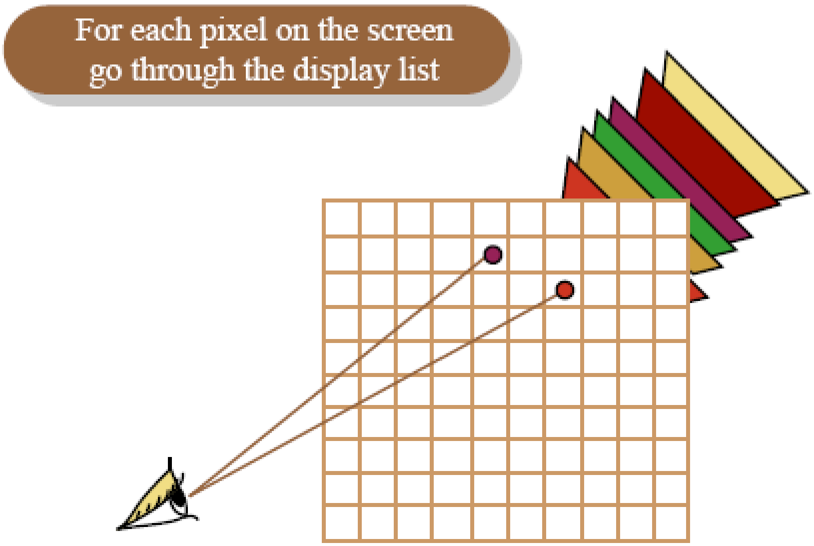
Graphics Pipeline

CS535

Daniel G. Aliaga
Department of Computer Science
Purdue University

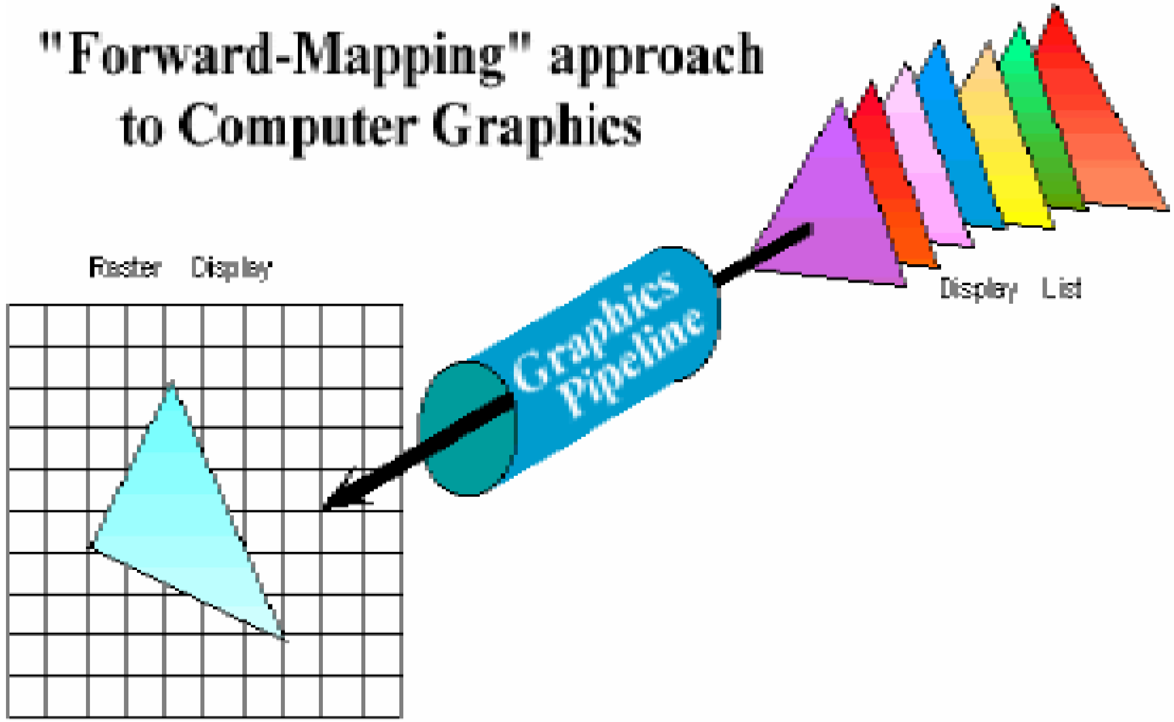
Ray-tracing – Inverse mapping

for every pixel
    construct a ray from the eye
    for every object in the scene
        intersect ray with object
        find closest intersection with the ray
        compute normal at point of intersection
        compute color for pixel
        shoot secondary rays

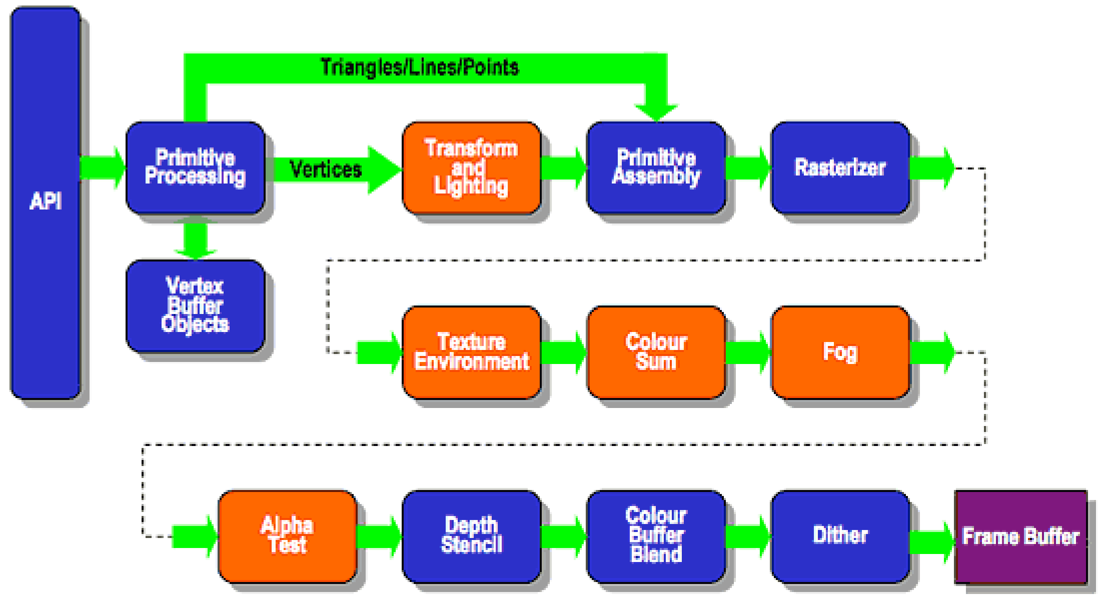


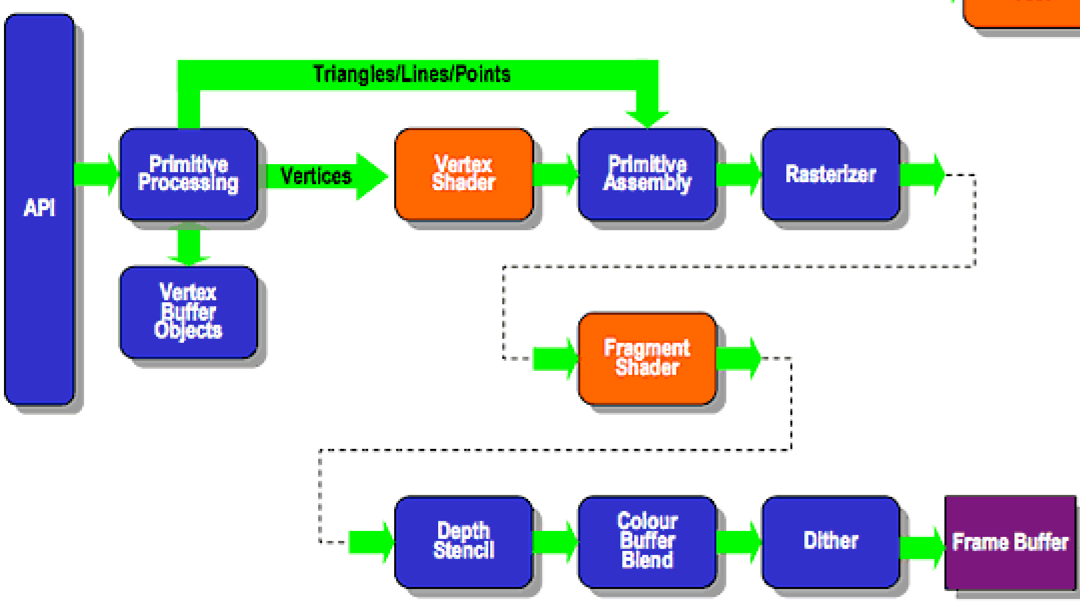
Pipeline – Forward mapping

Start from the geometric primitives to find the values of the pixels



Fixed Pipeline

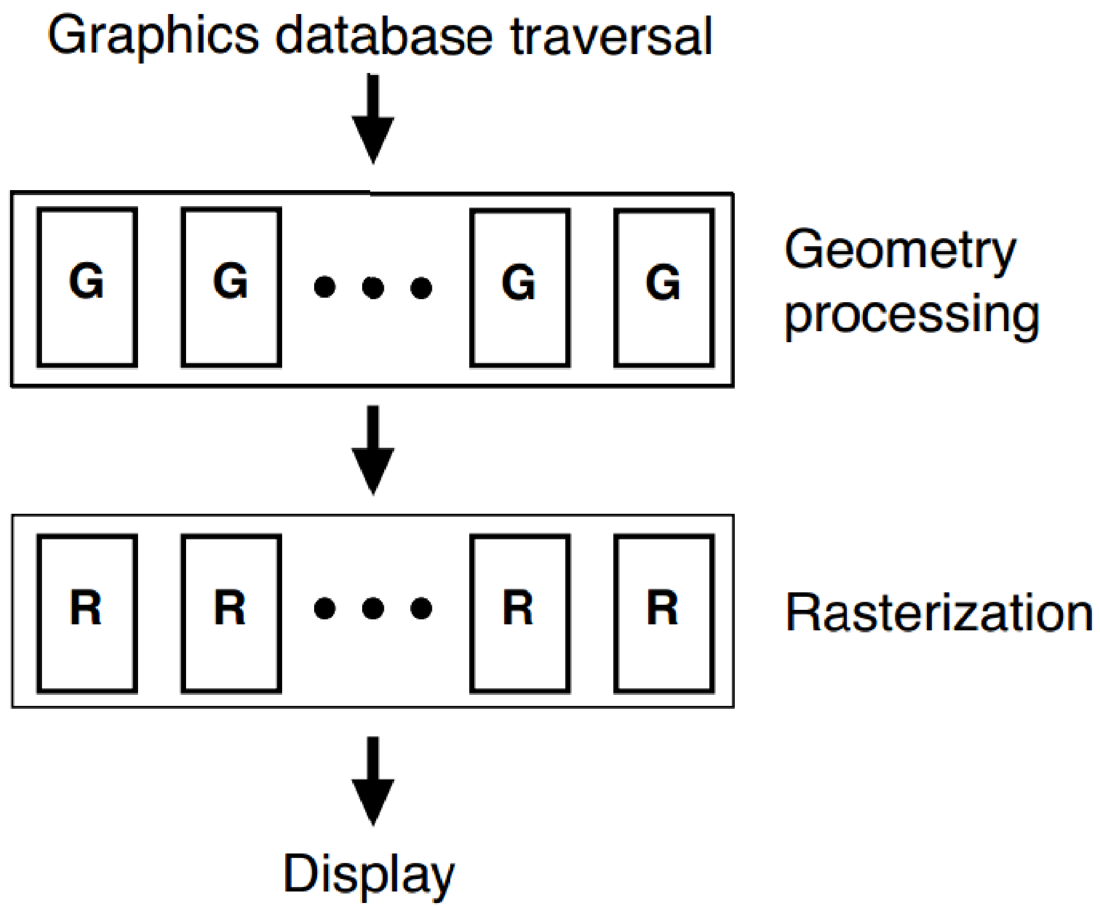




Programmable Pipeline

(High-level Shading Language)

Alternate Pipelines?

