Graphics Pipeline (cont.)
Graphics Pipeline

Geometric Pipeline:
- Transform
- Project
- Clip

Pixel Pipeline:
- OpenGL application program
- Pixel operations
- Rasterizer
- Frame buffer
Transform

Geometric Pipeline

Pixel Pipeline

OpenGL application program

Transform

Project

Clip

Pixel operations

Rasterizer

Frame buffer
“Modelview” Transformation

Object coordinates → Model

World coordinates

Eye coordinates → View

Model

View
Project
Projection: map 3D scene to 2D image
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

\[ \text{glFrustum}(x_{\min}, x_{\max}, y_{\min}, y_{\max}, \text{near}, \text{far}) \]

View volume for a perspective projection is a frustum
Clip
Clip against view volume
Hidden Surface Removal
Occlusion

“painter’s algorithm”

draw primitives in back-to-front order

[Wikimedia Commons]
Occlusion

“painter’s algorithm” draw primitives in back-to-front order

problem: triangle intersection
Occlusion

“painter’s algorithm”
draw primitives in back-to-front order

**problem:**
occlusion cycle
Use a *z-buffer* for hidden surface removal

test depth on a pixel by pixel basis

red drawn last

without z-buffer  with z-buffer
Use a **z-buffer** for hidden surface removal

at each pixel, record distance to the closest object that has been drawn in a depth buffer
Use a *z-buffer* for hidden surface removal
Use a z-buffer for hidden surface removal

http://www.beyond3d.com/content/articles/41/
Backface culling: another way to eliminate hidden geometry
Hidden Surface Removal in OpenGL

```c
glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGB | GLUT_DEPTH);

 glEnable(GL_DEPTH_TEST);

 glEnable(GL_CULL_FACE);
```

For a perspective transformation, there is more precision in the depth buffer for z-values closer to the near plane.