OpenGL ARB Vertex Program

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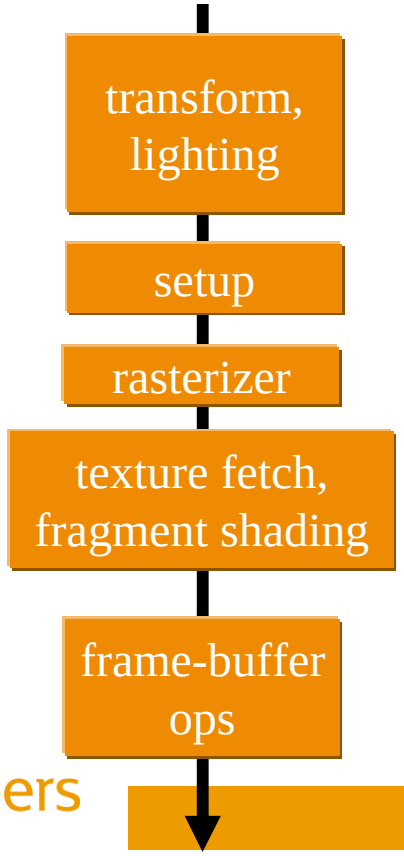
Overview

- ARB Vertex Programming Overview
- Loading Vertex Programs
- Register Set
- Variables and Variable “Binding”
- Assembly Instruction Set
- Example Programs
- Wrap-Up

ARB Vertex Programming Overview

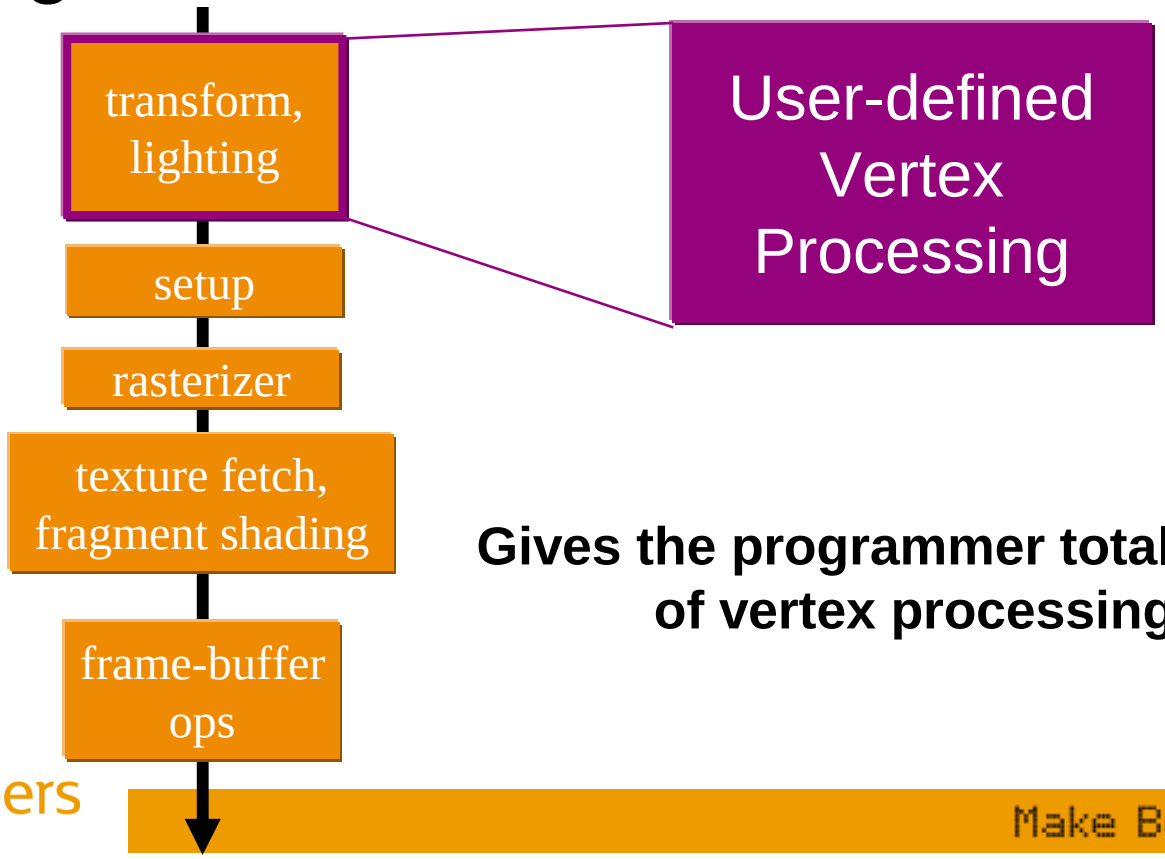
- **Traditional Graphics Pipeline**



Each unit has specific function (usually with configurable "modes" of operation)

ARB Vertex Programming Overview

- **Vertex Programming offers programmable T&L unit**



Gives the programmer total control of vertex processing.

