CS770/870 Spring 2017 Open GL Shader Language GLSL

Based on material from

Angel and Shreiner, *Interactive Computer Graphics, 6th Edition*, Addison-Wesley, 2011

Bailey and Cunningham, *Graphics Shaders 2nd Edition,* CRC Press, 2012

web source too numerous to remember

Preview

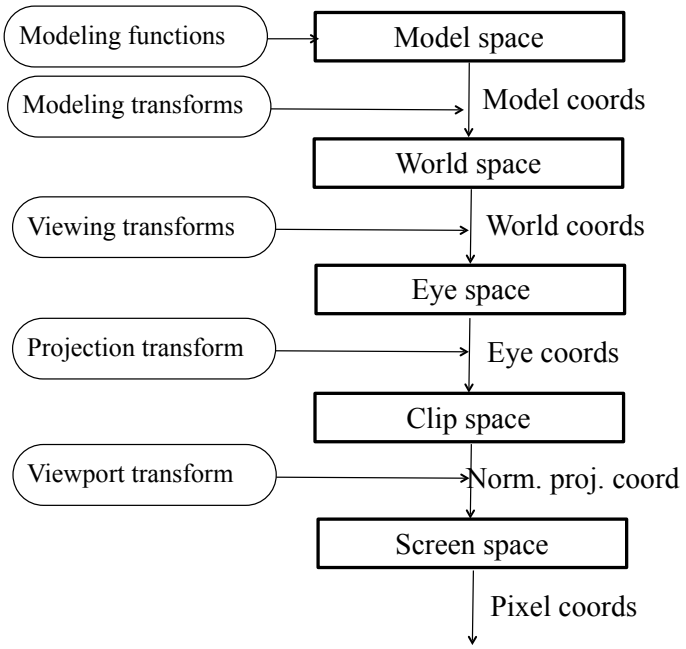
- Review traditional graphics pipeline
- CPU/GPU mixed pipeline issues
- Shaders
- GLSL graphics pipeline

Traditional Graphics Pipeline

- Original OpenGL based on traditional graphics pipeline
- Programmer specifies
  - Geometry, viewing, and projection
  - Object properties: vertices, normals
  - Appearance properties: colors, textures, shading, light
- Traditional OpenGL processing was predefined and straightforward with 2 major connected operations:
  - Vertex processing
    - Create and transform polygons into screen coords, rasterize polys
  - Pixel processing (now called *fragment* processing)
    - Color pixels

Traditional Vertex Pipeline

- View of graphics pipeline based on processing of vertex information
- OpenGL provides a fixed set of functions to control each step
- Programmer specifies parameters to the functions

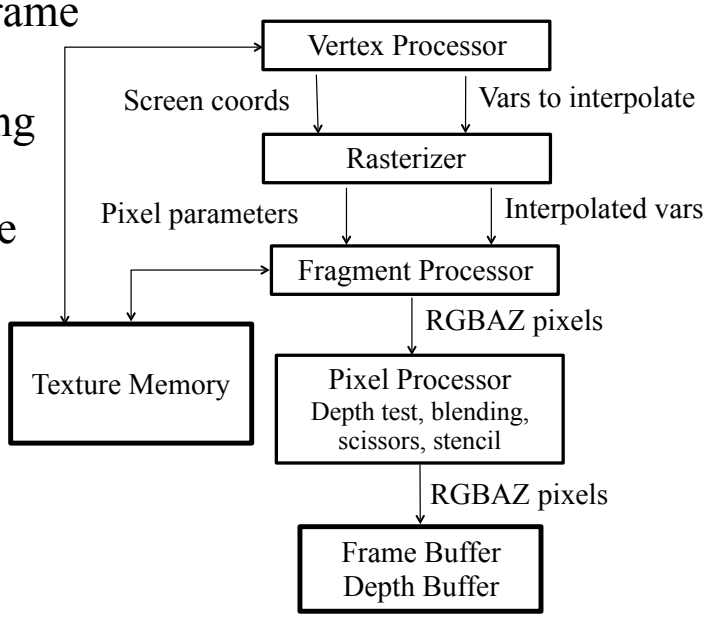


Shaders

- 1984: Rob Cook (Pixar) invented *shade trees*
  - Allow programmers to modify standard graphics pipeline with small shader scripts inserted in pipeline
  - Greatly expanded flexibility of (software) pipelines
  - Lots of others expanded nature and power of shaders
- Silicon Graphics' GL was hardware-oriented and used fixed function pipeline
- OpenGL 1.0 (1993) generalized GL and made it opensource – still fixed function
- OpenGL 2.0 (2004) added shader language, GLSL and support for GPU programming; cpu-driven, gpu adjunct
- OpenGL 3.0 (2008) far more emphasis on gnu
- OpenGL 4.0 (2012) all "old" functionality deprecated