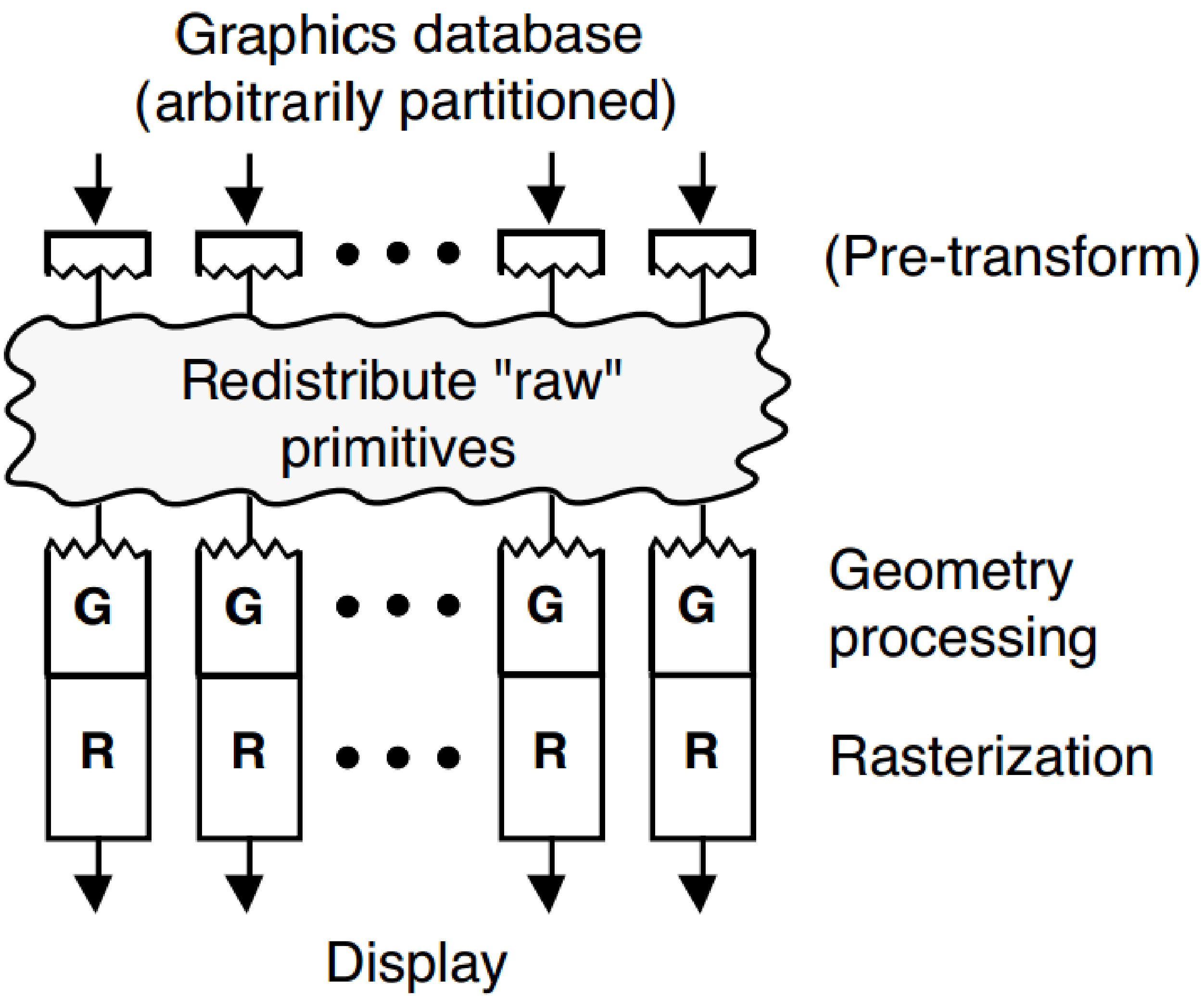


Standard pipeline….

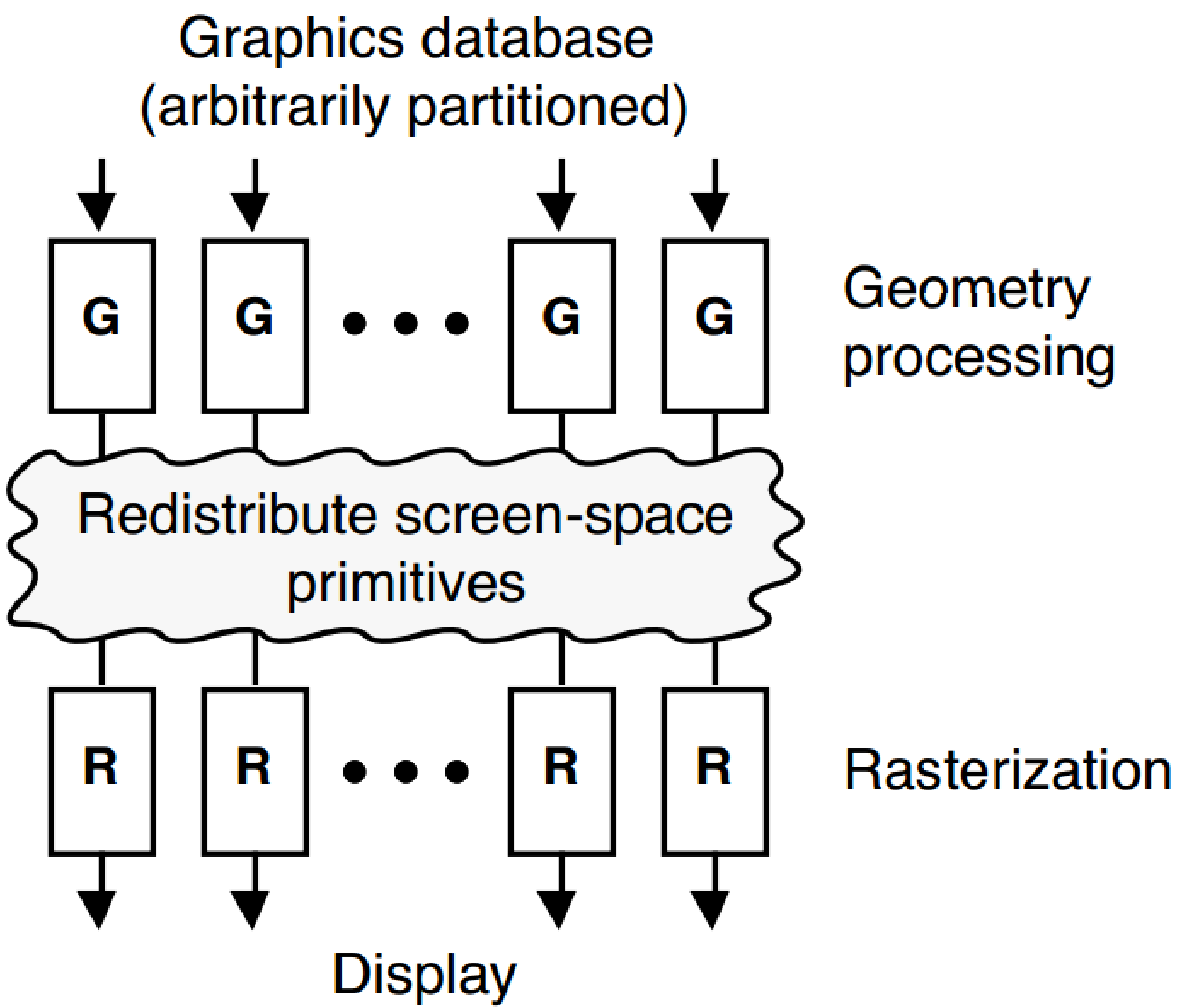
A Sorting Classification of (Parallel) Graphics Pipelines

