NVIDIA®

GeForce 8800 OpenGL Extensions

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Roadmap

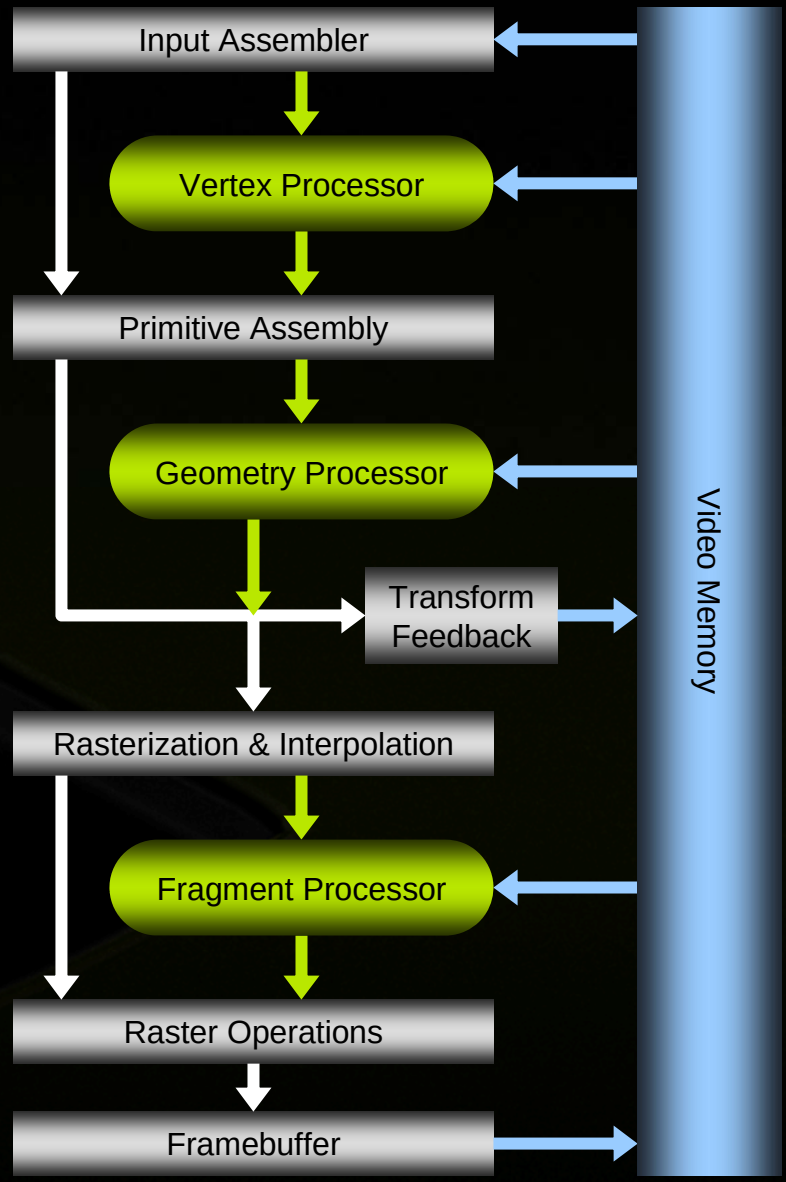
- What's different
- The programmable core
- Feeding it
- New pathways
- The backend

GeForce 8800 Differences

- Pipeline modifications
  - Additional geometry shader stage
  - Feedback available midstream
- Unified shading hardware
  - Same instructions and characteristics across shaders

