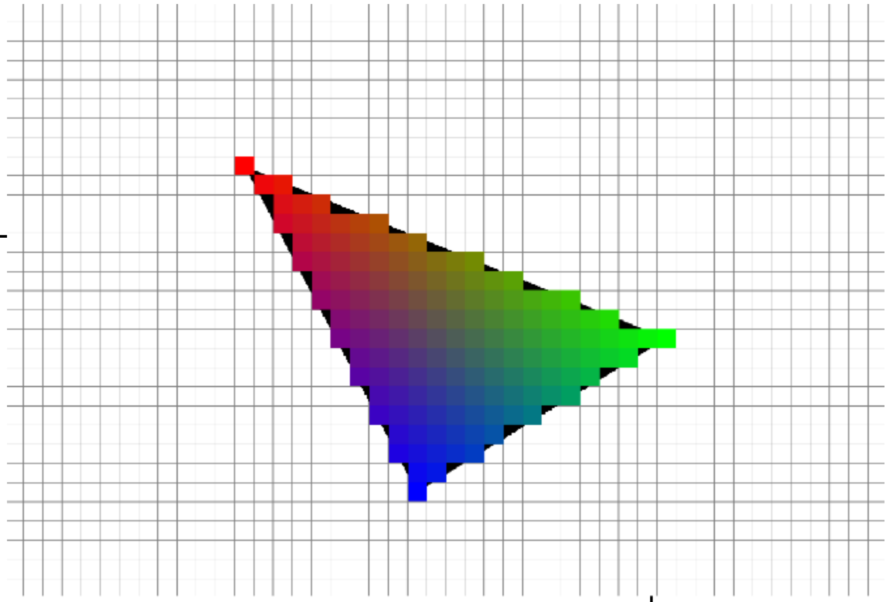
Use an approach based on **barycentric coordinates**



Advantage: we can easily interpolate attributes using barycentric coordinates

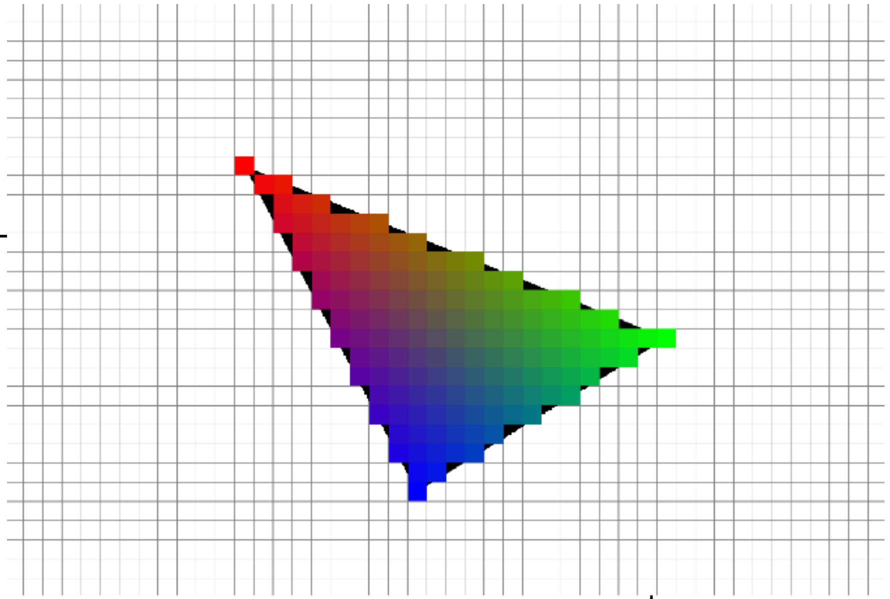


Triangle rasterization algorithm



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

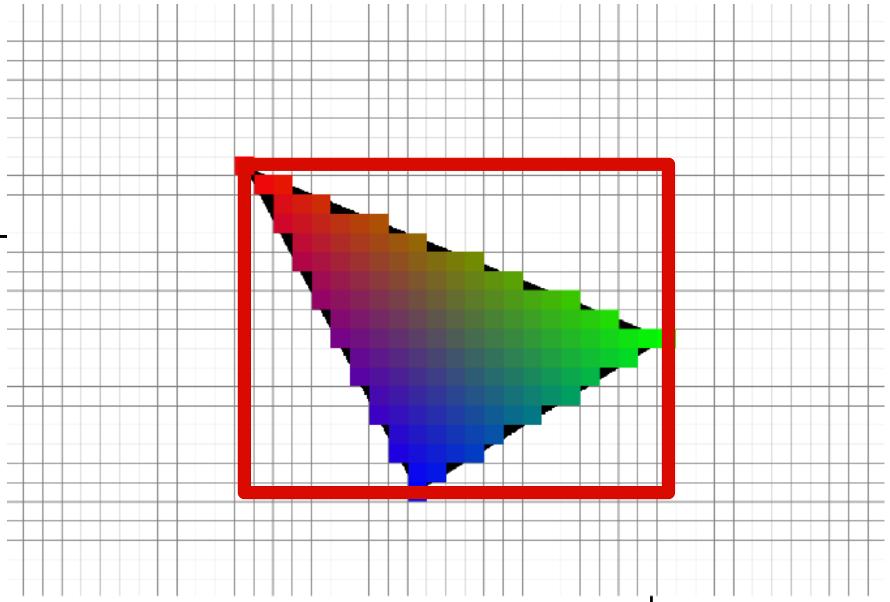


for all x do
    for all y do
        compute (α, β, γ) for (x,y)
        if $(\alpha \in [0, 1]$ and $\beta \in [0, 1]$ and $\gamma \in [0, 1])$ then
            $\mathbf{c} = \alpha \mathbf{c}_0 + \beta \mathbf{c}_1 + \gamma \mathbf{c}_2$
            drawpixel(x,y) with color c

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

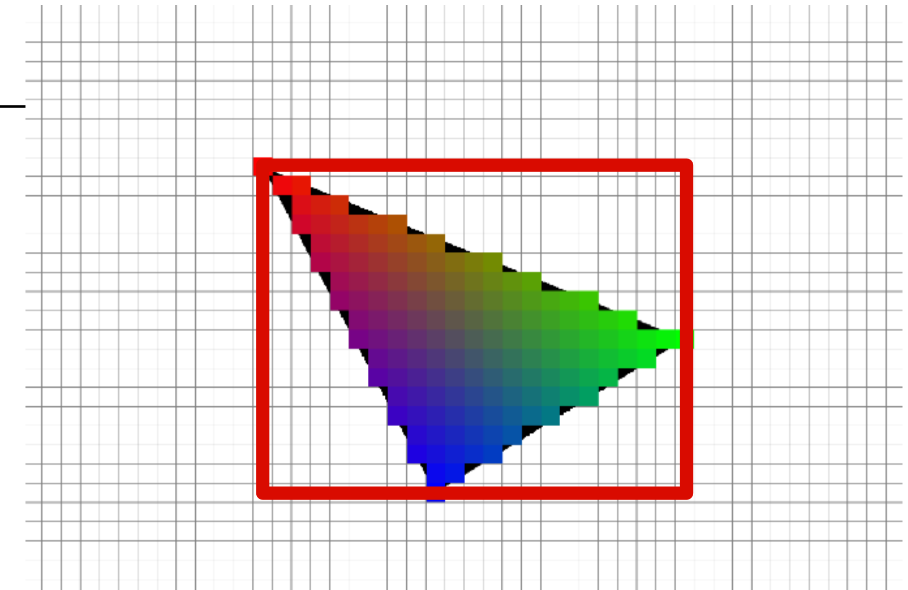
Triangle rasterization algorithm

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 $(\alpha \in [0,1] \text{ and } \beta \in [0,1] \text{ and } \gamma \in [0,1])$ then
            $\mathbf{c} = \alpha\mathbf{c}_0 + \beta\mathbf{c}_1 + \gamma\mathbf{c}_2$
            drawpixel(x,y) with color c

Triangle rasterization algorithm

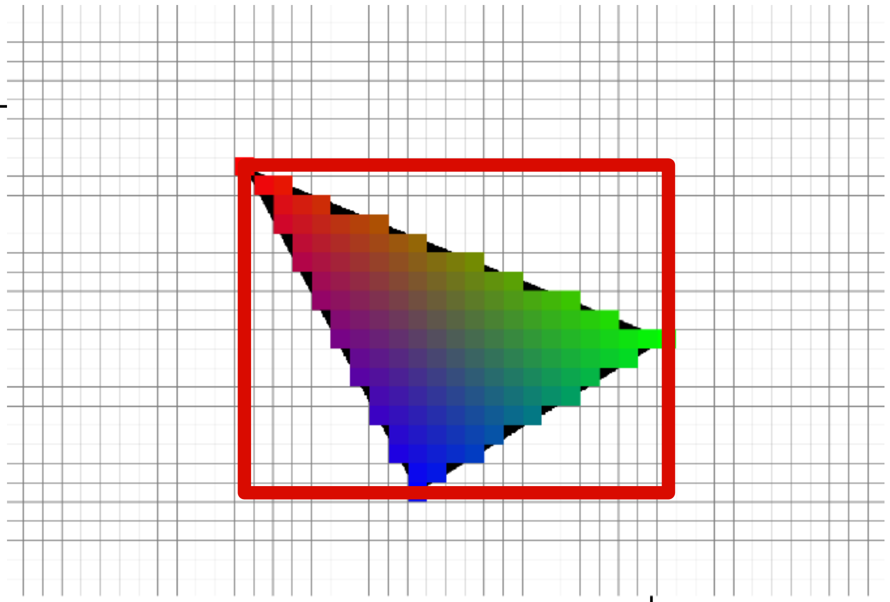


for x in [x_min, x_max]
    for y in [y_min, y_max]
        $\alpha = f_{bc}(x,y)/f_{bc}(x_a,y_a)$
        $\beta = f_{ca}(x,y)/f_{ca}(x_b,y_b)$
        $\gamma = f_{ab}(x,y)/f_{ab}(x_c,y_c)$
        if $(\alpha \in [0,1] \text{ and } \beta \in [0,1] \text{ and } \gamma \in [0,1])$ then
            $\mathbf{c}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

