ROYAL INSTITUTE OF TECHNOLOGY

DH2323 DGI17

INTRODUCTION TO COMPUTER GRAPHICS AND INTERACTION

RASTERISED RENDERING

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Based on DGI12 notes by Carl Henrik Ek

The Rendering Equation

Emitted radiance

BRDF

Account for angle w.r.t. light

$$L_o(\mathbf{x}, \omega_o, \lambda, t) = L_e(\mathbf{x}, \omega_o, \lambda, t) + \int_\Omega f_r(\mathbf{x}, \omega_i, \omega_o, \lambda, t)\, L_i(\mathbf{x}, \omega_i, \lambda, t)\, (\omega_i \cdot \mathbf{n})\, d\,\omega_i$$

Incoming radiance

Describes:

- Total amount of light emitted from a point x along a specific viewing direction

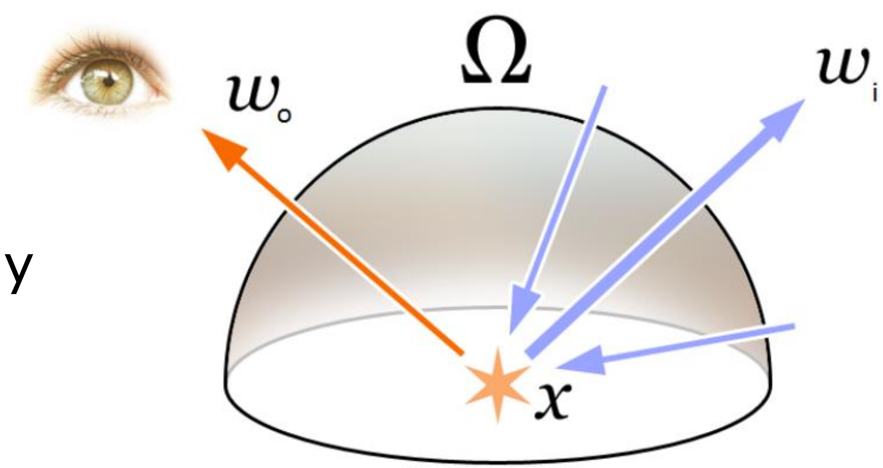
Given:

- Incoming light function
- BRDF

Basis:

- Law of conservation of energy

Hemisphere containing all w_i

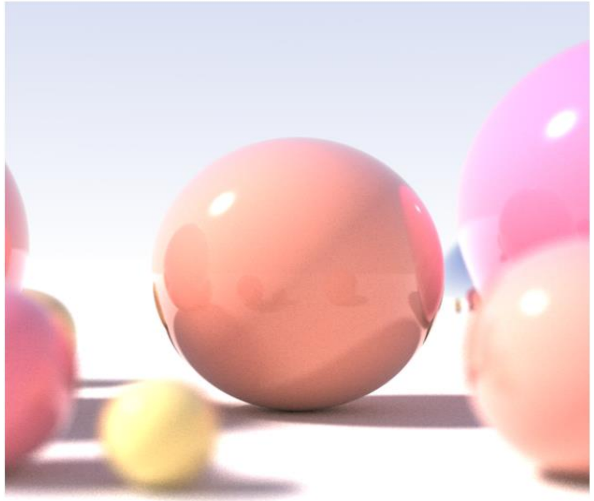


Global Illumination

Ray tracing:
- Good for specular
- Bad for diffuse

Radiosity:
- Good for diffuse
- Bad for specular

Hybrid techniques



Caustics

- Curved regions of bright reflected or refracted light

Sub-surface scattering

- Light bouncing around inside material before exiting

Ray tracing

Pixel order rendering technique

- Trace at least one ray through each image pixel
- Maintains primitives in geometric scene model
- Queries this for each ray
- Determine which primitive is visible for each pixel

Geometry queries can have high cost

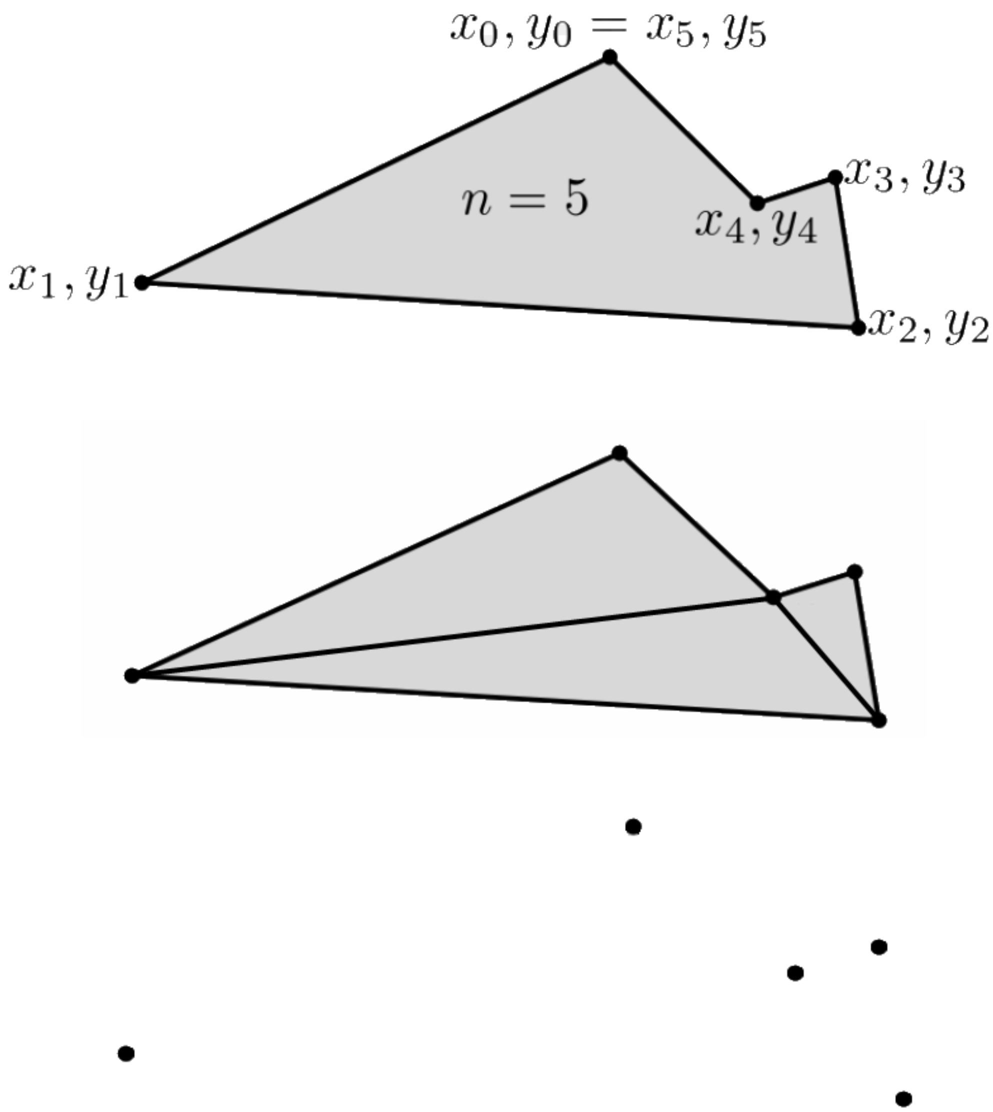
Rasterisation

- Scanline: object order based
- *Fragments*
  - Data for single pixel
  - Frame buffer
- Handle occlusion using depth buffer
  - Later details (more specifically, *fragments*) overwrite earlier ones if closer to camera
- Shade based on vertices and interpolate
  - See lighting and shading lecture

Rasterisation

Process of converting geometry into a raster image (series of pixels)

- 3D scene converted into 2D image
- Polygons
- ...composed of *triangles*
- ...composed of *vertices*



Rasterisation

Rasteriser takes stream of vertices

Project them onto the 2D surface of the screen

Fill in the interior of the 2D triangles

Core concepts:

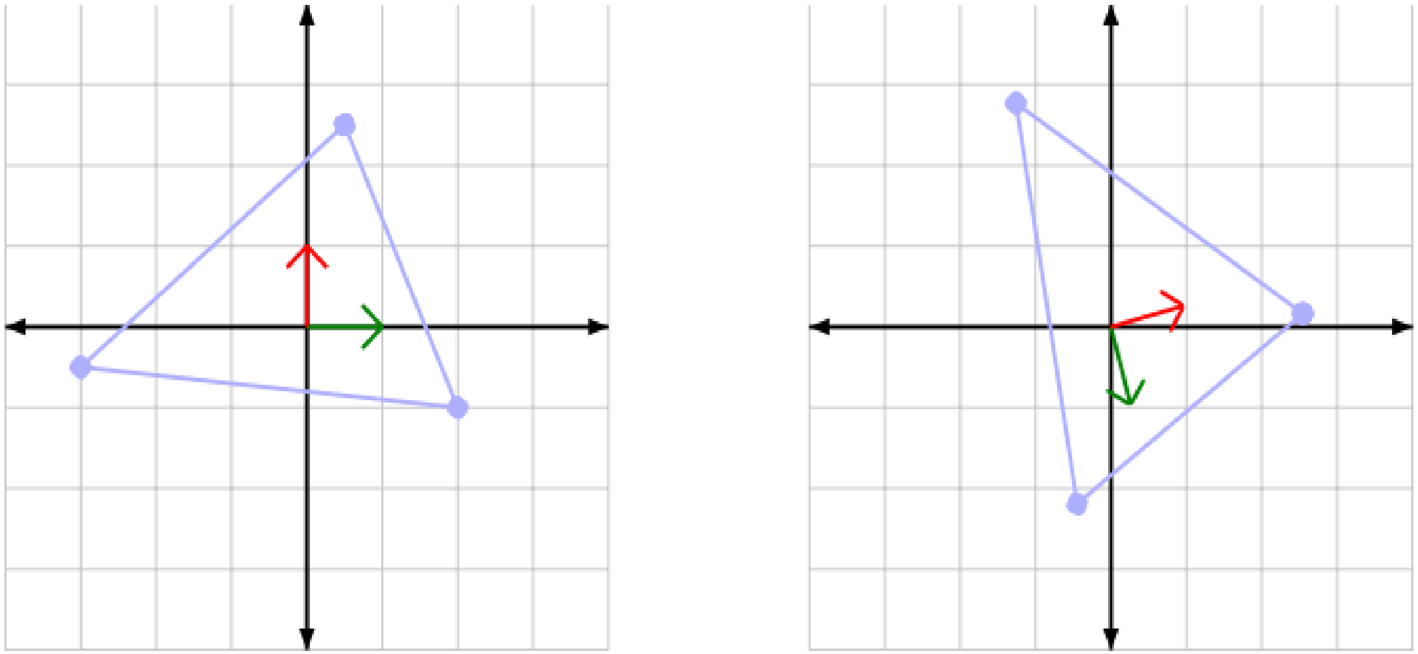
- Geometry and transformations
- Projection
- Clipping
- Scanline Conversion

Geometry Transformations

Matrix multiplication

Translation, scaling, rotation, projection

Familiar?



