Graphics Pipeline: Transformation, Shading/Lighting, Projection, Texturing, and more!

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Computer Graphics Pipeline

Geometry

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Modeling Transformation	Transform into 3D *world* coordinate system
Lighting	Simulate illumination and reflectance
Viewing Transformation	Transform into 3D *camera* coordinate system
Clipping	Clip primitives outside camera's view
Projection	Transform into 2D camera coordinate system
Scan Conversion	Draw pixels (incl. texturing, hidden surface…)

↓

Image

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Image

Modeling Transformations

- Most popular transformations in graphics
  - Translation
  - Rotation
  - Scale
  - Projection
- In order to use a single matrix for all, we use homogeneous coordinates…

Modeling Transformations

$$\begin{bmatrix} x' \\ y' \\ z' \\ w \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

Identity

$$\begin{bmatrix} x' \\ y' \\ z' \\ w \end{bmatrix} = \begin{bmatrix} sx & 0 & 0 & 0 \\ 0 & sy & 0 & 0 \\ 0 & 0 & sz & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

Scale

$$\begin{bmatrix} x' \\ y' \\ z' \\ w \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & tx \\ 0 & 1 & 0 & ty \\ 0 & 0 & 1 & tz \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

Translation

$$\begin{bmatrix} x' \\ y' \\ z' \\ w \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

Mirror over X axis

Modeling Transformations

Rotate around Z axis:

$$\begin{bmatrix} x' \\ y' \\ z' \\ w \end{bmatrix} = \begin{bmatrix} \cos\Theta & -\sin\Theta & 0 & 0 \\ \sin\Theta & \cos\Theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

Rotate around Y axis:

$$\begin{bmatrix} x' \\ y' \\ z' \\ w \end{bmatrix} = \begin{bmatrix} \cos\Theta & 0 & -\sin\Theta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\Theta & 0 & \cos\Theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

And many more…

Rotate around X axis:

$$\begin{bmatrix} x' \\ y' \\ z' \\ w \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\Theta & -\sin\Theta & 0 \\ 0 & \sin\Theta & \cos\Theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ w \end{bmatrix}$$

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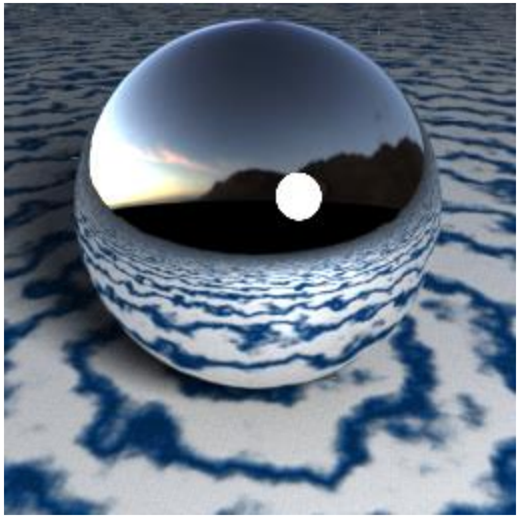
Image

Diffuse

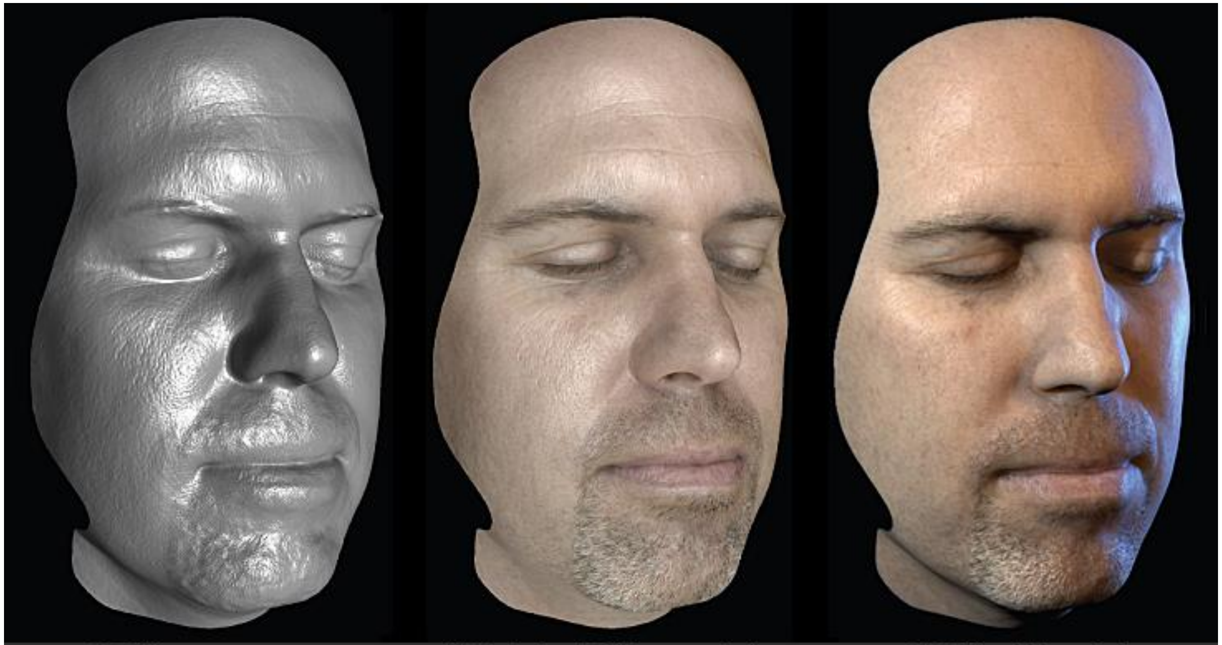
(mostly)

Specular++



Environment Mapping

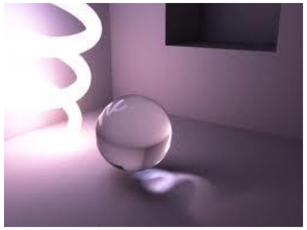
Subsurface Scatterring

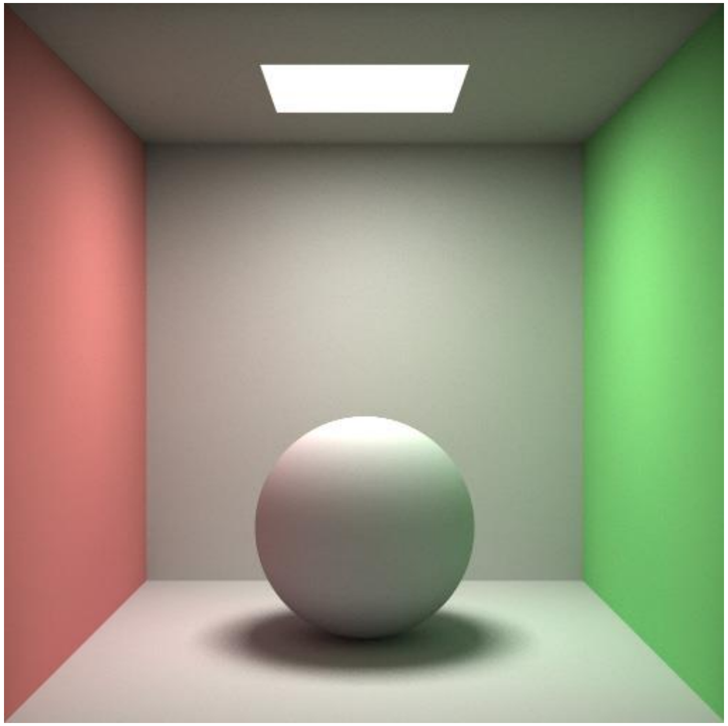


(a) High-res geometry (b) Real-time hybrid map rendering (c) Offline SSS rendering