- Sort-first
- Sort-middle
- Sort-last

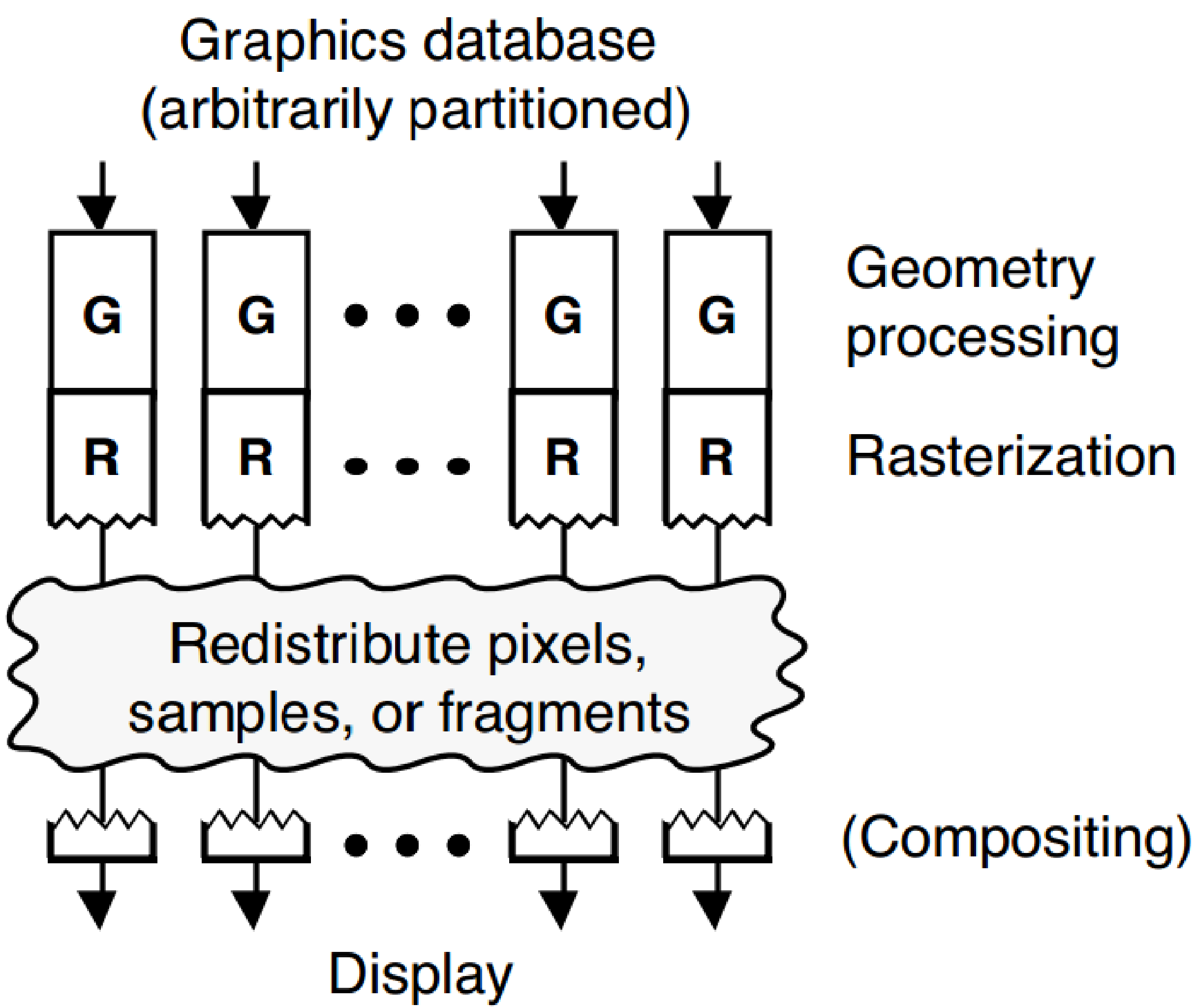
Sort First


Graphics database
(arbitrarily partitioned)
(Pre-transform)
Redistribute "raw" primitives
G
G
G
G
Geometry processing
R
R
R
R
Rasterization
Display

Sort Middle


Graphics database
(arbitrarily partitioned)
G
G
G
G
Geometry processing
Redistribute screen-space primitives
R
R
R
R
Rasterization
Display

Sort Last


Graphics database
(arbitrarily partitioned)
G
G
G
G
Geometry
processing
R
R
R
R
Rasterization
Redistribute pixels,
samples, or fragments
(Compositing)
Display

Sort First

- **Advantages:**
  - Low communication requirements when the tessellation ratio and the degree of oversampling are high, or when frame-to-frame coherence can be exploited.
  - Processors implement entire rendering pipeline for a portion of the screen.
- **Disadvantages**:
  - Susceptible to load imbalance. Primitives may clump into regions, concentrating the work on a few renderers.
  - To take advantage of frame-to-frame coherence, retained mode and complex data handling code are necessary.

Sort Middle

- **Advantages**:
  - General and straightforward; redistribution occurs at a natural place in the pipeline.
- **Disadvantages**:
  - High communication costs if tessellation ratio is high.
  - Susceptible to load imbalance between rasterizers when primitives are distributed unevenly over the screen.

Sort Last

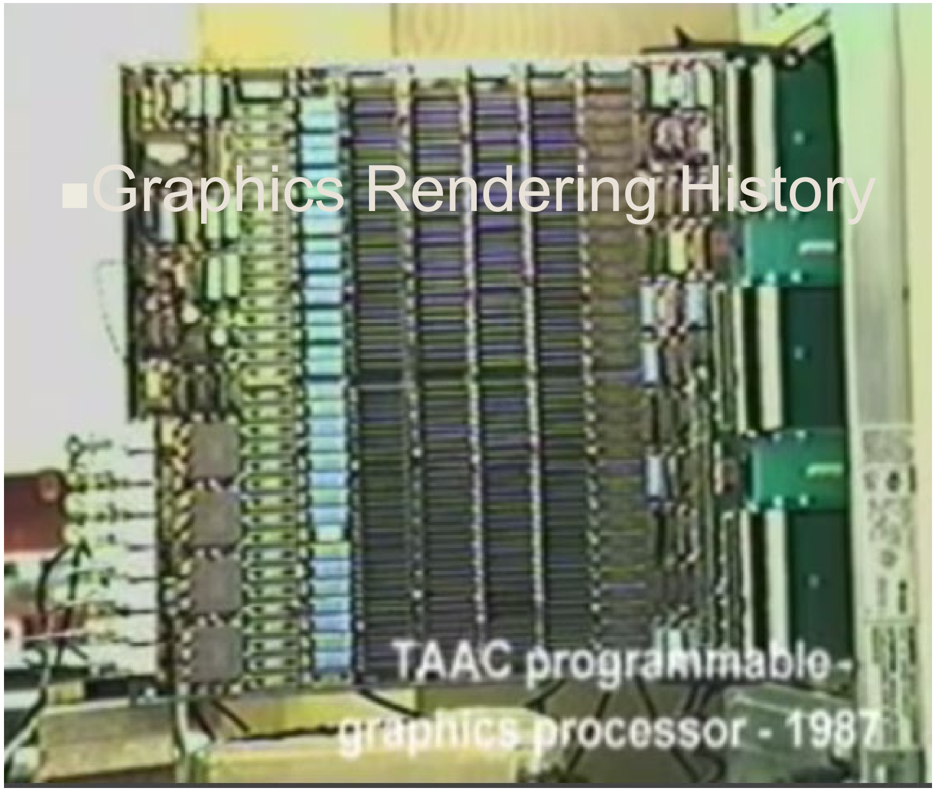
- **Advantages**:
  - Renderers implement the full rendering pipeline and are independent until pixel merging.
  - Less prone to load imbalance.
  - SL-full merging can be embedded in a linear network, making it linearly scalable.
- **Disadvantage**:
  - Pixel traffic may be extremely high, particularly when oversampling.

Graphics Rendering History

- IKONAS Graphics System (1978)
  - (basically a dedicated CPU)

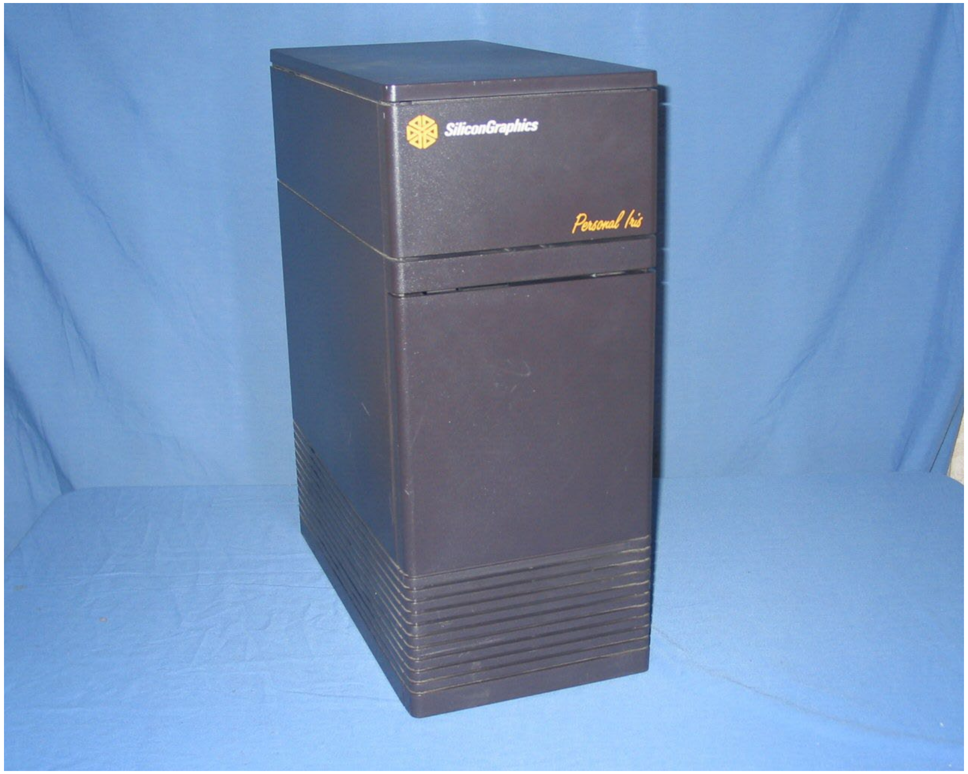
Graphics Rendering History

- [TAAC Graphics Accelerator Board (a GPU…)]



Graphics Rendering History

- Silicon Graphics Personal Iris (1986)
  - CPU and GPU (a *sort first* architecture)
  - "gl" appeared
  - HP had "starbase"
  - (OpenGL appeared in 1991)

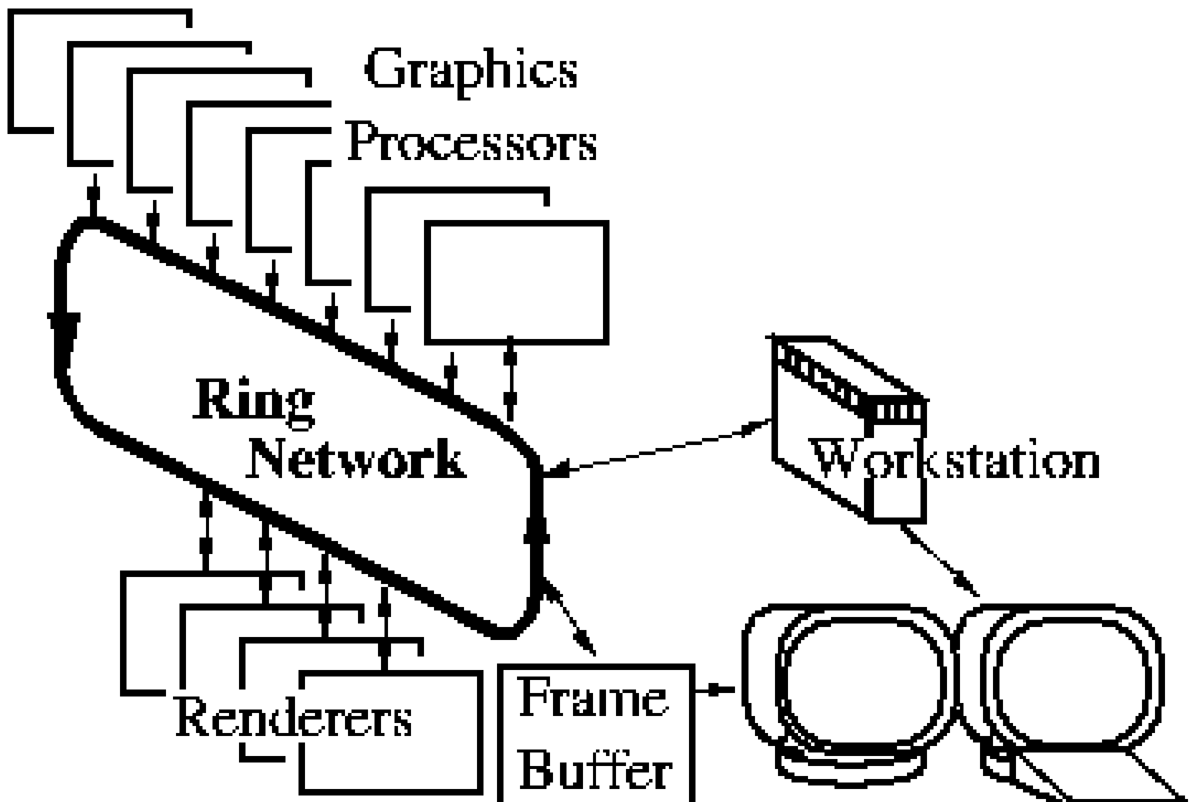


Graphics Rendering History

- Renderman: a programmable shading language (1986)

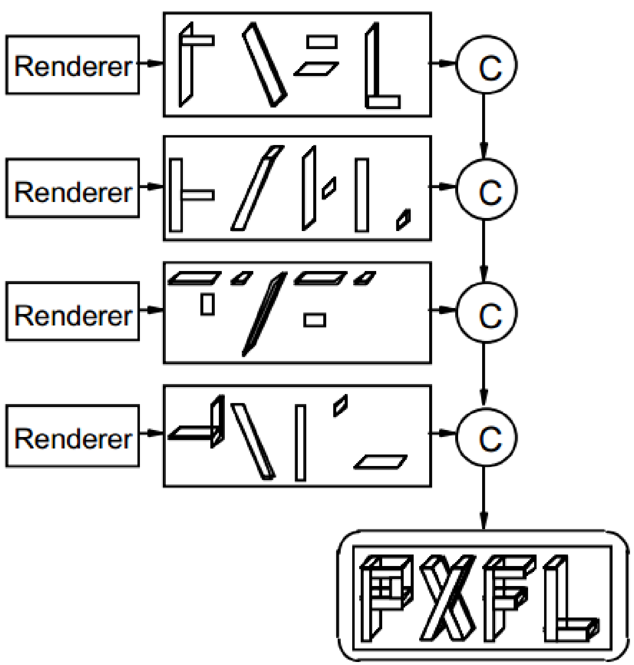
Graphics Rendering History

- PixelPlanes 1,2,3,4,5
  - (a *sort middle* architecture)



Graphics Rendering History

- PixelFlow
  - A sort-last architecture
  - Formally supports programmable shading



Graphics Rendering History

- PixelFlow -> HP

Graphics Rendering History

- ~~PixelFlow -> HP~~

Graphics Rendering History

- PixelFlow -> NVIDIA

Graphics Rendering History

“Standard” Graphics Pipeline

Geometry

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
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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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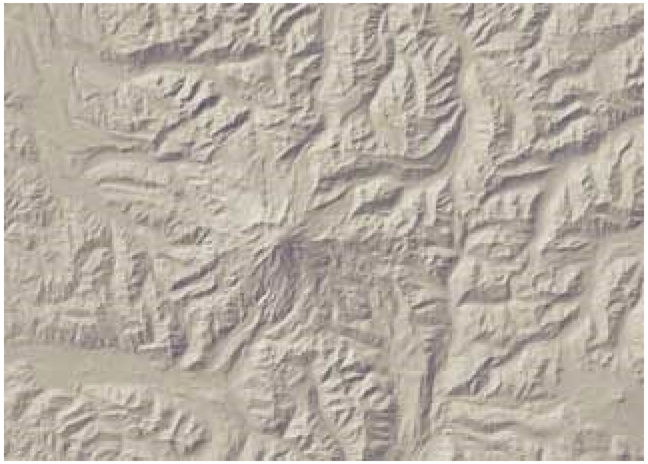
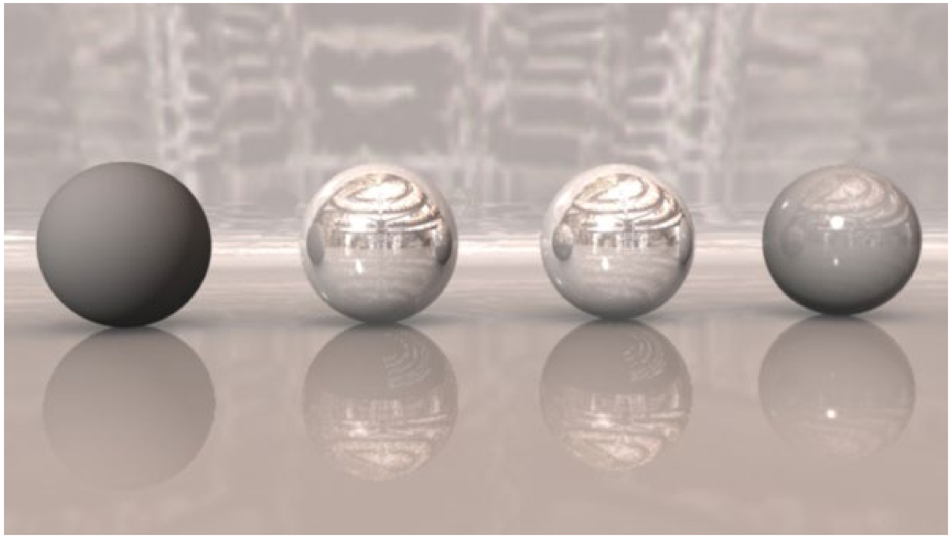
Image

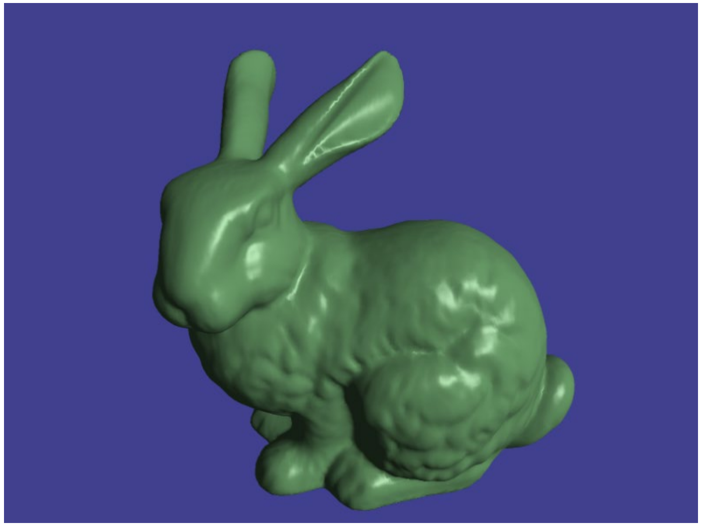
Diffuse

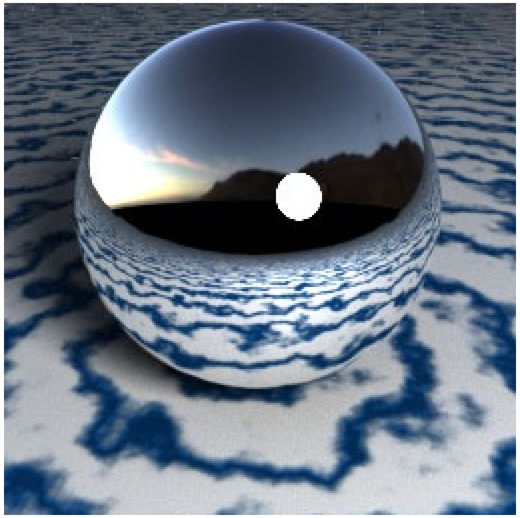


(mostly)

Specular++

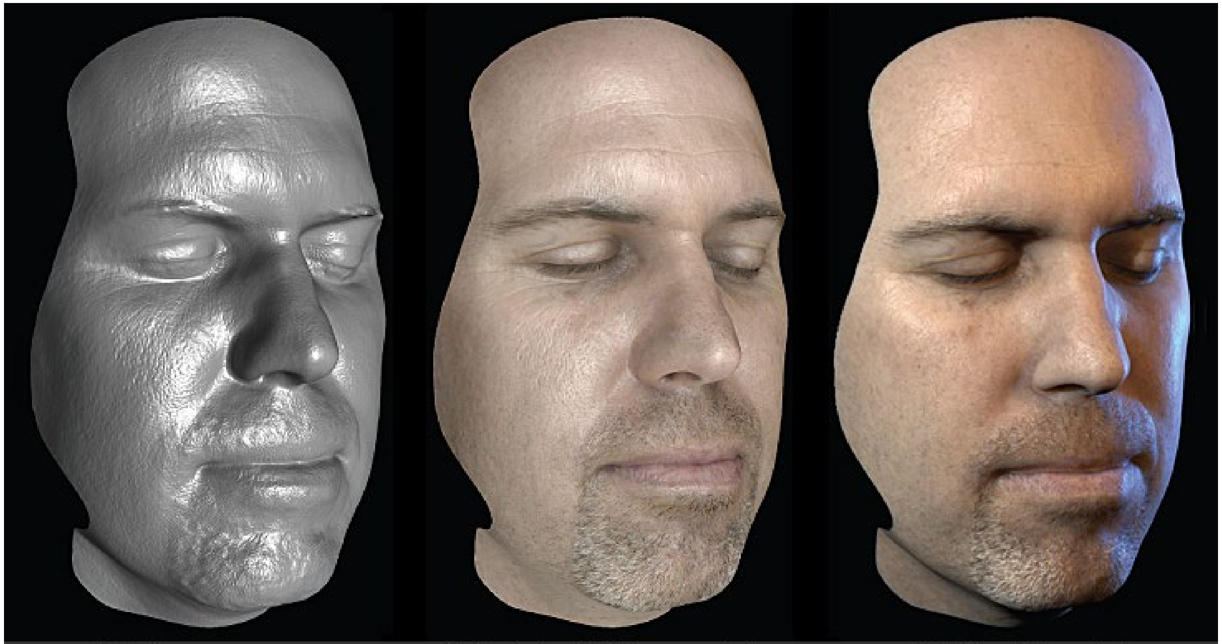






Environment Mapping

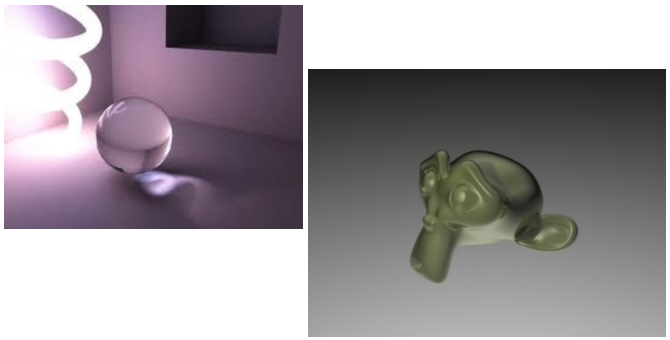
Subsurface Scatterring

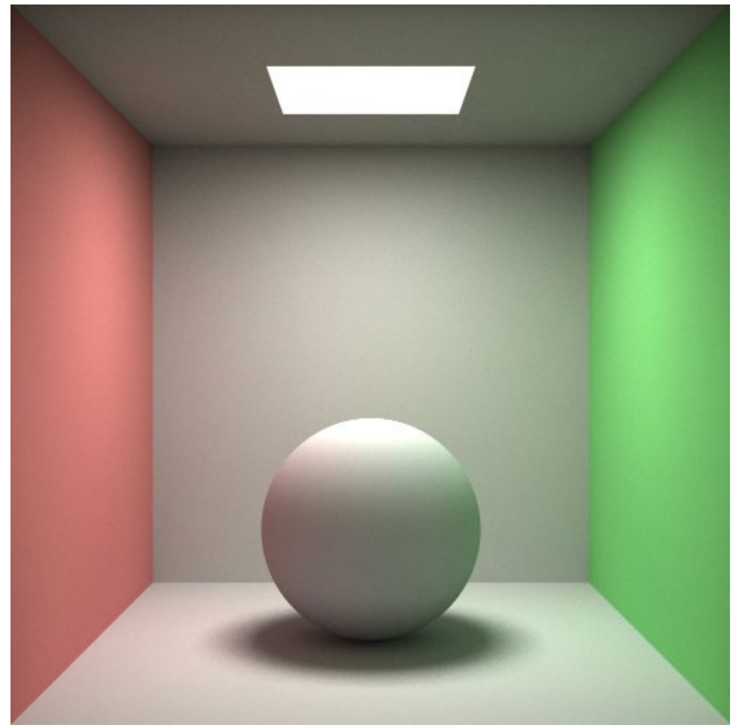


(a) High-res geometry (b) Real-time hybrid map rendering (c) Offline SSS rendering

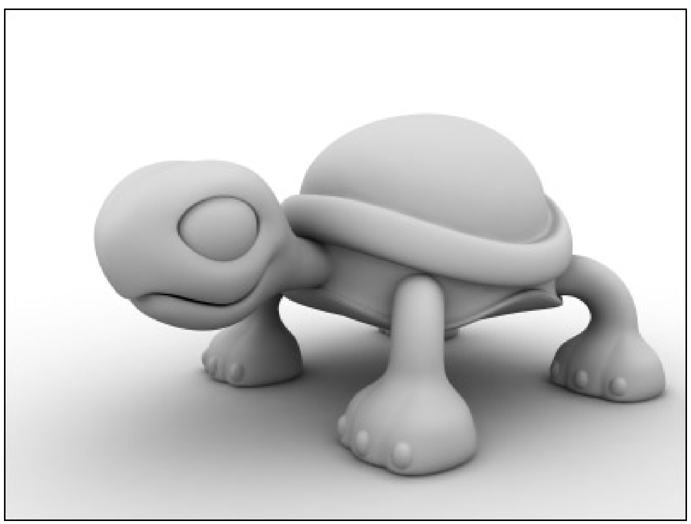
Others

Transparency



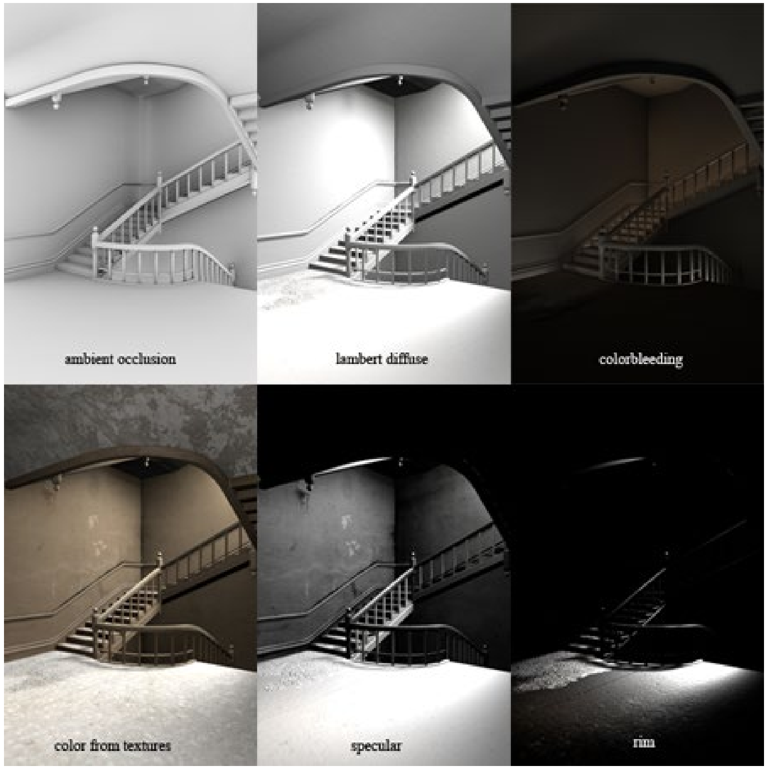


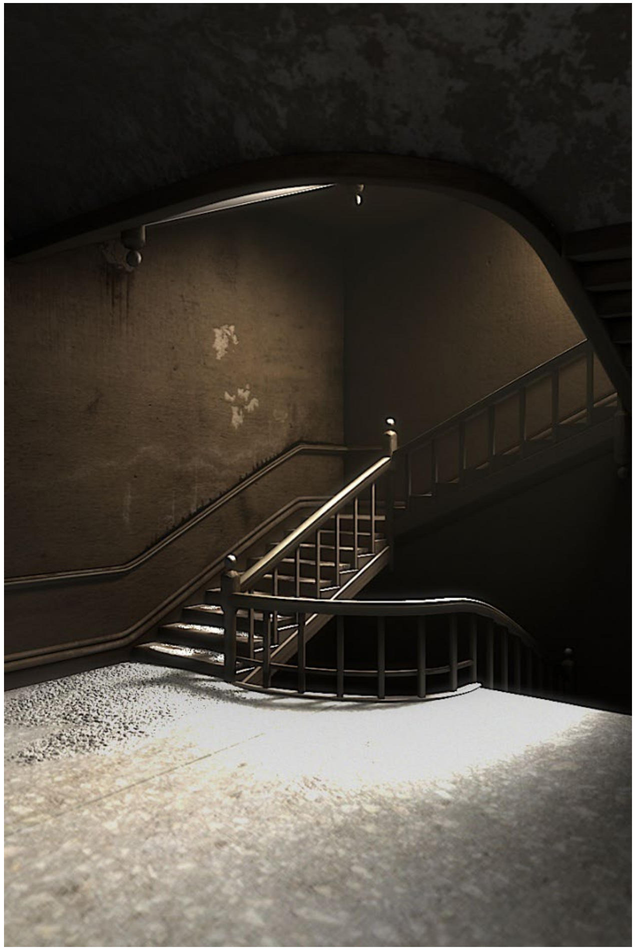
Radiosity



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

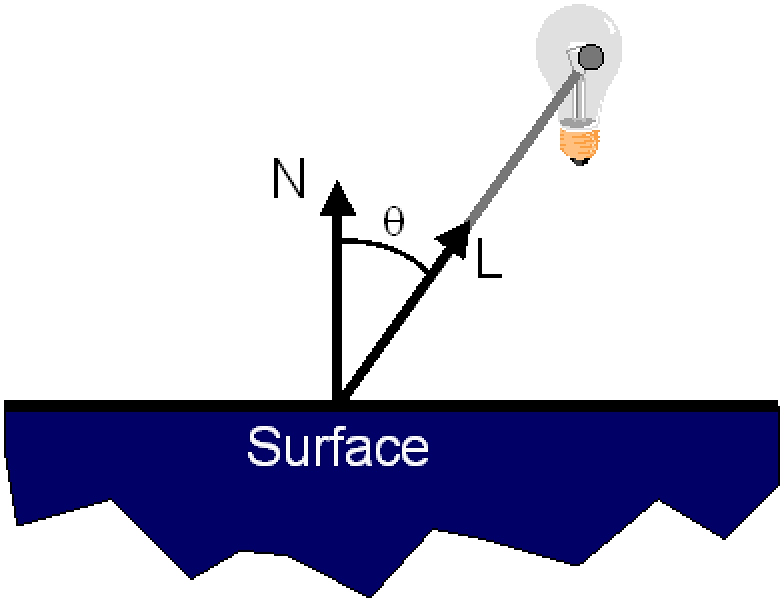
- Shade model
  - Ambient shading
  - Diffuse reflection
  - Specular reflection