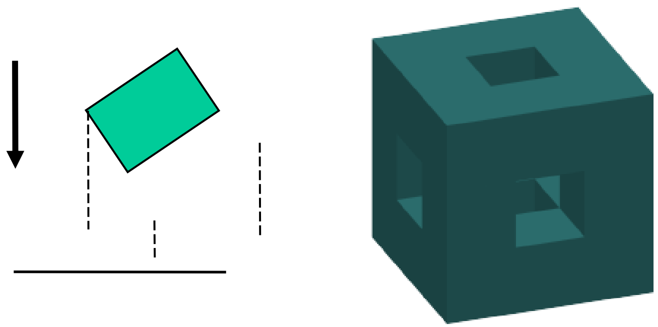
Transformation Stack

- *Stack* of transforms (i.e. matrices)
  - Push and pop
- Position stream of input vertices
- Incoming vertices transformed according to the transformation stack
- Remember: local coordinate marker idea

Projection

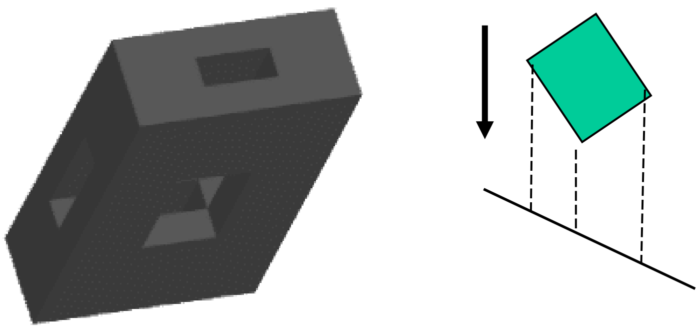
- Remove depth
  - Convert 3D geometry to flat 2D representation
  - Do so for each vertex of each polygon
- Orthographic projection
  - Simply remove z coordinate
  - Viewing volume is a cube
- Perspective projection
  - Single point of projection (focal point)
  - Viewing volume is a pyramid