<whiteboard>

Triangle rasterization algorithm

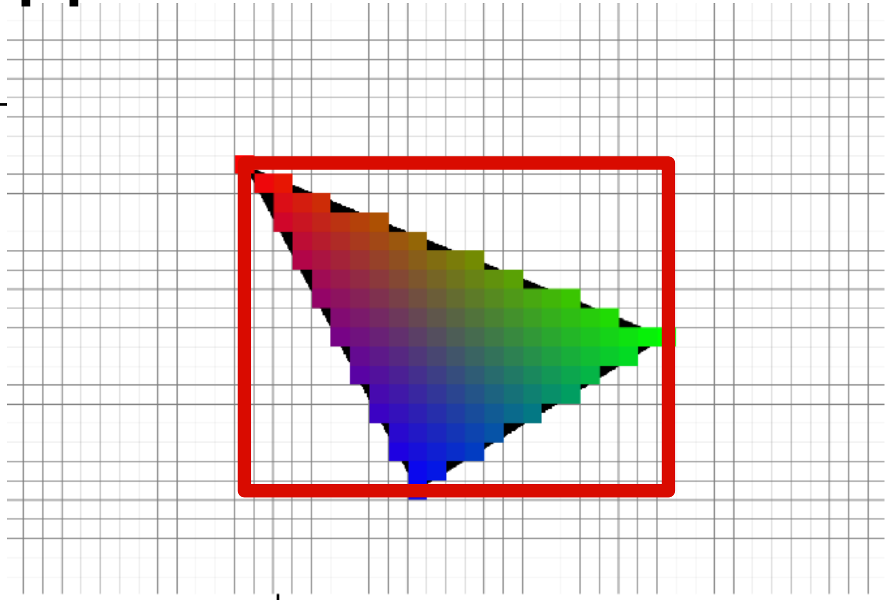
Optimizations?



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 $(\alpha \in [0,1]$ 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

Triangle rasterization algorithm

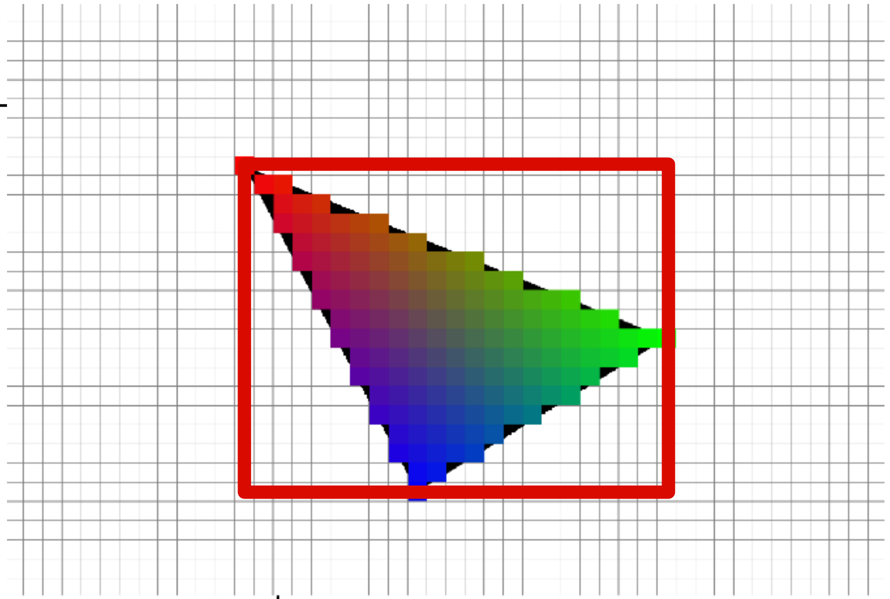
Optimizations? don't need to check upper bound



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

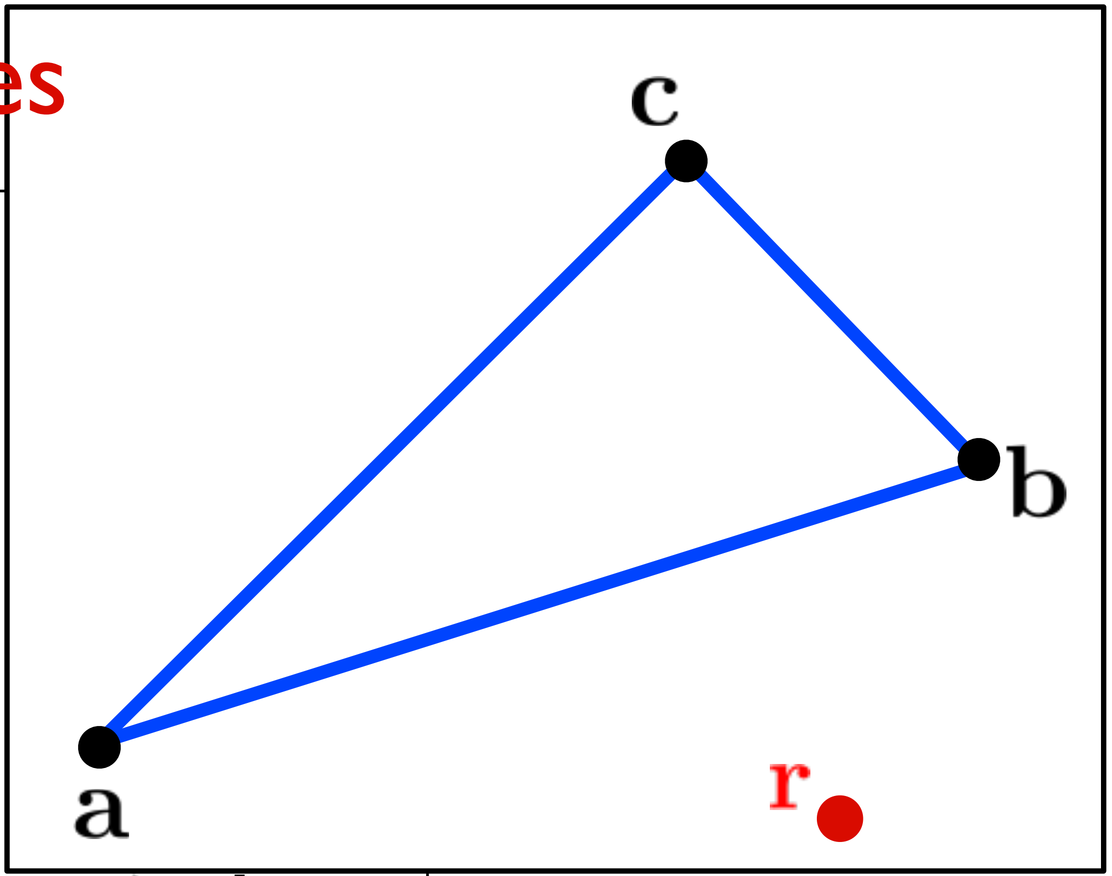
Optimizations? compute bary. coord. and colors incrementally



