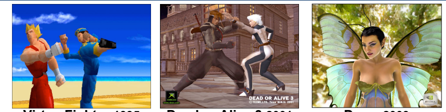
Introduction to Programmable GPUs

CPSC 314

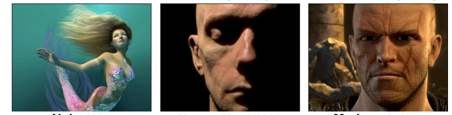
News

- Homework: no new homework this week (focus on quiz prep)
- Quiz 2
  - this Friday
  - topics:
    - everything after transformations up until last Friday's lecture
    - questions on rendering pipeline as a whole
- Office hours (Wolfgang) Thursday, Friday 11:30-12:30

Real Time Graphics



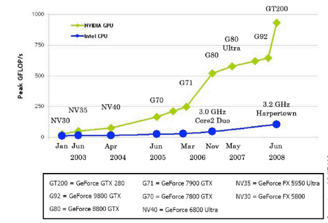
Virtua Fighter 1995 (SEGA Corporation) NV1 | Dead or Alive 3 2001 (Tecmo Corporation) Xbox (NV2A) | Dawn 2003 (NVIDIA Corporation) GeForce FX (NV30)



Nalu 2004 (NVIDIA Corporation) GeForce 6 | Human Head 2006 (NVIDIA Corporation) GeForce 7 | Medusa 2008 (NVIDIA Corporation) GeForce GTX 200

GPUs vs CPUs

- 800 GFLOPS vs 80 GFLOPS
- 86.4 GB/s vs 8.4 GB/s



[courtesy NVIDIA]

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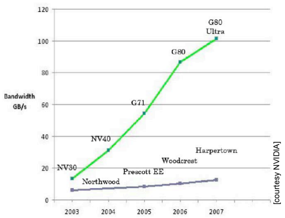
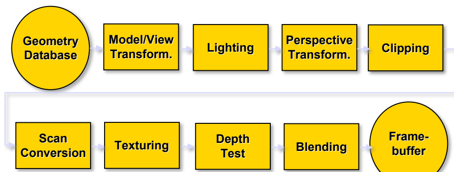


[courtesy NVIDIA]

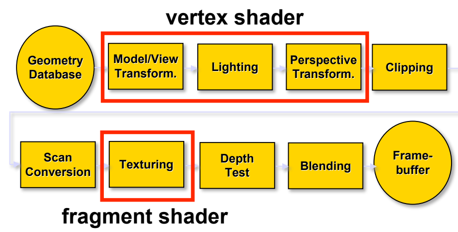
Programmable Pipeline

- so far:
  - have discussed rendering pipeline as specific set of stages with **fixed functionality**



Programmable Pipeline

- now: programmable rendering pipeline!



Vertex Shader

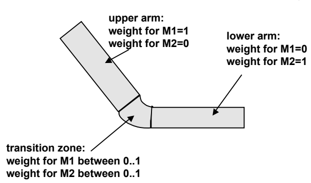
- performs all **per-vertex** computation (transform & lighting):
  - model and view transform
  - perspective transform
  - texture coordinate transform
  - per-vertex lighting

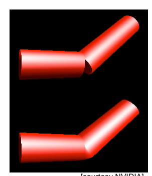
Vertex Shader

- input:
  - vertex position and normal (sometimes tangent)
  - (multi-)texture coordinate(s)
  - modelview, projection, and texture matrix
  - vertex material or color
  - light sources – color, position, direction etc.
- output:
  - 2D vertex position
  - transformed texture coordinates
  - vertex color

Vertex Shader - Applications

- deformable surfaces: skinning
- different parts have different rigid transformations
- vertex positions are blended
- used in facial animations – many transformations!



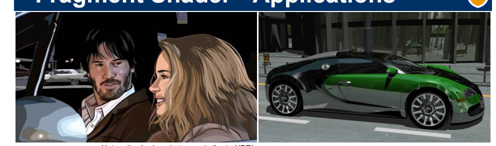


[courtesy NVIDIA]

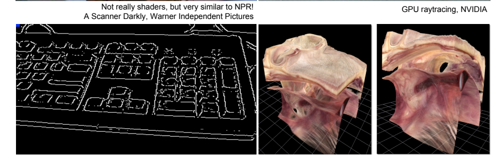
Fragment Shader

- performs all **per-fragment** computation:
  - texture mapping
  - fog
- input (interpolated over primitives by rasterizer):
  - texture coordinates
  - color
- output:
  - fragment color

Fragment Shader - Applications



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



OpenVIDIA Image Processing | Volume Ray Casting, Peter Trier

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

Vertex Shader - Instructions

- Arithmetic Operations on 4-vectors:
  - ADD, MUL, MAD, MIN, MAX, DP3, DP4
- Operations on Scalars
  - RCP (1/x), RSQ (1/√x), EXP, LOG
- Specialty Instructions
  - DST (distance: computes length of vector)
  - LIT (quadratic falloff term for lighting)
- Later generation:
  - Loops and conditional jumps

