Computergrafik

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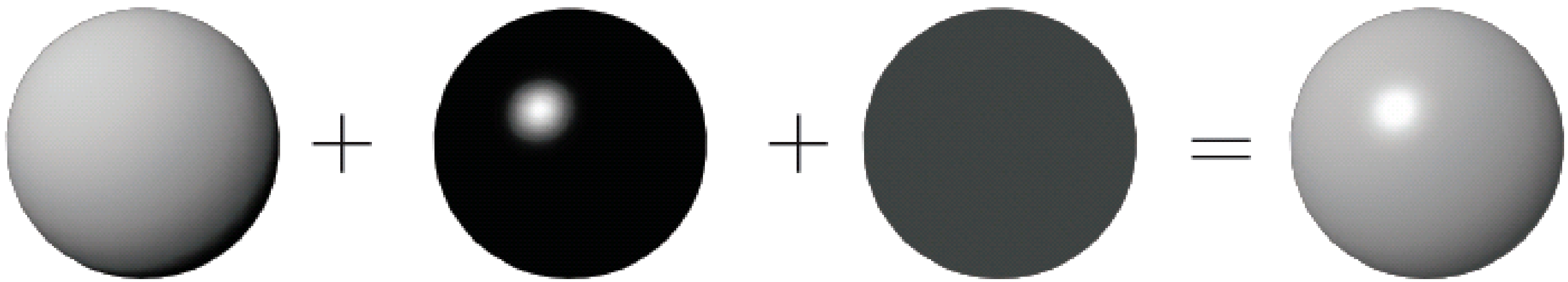
Today

- Shader programming
- More texture mapping & antialiasing

Complete model

- Blinn model with several light sources i

$$c = \sum_i c_{l_i} \left(k_d \left(\mathbf{L}_i \cdot \mathbf{n}\right) + k_s \left(\mathbf{h}_i \cdot \mathbf{n}\right)^s\right) + k_a c_a$$

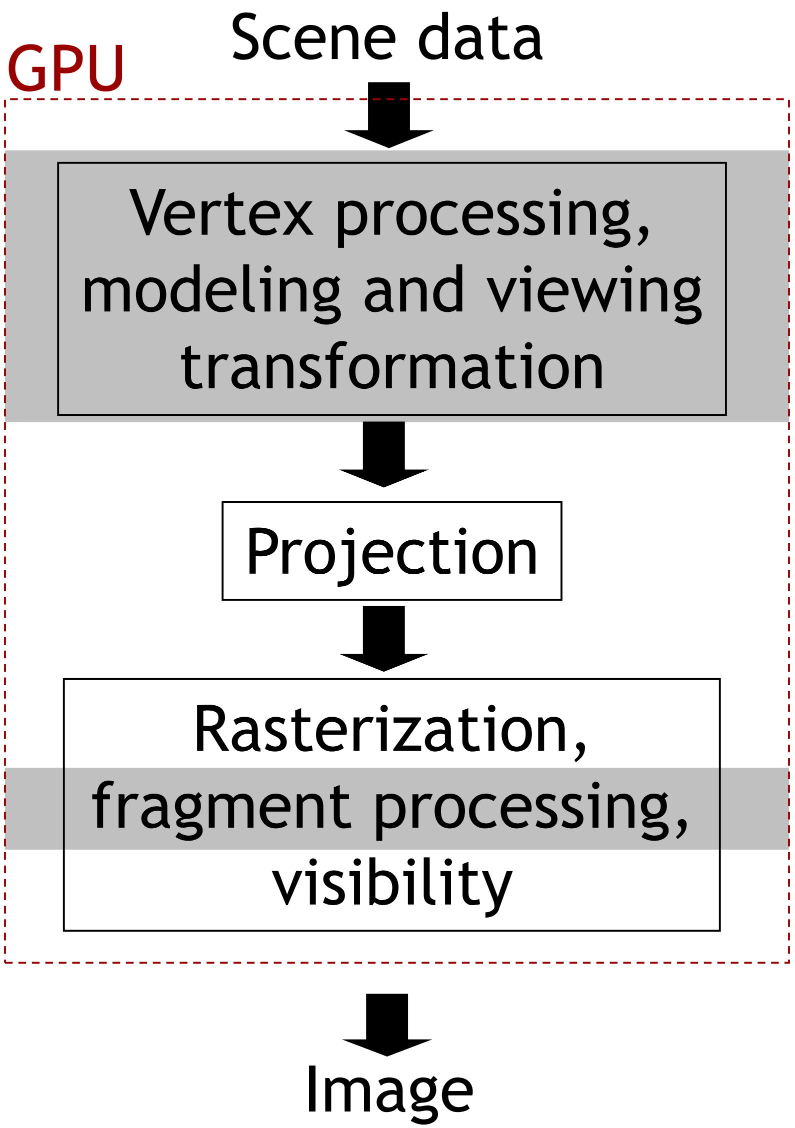


diffuse | specular | ambient

How is this implemented on the graphics processor (GPU)? Shader programming!

