Graphics Processing

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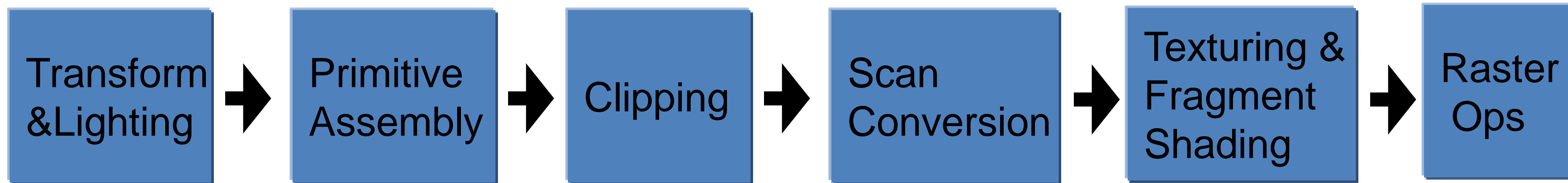
1. Review of the OpenGL pipeline

Input: Vertices, Attributes, Textures



Output: a 2D pixel array

2. History of Graphics Hardware

- Pixel Pipelines
- Hardware Accelerated T&L (e.g.GF 256)
- Configurable vs. Programmable GPUs (e.g.GF3)
- Unified Shader Architectre GPUs (e.g. GF8)
- The Fermi Architecture

Pixel Pipelines

- 3dfx Voodoo (1996) – A single pipeline 3D accelerator (required a separate 2D VGA)3

- nVidia Riva (1997) – One of the first integrated 2D and 3D videocards.

Hardware Accelerated T&L

- The technical definition of a GPU is:

  “A single-chip processor with integrated transform, lighting, triangle setup/clipping, and rendering engines that is capable of processing a minimum of 10 million polygons per second.“

- GeForce 256 and Savage 2000 – the first GPUs

Transform & Lighting

- MV matrix

```
vec4 transformed = gl_ModelViewMatrix * gl_Vertex;
```

- Projection Matrix

```
vec4 projected = gl_ProjectionMatrix * transformed;
```

- Normal Matrix

```
vec3 transformed_normal = gl_NormalMatrix * gl_Normal;
```

- Texture Matrix

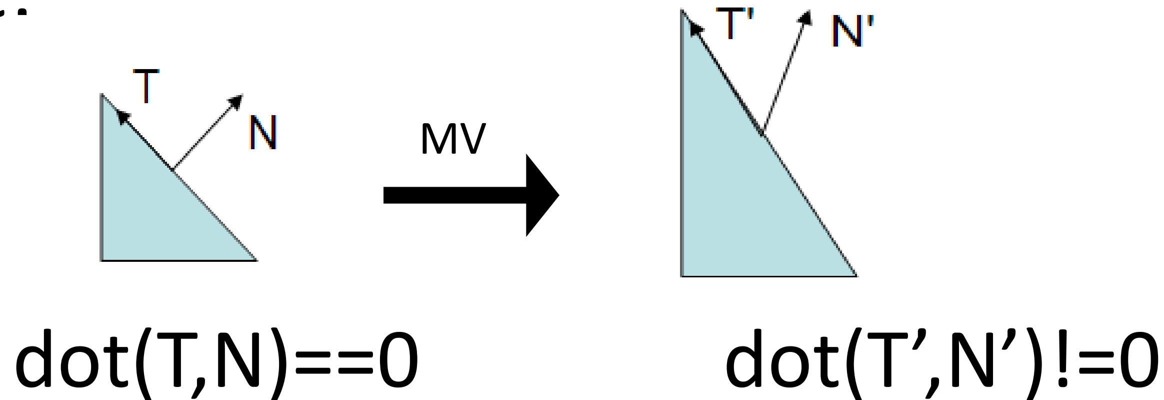
```
gl_TexCoord[0] = gl_TextureMatrix[0] * gl_MultiTexCoord0;
```

- Gouraud Shading

  per-Vertex Lighting

The Normal Matrix

- Issue:



dot(T,N)==0 dot(T’,N’)!=0

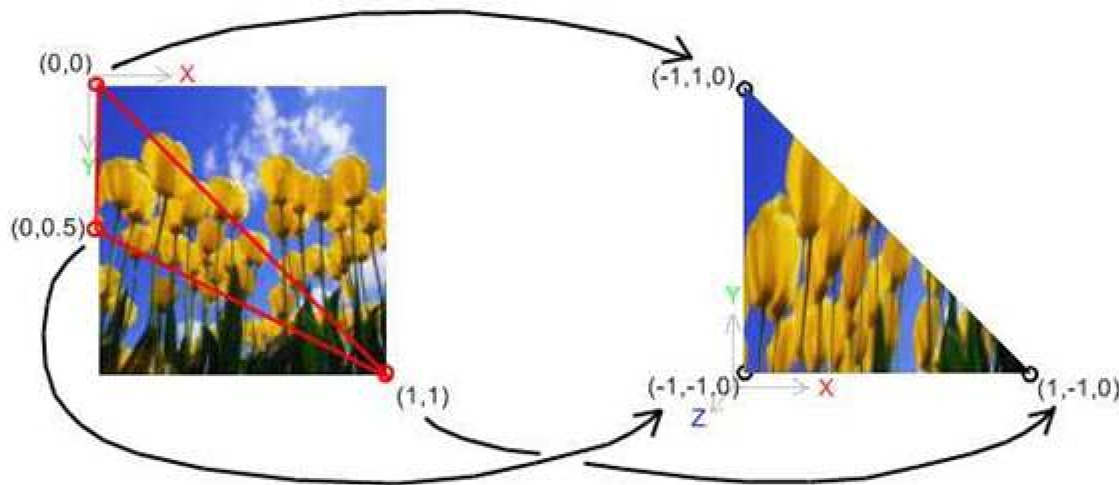
- Solution: T’ = MV . T

$$N' = (MV^{-1})^T . N = NM . N$$

Note: NM can be a 3x3matrix, since $N_w = N'_w = 0$.

Texture Matrix

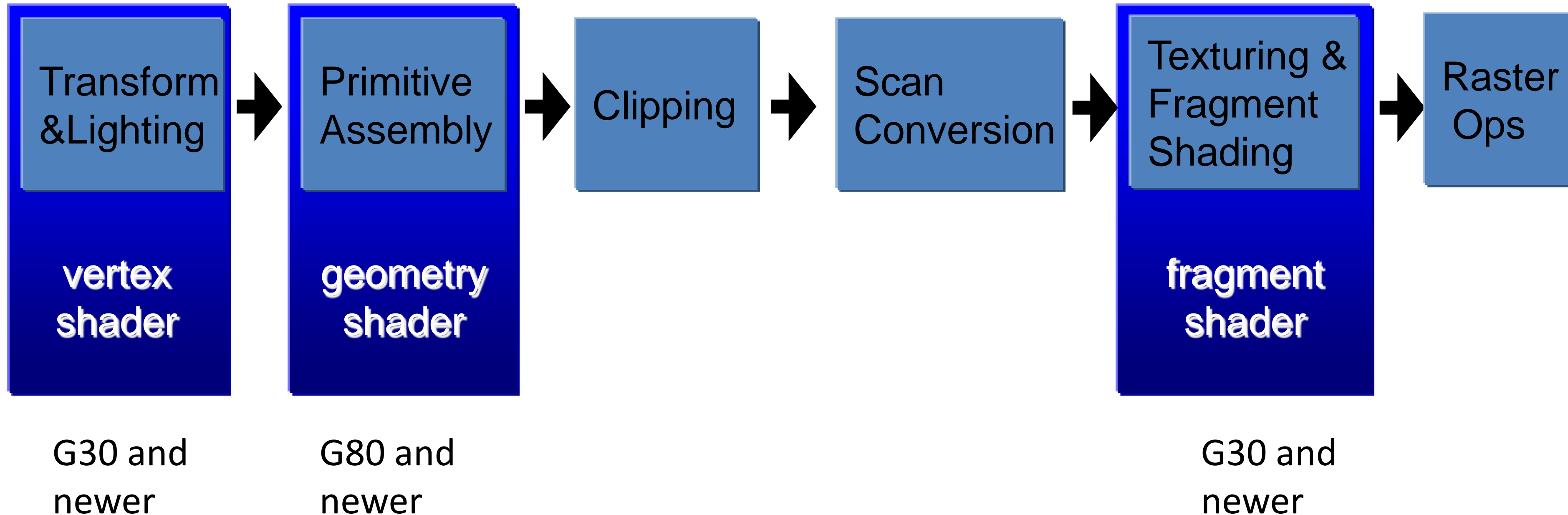
- Transforming texture coordinates is like transforming geometry in texture space!



Gouraud Shading

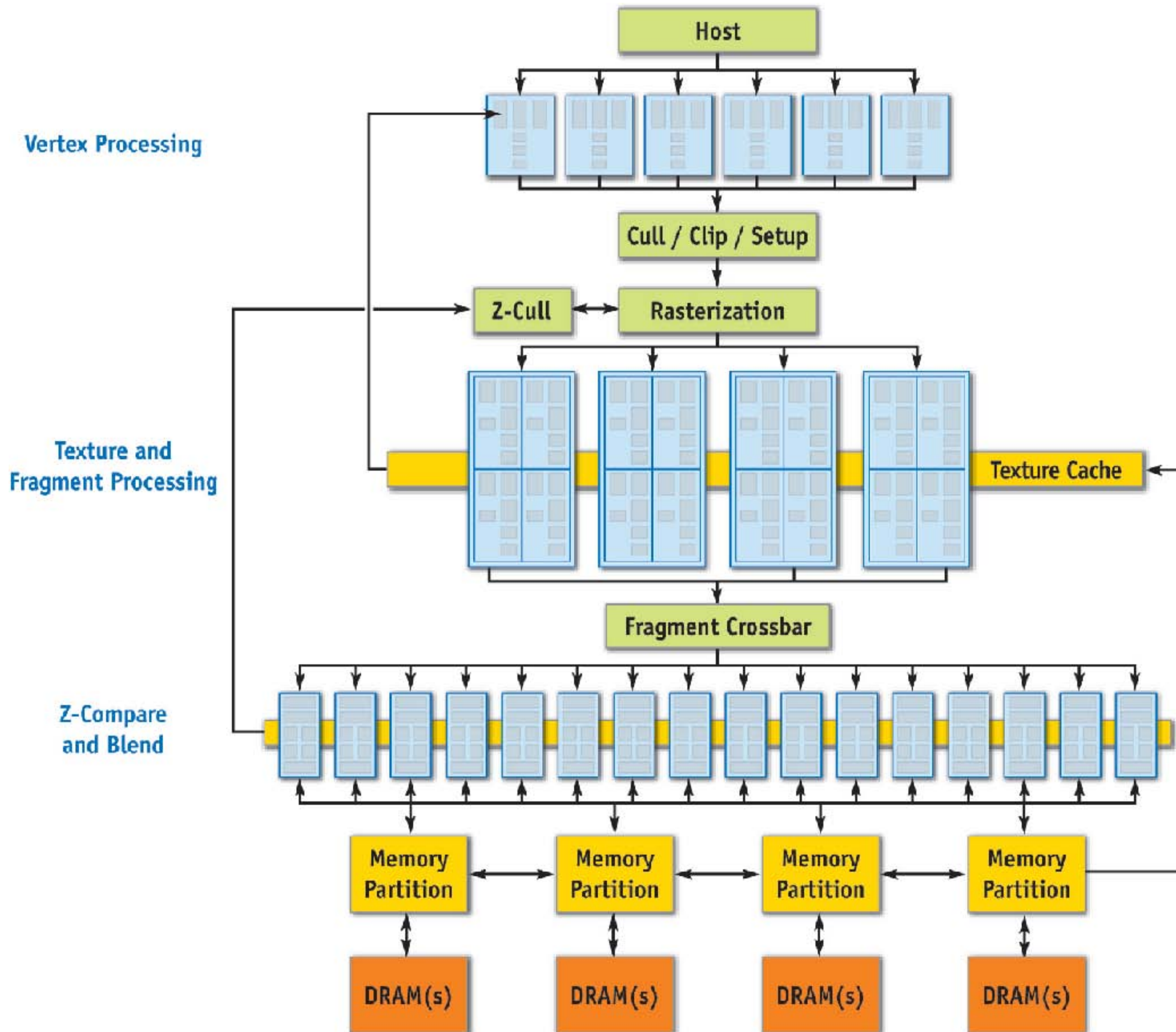
```
void main(void)
{
	// vertex MVP transform
	gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
	// eye-space normal
	N = normalize(gl_NormalMatrix * gl_Normal);
	// vertex MV transform
	vec4 V = gl_ModelViewMatrix * gl_Vertex;
	//vector to the light source
	vec3 L = normalize(gl_LightSource[0].position.xyz - V.xyz);
	// average of the L and Eye vectors
	vec3 H = normalize(L + vec3(0.0, 0.0, 1.0)); //assuming the eye(camera) is in the +z direction

	float d_intensity = max(0.0, dot(N, L));
	float s_intensity = pow(max(0.0, dot(N, H)), gl_FrontMaterial.shininess);
	gl_FrontColor.rgb = (gl_FrontMaterial.diffuse.rgb * gl_FrontLightProduct[0].diffuse.rgb * d_intensity)  +
			(gl_FrontMaterial.specular.rgb * gl_FrontLightProduct[0].specular.rgb * s_intensity) +
			(gl_FrontMaterial.ambient.rgb * gl_FrontLightProduct[0].ambient.rgb) ;
	gl_FrontColor.a = gl_Color.a; //or gl_FrontColor.a = 1.0;
}
```

Configurable vs. Programmable GPUs



- Definition: a *fragment* describes the information associated with a pixel prior to the generation of the pixel.

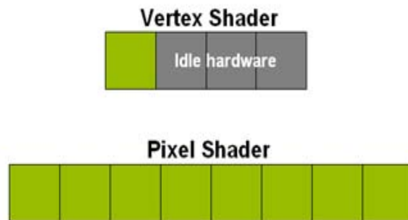
The GeFroce 6 Architecture



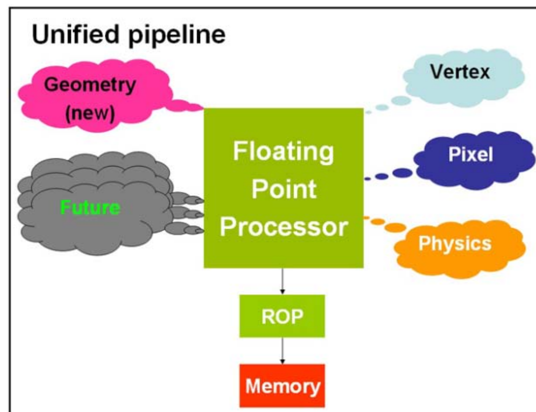
The need for unified shader designs, based on scalar stream processors

Why unify?

Heavy Geometry
Workload Perf = 4



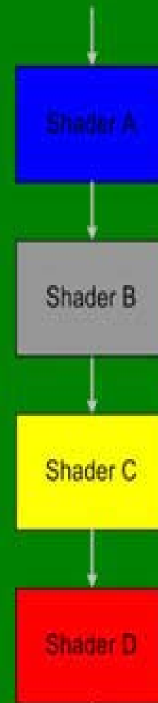
Heavy Pixel
Workload Perf = 8

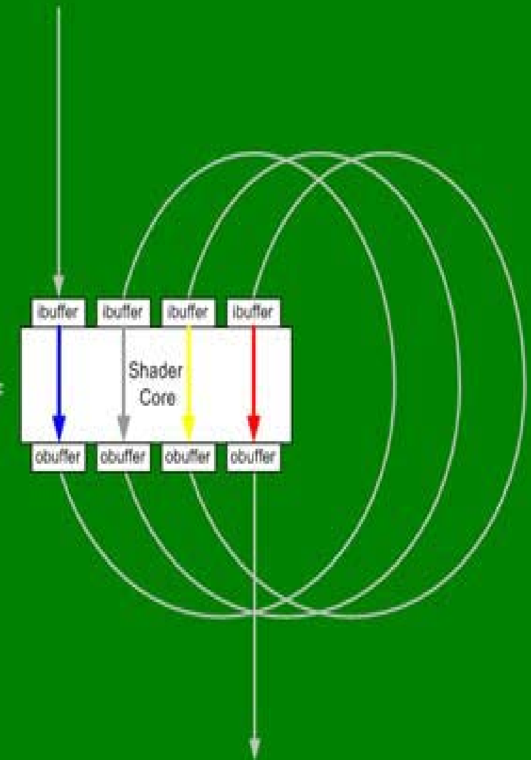


Unified Design

Discrete Design

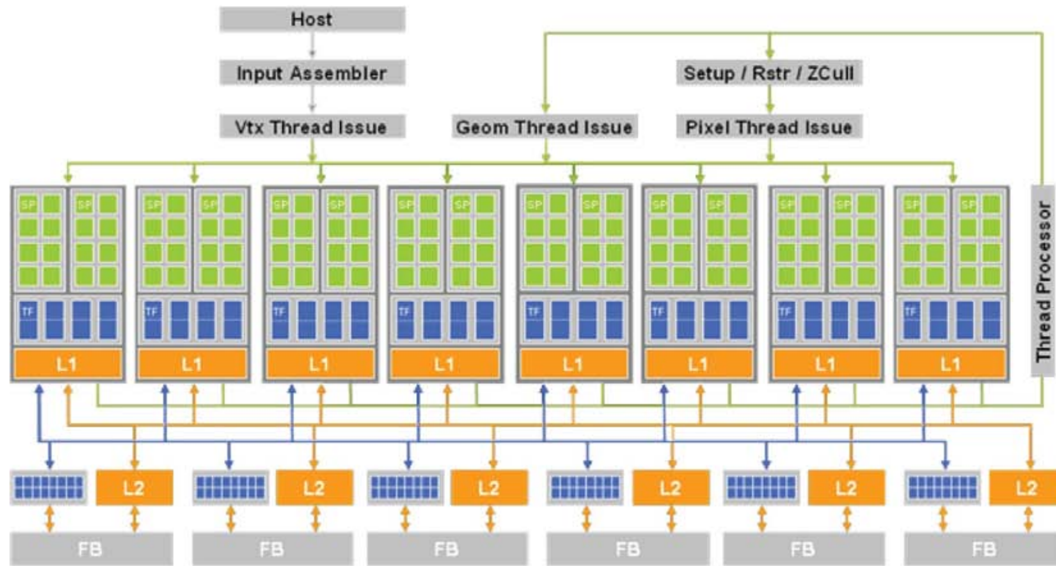
Unified Design





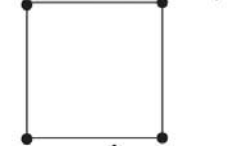
Unified Shader Architectre GPUs

The GPU Pipeline



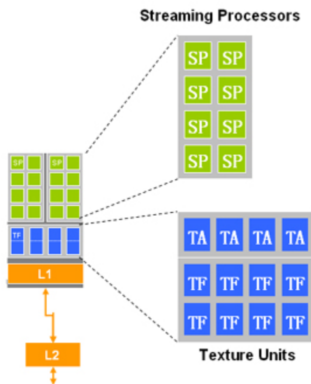
1. Transform the vertics

2. Generate the primitives



3. Synthesize the image

Streaming Processors, Texture Units, and On-chip Caches



- **SP = Streaming Processors**
- **TF = Texture Filtering Unit**
- **TA = Texture Address Unit**
- **L1/L2 = Caches**

Specifications:
1.35 GHz cores
up to 512 threads/block
32 threads/warp
4 cycles/warp for most arithmetic instructions

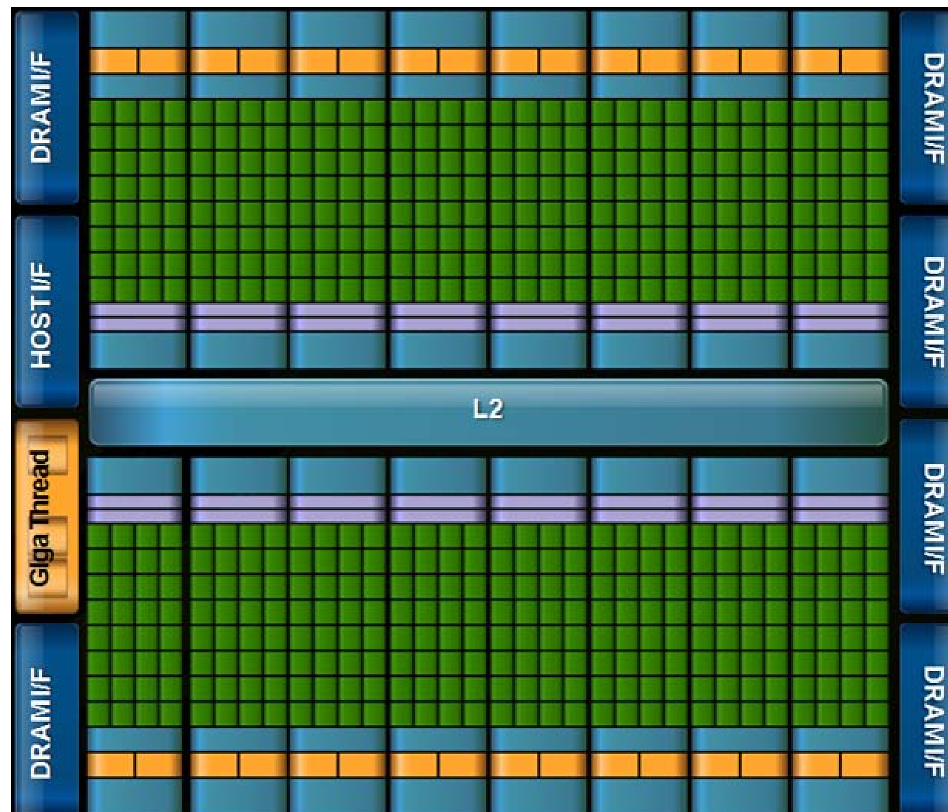
up to 768 Threads/SM
up to 24 warps/SM
up to 8 blocks/SM

AG80 Scalar Stream Multiprocessor

- Increased hardware utilization due to:
    - Shader unification
    - Use of scalar processors
    - Decoupled texture and math operations
    - Some shared memory
    - Broadcast capabilities for shared memory lookups
- Has issues with:
    - Lack of fast shared memory between all multiprocessors
    - Lack of control over the thread scheduling process
    - No access to the lowest level code ☹

The Fermi Architecture

- Full Cache hierarchy:



3. GLSL

- Overview
  - Vertex Shaders
  - Geometry Shaders
  - Fragment Shaders
  - Compiling and Using a GLSL program from OpenGL

Note: GLSL is an extension to OpenGL. To access it, use GLEW for instance:

```
//In main call:
glewInit();
//Before compiling your shaders check:
glewIsSupported("GL_VERSION_1_4 GL_ARB_vertex_shader\GL_ARB_fragment_shader \
        GL_EXT_geometry_shader4 \
        GL_ARB_shader_objects \
        GL_ARB_shading_language_100");
```

Shader Data Characteristics

- Attribute variables - per-vertex input to a Vertex shader from the application (READ-ONLY)
- Unifrom variables - input to Vertex and Fragment shaders from the application (READ-ONLY). Also, textures are accessed through uniform samplers of 1,2,or 3 dimensions (e.g. *uniform sampler2D tex*;)
- Varying variables - output from a Vertex shader (READ/WRITE), which is interpolated, and then input to a Fragment shader (READ-ONLY)

A Simple Vertex Shader

At the very least, a vertex shader needs to write to the predefined output variable gl_Position, which is needed by the subsequent stages of the pipeline.

```
//Used Inputs :
// uniform mat4 gl_ModelViewProjectionMatrix;
// attribute vec4 gl_Vertex;
// attribute vec4 gl_Color;

//Produced Outputs:
// vec4 gl_Position;
// varying vec4 gl_FrontColor;

//The Shader:
void main(void)
{
    // vertex MVP transform
    gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
     // pass the source color further down the pipeline
    gl_FrontColor = gl_Color;
}
```

A Simple Geometry Shader

Geometry shaders come with two special functions EmitVertex() and EndPrimitive(), which are used for the generation of geometry in the scene. Calling EndPrimitive(), when possible, creates a primitive from the outstanding emitted vertices.

```
//Used Inputs :
// int gl_VerticesIn; //number of input vertices
// varying in vec4 gl_PositionIn[gl_VerticesIn];
// varying in vec4 gl_FrontColorIn[gl_VerticesIn];

//Produced Outputs:
// vec4 gl_Position; // the shader must write to this variable
// varying out vec4 gl_FrontColor;

//The Shader:
#version 120
#extension GL_EXT_geometry_shader4 : enable
void main(void)
{
	for (int i=0; i<= gl_VerticesIn-1; i++) {
			gl_Position = gl_PositionIn[i];
			gl_FrontColor = gl_FrontColorIn[i];
			EmitVertex();
	}
	EndPrimitive();
}
```