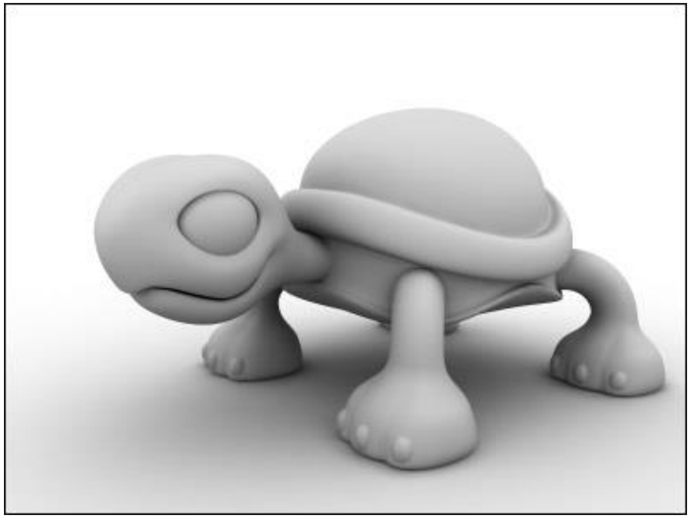
Others

Transparency



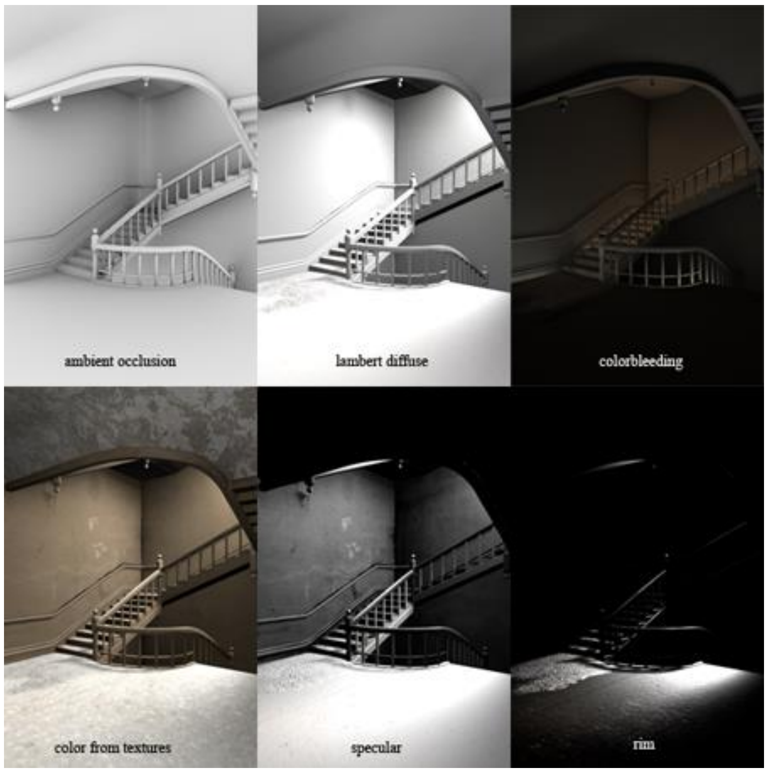


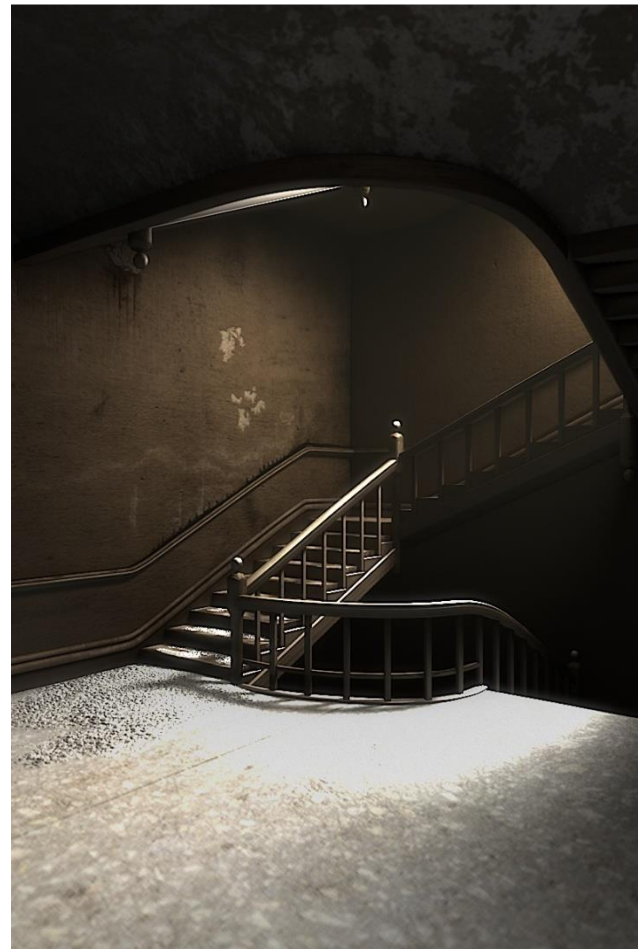
Radiosity



Ambient occlusion

Others


ambient occlusion
lambert diffuse
colorbleeding
color from textures
specular
rim



Lighting and Shading

- Light sources
  - Point light
    - Models an omnidirectional light source (e.g., a bulb)
  - Directional light
    - Models an omnidirectional light source at infinity
  - Spot light
    - Models a point light with direction

- Light model
  - Ambient light
  - Diffuse reflection
  - Specular reflection

Lighting and Shading

- Diffuse reflection
  - Lambertian model

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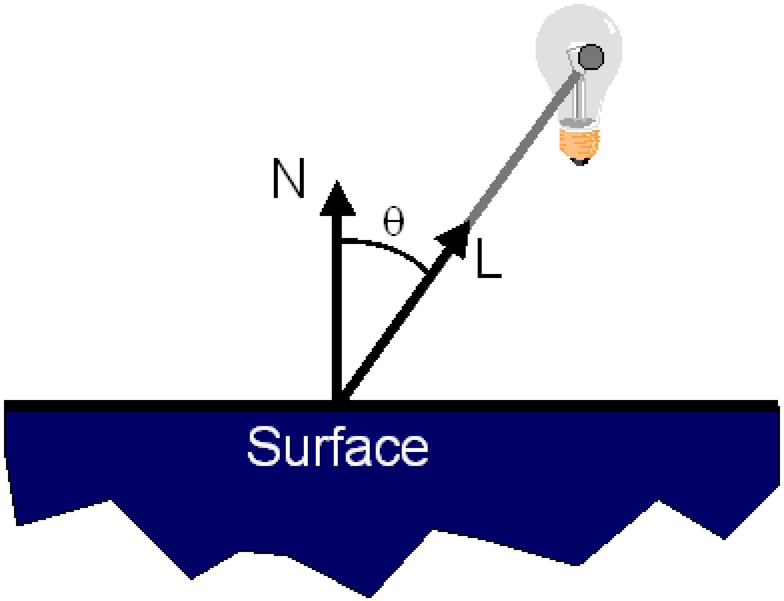

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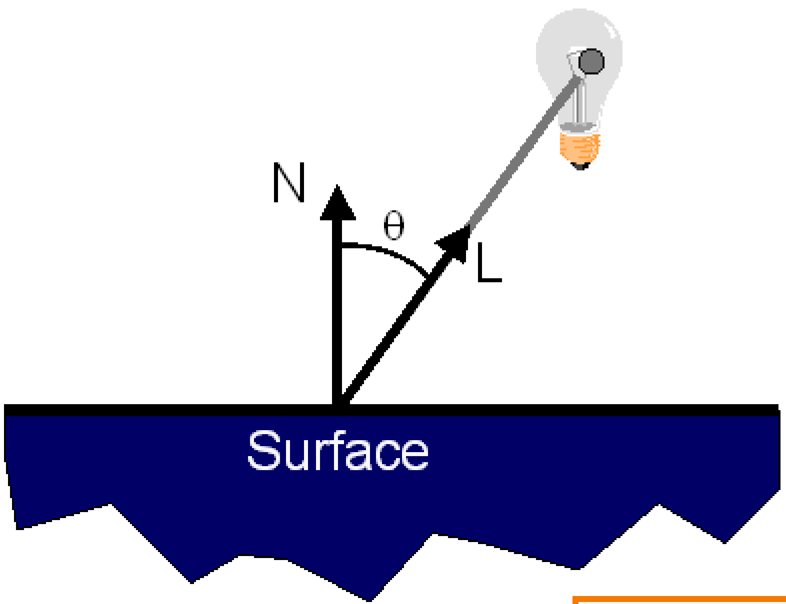
- Diffuse reflection
  - Lambertian model



