Noggin
(BYU Students, SIGGRAPH 2006)

Introduction to OpenGL Programming

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COMP 575
September 11, 2007

Announcements

- Reminder: Homework 1 is due Thursday
  - Questions?
- Class next Tuesday (9/18) will be held in SN 014

Last Time

- Extended transformations to 3D
- Introduced some principles of computer animation
  - Lasseter's "Principles of Traditional Animation Applied to 3D Computer Graphics"
  - How to create "The Illusion of Life"

Today

- Learning how to program in OpenGL
  - OpenGL
  - C/C++
  - GLUT, FLTK, Cocoa

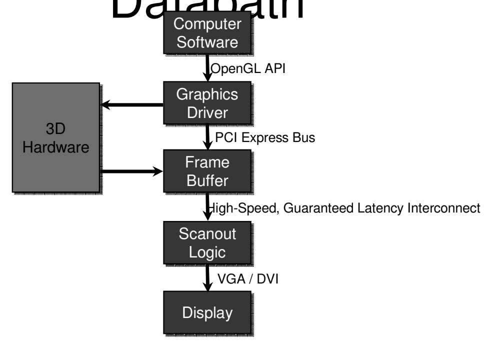
OpenGL in Java

- I have never used Java for OpenGL programming
  - I can't be much help in getting it set up
- If you really want to try using OpenGL in Java
  - The JOGL API Project
    - https://jogl.dev.java.net/
    - Go there and follow the instructions

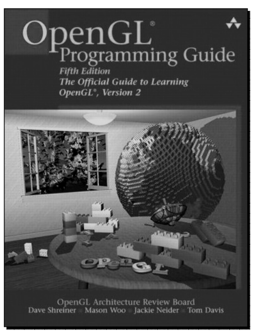
What is OpenGL?

- The standard specification defining an API that interfaces with the computer's graphics system
  - Cross-language
  - Cross-platform
  - Vendor-independent
- Competes with DirectX on Windows

The Rendering Datapath



The "Red Book"



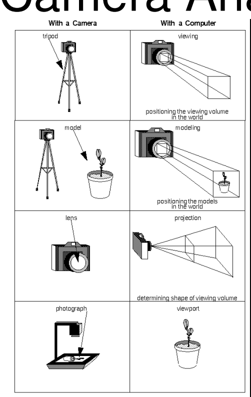
~~An older version is available (free!)~~ online: http://fly.cc.fer.hr/~unreal/theredbook/

Online Resources

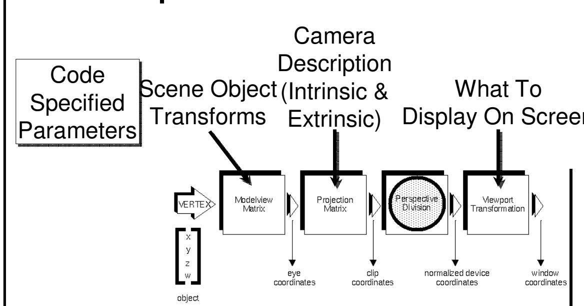
http://nehe.gamedev.net

http://www.opengl.org

The Camera Analogy



OpenGL's World



Contexts and Viewports?

- Each OpenGL application creates a <u>context</u> to issue rendering commands to
- The application must also define a <u>viewport</u>, a region of pixels on the screen that can see the context
  - Can be
    - Part of a window
    - An entire window
    - The whole screen

OpenGL as a State Machine

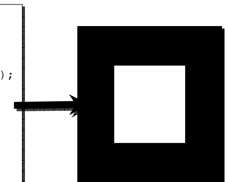
- OpenGL is designed as a finite state machine
  - Graphics system is a “black box”
- Most functions change the state of the machine
- One function runs input through the machine

OpenGL State

- Some attributes of the OpenGL state
  - Current color
  - Camera properties (location, orientation, field of view, etc.)
  - Lighting model (flat, smooth, etc.)
  - Type of primitive being drawn
  - And many more...