Lighting and Shading

- Diffuse reflection
  - Lambertian model

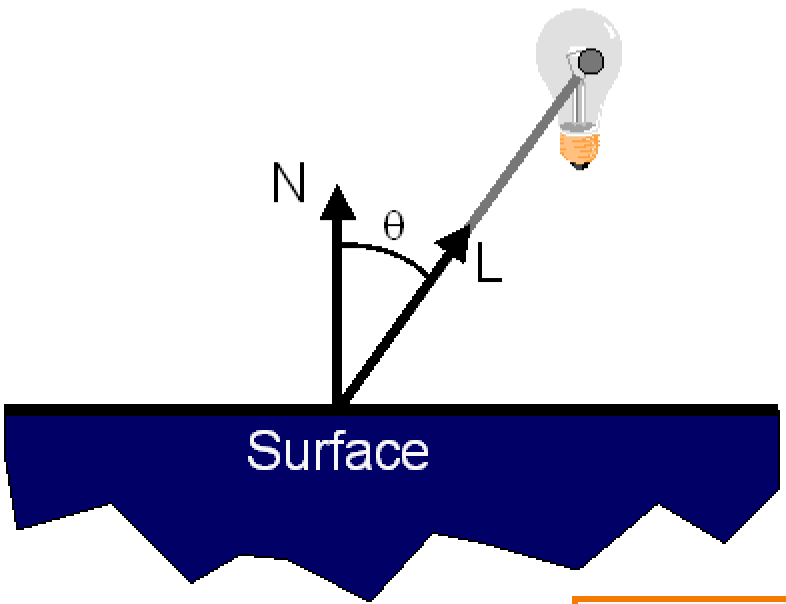
Lighting and Shading

- Diffuse reflection
  - Lambertian model



Lighting and Shading

- Diffuse reflection
  - Lambertian model



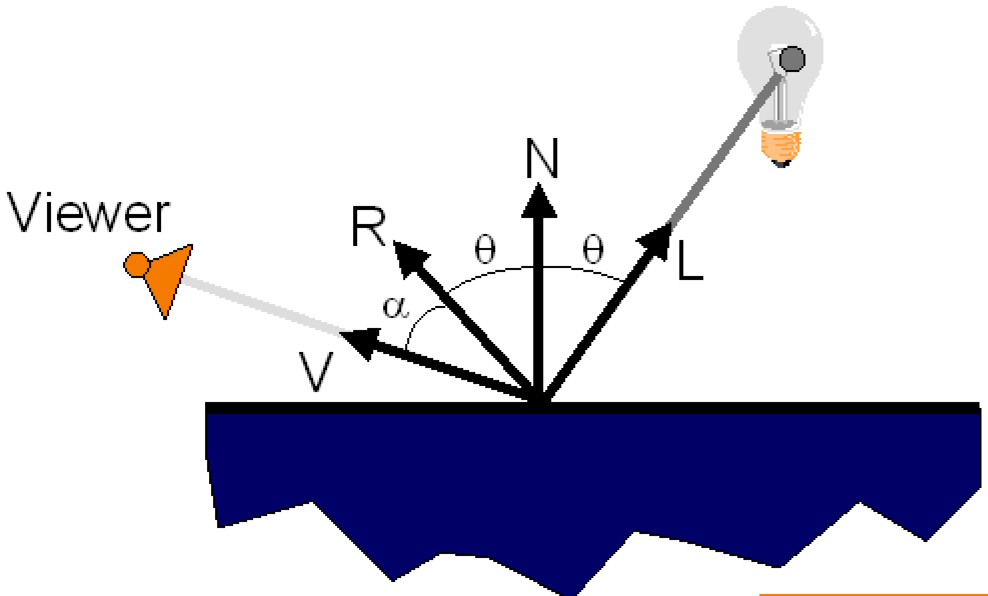
$$I_D = K_D (N \bullet L) I_L$$

Lighting and Shading

- Specular reflection
  - Phong model

Lighting and Shading

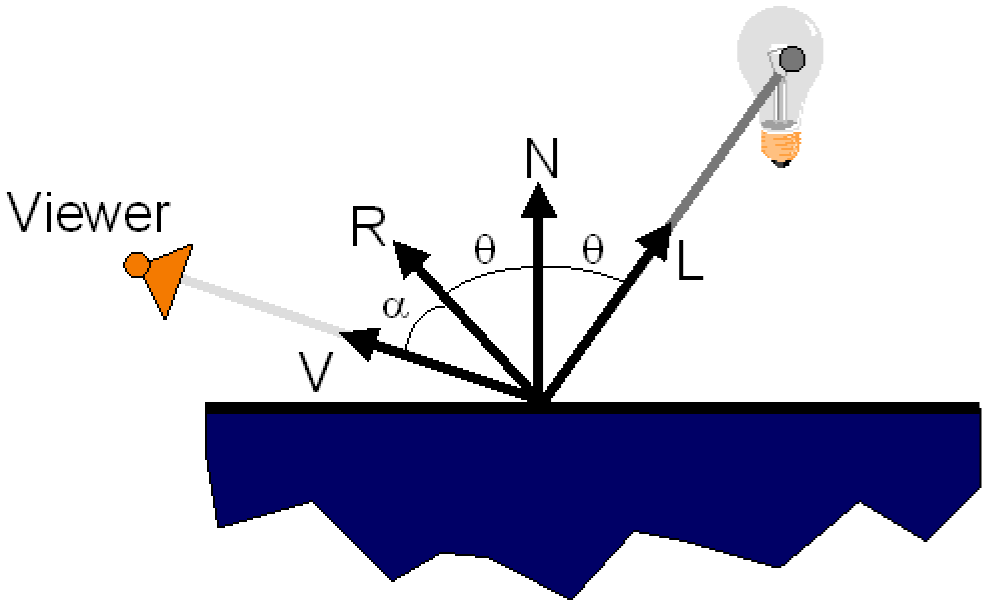
- Specular reflection
  - Phong model



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

Lighting and Shading

- Specular reflection
  - Phong model



Computer Graphics Pipeline

Geometry

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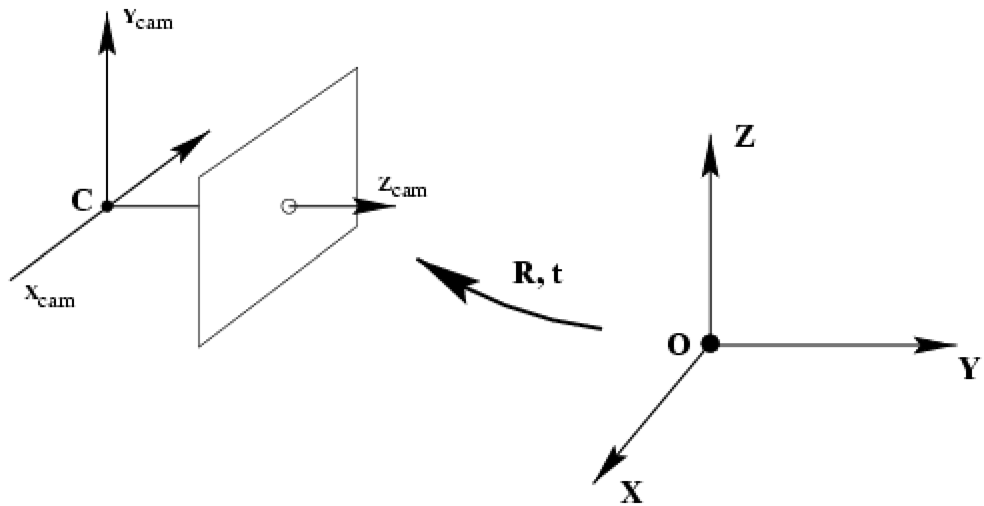
Image

Viewing Transformation



$$\tilde{x}_c = R(\tilde{X} - C)$$

$$\tilde{x}_c = R\tilde{X} - RC$$

$$-t$$

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

$$R = R_x R_y R_z$$

3x3 rotation matrices

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

translation vector

World-to-camera matrix M

“Standard” Graphics Pipeline

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Image

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- **Modeling Transformation** — Transform into 3D *world* coordinate system
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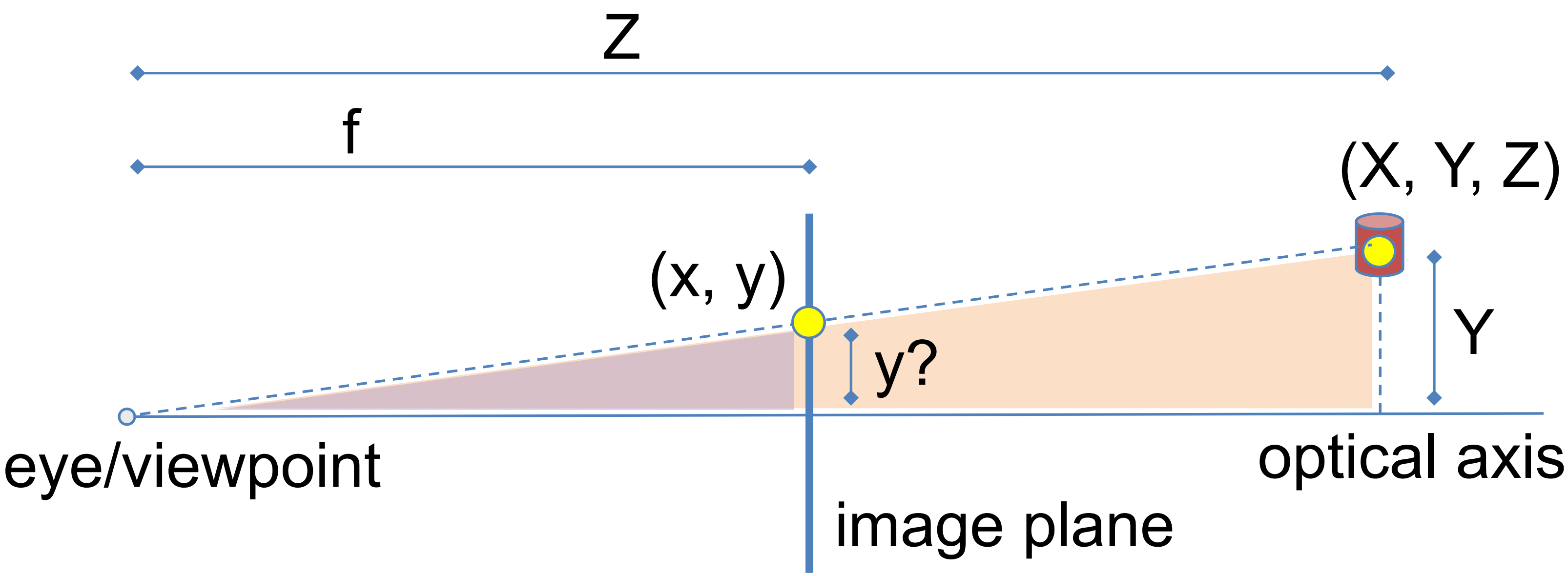
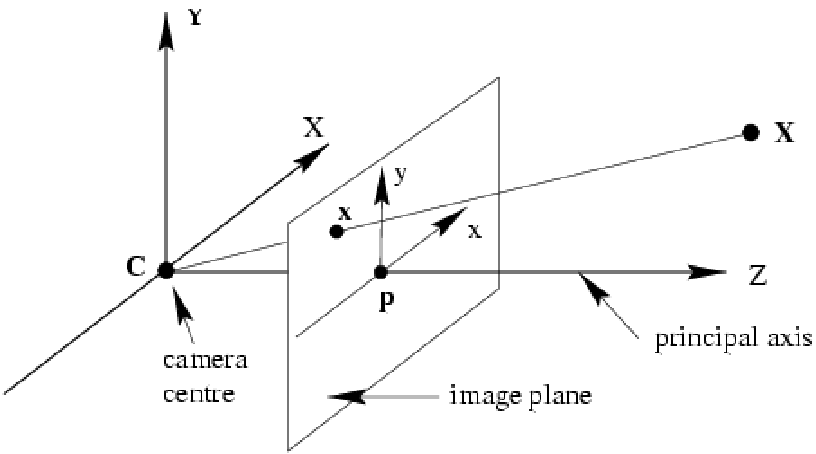
Image

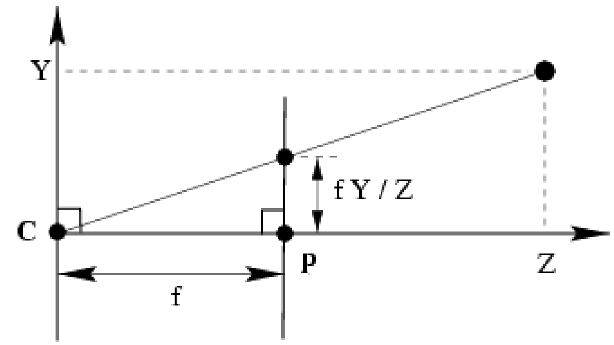
Perspective projection



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

Perspective Projection





$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} fX/Z \\ fY/Z \end{pmatrix}$$

$$\begin{pmatrix} fX \\ fY \\ Z \end{pmatrix} = \begin{bmatrix} & & & \\ & & & \\ & & & \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

OpenGL 3D Viewing

3D Viewing in OpenGL:

Position camera;

Specify projection.

