King Abdullah University of Science and Technology

KAUST

CS 380 - GPU and GPGPU Programming
Lecture 3: GPU Architecture, Pt. 1

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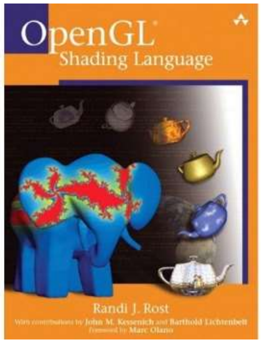
Reading Assignment #2 (until Sep 9)



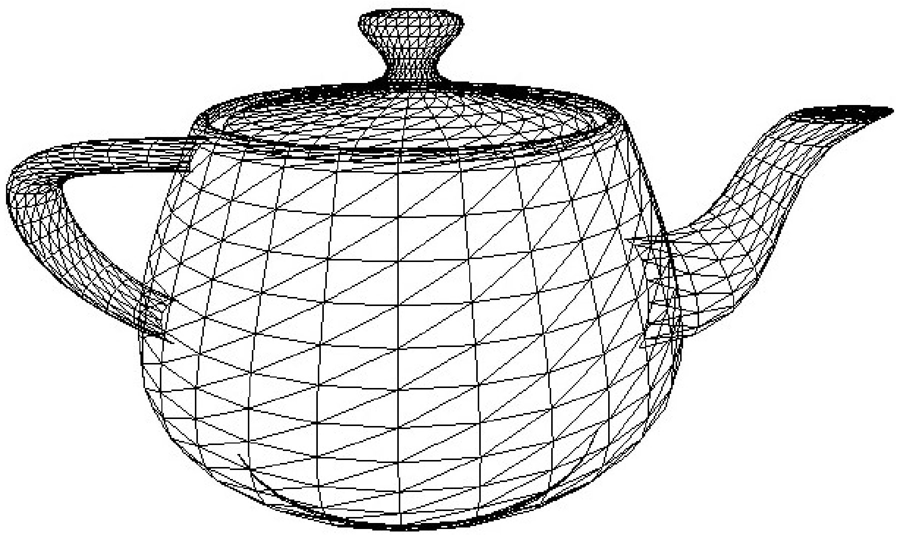
Read (required):

- Orange book (GLSL), Chapter 4
  (*The OpenGL Programmable Pipeline*)
- Nice brief overviews of GLSL and legacy assembly shading language
  `https://en.wikipedia.org/wiki/OpenGL_Shading_Language`
  `https://en.wikipedia.org/wiki/ARB_assembly_language`
- Read:
  `https://en.wikipedia.org/wiki/Instruction_pipelining`
  `https://en.wikipedia.org/wiki/Classic_RISC_pipeline`
- Get an overview of NVIDIA Hopper (H100) Tensor Core GPU white paper:
  `https://resources.nvidia.com/en-us-tensor-core`

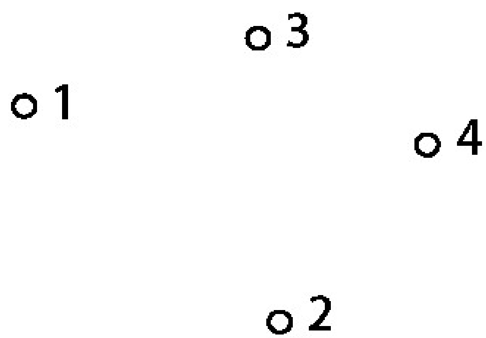
Read (optional):

- GPU Gems 2 book, Chapter 30
  (*The GeForce 6 Series GPU Architecture*)
  `http://download.nvidia.com/developer/GPU_Gems_2/GPU_Gems2_ch30.pdf`

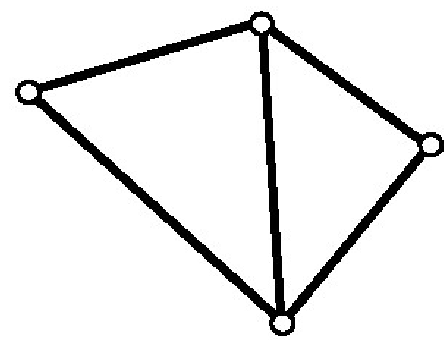
Real-time graphics primitives (entities)



Represent surface as a 3D triangle mesh



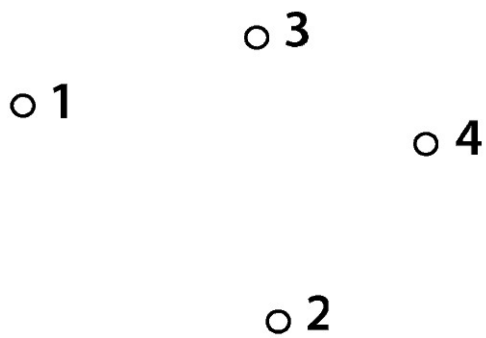
Vertices



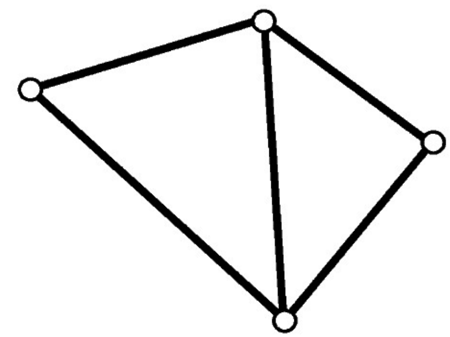
Primitives
(e.g., triangles, points, lines)

Courtesy Kayvon Fatahalian, CMU

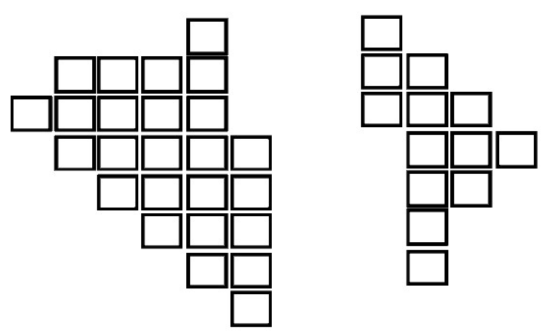
Real-time graphics primitives (entities)



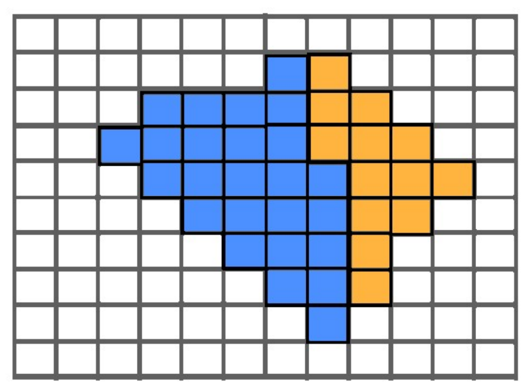
Vertices



Primitives
(e.g., triangles, points, lines)



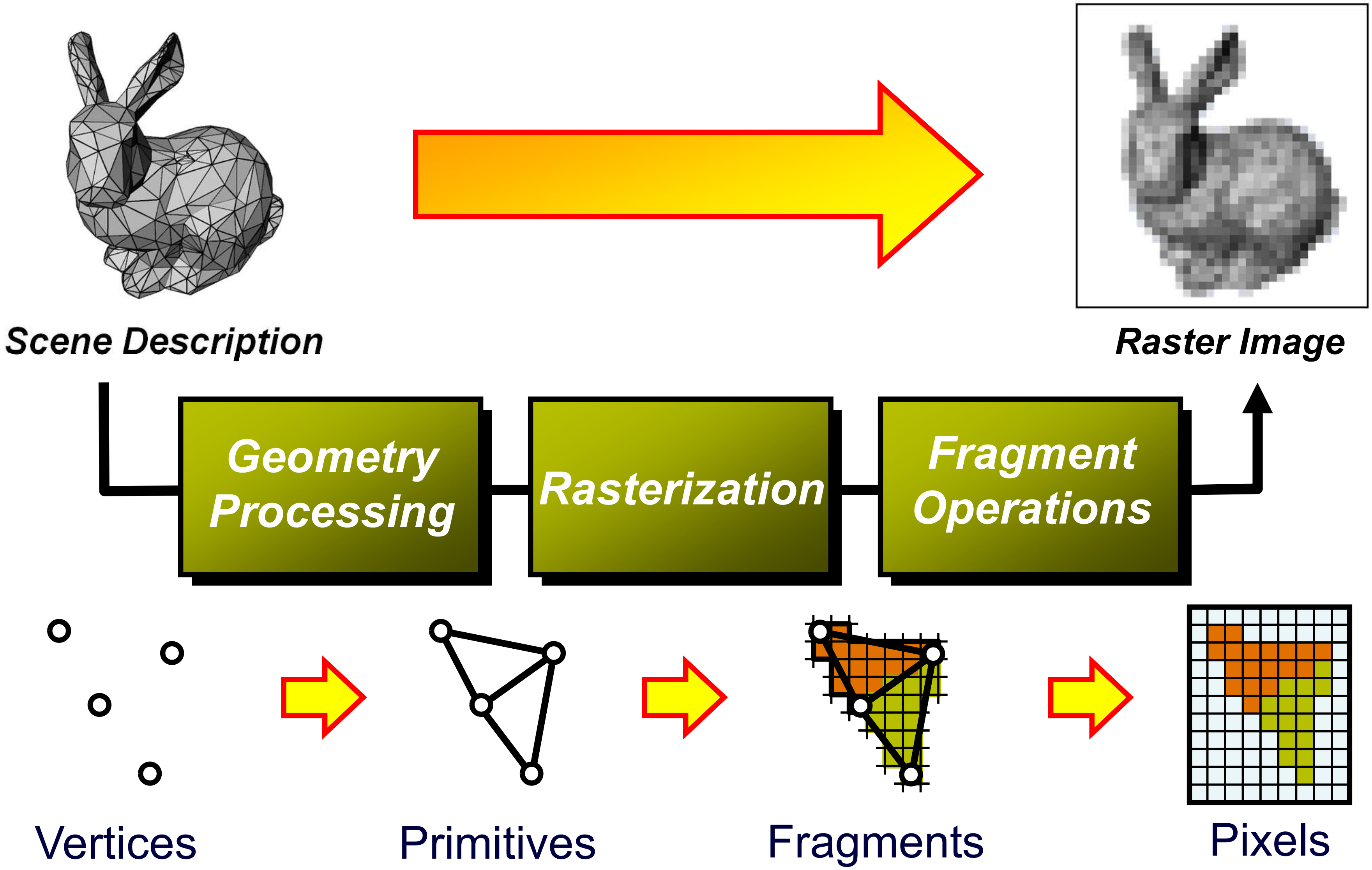
Fragments



Pixels (in an image)

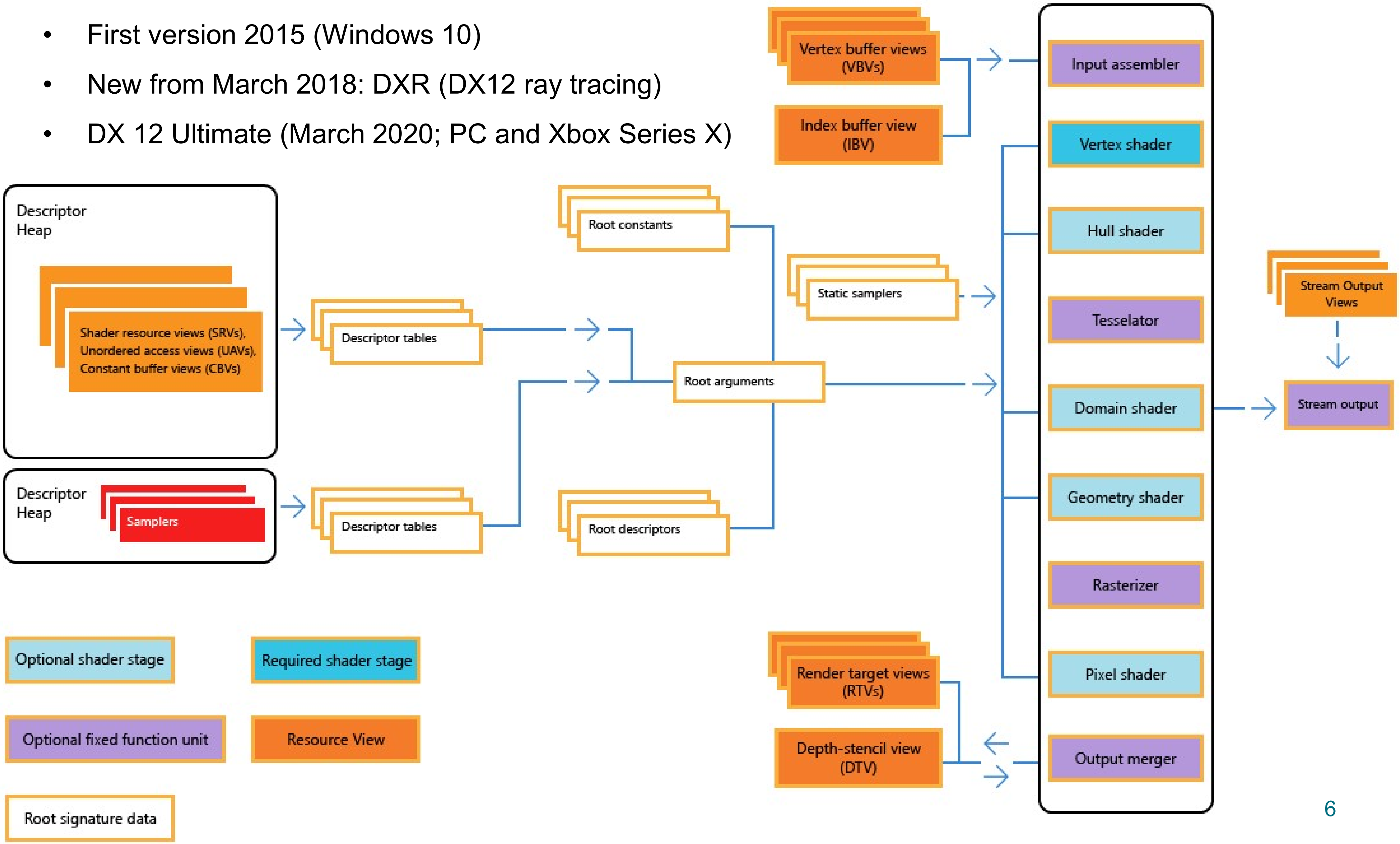
Courtesy Kayvon Fatahalian, CMU

Graphics Pipeline



Direct3D 12 Traditional Geometry Pipeline

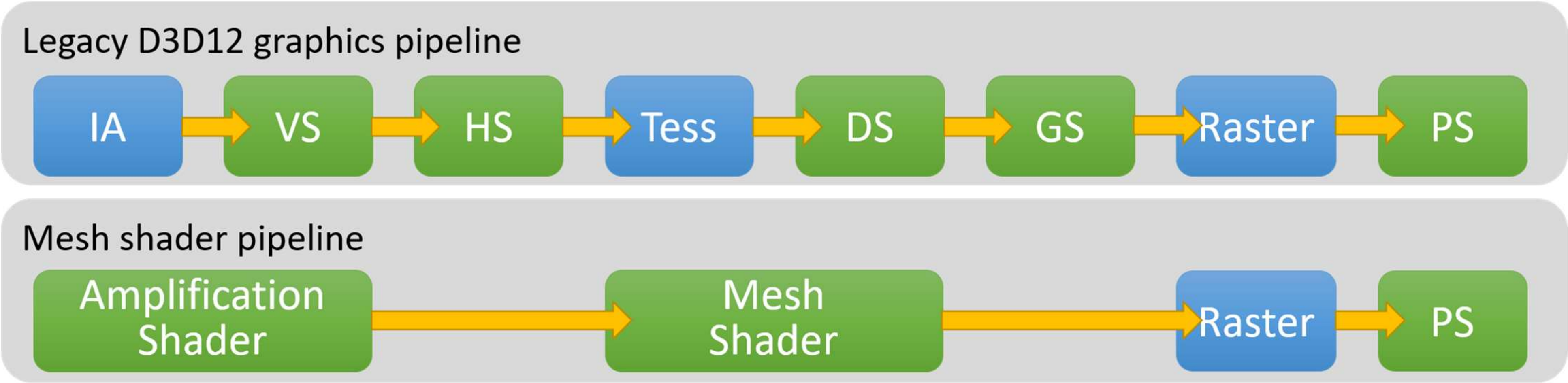
- First version 2015 (Windows 10)
- New from March 2018: DXR (DX12 ray tracing)
- DX 12 Ultimate (March 2020; PC and Xbox Series X)