Programmable pipeline

- Functionality in parts (grey boxes) of the GPU pipeline specified by user programs
- Called shaders, or shader programs, executed on GPU
- Not all functionality in the pipeline is programmable



Shader programs

- Written in a shading language
- Examples
  - Cg, early shading language by NVidia
  - OpenGL's shading language GLSL
    http://en.wikipedia.org/wiki/GLSL
  - DirectX' shading language HLSL (high level shading language)
    http://en.wikipedia.org/wiki/High_Level_Shader_Language
  - RenderMan shading language (film production)
  - All similar to C, with specialties
- Recent, quickly changing technology
- Driven by more and more flexible GPUs

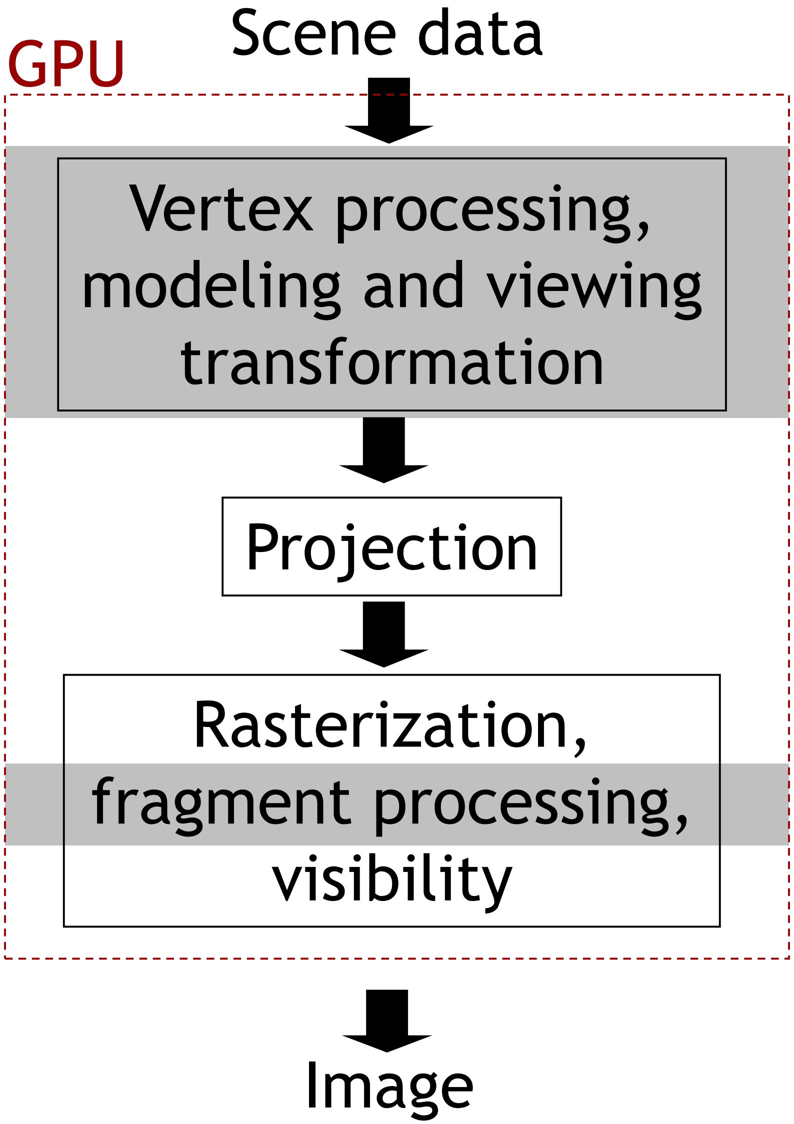
Programmable pipeline (2006)

Two types of shader programs

1. Vertex program

2. Fragment program

(fragment: pixel location inside a triangle and interpolated data)



GPU architecture (2006)