Our First OpenGL Code

```
...
   glClearColor(0.0, 0.0, 0.0, 0.0);
   glClear(GL_COLOR_BUFFER_BIT);
   glColor3f(1.0, 1.0, 1.0);
   glOrtho(-1.0, 1.0, -1.0, 1.0, -1.0, 1.0);
   glBegin(GL_POLYGON);
      glVertex2f(-0.5, -0.5);
      glVertex2f(-0.5, 0.5);
      glVertex2f(0.5, 0.5);
      glVertex2f(0.5, -0.5);
   glEnd();
   glFlush();
...
```



OpenGL Input

- All inputs (i.e. geometry) to an OpenGL context are defined as vertex lists
- glVertex*
  - * = nt OR ntv
    - n - number (2, 3, 4)
    - t - type (i = integer, f = float, etc.)
    - v - vector

OpenGL Types

Suffix	Data Type	Typical Corresponding C-Language Type	OpenGL Type Definition
b	8-bit integer	signed char	GLbyte
s	16-bit integer	short	GLshort
i	32-bit integer	long	GLint, GLsizei
f	32-bit floating-point	float	GLfloat, GLclampf
d	64-bit floating-point	double	GLdouble, GLclampd
ub	8-bit unsigned integer	unsigned char	GLubyte, GLboolean
us	16-bit unsigned integer	unsigned short	GLushort
ui	32-bit unsigned integer	unsigned long	GLuint, GLenum, GLbitfield

OpenGL Input

- Examples:
  - glVertex2i(5, 4);
    - Specifies a vertex at location (5, 4) on the z = 0 plane
      - “2” tells the system to expect a 2-vector (a vertex defined in 2D)
      - “i” tells the system that the vertex will have integer locations

OpenGL Input

- More examples:
  - glVertex3f(.25, .25, .5);
  - double vertex[3] = {1.0, .33, 3.14159}; glVertex3dv(vertex);
    - “v” tells the system to expect the coordinate list in a single data structure, instead of a list of n numbers

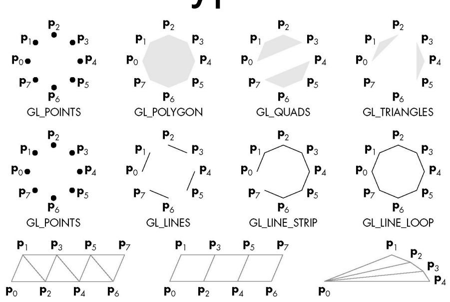
OpenGL Primitive Types

- All geometry is specified by vertex lists
  - But can draw multiple types of things
    - Points
    - Lines
    - Triangles
    - etc.
- The different things the system knows how to draw are the system <u>primitives</u>

Specifying the OpenGL Primitive Type

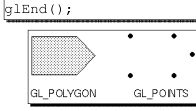
- glBegin(primitiveType);
  // A list of glVertex* calls goes here
  // ...
  glEnd();
- primitiveType can be any of several things
  - See the next slide

OpenGL Primitive Types



OpenGL Primitives Example

```
glBegin(GL_POLYGON);
   glVertex2f(0.0, 0.0);
   glVertex2f(0.0, 3.0);
   glVertex2f(3.0, 3.0);
   glVertex2f(4.0, 1.5);
   glVertex2f(3.0, 0.0);
glEnd();
```



Color in OpenGL

- Monitors can have different color resolutions
  - Black & white
  - 256 color
  - 16.8M color
- Want to specify color in a device-independent way

Color in OpenGL

- glColor4f(r, g, b, a);
  - r, g, b, a - should all be between [0.0, 1.0]
  - r, g, b - amounts of red, green, and blue
  - a - alpha
    - Defines how opaque a primitive is
      - 0.0 = totally transparent, 1.0 = totally opaque
      - Usually want a = 1.0

