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Introduction to OpenGL

Ensimag 3D Graphics, 2013

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Available at

https://intranet.ensimag.fr/KIOSK/Matieres/4MMG3D/index.html

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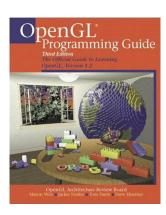
Conclusion

D. Shreiner, M. Woo, J. Neider, T. Davis OpenGL Programming Guide

aka the red book

http://opengl-redbook.com

References



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What is it?

- API (Application Programming Interface) for graphics hardware
- Non-dependant on the architecture or programming language
- Developped in 1989 (GL) by Silicon Graphics, extended to other architectures in 1993 (OpenGL)
- About 250 commands

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Things it can **NOT** do

- Can NOT create nor manage a viewer
- Can NOT manage complex objects: only 3 types of geometric primitives (points, lines, polygons)

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Things it can **NOT** do

- Can NOT create nor manage a viewer
- Can NOT manage complex objects: only 3 types of geometric primitives (points, lines, polygons)

- > Additional libraries needed :
 - GLU: openGL Utility library: more complex 3D models
 - GLUT: openGL Utility Toolkit: viewer
 - QGLViewer: Qt library handling OpenGL
 - ...

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Graphics Pipeline



① Create 3D models (modeling)

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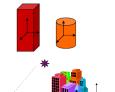
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Graphics Pipeline



- ① Create 3D models (modeling)
- 2 Build the scene from instances of models placed in a world frame (modeling transformation)

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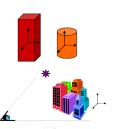
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frustrum

Graphics Pipeline

- 1 Create 3D models (modeling)
- 2 Build the scene from instances of models placed in a world frame (modeling transformation)
- 3 Convert to camera frame (culling, frustrum)

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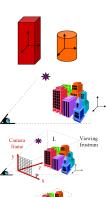
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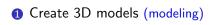
Graphics Pipeline

- 1 Create 3D models (modeling)
- ② Build the scene from instances of models placed in a world frame (modeling transformation)
- 3 Convert to camera frame (culling, frustrum)
- 4 Convert to screen frame (projection)

Graphics pipeline

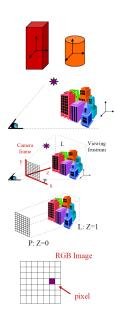
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Graphics Pipeline



- Build the scene from instances of models placed in a world frame (modeling transformation)
- 3 Convert to camera frame (culling, frustrum)
- 4 Convert to screen frame (projection)

5 Compute image (rasterization)



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Create OpenGL context Loop :

Manage mouse/keyboard events

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OpenGL Pipeline

- Manage mouse/keyboard events
- ② Display

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OpenGL Pipeline

- Manage mouse/keyboard events
- ② Display
 - Clear screen

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OpenGL Pipeline

- Manage mouse/keyboard events
- 2 Display
 - Clear screen
 - 2 Viewpoint

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OpenGL Pipeline

- Manage mouse/keyboard events
- ② Display
 - Clear screen
 - 2 Viewpoint
 - 3 For each object :

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- Manage mouse/keyboard events
- ② Display
 - Clear screen
 - 2 Viewpoint
 - 3 For each object :
 - 1 Place object

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OpenGL Pipeline

- Manage mouse/keyboard events
- ② Display
 - 1 Clear screen
 - 2 Viewpoint
 - 3 For each object :
 - Place object
 - 2 Draw

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It's a state machine!

State machine = each parameter retains its value and is used with that value until being explicitely changed

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It's a state machine!

State machine = each parameter retains its value and is used with that value until being explicitely changed

Parameters can be:

• modes: shading mode, matrix manipulated ...

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It's a state machine!

State machine = each parameter retains its value and is used with that value until being explicitely changed

Parameters can be:

- modes : shading mode, matrix manipulated . . .
- **booleans**: lights on/off, blend colors, ...

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It's a state machine!

State machine = each parameter retains its value and is used with that value until being explicitely changed

Parameters can be :

- modes : shading mode, matrix manipulated . . .
- **booleans**: lights on/off, blend colors, ...
- scalar values : colors, viewpoint, ...

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OpenGL Syntax - 1/2

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Reminder:

• modes : gl[MODE]Mode(GL_VALUE)

OpenGL Syntax - 1/2

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Reminder:

• modes : gl[MODE]Mode(GL_VALUE)

• booleans : glEnable(GL_VALUE)

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OpenGL Syntax - 1/2

Reminder:

- modes : gl[MODE]Mode(GL_VALUE)
- booleans : glEnable(GL_VALUE)
 - \Rightarrow OpenGL constants start with **GL**_

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OpenGL Syntax - 1/2

Reminder:

- modes : gl[MODE]Mode(GL_VALUE)
- booleans : glEnable(GL_VALUE)
 - \Rightarrow OpenGL constants start with \textbf{GL}_{-}
- scalar values :

• gl : OpenGL command . . .