What is Vertex Programming?

- Complete control of transform and lighting HW
- Complex vertex operations accelerated in HW
- Custom vertex lighting
- Custom skinning and blending
- Custom texture coordinate generation
- Custom texture matrix operations
- Custom vertex computations of your choice

- Offloading vertex computations frees up CPU

What is Vertex Programming?

- **Vertex Program**
  - **Assembly language interface to T&L unit**
  - **GPU instruction set to perform all vertex math**
  - **Input: arbitrary vertex attributes**
  - **Output: a transformed vertex attributes**
    - **homogeneous clip space position (required)**
    - **colors (front/back, primary/secondary)**
    - **fog coord**
    - **texture coordinates**
    - **point size**

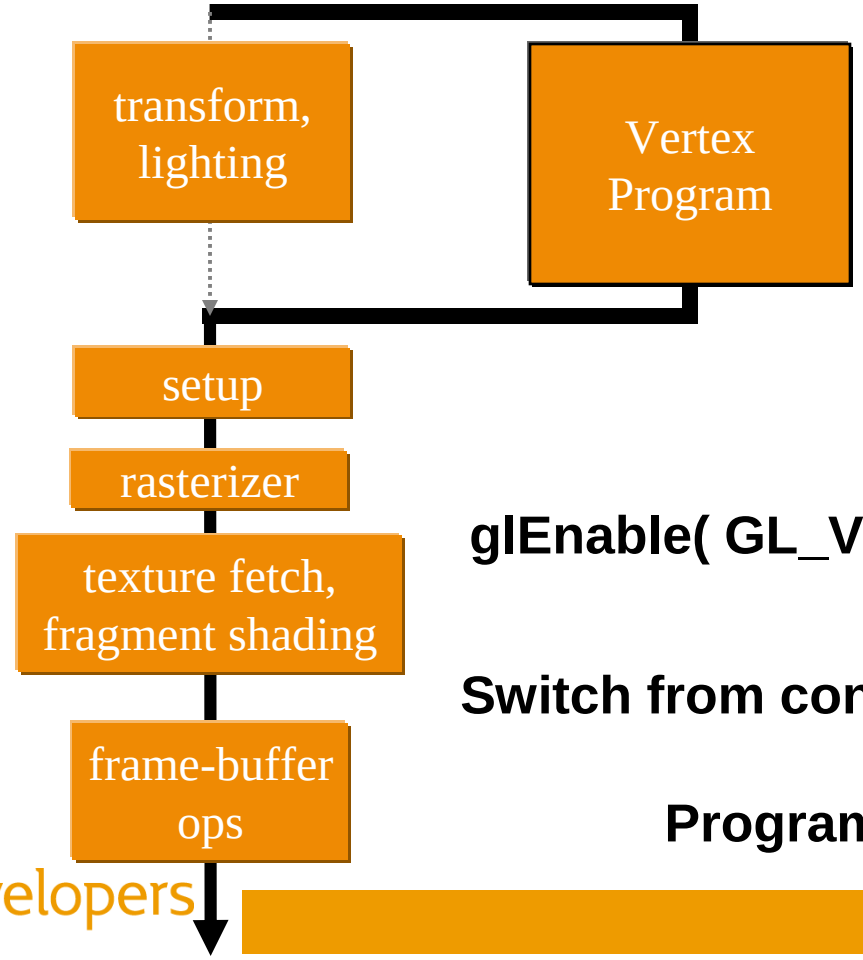
What is Vertex Programming?

- **Vertex Program**
  - **Does not generate or destroy vertexes**
    - **1 vertex in and 1 vertex out**
  - **No topological information provided**
    - **No edge, face, nor neighboring vertex info**
  - **Dynamically loadable**
  - **Exposed through NV_vertex_program and EXT_vertex_shader extensions**
  - **and now ARB_vertex_program**

What is ARB_vertex_program?