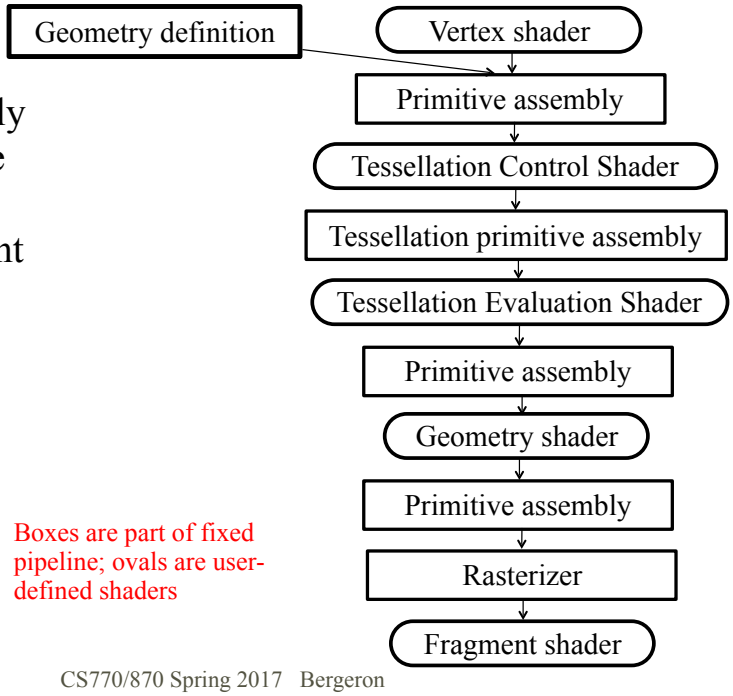
Fragment Processing Pipeline

- *pixel*: rgbaz for a frame buffer location
- *fragment*: everything needed to compute pixel: rgbaz, texture coords, and more



Expanded Graphics Pipeline

- Shaders can actually be inserted in more places in pipeline
- Vertex and fragment shaders are most important



Boxes are part of fixed pipeline; ovals are user-defined shaders

Rise of GPUs

- GPU processing has evolved incredibly rapidly
  - Early goal was pixel per processor (data parallelism)
  - Hardwire low level calculations
- Massively parallel computation meshes well with notion of user-written computations (shaders) for each pixel (*fragment shaders*)
- Architecture is also good for user-written computations for each vertex (*vertex shaders*) and for some geometric processing as well (*tesselation shaders*)

CPU/GPU Characteristics

- CPU strengths
  - General computational power
  - Access to large secondary storage
  - Well-known powerful software tools
  - Large commodity primary memory
- GPU strengths
  - Much faster for image/graphics computations
  - Massive parallelism
  - Large specialized memory

CPU/GPU Pipeline Distribution

- CPU best for
  - Application data access
  - Modeling
  - User interface
- GPU best for
  - Fragment processing
- Either can do vertex and tesselation processing
  - How decide?
    - Can depend on power of GPU
    - Can depend on nature of application processing
  - Let application programmer decide

CPU/GPU Pipeline Issues

- CPU/GPU normally have separate memories
  - GPU memory must already be dual-ported: GPU/display
- CPU/GPU data transfer is major bottleneck
- Need to distribute work so data transfer is minimized
- Standard OpenGL uses *direct* drawing
  - Every redraw event (30-60 time/sec during animation) must recreate entire image:
    - *glBegin; glVertex; glVertex ... glEnd;*
  - A lot of data transfer if vertices generated/stored on CPU.
- How can work distribution be defined by programmer?

Data Transfer Model

- Array based
- Buffers in GPU
- CPU code creates data
  - Asks GPU for buffer space
  - Uploads the data via arrays into buffer using buffer id
- Arrays can combine vertex, color and other info
- Can also define *uniform* variables: essentially global variables accessible to the shaders and to CPU code

Programming Framework

- CPU code
  - creates models
  - Specifies shader code to run on gpu
  - Compiles and uploads shader code
  - Can read and set *uniform* variables
  - Can read and get array information
- GPU pipeline code
  - Manages GPU pipeline and environment variables
    - Includes variables allowing shaders to communicate
  - Invokes user-written shader code
    - For each vertex, the vertex shader
    - For each fragment, the fragment shader
    - For each patch, the tesselation shaders