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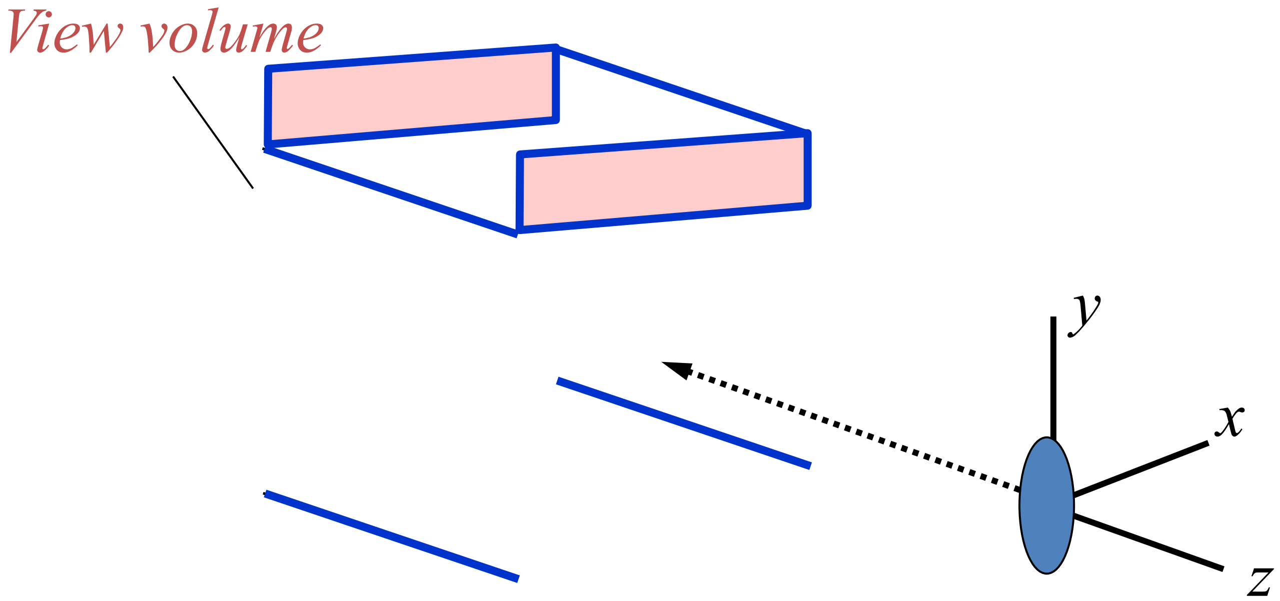
OpenGL 3D Viewing



Camera always in origin, in direction of negative z-axis.

Convenient for 2D, but not for 3D.

OpenGL 3D Viewing

Solution for view transform: Transform your model such that you look at it in a convenient way.

Approach 1: Carefully do it yourself. Apply rotations, translations, scaling, etc., before rendering the model.

Approach 2: Use `gluLookAt();`

OpenGL 3D Viewing

```
MatrixMode(GL_MODELVIEW);
gluLookAt(x0,y0,z0, xref,yref,zref, Vx,Vy,Vz);
```

`x0,y0,z0:` $\mathbf{P}_0$, viewpoint, location of camera;

`xref,yref,zref:` $\mathbf{P}_{ref}$, centerpoint;

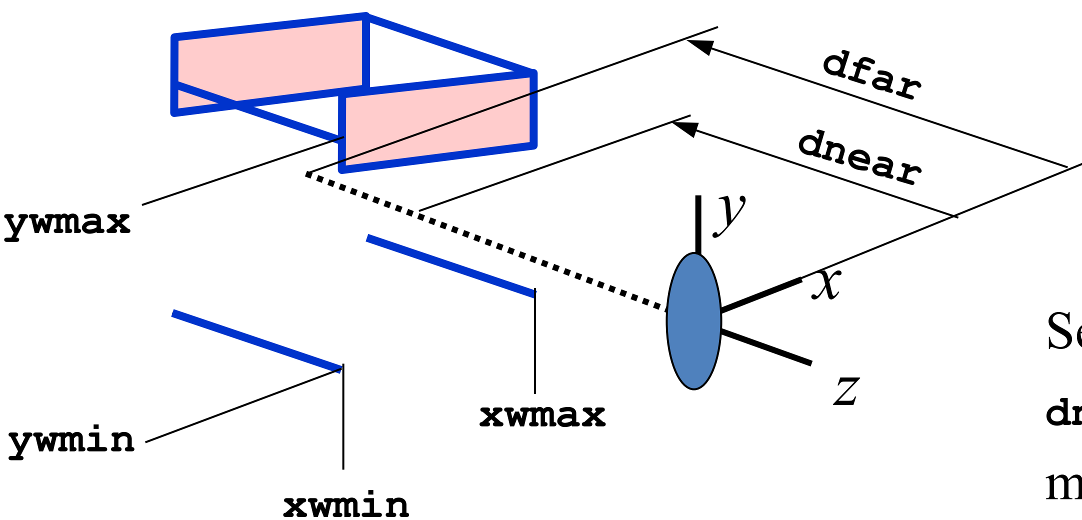
`Vx,Vy,Vz:` $\mathbf{V}$, view-up vector.

Default: $\mathbf{P}_0 = (0, 0, 0)$; $\mathbf{P}_{ref} = (0, 0, -1)$; $\mathbf{V}=(0, 1, 0)$.

OpenGL 3D Viewing

Orthogonal projection:

```
MatrixMode(GL_PROJECTION);
glOrtho(xwmin, xwmax, ywmin, ywmax, dnear, dfar);
```



xwmin, xwmax, ywmin,ywmax: specification window

dnear: *distance* to near clipping plane

dfar : *distance* to far clipping plane

Select **dnear** and **dfar** right:

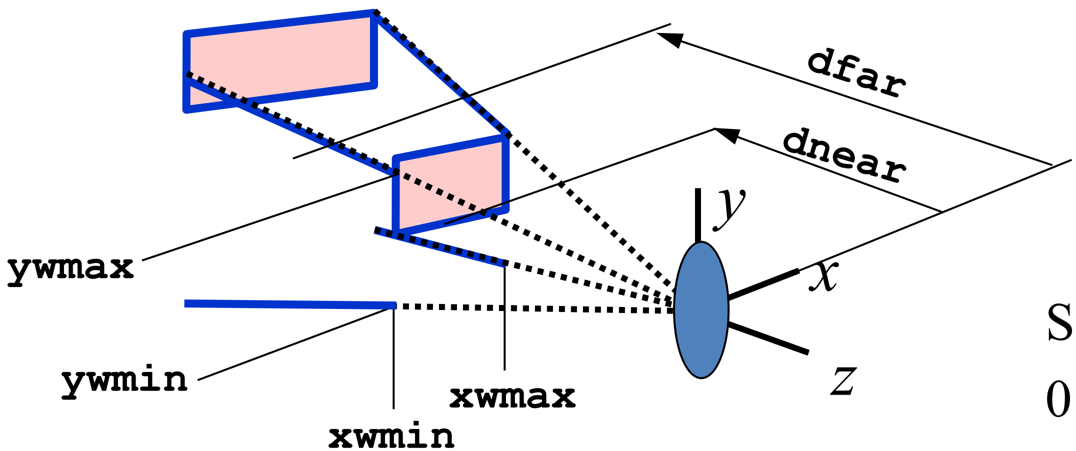
dnear < **dfar**,

model fits between clipping planes.

OpenGL 3D Viewing

Perspective projection:

```
MatrixMode(GL_PROJECTION);
glFrustrum(xwmin, xwmax, ywmin, ywmax, dnear, dfar);
```



xwmin, xwmax, ywmin, ywmax: specification window

dnear: *distance* to near clipping plane

dfar : *distance* to far clipping plane

Select **dnear** and **dfar** right:

0 < **dnear** < **dfar**,

model fits between clipping planes.

Standard projection: **xwmin = -xwmax,**

ywmin = -ywmax

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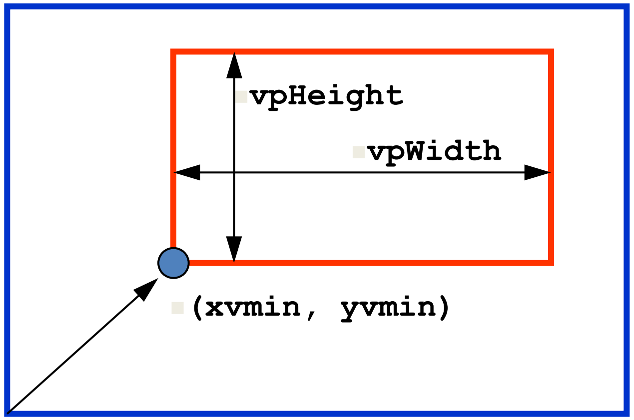
OpenGL 3D Viewing

Finally, specify the viewport (just like in 2D):

`glViewport(xvmin, yvmin, vpWidth, vpHeight);`

`xvmin, yvmin:` coordinates lower left corner (in pixel coordinates);

`vpWidth, vpHeight:` width and height (in pixel coordinates);



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OpenGL 2D Viewing

In short:

```
glMatrixMode(GL_PROJECTION);
glFrustrum(xwmin, xwmax, ywmin, ywmax, dnear, dfar);
glViewport(xvmin, yvmin, vpWidth, vpHeight);
glMatrixMode(GL_MODELVIEW);
gluLookAt(x0,y0,z0, xref,yref,zref, Vx,Vy,Vz);
```

To prevent distortion, make sure that:

(ywmax – ywmin)/(xwmax – xwmin) = vpWidth/vpHeight

Make sure that you can deal with resize/reshape of the (OS) window.

H&B 8-4:265-267

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↓

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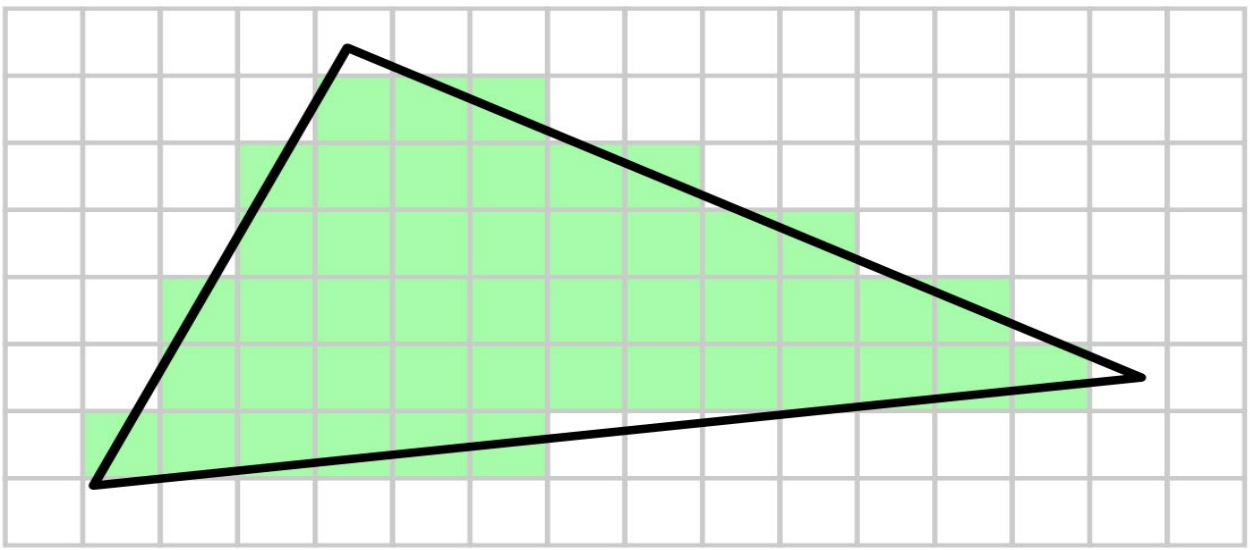
↓