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

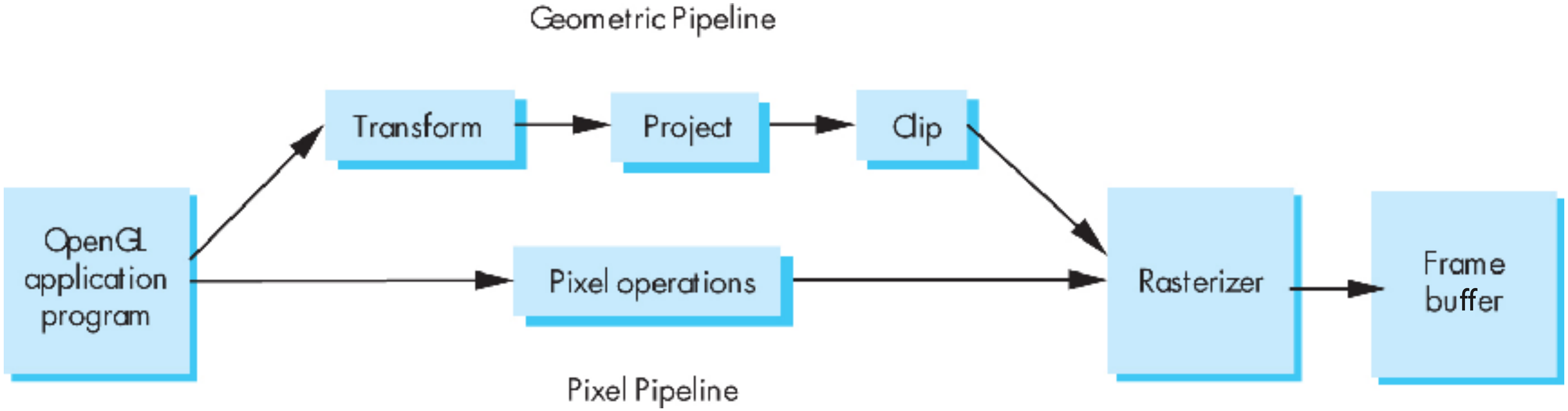
dealing with shared triangle edges



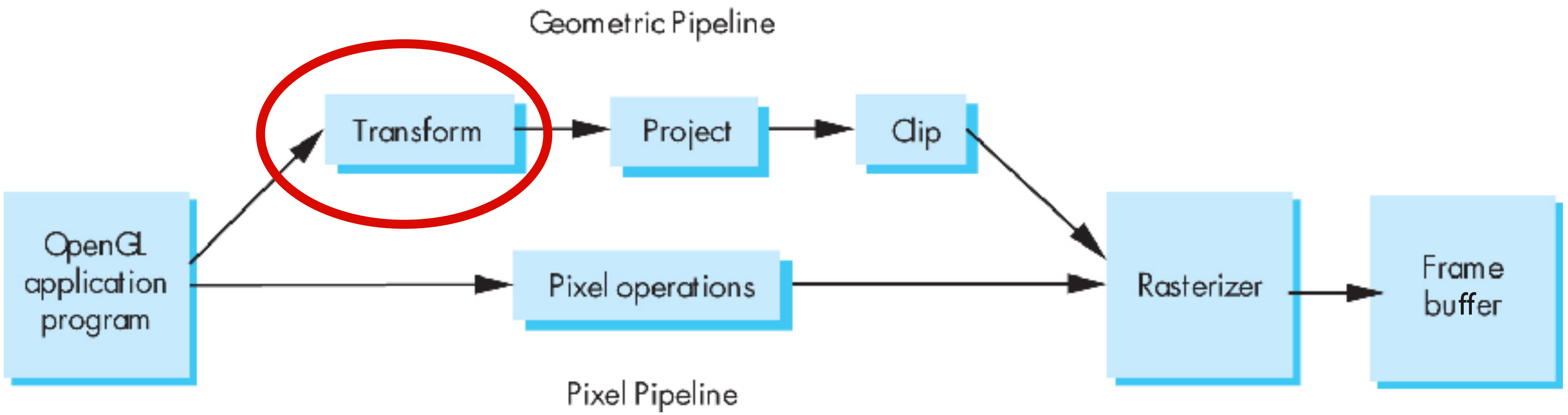
for x in [x_min, x_max]
    for y in [y_min, y_max]
        $\alpha = f_{bc}(x,y)/f_{bc}(x_a,y_a)$
        $\beta = f_{ac}(x,y)/f_{ac}(x_b,y_b)$
        $\gamma = f_{ab}(x,y)/f_{ab}(x_c,y_c)$
        if $(\alpha \geq 0 \text{ and } \beta \geq 0 \text{ and } \gamma \geq 0)$ then
            if $(\alpha > 0 \text{ or } f_{bc}(\mathbf{a})f_{bc}(\mathbf{r}) > 0)$ 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.)

