

Basic Graphics Programming

Graphics Pipeline
OpenGL API
Primitives: Lines, Polygons
Attributes: Color
Example
[Angel Ch. 2]

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What is OpenGL

- A low-level graphics library (API) for 2D and 3D interactive graphics.
- Descendent of GL (from SGI)
- First version in 1992; now: 4.2 (2012)
- Managed by Khronos Group (non-profit consortium)
- API is governed by Architecture Review Board (part of Khronos)



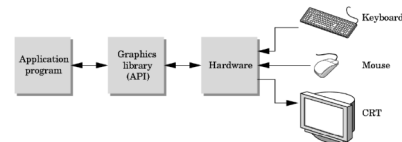
Where is OpenGL used

- CAD
- Virtual reality
- Scientific visualization
- Flight simulation
- Video games



Graphics library (API)

- Intermediary between applications and graphics hardware



- Other popular APIs:
 - Direct3D (Microsoft)
 - OpenGL ES (embedded devices)
 - X3D (successor of VRML)

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OpenGL is cross-platform

- Same code works with little/no modifications
- Implementations:
 - Windows, Mac, Linux: ships with the OS
 - Linux: Mesa, a freeware implementation.

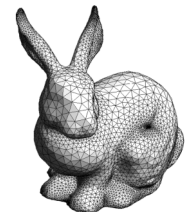
```
#if defined(WIN32) || defined(linux)
#include <GL/gl.h>
#include <GL/glu.h>
#include <GL/glut.h>
#elif defined(__APPLE__)
#include <OpenGL/gl.h>
#include <OpenGL/glu.h>
#include <GLUT/glut.h>
#endif
```

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How does OpenGL work

From the programmer's point of view:

1. Specify geometric objects
2. Describe object properties
 - Color
 - How objects reflect light



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How does OpenGL work (continued)

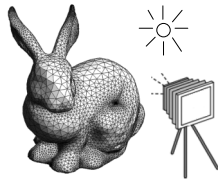
3. Define how objects should be viewed

- where is the camera
- what type of camera

4. Specify light sources

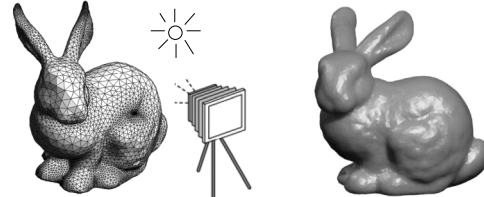
- where, what kind

5. Move camera or objects around for animation



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The result



the result

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OpenGL is a state machine

State variables: color, camera position, light position, material properties...

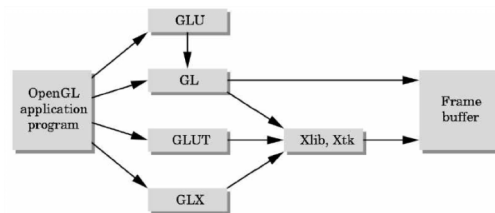
These variables (the *state*) then apply to every subsequent drawing command.

They persist until set to new values by the programmer.

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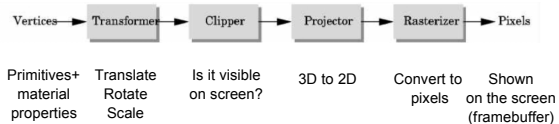
OpenGL Library Organization

- GL (Graphics Library): core graphics capabilities
- GLU (OpenGL Utility Library): utilities on top of GL
- GLUT (OpenGL Utility Toolkit): input and windowing



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Graphics Pipeline



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OpenGL uses *immediate-mode rendering*

- Application generates stream of geometric primitives (polygons, lines)
- System draws each one into the framebuffer
- Entire scene redrawn anew every frame
- Compare to: off-line rendering (e.g., Pixar Renderman, ray tracers)

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The pipeline is implemented by OpenGL, graphics driver and the graphics hardware



OpenGL programmer does not need to implement the pipeline.

However, pipeline is reconfigurable if needed

→ “shaders”

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Graphics Pipeline



- Efficiently implementable in hardware (but not in software)

- Each stage can employ multiple specialized processors, working in parallel, busses between stages

- #processors per stage, bus bandwidths are fully tuned for typical graphics use

- Latency vs throughput

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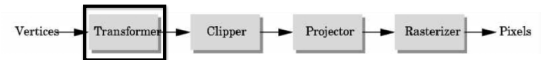
Vertices



- Vertices in world coordinates
- void glVertex3f(GLfloat x, GLfloat y, GLfloat z)
 - Vertex (x, y, z) is sent down the pipeline.
 - Function call then returns.
- Use GLtype for portability and consistency
- glVertex{234}{sfd}[v](TYPE coords)

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Transformer

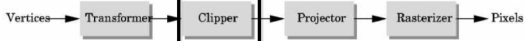


- Transformer in world coordinates
- Must be set before object is drawn!