Parallel Projections



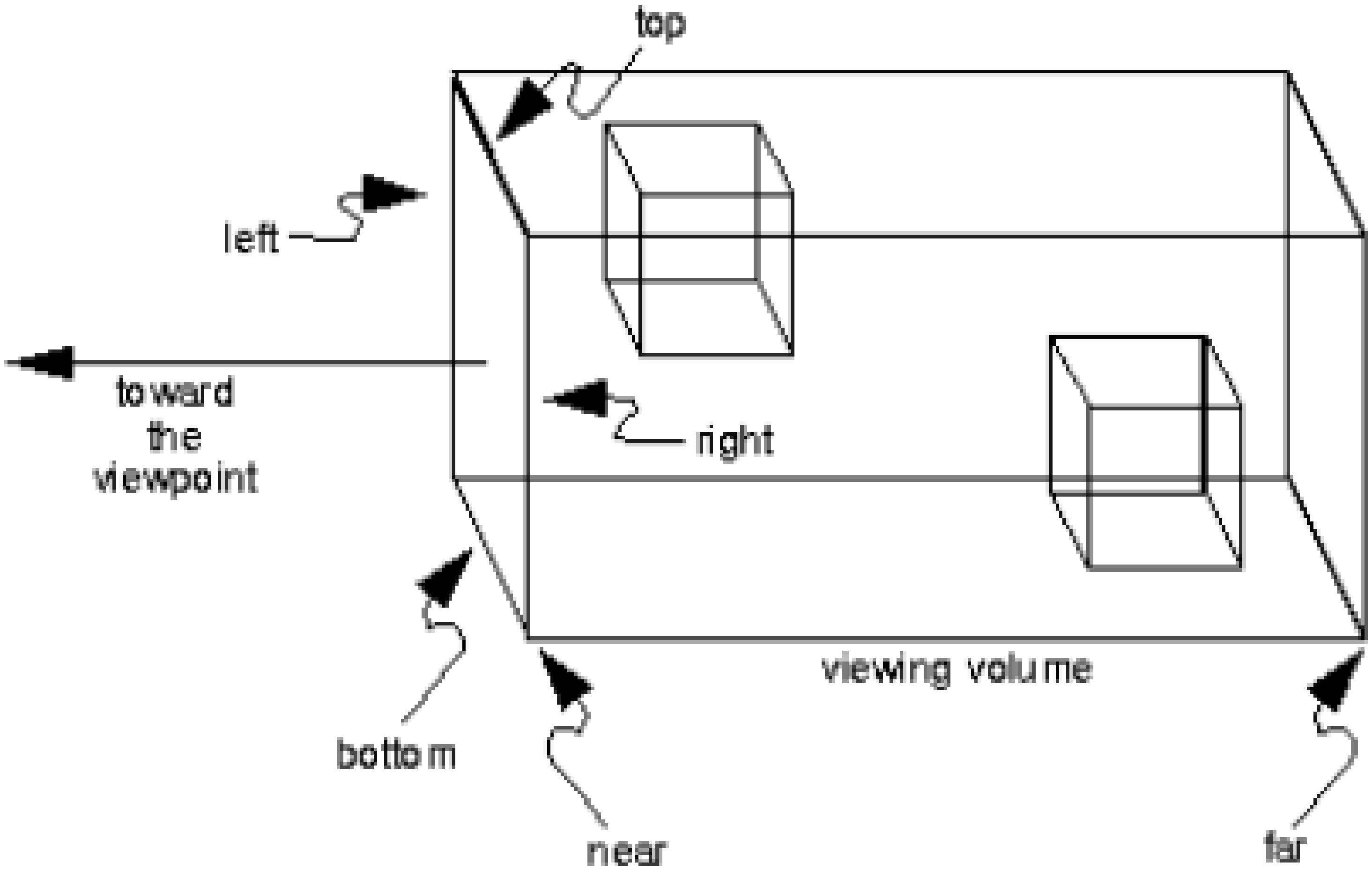
axonometric

orthographic



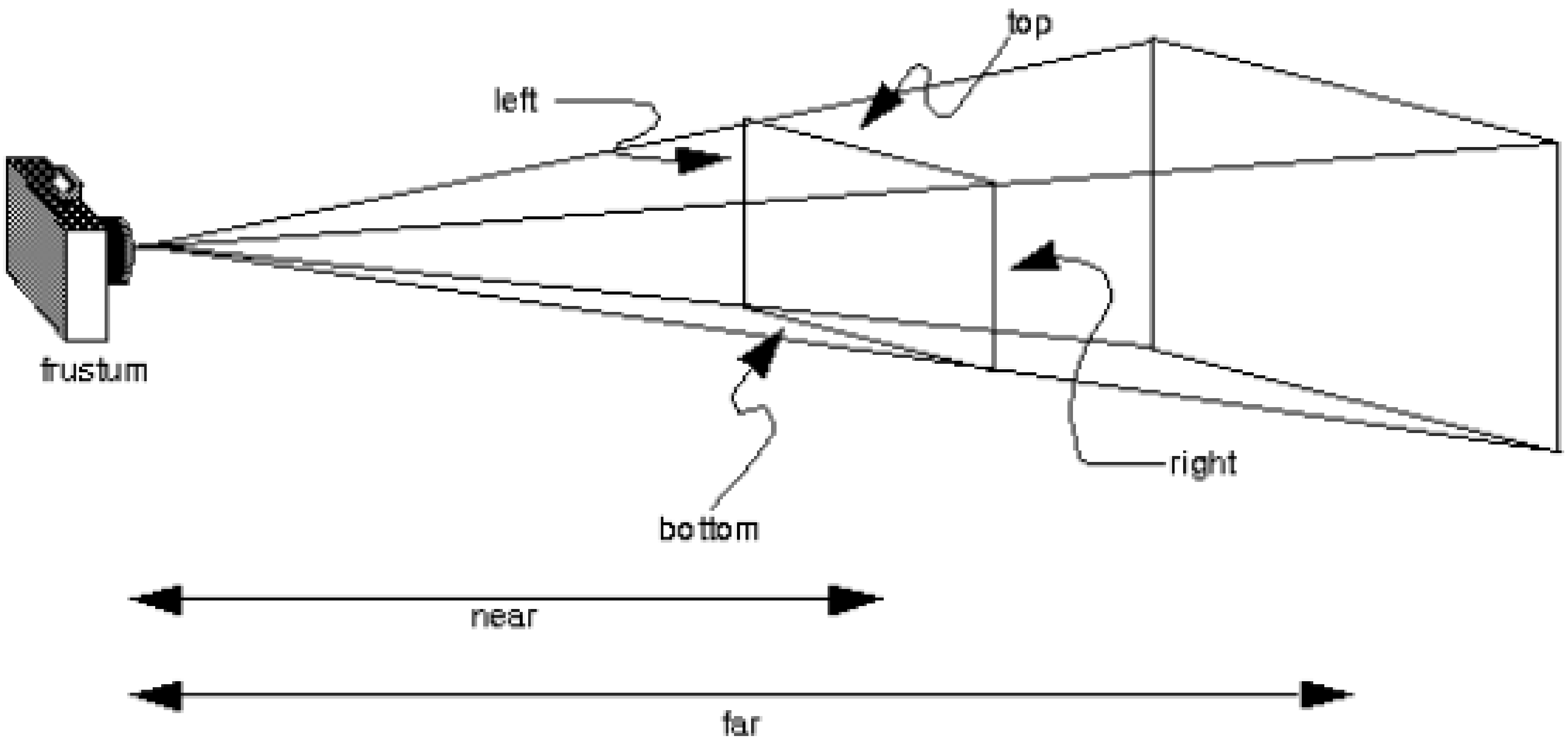
oblique

Orthographic Projection



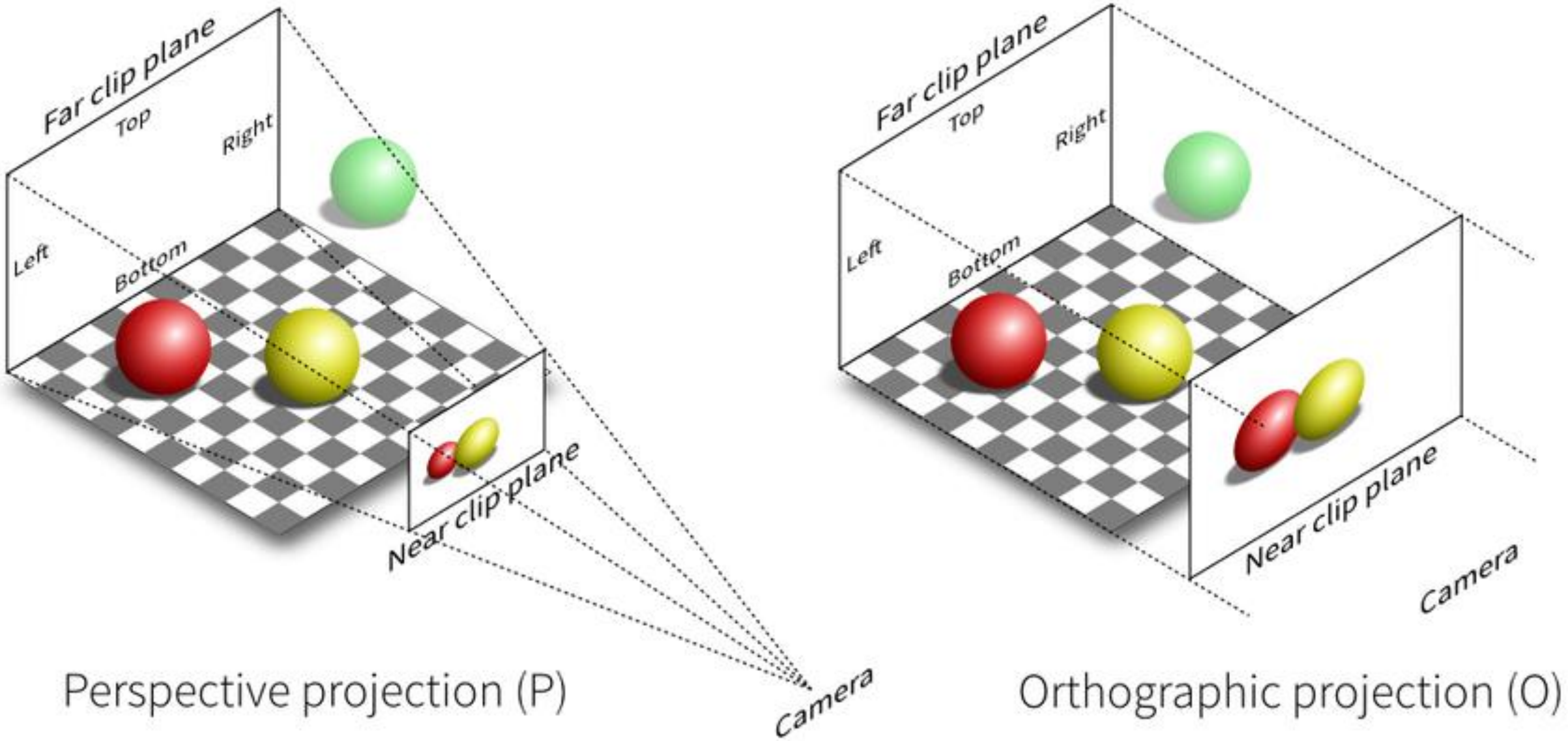
From OpenGL Programming Guide

Perspective Projection



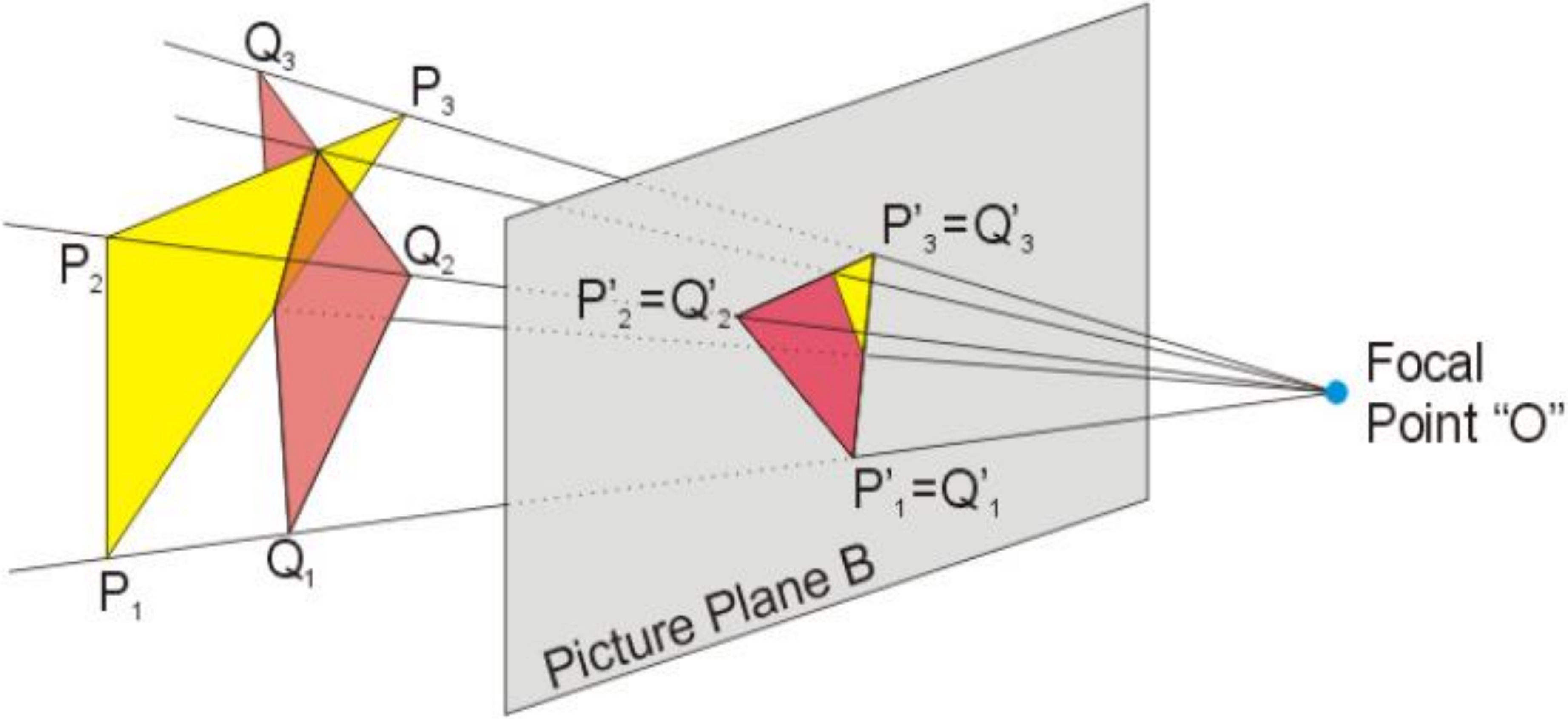
From OpenGL Programming Guide

Example



Nicolas P. Rougier, ERSF Code camp

Projection



Camera Specification

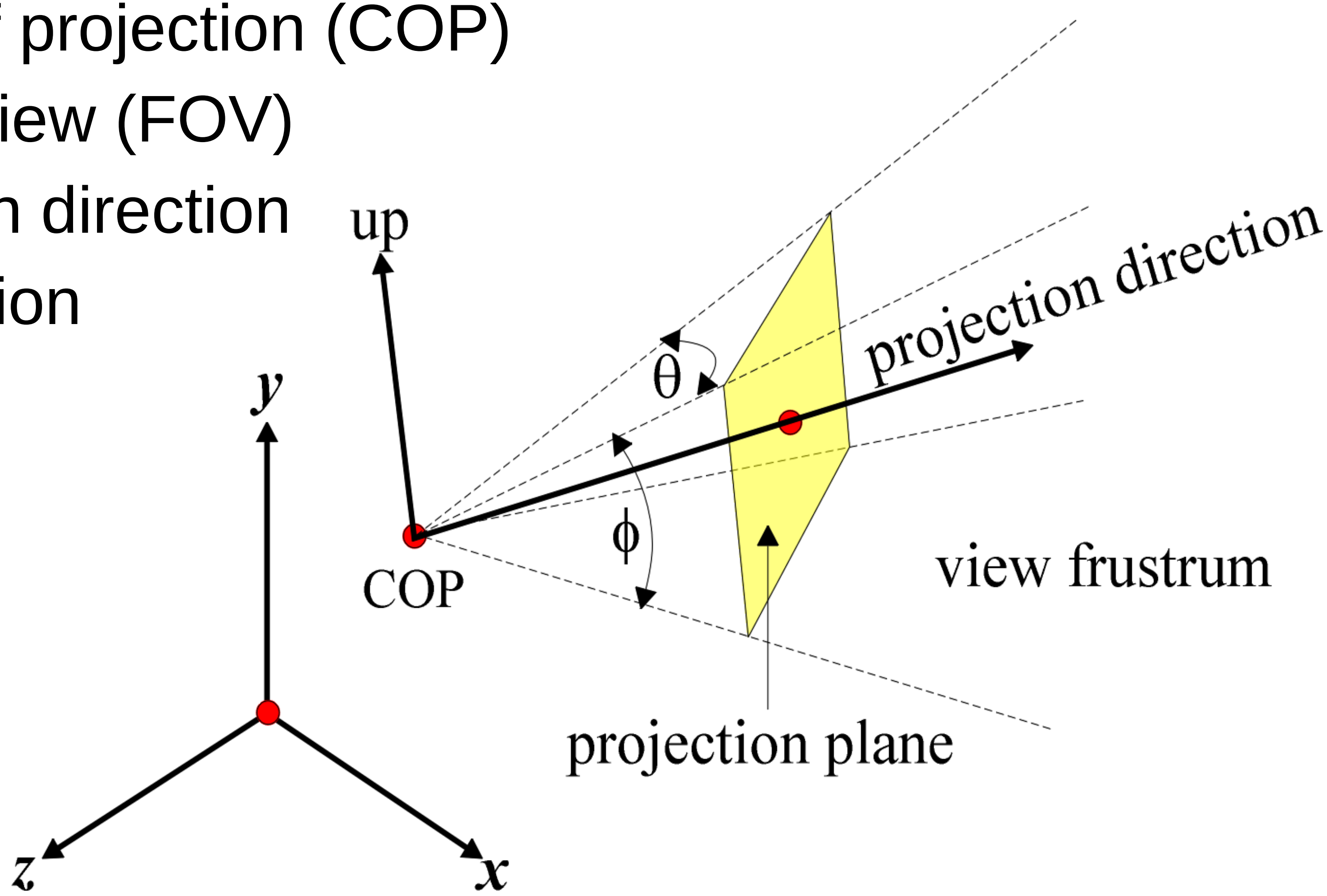
<u>Parameters</u>

Centre of projection (COP)

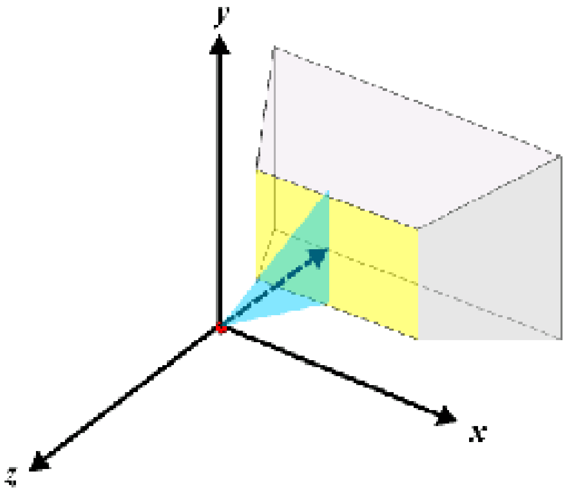
Field of view (FOV)