- ARB_vertex_program is similar to NV_vertex_program with the addition of:
  - variables
  - local parameters
  - access to GL state
  - some extra instructions
  - implementation-specific resource limits

What is Vertex Programming?



glEnable(GL_VERTEX_PROGRAM_ARB);

Switch from conventional T&L model to Programmable mode

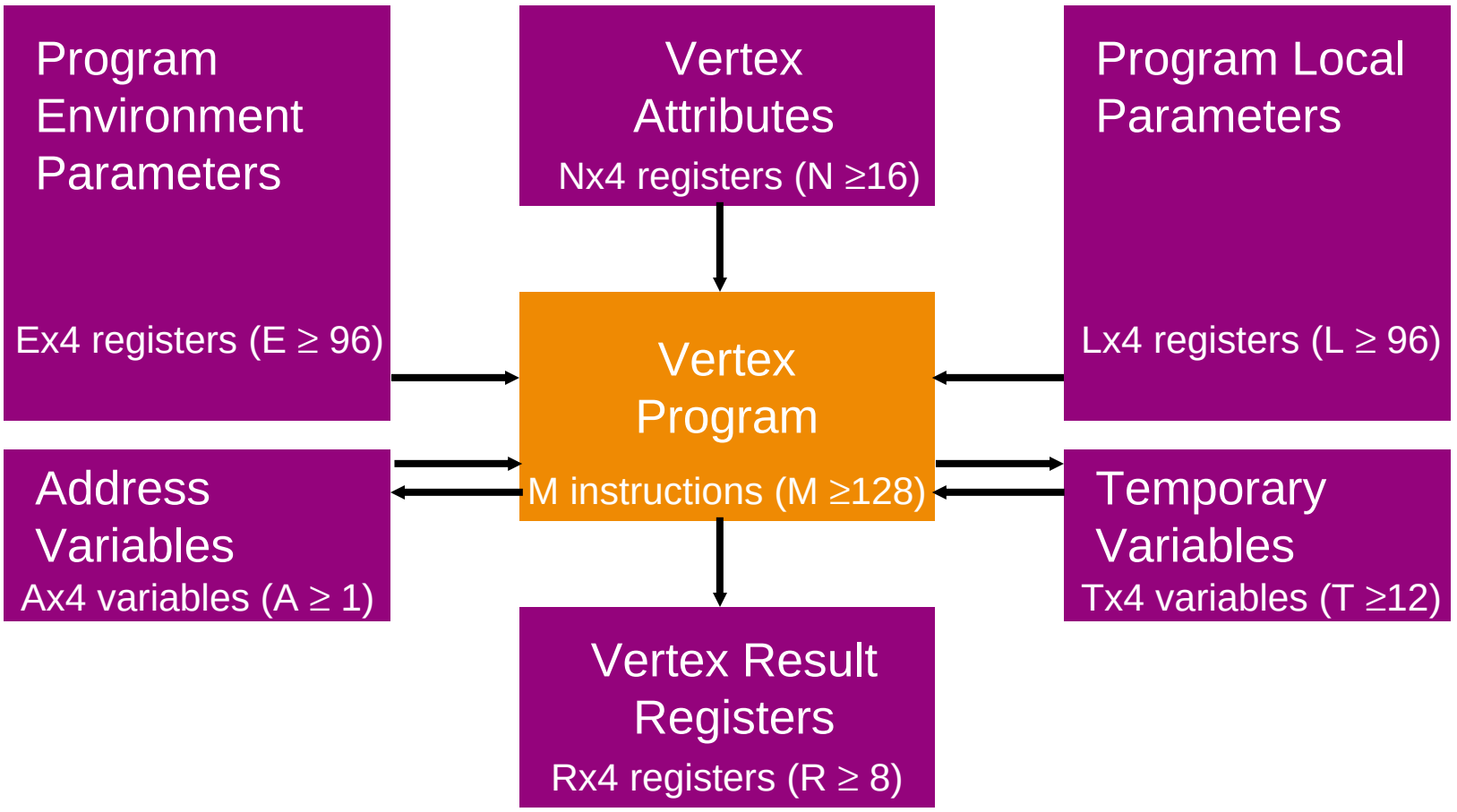
Specifically, what gets bypassed?

- Modelview and projection vertex transformations
- Vertex weighting/blending
- Normal transformation, rescaling, normalization
- Color material
- Per-vertex lighting
- Texture coordinate generation and texture matrix transformations
- Per-vertex point size and fog coordinate computations
- User-clip planes

What does NOT get bypassed?

- Evaluators
- Clipping to the view frustum
- Perspective divide
- Viewport transformation
- Depth range transformation
- Front and back color selection (for two-sided)
- Clamping of primary and secondary colors to [0,1]
- Primitive assembly, setup, rasterization, blending

Vertex Programming Conceptual Overview



Creating a Vertex Program

- Programs are arrays of GLubytes (“strings”)
- Created/managed similar to texture objects
  - notion of a *program object*
  - glGenProgramsARB(sizei n, uint *ids)
  - glBindProgramARB(enum target, uint id)
  - glProgramStringARB(enum target,
    enum format,
    sizei len,
    const ubyte *program)