$$I_D = K_D (N \bullet L) I_L$$

Lighting and Shading

- Specular reflection
  - Phong model

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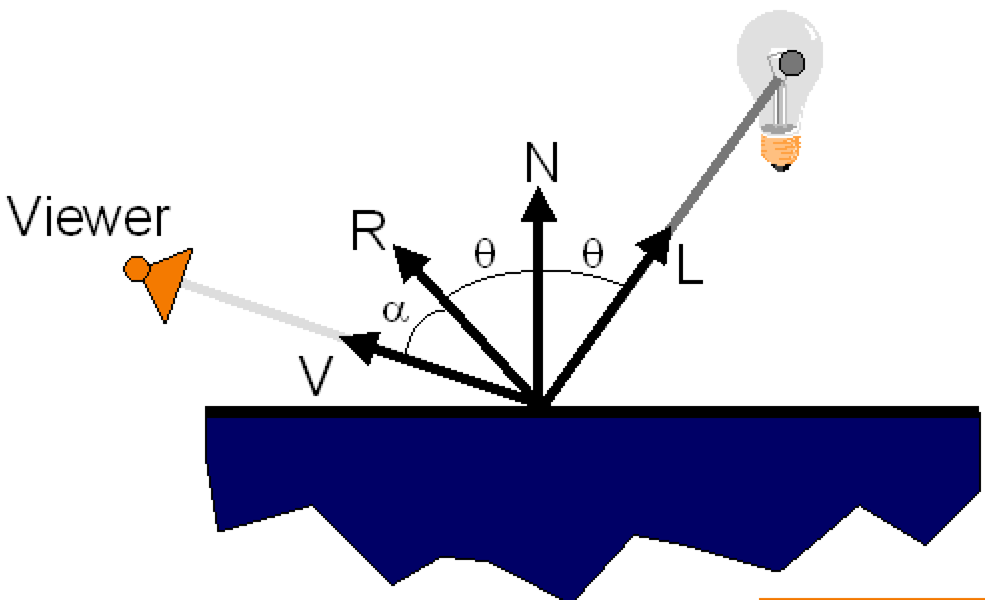
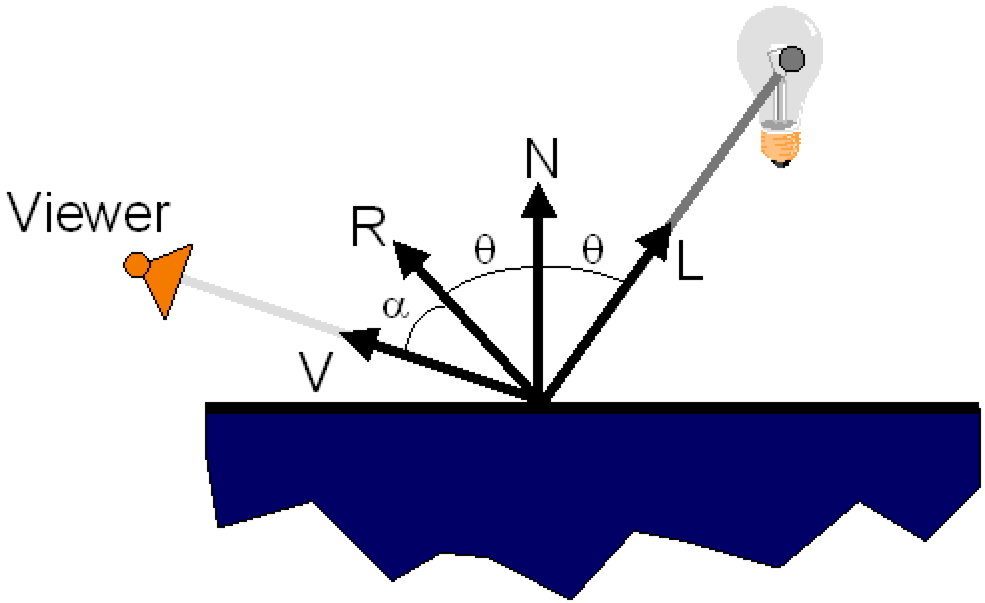


$$I_S = K_S (V \bullet R)^n I_L$$

Lighting and Shading

- Specular reflection
  - Phong model



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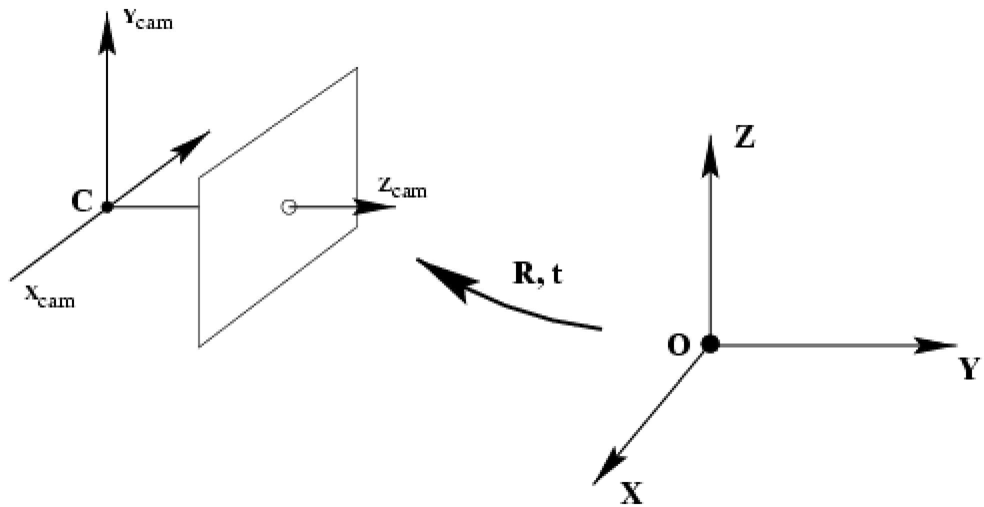
↓

Image

Viewing Transformation



$$\tilde{x}_c = R(\tilde{X} - C)$$
$$\tilde{x}_c = R\tilde{X} - \underbrace{RC}_{-t}$$

$$\tilde{x}_c = \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

$\boxed{\text{World-to-camera matrix } M}$

$$R = R_x R_y R_z$$

3x3 rotation matrices

$$t = \begin{bmatrix} t_x & t_y & t_z \end{bmatrix}^T$$

translation vector

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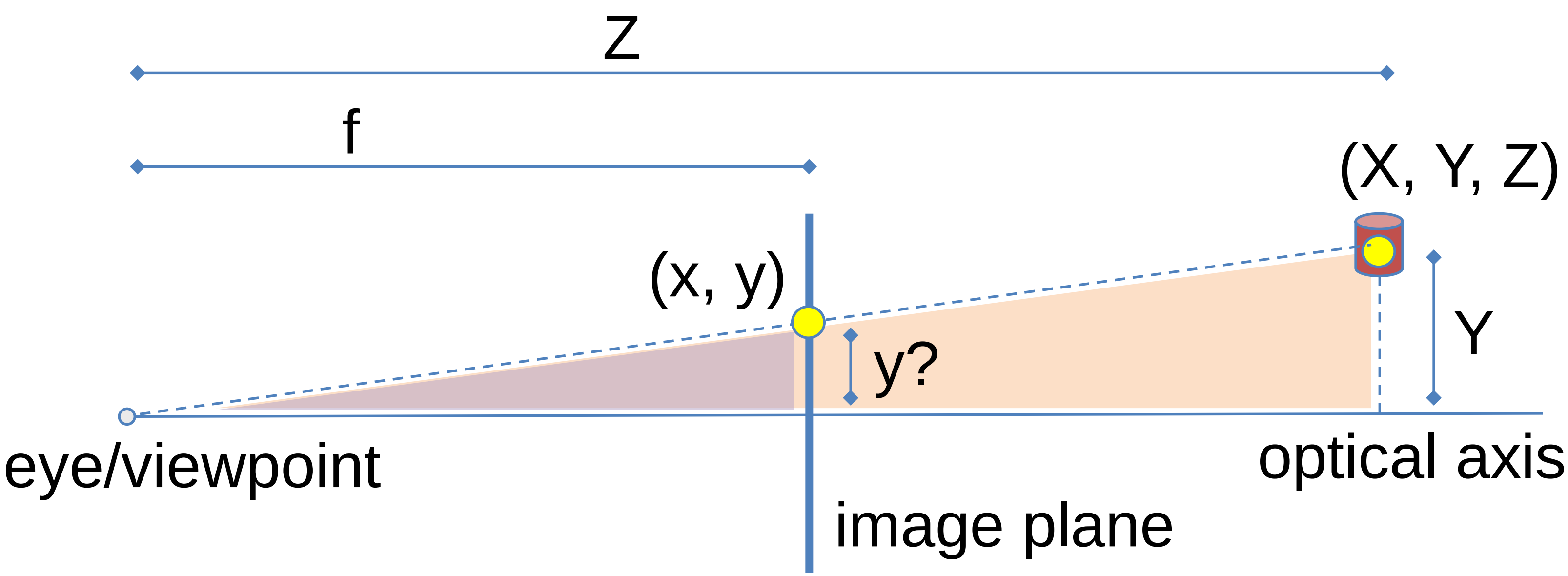
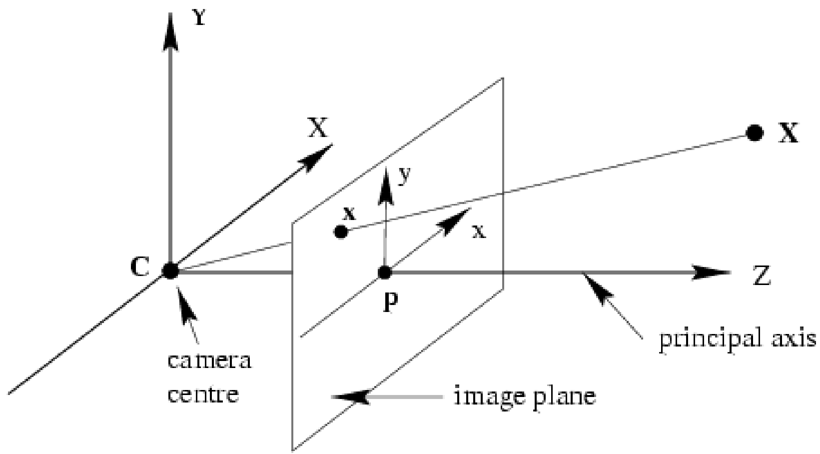
Image