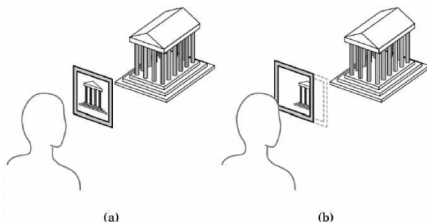

```
glRotatef(45.0, 0.0, 0.0, -1.0);
glVertex2f(1.0, 0.0);
```
- Complex [Angel Ch. 4]

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Clipper



- Mostly automatic (must set viewport)

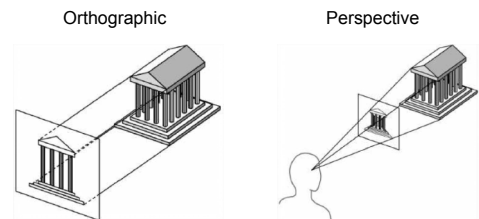


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Projector



- Complex transformation [Angel Ch. 5]

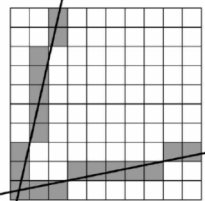


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Rasterizer

Vertices → Transformer → Clipper → Projector → **Rasterizer** → Pixels

- Interesting algorithms [Angel Ch. 7]
- To window coordinates
- Antialiasing



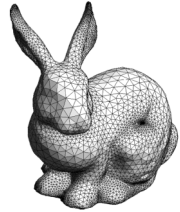
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Primitives

- Specified via vertices
- General schema

```
glBegin(type);
  glVertex3f(x1, y1, z1);
  ...
  glVertex3f(xN, yN, zN);
glEnd();
```

- *type* determines interpretation of vertices
- Can use glVertex2f(x,y) in 2D

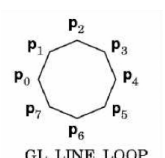


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Example: Draw Square Outline

- *Type* = GL_LINE_LOOP

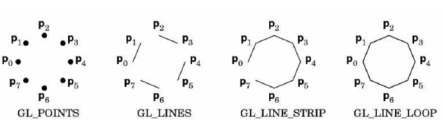
```
glBegin(GL_LINE_LOOP);
  glVertex3f(0.0, 0.0, 0.0);
  glVertex3f(1.0, 0.0, 0.0);
  glVertex3f(1.0, 1.0, 0.0);
  glVertex3f(0.0, 1.0, 0.0);
glEnd();
```



- Calls to other functions are allowed between glBegin(*type*) and glEnd();

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Points and Line Segments



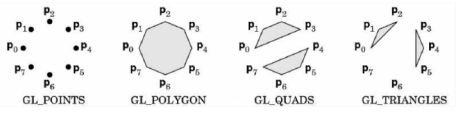
```
glBegin (GL_POINTS);
  glVertex3f(...);
  ...
  glVertex3f(...);
glEnd();
```

Draw points

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Polygons

- Polygons enclose an area

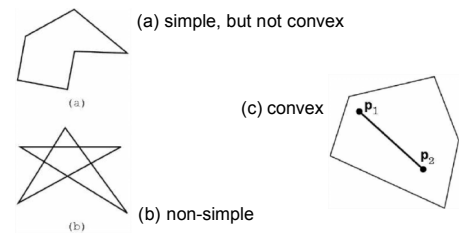


- Rendering of area (fill) depends on attributes
- All vertices must be in one plane in 3D

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Polygon Restrictions

- OpenGL Polygons must be simple
- OpenGL Polygons must be convex



(a) simple, but not convex

(b) non-simple

(c) convex

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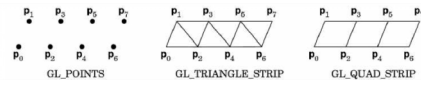
Why Polygon Restrictions?

- Non-convex and non-simple polygons are expensive to process and render
- Convexity and simplicity is expensive to test
- Behavior of OpenGL implementation on disallowed polygons is "undefined"
- Some tools in GLU for decomposing complex polygons (tessellation)
- Triangles are most efficient

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Polygon Strips

- Efficiency in space and time
- Reduces visual artefacts



- Polygons have a front and a back, possibly with different attributes!

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Attributes:

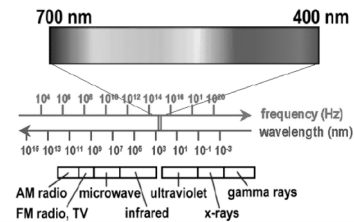
color, shading and reflection properties

- Part of the OpenGL state
- Set before primitives are drawn
- Remain in effect until changed!

