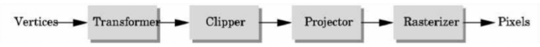
CSCI 420 Computer Graphics
Lecture 3

Graphics Pipeline

Graphics Pipeline
Primitives: Points, Lines, Triangles
[Angel Ch. 2]

Jernej Barbic
University of Southern California

Graphics Pipeline



Primitives+ material properties	Translate Rotate Scale	Is it visible on screen?	3D to 2D	Convert to pixels	Shown on the screen (framebuffer)

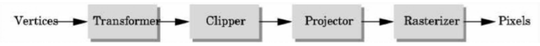
The Framebuffer

- Special memory on the graphics card
- Stores the current pixels to be displayed on the monitor
- Monitor has no storage capabilities
- The framebuffer is copied to the monitor at each refresh cycle

Rendering with OpenGL

- Application generates the 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)

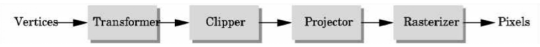
The pipeline is implemented by OpenGL, graphics driver and the graphics hardware



OpenGL programmer does not need to implement the pipeline.

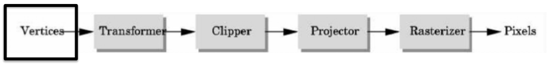
However, pipeline is reconfigurable
➔ “shaders”

Graphics Pipeline



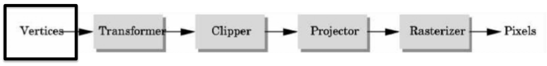
- Efficiently implementable in hardware (but not in software)
- Each stage can employ multiple specialized processors, working in parallel, buses between stages
- #processors per stage, bus bandwidths are fully tuned for typical graphics use
- Latency vs throughput

Vertices (compatibility profile)



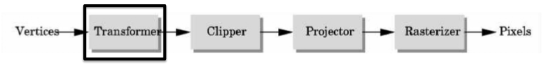
- Vertices in world coordinates
  void glVertex3f(GLfloat x, GLfloat y, GLfloat z)
  – Vertex (x, y, z) is sent down the pipeline.
  – Function call then returns.
- Use GL*type* for portability and consistency
- glVertex{234}{sfid}[v](*TYPE coords*)

Vertices (core profile)



- Vertices in world coordinates
- Store vertices into a Vertex Buffer Object (VBO)
- Upload the VBO to the GPU during program during program initialization (before rendering)
- OpenGL renders directly from the VBO

Transformer (compatibility profile)

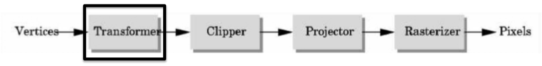


- Transformer in world coordinates
- Must be set before object is drawn!

```
glRotatef(45.0, 0.0, 0.0, -1.0);
glVertex2f(1.0, 0.0);
```

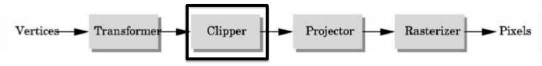
- Complex [Angel Ch. 3]

Transformer (core profile)

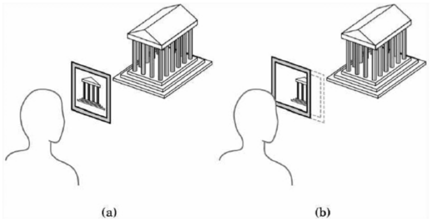


- Transformer in world coordinates
- 4x4 matrix
- Created manually by the user
- Transmitted to the shader program before rendering

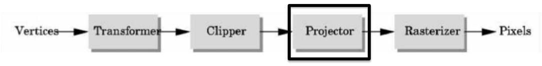
Clipper



- Mostly automatic (must set viewing volume)

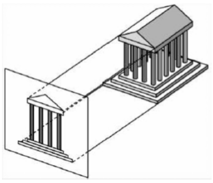


Projector

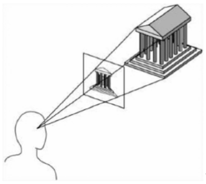


- Complex transformation [Angel Ch. 4]

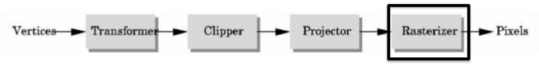
Orthographic



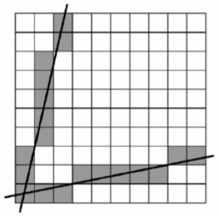
Perspective



Rasterizer

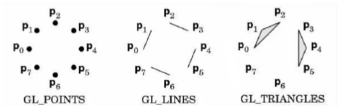


- Interesting algorithms [Angel Ch. 6]
- To window coordinates
- Antialiasing



Geometric Primitives

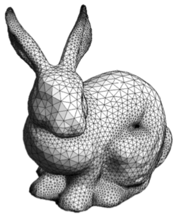
- Suppose we have 8 vertices:
  p_0, p_1, p_2, p_3, p_4, p_5, p_6, p_7
- Then, one can interpret them as:



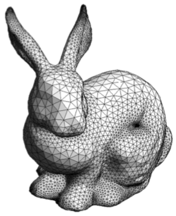
- GL_POINTS, GL_LINES, GL_TRIANGLES are examples of primitive *type*