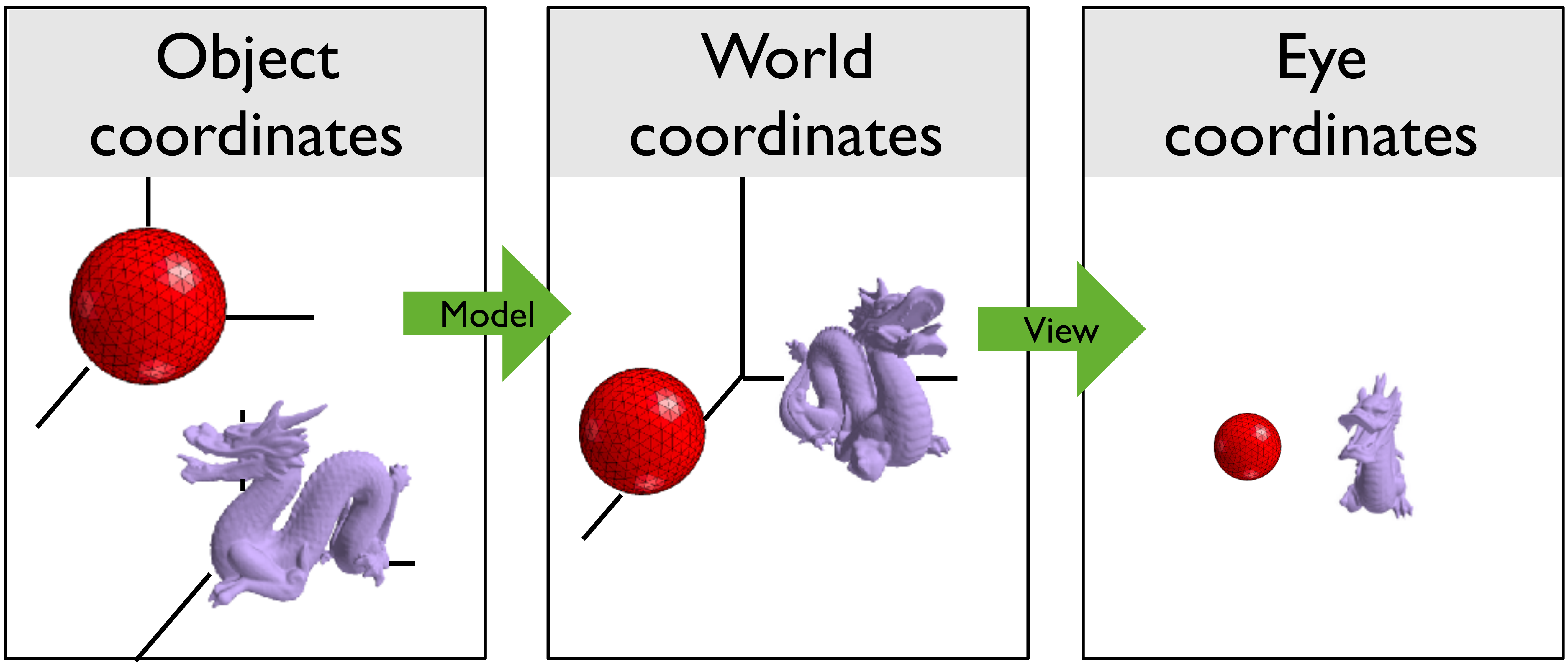
Graphics Pipeline



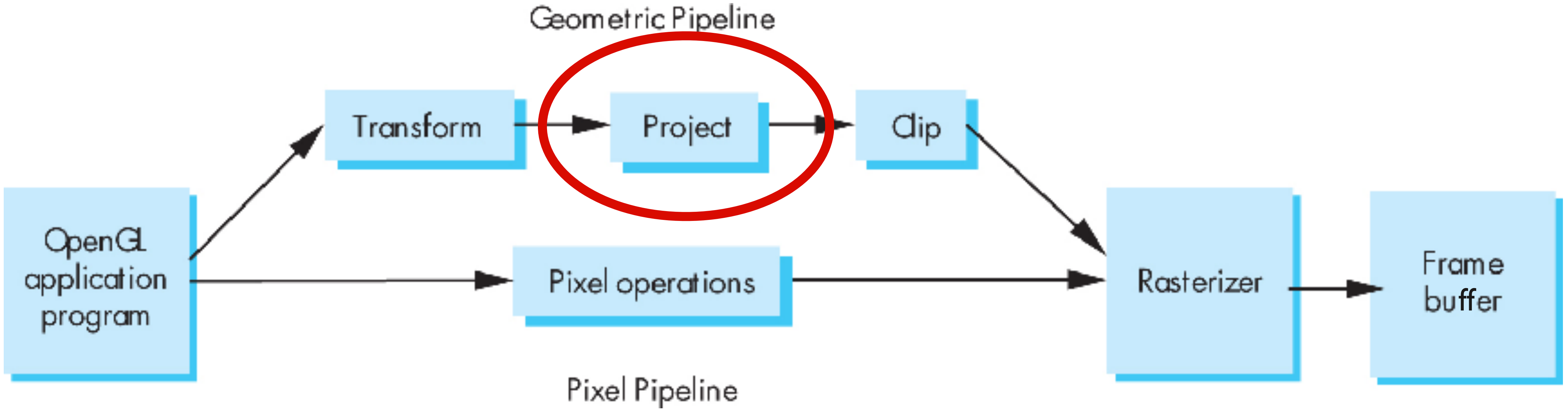
Transform


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

“Modelview” Transformation



Project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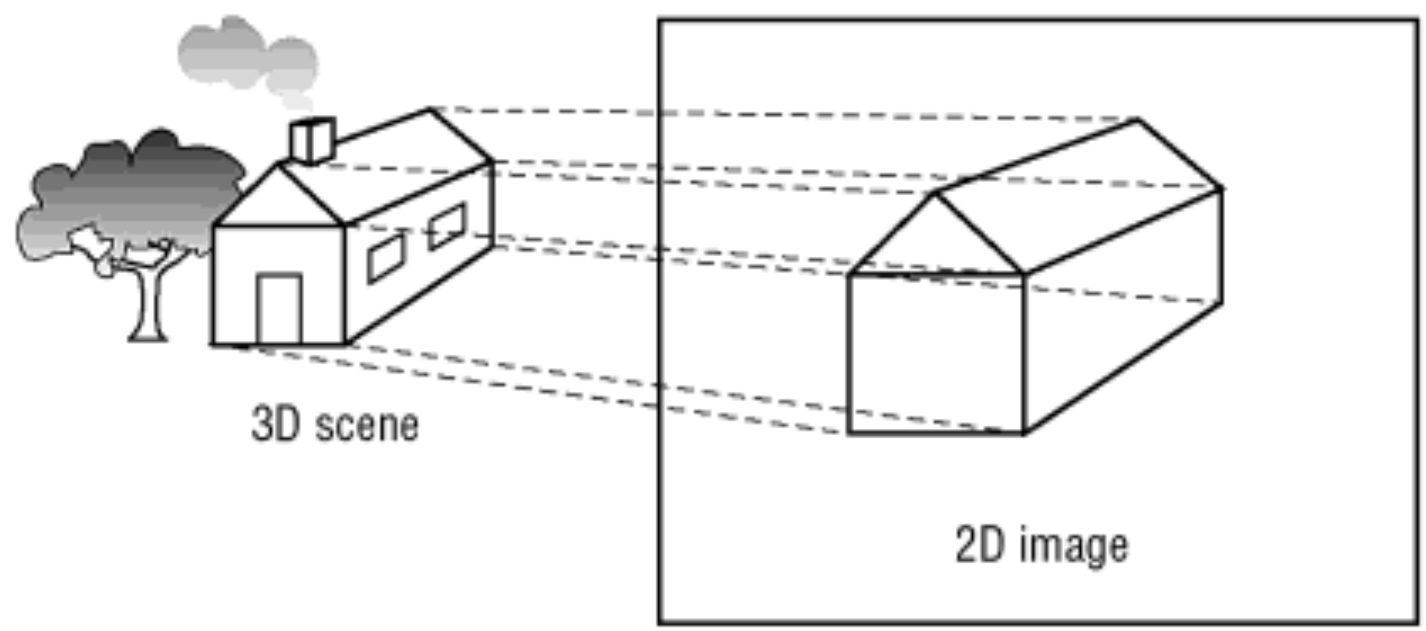