Direct3D 12 Mesh Shader Pipeline

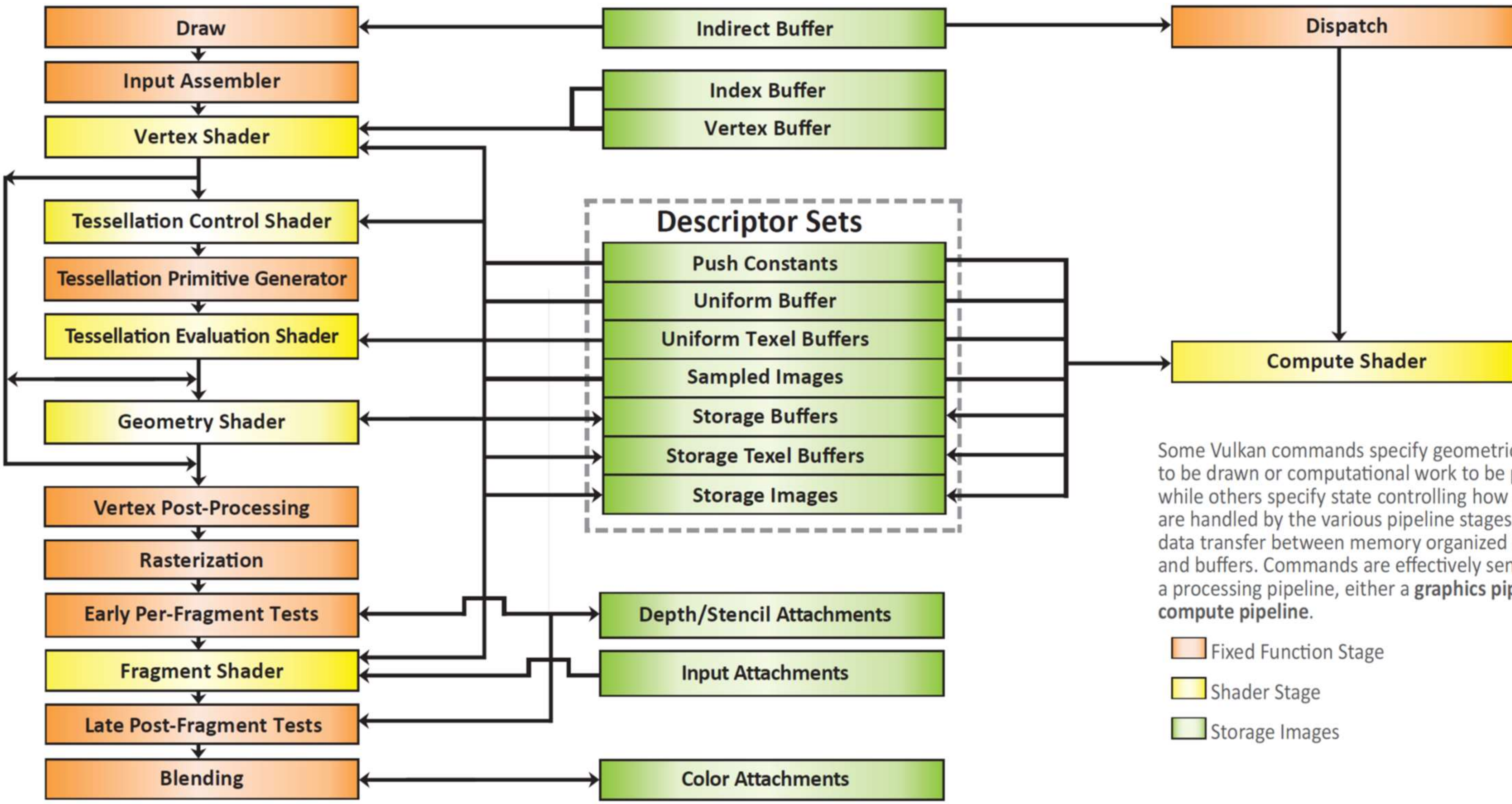
Reinventing the Geometry Pipeline

- Mesh and amplification shaders: new high-performance geometry pipeline based on compute shaders (DX 12 Ultimate / feature level 12.2)
- Compute shader-style replacement of IA/VS/HS/Tess/DS/GS



See talk by Shawn Hargreaves: `https://www.youtube.com/watch?v=CFXKTXtil34`

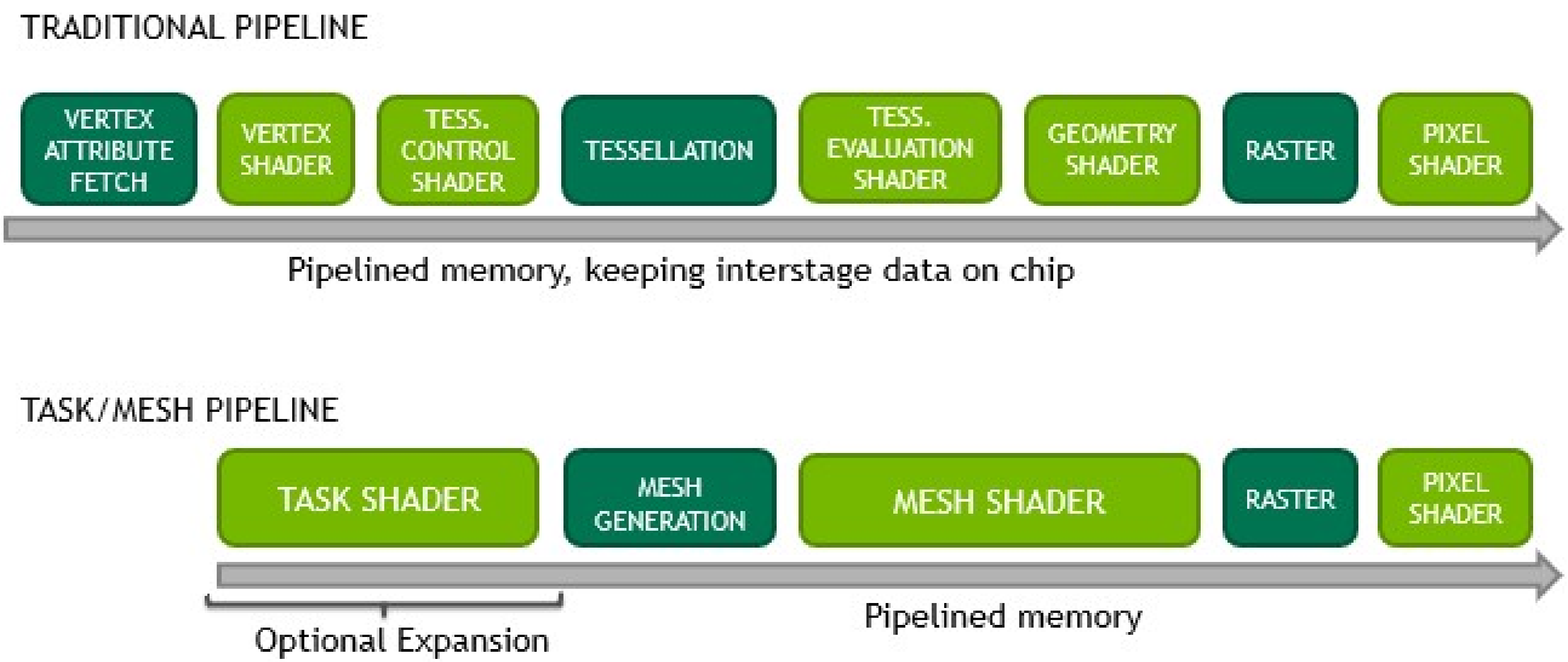
Vulkan (1.3)



Some Vulkan commands specify geometric objects to be drawn or computational work to be performed, while others specify state controlling how objects are handled by the various pipeline stages, or control data transfer between memory organized as images and buffers. Commands are effectively sent through a processing pipeline, either a **graphics pipeline** or a **compute pipeline**.

Vulkan (1.3)

- Mesh and task shaders: new high-performance geometry pipeline based on compute shaders
  (Mesh and task shaders also available as OpenGL 4.5/4.6 extension: `GL_NV_mesh_shader`)



vulkan.org
github.com/KhronosGroup/Vulkan-Guide
https://www.khronos.org/blog/mesh-shading-for-vulkan