GeForce 8800 OpenGL Pipeline

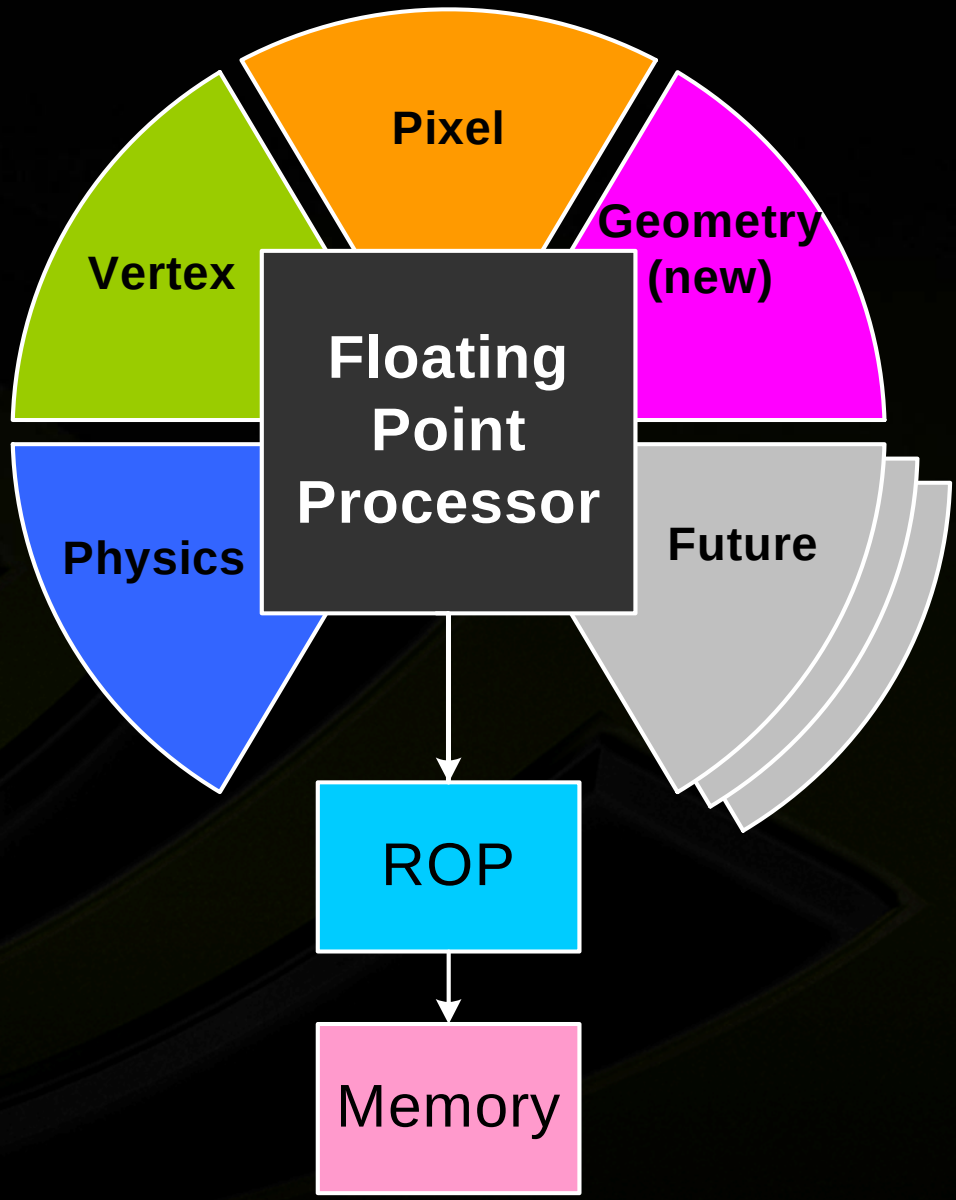
- More flexible memory access model
  - Multiple ways to read and write
- Additional pipeline stages
  - Fundamentally new capabilities



Fixed / Built in stream
Programmable stream
Video memory IO

Fixed stage
Programmable stage
Memory

Unified Shaders



Programmability

- #1 design concern of all extensions
  - Efficient for input
  - Efficient for computation
  - Efficient for output
- No concessions for fixed-function
  - Only the right choices for programmability
  - Most will not work with the fixed function pipeline

New Capabilities

- Unified instruction set for programs
- Integer instructions and data types
- Uniform set of structured branching constructs
- Indexable constants and temporaries
- New texture fetching instructions
- Attribute interpolation control
  - Flat shaded, perspective-incorrect or centroid sampled

New OpenGL Program Extensions

- OpenGL Shading Language
  - EXT_gpu_shader4
    - GLSL extension for fourth generation shaders
- ARB_vertex_program style asm-like programs
  - NV_gpu_program4
    - NV_vertex_program4
    - NV_fragment_program4
    - NV_geometry_program4
- Cg 2.0
  - Not a GL extension
  - Will support the capabilities