Creating a Vertex Program

```
Gluint progid;

// Generate a program object handle.
glGenProgramsARB( 1, &progid );

// Make the “current” program object progid.
glBindProgramARB( GL_VERTEX_PROGRAM_ARB, progid );

// Specify the program for the current object.
glProgramStringARB( GL_VERTEX_PROGRAM_ARB,
                    GL_PROGRAM_FORMAT_ASCII_ARB,
                    strlen(myString), myString );

// Check for errors and warnings...
```

Creating a Vertex Program

```
// Check for errors and warnings...
if ( GL_INVALID_OPERATION == glGetError() )
{
    // Find the error position
    GLint errPos;
    glGetIntergv( GL_PROGRAM_ERROR_POSITION_ARB,
                  &errPos );

    // Print implementation-dependent program
    // errors and warnings string.
    Glubyte *errString;
    glGetString( GL_PROGRAM_ERROR_STRING_ARB,
                 &errString );

    fprintf( stderr, “error at position: %d\n%s\n”,
             errPos, errString );
}
```

Creating a Vertex Program

- When finished with a program object, delete it

```
// Delete the program object.
glDeleteProgramsARB( 1, &progid );
```

Specifying Program Parameters

- Three types
  - Vertex Attributes – specifiable per-vertex
  - Program Local Parameters
  - Program Environment Parameters

  Program Parameters modifiable outside of a Begin/End block

Specifying Vertex Attributes

- Up to Nx4 per-vertex “generic” attributes
- Values specified with (several) new commands

```
glVertexAttrib4fARB( index, x, y, z, w )
glVertexAttribs4fvARB( index, values )
```

- Some entry points allow component-wise linear re-mapping to [0,1] or [-1,1]

```
glVertexAttrib4NubARB( index, x, y, z, w )
glVertexAttrib4NbvARB( index, values )
```

  similar to `glColor4ub()` and `glColor4b()`

Specifying Vertex Attributes

Component-wise linear re-mapping

Suffix	Data Type	Min Value	Min Value Maps to
b	1-byte integer	-128	-1.0
s	2-byte integer	-32,768	-1.0
i	4-byte integer	-2,147,483,648	-1.0
ub	unsigned 1-byte integer	0	0.0
us	unsigned 2-byte integer	0	0.0
ui	unsigned 4-byte integer	0	0.0

Suffix	Data Type	Max Value	Max Value Maps to
b	1-byte integer	127	1.0
s	2-byte integer	32,767	1.0
i	4-byte integer	2,147,483,647	1.0
ub	unsigned 1-byte integer	255	1.0
us	unsigned 2-byte integer	65,535	1.0
ui	unsigned 4-byte integer	4,294,967,295	1.0

Specifying Vertex Attributes

- Vertex Array support
- `glVertexAttribPointerARB(`
  ```
  uint index,
  int size,
  enum type,
  boolean normalize,
  sizei stride,
  const void *pointer )
  ```
- “normalize” flag indicates if values should be linearly remapped

Specifying Vertex Attributes

- Setting vertex attribute 0 provokes vertex program execution
- Setting any other vertex attribute updates the current values of the attribute register

- Conventional attributes may be specified with conventional per-vertex calls
  - glColor, glNormal, glWeightARB, etc.
- Not strict aliasing (like NV_vertex_program)
  - More on this later…

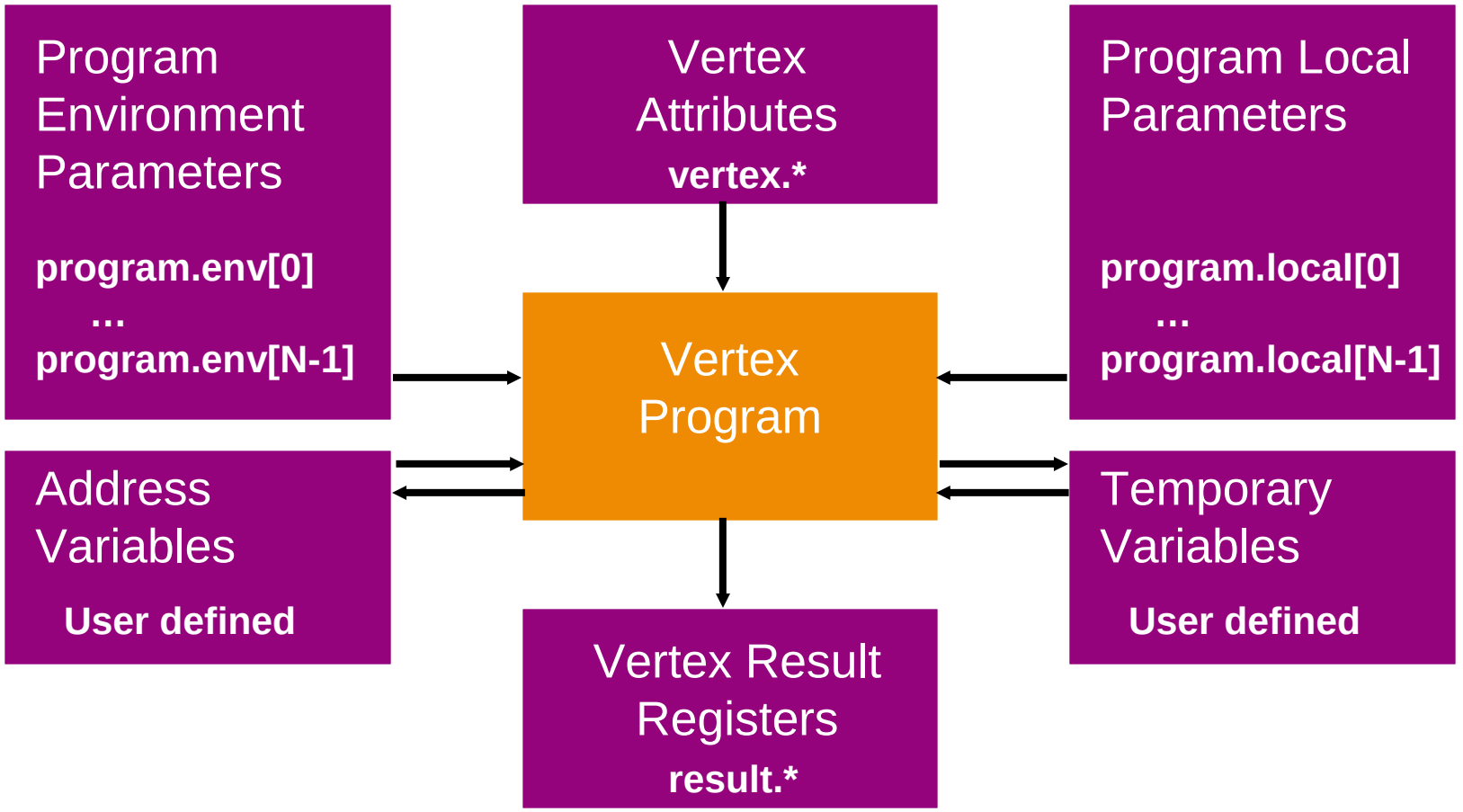
Specifying Program Local Parameters

- Each program object has an array of (N ≥ 96) four-component floating point vectors
  - Store program-specific parameters required by the program
- Values specified with new commands
  - glProgramLocalParameter4fARB(GL_VERTEX_PROGRAM_ARB, index, x, y, z, w)
  - glProgramLocalParameter4fvARB(GL_VERTEX_PROGRAM_ARB, index, params)
- Correspond to 96+ local parameter registers

Specifying Program Environment Parameters

- Shared array of (N ≥ 96) four-component registers accessible by any vertex program
  - Store parameters common to a set of program objects (i.e. Modelview matrix, MVP matrix)
- Values specified with new commands
  - glProgramEnvParameter4fARB(GL_VERTEX_PROGRAM_ARB, index, x, y, z, w)
  - glProgramEnvParameter4fvARB(GL_VERTEX_PROGRAM_ARB, index, params)
- Correspond to 96+ environment registers

The Register Set



Program Environment and Program Local Registers

- **Program environment registers**

  access using: `program.env[i]`

  i in [0,GL_MAX_PROGRAM_ENV_PARAMETERS_ARB-1]

- **Program local registers**

  access using: `program.local[i]`

  i in [0,GL_MAX_PROGRAM_LOCAL_PARAMETERS_ARB-1]

Vertex Attribute Registers

Attribute Register	Components	Underlying State
vertex.position	(x,y,z,w)	object position
vertex.weight	(w,w,w,w)	vertex weights 0-3
vertex.weight[n]	(w,w,w,w)	vertex weights n-n+3
vertex.normal	(x,y,z,1)	normal
vertex.color	(r,g,b,a)	primary color
vertex.color.primary	(r,g,b,a)	primary color
vertex.color.secondary	(r,g,b,a)	secondary color
vertex.fogcoord	(f,0,0,1)	fog coordinate
vertex.texcoord	(s,t,r,q)	texture coordinate, unit 0
vertex.texcoord[n]	(s,t,r,q)	texture coordinate, unit n
vertex.matrixindex	(i,i,i,i)	vertex matrix indices 0-3
vertex.matrixindex[n]	(i,i,i,i)	vertex matrix indices n-n+3
vertex.attrib[n]	(x,y,z,w)	generic vertex attribute n

Semantics defined by program, NOT parameter name

Vertex Result Registers

Result Register	Components	Description
result.position	(x,y,z,w)	position in clip coordinates
result.color	(r,g,b,a)	front-facing, primary color
result.color.primary	(r,g,b,a)	front-facing, primary color
result.color.secondary	(r,g,b,a)	front-facing, secondary color
result.color.front	(r,g,b,a)	front-facing, primary color
result.color.front.primary	(r,g,b,a)	front-facing, primary color
result.color.front.secondary	(r,g,b,a)	front-facing, secondary color
result.color.back	(r,g,b,a)	back-facing, primary color
result.color.back.primary	(r,g,b,a)	back-facing, primary color
result.color.back.secondary	(r,g,b,a)	back-facing, secondary color
result.fogcoord	(f,*,*,*)	fog coordinate
result.pointsize	(s,*,*,*)	point size
result.texcoord	(s,t,r,q)	texture coordinate, unit 0
result.texcoord[n]	(s,t,r,q)	texture coordinate, unit n

Semantics defined by down-stream pipeline stages

Address Register Variables

- four-component signed integer vectors where only the ‘x’ component is addressable.

- Must be “declared” before use – address register variables

```
ADDRESS Areg;
ADDRESS A0;
ADDRESS A1, Areg;
```

- Number of variables limited to GL_MAX_PROGRAM_ADDRESS_REGISTERS_ARB

Temporary Variables

- Four-component floating-point vectors used to store intermediate computations
- Temporary variables declared before first use

```
TEMP flag;
TEMP tmp, ndotl, keenval;
```

- Number of temporary variables limited to GL_MAX_PROGRAM_TEMPORARIES_ARB

Identifiers and Variable Names

- Any sequence of one or more
  - letters (A to Z, a to z),
  - digits (“0” to ”9”)
  - underscores (“_”)
  - dollar signs “$”
- First character may not be a digit
- Case sensitive
- Legal: A, b, _ab, $_ab, a$b, $_
- Not Legal: 9A, ADDRESS, TEMP (other reserved words)

Program Constants

- Floating-point constants may be used in programs
- Standard format

<integer portion> . <fraction portion> {“e”<integer>| “E”<integer>}

One (not both) may be omitted
Decimal or exponent (not both) may be omitted

- Some Legal examples

4.3, 4., .3, 4.3e3, 4.3e-3, 4.e3, 4e3, 4.e-3, .3e3

Program Parameter Variables

- Set of four-component floating point vectors used as constants during program execution
- May be single four-vector or array of four-vectors
- Bound either
  - Explicitly (declaration of “param” variables)
  - Implicitly (inline usage of constants)

Program Parameter Variable Bindings

- Explicit Constant Binding
- Single Declaration

```
PARAM a = {1.0, 2.0, 3.0, 4.0};   (1.0, 2.0, 3.0, 4.0)
PARAM b = {3.0};                  (3.0, 0.0, 0.0, 1.0)
PARAM c = {1.0, 2.0};             (1.0, 2.0, 0.0, 1.0)
PARAM d = {1.0, 2.0, 3.0 };       (1.0, 2.0, 3.0, 1.0)
PARAM e = 3.0;                    (3.0, 3.0, 3.0, 3.0)
```

- Array Declaration

```
PARAM arr[2] = { {1.0, 2.0, 3.0, 4.0},
                 {5.0, 6.0, 7.0, 8.0} };
```

Program Parameter Variable Bindings

- **Implicit Constant Binding**

```
ADD a, b, {1.0, 2.0, 3.0, 4.0};   (1.0, 2.0, 3.0, 4.0)
ADD a, b, {3.0};                  (3.0, 0.0, 0.0, 1.0)
ADD a, b, {1.0, 2.0};             (1.0, 2.0, 0.0, 1.0)
ADD a, b, {1.0, 2.0, 3.0};        (1.0, 2.0, 3.0, 1.0)
ADD a, b, 3.0;                    (3.0, 3.0, 3.0, 3.0)
```

- **Number of program parameter variables (explicit+implicit) limited to GL_MAX_PROGRAM_PARAMETERS_ARB**

Program Parameter Variable Bindings

- **Program Environment/Local Parameter Binding**

```
PARAM a = program.local[8];
PARAM b = program.env[9];
PARAM arr[2] = program.local[4..5];
PARAM mat[4] = program.env[0..3];
```

- **Essentially creates a “Reference”**

Program Parameter Variable Bindings

- Material Property Binding
  - Bind to current GL material properties

```
PARAM ambient = state.material.ambient;
PARAM diffuse = state.material.diffuse;
```