Projection direction

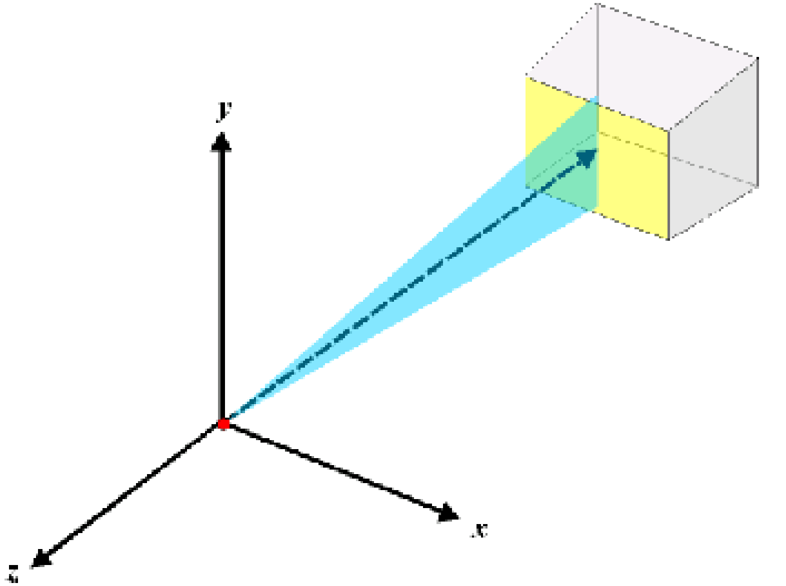
Up direction



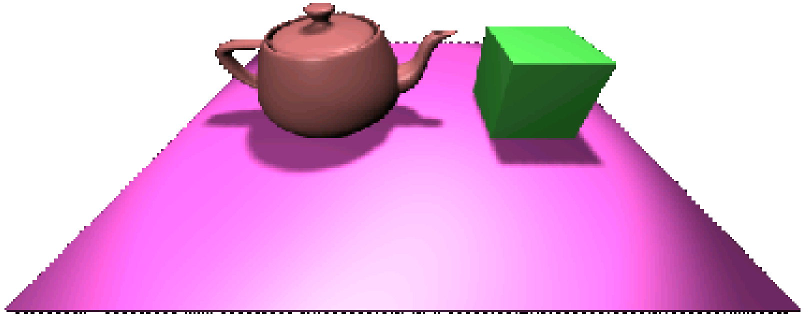
Outcomes

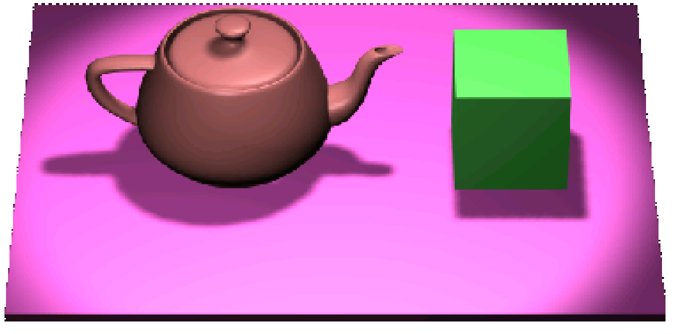


Large FOV



Small FOV



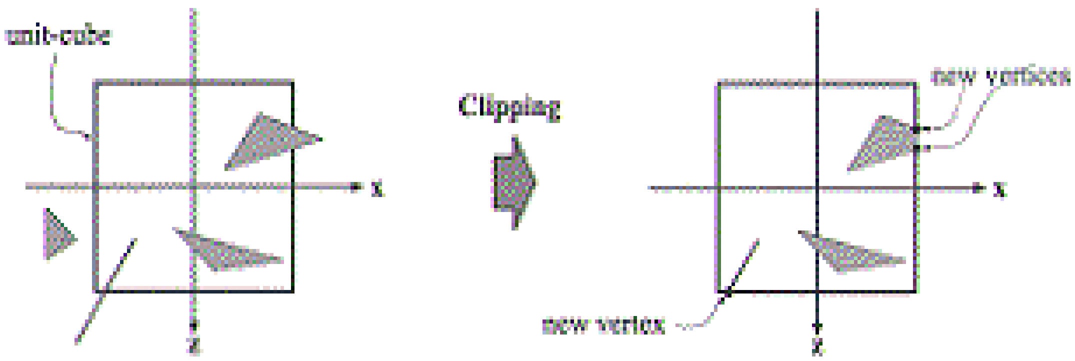


Clipping

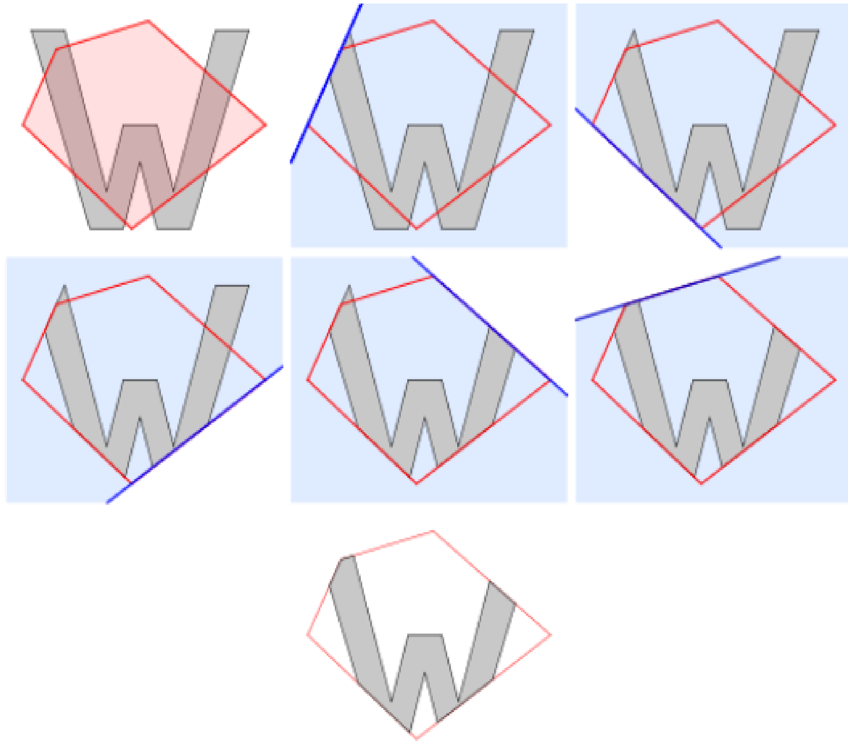
Projected locations may be outside the viewing window

Truncate triangles to fit them inside the viewing area

– e.g. Sutherland-Hodgeman algorithm

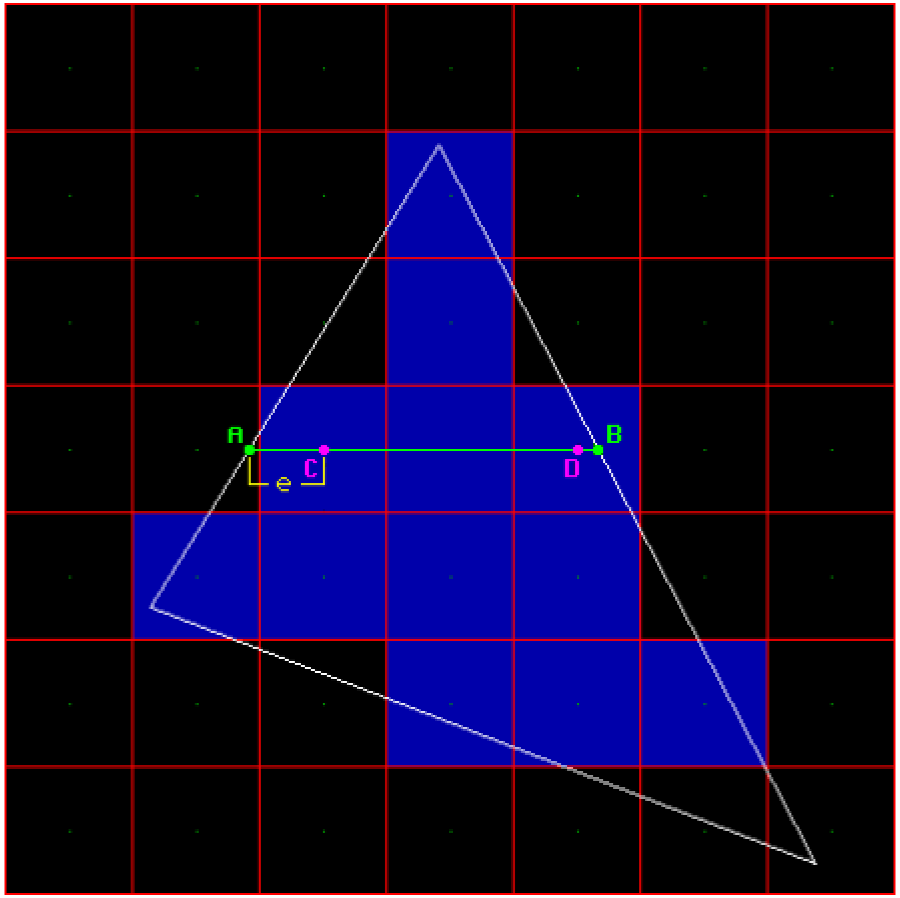


Real-time Rendering, Akenine-Moller, Haines and Hoffman



Scan Conversion

- Fill interior of triangles in image plane
- Use *scanline fill algorithm* to fill polygons
- Framebuffer

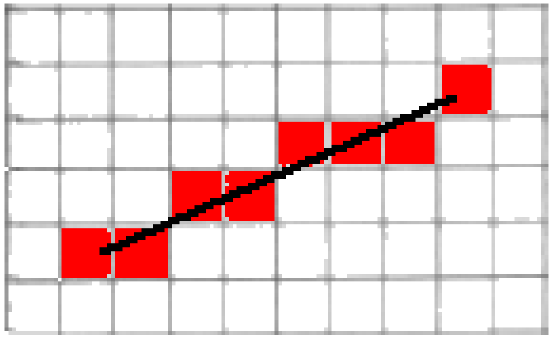


Line Drawing

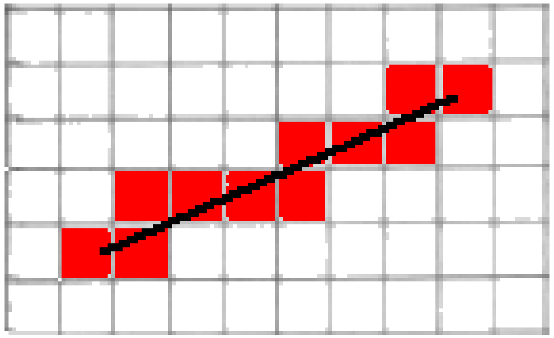
A line usually defined as infinitely thin

How to display using pixels?

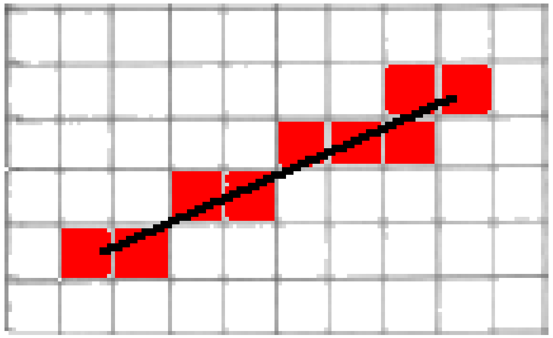
- Fixed and finite area
- Choose pixels that best represent the line
- Different algorithms, providing different results:



mid-point



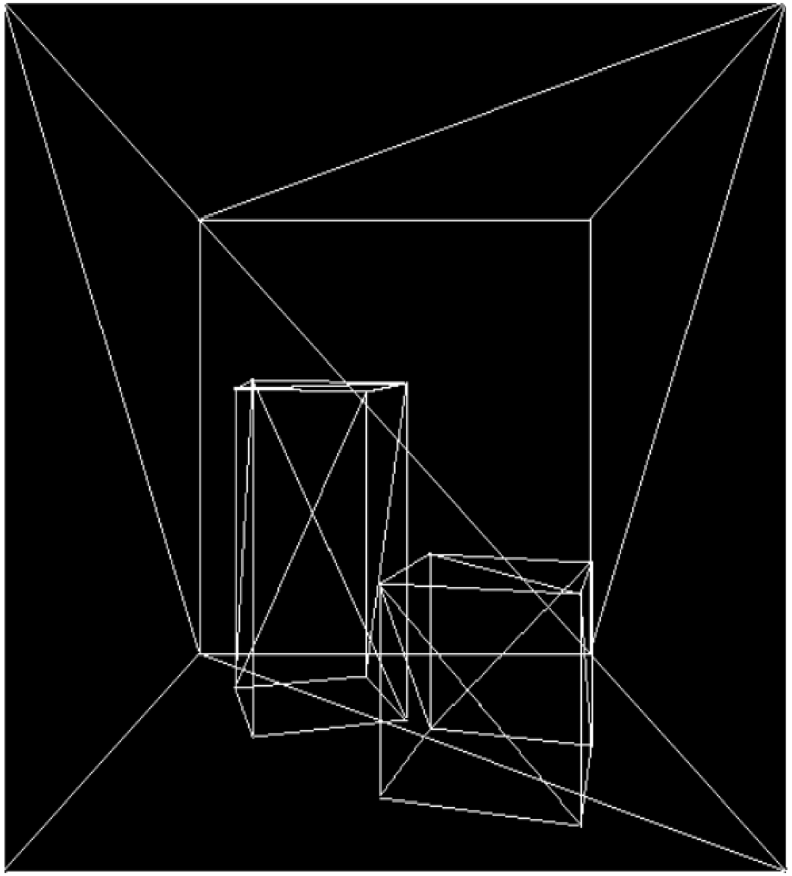
neighbourhood



weighted area

Line Drawing

Bresenham's line algorithm



```
dx = x_end - x_start
dy = y_end - y_start
d = 2 * dy - dx
x = x_start
y = y_start
while x < x_end
if d <= 0 then
    d = d + (2 * dy)
    x = x + 1
else
    d = d + 2 * (dy - dx)
    x = x + 1
    y = y + 1
endif
SetPixel(x,y)
endwhile
```