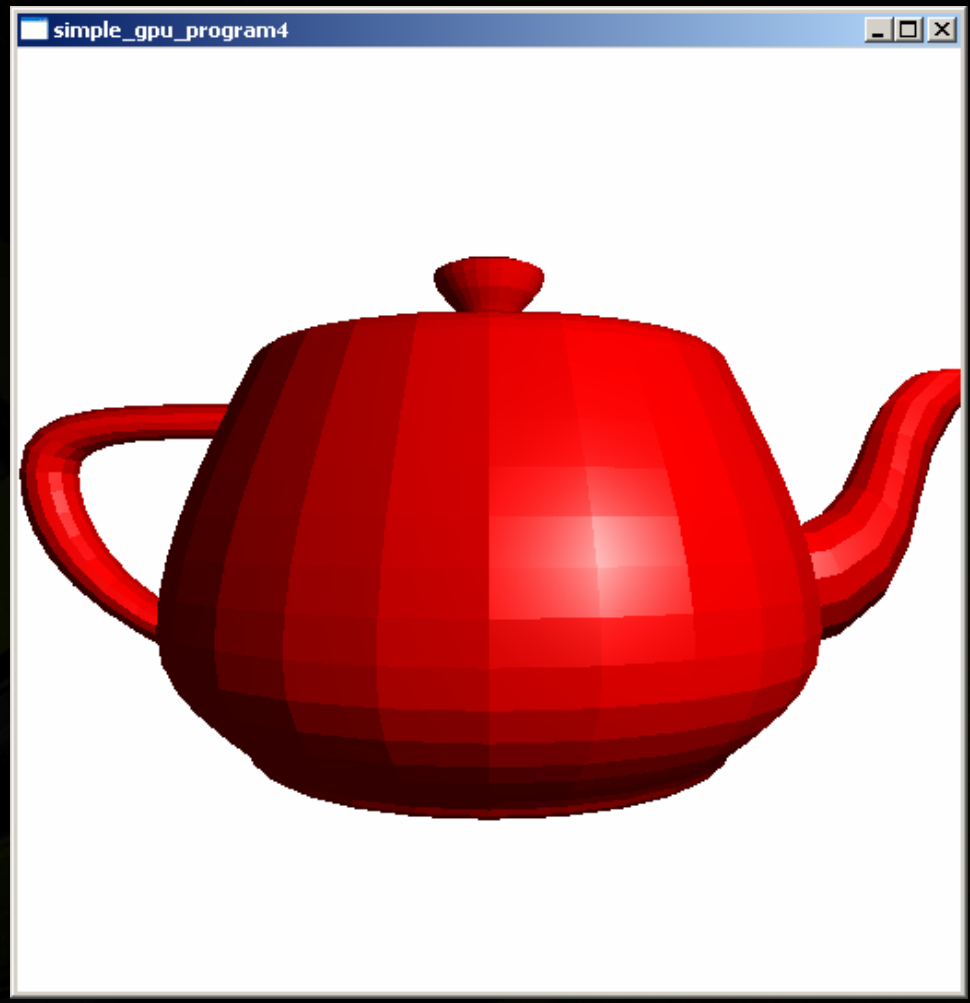
GL_EXT_gpu_shader4

- New integer support
  - unsigned int, uvec2, uvec3, uvec4
  - Integer varying and attributes
  - Integer texture samplers: isampler*, usampler*
  - Real integer ops
    - %, &, |, ^, >>, <<, ~

GL_EXT_gpu_shader4 cnt'd

- Extends varying type qualifiers
  - Centroid – keeps the value inside the covered region
  - Flat – no interpolation, like flat shading
  - Noperspective – interpolate in screen-space

Flat interpolation



GL_EXT_gpu_shader4 cnt'd

- Instancing and procedural generation
  - gl_VertexID
    - Integer index derived from glDrawElements, etc
    - Only with vertex arrays (no display lists)
    - Only when using VBOs
  - gl_InstanceID
    - Integer index of the current primitive
    - Only available when using DrawElementsInstancedEXT
  - gl_PrimitiveID
    - Integer describing the primitive number

GL_EXT_gpu_shader4 cnt'd

- User-defined output variables
  - Declared as "varying out"
  - Allow more flexible outputs from the fragment shader
    - Integers
    - Integers and floats simultaneously
  - Used instead of gl_FragColor or gl_FragData

GL_EXT_gpu_shader cnt'd

- Exact texel fetches
  - texelFetch*(sampler, icoord, lod)
  - Treats a texture as a directly addressable array of texels
- Texture size query
  - textureSize*(sampler, lod)
  - Returns the dimensions of the texture level
- Shadow cubemaps
  - Depth is compared against the 4^{th} component
- Texture Gradient fetches
  - texture*Grad(sampler, coord, dx, dy)
  - Allows custom lod/anisotropy control

GL_EXT_gpu_shader4 cnt'd

- Offset texture fetches
  - texture*Offset(sampler, coord, offset)
  - Offset must be compile-time constant expression
  - Allow convenient shortcut for building filter kernels
  - Offset size has an implementation dependent limit

GL_NV_gpu_program4

- Composed of three sub-extensions
  - GL_NV_vertex_program4
  - GL_NV_fragment_program4
  - GL_NV_geometry_program4
- Still based on 4-wide registers
  - No longer really matches HW
  - Enhances backward compatibility
- Provides same capabilities as EXT_gpu_shader4

Feeding the Shader

- Instancing
  - Optimized rendering of multiple copies of an object
- New texture types
  - Texture arrays
- New texture formats
  - Integer textures
  - Additional HDR formats
- Data buffers
  - Fast flexible ways to swap blocks of constants
- Texture buffers
  - Massive data store for shaders

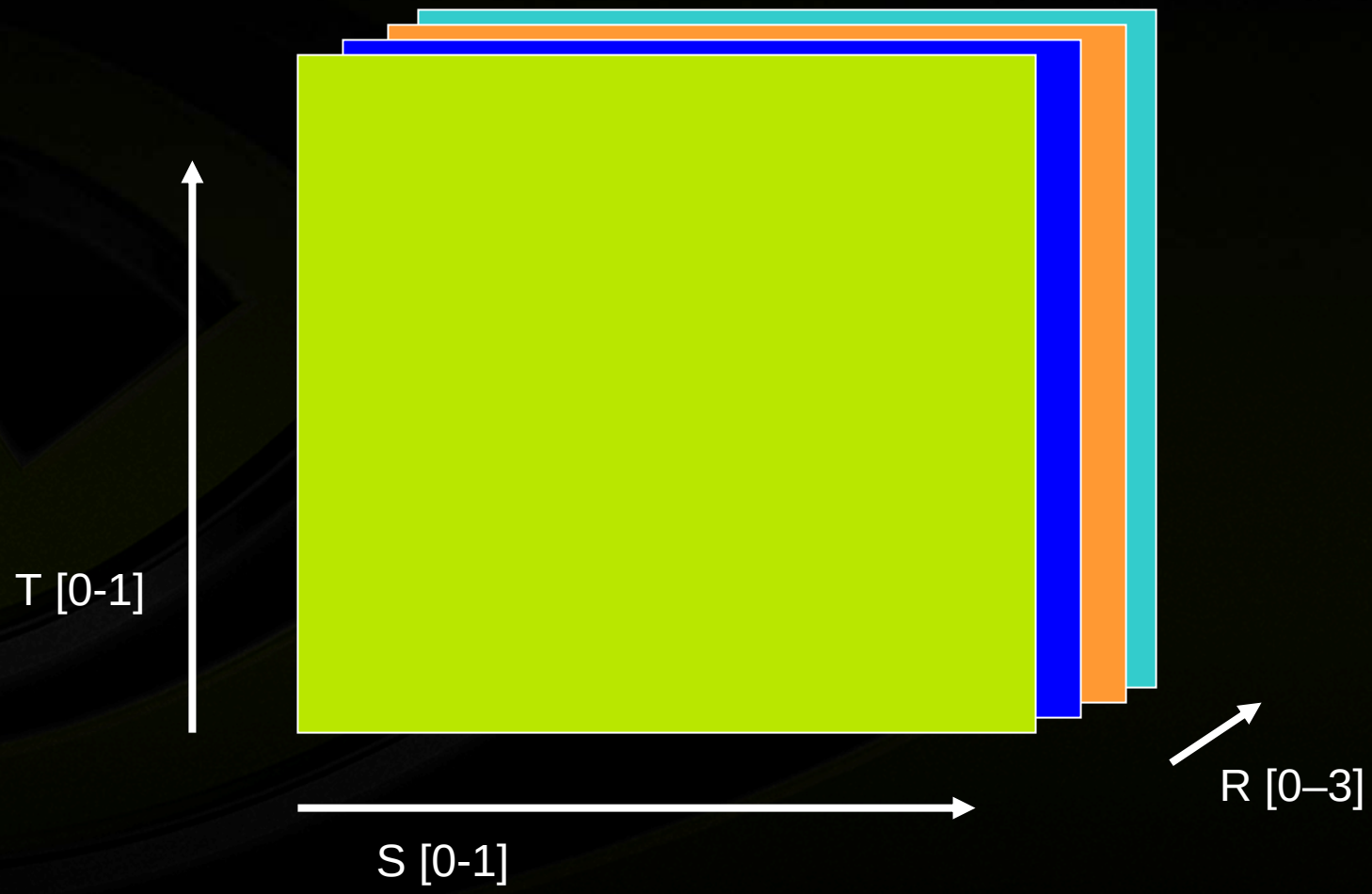
EXT_draw_instanced

- Efficient rendering for large numbers of objects
- Vertex array only
  - glDrawArraysInstancedEXT
  - glDrawElementsInstancedEXT
- Draw calls take one additional parameter
  - # of instances to draw
- Each instance has a separate instance ID
  - Used by the shader to change behavior
    - Select transform matrix
    - Select material
- Clever shaders can even draw different objects

EXT_texture_array

- Array Textures
- Generalizes 1D and 2D textures to consist of an array of 1D or 2D textures
  - 1D array loaded using glTexImage2D
  - 2D array loaded using glTexImage3D
- Array indexable from shader program
  - Access layer using r texture coordinate
- Layers must be same size and format
- No filtering between layers
- Arrays of cubemaps not currently supported
- Removes need for texture atlases
  - Useful for instancing, terrain texturing

Array Textures Cont'd



Texture Format Extensions

- EXT_texture_integer
  - Adds integer texture formats
- EXT_packed_float
  - Space-efficient float format
  - Relatively low precision
    - More than good enough most times
- EXT_texture_shared_exponent
  - Space-efficient float format
  - Variable accuracy
    - Can be more or less accurate than packed float
    - Also more than good enough

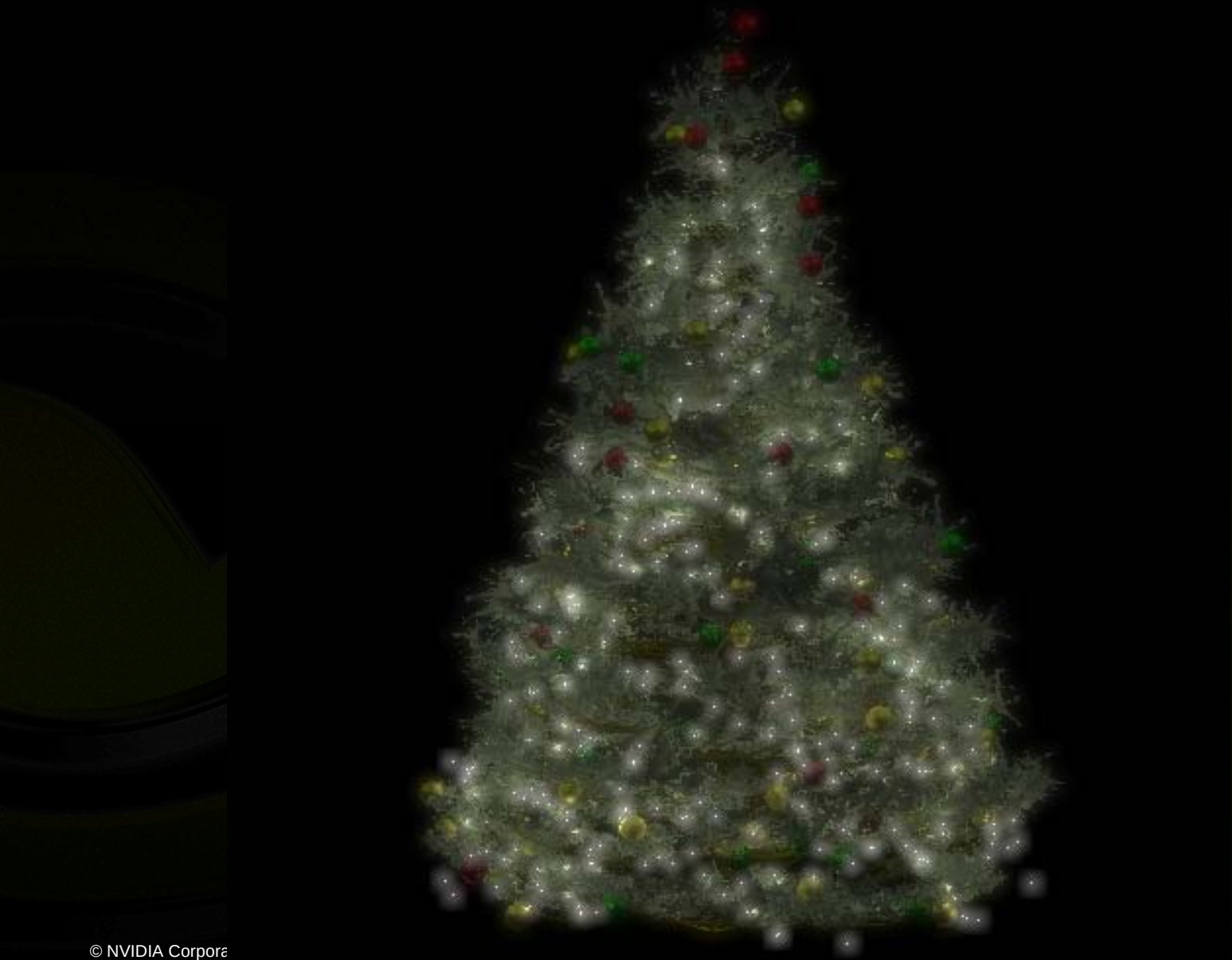
Integer texture formats

- EXT_texture_integer
  - Adds integer texture formats
  - 8, 16, and 32 bit per component
  - Signed and unsigned
  - RGB, RGBA, Luminance, Alpha, Intensity, and LA
  - Lack filtering support
  - Only available with EXT_gpu_shader4 / NV_gpu_program4
- Uses
  - Bitfields
  - Color index emulation
  - Lookup tables

Packed Float Textures

- EXT_packed_float
  - 11/11/10 floating point format
  - 5 bit exponent per component
    - Bias of -15
  - Only supports positive values (no sign bit)
  - Can be used as framebuffer format
  - Max values
    - R/G – 65024
    - B – 64512
  - Size advantage can make it much faster than float16
  - Supports filtering, blending, and MSAA

Packed Float Texture Usage



RGBE / Shared Exponent textures

- EXT_texture_shared_exponent
  - 9/9/9/5 RGBE format
  - Similar to Radiance 8/8/8/8 RGBE format
  - Shared 5 bit exponent (bias of -15)
  - Source texture format only (not renderable to)
  - Only supports positive values (no sign bit)

New compressed texture formats

- EXT_texture_compression_latc
  - Good format for greyscale w/ alpha compression
  - 8-bits per texel
  - Stored in 4x4 blocks (like DXT formats)
  - Components are compressed independently
- EXT_texture_compression_rgtc
  - Same properties as latc
  - Returns (r,g,0,1) instead of (l,l,l,a)
  - Useful for normal map compression
    - (x,y) = 2 * (r,g) – 1
    - $Z = \mathrm{sqrt}(1 – (x^2 + y^2))$