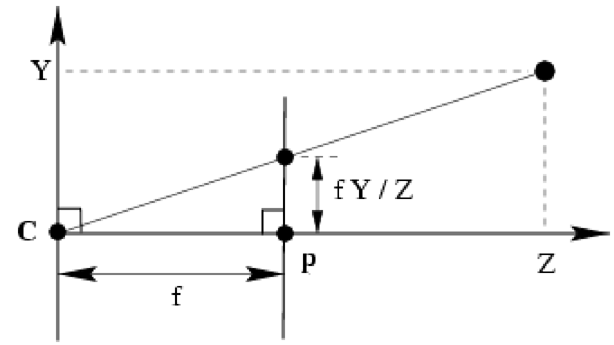
Perspective projection



$$\frac{y}{f} = \frac{Y}{Z} \Rightarrow y = f\frac{Y}{Z} \quad \& \quad x = f\frac{X}{Z}$$

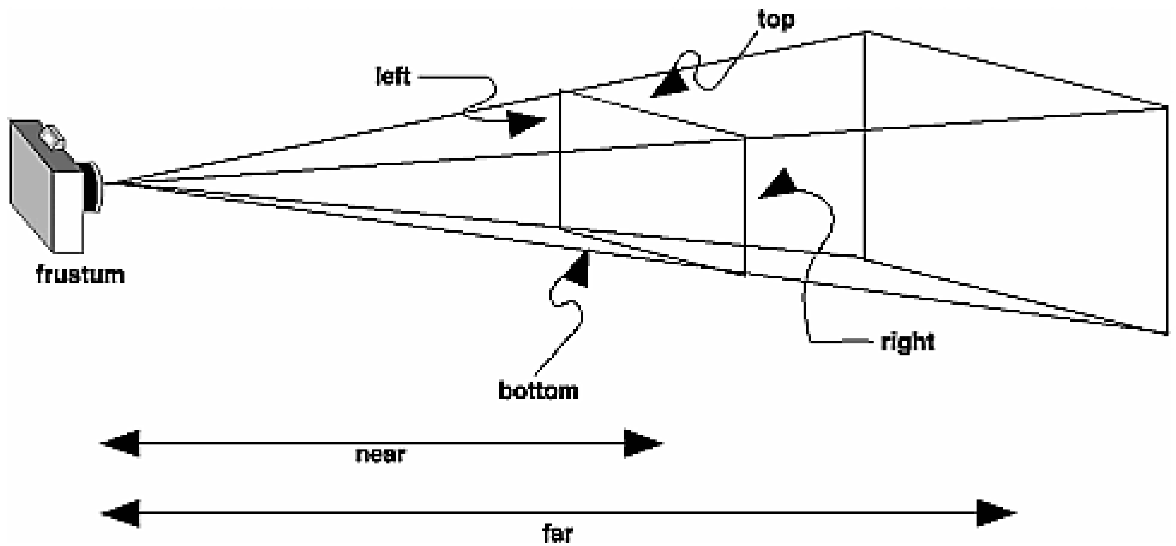
Perspective Projection





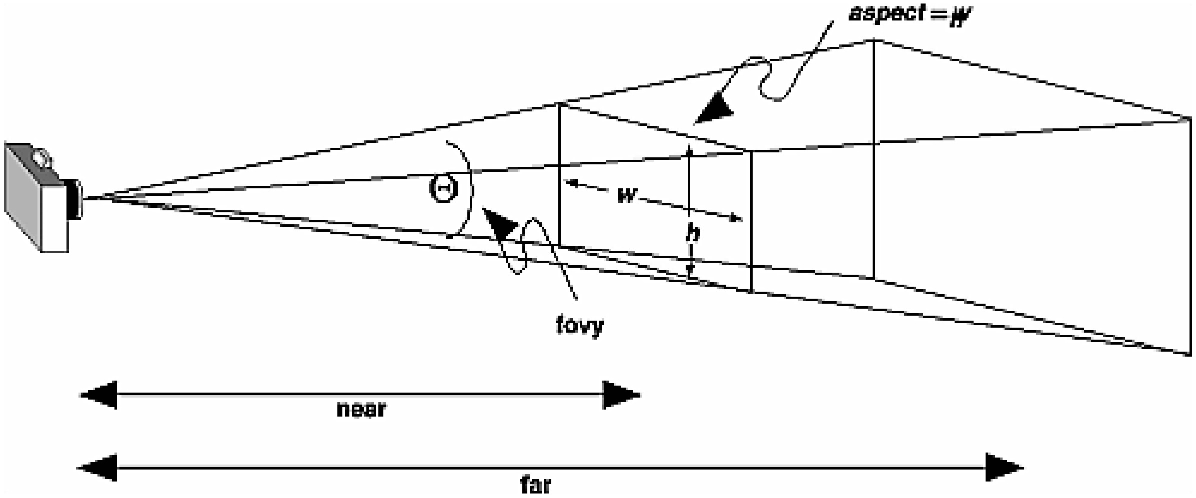
$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} fX/Z \\ fY/Z \end{pmatrix} \Leftarrow \begin{pmatrix} fX \\ fY \\ Z \end{pmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

Projection Transformations



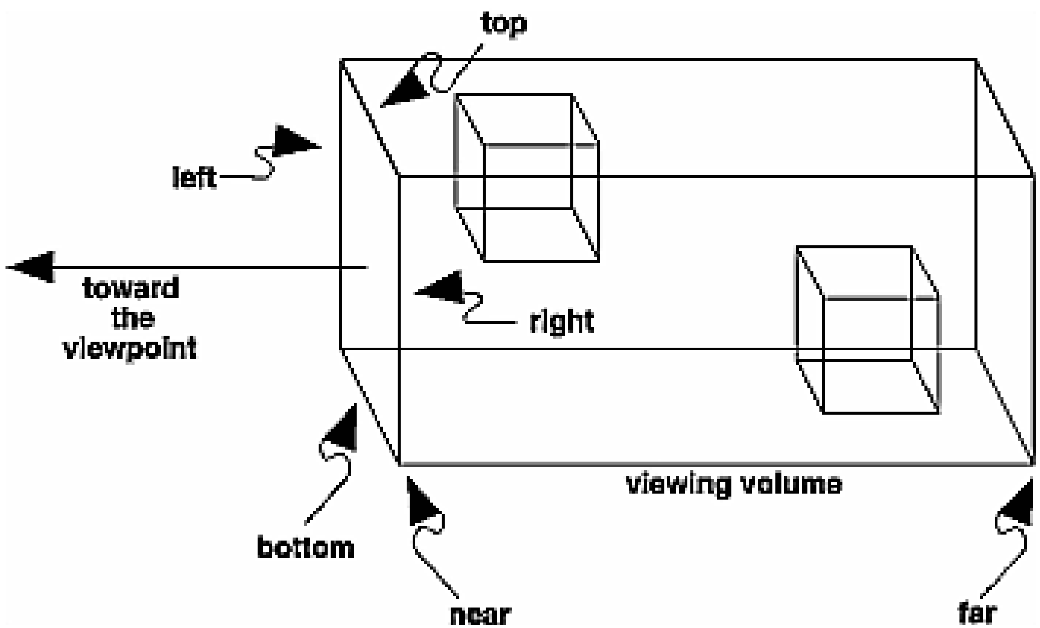

```
void glFrustum(GLdouble left, GLdouble right, GLdouble
  bottom, GLdouble top, GLdouble near, GLdouble far);
```

Projection Transformations




```
void gluPerspective(GLdouble fovy, GLdouble aspect, GLdouble
   near, GLdouble far);
```

Projection Transformations




```
void glOrtho(GLdouble left, GLdouble right, GLdouble
  bottom,
  GLdouble top, GLdouble near, GLdouble far);

void gluOrtho2D(GLdouble left, GLdouble right,
  GLdouble bottom, GLdouble top);
```

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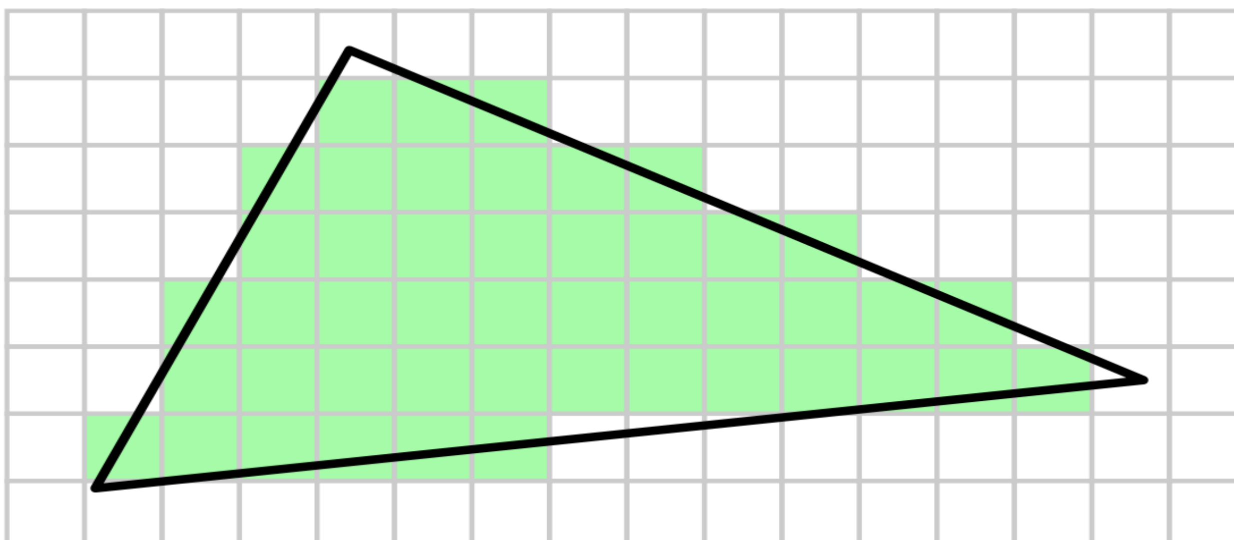
Scan Conversion/Rasterization

- Determine which fragments get generated
- Interpolate parameters (colors, textures, normals, etc.)



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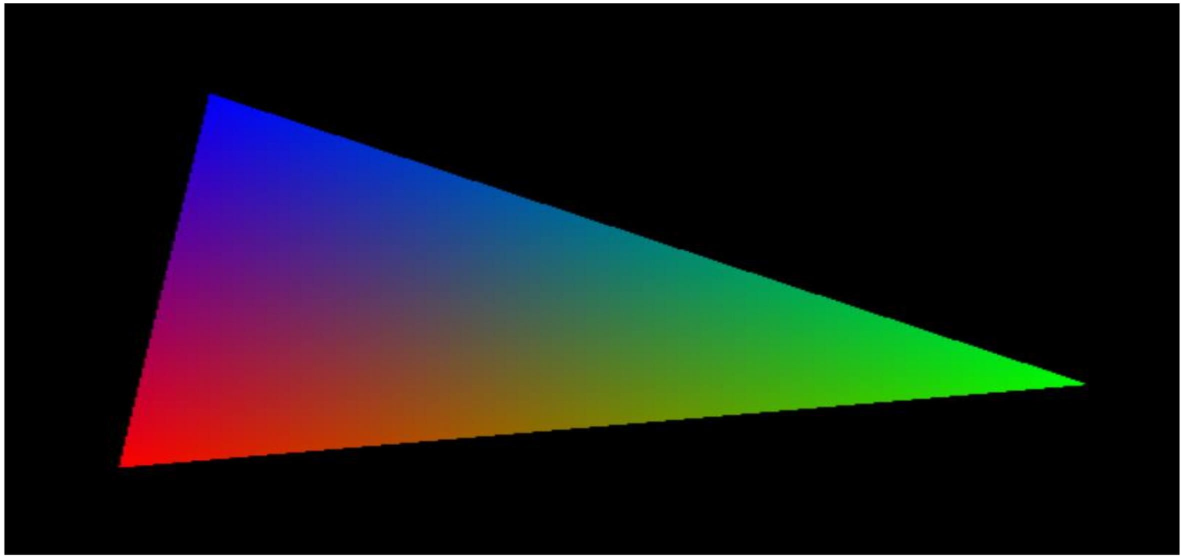

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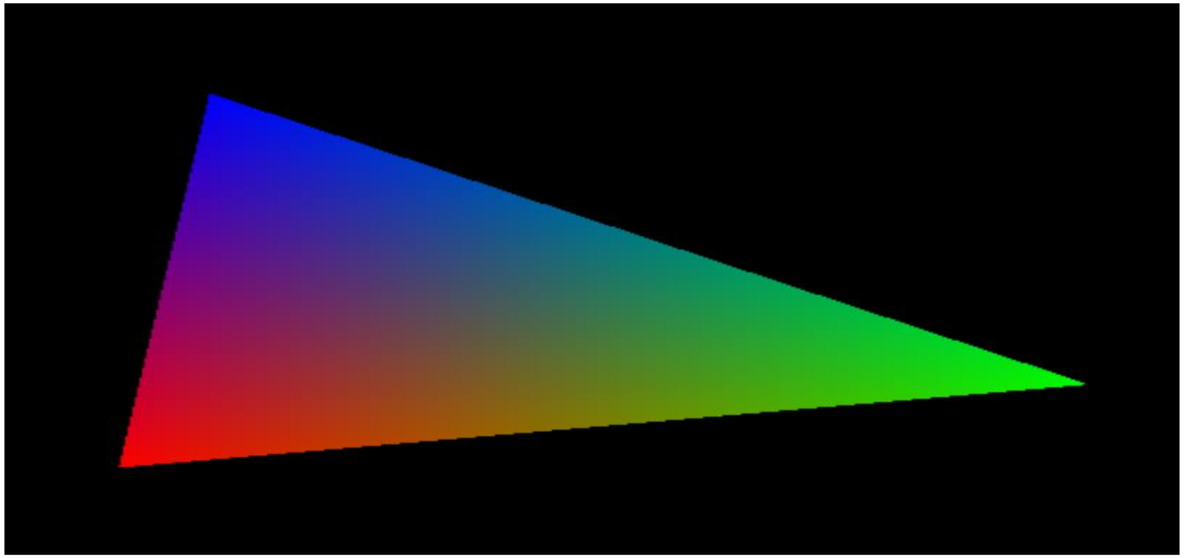

- How?

Scan Conversion/Rasterization

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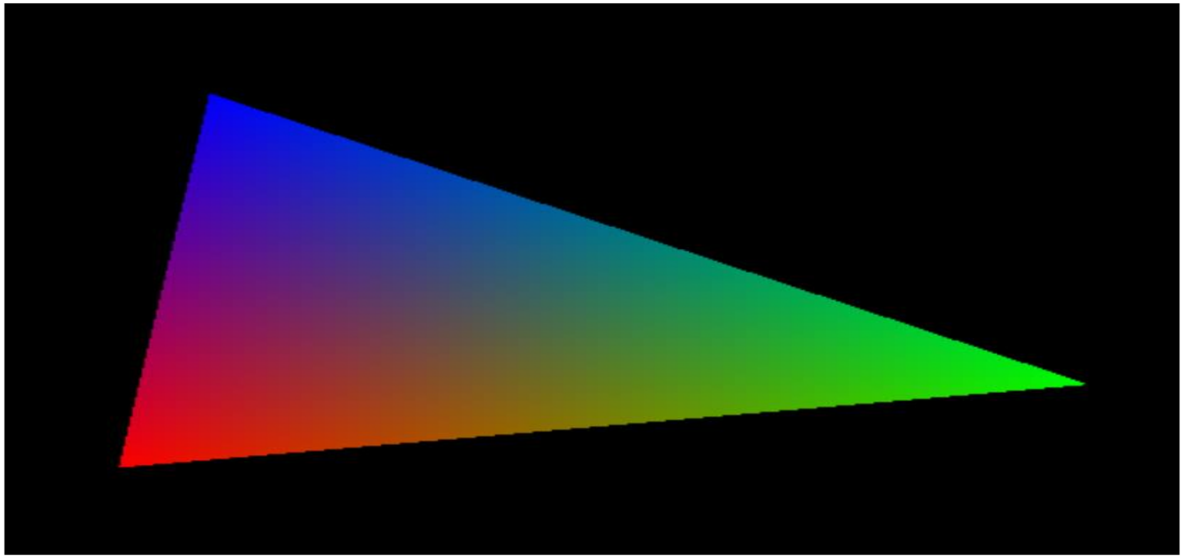
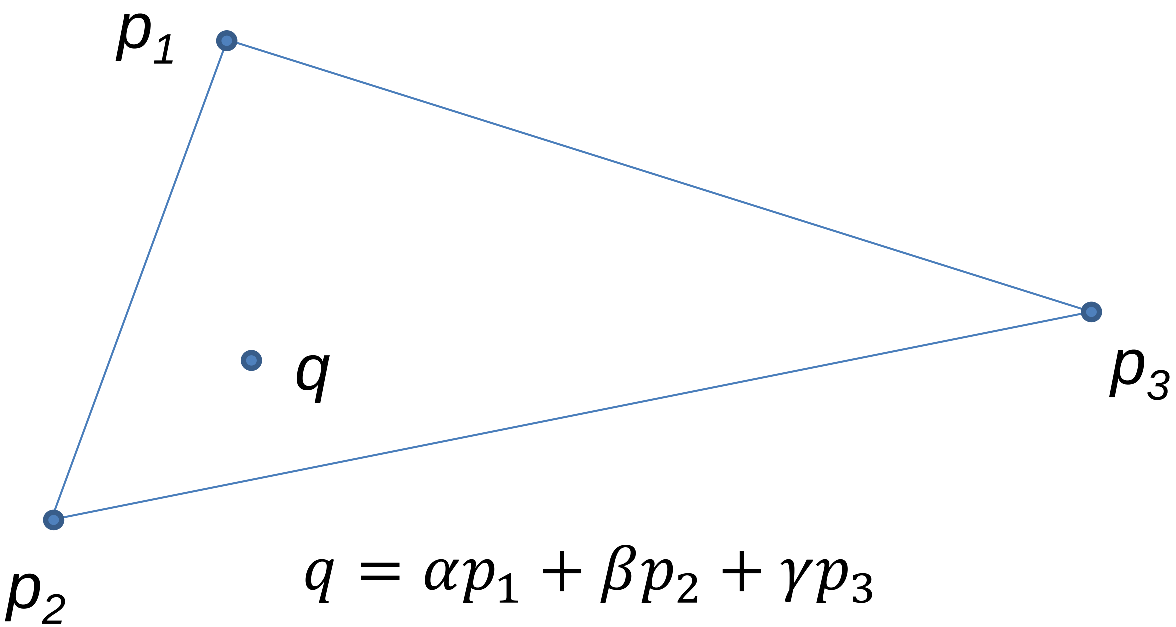


