Getting started
Initialization
Drawing
Transformations
  • Cameras
  • Animation
Input
  • Keyboard
  • Mouse
  • Joystick?
Textures
Lights
Programmable pipeline elements (shaders)
Accepts some representation of primitives (2D or 3D) as input and results in 2D raster image

Reading: textbook 22-2 The OpenGL Pipeline
Open Graphics Library

- Industry standard
- Open source
- Cross-platform API
- 2D/3D graphics
- OpenGL 1.x
  - fixed rendering pipeline
- OpenGL 2+
  - Partially programmable pipeline via GLSL (OpenGL Shading Language)
- OpenGL 4.1 – as of July 2010
  - 5 programmable stages of pipeline
- OpenGL ES – for mobile devices
- Reading: textbook appendix C
OpenGL Utility Toolkit

What
- Cross-platform system-level IO
  - Window definition
  - Window control
  - Monitoring keyboard/mouse input
- Drawing some primitives
  - Sphere
  - Cube
  - Utah teapot
GLUT

Why?

- OpenGL relies on application to provide platform dependent draw context
- GLUT provides means to make application code rather cross-platform
- Makes learning easier and starting faster
OpenGL comes installed with most modern Operating systems

Get glut

- Windows:
  - glut.h – to build -> SDKs/include
  - glut32.lib – to link -> SDKs/libs
  - glut32.dll – to run -> Windows/system32

Other OS and IDE:

Including headers

```c
#if defined(_WIN32) || defined(__CYGWIN__)
    # include <windows.h>
    # include <GL/glut.h>
#elif defined(__APPLE__)
    # include <GLUT/glut.h>
#else
    # include <GL/glut.h>
#endif

Tip: can be found in assignment 1 skeleton code file cos426_opengl.h
```
```c
void main(int argc, char **argv) {
    glutInit(&argc, argv);
    glutInitDisplayMode(GLUT_DEPTH | GLUT_DOUBLE | GLUT_RGB);
    glutInitWindowPosition(100, 100);
    glutInitWindowSize(320, 320);
    glutCreateWindow("GLUT tutorial");

    glEnable(GL_DEPTH_TEST); //glDisable(GL_DEPTH_TEST)
    glutDisplayFunc(renderScene);
    glutMainLoop();
}
```
Registers a redraw callback function with glut

In main:

```c
... glutDisplayFunc(renderScene);
...
```

We implement `renderScene()` before the main():

```c
void renderScene(void)
{
    glClear(GL_COLOR_BUFFER_BIT|GL_DEPTH_BUFFER_BIT);
    glBegin(GL_POLYGON);
    glColor3f(1, 0, 0);
    glVertex3f(-0.5, -0.5, 0.0);
    glColor3f(0, 1, 0); // glColor4f(0, 1, 0, 0), glColor3ub(255, 255, 255), glColor4i etc
    glVertex3f(0.5, 0.0, 0.0);
    glColor3f(0, 0, 1);
    glVertex3f(0.0, 0.5, 0.0);
    glEnd();
    glFlush();
}
```
Result
glClear()

- **GL_COLOR_BUFFER_BIT**
  - Indicates the color buffer.
  - Color can be set with `glClearColor()`

- **GL_DEPTH_BUFFER_BIT**
  - Indicates the depth buffer.
  - Value can be set with `glClearDepth()`

- **GL_STENCIL_BUFFER_BIT**
  - Indicates the stencil buffer
  - Value can be set with `glClearStencil()`

- More here
**glBegin()**

- **GL_POLYGON**
  - Draw filled convex polygon.

- **GL_TRIANGLES**
  - Pass $3n$ vertices, draws $n$ triangles.

- **GL_QUADS**
  - Pass $4n$ vertices, draws $n$ quads.

- **GL_LINES**
  - Pass $2n$ vertices, draws $n$ line segments.

- **GL_LINE_LOOP**
  - Draws outline of polygon.

- **GL_LINE_STRIP**
  - Draw segments $(v1,v2), (v2,v3), \ldots, (vn-1, vn)$.

- **GL_POINTS**
  - Pass $n$ vertices, draws $n$ points.

For more, see `glBegin` man page, e.g. here: [http://www.opengl.org/sdk/docs/man/xhtml/glBegin.xml](http://www.opengl.org/sdk/docs/man/xhtml/glBegin.xml)
glBegin(GL_POLYGON);
glColor3f(1, 0, 0);
glVertex3f(-0.5, -0.5, 0.0);
glColor3f(0, 1, 0);
glVertex3f(0.5, 0.0, 0.0);
glColor3f(0, 0, 1);
glVertex3f(0.0, 0.5, 0.0);
glEnd();

glLineWidth(3);
// optional line width,
// default is 1
glEnable(GL_LINE_SMOOTH);
// enable antialiasing

glBegin(GL_LINE_LOOP);
glColor3f(1, 0, 0);
glVertex3f(-0.5, -0.5, 0.0);
glColor3f(0, 1, 0);
glVertex3f(-0.5, -0.5, 0.0);
glColor3f(0, 1, 0);
glVertex3f(0.5, 0.0, 0.0);
glColor3f(0, 0, 1);
glVertex3f(0.5, 0.0, 0.0);
glColor3f(0, 0, 1);
glVertex3f(0.0, 0.5, 0.0);
glColor3f(0, 0, 1);
glVertex3f(0.0, 0.5, 0.0);
glEnd();
General three-dimensional transformation pipeline, from modeling coordinates to world coordinates to viewing coordinates to projection coordinates to normalized coordinates and, ultimately, to device coordinates.
Transformations

“Camera” – GL_PROJECTION matrix
- Update the view perspective
  - when resizing the window
  - when user or event changes the “camera” position