OpenGL Data Buffer Extensions

- EXT_bindable_uniform
  - Used with EXT_gpu_shader4
  - Allows a uniform to be bound to a buffer object
  - Quickly switch all values in a large structure or array
- NV_parameter_buffer_object
  - Used with NV_gpu_program4
  - Defines new object containing banks of uniform parameters
  - Enables rendering to parameter buffers
  - Useful for instancing
  - Provides a very large parameter store

EXT_texture_buffer_object

- Bind buffer object as a texture
- Jumbo 1D texture
  - Larger size limit (128 Mtexels)
- Does not support filtering
- Addressed by element
  - Not normalized [0-1]
- Limited format support
  - No RGB support (RGBA is OK)
  - Minimum of 1 byte per component
  - No compressed formats

Texture buffer usage

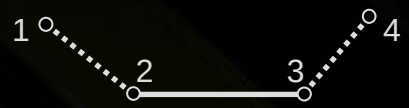
- Large constant store
  - Significantly larger than EXT_bindable_uniform
  - Jumbo bone list for skinning
- Instancing data
  - Transform matrices
  - Materials
- Custom indexing
  - Separate ‘index’ for position, normal, texture coordinate
  - Less efficient than normal vertex fetching
    - Not as coherent
  - Can be useful interactive editing due to reduced sw cost

New Pathways

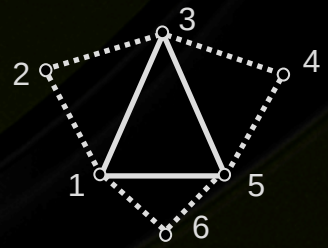
- Geometry Shaders
  - New pipeline stage
- Render target arrays
  - Geometry shader indexing of texture arrays
- Transform feedback
  - Export vertices mid-stream

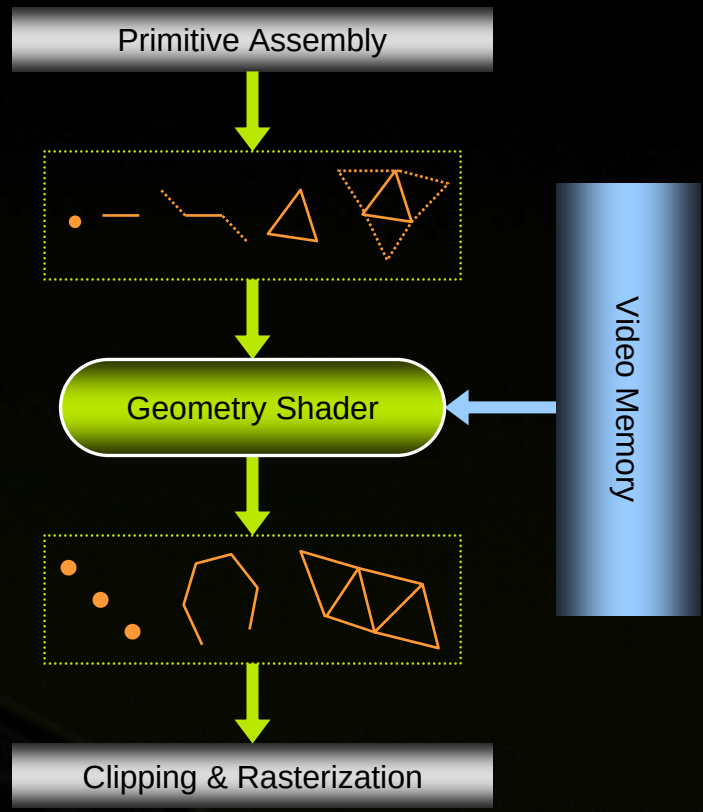
Geometry Shader Basics

- Input
  - Standard primitives
    - point, line, triangle…
  - New primitive types include neighboring vertices
    - Line with adjacency



    - Triangle with adjacency





- Output
  - Unique output type (independent from input type)
  - Points, line strips or triangle strips
  - Can output zero or more primitives
  - Generated primitive stream is in the same order as inputted

Geometry Shader Applications

- Better point sprites
  - Rotation, non-square, motion blur
- Simple subdivision
- Single pass cube map creation
- Automatic stencil shadow polygon generation
- Fur rendering
  - Fin generation
- Curve rendering
  - 2D rendering, hair/fur
- Particle systems
- GPGPU
  - Data amplification – variable number of outputs

Geometry Shader Extensions

- EXT_geometry_shader4
  - GLSL geometry shaders
- NV_geometry_shader4
  - Adds to EXT_geometry_shader4
- NV_geometry_program4
  - ARB_vertex_program style
  - Part of NV_gpu_program4

EXT_geometry_shader

- New link-time parameters
  - Primitive input and output type
  - Max vertices output
- New shader variables
  - gl_VerticesIn – number of input vertices
  - gl_Layer – texture array layer target
  - gl_PrimitiveID – Set primitive ID seen by the fragments
  - gl_PrimitiveIDIn – Primitive ID based on input prims