- Barycentric coords amongst many other ways…

Barycentric coordinates

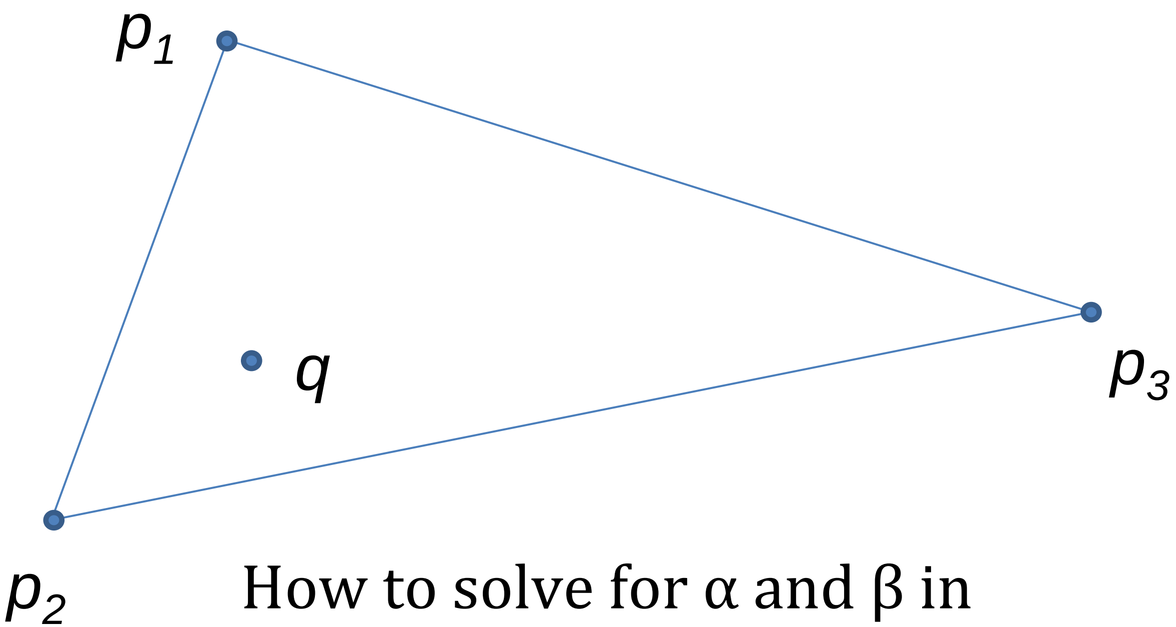


$$q = \alpha p_1 + \beta p_2 + \gamma p_3$$

If $[\alpha + \beta + \gamma = 1 \;\; and \;\; \{\alpha, \beta, \gamma\} \geq 0]$,
then q inside triangle (p_1, p_2, p_3)

Can also write:
$$q = \alpha p_1 + \beta p_2 + (1 - \alpha - \beta) p_3$$

Barycentric coordinates



How to solve for α and β in
$q = \alpha p_1 + \beta p_2 + (1 - \alpha - \beta) p_3$?

Two equations, two unknowns:
use 2x2 matrix inversion…

Additional concept: Texture mapping

- Model surface-detail with images
  - wrap object with photograph(s)
  - graphics object itself is a simpler model but "looks" more complex

Texture mapping

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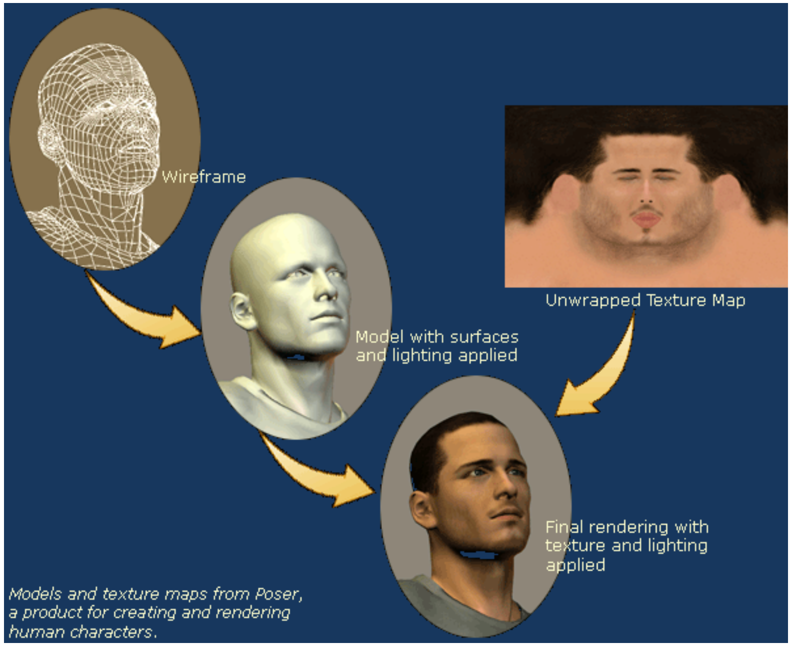
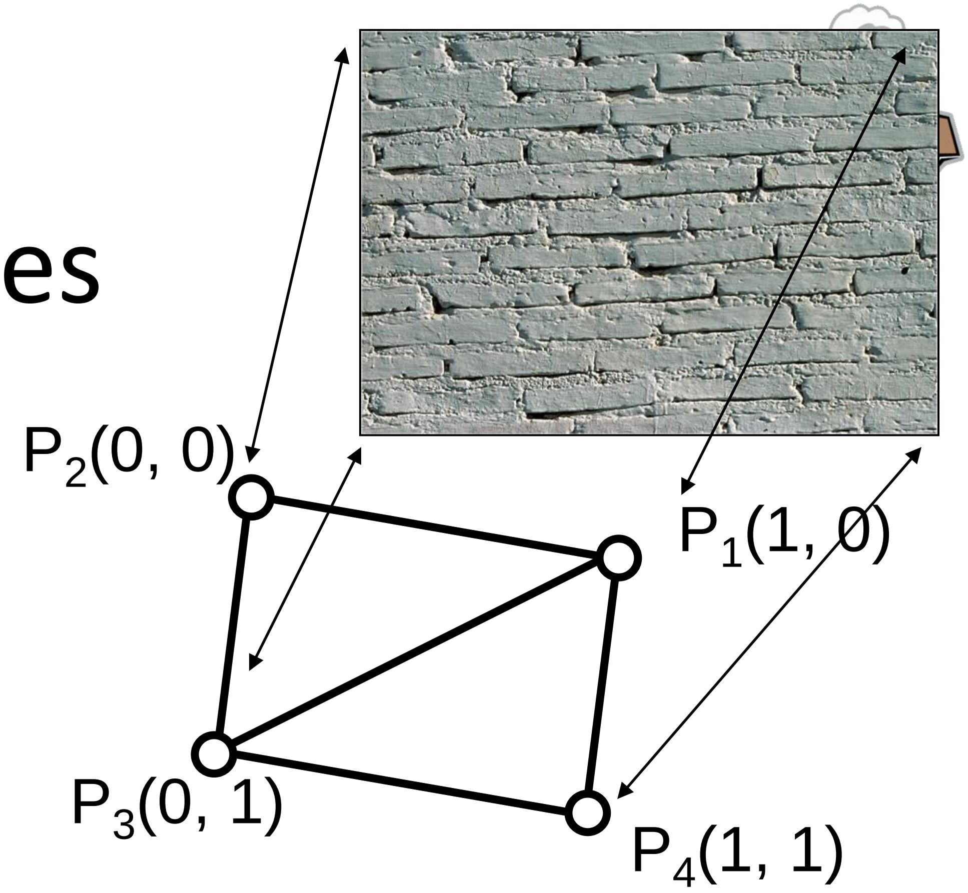
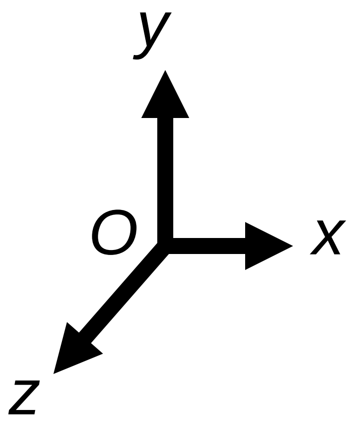