Finishing Up Your OpenGL Program

- OpenGL commands are not executed immediately
  - They are put into a command buffer that gets fed to the hardware
- When you're done drawing, need to send the commands to the graphics hardware
  - glFlush() or glFinish()

glFlush vs. glFinish

- glFlush();
  - Forces all issued commands to begin execution
  - Returns immediately (asynchronous)
- glFinish();
  - Forces all issued commands to execute
  - Does not return until execution is complete (synchronous)

Matrices in OpenGL

- Vertices are transformed by 2 matrices:
  - ModelView
    - Maps 3D to 3D
    - Transforms vertices from object coordinates to eye coordinates
  - Projection
    - Maps 3D to 2D (sort of)
    - Transforms vertices from eye coordinates to clip coordinates

The ModelView Matrix

- In OpenGL, the viewing and modeling transforms are combined into a single matrix - the modelview matrix
  - Viewing Transform - positioning the camera
  - Modeling Transform - positioning the object
- Why?
  - Consider how you would "translate" a fixed object with a real camera

Placing the Camera

- gluLookAt(
  GLdouble *eyeX*, GLdouble *eyeY*, GLdouble *eyeZ,* GLdouble *midX*, GLdouble *midY*, GLdouble *midZ,*
  GLdouble *upX*, GLdouble *upY*, GLdouble *upZ*)
  - (*eyeX, eyeY, eyeZ*) - location of the viewpoint
  - (*midX, midY, midZ)* - location of a point on the line of sight
  - (*upX, upY, upZ)* - direction of the up vector
- By default the camera is at the origin, looking down negative z, and the up vector is the positive y axis

WARNING! OpenGL Matrices

- In C/C++, we are used to row-major matrices
- In OpenGL, matrices are specified in column-major order

$$\begin{bmatrix} A_0 & A_1 & A_2 & A_3 \\ A_4 & A_5 & A_6 & A_7 \\ A_8 & A_9 & A_{10} & A_{11} \\ A_{12} & A_{13} & A_{14} & A_{15} \end{bmatrix}$$

Row-Major Order

$$\begin{bmatrix} A_0 & A_4 & A_8 & A_{12} \\ A_1 & A_5 & A_9 & A_{13} \\ A_2 & A_6 & A_{10} & A_{14} \\ A_3 & A_7 & A_{11} & A_{15} \end{bmatrix}$$

Column-Major Order

Using OpenGL Matrices

- Use the following function to specify which matrix you are changing:
- glMatrixMode(whichMatrix);
  - whichMatrix = GL_PROJECTION | GL_MODELVIEW
- To guarantee a “fresh start”, use glLoadIdentity();
  - Loads the identity matrix into the active matrix

Using OpenGL Matrices

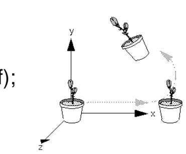
- To load a user-defined matrix into the current matrix:
  - glLoadMatrix{fd}(TYPE *m)
- To multiply the current matrix by a user defined matrix
  - glMultMatrix{fd}(TYPE *m)
- SUGGESTION: To avoid row-/column-major confusion, specify matrices as m[16] instead of m[4][4]

Transforms in OpenGL

- OpenGL uses 4x4 matrices for all its transforms
  - But you don’t have to build them all by hand!
- glRotate{fd}(angle, x, y, z)
  - Rotates counter-clockwise by *angle* degrees about the vector (x, y, z)
- glTranslate{fd}(x, y, z)
- glScale{fd}(x, y, z)

WARNING!Order of Transforms

- In OpenGL, the last transform in a list is applied FIRST
  - Think back to right-multiplication of transforms
- Example:
  - glRotatef(45.0f, 0.0f, 0.0f, 0.0f);
    glTranslatef(10.0f, 0.0f, 0.0f);
    drawSomeVertices();