EXT_geometry_shader code

```
varying in vec3 eyeNormal[gl_VerticesIn];

varying out vec3 oEyeNormal;

for ( int i = 0; i < gl_VerticesIn; i++) {
    oEyeNormal = eyeNormal[i];
    //causes all output varying to submit
    EmitVertex();
}

//Start a new strip
RestartPrimitive();
```

NV_geometry_shader4

- Relax restrictions of EXT_geometry_shader4
  - Changing input/output primitive without a relink
  - Changing max output vertices without a relink
- Defines additional behavior
  - Quads and polygons at turned into triangles
    - Shader accepting triangle accepts quads

NV_geometry_program4

- Same capabilities as geometry_shader4
- ARB_vertex_program style syntax
- Inputs are ‘ATTRIB’
- Outputs are ‘RESULT’
- Input primitive, output primitive, and max vertices
  - Declared in the shader

Rendering to Texture Arrays

- Can select destination layer for each primitive in geometry program
  - Write to “gl_Layer” or “result.layer”
- Can be used for single-pass render-to-cubemap
  - Read input triangle
  - Output to 6 cube map faces, transformed by correct face matrix
  - No real savings for GPU
    - Same transform and rasterization load
    - Additional geometry shader work
  - Simple culling may help

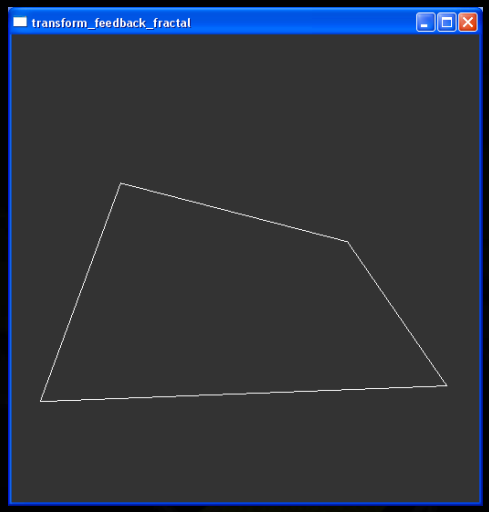
EXT_transform_feedback

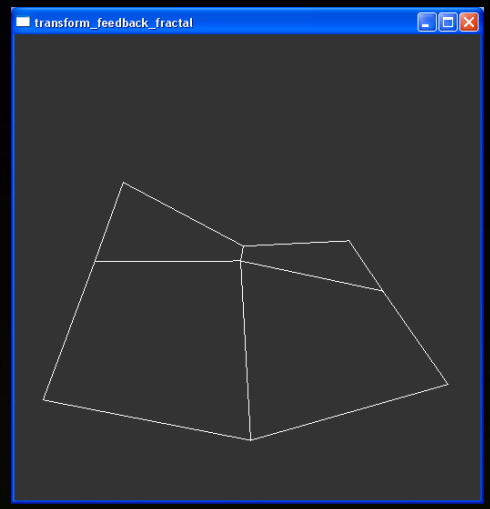
- Allows storing output from a vertex program or geometry program to buffer object
- Enables multi-pass operations on geometry, e.g.
  - Store results of animation (skinning) to buffer, reuse for multiple lights
  - Recursive subdivision
- Provides queries for number of primitives generated by geometry program

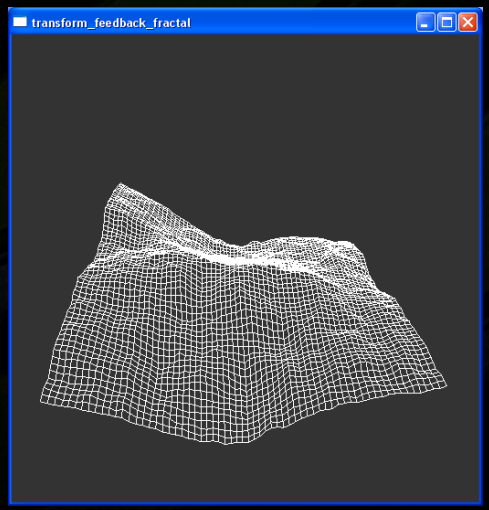
Example: Terrain Subdivision

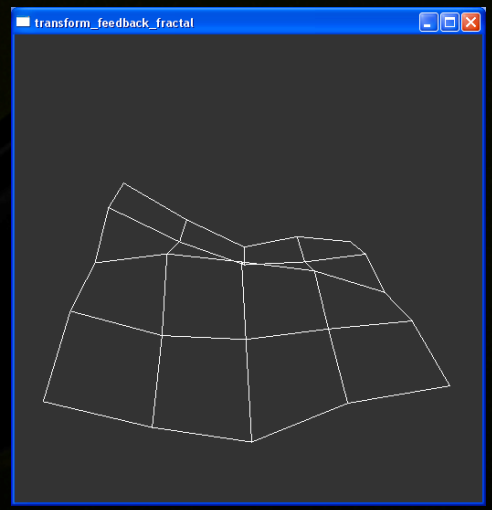
- Takes quad as input (actually line_adj primitive)
- Geometry program subdivides into 4 new quads using diamond-square subdivision
- Uses two VBOs, reads from one, writes to the other using transform feedback
- Then swap