GLSL Vertex Shaders

- GLSL provides access in vertex shaders to
  - One vertex
  - *uniform* variables (user/shader defined)
  - *in* variables (position, normal, texture coords, color) passed to the shader from previous shader in pipeline
  - *out* variables (position, etc): passed to next shader
- Vertex shaders are responsible for
  - Vertex transformations
  - Normal transformations
  - Normal normalization (making unit length)
  - Handling per-vertex lighting
  - Handling texture coordinates at vertex

GLSL Fragment Shader

- For each fragment, maps fragment information (and *uniform* variables) to pixel information
- Rasterizer interpolates colors, normals, depths, texture coordinates, user variables defined for vertex: all are fragment shader variables
- Fragment shaders are responsible for
  - Color computation
  - Texturing
  - Per-pixel lighting
  - Fog
  - Discarding pixel fragments

GLSL Language Overview

- Simplified C++ (or extended C) with some Java-like features
  - "classes" are based on *struct*, so no inheritance
  - Predefined vector and matrix objects
  - No pointers
  - Arrays are first class objects
  - No *new*; dynamic allocation via function entry/exit
  - Function parameters passed by *value-return*
  - Variable qualifiers: in, out, uniform and more
  - Predefined variable names for each shader
  - Shared namespace between shaders

Vectors and Matrices

- GLSL has builtin vector and matrix objects:
  - vec2, vec3, vec4
  - mat2, mat3, mat4
- Predefined arithmetic operators:
  vec op vec : +,-,*,/ corresponding elements
  mat * vec : matrix * vector yields vector
  mat * mat : matrix * matrix yields matrix
- Multiple valid *vec* "field" names (*name sets*)
  - vec.x, vec.y, vec.z, vec.w for point variables
  - vec.r, vec.g, vec.b, vec.a for color variables
  - vec.s, vec.t, vec.p, vec.q for texture variables

Shared Namespace

- Each shader occurs in a pipeline
  - compute variables for shaders later in the piple
- How do shaders in a shader program communicate?
  - shared *namespace* for variables created in gpu memory
- *attribute* namespace
  - attributes are values associated with a vertex
  - defined in application program using a call such as
    `glVertexAttribPointer( index,size, … , GLvoid* )`
    where index is an identifier
  - same array can contain position, normal, color and more
- *uniform* variables created by applic as *read-only*
- *shader-defined* variables

General Storage Qualifiers

- Storage qualifiers describe where storage comes from
- global variable qualifiers:
  - <none> : scope is shader stage, so 2 vertex shaders with same named global variable, reference the same variable.
  - *const*: compile time constant; value can never be changed
  - *in*: input variable set by previous stages; cannot be changed
  - *out*: output variables that are passed to next stage, must be set
    - *in/out* variables cannot be structs; can be arrays
  - *uniform*: parameters passed to shader from user; do not change value during a single rendering call
- local variable qualifiers
  - <none> for local variable that can be changed by the shader
  - *const*: compile time constant; value can never be changed

Uniform Variables

Shader code

```
uniform vec4 ambientProduct;
uniform vec4 diffuseProduct;
uniform mat4 ModelView;
uniform vec4 LightPosition;
uniform float Shininess;
```

- CPU application

```
vec4 ambProduct = lightAmbient * materialAmbient;
GLuint ambLoc  // identifier for gpu location
    = glGetUniformLocation(program, "ambientProduct”);
glUniformv( ambLoc, 1, ambProduct ); // set value
vec4 diffProduct = lightDiffuse * materialDiffuse;
Gluint diffLoc = . . .
. . .
```

Interpolation Qualifiers

- A fragment shader *in* parameter can also have an interpolation qualifier:
  - *flat*: no interpolation is done; desired value (such as for color) is taken from first vertex (by default, but changeable)
  - *noperspective*: linear interpolation is done in window space (seldom desirable)
  - *smooth*: interpolation is correct for perspective distortion

  Other variable qualifiers can affect the interpolation
  - *centroid* and *sample* have effect in pixel *multisampling* mode

Interface Blocks

- *uniform*, *in*, and *out* storage specification can use interface blocks to group variables
- It's a *struct*-like notation, but they are not structs.

```
uniform Transformations
{
   mat4 modelView;
   mat4 projection;
} name;
```

can refer to components as name.modelView, etc.
name is optional
name can use array notation, such as *many[3]*

GLSL Status

- GLSL has evolved rapidly and unevenly
  - Windows, Linux, Mac OS X have been at significantly different stages until very recently; the gaps are closing
  - Hard to write portable code
  - Debugging tools are pretty primitive

Key Features

- Data buffers
  - See basic GLSL demo:
    - glGenVertexArrays, glGenBuffers, glBufferData
- Projection/viewing
  - GLSL: no predefined matrix stacks nor viewing functions
    - Implement your own viewing/projection in shader program