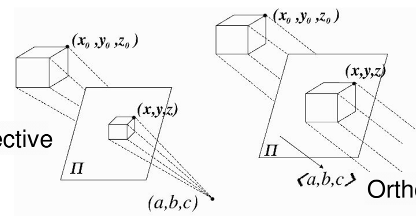
  - Translates first, then rotates

Projection Transforms

- The projection matrix defines the viewing volume
  - Used for 2 things:
    - Projects an object onto the screen
    - Determines how objects are clipped
- The viewpoint (the location of the "camera") that we've been talking about is at one end of the viewing volume

Projection Transforms

- Perspective
  - Viewing volume is a truncated pyramid
    - aka *frustum*
- Orthographic
  - Viewing volume is a box

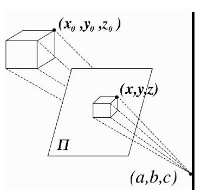


Perspective

Orthographic

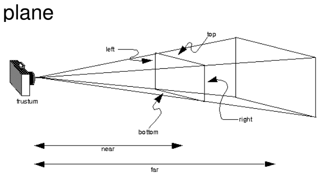
Perspective Projection

- The most noticeable effect of perspective projection is foreshortening
- OpenGL provides several functions to define a viewing frustum
  - glFrustum(...)
  - gluPerspective(...)



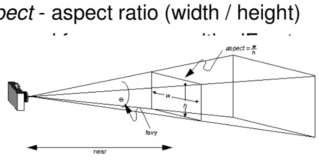
glFrustum

- glFrustum(GLdouble *left*, GLdouble *right,* GLdouble *bottom,* GLdouble *top,* GLdouble *near*, GLdouble *far)*
  - (*left, bottom, -near*) and (*right, top, -near*) are the bottom-left and top-right corners of the near clip plane
- *far* is the distance to the far clip plane
- *near* and *far* should always be positive



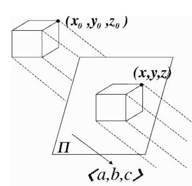
gluPerspective

- This GL Utility Library function provides a more intuitive way (I think) to define a frustum
- gluPerspective(GLdouble *fovy*, GLdouble *aspect*, GLdouble *near*, GLdouble *far*)
  - *fovy* - field of view in y (in degrees)
  - *aspect* - aspect ratio (width / height)
  - *ne*)



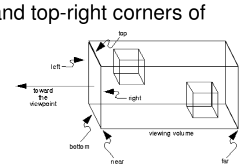
Orthographic Projection

- With orthographic projection, there is no foreshortening
  - Distance from the camera does not change apparent size
- Again, there are several functions that can define an orthographic projection
  - glOrtho()
  - gluOrtho2D()



glOrtho

- glOrtho(GLdouble *left*, GLdouble *right,* GLdouble *bottom,* GLdouble *top,* GLdouble *near*, GLdouble *far)*
  - Arguments are the same as glPerspective()
  - (*left, bottom, -near*) and (*right, top, -near*) are the bottom-left and top-right corners of the near clip plane
- *near* and *far* can be any values, but they should not be the same



gluOrtho2D

- This GL Utility Library function provides a more intuitive way (I think) to define a frustum
- gluOrtho2D(GLdouble *left*, GLdouble *right*, GLdouble *bottom*, GLdouble *top*)
  - (*left, bottom*) and (*right, top*) define the (x, y) coordinates of the bottom-left and top-right corners of the clipping region
  - Automatically clips to between -1.0 and 1.0 in z

Viewport

- The viewport is the part of the window your drawing is displayed to
  - By default, the viewport is the entire window
- Modifying the viewport is analogous to changing the size of the final picture
  - From the camera analogy
- Can have multiple viewports in the same window for a split-screen effect

Setting the Viewport

- glViewport(int x, int y, int width, int height)
  - (x, y) is the location of the origin (lower-left) within the window
  - (width, height) is the size of the viewport
- The aspect ratio of the viewport should be the same as that of the viewing volume