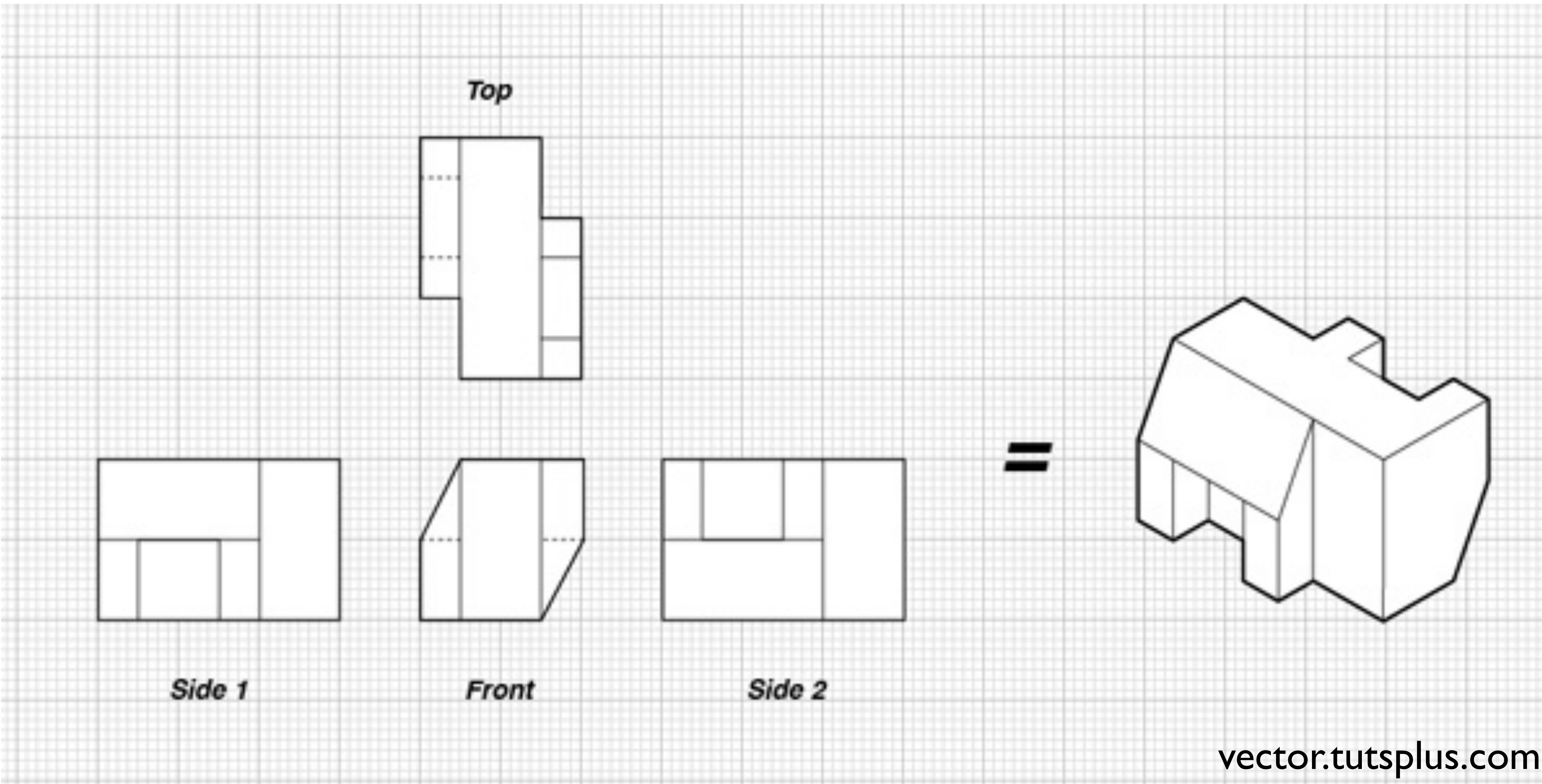
Projection: map 3D scene to 2D image



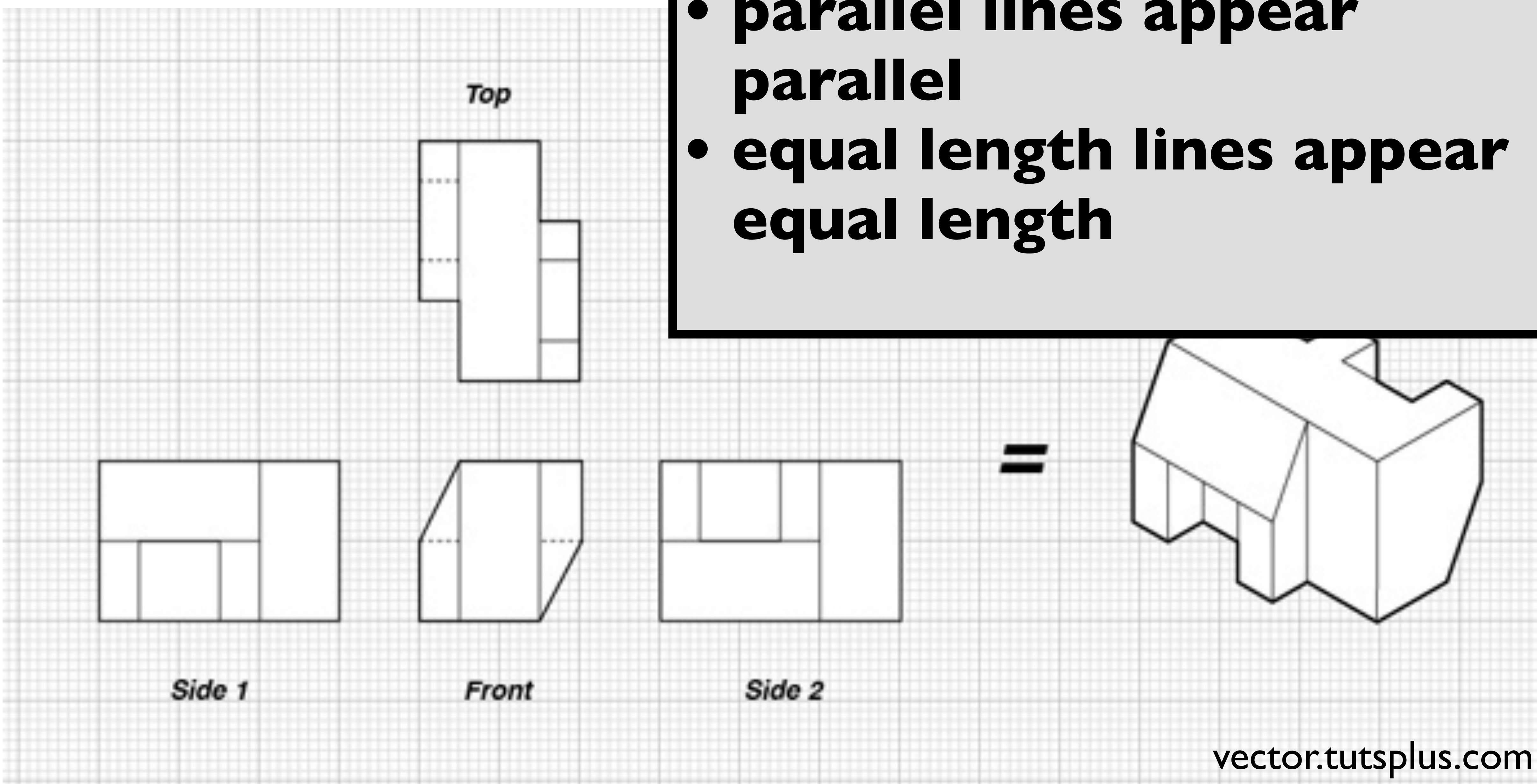
OpenGL Super Bible, 5th Ed.

Orthographic projection



Orthographic projection

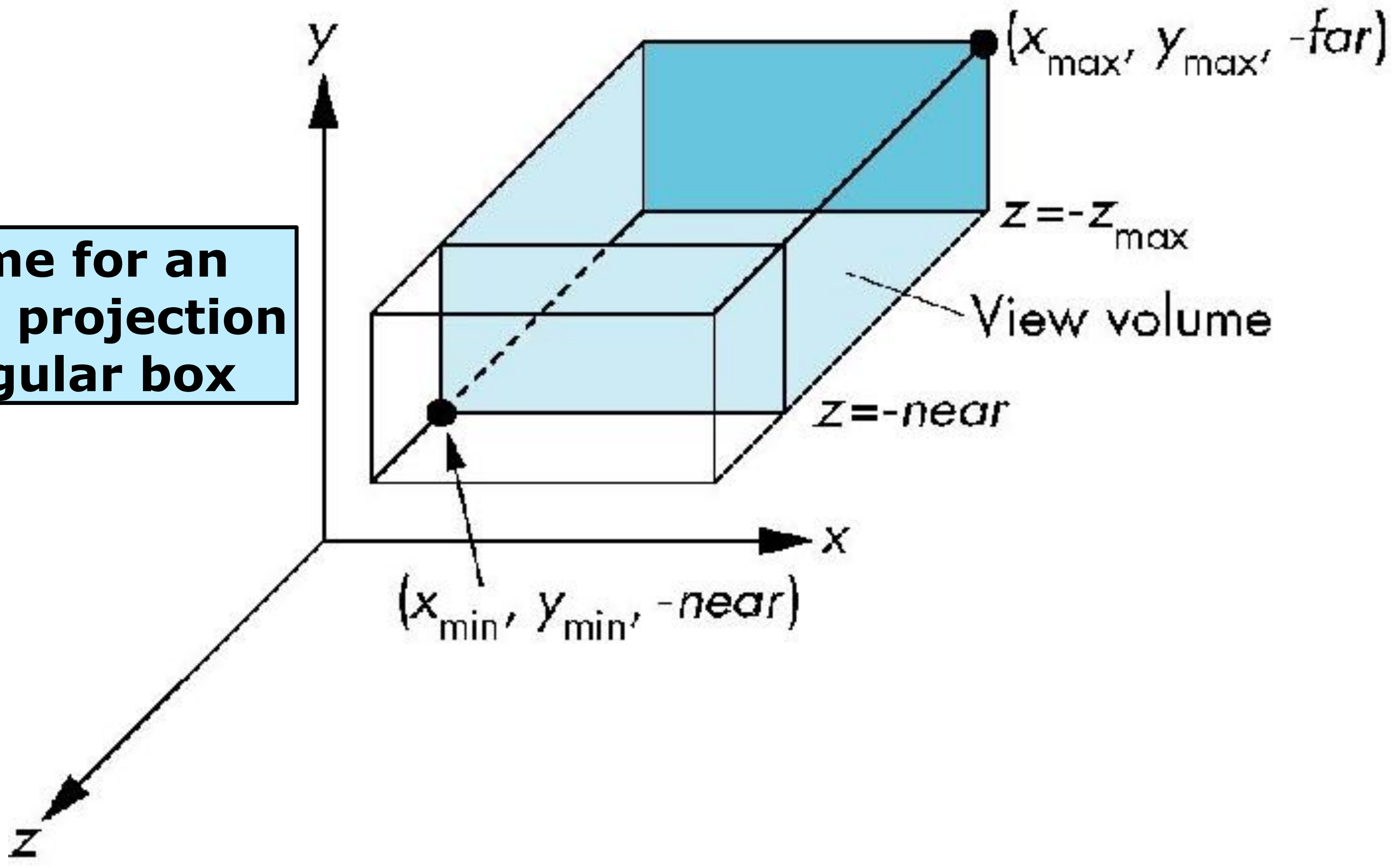
- **parallel lines appear parallel**
- **equal length lines appear equal length**