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OpenGL Syntax - 1/2

Reminder:

- modes : gl[MODE]Mode(GL_VALUE)
- booleans : glEnable(GL_VALUE)
 - ⇒ OpenGL constants start with GL_
- scalar values :

- gl : OpenGL command ...
- 3 : ...that has 3 arguments ...

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OpenGL Syntax - 1/2

Reminder:

- modes : gl[MODE]Mode(GL_VALUE)
- booleans : glEnable(GL_VALUE)
 - ⇒ OpenGL constants start with GL_
- scalar values :

- gl : OpenGL command . . .
- 3 : ...that has 3 arguments ...
- **f**:...of type float.

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OpenGL Syntax - 1/2

Reminder:

- modes : gl[MODE]Mode(GL_VALUE)
- booleans : glEnable(GL_VALUE)
 - \Rightarrow OpenGL constants start with GL_
- scalar values :

```
glColor3f(1.0,1.0,1.0);
```

- gl : OpenGL command ...
- 3 : ...that has 3 arguments ...
- **f**: ... of type float.

```
glColor3fv(color_array);
```

⇒ The argument is a **v**ector (or array) of 3 floats (GLfloat color_array[] = { 1.0,0.0,0.0 } ;)

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OpenGL Syntax - 2/2

OpenGL suffixes and types

| b | integer (8 bits) |
|----|----------------------------|
| S | integer (16 bits) |
| i | integer (32 bits) |
| f | real (32 bits) |
| d | real (64 bits) |
| ub | unsigned integer (8 bits) |
| us | unsigned integer (16 bits) |
| ul | unsigned integer (32 bits) |
| | |

| signed char | GLbyte |
|----------------------|----------------|
| short | GLshort |
| int ou long | GLint |
| float | GLfloat |
| double | GLdouble |
| unsigned char | GLubyte |
| unsigned long | GLushort |
| unsigned int ou long | GLuint |

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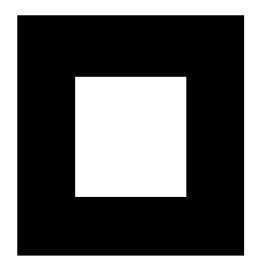
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Basic example - the Square



Basic example - the Code

Display:

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Basic example - the Code

Display:

void display () {

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Basic example - the Code

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Display: void display () {



Clear screen

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Basic example - the Code

```
Display :
void display () {
```

Clear screen

glClear(GL_COLOR_BUFFER_BIT);

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Basic example - the Code

```
Display:
```

void display () {

- Clear screen
 - glClear(GL_COLOR_BUFFER_BIT);
- 2 Viewpoint

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GLUT primitives

Basic example - the Code

```
Display:
```

```
Clear screen
      glClear(GL_COLOR_BUFFER_BIT);
```

void display () {

2 Viewpoint glMatrixMode(GL_PROJECTION); glOrtho(0.0,1.0,0.0,1.0,-1.0,1.0);

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```
Display:
```

- void display () $\{$
 - 1 Clear screen
 glClear(GL_COLOR_BUFFER_BIT);
 - Viewpoint
 glMatrixMode(GL_PROJECTION);
 glOrtho(0.0,1.0,0.0,1.0,-1.0,1.0);
 - 3 For each object :

Basic example - the Code

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```
Display :
void display () {
```

- 1 Clear screen
 glClear(GL_COLOR_BUFFER_BIT);
 - Viewpoint
 glMatrixMode(GL_PROJECTION);
 glOrtho(0.0,1.0,0.0,1.0,-1.0,1.0);
- 3 For each object :
 - 1 Place object

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Basic example - the Code

```
Display:

void display () {

1 Clear screen
    glClear(GL_COLOR_BUFFER_BIT);

2 Viewpoint
    glMatrixMode(GL_PROJECTION);
    glOrtho(0.0,1.0,0.0,1.0,-1.0,1.0);

3 For each object:
    1 Place object
```

glMatrixMode(GL_MODELVIEW);

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```
Display:
void display () {

1  Clear screen
    glClear(GL_COLOR_BUFFER_BIT);

2  Viewpoint
    glMatrixMode(GL_PROJECTION);
    glOrtho(0.0,1.0,0.0,1.0,-1.0,1.0);

3  For each object:
    1  Place object
    glMatrixMode(GL_MODELVIEW);
    2  Modify state machine
```

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```
Display:
void display () {
  Clear screen
        glClear(GL_COLOR_BUFFER_BIT);
  2 Viewpoint
        glMatrixMode(GL_PROJECTION);
        glOrtho(0.0,1.0,0.0,1.0,-1.0,1.0);
  3 For each object :
       1 Place object
         glMatrixMode(GL_MODELVIEW);
       2 Modify state machine
         glColor3f(1.0,1.0,1.0);
```