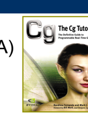
Vertex Shader - Example

- morph between cube and sphere & lighting
- vertex attributes: *v[0..N]*, matrices *c[1..N]*, registers *R*

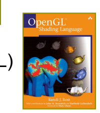
```
#blend normal and position
# v= αv1+(1-α)v2 = α(v1-v2)+ v2
MOV R3, v[3] ;
MOV R5, v[2] ;
ADD R8, v[1], -R3 ;
ADD R6, v[0], -R5 ;
MAD R8, v[15].x, R8, R3
MAD R6, v[15].x, R6, R5 ;

# transform normal to eye space
DP3 R9.x, R8, c[12] ;
DP3 R9.y, R8, c[13] ;
DP3 R9.z, R8, c[14] ;

# transform position and output
DP4 o[HPOS].x, R6, c[4] ;
DP4 o[HPOS].y, R6, c[5] ;
DP4 o[HPOS].z, R6, c[6] ;
DP4 o[HPOS].w, R6, c[7] ;

# normalize normal
DP3 R9.w, R9, R9 ;
RSQ R9.w, R9.w ;
MUL R9, R9.w, R9 ;

# apply lighting and output color
DP3 R0.x, R9, c[20] ;
DP3 R0.y, R9, c[22] ;
MOV R0.zw, c[21] ;
LIT R1, R0 ;
DP3 o[COL0], c[21], R1 ;
```


Shading languages

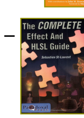
- Cg (C for Graphics – NVIDIA)



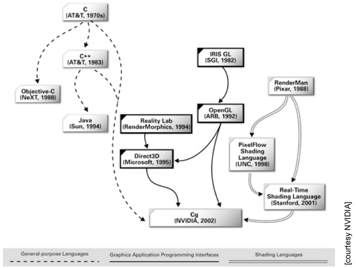
- GLSL (GL Shading Language – OpenGL)



- HLSL (High Level Shading Language – MS Direct3D)

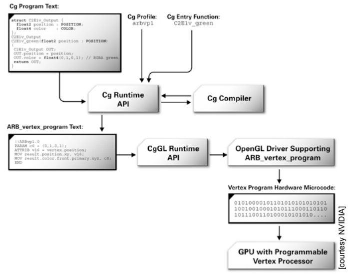


Cg History



[courtesy NVIDIA]

Cg – How does it work?



[courtesy NVIDIA]

Cg – Integration into OpenGL

```
void initShader(void) {

    // get fragment shader profile
    _cgFragmentProfile = \
        cgGLGetLatestProfile(CG_GL_FRAGMENT);

    // init Cg context
    _cgContext = cgCreateContext();

    // load shader from file
    _cgProgram = \
        cgCreateProgramFromFile( _cgContext,
                CG_SOURCE,
                "MyShader.cg",
                _cgFragmentProfile,
                NULL, NULL);

    // upload shader on GPU
    cgGLLoadProgram( _cgProgram );

    // get handles to shader parameters
    _cgTexture = \
        cgGetNamedParameter(_cgProgram, "texture");
    _cgParameter = \
        cgGetNamedParameter(_cgProgram, "parameter");
}
```

```
void displayLoop(void) {

    // setup transformation
    ...

    // enable shader and set parameters
    cgGLEnableProfile( _cgFragmentProfile );
    cgGLBindProgram( _cgProgram );

    // set Cg texture
    cgGLSetTextureParameter(_cgTexture, _textureID);
    cgGLEnableTextureParameter(_cgTexture);

    // set gamma
    cgGLSetParameter1f(_cgParameter, _parameter);

    // draw geometry
    ...

    // disable Cg texture and profile
    cgGLDisableTextureParameter(_cgTexture);
    cgGLDisableProfile( _cgFragmentProfile );

    // swap buffers
    ...
}
```

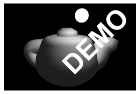

Cg Example – Fragment Shader

- Fragment Shader: gamma mapping


```
void main( float4                texcoord : TEXCOORD,
           uniform samplerRECT   texture,
           uniform float         gamma,
           out float4            color    : COLOR )
{
        // perform texture look up
        float3 textureColor = f4texRECT( texture, texcoord.xy ).rgb;

        // set output color
        color.rgb = pow( textureColor, gamma );
}
```