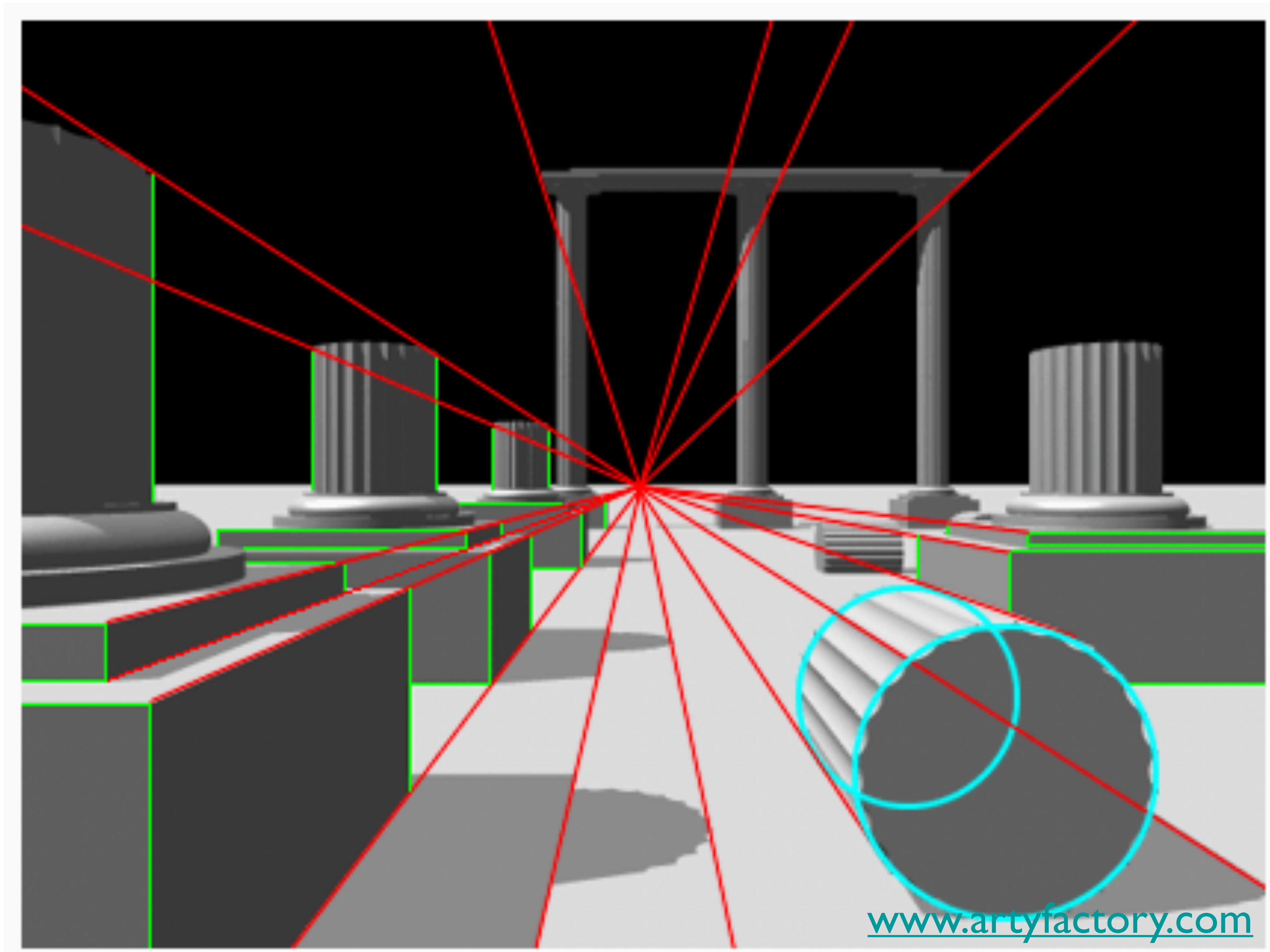
OpenGL Orthogonal Viewing

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

View volume for an orthographic projection is a rectangular box



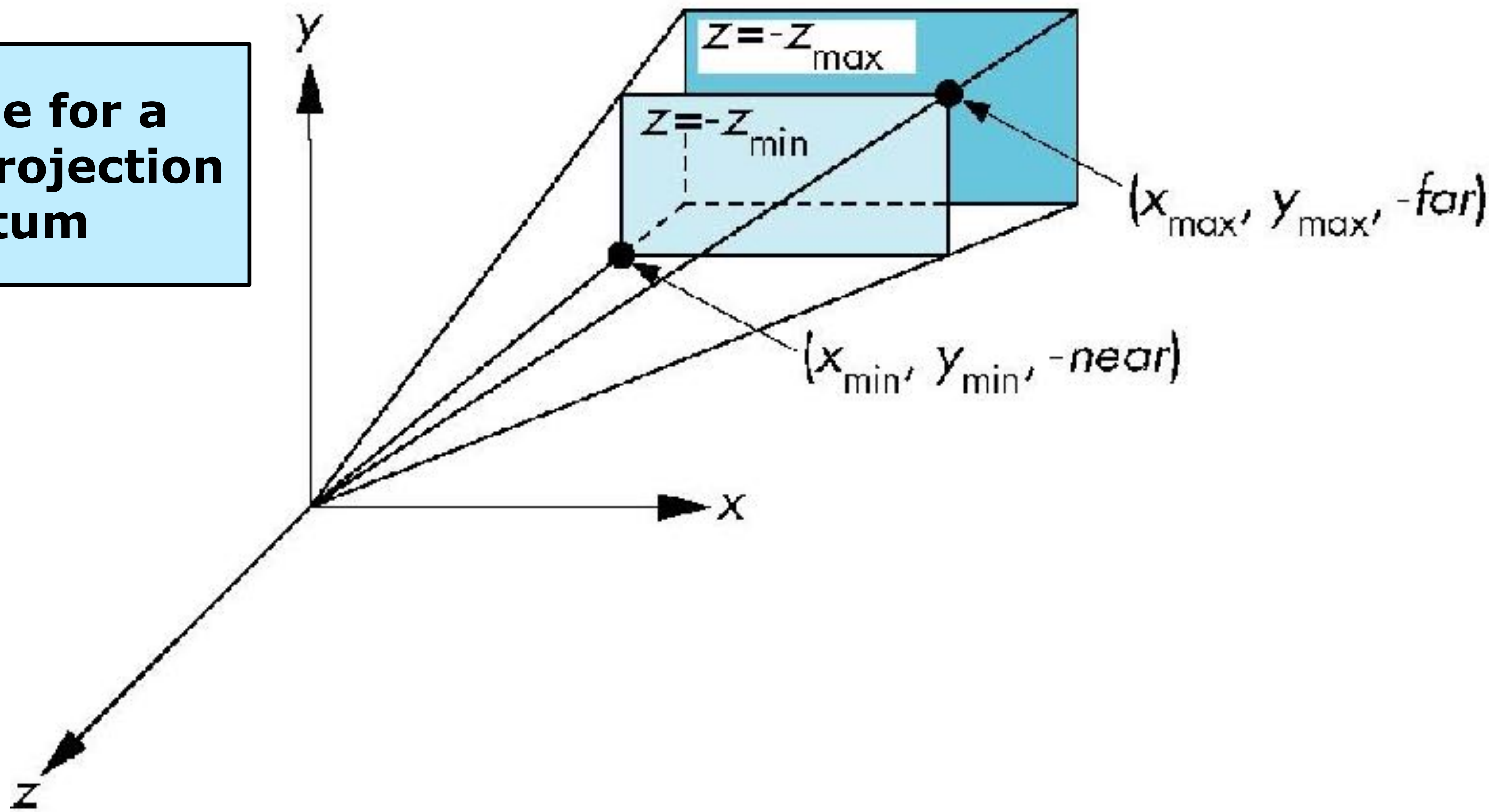
Perspective projection



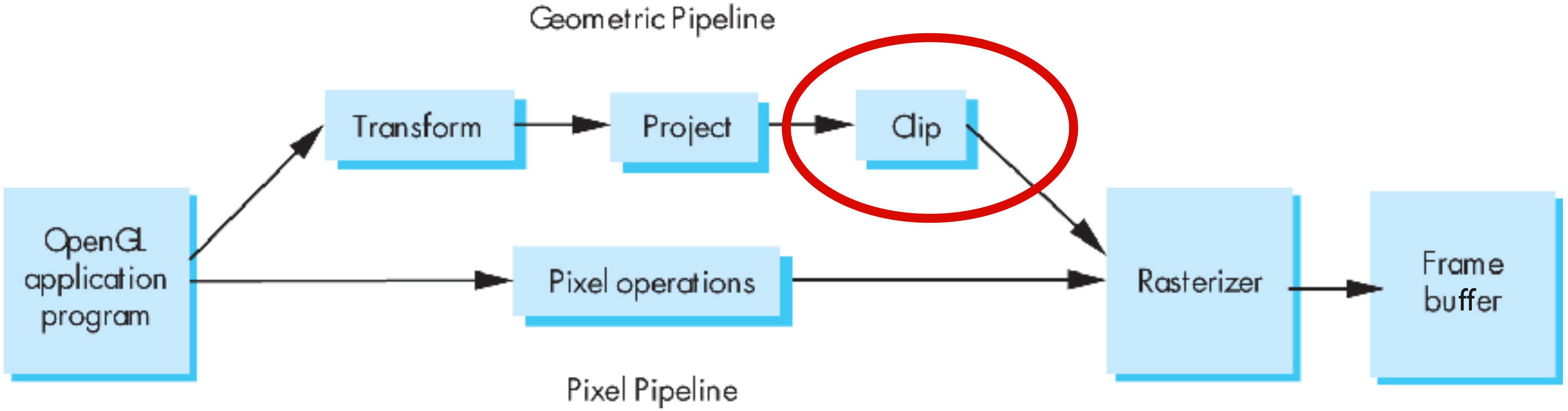
OpenGL Perspective Viewing

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

View volume for a perspective projection is a frustum



Clip



Geometric Pipeline
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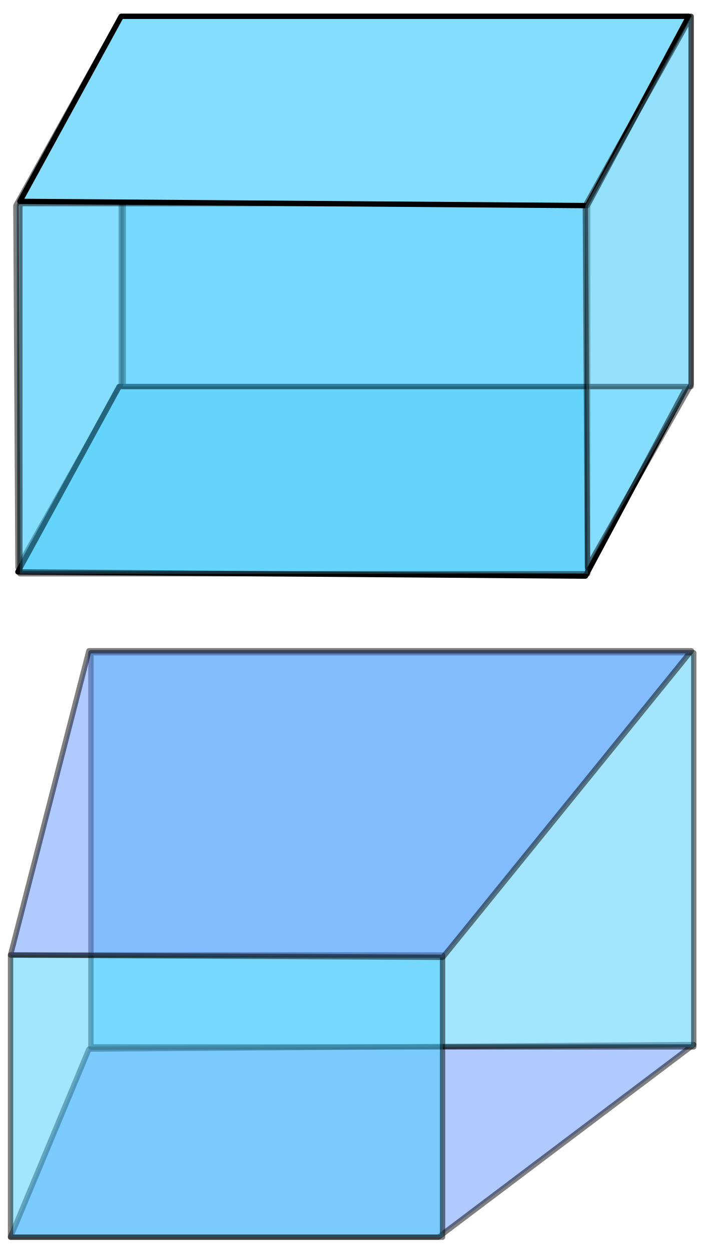
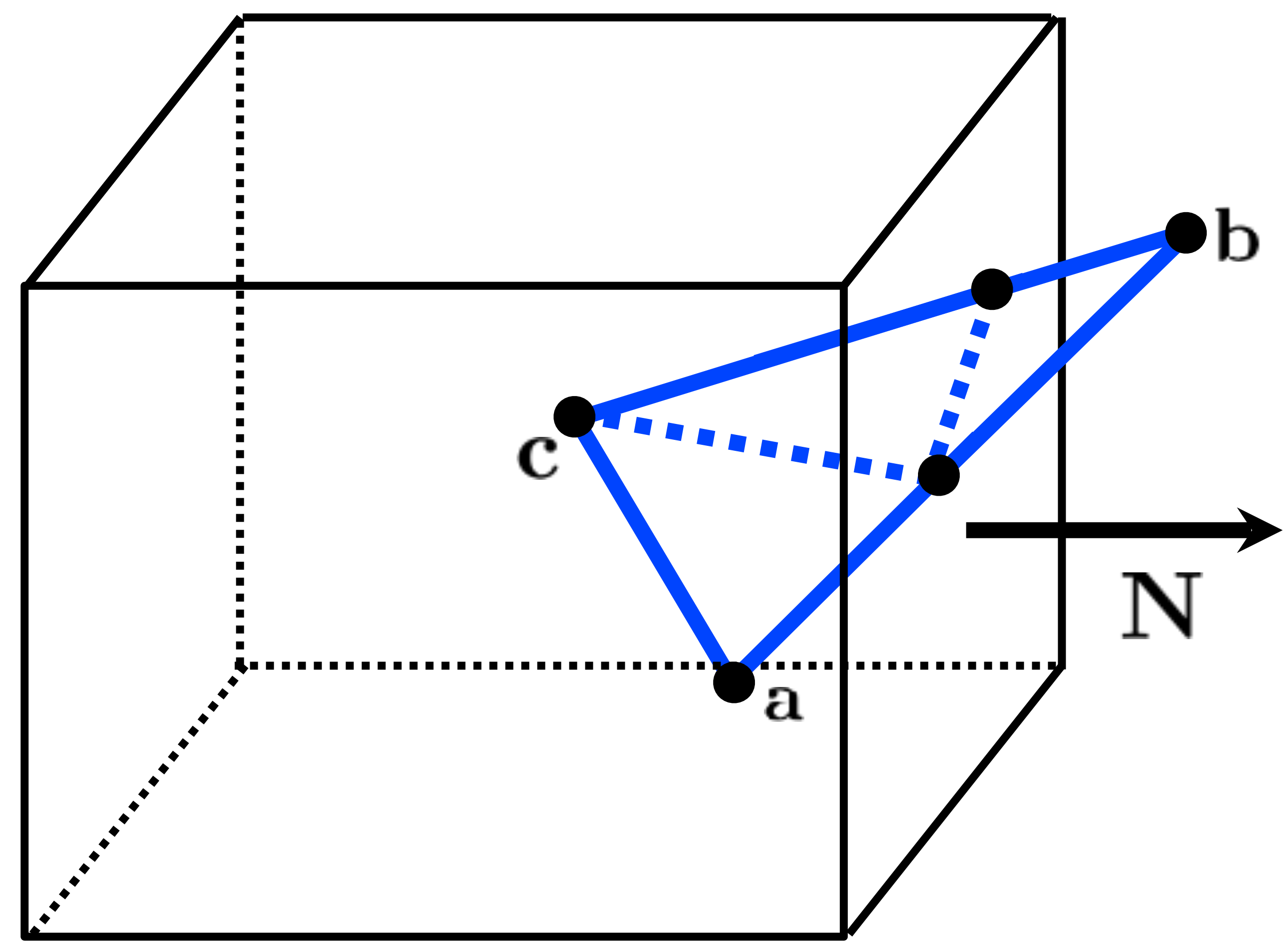
Pixel Pipeline