GPU Architecture
Fast Forward to Today

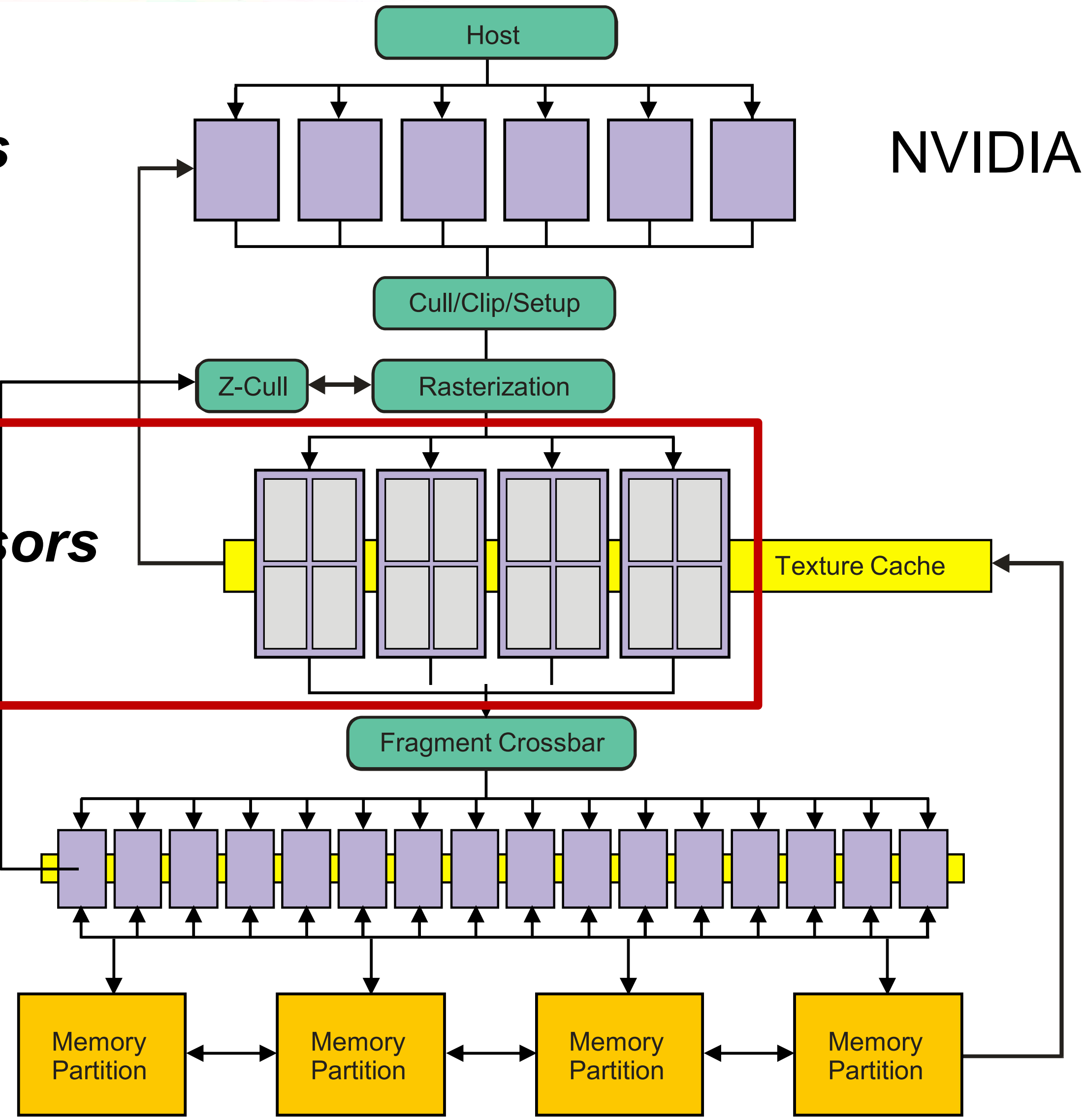
GPU Structure Before Unified Shaders

NVIDIA Geforce 6/7
(NV40)
2004, 2005

Vertex Processors

Fragment Processors

Memory Access
Z-Compare and
Blending (ROPs)

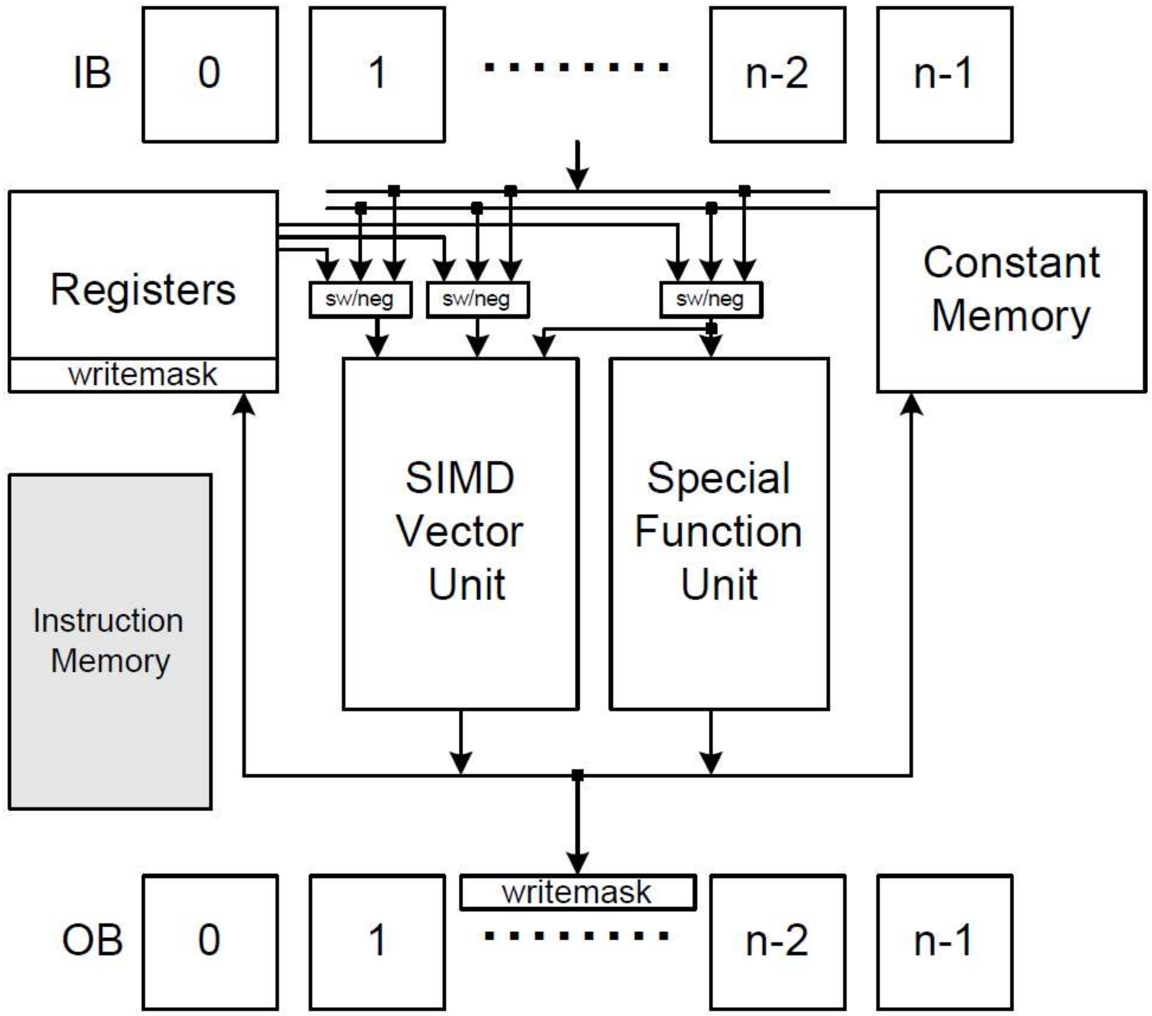


Legacy Vertex Shading Unit (1)