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Physics of Color

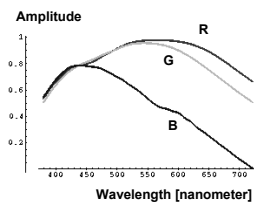
- Electromagnetic radiation
- Can see only tiny piece of the spectrum



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Color Filters

- Eye can perceive only 3 basic colors
- Computer screens designed accordingly



Source: Vos & Walraven

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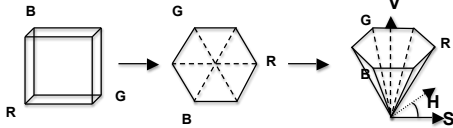
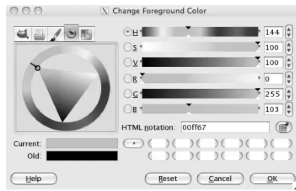
Color Spaces

- RGB (Red, Green, Blue)
 - Convenient for display
 - Can be unintuitive (3 floats in OpenGL)
- HSV (Hue, Saturation, Value)
 - Hue: what color
 - Saturation: how far away from gray
 - Value: how bright
- Other formats for movies and printing

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RGB vs HSV

Gimp Color Picker



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Example: Drawing a shaded polygon

- Initialization: the "main" function

```
int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode (GLUT_DOUBLE | GLUT_RGB);
    glutInitWindowSize (500, 500);
    glutInitWindowPosition (100, 100);
    glutCreateWindow (argv[0]);
    init ();
    ...
}
```

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GLUT Callbacks

- Window system independent interaction
- glutMainLoop processes events

```
...
glutDisplayFunc(display);
glutReshapeFunc(reshape);
glutKeyboardFunc (keyboard);
glutMainLoop();
return 0;
}
```

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Initializing Attributes

- Separate in "init" function

```
void init(void)
{
    glClearColor (0.0, 0.0, 0.0, 0.0);

    /* glShadeModel (GL_FLAT); */
    glShadeModel (GL_SMOOTH);
}
```

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The Display Callback

- The routine where you render the object
- Install with glutDisplayFunc(display)

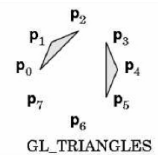
```
void display(void)
{
    glClear (GL_COLOR_BUFFER_BIT); /* clear buffer */
    setupCamera(); /* set up the camera */
    triangle (); /* draw triangle */
    glutSwapBuffers (); /* force display */
}
```

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Drawing

- In world coordinates; remember state!

```
void triangle(void)
{
    glBegin (GL_TRIANGLES);
    glColor3f (1.0, 0.0, 0.0); /* red */
    glVertex2f (5.0, 5.0);
    glColor3f (0.0, 1.0, 0.0); /* green */
    glVertex2f (25.0, 5.0);
    glColor3f (0.0, 0.0, 1.0); /* blue */
    glVertex2f (5.0, 25.0);
    glEnd();
}
```

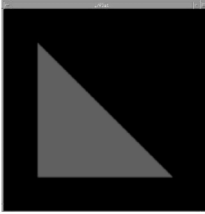


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The Image

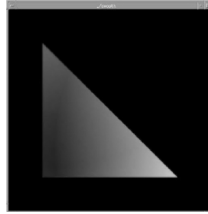
`glShadeModel(GL_FLAT)`

color of last vertex



`glShadeModel(GL_SMOOTH)`

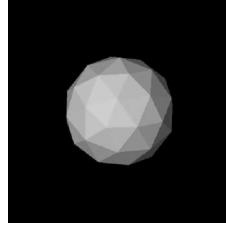
each vertex separate color smoothly interpolated



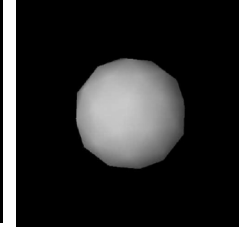
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Flat vs Smooth Shading

Flat Shading



Smooth Shading



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Projection

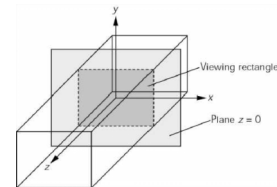
- Mapping world to screen coordinates

```
void reshape(int w, int h)
{
    glViewport(0, 0, (GLsizei) w, (GLsizei) h);
    glMatrixMode(GL_PROJECTION);
    glLoadIdentity();
    if (w <= h)
        gluOrtho2D(0.0, 30.0, 0.0, 30.0 * (GLfloat) h/(GLfloat) w);
    else
        gluOrtho2D(0.0, 30.0 * (GLfloat) w/(GLfloat) h, 0.0, 30.0);
    glMatrixMode(GL_MODELVIEW);
}
```

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Orthographic Projection

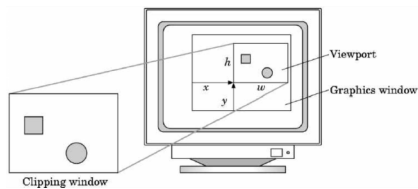
- 2D and 3D versions
- `glOrtho2D(left, right, bottom, top)`
- In world coordinates!



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Viewport

- Determines clipping in window coordinates
- `glViewPort(x, y, w, h)`



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Summary

1. A Graphics Pipeline
2. The OpenGL API
3. Primitives: vertices, lines, polygons
4. Attributes: color
5. Example: drawing a shaded triangle



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