GeForce 6 Series OpenGL Extensions

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Overview

- Brief History of Programmability OpenGL
- Why extensions?
- New NVIDIA extensions for GeForce 6 series
  - NV_vertex_program3
  - NV_fragment_program2
  - Multiple draw buffers
  - Floating point filtering and blending
  - Render to vertex array
- Demos!

Why Extensions?

- Vendors want to expose as much hardware functionality as possible
- Lets early adopters try new features as soon as possible
- Proven functionality is then incorporated into multi-vendor extensions

Life of an Extension

- GL_NVX_foo – eXperimental
- GL_NV_foo – vendor specific
- GL_EXT_foo – multi-vendor
- GL_ARB_foo
- Core OpenGL

History of Programmability in OpenGL

EXT_texture_env_combine	
NV_register_combiners	GeForce 256
NV_vertex_program	GeForce 3
NV_texture_shader	GeForce 3
NV_texture_shader3	GeForce 4
NV_vertex_program2	GeForce FX
NV_fragment_program	GeForce FX
ARB_vertex_program	
ARB_fragment_program	

New Extensions

- Two new program extensions
  - NV_vertex_program3
  - NV_fragment_program2
- Superset of DirectX 9 VS 3.0 and PS 3.0 functionality
- Exposed as options to ARB_vertex_program / ARB_fragment_program
  - `OPTION NV_vertex_program3;`
  - `OPTION NV_fragment_program2;`
  - No new entry points, can use named parameters, temporaries etc.
  - Previous program exts. also now available as options
- Functionality will also be exposed in Cg 1.3 and the OpenGL Shading Language

GL_NV_vertex_program3

- New features:
- Textures lookups in vertex programs!
- Index-able vertex attributes and result arrays
  - `MOV R0, vertex.attrib[A0.x+3];`
  - `MOV result.texcoord[A0.x+7], R0;`
  - More flexible skinning, animation (blend shapes)
- Additional condition code register (2 total)
- Can push/pop address registers on stack
  - For loop nesting, subroutine call / return
  - `PUSHA A0; POPA A0;`
- Up to 512 instructions

Vertex Texture

- Supports mip-mapping
  - Need to calculate LOD yourself
  - Use TXL instruction (explicit LOD)
- Currently supports GL_NEAREST filtering only
  - Can do own filtering in shader if necessary
- Multiple vertex texture units
  - `glGetIntegerv(MAX_VERTEX_TEXTURE_IMAGE_UNITS_ARB)`
  - 4 units supported on GeForce 6800
- Uses standard 2D texture targets
  - `glBindTexture(GL_TEXTURE_2D, displace_tex);`
- Currently must use `LUMINANCE_FLOAT32_ATI` or `RGBA_FLOAT32_ATI` texture formats

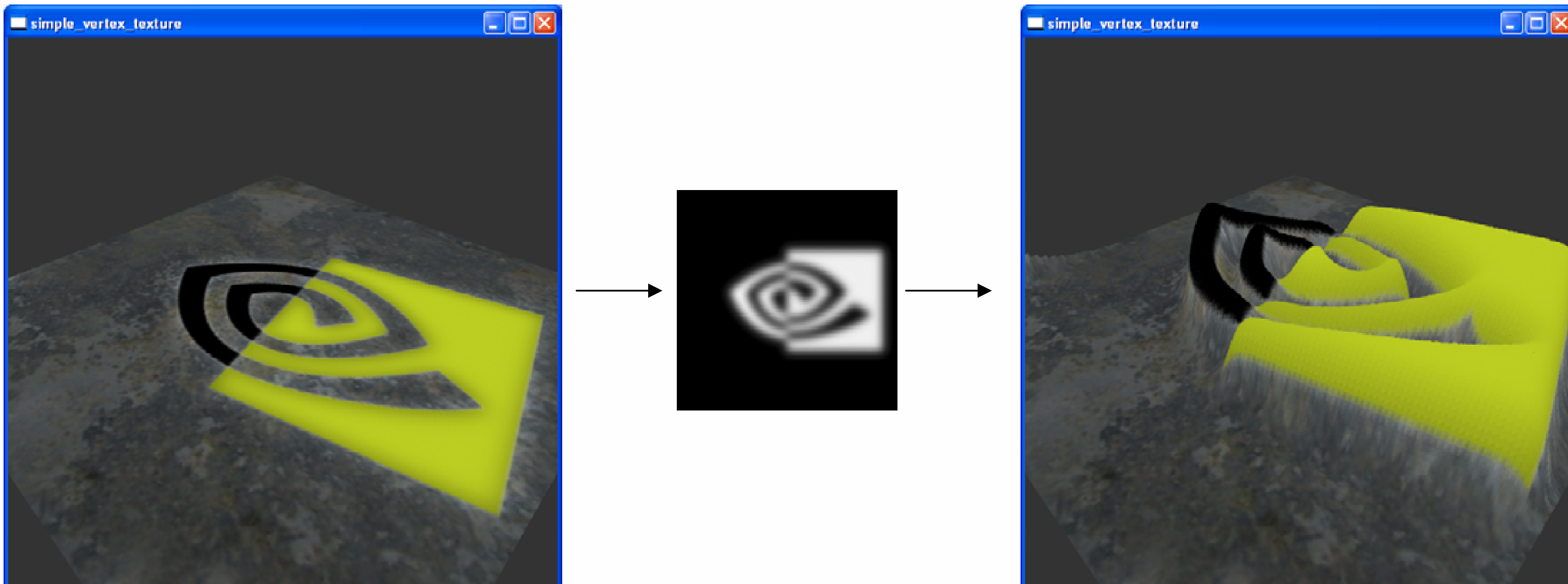
Vertex Texture Applications

- Simple displacement mapping
  - Note – not real adaptive displacement mapping
  - Hardware doesn't tessellate for you
  - Terrain, ocean surfaces
- Render to vertex texture
  - Provides feedback path from fragment program to vertex program
- Particle systems
  - Calculate particle positions using fragment program, read positions from texture in vertex program, render as points
- Character animation
  - Can do arbitrarily complex character animation using fragment programs, read final result as vertex texture
  - Not limited by vertex attributes – can use lots of bones, lots of blend shapes
- Vertex textures are NOT practical for use as extra constant memory

Vertex Texture Example

```
!!ARBvp1.0
OPTION NV_vertex_program3;
PARAM mvp[4] = { state.matrix.mvp };
PARAM scale = program.local[0];
TEMP pos, displace;
# vertex texture lookup
TEX displace, vertex.texcoord, texture[0], 2D;
MUL displace.x, displace.x, scale;
# displace along normal
MAD pos.xyz, vertex.normal, displace.x, vertex.position;
MOV pos.w, 1.0;
# transform to clip space
DP4 result.position.x, mvp[0], pos;
DP4 result.position.y, mvp[1], pos;
DP4 result.position.z, mvp[2], pos;
DP4 result.position.w, mvp[3], pos;
MOV result.color, vertex.color;
MOV result.texcoord[0], texcoord;
END
```

Vertex Texture Demo



GL_NV_vertex_program3 Performance

- Branching
  - Dynamic branches only have ~2 cycle overhead on GeForce 6800
    - Even if vertices take different branches (MIMD hardware)
    - Use this to avoid unnecessary vertex work (e.g. skinning)
- Vertex texture
  - Look-ups are not free!
  - Only worth using vertex texture it if texture coordinates or texture contents are dynamic
    - otherwise values could be baked into vertex attributes
  - Coherency of texture access affects performance
    - If you don’t need random access, may be get better performance using render to vertex array with VBO/PBO
- Try to cover texture fetch latency with other non-dependent instructions

Covering Vertex Texture Fetch Latency

```
!!ARBvp1.0
OPTION NV_vertex_program3;
PARAM mvp[4] = { state.matrix.mvp };
PARAM scale = program.local[0];
TEMP pos, displace;
# vertex texture lookup
TEX displace, vertex.texcoord, texture[0], 2D;
MUL displace.x, displace.x, scale;
# displace along normal
MAD pos.xyz, vertex.normal, displace.x, vertex.position;
MOV pos.w, 1.0;
# transform to clip space
DP4 result.position.x, mvp[0], pos;
DP4 result.position.y, mvp[1], pos;
DP4 result.position.z, mvp[2], pos;
DP4 result.position.w, mvp[3], pos;
MOV result.color, vertex.color;
MOV result.texcoord[0], texcoord;
END
```

GL_NV_fragment_program2

- New features:
- Branching
  - Limited static and data-dependent branching
  - Fixed iteration-count loops
- Subroutine calls: CAL, RET
- New instructions: NRM, DIV, DP2
- Texture lookup with explicit LOD (TXL)
- Indexed input attributes
- Facing register (front / back)
  - can be used for two-sided lighting
- Up to 65,536 instructions

Instruction Set

ABS	absolute value
ADD	add
BRK	break out of loop instruction
CAL	subroutine call
CMP	compare
COS	cosine with reduction to [-PI,PI]
DDX	partial derivative relative to X
DDY	partial derivative relative to Y
DIV	divide vector components by scalar
DP2	2-component dot product
DP2A	2-comp. dot product w/scalar add
DP3	3-component dot product
DP4	4-component dot product
DPH	homogeneous dot product
DST	distance vector
ELSE	start if test else block
ENDIF	end if test block
ENDLOOP	end of loop block
ENDREP	end of repeat block
EX2	exponential base 2
FLR	floor
FRC	fraction
IF	start of if test block
KIL	kill fragment
LG2	logarithm base 2
LIT	compute light coefficients
LOOP	start of loop block
LRP	linear interpolation
MAD	multiply and add
MAX	maximum
MIN	minimum
MOV	move
MUL	multiply
NRM	normalize 3-component vector
PK2H	pack two 16-bit floats
PK2US	pack two unsigned 16-bit scalars

PK4B	pack four signed 8-bit scalars
PK4UB	pack four unsigned 8-bit scalars
POW	exponentiate
RCP	reciprocal
REP	start of repeat block
RET	subroutine return
RFL	reflection vector
RSQ	reciprocal square root
SCS	sine/cosine without reduction
SEQ	set on equal
SFL	set on false
SGE	set on greater than or equal
SGT	set on greater than
SIN	sine with reduction to [-PI,PI]
SLE	set on less than or equal
SLT	set on less than
SNE	set on not equal
STR	set on true
SUB	subtract
SWZ	extended swizzle
TEX	texture sample
TXB	texture sample with bias
TXD	texture sample w/partials
TXL	texture same w/explicit LOD
TXP	texture sample with projection
UP2H	unpack two 16-bit floats
UP2US	unpack two unsigned 16-bit scalars
UP4B	unpack four signed 8-bit scalars
UP4UB	unpack four unsigned 8-bit scalars
X2D	2D coordinate transormation
XPD	cross product

Fragment Program Branching

- Three types of instruction blocks
  - LOOP / ENDLOOP
    - Uses loop index register A0.x
  - REP / ENDREP
    - Repeats a fixed number of times
  - IF / ELSE / ENDIF
    - Conditional execution based on condition codes
- BRK instruction can be used to conditionally exit loops or exit shader early
- Blocks may be nested

Looping Limitations

- Loop count cannot be computed at runtime
  - Must be a program parameter (i.e. constant)
- Number of iterations & nesting depth are limited
- Loop index register A0.x only available inside current loop
  - can only be used to index vertex attributes
  - if you want to do something else you can maintain your own loop counter
- Can't index into constant memory in fragment programs
  - Can read data from texture instead
  - Think of texture as fragment program's random access read-only memory

Branching Examples

```
LOOP {8, 0, 1};         # loop count, initial, increment
  ADD R0, R0, fragment.texcoord[A0.x];
ENDLOOP;

REP repCount;
  ADD R0, R0, R1;
ENDREP;

MOVC RC, R0;
IF GT.x;
  MOV R0, R1;           # executes if R0.x > 0
ELSE;
  MOV R0, R2;           # executes if R0.x <= 0
ENDIF;
```

Subroutine Calls

- CAL
  - Call subroutine, pushes return address on stack
- RET
  - address is popped off stack, execution continues at return address
  - execution stops if stack is empty, or overflows
  - can use as early exit from top level
- Note – no data stack
  - No recursion!
- Labels
  - Name followed by colon
  - Execution will start at “main:” if present

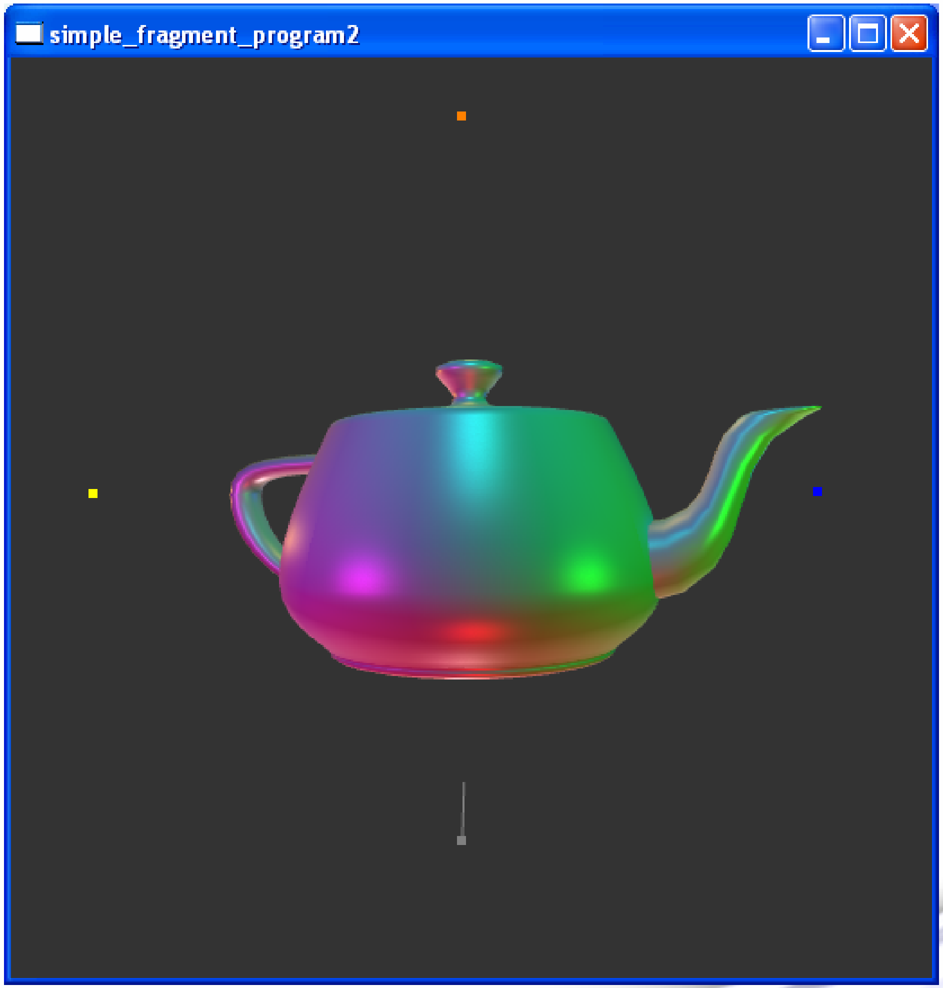
Looping Example

```
!!ARBfp1.0
OPTION NV_fragment_program2;
...
# loop over lights
MOV lightIndex.x, 0.0;
REP nlights;
    TEXC lightPos, lightIndex, texture[0], RECT;   # read light pos from texture
    TEX lightColor, lightIndex, texture[1], RECT;  # read light color from texture
    IF EQ.w;                                       # lightPos.w == 0
        CAL dirlight;
    ELSE;
        CAL pointlight;
    END
    ADD lightIndex.x, lightIndex, 1.0;             # increment loop counter
ENDREP;
MOV result.color, color;
RET;

pointlight:
…
RET;

dirlight:
…
RET
```

Fragment Program Branching Applications

- “Uber” shaders
  - Avoids writing separate shaders for different numbers, types of lights
  - Can help to increase batch size
- Image processing
  - Variable width filters
  - For fixed width, probably faster to unroll loops
- Early exit in complex shaders
  - Ray tracing
  - Volume rendering
    - can stop marching along ray when pixel is opaque
  - GP-GPU simulations

Multiple Lights Demo



Fragment Program Branching Performance

- Static branching is fast
  - But still may not be worth it for short branches (less than ~5 instructions)
  - Can use conditional execution instead
- Divergent (data-dependent) branching is more expensive
  - Depends on spatial coherency of branching - which pixels take which branches

More Performance Tips

- Use half-precision where possible
  - `OPTION ARB_precision_hint_fastest`
  - or
  - `SHORT TEMP normal;`
- Use NRM instruction for normalizing vectors, rather than DP3/RSQ/MUL
  - Very fast for half-precision data
- Always use write masks
  - `mul r0.x, r0.x, r2.w` (not `mul r0, r0.x, r2.w`)

Floating Point Filtering and Blending

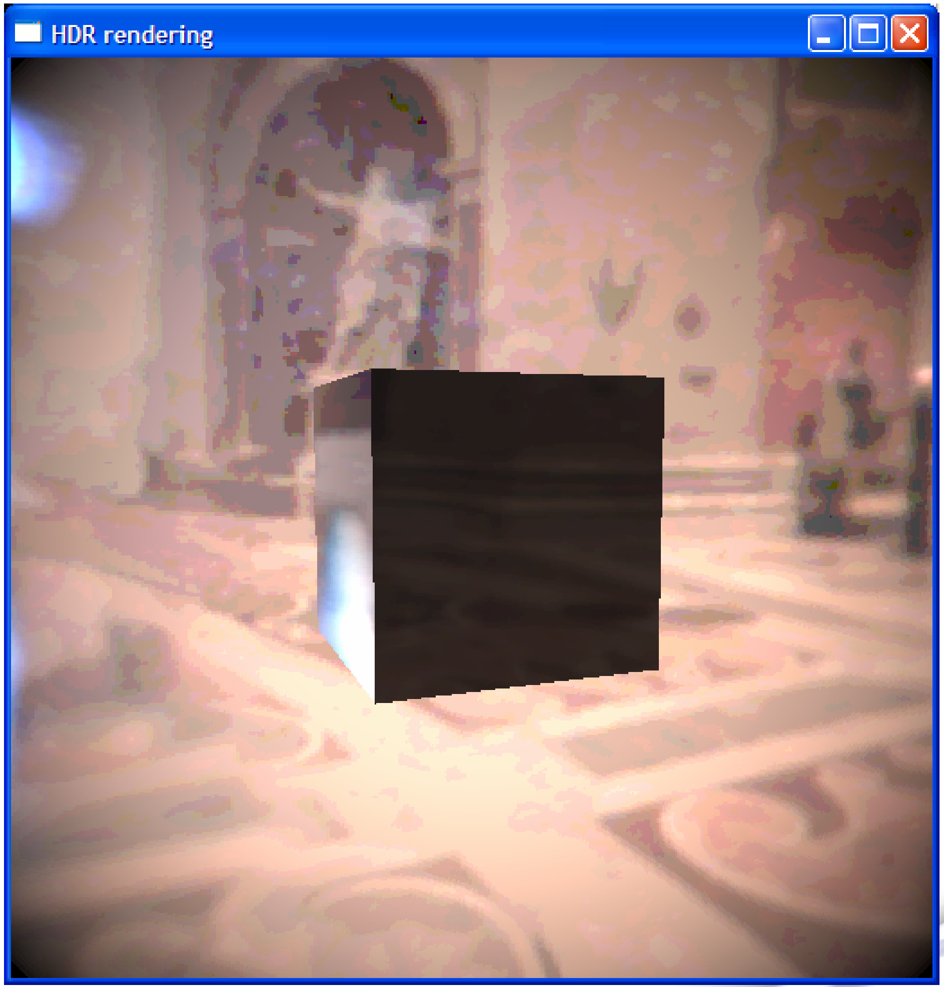
- GeForce 6 series has fully-featured support for floating point textures
  - Supports all texture targets, including cube maps, non-power-of-2 textures with mip-maps
  - Texture filtering for 16-bit float formats – including tri-linear, anisotropic filtering
  - Blending for 16-bit float formats – all blending modes supported
- Exposed currently using ATI extensions:
  - GL_ATI_texture_float
  - WGL_ATI_pixel_format_float
  - These will be replaced with new ARB float extensions

FP16 Blending Example

FP16 Applications

- High-Dynamic-Range Imagery
  - 16-bit integer texture formats are not enough for very high dynamic ranges – can cause banding
- Multi-pass algorithms
  - e.g. one pass per light
- Interactive HDR paint
  - fp16 Photoshop

HDR With Int 16 Format



Dynamic range: 200,000:1

HDR With FP 16 Format

Dynamic range: 200,000:1

Multiple Draw Buffers

- Equivalent to Direct3D Multiple Render Targets (MRT)
- Exposed via *ATI_draw_buffers* extension
- Allows outputting up to 4 colors from a fragment program in a single pass:

```
MOV result.color[0], color;
MOV result.color[1], N;
MOV result.color[2], pos;
MOV result.color[3], H;
```

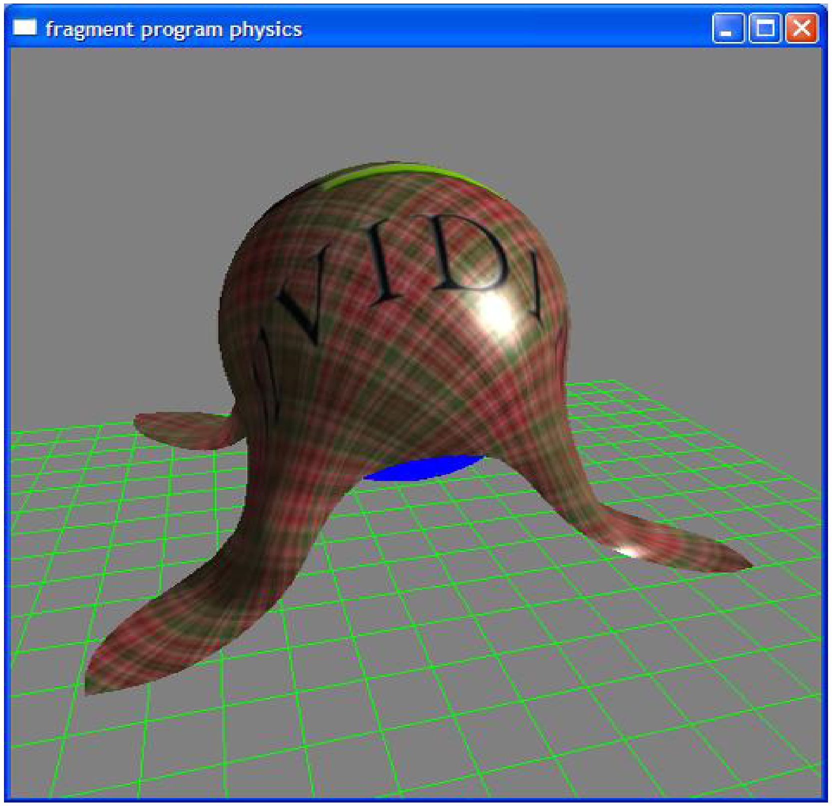
- Outputs are written to GL_AUX buffers
  - Need to request a pixel format with aux buffers
  - All must be same format, share a single depth buffer
  - AUX buffers are allocated lazily to save memory
- Useful for deferred shading, reducing number of passes in general purpose algorithms
- Supported in Cg 1.3, GLslang soon

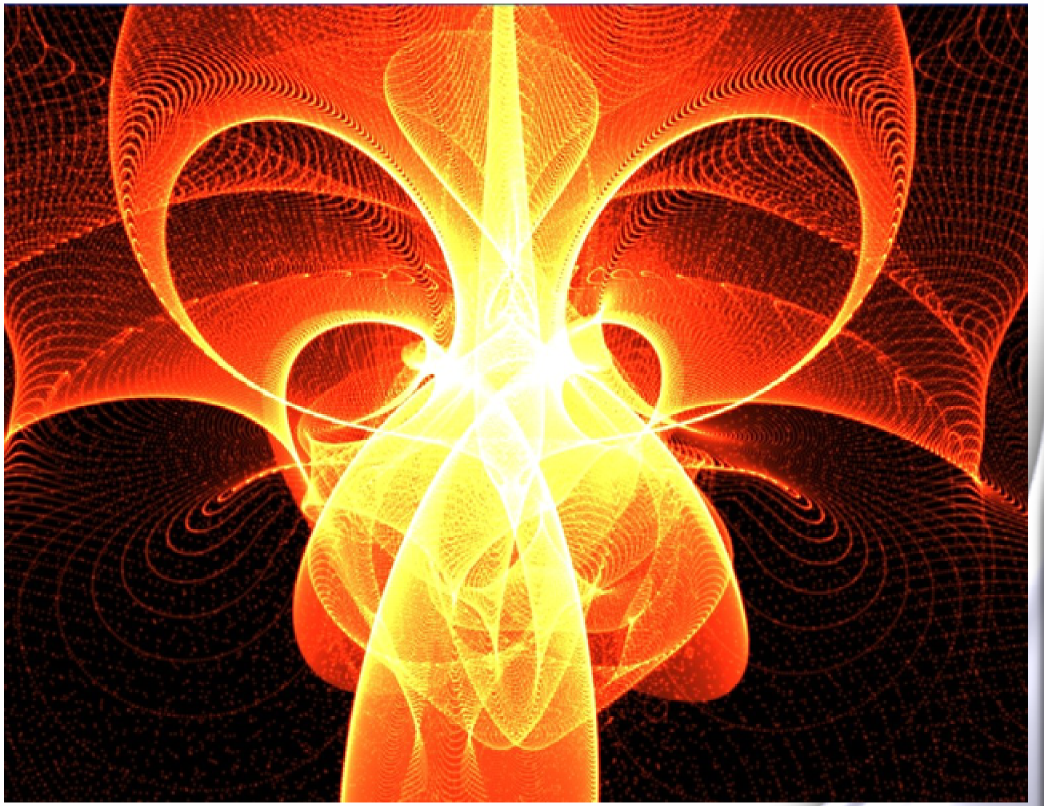
Draw Buffers Example

Render To Vertex Array

- Allows the GPU to interpret floating point frame buffer data as geometry – data stays resident on GPU
- Applications
  - GPU-based simulation – cloth, particles, soft bodies
- 3 possible implementations today:
  - VAR / PDR
    - presented at GDC 2003 for cloth simulation, now obsolete
  - VBO / PBO
    - uses new vertex / pixel buffer object extensions
    - works on all NV3x hardware
    - fast – 90M vertices / second measured on GeForce 6800!
  - Vertex texture (NV_vertex_program3)
    - easy, only works with GeForce 6 series
- Uber/super buffers extension coming soon

Render To Vertex Array Examples





Render To Vertex Array using VBO/PBO

- **Create buffer object for each vertex attribute you want to render to**
  - **use GL_STREAM_COPY usage flag**
- **Bind buffer object to pixel pack (destination) buffer**
- **Render vertex data to floating point pbuffer**
- **Do *glReadPixels* from pbuffer to buffer object**
  - **Implemented as fast copy in video memory by the driver**
- **Bind buffer object to vertex array**
- **Set vertex array pointers**
- **Draw geometry**
- **There will be example code in the new SDK**

Conclusion

- NV_vertex_program3 and NV_fragment_program2 expose the latest in programmable shading in OpenGL
- Available on Windows, Linux and MacOS (soon)
- Functionality will be available in vendor-independent extensions and OpenGL Shading Language
- Start thinking about these features now, future hardware will be even faster and more flexible
- Check out
  http://developer.nvidia.com/object/nvidia_opengl_specs.html