Scene – GL_MODELVIEW matrix
- Hierarchical scene representation
- Animation - Update the scene
  - with time
  - upon event
  - upon user input
OpenGL Transformations

- Vertex is transformed by
  - GL_MODELVIEW matrix,
  - then GL_PROJECTION matrix.
- After applying both matrices, vertex is in clip coordinates
- Divide by w component of vector to get normalized device coordinates (NDC).
- NDC: x, y, z values from -1 to 1.
- Initially, both matrices are identity.
OpenGL Transformations

- There is a stack of matrices for each matrix mode
- **Current matrix** is the matrix on top of the stack for each mode
- Initially stack has 1 element – an identity matrix
- `glPushMatrix()` – pushes a copy of current matrix on top of the stack
- `glPopMatrix()` – pops the stack, replacing the top matrix with the one below it

**WHY?**
- Convenient for hierarchical coordinate systems, e.g.
  - articulated bodies
  - Scene graphs
General matrix functions

- **glMatrixMode()** //GL_MODELVIEW, GL_PROJECTION
  - switch active matrix stack
- **glLoadIdentity()**
  - replaces current matrix with an identity matrix
- **glLoadMatrix**( float M[16]) –
  - replace current matrix with M (column major)
- **glMultMatrix**(float M[16])
  - Multiply current matrix with M

Tip: if T is the current matrix and M is matrix we’re multiplying by, the result is TM
Simple matrix manipulations

- \texttt{glRotatef}(\texttt{degrees, x,y,z})
- \texttt{glTranslatef}(x,y,z)
- \texttt{glScalef}(x,y,z)
Register a callback – add to main():
- glutIdleFunc(renderScene);

Replace the renderScene() body with the following:
- **Bold** font represents new code

```c
glClear(GL_COLOR_BUFFER_BIT|GL_DEPTH_BUFFER_BIT);

static float angle = 0.;
glMatrixMode(GL_MODELVIEW);
glPushMatrix();
glRotatef(angle,0,1,0);

glBegin(GL_POLYGON/*GL_LINE_LOOP*/);
    glColor3f(1, 0, 0);
    glVertex3f(-0.5,-0.5,0.0);
    glColor3f(0, 1, 0);
    glVertex3f(0.5,0.0,0.0);
    glColor3f(0, 0, 1);
    glVertex3f(0.0,0.5,0.0);

glEnd();

glPopMatrix();
glutSwapBuffers();
angle+=.05;
```
OpenGL supports several buffers
- Front
- Back
- Left
- Right
- Permutations thereof
- ...

To use this we did:
- Added GLUT_DOUBLE as an argument to glutInitDisplayMode()
- Called glutSwapBuffers() in the end of renderScene()
Our options are
- Change the entire scene through modifying bottom of the GL_MODELVIEW stack matrix
- Change the current GL_PROJECTION matrix
  - Using the previously shown matrix manipulations
    - glMatrixMode(GL_PROJECTION);
  - Call matrix manipulator functions
  - Helpful utilities from GL/glu.h
Camera with GLU

- #include <GL/glu.h> - just in case
- Describe the camera (either one)
  - gluPerspective()
  - gluOrtho2D()
- Point the camera
  - gluLookAt()
Sets up a perspective projection matrix

- **fovy**
  - field of view angle in camera’s y direction
- **aspect**
  - aspect ratio (x/y)
- **znear**
  - Distance from the camera to the near clipping plane
- **zfar**
  - Distance from the camera to the far clipping plane
Set up a 2D orthographic projection matrix

- left, right
  - Coordinates of the left and right clipping planes
- bottom, top
  - Coordinates of the bottom and top clipping planes
- Defines a viewing transformation (points the camera)
  - `eyeX, eyeY, eyeZ`
    - Specifies the position of the “eye” point
  - `centerX, centerY, centerZ`
    - Specifies the position of the reference point
  - `upX, upY, upZ`
    - Specifies the direction of the “up” vector
Defines the viewport transformation

- Specifies transformation NDC to window coordinates: `glViewport()`
Resize window example

- Register a callback - add to main():
  - glutReshapeFunc(changeSize);

- Add above the main():

```c
void changeSize(int w, int h)
{
    // Prevent a divide by zero, when window is too short
    // (you can't make a window of zero width).
    if(h == 0) h = 1;

    float ratio = 1.0* w / h;

    // Reset the coordinate system before modifying
    glMatrixMode(GL_PROJECTION);
    glLoadIdentity();

    // Set the viewport to be the entire window
    glViewport(0, 0, w, h);

    // Set the correct perspective.
    gluPerspective(45, ratio, 1, 1000);
    glMatrixMode(GL_MODELVIEW);
    glLoadIdentity();
    gluLookAt(0.0, 0.0, 5.0, 0.0, 0.0, -1.0, 0.0f, 1.0f, 0.0f);
}
```
To avoid drawing in order (painter’s algorithm) we do:

- Add GLUT_DEPTH to arguments in the glutInitDisplayMode call
  - Creates a z-buffer
- glEnable(GL_DEPTH_TEST);
  - Enables depth comparison and update of z-buffer
Drawing in 3D – Primitive Shapes

- **GLU:**
  - gluSphere()
  - gluCylinder()
  - gluDisk()
  - ...

- **GLUT:**
  - Solids
    - glutSolidTorus()
    - glutSolidTeapot()
    - ...
  - Wireframes
    - glutWireIcosahedron()
    - glutWireTeapot()
Topics for future discussions

- Getting started
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  - Cameras
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- Textures
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- Programmable pipeline elements (shaders)
Code from this precept:

More tutorials (partly used in the presentation):
http://www.lighthouse3d.com/opengl/glut
http://nehe.gamedev.net/
http://www.videotutorialsrock.com/

OpenGL quick reference: