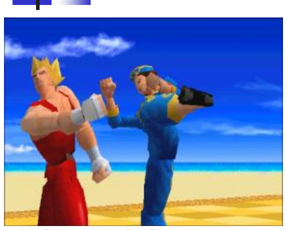
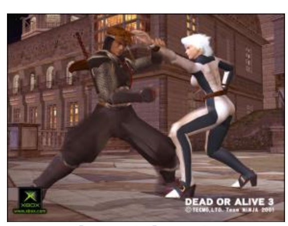
Programmable GPUs

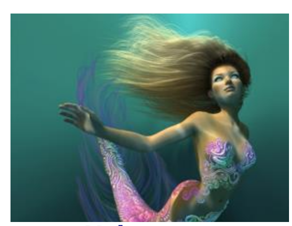
Real Time Graphics



Virtua Fighter 1995
(SEGA Corporation)
NV1



Dead or Alive 3 2001
(Tecmo Corporation)
Xbox (NV2A)



Nalu 2004
(NVIDIA Corporation)
GeForce 6

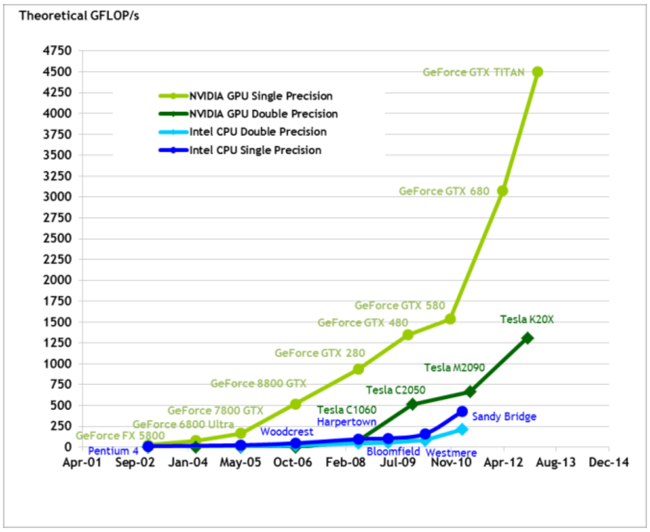
Human Head 2006
(NVIDIA Corporation)
GeForce 7

Medusa 2008
(NVIDIA Corporation)
GeForce GTX 200

Real-Time Dynamic Fracture 2013
(NVIDIA Corporation)
GeForce GTX 700

GPUs vs CPUs

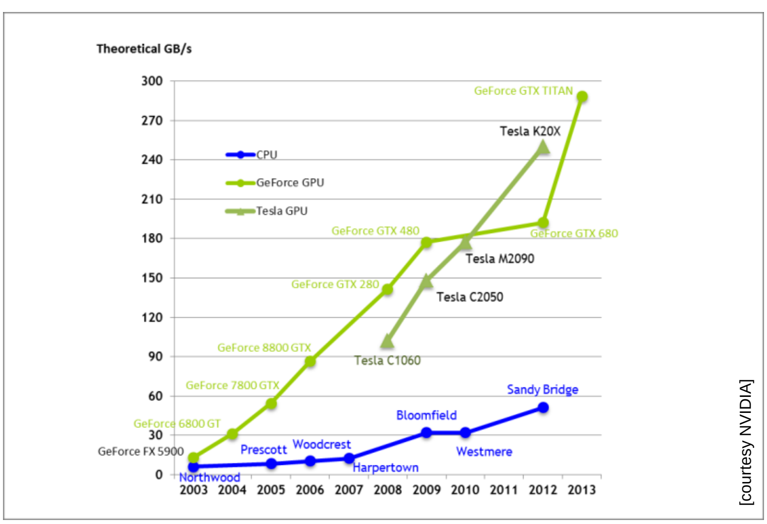
- 4500 GFLOPS vs ~500 GFLOPS



[courtesy NVIDIA]

GPUs vs CPUs

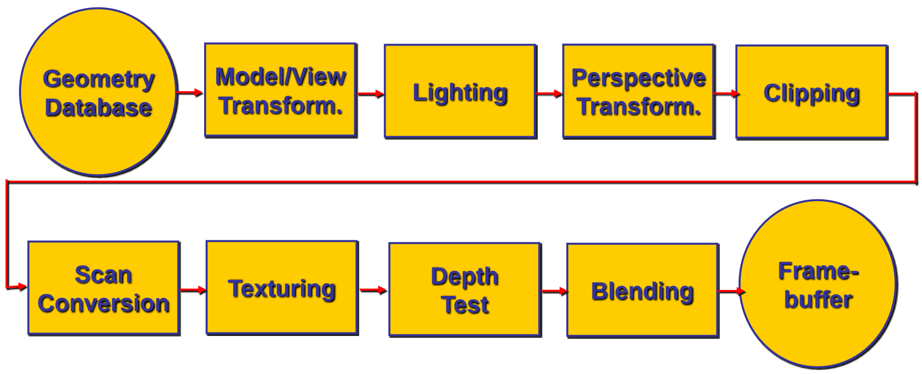
- 290 GB/s vs 60 GB/s



[courtesy NVIDIA]

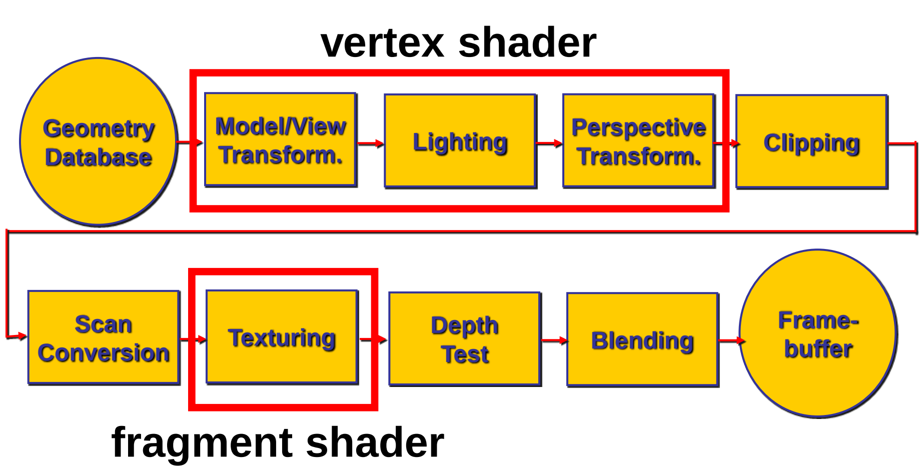
Programmable Pipeline

- so far:
  - rendering pipeline = set of stages with **fixed functionality**



Programmable Pipeline

- now: programmable rendering pipeline!



Vertex Shader

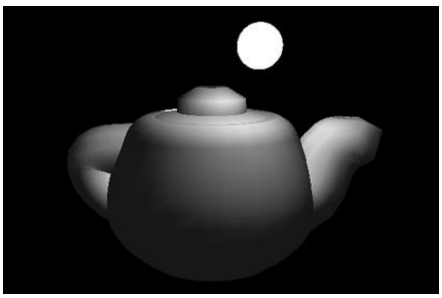
- Run once for every vertex in your scene:
  - Common Functionality:
    - Performs viewing transforms (MVP)
    - Transforms texture coordinates
    - Calculates per-vertex lighting
  - A "vertex" is a malleable definition, you can pass in, and perform pretty much any operation you want

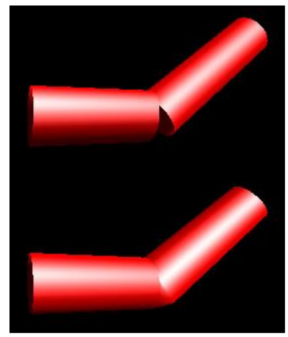
Vertex Shader

- Common Inputs:
  - vertex position
  - Normal texture coordinate(s)
  - Modelview and projection matrix
  - Vertex Material or color
  - Light sources – color, position, direction etc.
- Common Outputs:
  - Clip-space vertex position (mandatory)
  - transformed texture coordinates
  - vertex color

Vertex Shader - Applications

- deformable surfaces – on the fly vertex position computation
  - e.g. skinning





[courtesy NVIDIA]

Fragment Shader

- Runs for all "initialized" fragments:
  - "initialized" → rendered to after rasterization

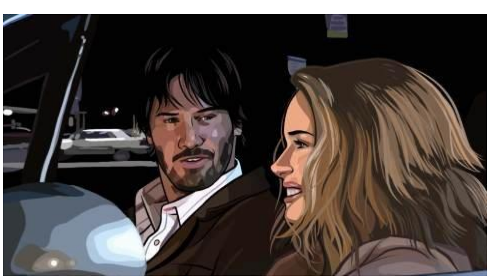
- Common Tasks:
  - texture mapping
  - Shading

- Synonymous with Pixel Shader

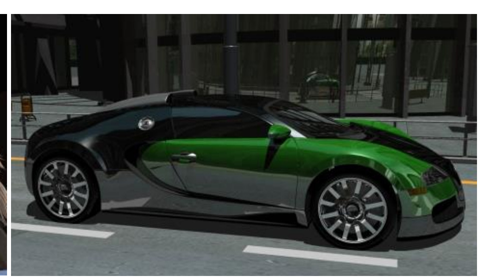
Fragment Shader

- input (interpolated over primitives by rasterizer):
  - Fragment coordinates (mandatory)
  - texture coordinates
  - color
- output:
  - fragment color (mandatory)
  - fragment depth

Fragment Shader - Applications



Not really shaders, but very similar to NPR!
A Scanner Darkly, Warner Independent Pictures



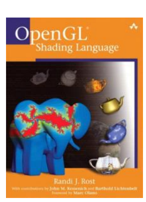
GPU raytracing, NVIDIA

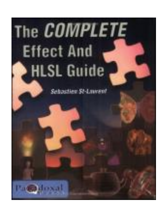
Vertex & Fragment Shader

- massively parallel computing by parallelization
- same shader is applied to all data (vertices or fragments) – SIMD (single instruction multiple data)
- parallel programming issues:
  - main advantage: high performance
  - main disadvantage: no access to neighboring vertices/fragments

Shader Languages

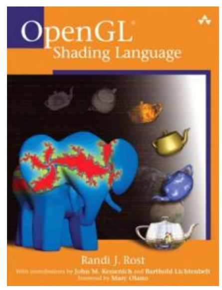
- Many languages exist to write shaders:
- GLSL – GL Shading Language (Opengl)
- HLSL – High Level Shading Language (Direct3D)
- CG (Nvidia mid-level language for both)



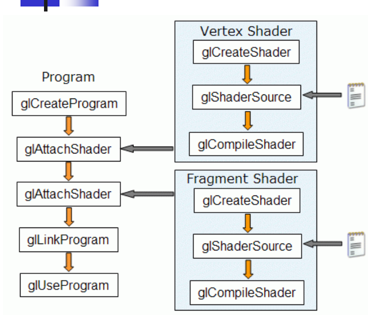


GLSL

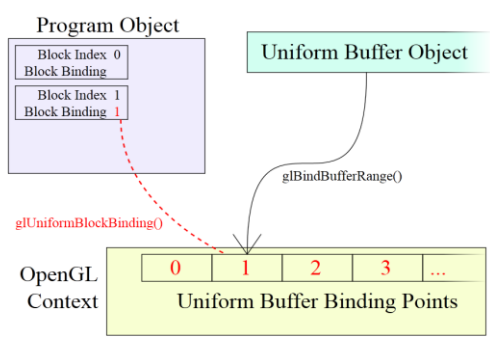
- We are using GLSL:
  - C-like programming language for GPUs
  - Highly Parallel (SIMD)
  - Differs greatly between versions



GLSL – Integration into Opengl



http://zach.in.tu-clausthal.de/teaching/cg_literatur/glsl_tutorial/



http://www.arcsynthesis.org/gltut/Positioning/UBOContextBinding.svg

GLSL - Types

- Has all the basic C types
- Has "vector" types: vec2, vec3, vec4
- Has "matrix" types: mat2, mat3, mat4
- Has "sampler" types
  - Used for reading data from textures and framebuffers
  - (might be worthwhile looking into for Assignment 4)

- Look at these links for more info:
  - http://www.opengl.org/wiki/Data_Type_%28GLSL%29
  - http://www.opengl.org/wiki/Sampler_%28GLSL%29#Sampler_types

GLSL – Built in Variables

- GLSL has some variables built in
  - These variables are always there and accessible in the corresponding shader

- Vertex Shader
  - In: gl_Vertex (position), gl_Normal, gl_Color
  - Out: gl_Position
- Fragment Shader
  - In: glFragCoord (fragment location), gl_Color
  - Out: gl_FragColor, gl_FragDepth

GLSL – Built in Variables

- Accessible in all shaders:
  - gl_ModelViewMatrix
  - gl_ModelViewProjectionMatrix
  - gl_ProjectionMatrix
- Here is a quick reference guide:
  - http://mew.cx/glsl_quickref.pdf

GLSL Example – Vertex Shader

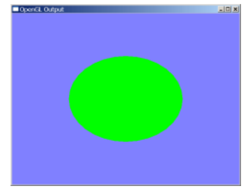
- Vertex Shader: scale vertices

```
#version 200

void main( )
{
// scale passed in vertex
vec4 a = gl_Vertex;
        a.x = a.x * 1.5;
        a.y = a.y * 1.5;

// transform vertex
        gl_Position = gl_ModelViewProjectionMatrix * a;
}
```

http://web.media.mit.edu/~gordonw/OpenGL/images/teapot_vertexShader.jpg

GLSL Example – Fragment Shader

- Fragment Shader: color green

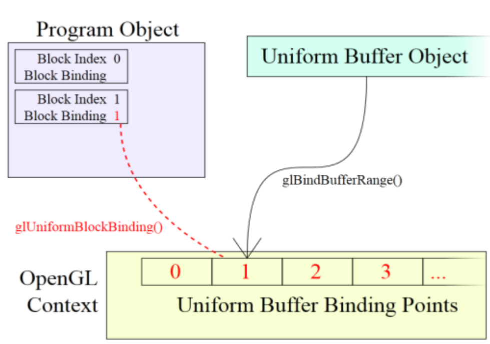


http://www.opengl.org/sdk/docs/tutorials/ClockworkCoders/loading.php

```
#version 200

void main( )
{
// color rendered fragments green
gl_FragColor = vec4(0.0, 1.0, 0.0, 1.0);
}
```

GLSL – Uniform Variables

- Used to access data from the CPU on the GPU
- Need to be given a value from the openGL side



GLSL Example – Uniform Variables

```
GLint loc1,loc2,loc3,loc4;
float specIntensity = 0.98;
float sc[4] = {0.8,0.8,0.8,1.0};
float threshold[2] = {0.5,0.25};
float colors[12] = {0.4,0.4,0.8,1.0,
                    0.2,0.2,0.4,1.0,
                    0.1,0.1,0.1,1.0};

loc1 = glGetUniformLocation(p,"specIntensity");
glUniform1f(loc1,specIntensity);

loc2 = glGetUniformLocation(p,"specColor");
glUniform4fv(loc2,1,sc);

loc3 = glGetUniformLocation(p,"t");
glUniform1fv(loc3,2,threshold);

loc4 = glGetUniformLocation(p,"colors");
glUniform4fv(loc4,3,colors);
```

http://www.lighthouse3d.com/tutorials/glsl-tutorial/uniform-variables/

GLSL Example – Uniform Variables

- Within shader:

```
#version 200

uniform float specIntensity;
uniform vec4 specColor;
uniform float t;
uniform vec4 colors;

void main( )
{
// do something
}
```

GLSL – Samplers

- A type of uniform used to read from a texture within shaders
- There are different samplers for the different types of textures
- 2D textures store square textures
- Rectangle textures store non-square textures, such as the image being processed in A4

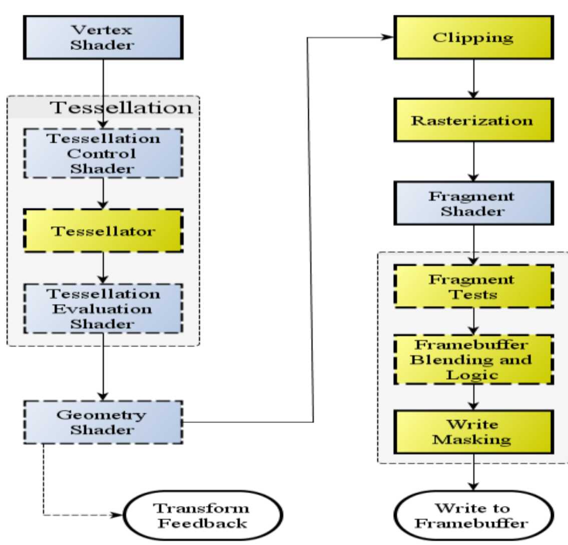
OpenGL Error Checking

- When Things go Wrong:
  - Opengl wont tell you
  - To ask, call glGetError()
    - Tells you the gl state (ok, error, etc)
  - For A4, this is all done for you, but you will need to break before the end of the program to read the output (in the black terminal)

OpenGL the old and the new

GL 1.2 – 2.1	GL 3.0 – 4.4
Vertex Shader	Vertex Shader
Pixel Shader	Tessellation (Control) Shader
	Tessellation Evaluation/Hull Shader
	Geometry Shader
	Fragment Shader
	... Compute Shader

OpenGL updated graphics pipeline



OpenGL 3.0+ changes

- Removed many of the GLSL built in variables
- Removed GLSL/Opengl built in matrices
- Removed glVertex(), glColor, glTexCoord, glMaterial(), …

OpenGL 3.0+ changes

- Why?
  - Efficiency
    - in most cases you don't need everything
    - lots of computation wasted checking what applies
  - Control
    - with less dictated, shaders can be used to do more

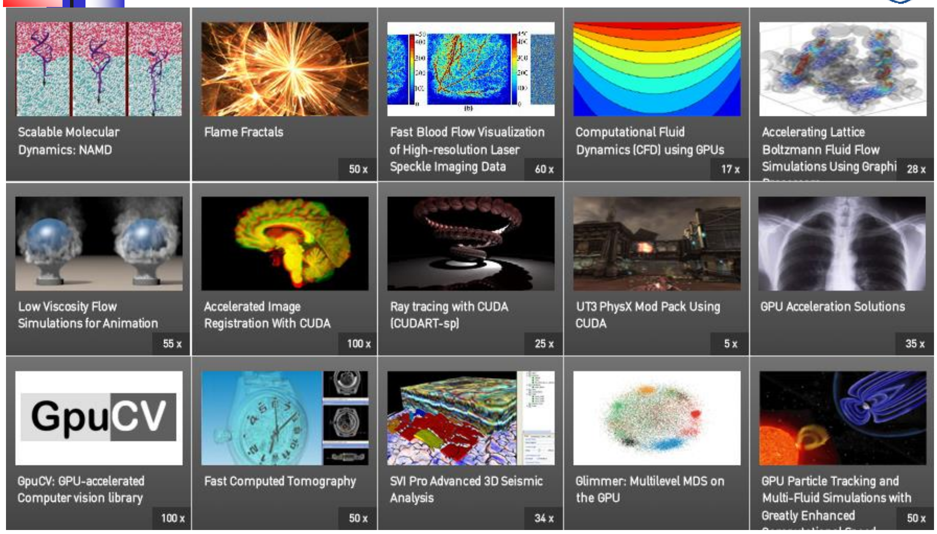
OpenGL 3.0+ Advanced Pipeline

- Tesselaton Control shader
  - Synonymous with Tesselation shader (d3d
  - Subdivide geometry based on vertices
- Tesselation Evaluation
  - Synonymous with Hull shader (d3d)
  - Rearrange new vertices from tesselation control

OpenGL 3.0+ Advanced Pipeline

- Geometry Shaders
  - Perform operations on groups of vertices
- Compute Shaders
  - Use the GPU to do math for you (no rendering)
  - This executes after the geometry shader, replacing the rest of the pipeline

GPGPU Applications



[courtesy NVIDIA]

References and Resources

- http://www.opengl.org/wiki/Uniform_%28GLSL%29
- http://www.lighthouse3d.com/tutorials/glsl-tutorial/uniform-variables/
- http://www.opengl.org/wiki/Rendering_Pipeline_Overview
- http://www.davidcornette.com/glsl/glsl.html
- http://nehe.gamedev.net/article/glsl%20an%20introduction/25007/
- http://www.opengl.org/wiki/Data_Type_%28GLSL%29
- http://www.opengl.org/wiki/Sampler_%28GLSL%29#Sampler_types
- http://zach.in.tu-clausthal.de/teaching/cg_literatur/glsl_tutorial/