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```
Display:
void display () {
  Clear screen
        glClear(GL_COLOR_BUFFER_BIT);
  2 Viewpoint
        glMatrixMode(GL_PROJECTION);
        glOrtho(0.0,1.0,0.0,1.0,-1.0,1.0);
  3 For each object :
       1 Place object
         glMatrixMode(GL_MODELVIEW);
       2 Modify state machine
         glColor3f(1.0,1.0,1.0);
       3 Draw
```

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```
Display:
void display () {
  Clear screen
        glClear(GL_COLOR_BUFFER_BIT);
  2 Viewpoint
        glMatrixMode(GL_PROJECTION);
        glOrtho(0.0,1.0,0.0,1.0,-1.0,1.0);
  3 For each object :
       1 Place object
         glMatrixMode(GL_MODELVIEW);
       2 Modify state machine
         glColor3f(1.0,1.0,1.0);
       O Draw
         glBegin(GL_POLYGON);
            glVertex3f(0.25,0.25,0.0);
            glVertex3f(0.75,0.25,0.0);
            glVertex3f(0.75,0.75,0.0);
            glVertex3f(0.25,0.75,0.0);
         glEnd();
```

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```
Display:
void display () {
  Clear screen
        glClear(GL_COLOR_BUFFER_BIT);
  2 Viewpoint
        glMatrixMode(GL_PROJECTION);
        glOrtho(0.0,1.0,0.0,1.0,-1.0,1.0);
  G For each object :
       1 Place object
         glMatrixMode(GL_MODELVIEW);
       2 Modify state machine
         glColor3f(1.0,1.0,1.0);
       O Draw
         glBegin(GL_POLYGON);
            glVertex3f(0.25,0.25,0.0);
            glVertex3f(0.75,0.25,0.0);
            glVertex3f(0.75,0.75,0.0);
            glVertex3f(0.25,0.75,0.0);
         glEnd():
         glFlush(); // Execute OpenGL commands in hold
```

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Complex object : combination of elementary elements :

- 1 Points (vertices): coordinates in a given reference frame
- 2 Lines : segments
- 3 Polygons : simple convex polygons

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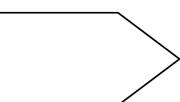
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Example - planar pentagon

```
glBegin(GL_POLYGON);
  glVertex2f(0.0, 0.0);
  glVertex2f(0.0, 3.0);
  glVertex2f(4.0, 3.0);
  glVertex2f(6.0, 1.5);
  glVertex2f(4.0, 0.0);
glEnd();
glFlush();
```



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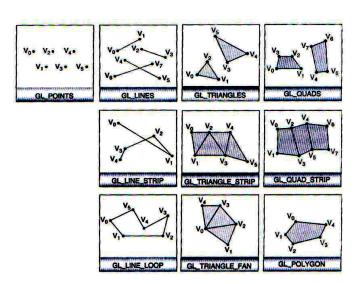
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- Point size (in pixels): glPointSize(2.0);
- Line width (in pixels) : glLineWidth(3.0);

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- Point size (in pixels): glPointSize(2.0);
- Line width (in pixels) : glLineWidth(3.0);
- Line drawing: many stippling styles
- Different renderings for front and back faces :

```
glPolygonMode(GL_FRONT,GL_FILL);
glPolygonMode(GL_BACK,GL_LINE);
```

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- Point size (in pixels): glPointSize(2.0);
- Line width (in pixels) : glLineWidth(3.0);
- Line drawing : many stippling styles
- Different renderings for front and back faces: glPolygonMode(GL_FRONT,GL_FILL); glPolygonMode(GL_BACK,GL_LINE);
- Culling: glCullFace(GL_BACK); : back-faces non-visible

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- Point size (in pixels) : glPointSize(2.0);
- Line width (in pixels) : glLineWidth(3.0);
- Line drawing : many stippling styles
- Different renderings for front and back faces: glPolygonMode(GL_FRONT,GL_FILL); glPolygonMode(GL_BACK,GL_LINE);
- Culling: glCullFace(GL_BACK); : back-faces non-visible
- The color, normal, ..., at each vertex can be specified
- •

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- Point size (in pixels) : glPointSize(2.0);
- Line width (in pixels): glLineWidth(3.0);
- Line drawing : many stippling styles
- Different renderings for front and back faces: glPolygonMode(GL_FRONT,GL_FILL); glPolygonMode(GL_BACK,GL_LINE);
- Culling: glCullFace(GL_BACK); : back-faces non-visible
- The color, normal, ..., at each vertex can be specified
- . .
- Get current values : glGetFloatv(GL_LINE_WIDTH);

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Immediate definition of an objet

Each vertices and polygons are directly defined. Example of a triangle :