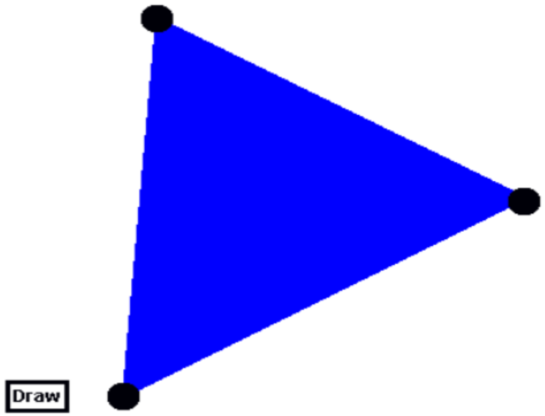
Polygon Filling

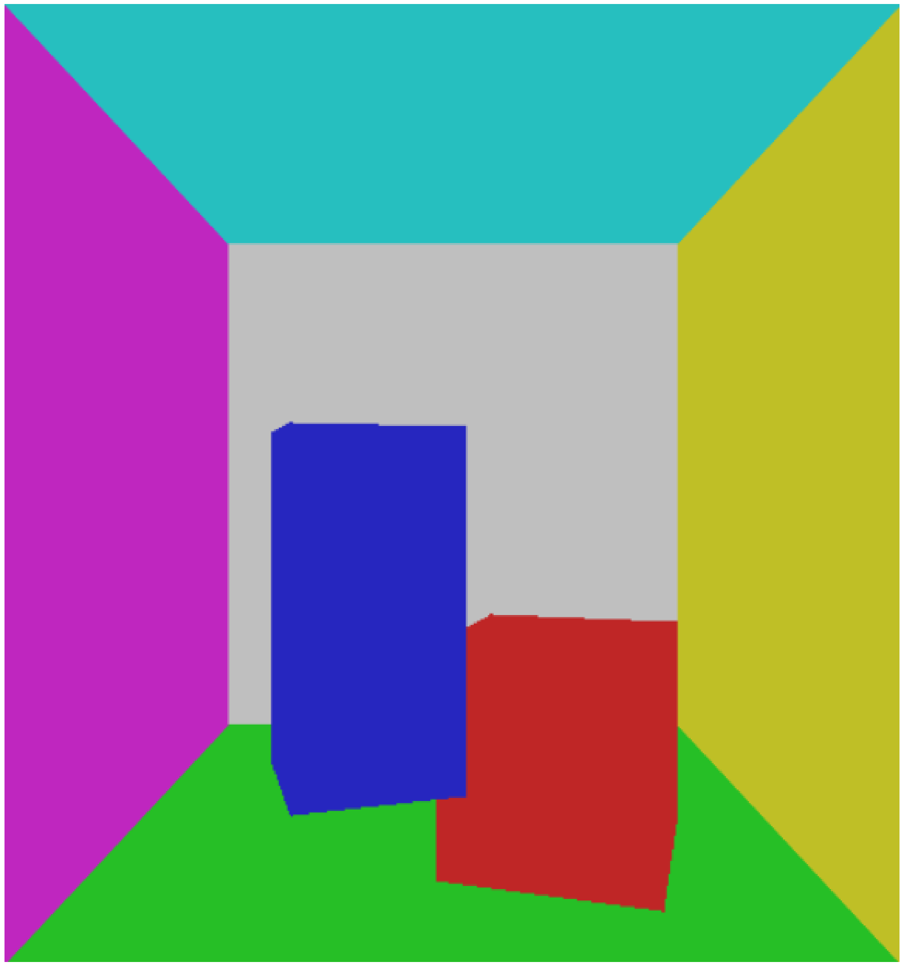
Fill surface

Triangles

Interpolation

Compute edges





Fixed Function Pipeline (FFP)

Beware: what follows is mostly deprecated

- Not programmable
  - Transform and rasterisation operations hardwired
- *Immediate mode* OpenGL
- Obsolete

Compare to modern *programmable pipeline*

- Vertex, pixel, etc shaders

Recommendation:

- Start with FFP to gain understanding of basics
- Learn programmable pipeline after

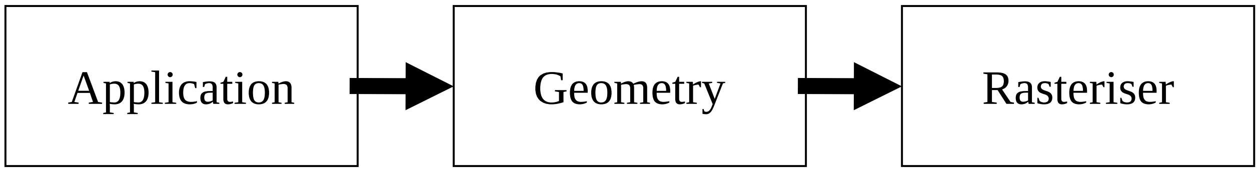
Graphics Pipeline Architecture

Can divide pipeline into three conceptual stages:

Application (input, animations, think SDL)

Geometry (transforms, projections, lighting)

Rasteriser (draw image as pixels)



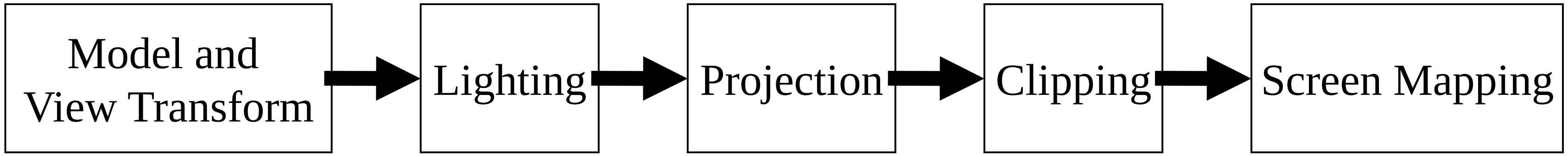
These define the core structure of the pipeline

Geometry Stage

Responsible for polygon and vertex operations

Consists of five sub-stages:

- Model and View Transform
- Lighting and Shading
- Projection
- Clipping
- Screen Mapping



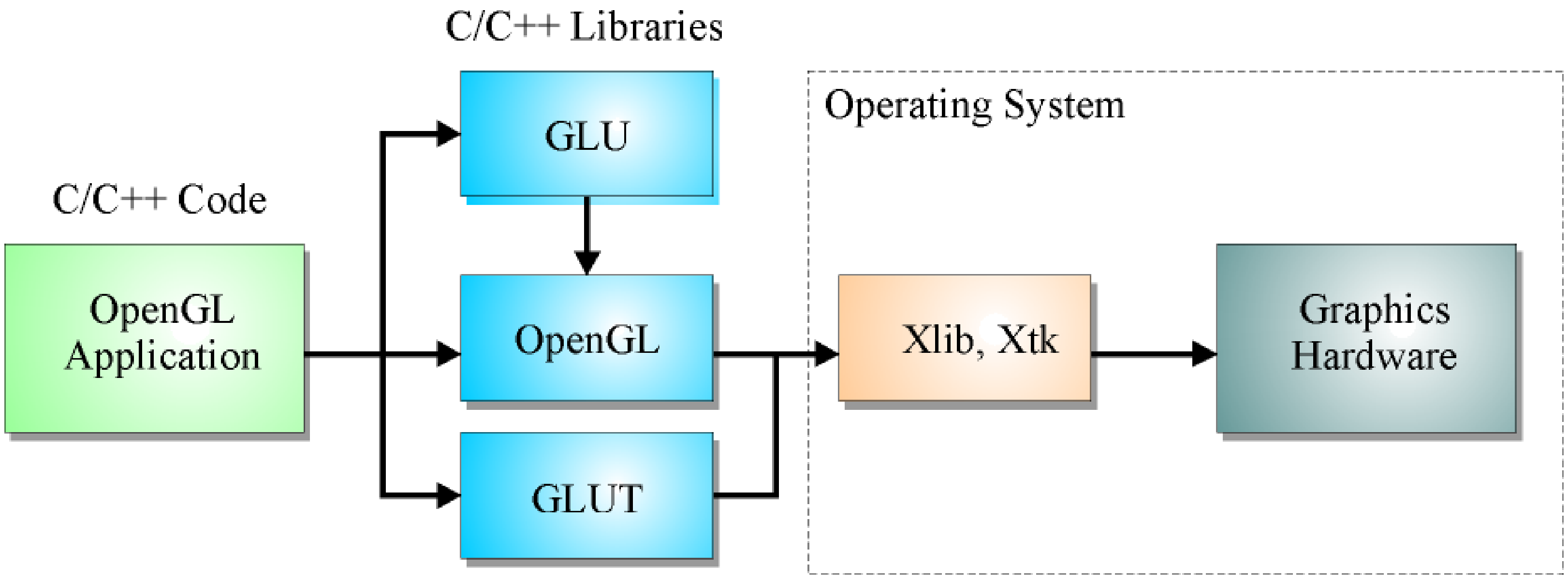
What is OpenGL ?

Software interface to graphics hardware

Commands for interactive three-dimensional graphics

Hardware independent interface

Drawing operations performed by underlying system and hardware



OpenGL Conventions

All function names begin with **gl**, **glu** or **glut**

- glVertex(…)
- gluSphere(…)
- glutMouseFunc(…)

Constants begin with **GL_**, **GLU_** or **GLUT_**

- GL_FLOAT

Function names show parameter types

- glVertex**2i**(1, 3)
- glVertex**3f**(1.0, 3.0, 2.5)
- glVertex**4fv**(array_of_4_floats)