Pipeline

GPU

Scene data

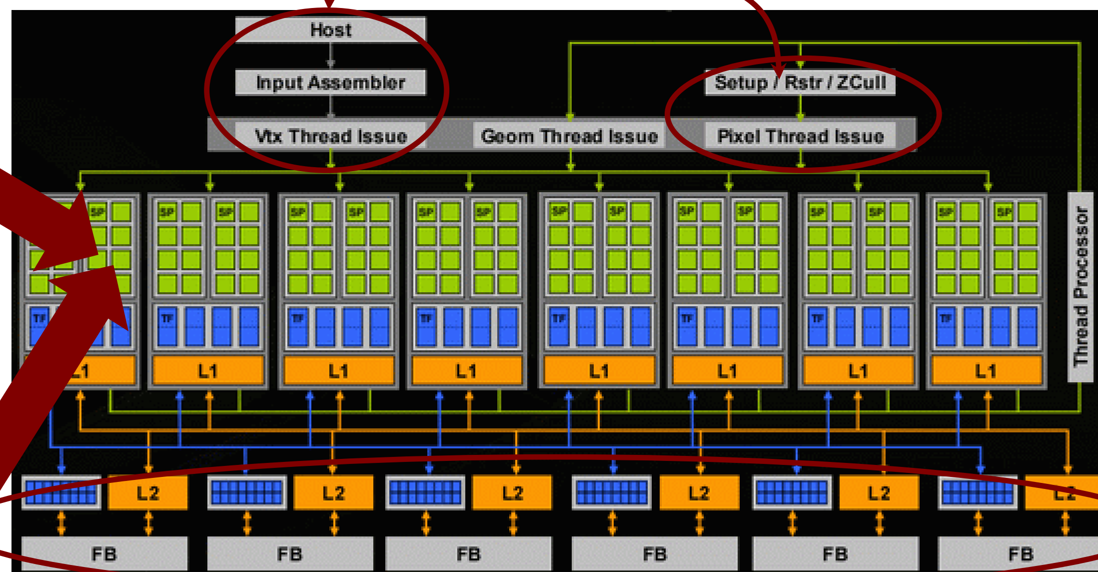
Vertex processing, modeling and viewing transformation

Projection

Rasterization, fragment processing, visibility

Image

GPU Architecture



NVidia NV80 (GeForce 8800 Series)

128 functional units, “stream processors”

http://arstechnica.com/news.ars/post/20061108-8182.html

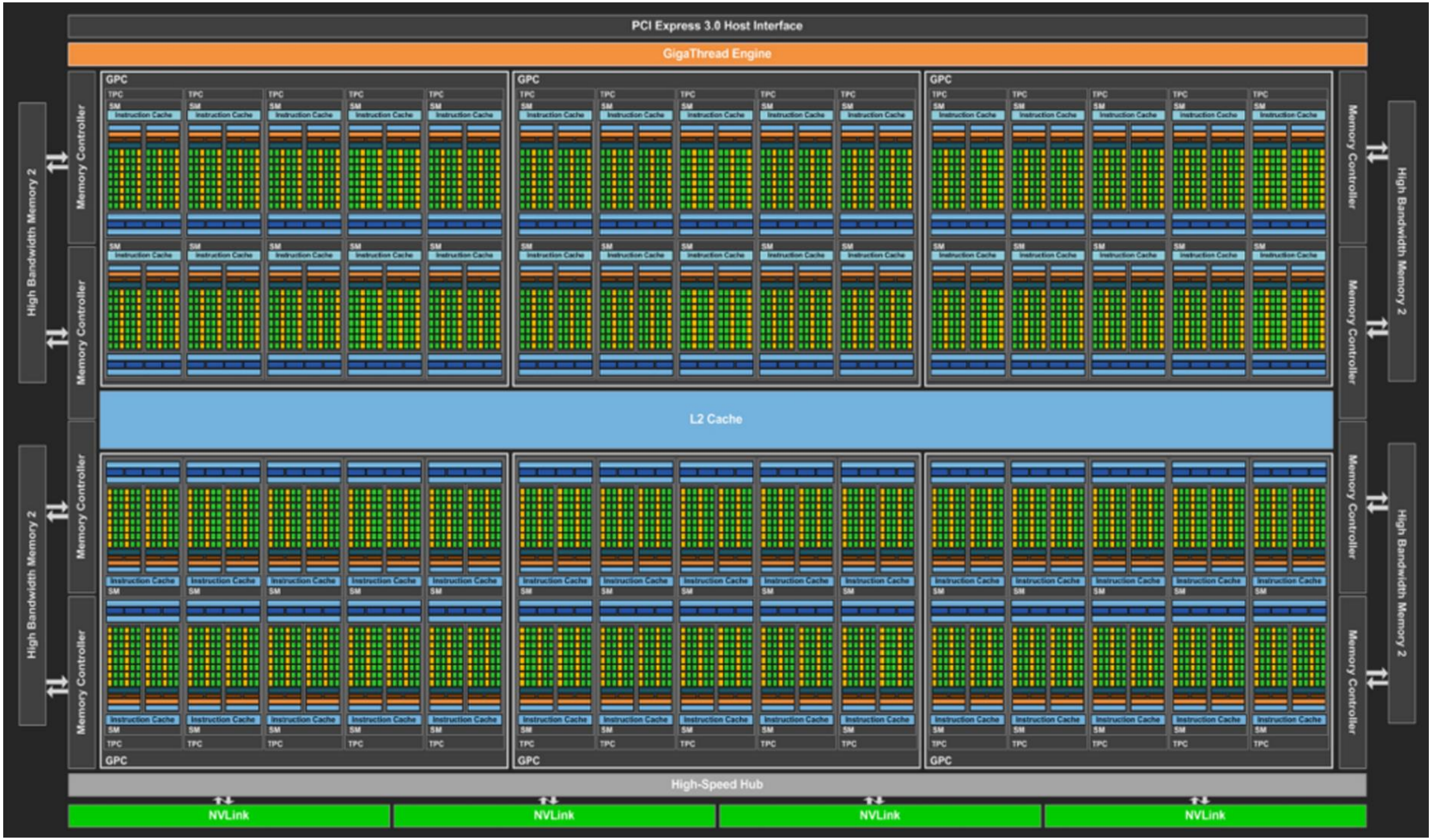
GPU architecture (2014)