Geforce 3 (NV20), 2001

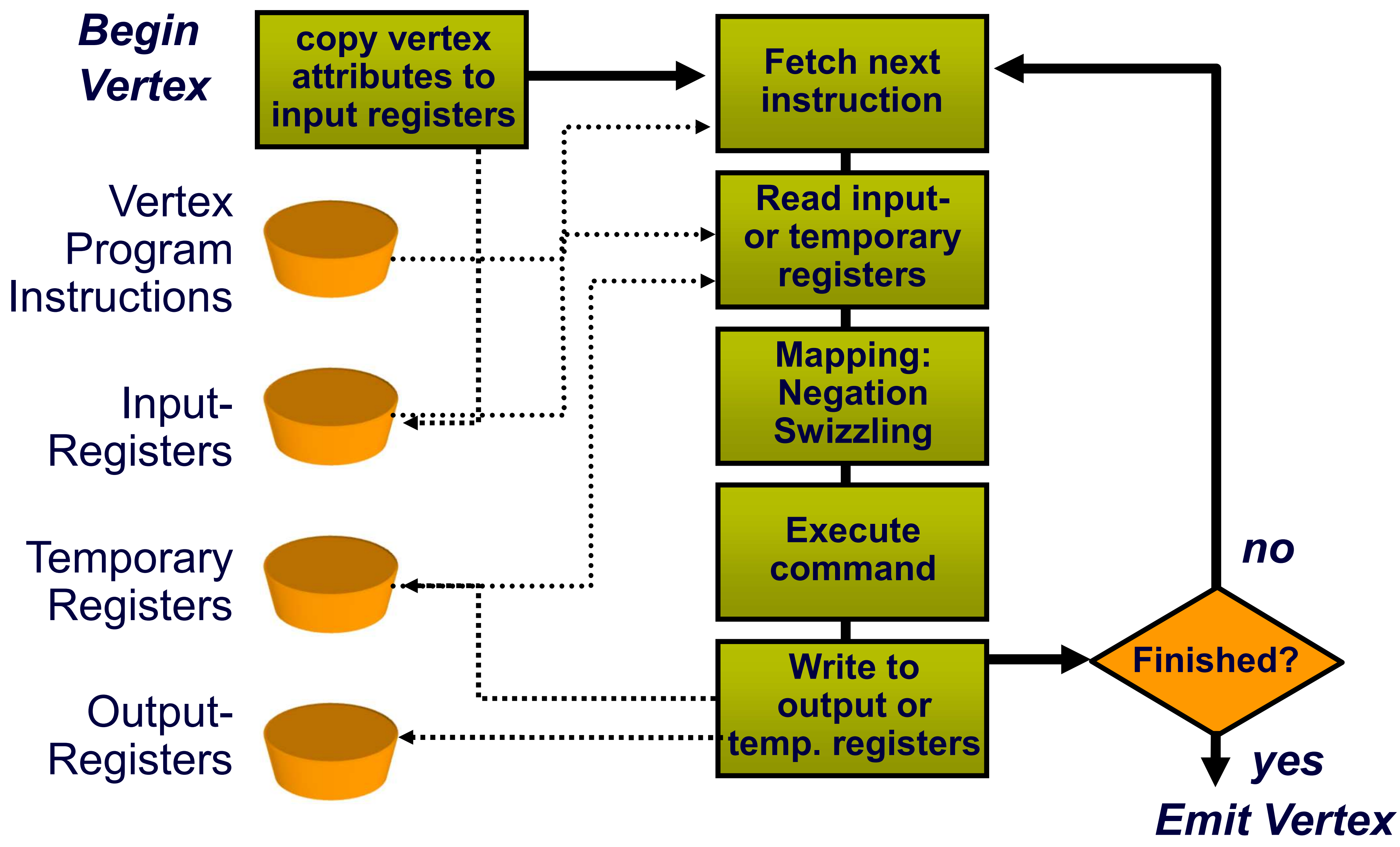
- floating point 4-vector vertex engine

- still very instructive for understanding GPUs in general



Lindholm et al., A User-Programmable Vertex Engine, SIGGRAPH 2001

Vertex Processor



Legacy Vertex Shading Unit (2)

Input attributes

Vertex Attribute Register	Conventional Per-vertex Parameter	Conventional Per-vertex Parameter Command	Conventional Component Mapping
0	Vertex position	glVertex	*x,y,z,w*
1	Vertex weights	glVertexWeightEXT	*w,0,0,1*
2	Normal	glNormal	
3	Primary color	glColor	*r,g,b,a*
4	Secondary color	glSecondaryColorEXT	*r,g,b,1*
5	Fog coordinate	glFogCoordEXT	*f,0,0,1*
6	-	–	-
7	-	–	-
8	Texture coord 0	glMultiTexCoordARB(GL_TEXTURE0…)	*s,t,r,q*
9	Texture coord 1	glMultiTexCoordARB(GL_TEXTURE1…)	*s,t,r,q*
10	Texture coord 2	glMultiTexCoordARB(GL_TEXTURE2…)	*s,t,r,q*
11	Texture coord 3	glMultiTexCoordARB(GL_TEXTURE3…)	*s,t,r,q*
12	Texture coord 4	glMultiTexCoordARB(GL_TEXTUER4…)	*s,t,r,q*
13	Texture coord 5	glMultiTexCoordARB(GL_TEXTUER5…)	*s,t,r,q*
14	Texture coord 6	glMultiTexCoordARB(GL_TEXTUER6…)	*s,t,r,q*
15	Texture coord 7	glMultiTexCoordARB(GL_TEXTUER7…)	*s,t,r,q*

Code examples

```
DP4 o[HPOS].x, c[0], v[OPOS];
```

```
MUL R1, R0.zxyw, R2.yzxw ;
MAD R1, R0.yzxw, R2.zxyw, -R1;
```

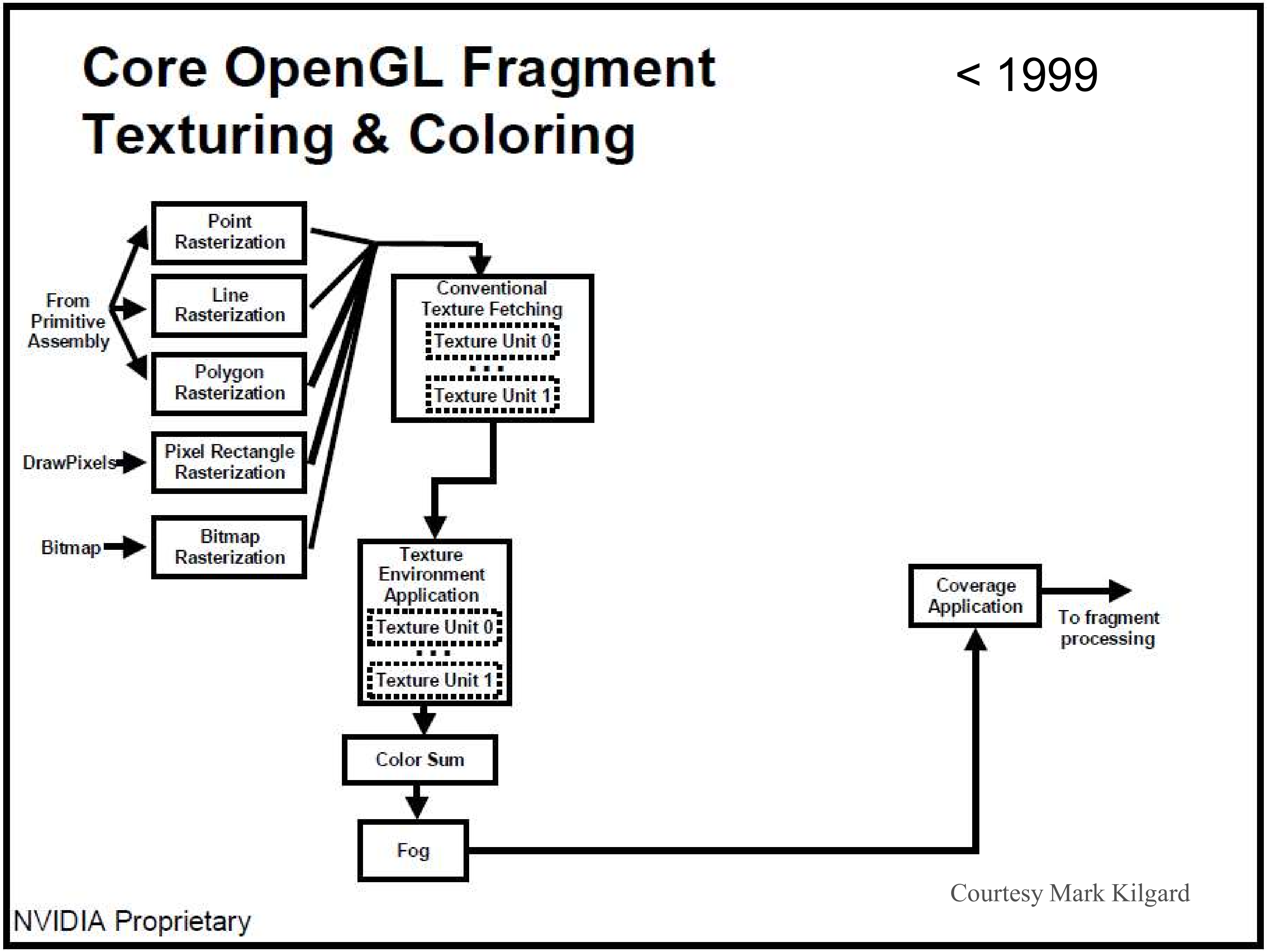
swizzling!

Legacy Vertex Shading Unit (3)

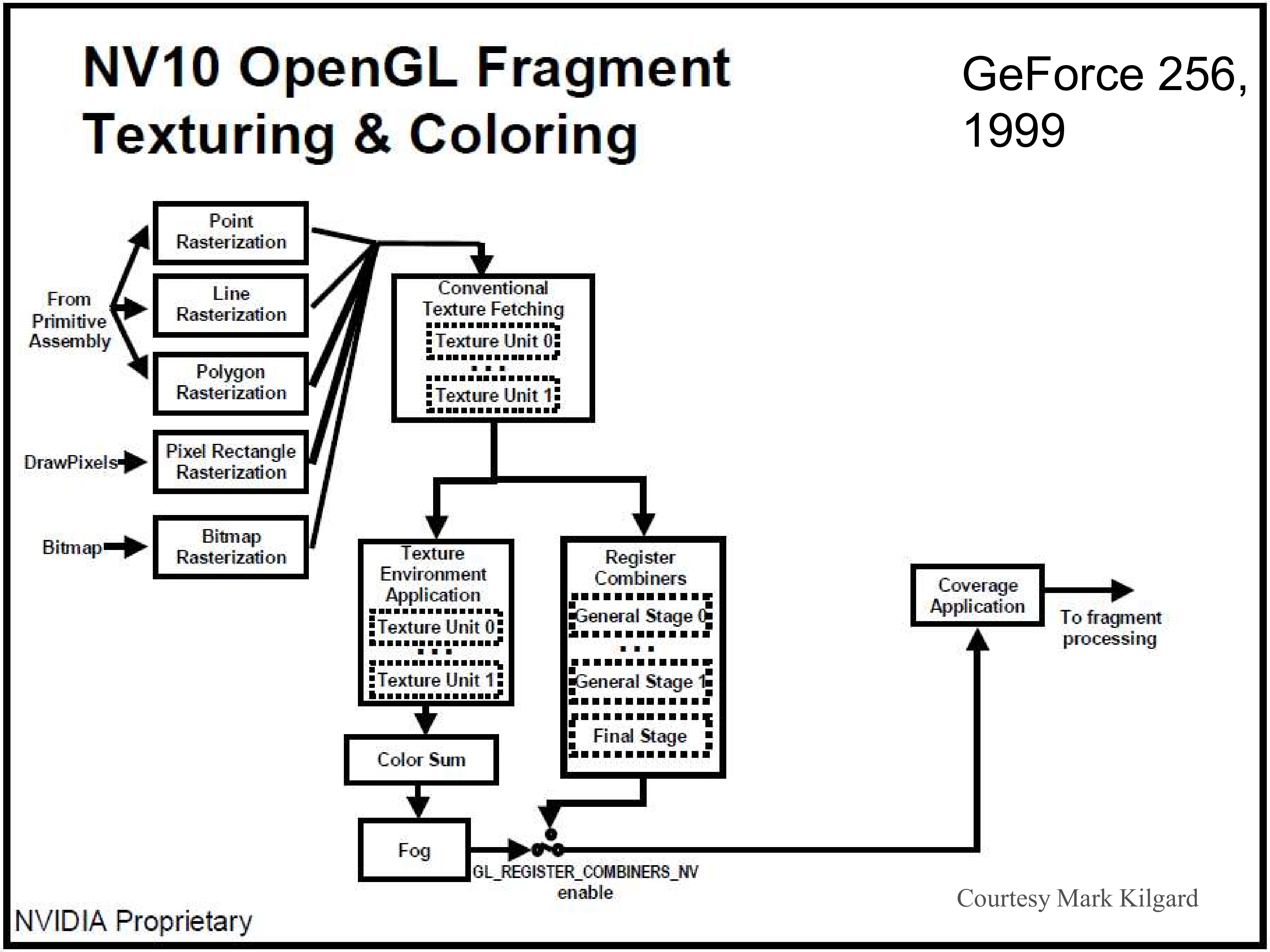
Vector instruction set, very few instructions; **no branching** yet!

OpCode	Full Name	Description
MOV	Move	vector -> vector
MUL	Multiply	vector -> vector
ADD	Add	vector -> vector
MAD	Multiply and add	vector -> vector
DST	Distance	vector -> vector
MIN	Minimum	vector -> vector
MAX	Maximum	vector -> vector
SLT	Set on less than	vector -> vector
SGE	Set on greater or equal	vector -> vector
RCP	Reciprocal	scalar-> replicated scalar
RSQ	Reciprocal square root	scalar-> replicated scalar
DP3	3 term dot product	vector-> replicated scalar
DP4	4 term dot product	vector-> replicated scalar
LOG	Log base 2	miscellaneous
EXP	Exp base 2	miscellaneous
LIT	Phong lighting	miscellaneous
ARL	Address register load	miscellaneous

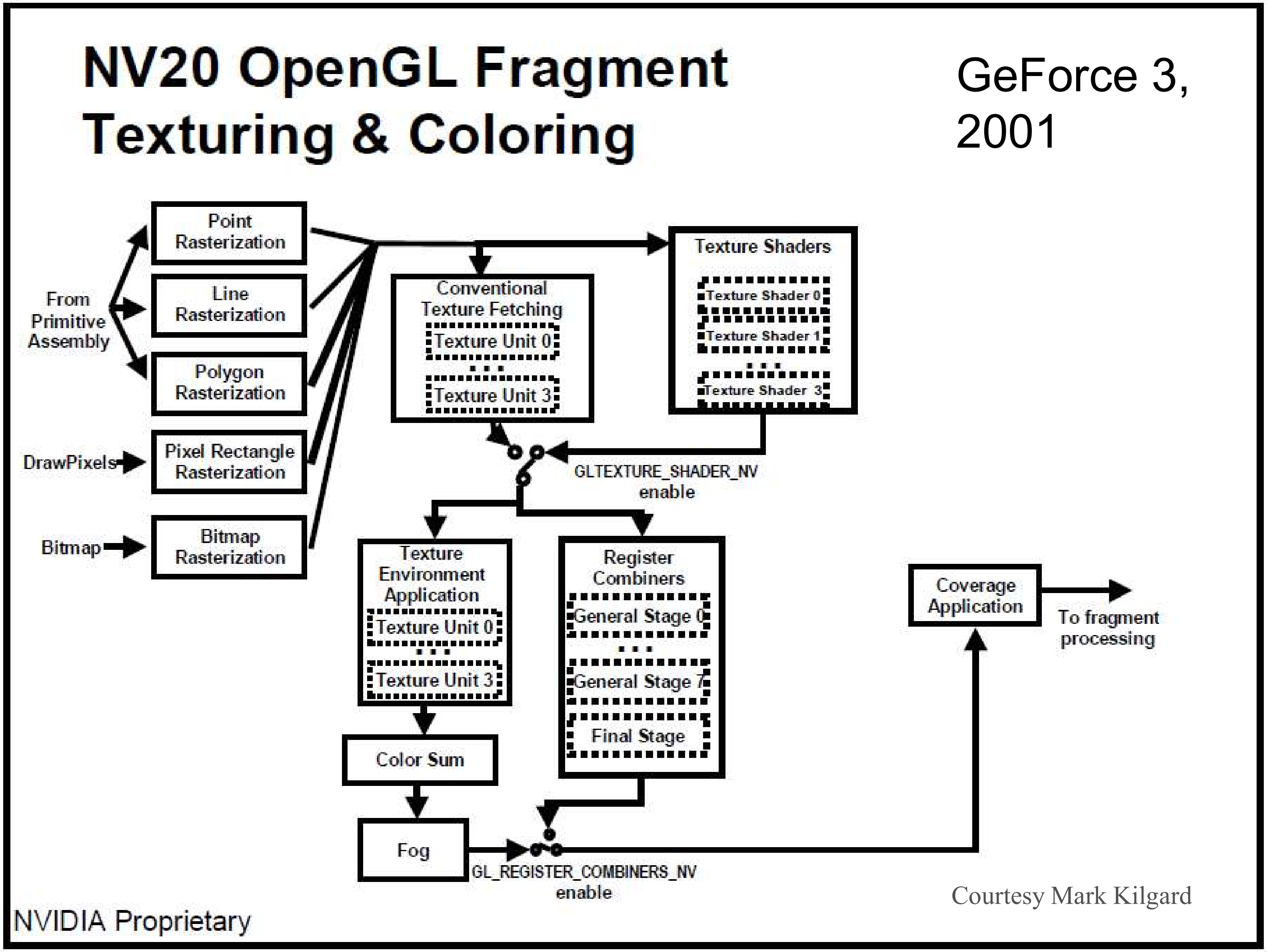
Fast Forward to Programm. Fragment Shading



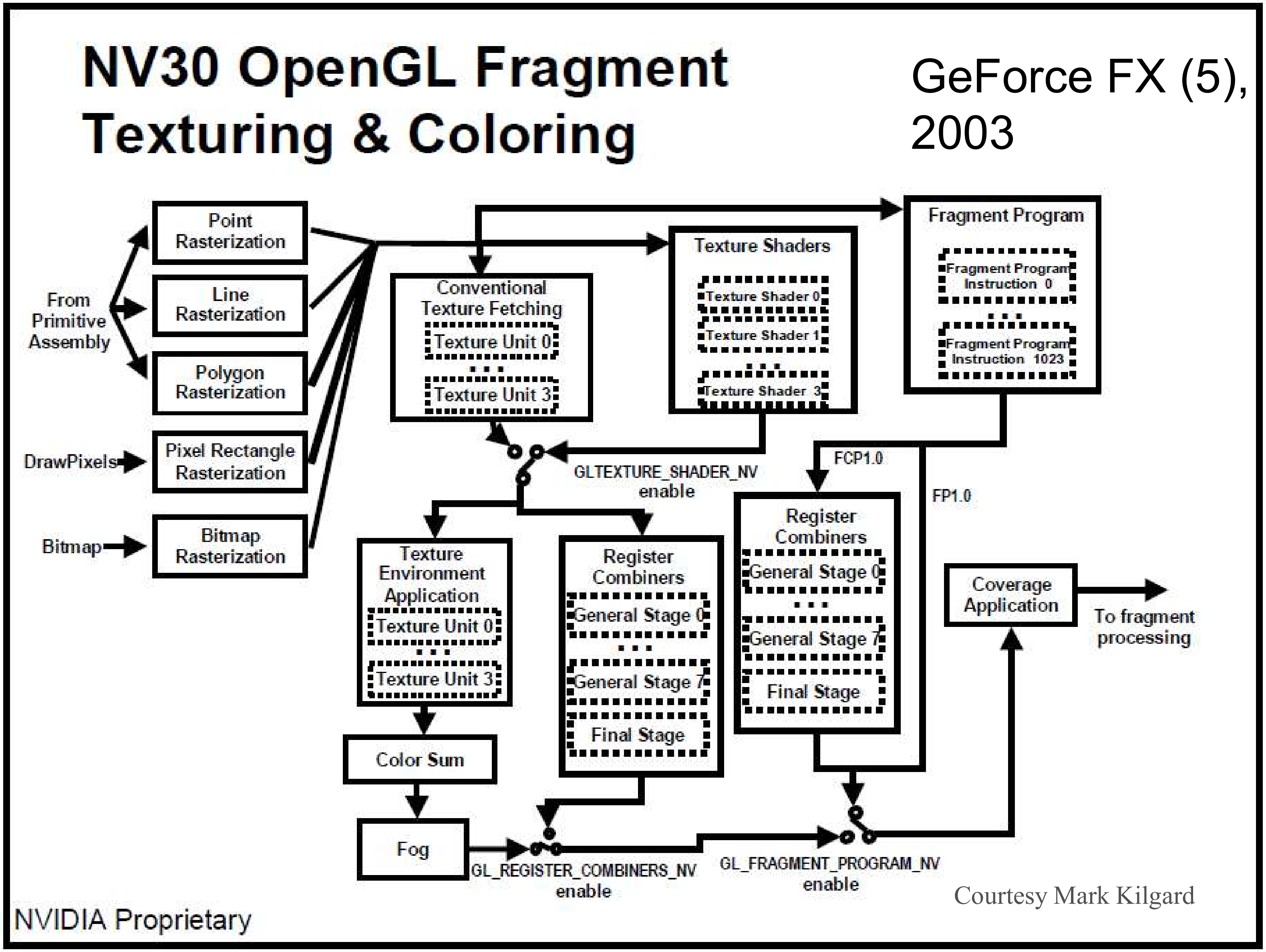
Fast Forward to Programm. Fragment Shading



Fast Forward to Programm. Fragment Shading



Fast Forward to Programm. Fragment Shading



GeForce FX (5), 2003

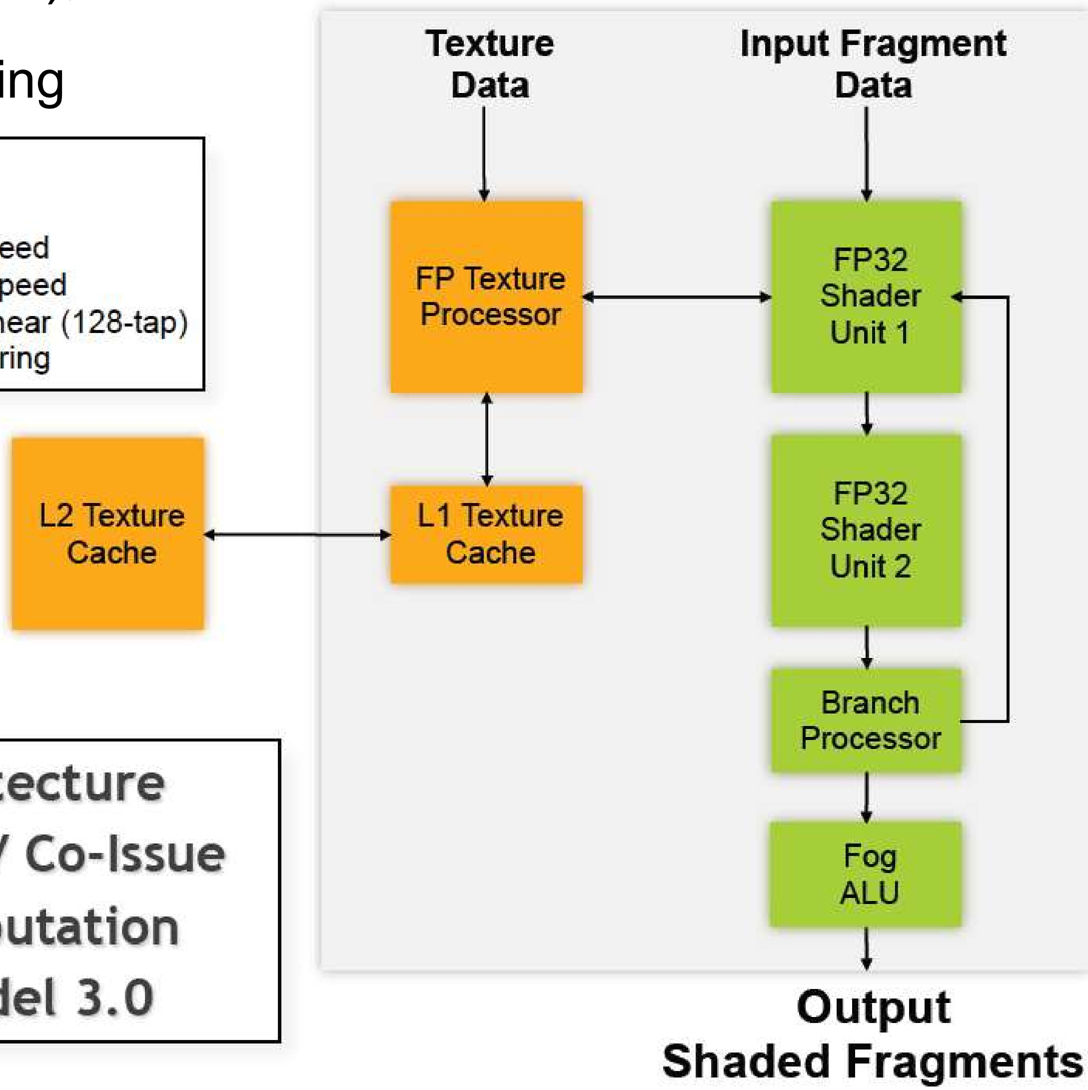
Courtesy Mark Kilgard

Legacy Fragment Shading Unit (1)

GeForce 6 (NV40), 2004

- dynamic branching

Texture Filter
Bi / Tri / Aniso
1 texture @ full speed
4-tap filter @ full speed
16:1 Aniso w/ Trilinear (128-tap)
FP16 Texture Filtering



Shader Unit 1
4 FP Ops / pixel
Dual/Co-Issue
Texture Address Calc
Free fp16 normalize
+ mini ALU

Shader Unit 2
4 FP Ops / pixel
Dual/Co-Issue
+ mini ALU

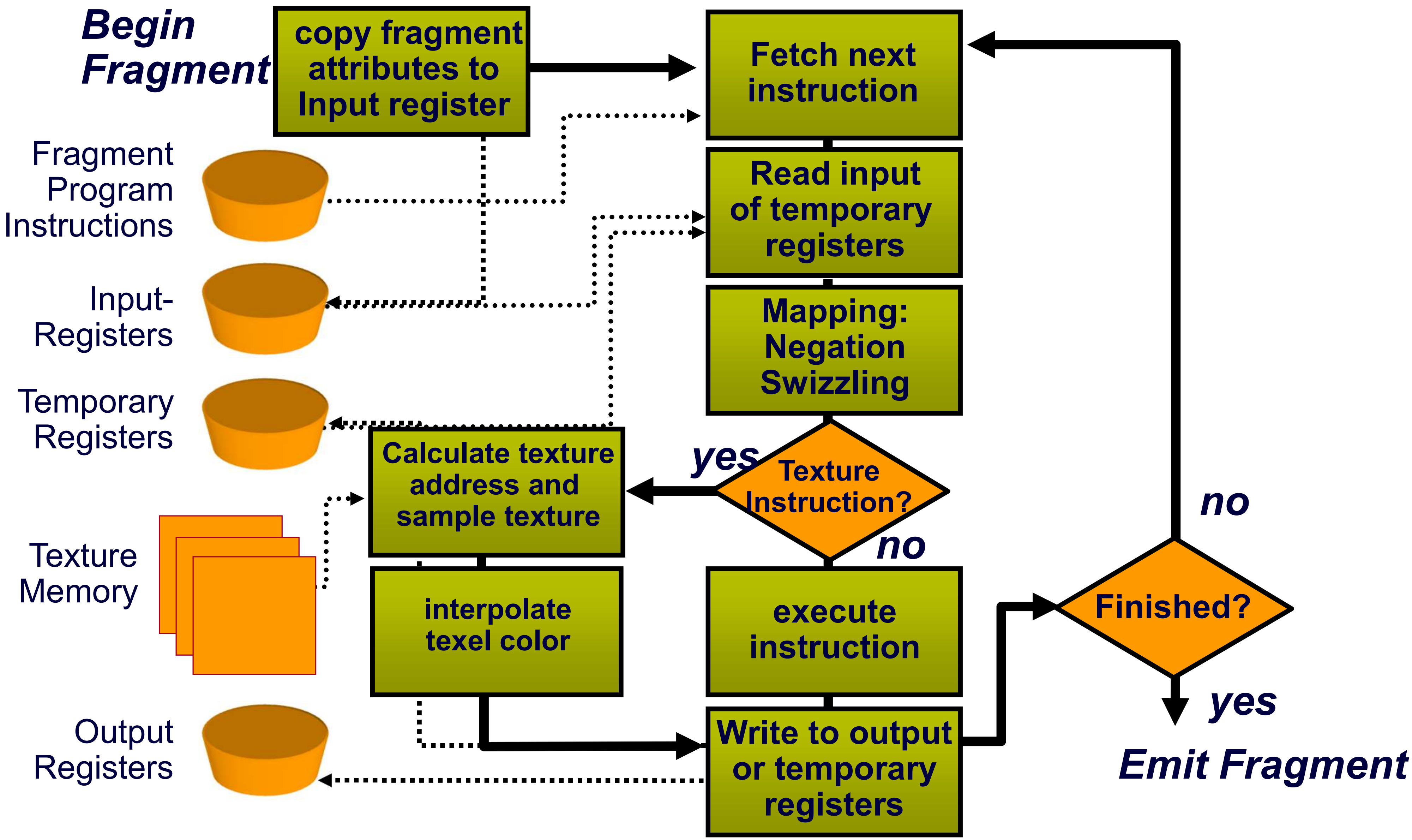
SIMD Architecture
Dual Issue / Co-Issue
FP32 Computation
Shader Model 3.0