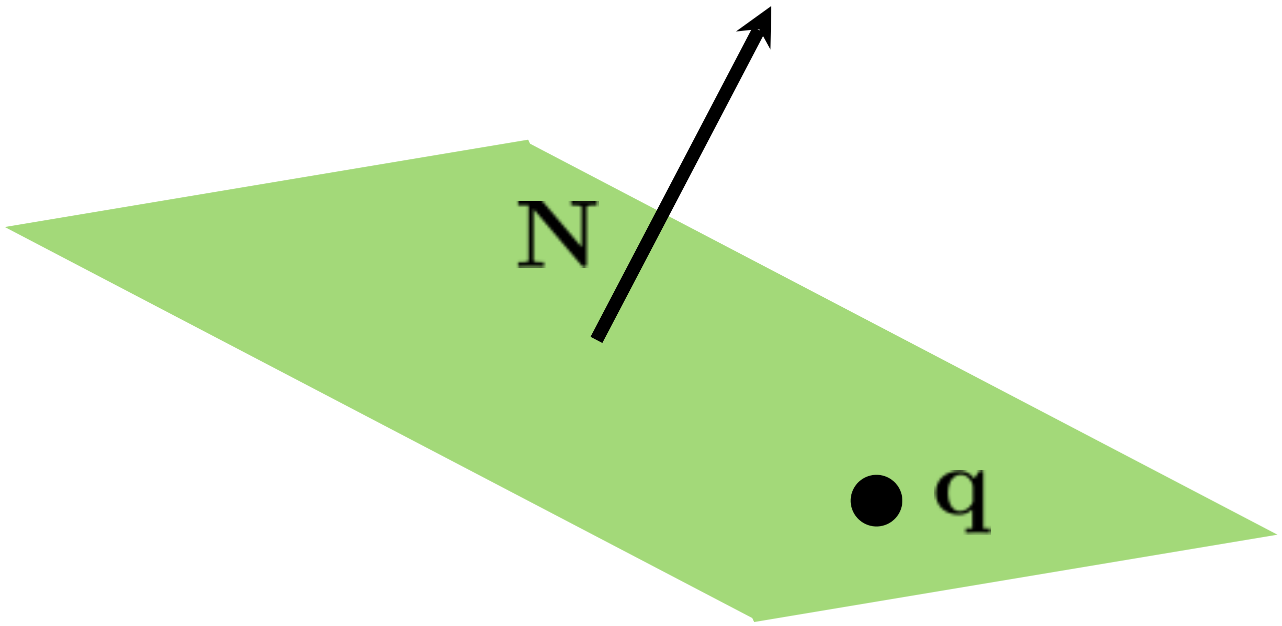
Clip against view volume

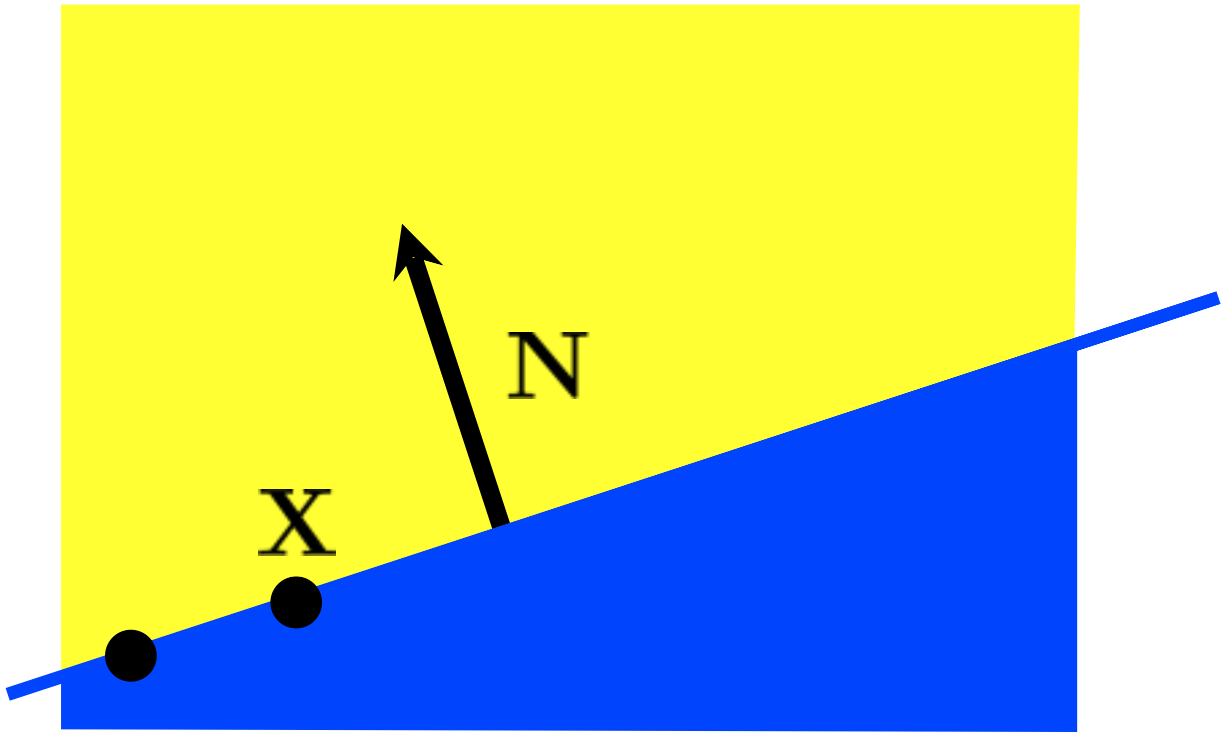




Clipping against a plane

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





implicit line equation:

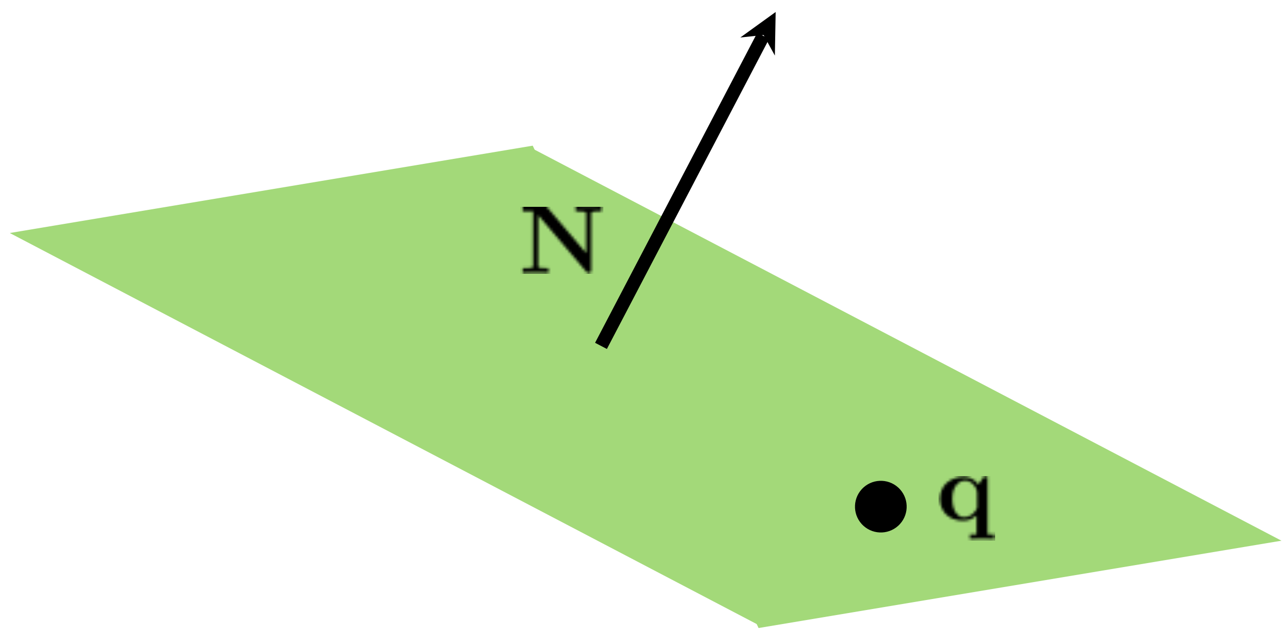
$$f(\mathbf{X}) = \mathbf{N} \cdot (\mathbf{X} - \mathbf{X}_0) = 0$$