```
glBegin(GL_POLYGON);
  glNormal3fv(n0);
  glVertex3fv(v0);
  glNormal3fv(n1);
  glVertex3fv(v1);
  glNormal3fv(n2);
  glVertex3fv(v2);
glEnd();
```

Beware of the order: parameter (i.e. normal) before coordinates (state machine)

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Non immediate methods: Arrays

 Vertex-related data (coordinates, normals, colors, ...) can also be stored in arrays in the CPU memory

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Non immediate methods: Arrays

- Vertex-related data (coordinates, normals, colors, ...) can also be stored in arrays in the CPU memory
- Polygons refer to vertices through indices in these arrays

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Non immediate methods: Arrays

- Vertex-related data (coordinates, normals, colors, ...) can also be stored in arrays in the CPU memory
- Polygons refer to vertices through indices in these arrays
- Object are then defined with a reduced number of primitives
 - glDrawArrays(GL_QUADS, 0, 24)
 - glDrawElements(GL_POLYGON, 5, GL_UNSIGNED_INT, vertices)

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Non immediate methods: Arrays

- Vertex-related data (coordinates, normals, colors, ...) can also be stored in arrays in the CPU memory
- Polygons refer to vertices through indices in these arrays
- Object are then defined with a reduced number of primitives
 - glDrawArrays(GL_QUADS, 0, 24)
 - glDrawElements(GL_POLYGON, 5, GL_UNSIGNED_INT, vertices)
- Advanced methods (non studied in this course)
 - Display lists
 - Vertex Buffer Objects (VBO) : arrays are directly stored in the graphics card memory.

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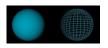
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GLUT primitives - 1/2



glutSolidSphere(radius, slices, stacks)
glutWireSphere(radius, slices, stacks)

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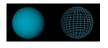
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glutSolidSphere(radius, slices, stacks)
glutWireSphere(radius, slices, stacks)



glutSolidCube(size)
glutWireCube(size)

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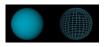
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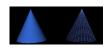
GLUT primitives - 1/2



glutSolidSphere(radius, slices, stacks)
glutWireSphere(radius, slices, stacks)



glutSolidCube(size)
glutWireCube(size)



glutSolidCone(base, height, slices, stacks)
glutWireCone(base, height, slices, stacks)

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OpenGL syntax

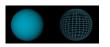
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Conclusio

GLUT primitives - 1/2



glutSolidSphere(radius, slices, stacks)
glutWireSphere(radius, slices, stacks)



glutSolidCube(size)
glutWireCube(size)



glutSolidCone(base, height, slices, stacks)
glutWireCone(base, height, slices, stacks)



glutSolidTorus(innerRadius, outerRadius,
nsides, rings)
glutWireTorus(innerRadius, outerRadius,
nsides, rings)

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Pineline

OpenGL syntax

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GLUT primitives - 2/2



glutSolidTetrahedron()
glutWireTetrahedron()

primitives **GLUT** primitives

GLUT primitives - 2/2





glutSolidTetrahedron() glutWireTetrahedron()

glutSolidOctahedron() glutWireOctahedron()

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GLUT primitives - 2/2







glutSolidTetrahedron()
glutWireTetrahedron()

glutSolidOctahedron()
glutWireOctahedron()

glutSolidDodecahedron()
glutWireDodecahedron()

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GLUT primitives - 2/2









glutSolidTetrahedron()
glutWireTetrahedron()

glutSolidOctahedron()
glutWireOctahedron()

glutSolidDodecahedron()
glutWireDodecahedron()

glutSolidIcosahedron()
glutWireIcosahedron()

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GLUT primitives - 2/2



glutSolidTetrahedron()
glutWireTetrahedron()



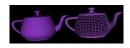
glutSolidOctahedron()
glutWireOctahedron()



glutSolidDodecahedron()
glutWireDodecahedron()



glutSolidIcosahedron()
glutWireIcosahedron()



glutSolidTeapot(size)
glutWireTeapot(size)

Remark: There is no Cylinder primitive.

Plan

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- Modeling Procedural modeling OpenGL primitives GLUT primitives
- 4 Conclusion

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OpenGL pipelin

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Conclusion

Conclusion:

- Done :
 - General process
 - Modeling : geometric primitives
- · Highlights:
 - State machine
 - Primitives
 - the redbook
- To do :
 - lab
 - modeling complex objects with primitives