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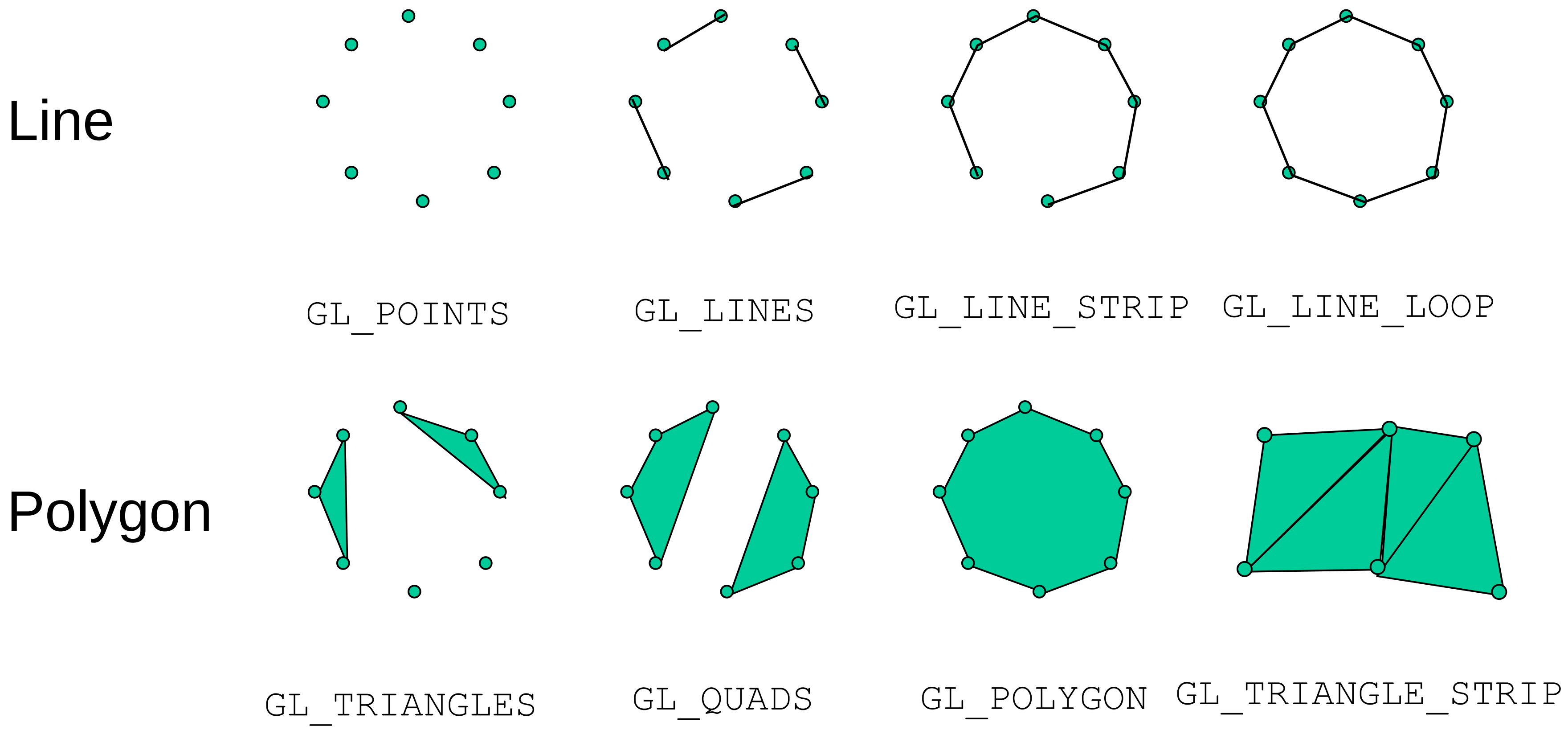
OpenGL Primitives

- Basic building blocks
- Line based primitives, and polygon based primitives:



Some OpenGL Code

To create a red polygon with 3 vertices:

```
glColor3f(1.0, 0.0, 0.0);
glBegin(GL_POLYGON);
  glVertex3f(0.0, 0.0, 3.0);
  glVertex3f(1.0, 0.0, 3.0);
  glVertex3f(1.0, 1.0, 3.0);
glEnd();
```

glBegin defines the start of a new *geometric primitive*:

3D vertices are defined using **glVertex3***

The colour is defined using **glColor***

- Colours remain selected until changed
- OpenGL operates as a state machine

FreeGLUT

High level library for OpenGL like SDL

GLUT works using an *event loop:*

```
while (GLUT is running)
e = get_next_event()
if (e == mouse moved)
    run the mouse_moved function provided by the user
if (e == redraw)
    run the draw function provided by the user
etc, etc
```

RGB Colour, depth testing and double buffering

```
glutInit(&argc, argv);
glutInitDisplayMode(GLUT_RGBA | GLUT_DEPTH | GLUT_DOUBLE);
glutCreateWindow("RGSquare Application");
glutReshapeWindow(400, 400);
```

Request for window size (not necessarily accepted)

Window title

Glut Callback Functions

Some of the callback registration functions:

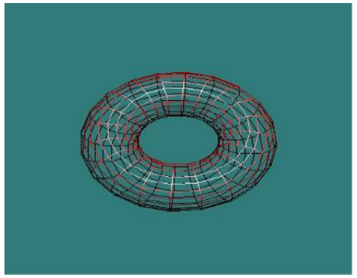
- ***void reshape(int w, int h) {…}***
- ***void keyhit(unsigned char c, int x, int y) {…}***
- ***void idle(void) {…}***
- ***void mouse(int button, int state, int x, int y) {…}***

`glutReshapeFunc(reshape);`	→	window resized
`glutKeyboardFunc(keyhit);`	→	key hit
`glutIdleFunc(idle);`	→	system idle
`glutDisplayFunc(draw);`	→	window exposed
`glutMotionFunc(motion);`	→	mouse moved
`glutMouseFunc(mouse);`	→	mouse button hit
`glutVisibilityFunc(visibility);`	→	window (de)iconified
`glutTimerFunc(timer);`	→	timer elapsed

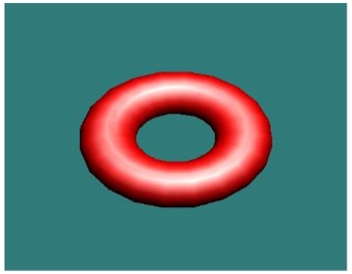
`glutMainLoop();` ← Begin event loop

Some Glut Objects

```
void glutSolidTorus(double inner_radius,
    double outer_radius, int nsides, int rings);
```

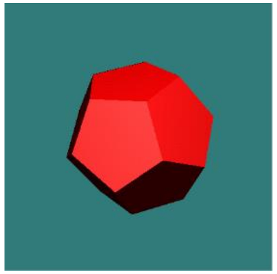


`glutWireTorus(0.3, 1.5, 20, 20);`



`glutSolidTorus(0.3, 1.5, 20, 20);`

`glutSolidTeapot(1.0);`



`glutSolidDodecahedron();`

Matrices in OGL

To initialise a matrix in OpenGL, use

```
glLoadIdentity();
```

Clears the currently selected OpenGL matrix (projection, transform, texture) to the *identity matrix*

Note: always be aware of what the matrix mode is activated!

To select a matrix as the current matrix, use

```
glMatrixMode(mode);
```

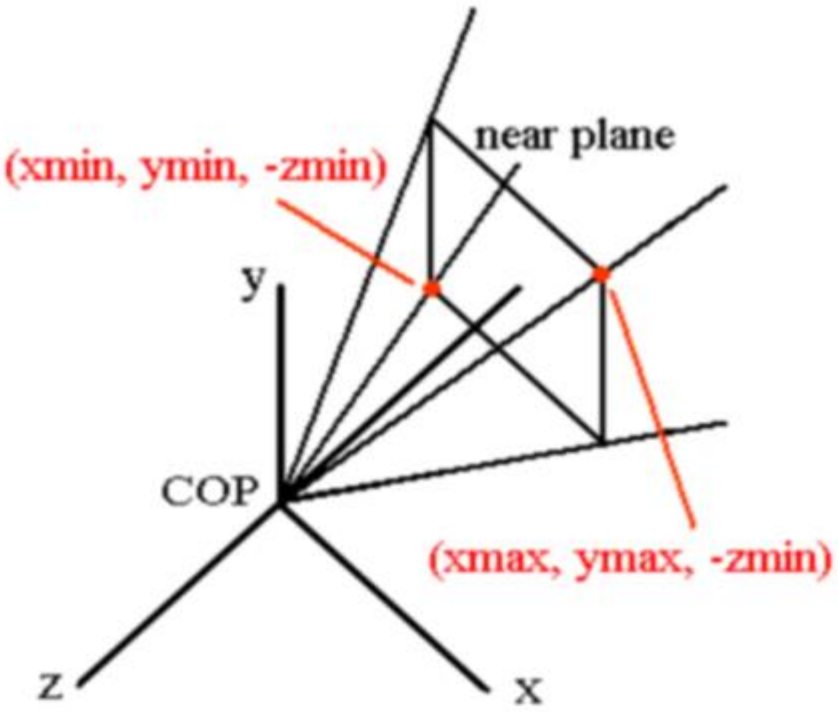
Mode can be one of:

GL_PROJECTION
GL_MODELVIEW
GL_TEXTURE

Perspective Projection

glFrustum(xmin, xmax, ymin, ymax, zmin, zmax);

- All points on the line defined by
  - (xmin, ymin, -zmin) and COP are mapped onto the lower left point on the viewport
  - (xmax, ymax, -zmin) and COP are mapped onto the upper right point on the viewport



Easier:

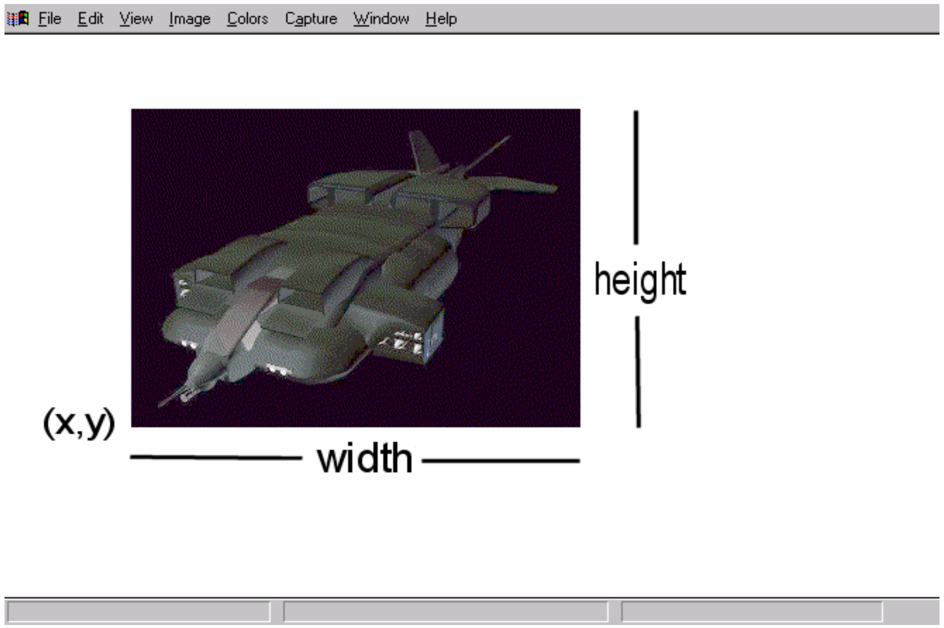
- ***gluPerspective(fov, aspect, near, far);***