- Additional material state to bind to…

Program Parameter Variable Bindings

Binding	Components	Underlying GL state
state.material.ambient	(r,g,b,a)	front ambient material color
state.material.diffuse	(r,g,b,a)	front diffuse material color
state.material.specular	(r,g,b,a)	front specular material color
state.material.emission	(r,g,b,a)	front emissive material color
state.material.shininess	(s,0,0,1)	front material shininess
state.material.front.ambient	(r,g,b,a)	front ambient material color
state.material.front.diffuse	(r,g,b,a)	front diffuse material color
state.material.front.specular	(r,g,b,a)	front specular material color
state.material.front.emission	(r,g,b,a)	front emissive material color
state.material.front.shininess	(s,0,0,1)	front material shininess
state.material.back.ambient	(r,g,b,a)	back ambient material color
state.material.back.diffuse	(r,g,b,a)	back diffuse material color
state.material.back.specular	(r,g,b,a)	back specular material color
state.material.back.emission	(r,g,b,a)	back emissive material color
state.material.back.shininess	(s,0,0,1)	back material shininess

Program Parameter Variable Bindings

- Light Property Binding

```
PARAM ambient = state.light[0].ambient;
PARAM diffuse = state.light[0].diffuse;
```

- Additional light state to bind to…
- Also bind to
  - Texture coord generation state
  - Fog property state
  - Clip plane state
  - Matrix state

Output Variables

- Variables that are declared bound to any vertex result register

```
OUTPUT ocol = result.color.primary;
OUTPUT opos = result.position;
```

- Write-only, essentially a “reference”

Aliasing of Variables

- Allows multiple variable names to refer to a single underlying variable

```
ALIAS var2 = var1;
```

- Do not count against resource limits

Additional Notes on Variables

- May be declared anywhere prior to first usage
- ARB spec. details specific rules with regards to resource consumption
  - Rule of thumb – generally minimize/remove unessential variables to keep resource counts
  - Can always load a program then query resource counts if desired

Vertex Programming Assembly Language

- Powerful SIMD instruction set
- Four operations simultaneously
- 27 instructions
- Operate on scalar or 4-vector input
- Result in a vector or replicated scalar output

Assembly Language

Instruction Format:

Opcode dst, [-]s0 [,[-]s1 [,[-]s2]]; #comment

Instruction Destination Source0 Source1 Source2

‘[’ and ‘]’ indicate optional modifiers

Examples:

MOV R1, R2;

MAD R1, R2, R3, -R4;

Assembly Language

Source registers can be negated:

```
MOV     R1, -R2;
```

before

R1		R2	
0.0	x	7.0	x
0.0	y	3.0	y
0.0	z	6.0	z
0.0	w	2.0	w

after

R1		R2	
-7.0	x	7.0	x
-3.0	y	3.0	y
-6.0	z	6.0	z
-2.0	w	2.0	w

Assembly Language

Source registers can be “swizzled":

```
MOV     R1, R2.yzwx;
```

	before		after	
	R1	R2	R1	R2
x	0.0	7.0	3.0	7.0
y	0.0	3.0	6.0	3.0
z	0.0	6.0	2.0	6.0
w	0.0	2.0	7.0	2.0

Note: MOV R1, R2.xxxx; ↔ MOV R1, R2.x;

Assembly Language

Destination register can mask which components are written to…

R1	⇒	**write all components**
R1.x	⇒	**write only x component**
R1.xw	⇒	**write only x, w components**

Vertex Programming Assembly Language

Destination register masking:

```
MOV     R1.xw, -R2;
```

before

R1		R2	
0.0	x	7.0	x
0.0	y	3.0	y
0.0	z	6.0	z
0.0	w	2.0	w

after

R1		R2	
-7.0	x	7.0	x
0.0	y	3.0	y
0.0	z	6.0	z
-2.0	w	2.0	w

Vertex Programming Assembly Language

There are 27 instructions in total …

- ABS
- ADD
- ARL
- DP3
- DP4
- DPH
- DST
- EX2
- EXP
- FLR
- FRC
- LG2
- LIT
- LOG
- MAD
- MAX
- MIN
- MOV
- MUL
- POW
- RCP
- RSQ
- SGE
- SLT
- SUB
- SWZ
- XPD

Example Program #1

Simple Transform to CLIP space

```
!!ARBvp1.0

ATTRIB pos = vertex.position;
PARAM  mat[4] = { state.matrix.mvp };

# Transform by concatenation of the
# MODELVIEW and PROJECTION matrices.
DP4    result.position.x, mat[0], pos;
DP4    result.position.y, mat[1], pos;
DP4    result.position.z, mat[2], pos;
DP4    result.position.w, mat[3], pos;

# Pass the primary color through w/o lighting.
MOV    result.color, vertex.color;

END
```