Cg Example – Vertex Shader

- Vertex Shader: animated teapot



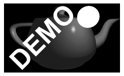

```
void main(  // input
            float4 position               : POSITION,  // position in object coordinates
            float3 normal                 : NORMAL,    // normal

            // user parameters
            uniform float4x4 objectMatrix,          // object coordinate system matrix
            uniform float4x4 objectMatrixIT,        // object coordinate system matrix inverse transpose
            uniform float4x4 modelViewMatrix,       // modelview matrix
            uniform float4x4 modelViewMatrixIT,     // modelview matrix inverse transpose
            uniform float4x4 projectionMatrix,      // projection matrix
            uniform float  deformation,             // deformation parameter
            uniform float3 lightPosition,           // light position
            uniform float3 lightAmbient,            // light ambient parameter
            uniform float3 lightDiffuse,            // light diffuse parameter
            uniform float3 lightSpecular,           // light specular parameter
            uniform float3 lightAttenuation,        // light attenuation parameter - constant, linear, quadratic
            uniform float3 materialEmission,        // material emission parameter
            uniform float3 materialAmbient,         // material ambient parameter
            uniform float3 materialDiffuse,         // material diffuse parameter
            uniform float3 materialSpecular,        // material specular parameter
            uniform float  materialShininess,       // material shininess parameter

            // output
            out float4 outPosition        : POSITION,  // position in clip space
            out float4 outColor           : COLOR )    // out color
{
```


Cg Example – Vertex Shader

```
// transform position from object space to clip space
float4 positionObject = mul(objectMatrix, position);

// transform normal into world space
float4 normalObject = mul(objectMatrixIT, float4(normal,1));
float4 normalWorld  = mul(modelViewMatrixIT, normalObject);

// world position of light
float4 lightPositionWorld = \
        mul(modelViewMatrix, float4(lightPosition,1));

// assume viewer position is in origin
float4 viewerPositionWorld = float4(0.0, 0.0, 0.0, 1.0);

// apply deformation
positionObject.xyz    = positionObject.xyz + \
        deformation * normalize(normalObject.xyz);
float4 positionWorld = mul(modelViewMatrix, positionObject);
outPosition           = mul(projectionMatrix, positionWorld);

// two vectors
float3 P = positionWorld.xyz;
float3 N = normalize(normalWorld.xyz);

// compute the ambient term
float3 ambient = materialAmbient*lightAmbient;

// compute the diffuse term
float3 L = normalize(lightPositionWorld.xyz - P);
float  diffuseFactor = max(dot(N, L), 0);
float3 diffuse = materialDiffuse * lightDiffuse * diffuseFactor;

// compute the specular term
float3 V = normalize( viewerPositionWorld.xyz - \
        positionWorld.xyz);
float3 H = normalize(L + V);
float specularFactor = \
        pow(max(dot(N, H), 0), materialShininess);
if (diffuseFactor <= 0) specularFactor = 0;
float3 specular = \
        materialSpecular * \
        lightSpecular * \
        specularFactor;

// attenuation factor
float distanceLightVertex = \
        length(P-lightPositionWorld.xyz);
float attenuationFactor = \
        1 / ( lightAttenuation.x + \
              distanceLightVertex*lightAttenuation.y + \
              distanceLightVertex*distanceLightVertex*\
              lightAttenuation.z );

// set output color
outColor.rgb =  materialEmission + \
                ambient + \
                attenuationFactor * \
                ( diffuse + specular );

outColor.w = 1;
}
```


Cg Example – Phong Shading

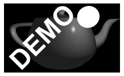
vertex shader




```
void main(  float4 position   : POSITION,  // position in object coordinates
            float3 normal     : NORMAL,    // normal

            // user parameters
            ...

            // output
            out float4 outTexCoord0 : TEXCOORD0,  // world normal
            out float4 outTexCoord1 : TEXCOORD1,  // world position
            out float4 outTexCoord2 : TEXCOORD2,  // world light position
            out float4 outPosition  : POSITION)   // position in clip space
{
            // transform position from object space to clip space
            ...
            // transform normal into world space
            ...

            // set world normal as out texture coordinate0
            outTexCoord0 = normalWorld;
            // set world position as out texture coordinate1
            outTexCoord1 = positionWorld;
            // world position of light
            outTexCoord2 = mul(modelViewMatrix, float4(lightPosition,1));
}
```


Cg Example – Phong Shading

fragment shader

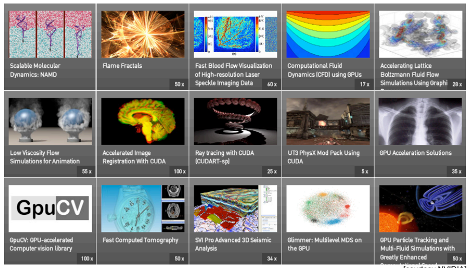



```
void main(  float4      normal        : TEXCOORD0,    // normal
            float4      position      : TEXCOORD1,    // position
            float4      lightPosition : TEXCOORD2,    // light position
            out float4  outColor      : COLOR )
{
            // compute the ambient term
            ...

            // compute the diffuse term
            ...

            // compute the specular term
            ...

            // attenuation factor
            ...

            // set output color
            outColor.rgb = materialEmission + ambient + attenuationFactor * (diffuse + specular);
}
```


GPGPU

- general purpose computation on the GPU
- in the past: access via shading languages and rendering pipeline
- now: access via cuda interface in C environment

GPGPU Applications



[courtesy NVIDIA]