Texture coordinates

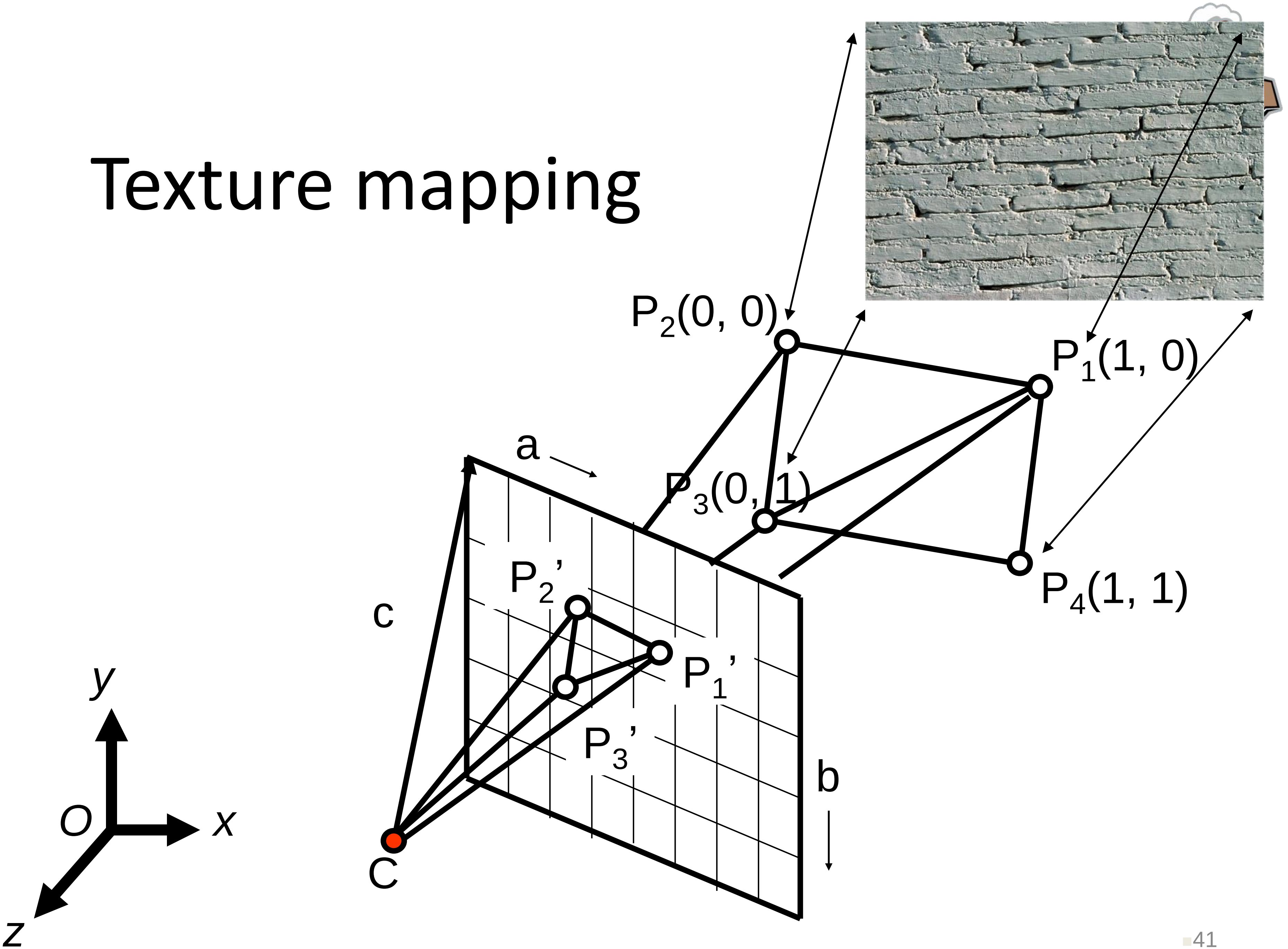
- Mechanism for attaching the texture map to the surface modeled
  - a pair of floats (s, t) for each triangle vertex
  - corners of the image are (0, 0), (0, 1), (1, 1), and (1, 0)
  - tiling indicated with tex. coords. > 1
  - *texels* – color samples in texture maps