Example Program #2

Simple ambient, specular, and diffuse lighting (single, infinite light, local viewer)

```
!!ARBvp1.0

ATTRIB iPos      = vertex.position;
ATTRIB iNormal   = vertex.normal;
PARAM  mvinv[4] = { state.matrix.modelview.invtrans };
PARAM  mvp[4]    = { state.matrix.mvp };
PARAM  lightDir = state.light[0].position;
PARAM  halfDir   = state.light[0].half;
PARAM  specExp   = state.material.shininess;
PARAM  ambientCol  = state.lightprod[0].ambient;
PARAM  diffuseCol  = state.lightprod[0].diffuse;
PARAM  specularCol = state.lightprod[0].specular;
TEMP   eyeNormal, temp, dots, lightcoefs;
OUTPUT oPos      = result.position;
OUTPUT oColor    = result.color;
```

Example Program #2

```
# Transform the vertex to clip coordinates.
DP4     oPos.x, mvp[0], iPos;
DP4     oPos.y, mvp[1], iPos;
DP4     oPos.z, mvp[2], iPos;
DP4     oPos.w, mvp[3], iPos;

# Transform the normal into eye space.
DP3     eyeNormal.x, mvinv[0], iNormal;
DP3     eyeNormal.y, mvinv[1], iNormal;
DP3     eyeNormal.z, mvinv[2], iNormal;

# Compute diffuse and specular dot products
# and use LIT to compute lighting coefficients.
DP3     dots.x, eyeNormal, lightDir;
DP3     dots.y, eyeNormal, halfDir;
MOV     dots.w, specExp.x;
LIT     lightcoefs, dots;

# Accumulate color contributions.
MAD     temp, lightcoefs.y, diffuseCol, ambientCol;
MAD     oColor.xyz, lightcoefs.z, specularCol, temp;
MOV     oColor.w, diffuseCol.w;
END
```

Program Options

- OPTION mechanism for future extensibility
- Only one option: ARB_position_invariant
  - Guarantees position of vertex is same as what it would be if vertex program mode is disabled
  - User clipping also performed
  - Useful for “mixed-mode multi-pass”
- At start of program
  - `OPTION ARB_position_invariant`
- Error if program attempts to write to result.position

Querying Implementation-specific Limits

- **Max number of instructions**

```
glGetProgramivARB( GL_VERTEX_PROGRAM_ARB,
    GL_MAX_PROGRAM_INSTRUCTIONS, &maxInsts );
```

- **Max number of temporaries**

```
glGetProgramivARB( GL_VERTEX_PROGRAM_ARB,
    GL_MAX_PROGRAM_INSTRUCTIONS, &maxTemps );
```

- **Max number of program parameter bindings**

```
glGetProgramivARB( GL_VERTEX_PROGRAM_ARB,
    GL_MAX_PROGRAM_PARAMETERS, &maxParams );
```

- **Others (including native limits)**

Query current program resource usage by removing “MAX_”

Generic vs. Conventional Vertex Attributes

- ARB_vertex_program spec allows for “fast and loose” storage requirements for generic and conventional attributes…
- Mapping between Generic Attributes and Conventional ones

- When a generic attribute is specified using glVertexAttrib*(), the current value for the corresponding conventional attribute becomes undefined
  - Also true for the converse

Generic vs. Conventional Vertex Attributes

- This allows implementations flexibility
- Mapping defined in the spec.
- Single programs may not access both

  A generic attribute register

  AND

  Its corresponding conventional attribute register

- Error if it attempts to

Generic and Conventional Attribute Mappings

Conventional Attribute	Generic Attribute
vertex.position	vertex.attrib[0]
vertex.weight	vertex.attrib[1]
vertex.weight[0]	vertex.attrib[1]
vertex.normal	vertex.attrib[2]
vertex.color	vertex.attrib[3]
vertex.color.primary	vertex.attrib[3]
vertex.color.secondary	vertex.attrib[4]
vertex.fogcoord	vertex.attrib[5]
vertex.texcoord	vertex.attrib[8]
vertex.texcoord[0]	vertex.attrib[8]
vertex.texcoord[1]	vertex.attrib[9]
vertex.texcoord[2]	vertex.attrib[10]
vertex.texcoord[3]	vertex.attrib[11]
vertex.texcoord[4]	vertex.attrib[12]
vertex.texcoord[5]	vertex.attrib[13]
vertex.texcoord[6]	vertex.attrib[14]
vertex.texcoord[7]	vertex.attrib[15]

In practice, probably use either conventional or generic not both

Wrap-Up

- Increased programmability
  - Customizable engine for transform, lighting, texture coordinate generation, and more.
- Widely available!
  - great, portable target for higher level abstractions
- Vendor extensions available for dynamic branching
  - will roll those into an ARBvp2 spec soon.

Questions?

- **cass@nvidia.com**