Legacy Fragment Shading Unit (2)

Example code

```
!!ARBfp1.0

ATTRIB unit_tc = fragment.texcoord[ 0 ];
PARAM  mvp_inv[]  = { state.matrix.mvp.inverse };
PARAM  constants  = {0, 0.999, 1, 2};

TEMP pos_win, temp;

TEX pos_win.z, unit_tc, texture[ 1 ], 2D;

ADD pos_win.w, constants.y, -pos_win.z;
KIL pos_win.w;

MOV result.color.w, pos_win.z;

MOV pos_win.xyw, unit_tc;
MAD pos_win.xyz, pos_win, constants.a, -constants.b;

DP4 temp.w, mvp_inv[ 3 ], pos_win;
RCP temp.w, temp.w;

MUL pos_win, pos_win, temp.w;

DP4 result.color.x, mvp_inv[ 0 ], pos_win;
DP4 result.color.y, mvp_inv[ 1 ], pos_win;
DP4 result.color.z, mvp_inv[ 2 ], pos_win;

END
```

Fragment Processor



A diffuse reflectance shader

```
sampler mySamp;
Texture2D<float3> myTex;
float3 lightDir;

float4 diffuseShader(float3 norm, float2 uv)
{
  float3 kd;
  kd = myTex.Sample(mySamp, uv);
  kd *= clamp( dot(lightDir, norm), 0.0, 1.0);
  return float4(kd, 1.0);
}
```

Independent, but no explicit parallelism

Compile shader

1 unshaded fragment input record

```
sampler mySamp;
Texture2D<float3> myTex;
float3 lightDir;

float4 diffuseShader(float3 norm, float2 uv)
{
  float3 kd;
  kd = myTex.Sample(mySamp, uv);
  kd *= clamp ( dot(lightDir, norm), 0.0, 1.0);
  return float4(kd, 1.0);
}
```

```
<diffuseShader>:
sample r0, v4, t0, s0
mul  r3, v0, cb0[0]
madd r3, v1, cb0[1], r3
madd r3, v2, cb0[2], r3
clmp r3, r3, l(0.0), l(1.0)
mul  o0, r0, r3
mul  o1, r1, r3
mul  o2, r2, r3
mov  o3, l(1.0)
```

1 shaded fragment output record

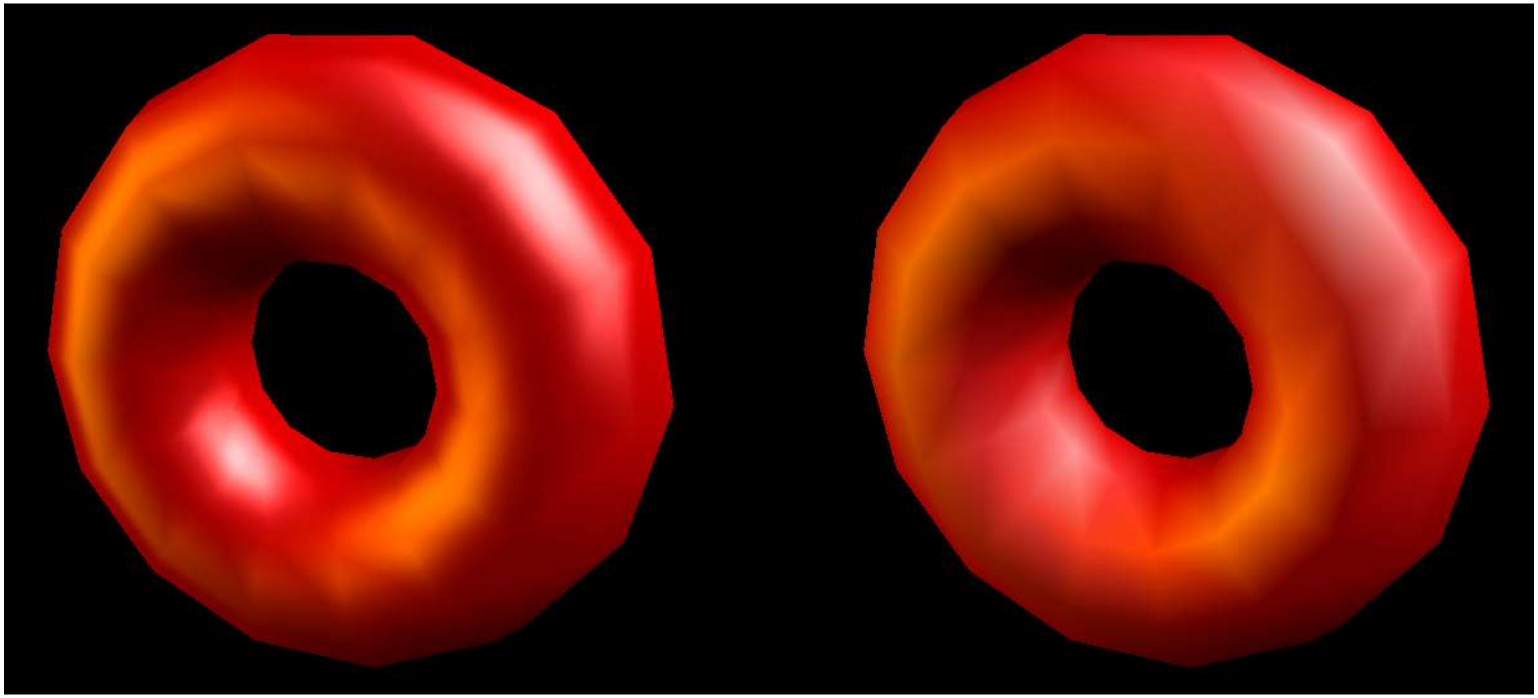
Per-Pixel(Fragment) Lighting

Simulating smooth surfaces by calculating illumination for each fragment

Example: specular highlights (Phong illumination/shading)

Phong shading:
per-fragment evaluation

Gouraud shading:
linear interpolation from vertices



Per-Pixel Phong Lighting (Cg)

```
void main(float4 position   : TEXCOORD0,
          float3 normal     : TEXCOORD1,

      out float4 oColor      : COLOR,

  uniform float3 ambientCol,
  uniform float3 lightCol,
  uniform float3 lightPos,
  uniform float3 eyePos,
  uniform float3 Ka,
  uniform float3 Kd,
  uniform float3 Ks,
  uniform float  shiny)
{
```

Per-Pixel Phong Lighting (Cg)

```
  float3 P = position.xyz;
  float3 N = normal;
  float3 V = normalize(eyePosition - P);
  float3 H = normalize(L + V);

  float3 ambient = Ka * ambientCol;

  float3 L         = normalize(lightPos - P);
  float  diffLight = max(dot(L, N), 0);
  float3 diffuse   = Kd * lightCol * diffLight;

  float specLight = pow(max(dot(H, N), 0), shiny);
  float3 specular = Ks * lightCol * specLight;

  oColor.xyz = ambient + diffuse + specular;
  oColor.w = 1;
}
```

Thank you.