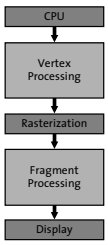
Graphics Pipeline & APIs



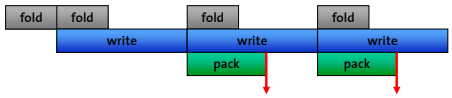

```
glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

glPushMatrix ();
   glTranslatef (-0.15, -0.15, solidZ);
   glMaterialfv(GL_FRONT, GL_EMISSION, mat_zero);
   glMaterialfv(GL_FRONT, GL_DIFFUSE, mat_solid);
   glCallList (sphereList);
glPopMatrix ();
```

Pipelines

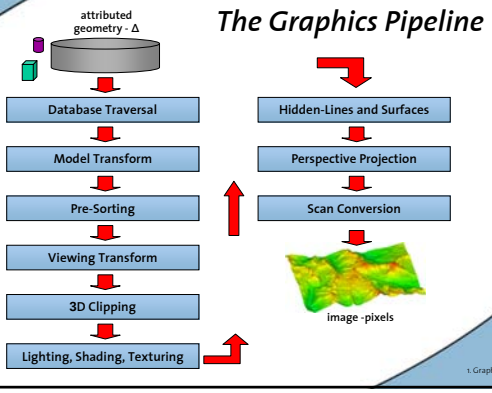
- One person prepares Xmas cards:

- Three persons prepare Xmas cars:

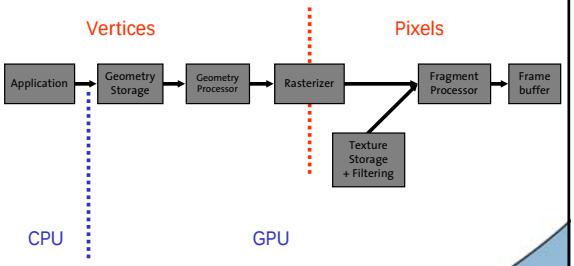


- Ideal: *n* stages → speedup *n*
- Bottleneck: slowest stage
- Graphics: Bottleneck determines frames/s

The Graphics Pipeline



The Graphics Pipeline



Application

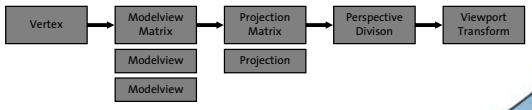
- Generate database
  - Usually only once
  - Load from disk
  - Build acceleration structures (hierarchies,...)
- Database traversal
- Input event handlers
- Modify data structures
- Simulation
- Primitive generation (e.g. triangles)
- other functions..

Geometry Storage

- Command buffering
- Command interpretation
- Unpack and perform format conversion
- Maintain graphics state

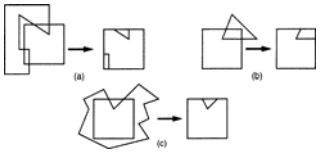
Geometry Processor

- Evaluation of polynomials for curved surfaces
- Transformation and projection



Geometry Processor (2)

- Evaluation of polynomials for curved surfaces
- Transformation and projection
- Clipping, culling, and primitive assembly

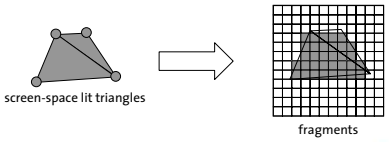


Geometry Processor (3)

- Evaluation of polynomials for curved surfaces
- Transformation and projection
- Clipping, culling, and primitive assembly
- Lighting
- Texture coordinate generation

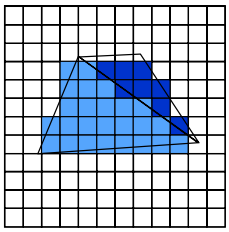
Rasterization

- Setup (per-triangle)
- Sampling (triangle = {fragments})
- Interpolation (interpolate colors and coordinates)



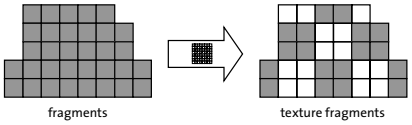
Rasterization (2)

- Separate rule for each primitive
- Non-ambiguous!
- Polygons:
  - Pixel center contained in polygon
  - On-edge pixels only one is rasterized