- Similar, but more processors (2048 ■)

http://hexus.net/tech/reviews/graphics/74849-nvidia-geforce-gtx-980-28nm-maxwell/

GPU architecture (2016)

- Similar, but even more processors (3840 ■)



https://devblogs.nvidia.com/parallelforall/inside-pascal/

Parallelism

- Task parallelism
  http://en.wikipedia.org/wiki/Task_parallelism
  - Processor performs different threads (sequences of instructions) simultaneously
  - Multi-core CPUs
- Data parallelism
  http://en.wikipedia.org/wiki/Data_parallelism
  - Processors performs same thread of instructions on different data elements
  - Single Instruction Multiple Data (SIMD)
  - GPUs

Parallelism

- GPUs up to now exploit mostly data parallelism
  - Perform same thread of operations (same shader) on multiple vertices and pixels independently
  - Massive parallelism (same operation on many vertices, pixels) enables massive number of operations per second
  - Currently: hundreds of parallel operations at several hundred megahertz
- Detailed description of Nvidia „Kepler“ architecture

  http://www.geforce.com/Active/en_US/en_US/pdf/GeForce-GTX-680-Whitepaper-FINAL.pdf

Still fixed functionality (2014)

- "Hardcoded in hardware"
- Projective division
- Rasterization
  - I.e., determine which pixels lie inside triangle
  - Vertex attribute interpolation (color, texture coords.)
- Access to framebuffer
  - Z-buffering
  - Texture filtering
  - Framebuffer blending

Shader programming

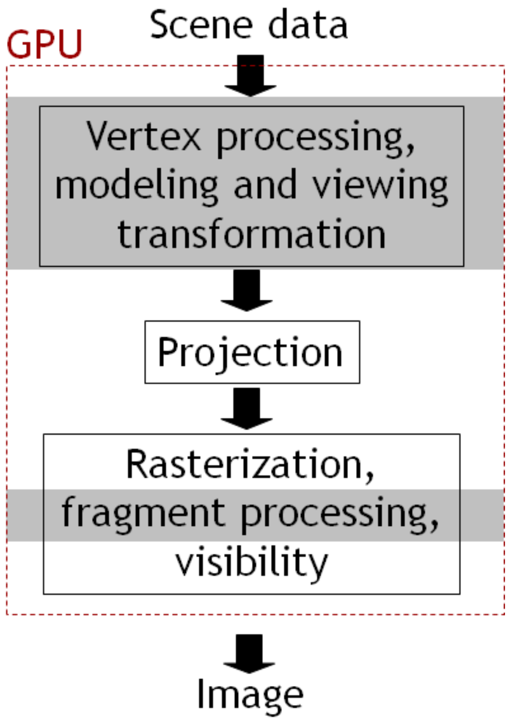
- Each shader (vertex or fragment) is a separate piece of code in a shading language (e.g. GLSL)
- Vertex shader
  - Executed automatically for each vertex and its attributes (color, normal, texture coordinates) flowing down the pipeline
  - Type and number of output variables of vertex shader are user defined
  - Every vertex produces same type of output
  - Output interpolated automatically at each fragment and accessible as input to fragment shader
- Fragment shader
  - Executed automatically for each fragment (pixel) being touched by rasterizer
  - Output (fragment color) is written to framebuffer

Shader programming

- Shaders are activated/deactivated by host program (Java, C++, …)
  - Can have different shaders to render different parts of a scene
- Shader programs can use additional variables set by user
  - Modelview and projection matrices
  - Light sources
  - Textures
  - Etc.
- Variables are passed by host (Java, C++) program to shader
  - In jrtr via jogl, see class jrtr.GLRenderContext
- Learn OpenGL details from example code, then (advanced) reference books, e.g. http://www.opengl.org/registry/doc/glspec40.core.20100311.pdf

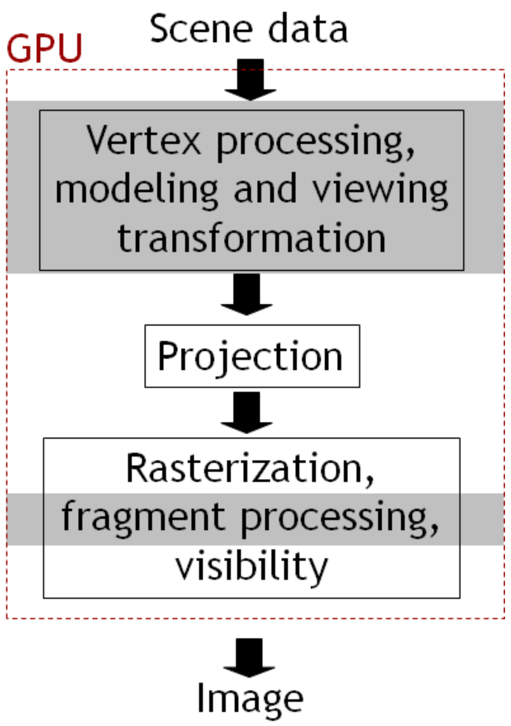
Vertex programs

- Executed once for every vertex
  - Or: “every vertex is processed by same vertex program that is currently active”
- Implements functionality for
  - Modelview, projection transformation (required!)
  - Per-vertex shading
- Vertex shader often used for animation
  - Characters
  - Particle systems



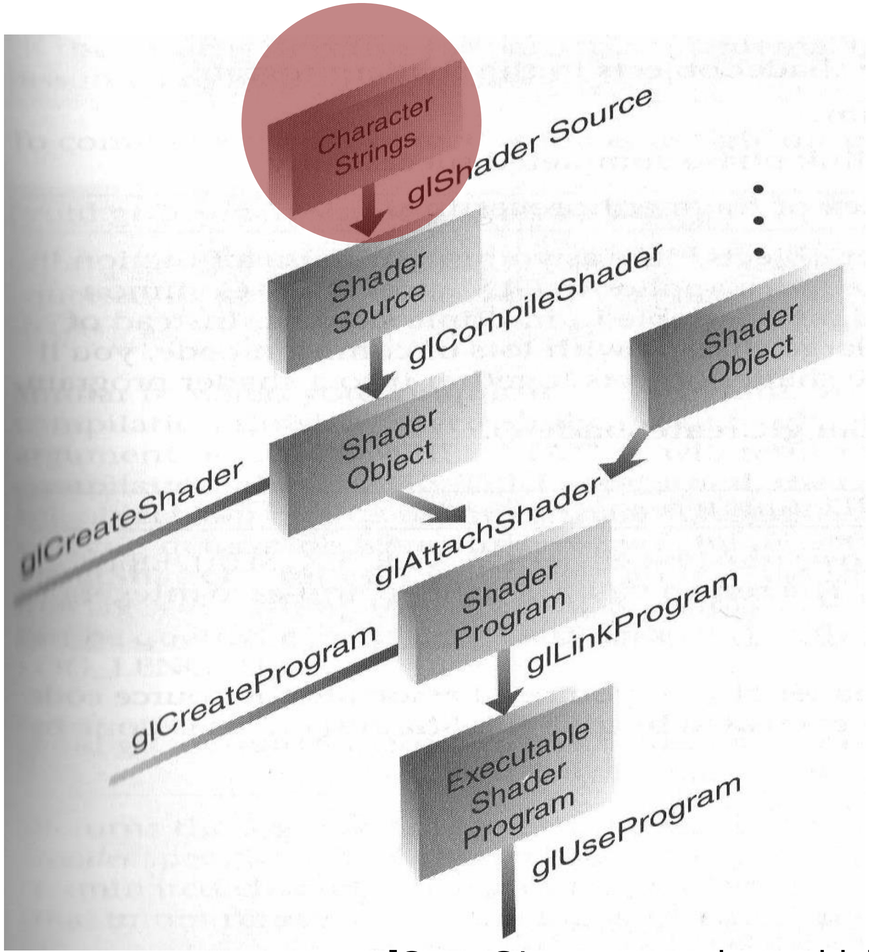
Fragment programs

- Executed once for every fragment
  - Or: “Every fragment is processed by same fragment program that is currently active”
- Implements functionality for
  - Output color to framebuffer
  - Texturing
  - Per-pixel shading
  - Bump mapping
  - Shadows
  - Etc.



Creating shaders in OpenGL

- Sequence of OpenGL API calls to load, compile, link, activate shaders
  - Mostly taken care of in `Shader.java`
- Input is a string that contains shader program
  - String usually read from file
  - Separate files for fragment and vertex shaders

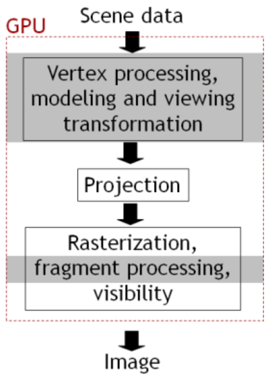


[OpenGL programming guide]

Creating shaders in OpenGL

- You can switch between different shaders during runtime of your application
  - Setup several shaders as shown before
  - Call `glUseProgram(s)` whenever you want to render using a certain shader `s`
  - Shader is active until you call `glUseProgram` with a different shader
- In `jrtr`, this functionality is encapsulated in the `Shader` class

Vertex programs



Vertices with attributes
storage classifier `in`
Coordinates in object space,
additional vertex attributes

From application

Uniform parameters
storage classifier `uniform`
OpenGL state,
application specified
parameters

Vertex program

To rasterizer

Output
storage classifier `out`
Transformed vertices,
processed vertex attributes

“Hello world” vertex program

- `main()` function is executed for every vertex
- Three storage classifiers: **in**, **out**, **uniform**

```
in vec4 position;            // position, vertex attribute
uniform mat4 projection; // projection matrix, set by host (Java)
uniform mat4 modelview;  // modelview matrix, set by  host (Java)

void main()
{
  gl_Position =              // required, predefined output variable
  projection *               // apply projection matrix
  modelview *                // apply modelview matrix
  position;                  // vertex position
}
```

Vertex attributes

- "Data that flows down the pipeline with each vertex"
- Per-vertex data that your application sends to rendering pipeline
- E.g., vertex position, color, normal, texture coordinates
- Declared using `in` storage classifier in your shader code
  - Read-only

Vertex attributes

- Application needs to tell OpenGL which vertex attributes are mapped to which **`in`** variables

- In host (Java) program, sequence of calls

```
glGenBuffers  // Get reference to OpenGL buffer object
glBindBuffer  // Activate buffer object
glBufferData  // Write data into buffer
glGetAttribLocation    // Get reference of uniform variable
                       //   in shader
glVertexAttribPointer // Link buffer object with uniform
                      // shader variable
glEnableVertexAttribArray // Enable the link
```

- Details see `GLRenderContext.draw`
  - No need to modify it

Uniform parameters

- Parameters that are set by the application, but do not change on a per-vertex basis!
  - Transformation matrices, parameters of light sources, textures
- Will be the same for each vertex until application changes it again
- Declared using `uniform` storage classifier in vertex shader
  - Read-only

Uniform parameters

- To set parameters, use `glGetUniformLocation, glUniform*` in application
  - After shader is active, before rendering
- Example
  - In shader declare
    ```
    uniform float a;
    ```
  - In application, set `a` using
    ```
    GLuint p;
    //… initialize program p
    int i=glGetUniformLocation(p,"a");
    glUniform1f(i, 1.f);
    ```

Output variables

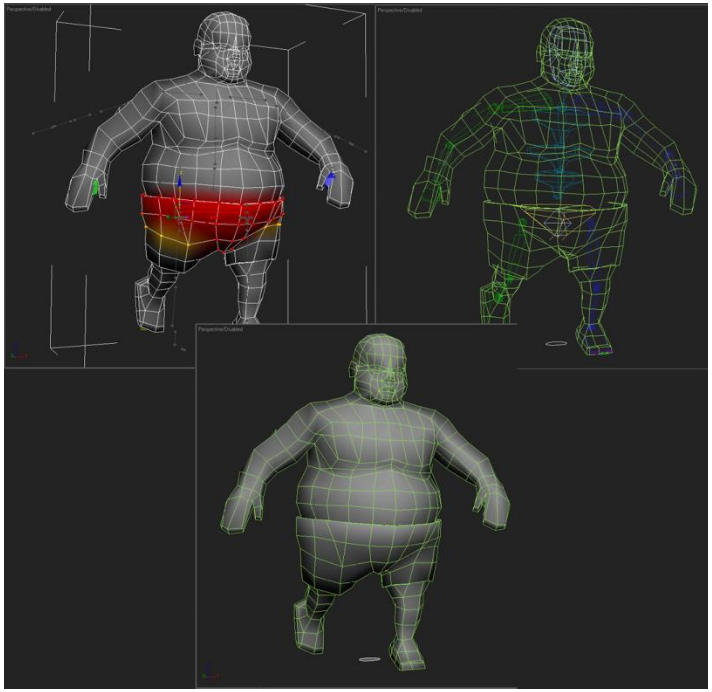
- Required, predefined output variable: homogeneous vertex coordinates
  `vec4 gl_Position`
- Additional user defined outputs
  - Mechanism to send data to the fragment shader
  - Will be interpolated during rasterization
  - Interpolated values accessible in fragment shader (using same variable names)
- Storage classifier **`out`**

Limitations (2014)

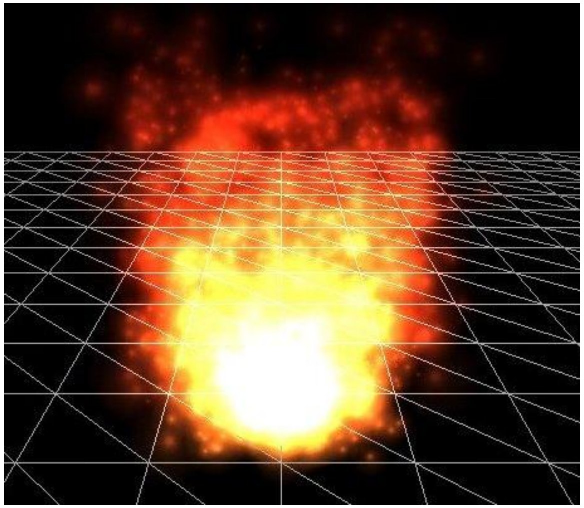
- Cannot write data to any memory accessible directly by application (Java, C++, etc.)
- Cannot pass data between vertices
  - Each vertex is independent
- One vertex in, one vertex out
  - Cannot generate new geometry
  - Note: “Geometry shaders” (not discussed here) can do this

Examples

- Animation
  - Offload as much as possible to the GPU
- Character skinning
- Particle systems
- Water

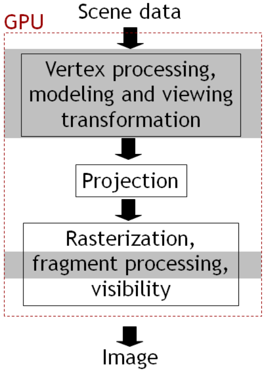


Character skinning



http://www.youtube.com/watch?v=on4H3s-W0NY

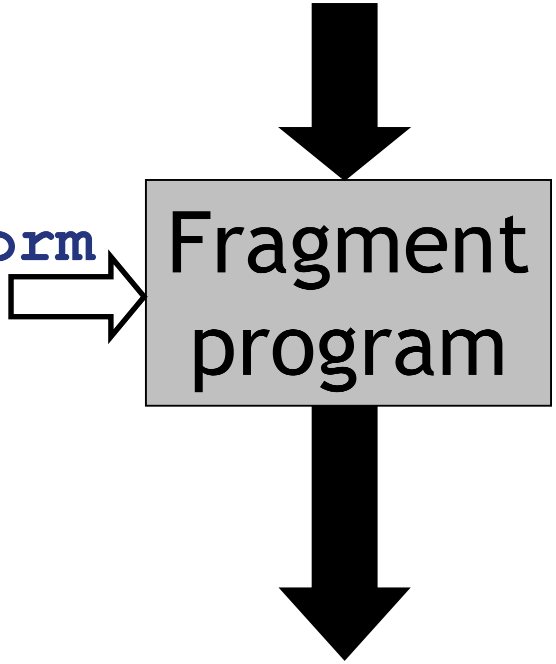
Fragment programs



Fragment data
storage classifier `in`
Interpolated vertex attributes, additional fragment attributes

From rasterizer

Uniform parameters
storage classifier `uniform`
OpenGL state, application specified parameters



To fixed framebuffer access functionality (z-buffering, etc.)

Output
storage classifier `out`
Fragment color, depth

Fragment data

- Change for each execution of the fragment program
- Interpolated from vertex output during rasterization
  - Fragment color, texture coordinates, etc.
- Declared as **`in`** variables
  - Need to have same variable name as output (declared as **`out`**) of vertex shader

Uniform parameters

- Work same as in vertex shader
- Typically transformation matrices, parameters of light sources, textures
- Pass from host application via `glGetUniformLocation, glUniform*`

Output variables

- Typically fragment color
- Declared as `out`
- Will be written to frame buffer (i.e., output image) automatically

"Hello world" fragment program

- `main()` function is executed for every fragment
- Draws everything in bluish color

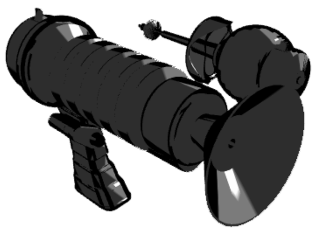
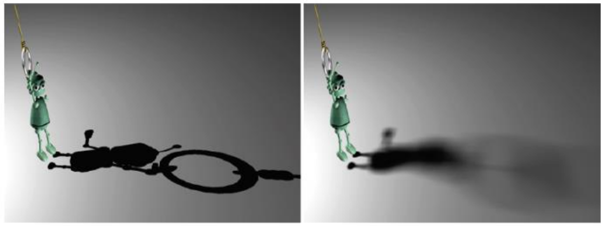
```
out vec4 fragColor;

void main()
{
  fragColor = vec4(0.4,0.4,0.8,1.0);
}
```

Examples

- Per pixel shading as discussed in class
- Bump mapping
- Displacement mapping
- Realistic reflection models
- Cartoon shading
- Shadows
- Etc.
- Most often, vertex and fragment shader work together to achieve desired effect



Limitations (2014)

- Cannot read framebuffer
  - Current pixel color, depth, etc.
- Can only write to framebuffer pixel that corresponds to fragment being processed
  - No random write access to framebuffer
- Number of variables passed from vertex to fragment shader is limited
- Number of application defined uniform parameters is limited

GLSL built in functions and data types

- See OpenGL/GLSL quick reference card
  http://www.khronos.org/files/opengl-quick-reference-card.pdf
- Matrices, vectors, textures
- Matrix, vector operations
- Trigonometric functions
- Geometric functions on vectors
- Texture lookup

Summary

- Shader programs specify functionality of parts of the rendering pipeline
- Written in special shading language (GLSL in OpenGL)
- Sequence of OpenGL calls to compile/activate shaders
- Several types of shaders, discussed here:
  - Vertex shaders
  - Fragment shaders

GLSL main features

- Similar to C, with specialties
- Most important: `in`, `out`, `uniform` storage classifiers
- Parameters of shader (`uniform` variables) passed from host application via specific API calls
- Built in vector data types, vector operations
- No pointers, classes, inheritance, etc.

Debugging shaders

- No direct way to debug (setting breakpoints, inspecting values)
- Practical technique
  - Render intermediate steps of your shader
  - Color code information that you want to see (e.g, paint pixel a specific color if you reach certain part of shader code)
- Forum discussions

  http://stackoverflow.com/questions/2508818/how-to-debug-a-glsl-shader

Tutorials and documentation

- OpenGL and GLSL specifications
  http://www.opengl.org/documentation/specs/
- OpenGL/GLSL quick reference card
  http://www.khronos.org/files/opengl-quick-reference-card.pdf
- Learn from example code and use the Ilias forum!

GPGPU programming

- "General purpose" GPU programming
- Special GPU programming languages
  - CUDA
    http://en.wikipedia.org/wiki/CUDA
  - OpenCL
    http://en.wikipedia.org/wiki/OpenCL
- Exploit data parallelism
- SIMT (single instruction multiple threads) programming model
  - Each thread has unique ID
  - Each thread operates on single data item (as opposed to vector of data items in SIMD)
  - Data items accessed via thread ID

Next time

- More texture mapping, texture filtering