Triangles

- Can be any shape or size
- Well-shaped triangles have advantages for numerical simulation
- Shape quality makes little difference for basic OpenGL rendering



Geometric Primitives (compatibility profile)



- Specified via vertices
- General schema

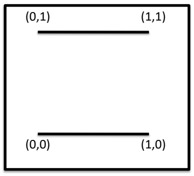
```
glBegin(type);
   glVertex3f(x1, y1, z1);
   ...
   glVertex3f(xN, yN, zN);
glEnd();
```

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

Example: Draw Two Square Edges (compatibility profile)

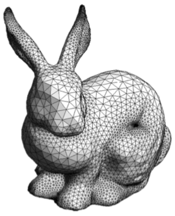
- *Type* = GL_LINES

```
glBegin(GL_LINES);
   glVertex3f(0.0, 0.0, -1.0);
   glVertex3f(1.0, 0.0, -1.0);
   glVertex3f(1.0, 1.0, -1.0);
   glVertex3f(0.0, 1.0, -1.0);
glEnd();
```



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

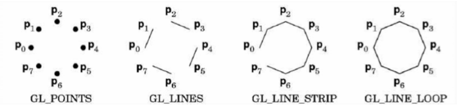
Geometric Primitives (core profile)



- Specified via vertices
- Stored in a Vertex Buffer Object (VBO)

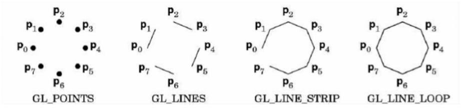
```
int numVertices = 300;
float vertices[3 * numVertices];
// (… fill the "vertices" array …)
// create the VBO:
GLuint vbo;
glGenBuffers(1, &vbo);
glBindBuffer(GL_ARRAY_BUFFER, vbo);
glBufferData(GL_ARRAY_BUFFER, sizeof(vertices),
             vertices, GL_STATIC_DRAW);
```

Render Points and Line Segments (compatibility profile)



```
glBegin (GL_POINTS); // or GL_LINES to render lines
  glVertex3f(…);
   …
  glVertex3f(…);
glEnd();
```

Render Points and Line Segments (core profile)



```
glDrawArrays(GL_POINTS, 0, numVertices); // render points
glDrawArrays(GL_LINES, 0, numVertices); // render lines
```

Main difference between the two profiles

Compatibility:

Rendering:

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

Core:

Initialization:

```
int numVertices = 300;
float vertices[3 * numVertices];
// (… fill the “vertices” array …)
// create the VBO:
GLuint vbo;
glGenBuffers(1, &vbo);
glBindBuffer(GL_ARRAY_BUFFER, vbo);
glBufferData(GL_ARRAY_BUFFER,
   sizeof(vertices), vertices, GL_STATIC_DRAW);
```

Rendering:

```
glDrawArrays(type, 0, numVertices);
```

Common Bug

```
int numVertices = 50000;
float * vertices = (float*) malloc (sizeof(float) * 3 * numVertices);
…
glBufferData(GL_ARRAY_BUFFER,
   sizeof(vertices), vertices, GL_STATIC_DRAW);
```

What is wrong?

Common Bug

int numVertices = 50000;

float * vertices = (float*) malloc (sizeof(float) * 3 * numVertices);

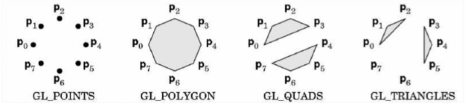
…

~~glBufferData(GL_ARRAY_BUFFER,~~
~~sizeof(vertices), vertices, GL_STATIC_DRAW);~~

glBufferData(GL_ARRAY_BUFFER,
sizeof(float) * 3 * numVertices, vertices, GL_STATIC_DRAW); ✓

Polygons

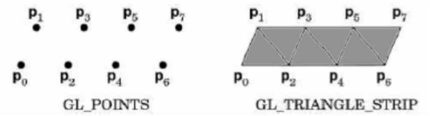
- Polygons enclose an area



- Rendering of area (fill) depends on attributes
- All vertices must be in one plane in 3D
- GL_POLYGON and GL_QUADS are only available in the compatibility profile (removed in core profile since OpenGL 3.1)

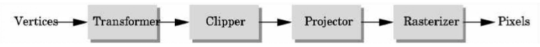
Triangle Strips

- Efficiency in space and time
- Reduces visual artefacts on old graphics cards


$\mathbf{p}_1$ $\mathbf{p}_3$ $\mathbf{p}_5$ $\mathbf{p}_7$
$\mathbf{p}_0$ $\mathbf{p}_2$ $\mathbf{p}_4$ $\mathbf{p}_6$
GL_POINTS
$\mathbf{p}_1$ $\mathbf{p}_3$ $\mathbf{p}_5$ $\mathbf{p}_7$
$\mathbf{p}_0$ $\mathbf{p}_2$ $\mathbf{p}_4$ $\mathbf{p}_6$
GL_TRIANGLE_STRIP

Summary

1. Graphics pipeline
2. Primitives: vertices, lines, triangles


Vertices
Transformer
Clipper
Projector
Rasterizer
Pixels