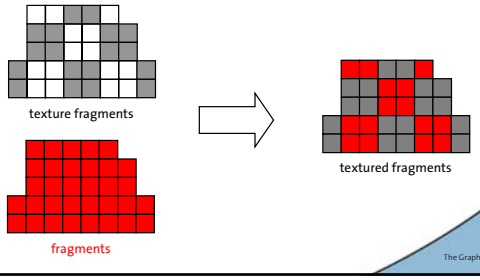
Texture

- Texture transformation and projection
- Texture address calculation
- Texture filtering



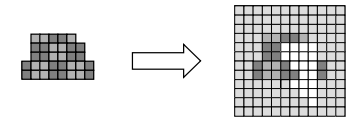
Texture (2)

- Texture combiners

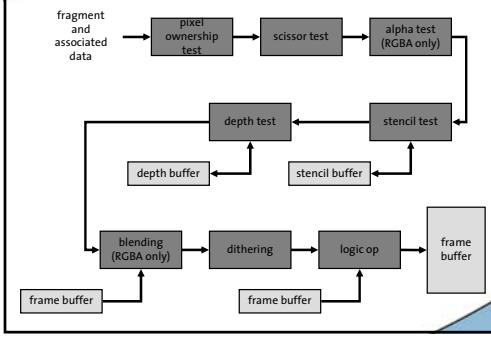


Fragment - Processing

- Texture combiners and fog
- Owner, scissor, depth, alpha, stencil tests
- Blending or compositing
- Dithering and logical operations



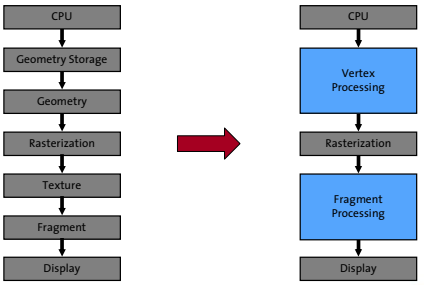
Fragment – Processing Diagram



Display

- Frame buffer pixel format
  - RGBA vs. indexed color
- Bits: 16-bit, 32-bit, 128-bit floating point
- Double buffer vs. single buffer
- Quad-buffer stereo
- Overlays (extra bit planes)
- Auxiliary buffers: alpha, stencil

Contemporary Graphics Pipeline



Contemporary Graphics Pipeline (2)

- Vertex Processing = per-vertex
  - Transform & Lighting (T&L)
  - Historically: hardwired complex operations (floating point)
  - Today: programmable
  - flow control, texture lookup
  - 400 million vertices per second
- Fragment Processing = per-fragment
  - Blending and texture combination
  - Historically: fixed point and limited operations
  - Today: programmable
  - 4 billion fragments ("Gigapixel") per second
  - New: floating point, complex operations

Graphics Application Programming Interfaces (APIs)

```
glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

  glPushMatrix ();
     glTranslatef (-0.15, -0.15, solidZ);
     glMaterialfv(GL_FRONT, GL_EMISSION, mat_zero);
     glMaterialfv(GL_FRONT, GL_DIFFUSE, mat_solid);
     glCallList (sphereList);
  glPopMatrix ();
```

Graphics Libraries (API's)

- Give access to graphics hardware
- Declarative (what, not how)
  - Describe the scene
  - Scene Graph API (retained mode)
  - e.g. SGI Open Inventor, SGI Performer, Renderman
- Imperative (how, not what)
  - Sequence of drawing commands
  - Immediate mode API
  - e.g. OpenGL, DirectX (D3D), Postscript
  - More direct control

OpenGL (Open Graphics Library)

- Initially defined by Silicon Graphics Inc.
  - http://www.opengl.org/
  - http://www.sgi.com/software/opengl/
- OpenGL Architectural Review Board (ARB)
  - 3DLabs, Apple, ATI, Compaq, Evans&Sutherland, hp, IBM, Intel, Microsoft, nVidia, sgi, SUN
- Available on many platforms
  - Windows NT/v4, Windows XP/2000/98/95
  - various UNIX (IRIX, Solaris, etc.)
  - Linux (Debian, RedHat, SuSE, Caldera)
  - Mac OS 8/9/X

OpenGL (2)

- Scales from PC to image engines
- Intuitive, procedural interface
- Versions
  - 1.4 widespread
  - 2.0 available since August 2004
- Language bindings
  - C, Java, Ada, Fortran, Perl, Python