Texture coordinates

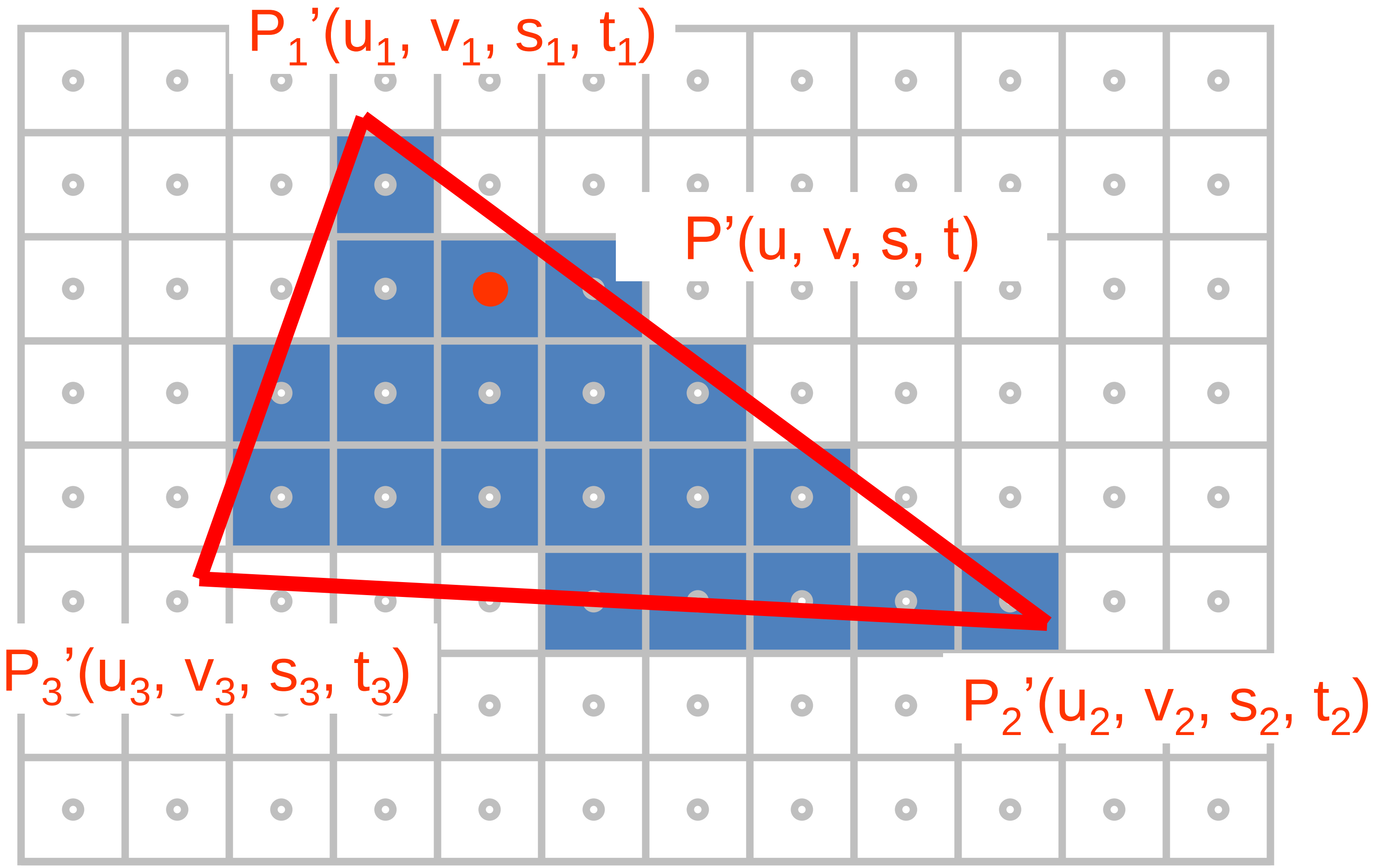




Texture mapping

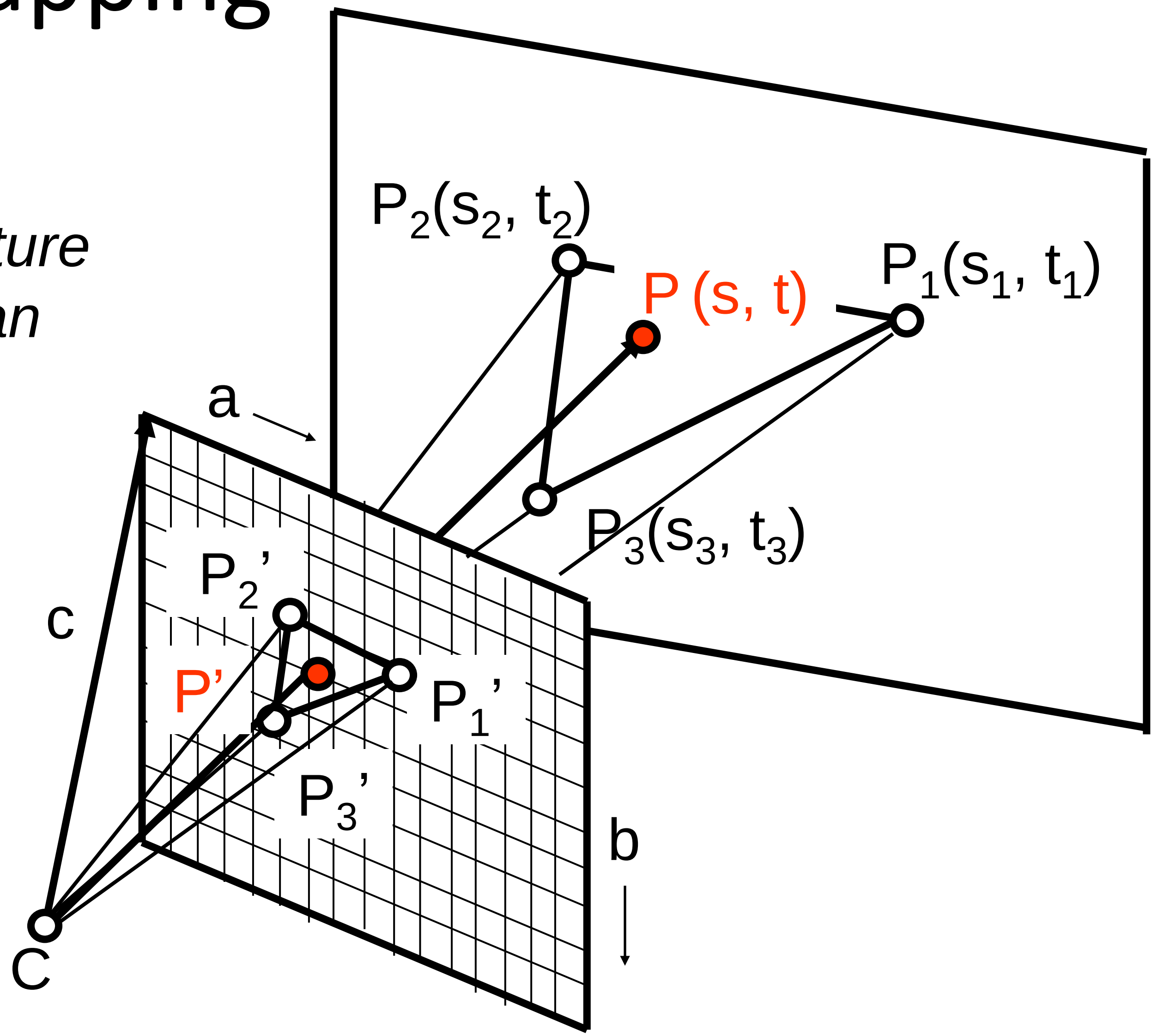


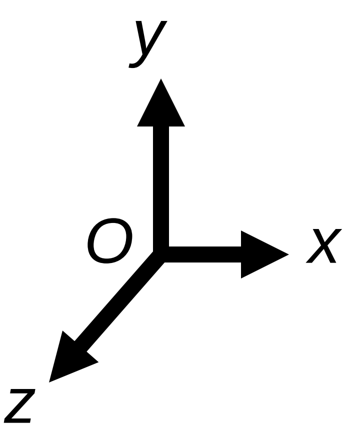
Texels: texture elements



Texture mapping

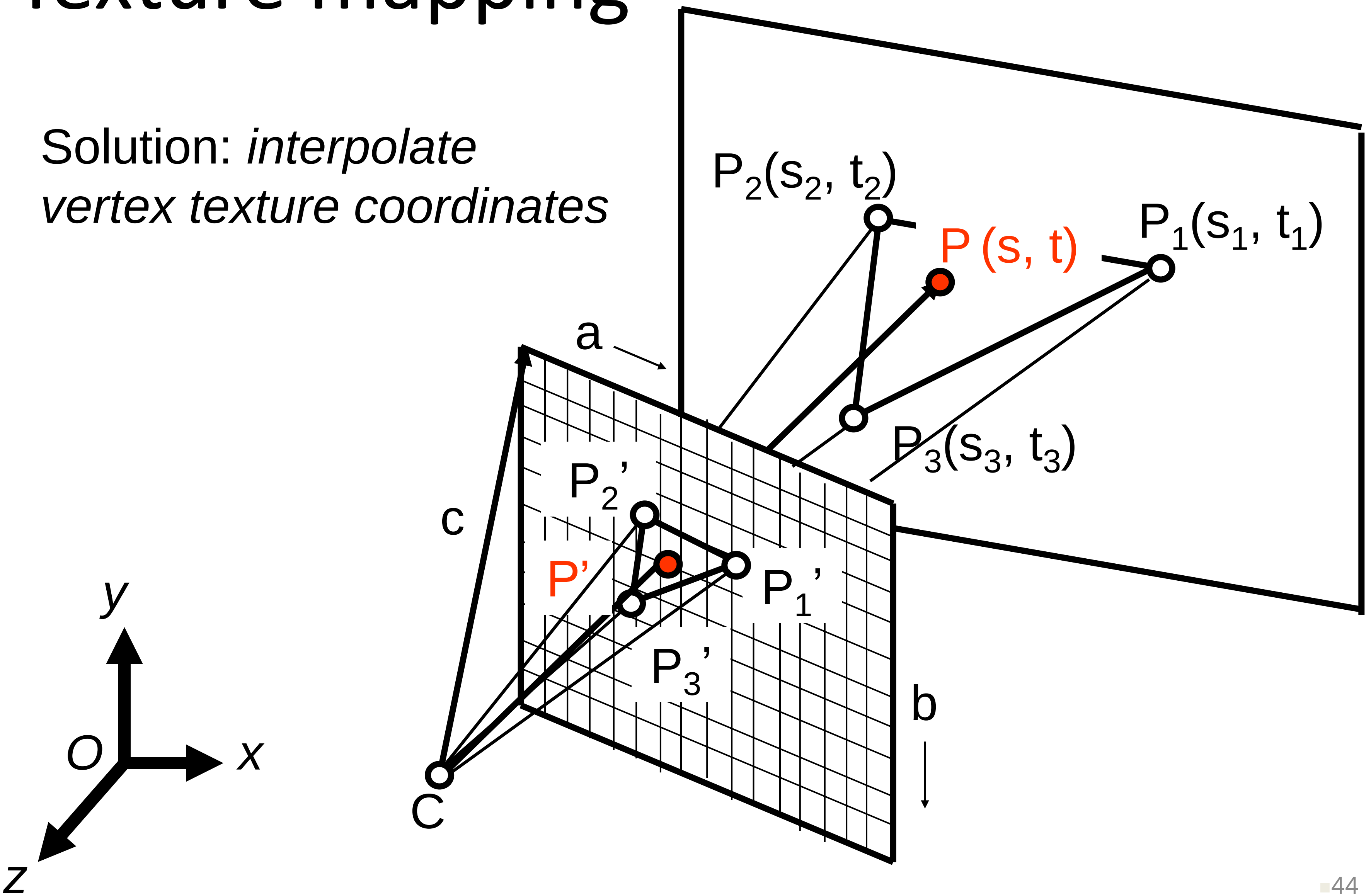
Problem*: how to compute the texture coordinates for an interior pixel?*





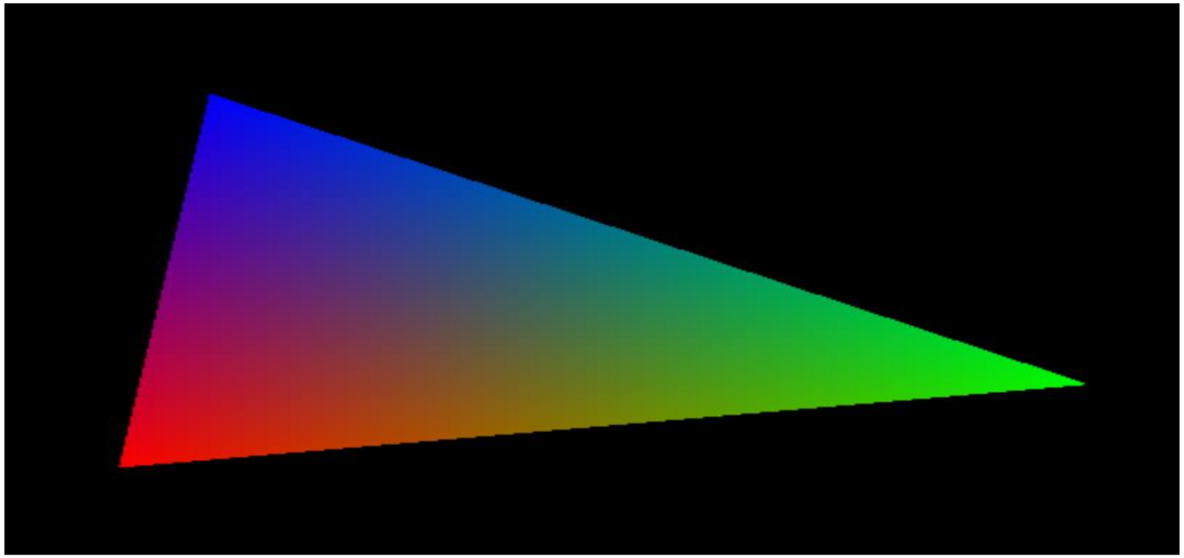
Texture mapping

Solution: *interpolate vertex texture coordinates*



Parameter Interpolation

- Texture coordinates, colors, normals, etc.



- How?
  - Again, use barycentric coordinates…