Geometry Shader I/O Types

Input Type	Allowed GL primitives	# of Input Vertices
Points	POINTS	1
Lines	LINES, LINE_STRIP, LINE_LOOP	2
Lines with Adjacency	LINES_ADJACENCY, LINE_STRIP_ADJACENCY	4
Triangles	TRIANGLES, TRIANGLE_STRIP, TRIANGLE_FAN	3
Triangles with Adjacency	TRIANGLES_ADJACENCY, TRIANGLE _STRIP_ADJACENCY	6

Table 1: Shows the allowed GL primitives and the number of accepted vertices for a geometry shader defined for a certain input type.

- Note: GL_QUADS are processes as GL_TRIANGLES

A Simple Fragment Shader

At the very least, a fragment shader needs to write to the predefined output variable gl_FragColor.

```
//Used Inputs :
// varying vec4 gl_Color;

//Produced Outputs:
// vec4 gl_FragColor;

//The Shader:
void main(void)
{
    // pass the source color further down the pipeline
    gl_FragColor = gl_Color;
}
```

Compiling GLSL code

```
GLhandleARB vShader, gShader, fShader;
GLcharARB *vsStringPtr[1], *gsStringPtr[1], *fsStringPtr[1];
GLcharARB vsString[] = “Vertex Shader source goes here”
GLcharARB gsString[] = “Geometry Shader source goes here”
GLcharARB fsString[] = “Fragment Shader source goes here”

vShader = glCreateShaderObjectARB(GL_VERTEX_SHADER_ARB);
vsStringPtr[0] = vsString; // Do this to avoid warnings
glShaderSourceARB(vShader, 1, vsStringPtr, NULL);
glCompileShaderARB(vShader);

gShader = glCreateShaderObjectARB(GL_GEOMETRY_SHADER_EXT);
gsStringPtr[0] = gsString; // Do this to avoid warnings
glShaderSourceARB(gShader, 1, gsStringPtr, NULL);
glCompileShaderARB(gShader);

fShader = glCreateShaderObjectARB(GL_FRAGMENT_SHADER_ARB);
fsStringPtr[0] = fsString; // Do this to avoid warnings
glShaderSourceARB(fShader, 1, fsStringPtr, NULL);
glCompileShaderARB(fShader);
```

Linking GLSL Code

```
// Create a program object, attach shaders, then link
GLhandleARB progObj = glCreateProgramObjectARB();
glAttachObjectARB(progObj, vShader);
glAttachObjectARB(progObj, gShader);
glAttachObjectARB(progObj, fShader);

//Geometry Shader Setup
glProgramParameteriEXT(progObj,GL_GEOMETRY_INPUT_TYPE_EXT,GL_TRIANGLES);
glProgramParameteriEXT(progObj,GL_GEOMETRY_OUTPUT_TYPE_EXT,GL_TRIANGLES);

//64 is just an example for the maximum number of output vertices
GLint numOutVertices = 64;
glProgramParameteriEXT(progObj,GL_GEOMETRY_VERTICES_OUT_EXT,
    numOutVertices);

glLinkProgramARB(progObj);
```

Using GLSL Shaders

//Attach the shading program:
glUseProgramObjectARB(progObj); // Pass 0 to switch back to fixed functionality

//To initialize the unifrom variable varName with 0, do:

```
GLint value = 0;
GLint address = glGetUniformLocationARB(progObj, “varName");
if (address != -1)
    glUniform1iARB(address, value);
else fprintf(stderr, "Failed to load uniform\n");
```

Caution:

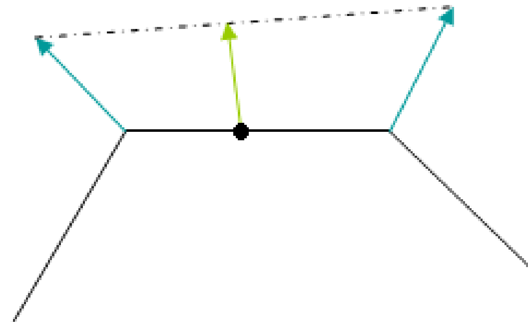
1) Unused variables get optimized out from the shaders during compilation
2) The types of *value*, *varName*, and glUniform[1,2,3,4][i,f]{v} MUST match
3) For texture samplers (e.g. *uniform sampler2D tex*;) use glUnifrom1iARB, and pass the texture unit index as a parameter. Inside the shader use texture[1,2,3]D (e.g. *texture2D(tex, gl_TexCoord[0].st)*)

GLSL Reference Guide

- Link

Shading Examples

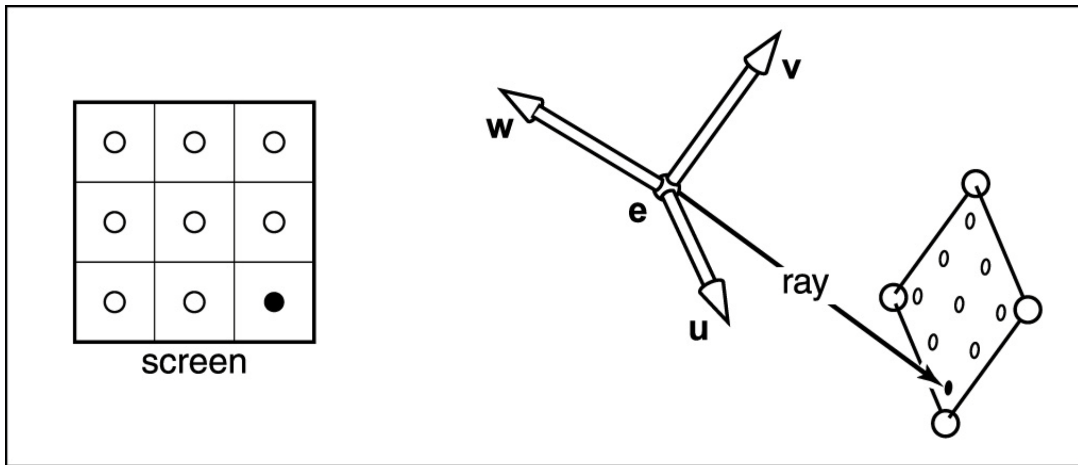
- Gouraud Shading (Vetrex Shader)
- Phong Shading(Fragment Shader)
  - Note: Interpolated normals are not unit length, so you need to renormalize them in the fragment shader!

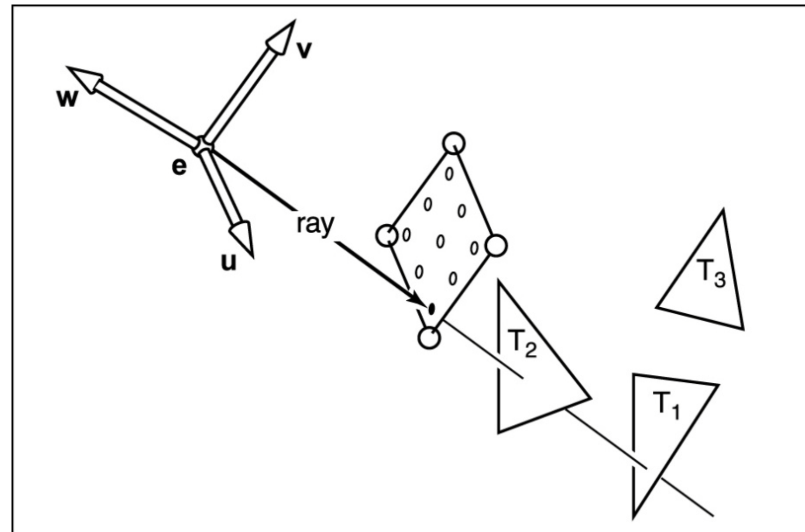


4. Ray-Tracing

- Overview
    - Basic Ray-Tracing
    - Reflection Model
    - Smooth Shadows

Defining the Image Plane (frame)





Defining the Image Plane (frame)

For a camera looking down the –w axis:

$u_s = l + (r-l) * (i + 0.5)/n_x$;

$v_s = b + (t-b) * (j + 0.5)/n_y$;

$w_s = -n$; //near clipping plane

We can parametrize a ray *s* as:

$s(t) = t*(u_s, v_s, w_s)$, and look for objects that intersect *s* at $t>1$, and $t<=(far/n)$, where *far* is the *w* coordinate of the far clipping plane.

In general: $s(t) = \mathbf{eye} + t* ((u_s, v_s, w_s) - \mathbf{eye})$;

Intersecting a sphere

An implicit equation for a sphere:

$$(\mathbf{p} - \mathbf{c}) \bullet (\mathbf{p} - \mathbf{c}) - R^2 = 0$$

Take: $\mathbf{p} = \boldsymbol{eye} + t^* ((u_s, v_s, w_s) - \boldsymbol{eye}) = \boldsymbol{eye} + t\boldsymbol{d}$

Solve for t in:

$$(\mathbf{d} \bullet \mathbf{d})t^2 + 2\mathbf{d} \bullet (\mathbf{eye} - \mathbf{c})t + (\mathbf{eye} - \mathbf{c}) \bullet (\mathbf{eye} - \mathbf{c}) - R^2 = 0$$

Intersecting a triangle

For a triangle with points **p0**, **p1**, **p2**, and normal **n**, solve for t in: $(s(t) - \mathbf{p0}) \bullet \mathbf{n} = 0$

$t = ((\mathbf{p0} - \mathbf{eye}) \bullet \mathbf{n}) / (\mathbf{d} \bullet \mathbf{n})$

To detect an intersection:

1) Make sure that $(\mathbf{d} \bullet \mathbf{n}) \neq 0$;
2) Compute t by the above formula
3) Compute $s(t)$ – the intersection point with the triangle's plane
4) Make sure that the following inequalities hold:

$$((\mathbf{p1}-\mathbf{p0}) \times (s(t)-\mathbf{p0})) \bullet \mathbf{n} > 0$$

$$((\mathbf{p2}-\mathbf{p1}) \times (s(t)-\mathbf{p1})) \bullet \mathbf{n} > 0$$

$$((\mathbf{p0}-\mathbf{p2}) \times (s(t)-\mathbf{p2})) \bullet \mathbf{n} > 0$$

Basic Ray-Tracer Implementation

Using a software renderer

Algorithm for a single ray and a single light source:

1) Trace the ray from the eye through the frame and to an objects inside the clipping volume

2) Take the intersection point with the nearest intersected object

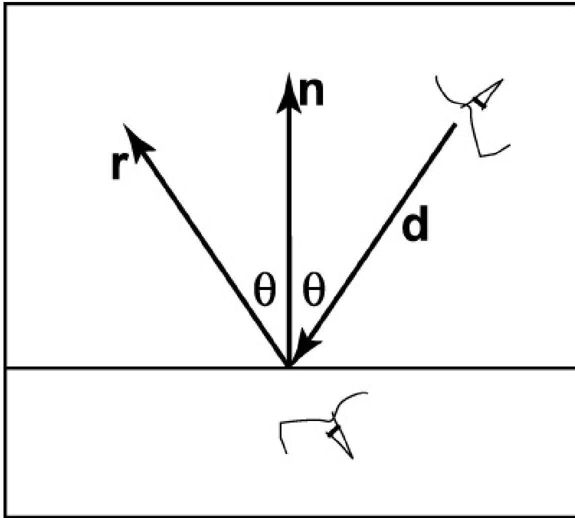
3) Trace a ray from the light source to the intersection point

4) If the light ray make it to the intersection point, then compute color for a lit pixel at the given frame location.

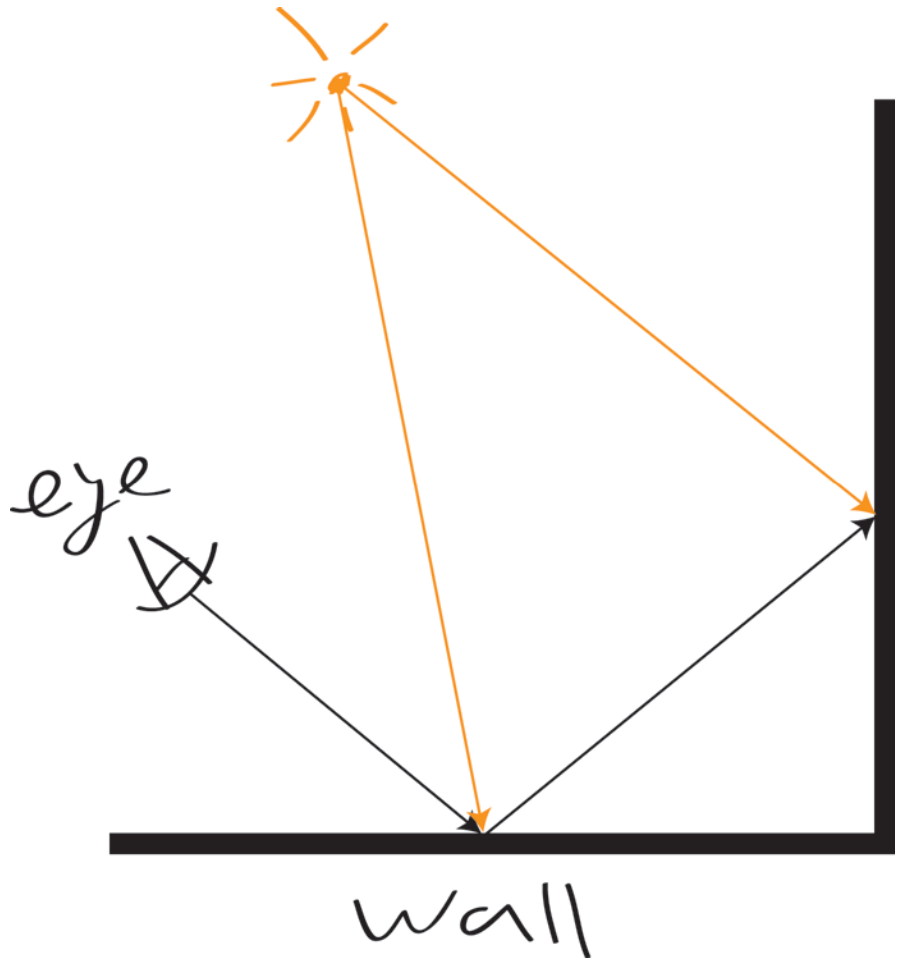
Caution:

- Avoid self Intersections!
- Consider back-faces!

Reflection



r = **d** - 2(**d•n**)**n**



Soft Shadows

Problem:

Point lights produce hard shadows.

Solution:

Use an array of point lights instead.

Problem:

Tracing multiple lights is slow and yet does not remove all sharp transitions in the penumbra(p)

Solution:

Use an area light and sample it randomly