Image

Scan Conversion/Rasterization

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



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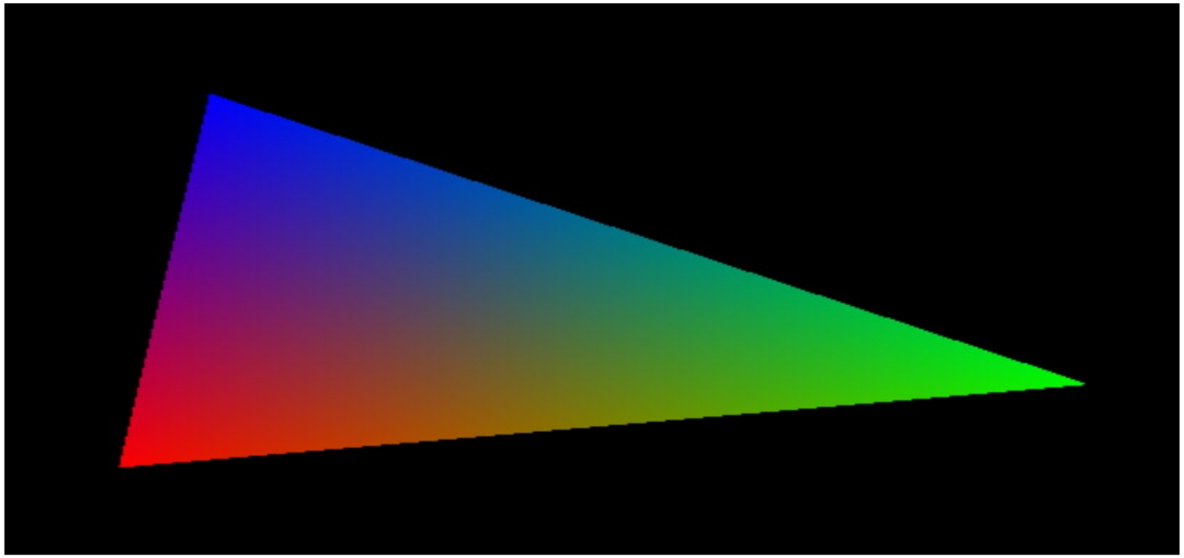

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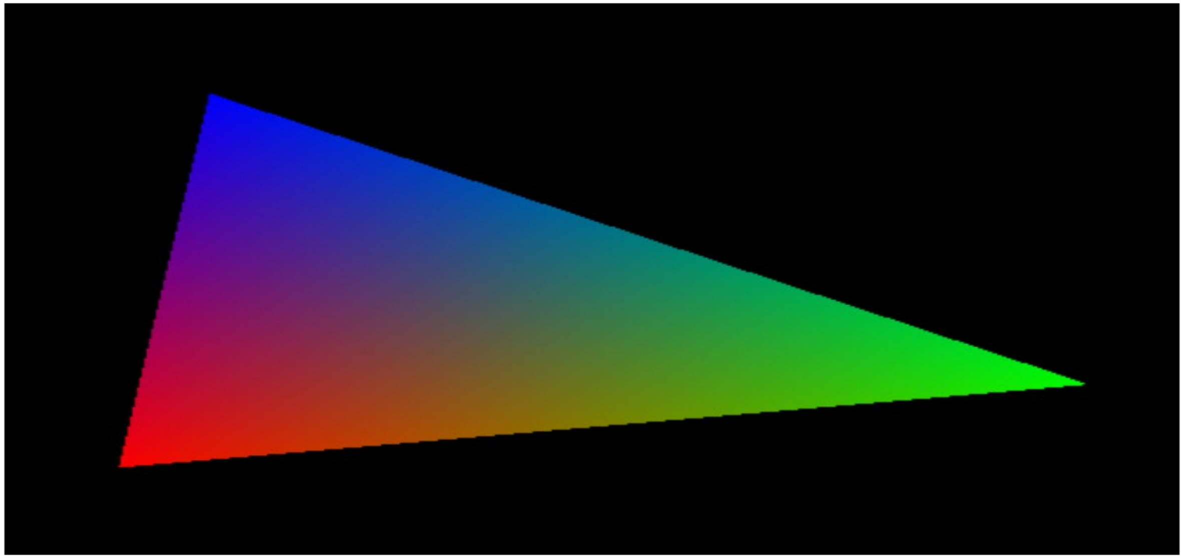
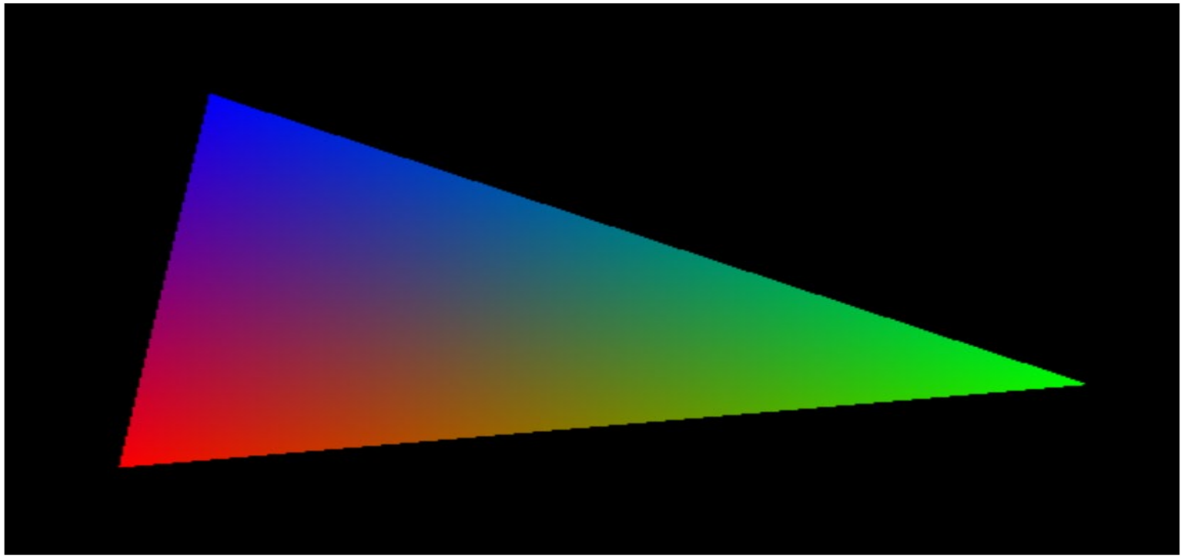


- How?

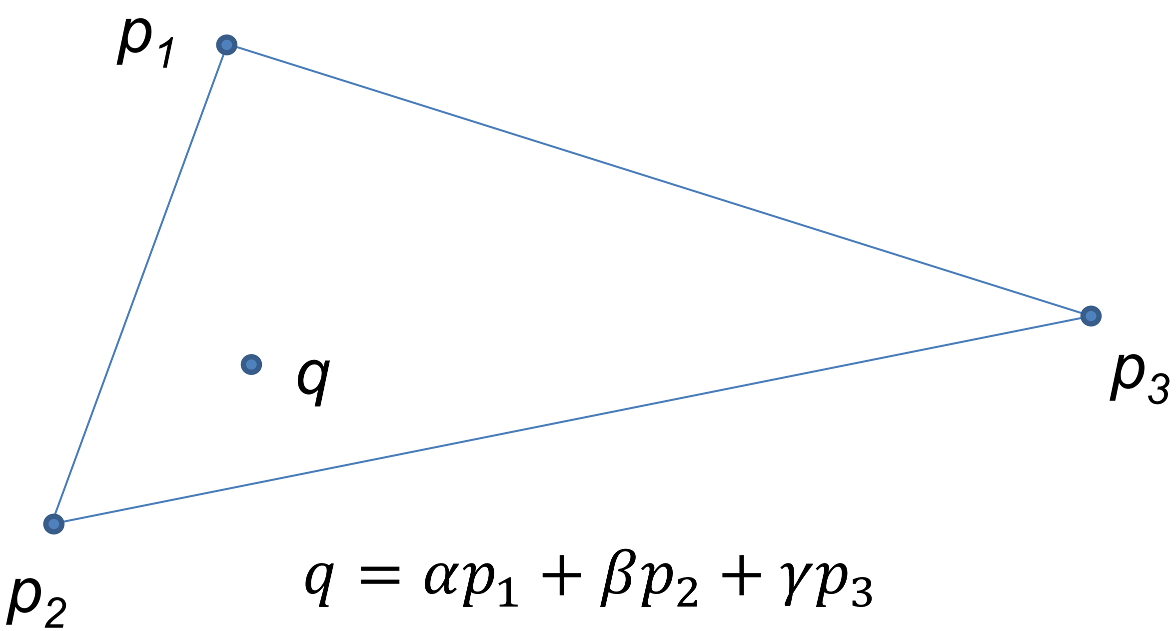
Scan Conversion/Rasterization

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



- E.g., Barycentric coords (see whiteboard!)

Barycentric coordinates



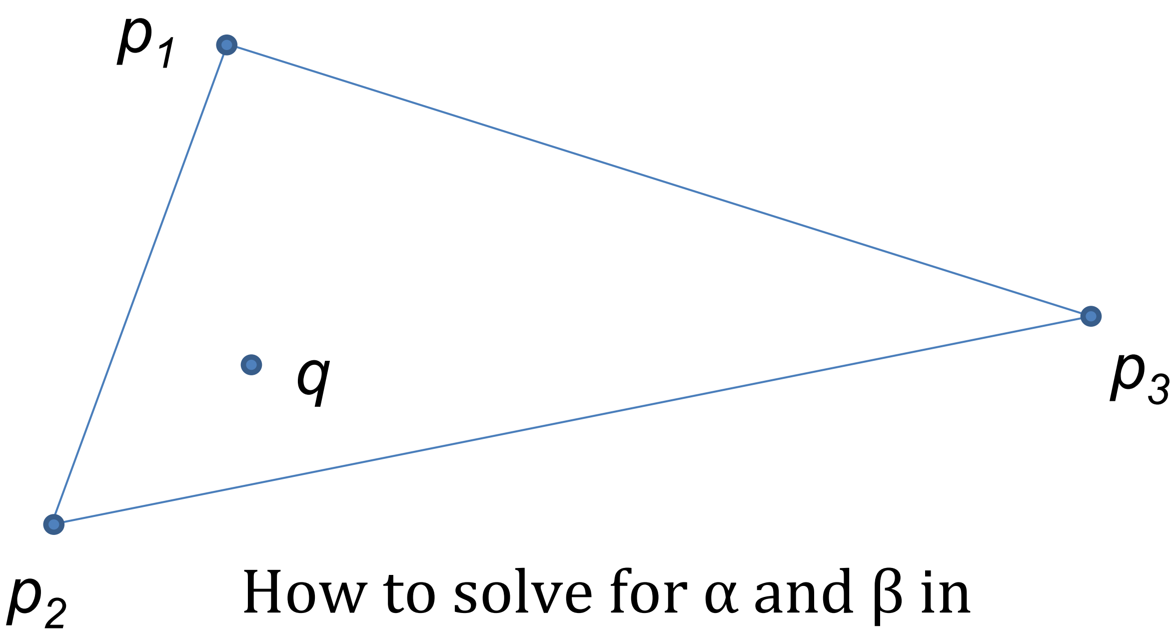
$$q = \alpha p_1 + \beta p_2 + \gamma p_3$$

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…