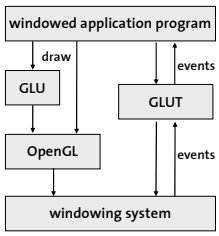
A 2D OpenGL Example

```
#include <GL\gl.h>
#include <GL\glu.h>

main() {
   OpenAWindow();
   glClearColor(0.0, 0.0, 0.0, 0.0);
   glClear(GL_COLOR_BUFFER_BIT);
   glOrtho(-1.0, 1.0, -1.0, 1.0, -1.0, 1.0);
   glBegin(GL_POLYGON);
        glColor3f(1.0, 0.0, 0.0); glVertex2f( 0.9, -0.9);
        glColor3f(0.0, 1.0, 0.0); glVertex2f( 0.0,  0.9);
        glColor3f(0.0, 0.0, 1.0); glVertex2f(-0.9, -0.9);
   glEnd();
   glFlush();
   SomeMainLoop();
}
```


Integration

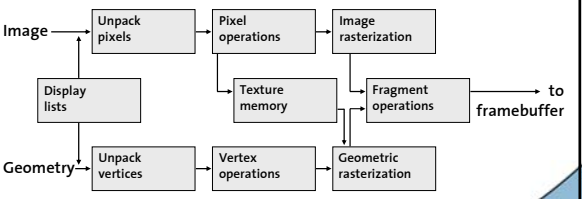
- **gl.lib:** main library
- **glu.lib:** utilities
  - supports NURBS,
  - complex polygons,
  - quadric shapes, etc.
- **glut.lib:** toolkit
  - simplifies & abstracts window handling



Basics

- OpenGL is a state machine
  - State encapsulates control for lighting, shading, texturing, etc.
  - Current state affects transforms, color, lighting, shading, etc.
- Vertices and pixels are fundamental primitives
- Display lists to optimize performance
  - **`glNewList(<id>, GL_COMPILE);`**
- Caching of graphics commands

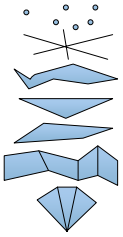
Data Flow



[fragment = pixel]

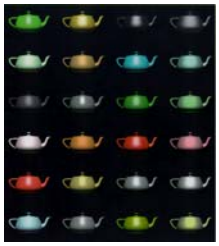
Geometric Primitives

```
glBegin(X);
   X:  GL_POINTS,
       GL_LINES,
       GL_POLYGON,
       GL_TRIANGLES,
       GL_QUADS,
       GL_TRIANGLE_STRIP,
       GL_TRIANGLE_FAN,
glEnd();
```



Rendering Features

- Materials & colors
- Texture mapping
- Texture animation
- MipMaps
- Advanced shading and lighting
- Fog
- Antialiasing
- Framebuffer Ops



A 3D OpenGL Example

```
glClearColor(0.0, 0.0, 0.0, 0.0);
GLfloat gray[]  = {0.5, 0.5, 0.5, 1.0};
GLfloat white[] = {1.0, 1.0, 1.0, 1.0};
GLfloat ldir[]  = {1.0, 1.0, 1.0, 0.0};
glEnable(GL_LIGHTING);
glEnable(GL_LIGHT0);
glLightfv(GL_LIGHT0, GL_AMBIENT, gray);
glLightfv(GL_LIGHT0, GL_DIFFUSE, white);
glLightfv(GL_LIGHT0, GL_POSITION, ldir);
glEnable(GL_COLOR_MATERIAL);
glEnable(GL_DEPTH_TEST);
```

Lighting

```
glMatrixMode(GL_PROJECTION);
glLoadIdentity();
gluPerspective(40, 1.0, 0.1, 10); // fovy, aspect, near, far
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
gluLookAt(0.0,0.0,2.0, 0.0,0.0,0.0, 0.0,1.0,0.0); // eye, center, up
```

Transforms

```
glClear( GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
glColor3f(0.5, 0.3, 0.3);
glMatrixMode(GL_MODELVIEW);
glPushMatrix();
glRotatef(30, 1.0, 1.0, 1.0);
glutSolidTeapot(0.5);
glPopMatrix();
```

Geometry

OpenGL Extensions

- Enables access to hardware-specific features
- Specified by 3D video card manufacturers & OpenGL vendors
- Extensions defined in **`glext.h`**
- Extensions have manufacturer's postfix, e.g.
  - ARB = official extensions by OpenGL Architectural Review Board
  - EXT = agreed upon by multiple OpenGL vendors
  - SGI = Silicon Graphics
  - NV = nVidia Corporation
- Examples:
  - **`glEnable(GL_VERTEX_PROGRAM_NV)`**
  - **`glLoadProgramNV()`**