The Viewport

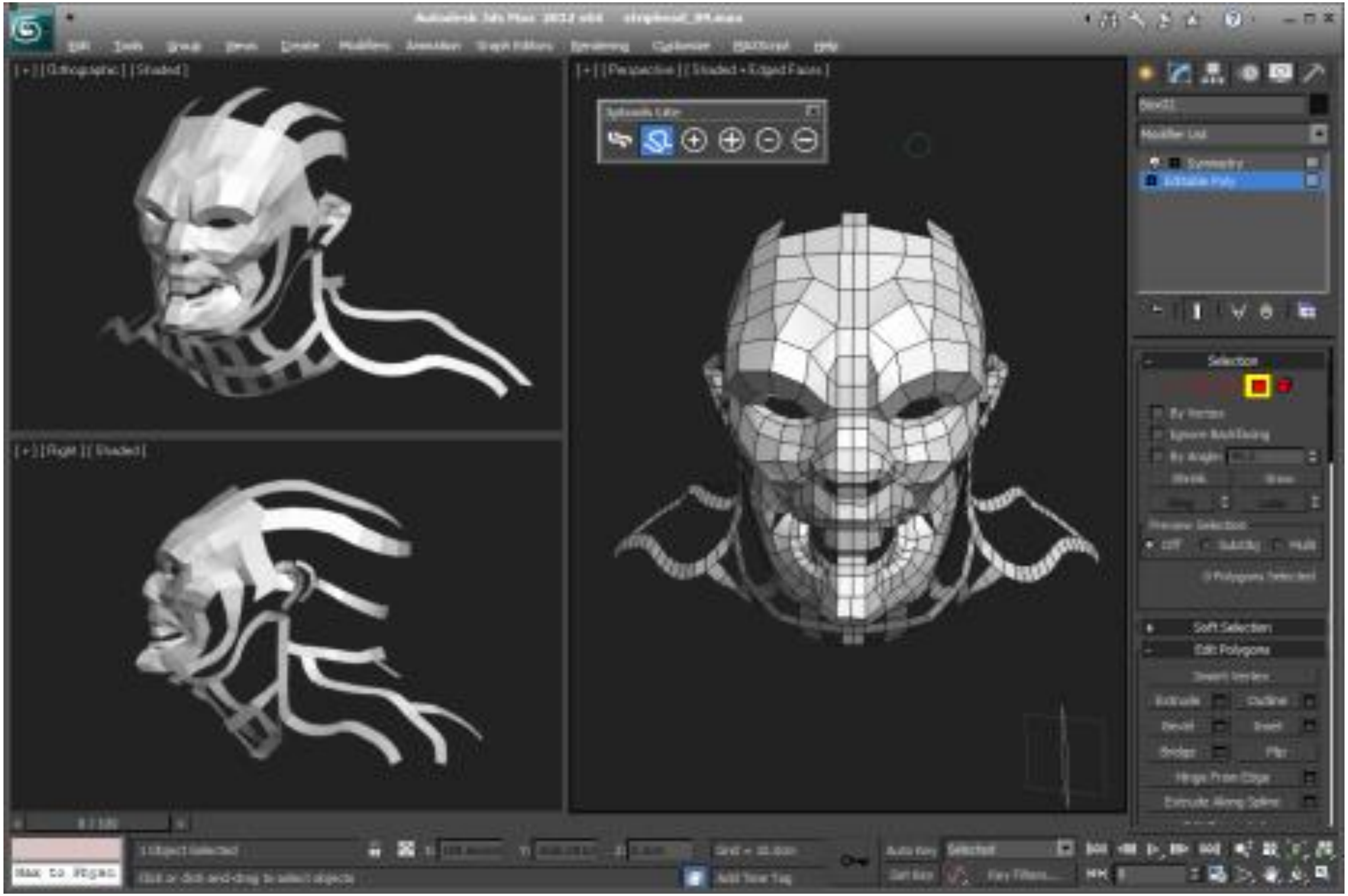
glViewport(x, y, width, height);

(x, y) is the location of the **bottom left** of the viewport within the window

- (0,0) is the bottom left hand side of the window
- *Width*, *height* specify the dimension in pixels of the viewport

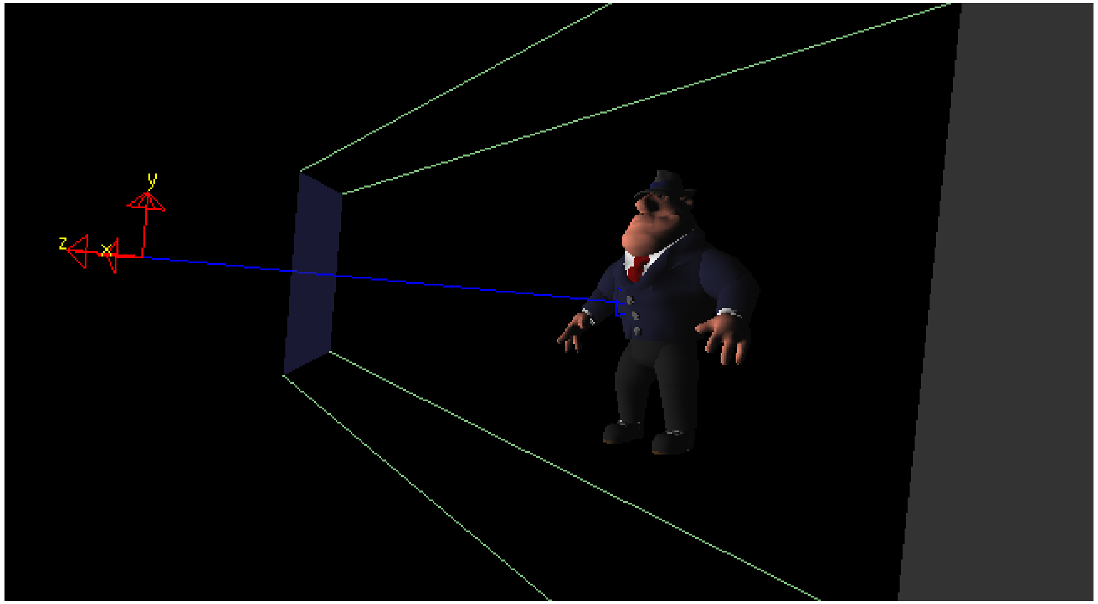


Useful for doing this...



3DS Max, 3ptools Lite, polycount

Positioning the Camera



gluLookAt(eye pos x, eye pos y, eye pos z, look at x, look at y, look at z, up x, up y, up z);

- Position camera at *eye pos (x,y,z)*
- Make camera viewing direction *look at (x,y,z)*
- Set camera up vector to *up (x,y,z)*

Projection and Camera

The following code will:

Create a viewport the size of the entire window

Create perspective projection with:

70 degree fovy, aspect ratio of 1, near plane at 1 and far plane at 50

Position the camera at (0.0,0.0,5.0) looking at (0.0,0.0,0.0)

```
glViewport(0,0,window_width, window_height);
glMatrixMode(GL_PROJECTION);
glLoadIdentity();
gluPerspective(70.0, 1.0, 1, 50);
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
gluLookAt(0.0,0.0,5.0,0.0,0.0,0.0,0.0,1.0,0.0);
```

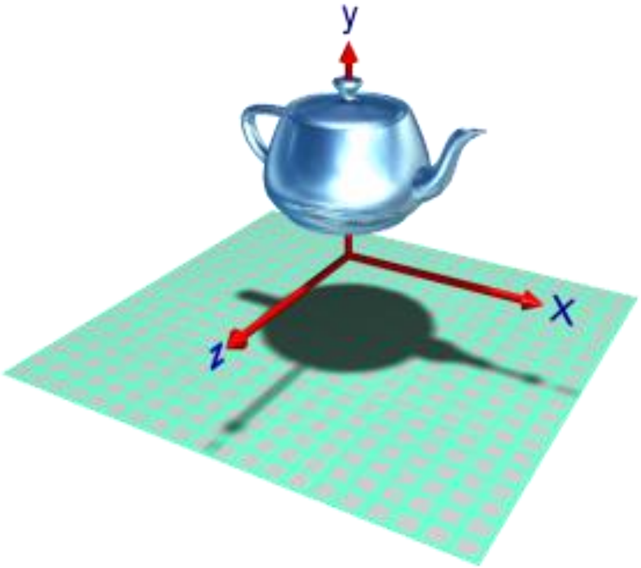
Transformations in OpenGL

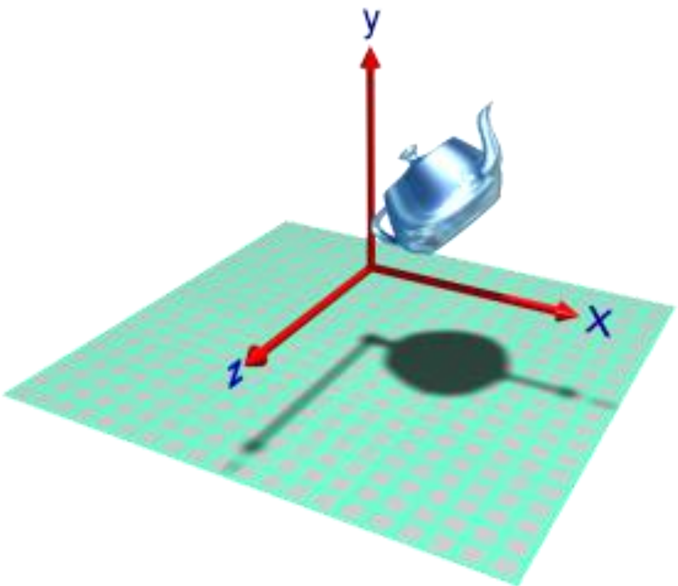
glTranslate(dx, dy, dz);

Translates by a displacement *(dx, dy, dz)*

Concatenates the specified translation to the current model-view matrix

Primitives drawn after this are modified by the specified translation





glRotatef(angle, vx, vy, vz);

Rotates around the axis *(vx, vy, vz)* by *angle* degrees

Concatenates the specified rotate to the current model-view matrix

Primitives drawn after this are modified by the specified rotation

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Pushing and Popping

OpenGL allows us to push and pop matrices on a stack

- Remember the ***transform stack***
- ***`glPushMatrix();`***
- ***`glPopMatrix();`***

Pushing: save current local coordinate marker

Popping: retrieve/load previous local coordinate marker

There should always be the same number of matrix push operations as matrix pops

Why?

Example code

In order to draw two squares in different world-space positions:

```
glPushMatrix();
 glTranslate(square 1 WS position);
 glRotate(square 1 orientation);
 Draw_square();
glPopMatrix();

glPushMatrix();
 glTranslate(square 2 WS position);
 glRotate(square 2 orientation)
 Draw_square();
glPopMatrix();
```

Lighting and Shading

Enabling lighting: `glEnable(GL_LIGHTING);`

Select shading: `glShadeModel(GL_SMOOTH);`

Enable a light source: `glEnable(GL_LIGHT1);`

Specify parameters:

```
glLightf{iv}(GL_LIGHT0, param, value);
```

Material Properties

To assign material properties:

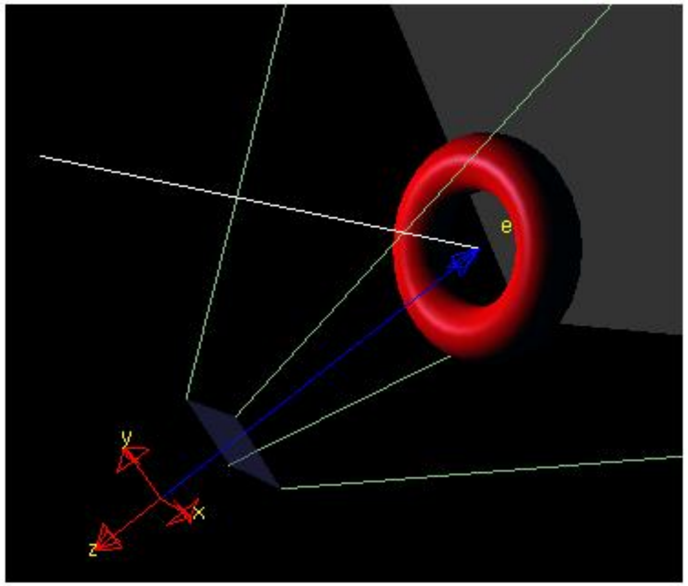
```
glMaterial{if}v(face, param, value);
```

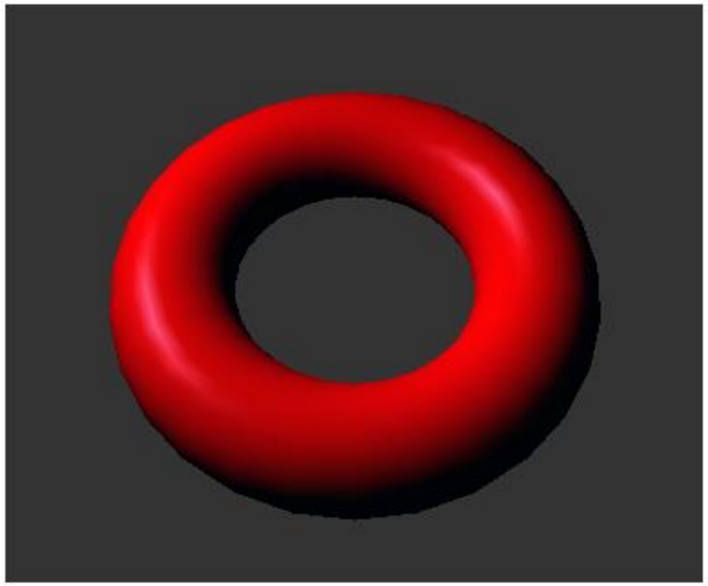
face:

- GL_FRONT
- GL_BACK
- GL_FRONT_AND_BACK

param:

- GL_AMBIENT
- GL_DIFFUSE
- GL_AMBIENT_AND_DIFFUSE
- GL_SPECULAR
- GL_EMISSION
- GL_SHININESS





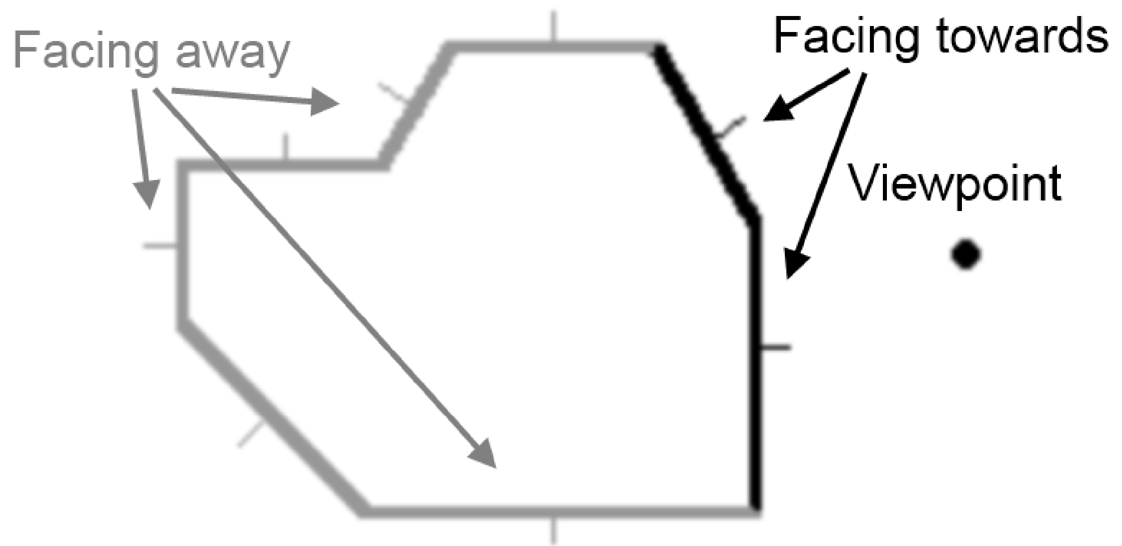
Backface Culling

Objects within the view-frustum may have polygons pointing away from the viewer

Not visible

Back-faces

The process is known as *back-face culling*



Backface Culling

To eliminate back-faces:

For each polygon in the scene {

Take its normal vector

Take the view direction vector

Use the dot product the find the angle between normal and view direction

If the angle is LESS than 90 degrees, then the polygon is *culled*

}

Visible Surface Determination

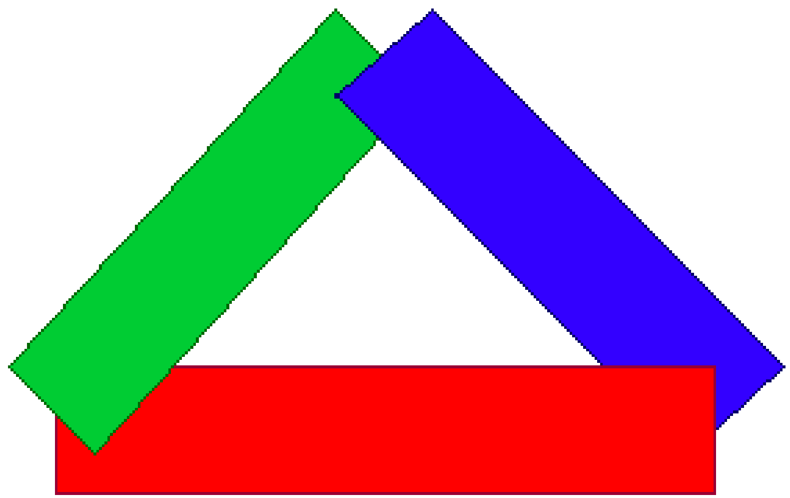
Painter's algorithm
Sort polygons relative to the viewpoint
Render those polygons that are nearer the viewpoint *after* those polygons that are further away from the viewpoint

Problems?

Visible Surface Determination

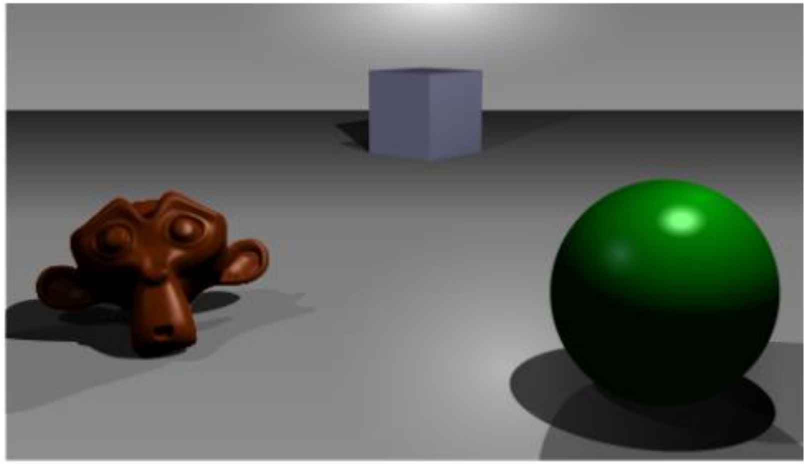
Painter's algorithm
Sort polygons relative to the viewpoint
Render those polygons that are nearer the viewpoint *after* those polygons that are further away from the viewpoint

Problems?

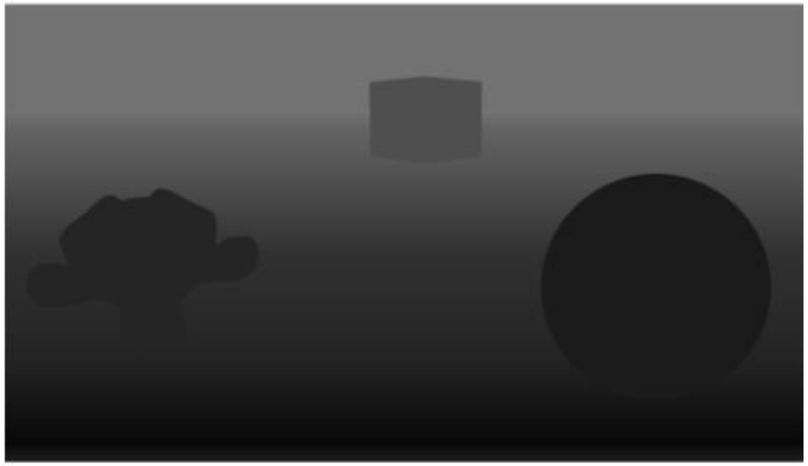


Depth Buffer

- Image-space visibility algorithm
- Buffer is 2D array, one element per pixel
- Compute depth of each generated pixel
  - Overwrite depth buffer value if new value is nearer to camera than previous
  - Non-linear, Z-fighting



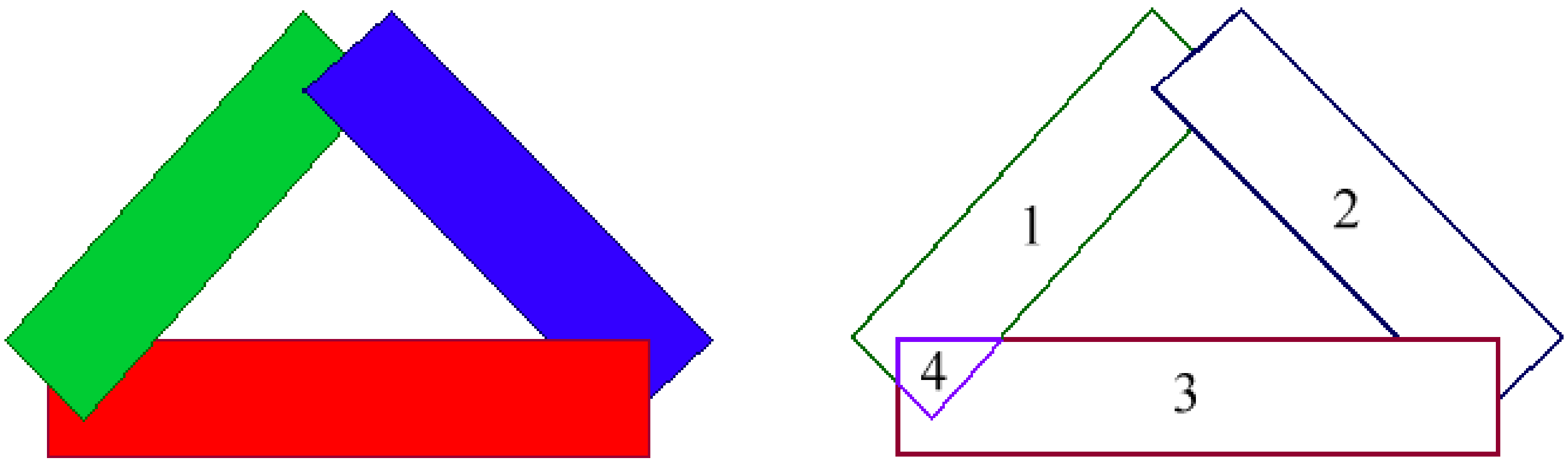
A simple three-dimensional scene



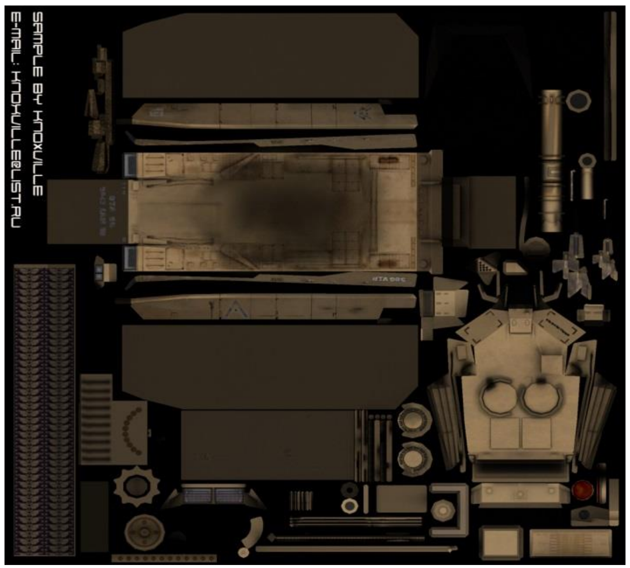
Z-buffer representation

Note: BSP Trees

Used by Quake, Quake 2, etc
World-space visibility algorithm
Visibility calculations on a *per polygon* basis
Split polygons
Compare with Z-buffer algorithm



Texturing



- Bitmap (2D image) applied to a triangle
- Each triangle associated with an image
- Each vertex associated with a texture coordinate *(u,v)*
- For each rendered pixel:
  – Lookup corresponding texture element (*texel*)
  – Interpolation

Lab Help Sessions

- Visualisation (VIC) Studio:

  Thurs 27th April, 10-12

  Thurs 4th May, 13-15

  Thurs 11th May, 15-17

- Purposes:
  - Ask questions/get help if in process of completing a lab task
  - Obtain **feedback** if you have work-in-progress
    - Code / report
    - Documentation