Clipping against a plane

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

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

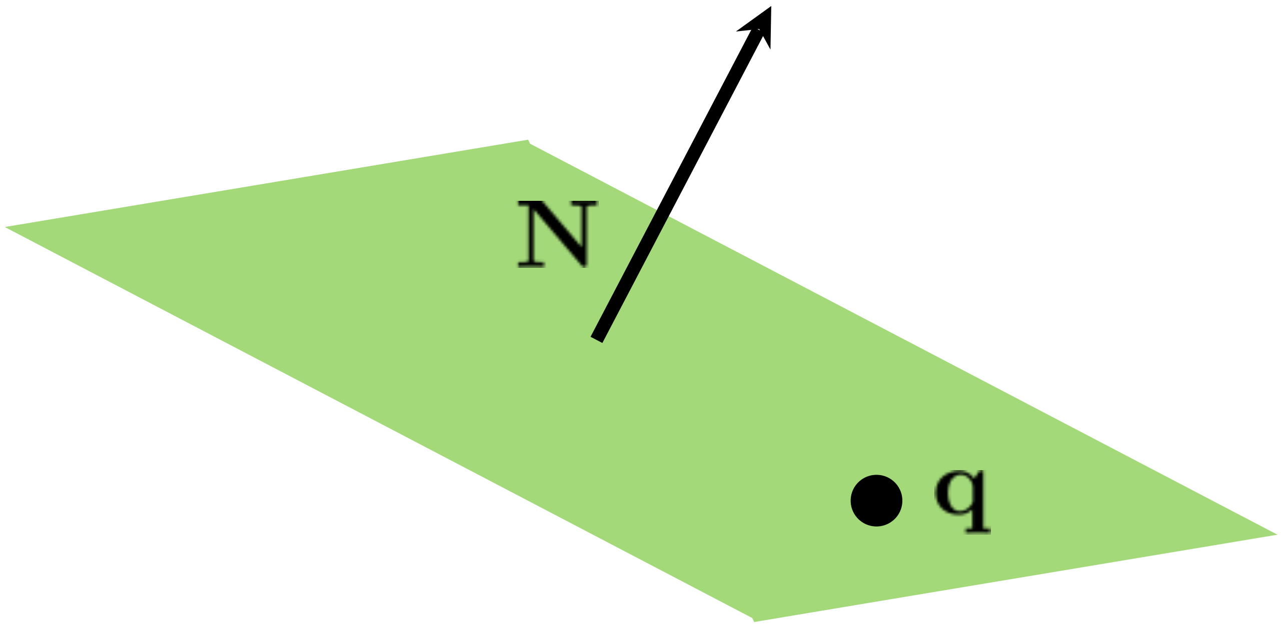
<whiteboard>



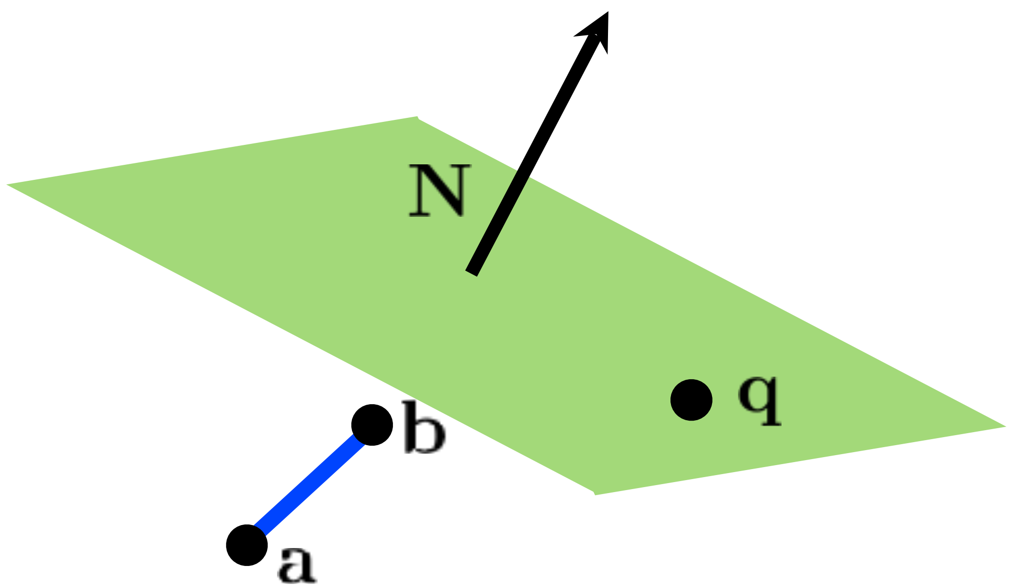
Clipping against a plane

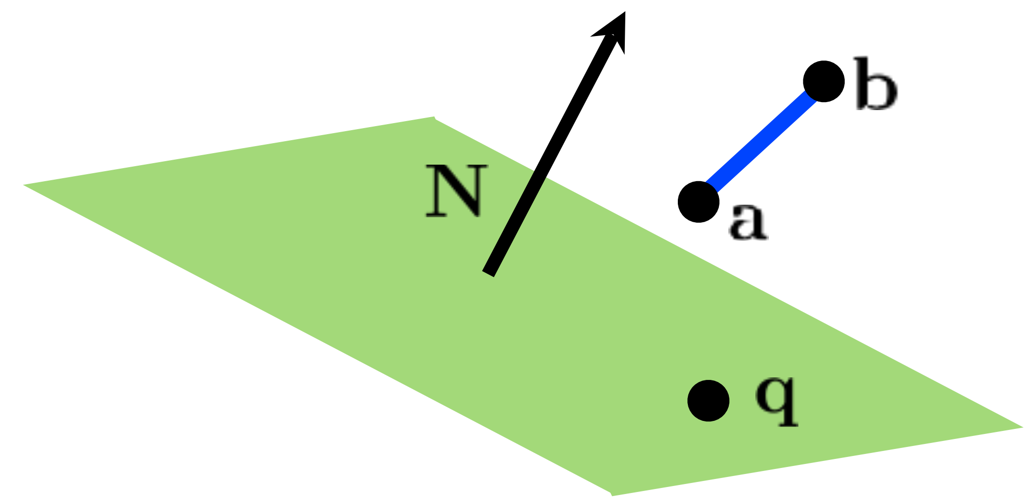
What's the equation for the plane through **q** with normal **N**?

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

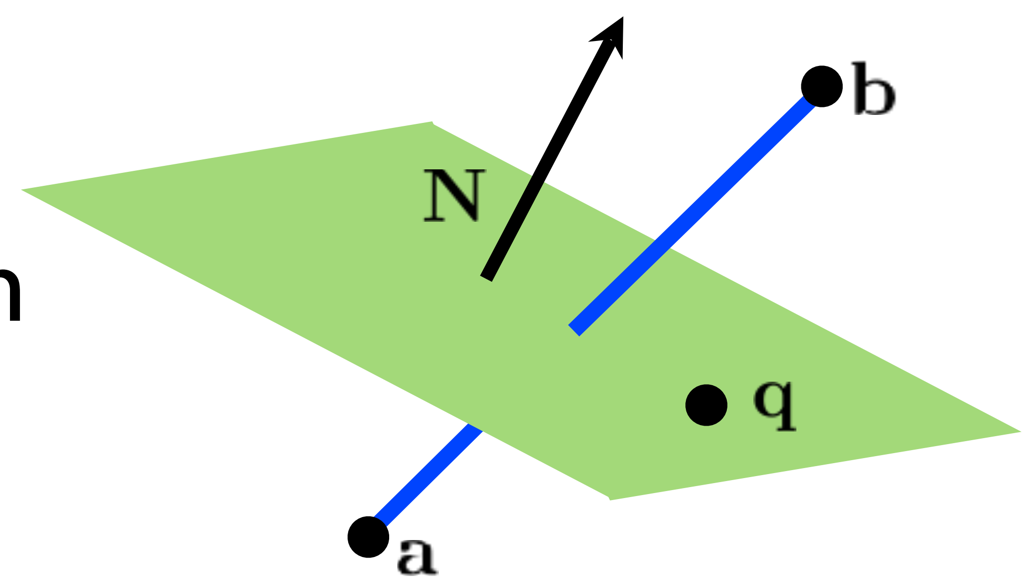


Intersection of line and plane



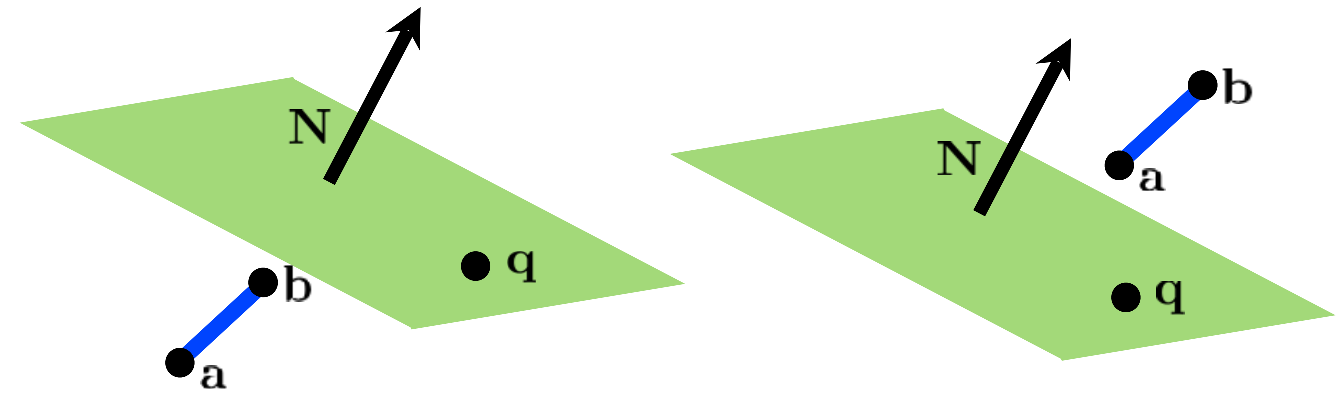


How can we distinguish between these cases?

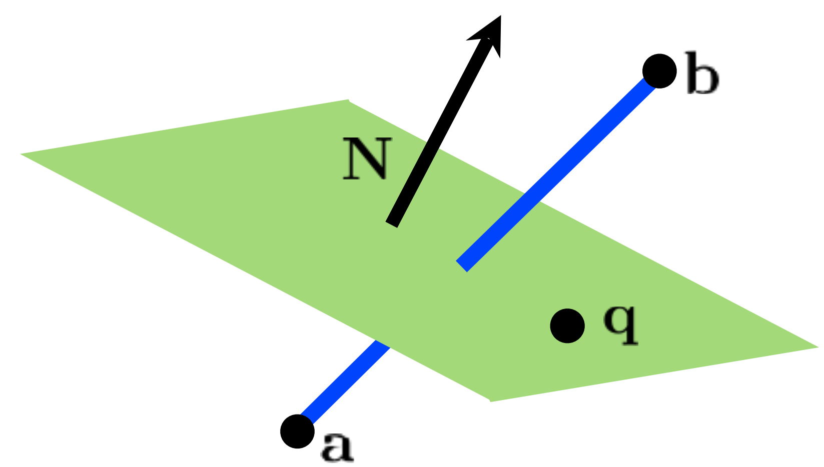


Intersection of line and plane

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

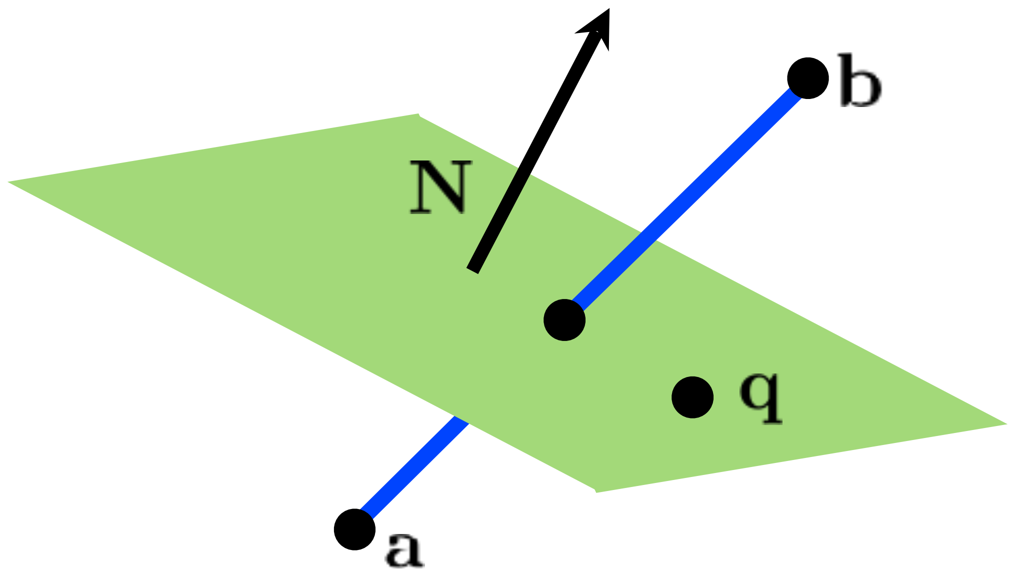


$$f(\mathbf{a})f(\mathbf{b}) < 0$$



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