Terrain Subdivision









The backend

- Floating point depth buffers
- EXT_draw_buffers2
- sRGB Framebuffers
- Coverage sample anti-aliasing

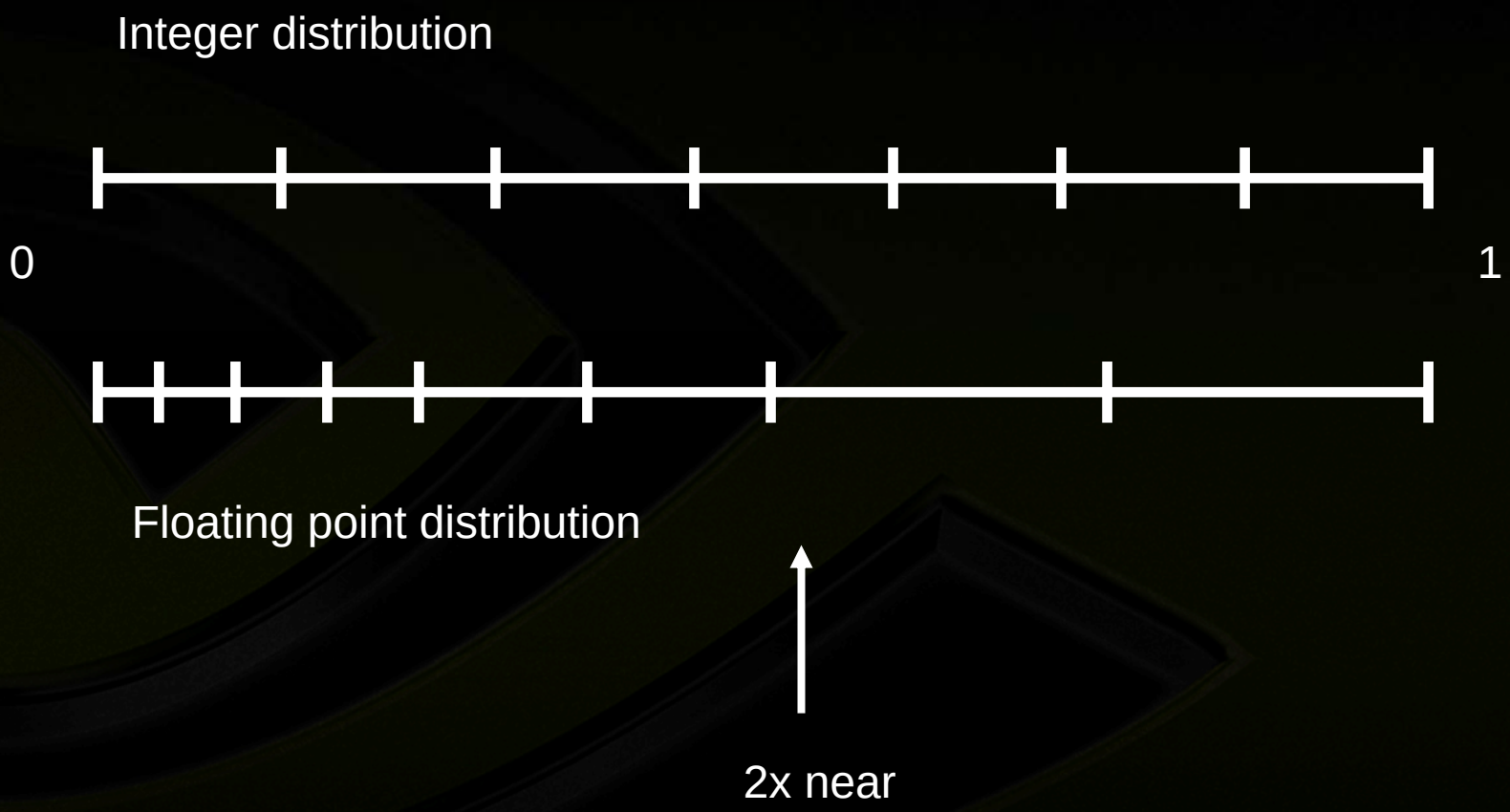
NV_depth_float

- Provides floating point depth buffers and textures
- Range extended to [–MAX_FLOAT, MAX_FLOAT]
- New functions for non-normalized values
  - glDepthRangedNV
  - glClearDepthdNV
  - glDepthBoundsdNV
- Multiple formats
  - DEPTH_COMPONENT32F_NV
  - DEPTH32F_STENCIL8_NV
- FBO only
- Care must be taken in using the extra precision

Float depth precision

- Normal [0-1] mapping is ineffective
  - Precision bunches up at 0
    - Logarithmic distribution of floats
    - 24 bits of precision [0.5 (2^-1) – 1.0 (2^0)]
  - Perspective projection pushes scene toward 1
    - 2x near maps to roughly 0.5
    - 90%+ of scene [0.5 – 1.0] range
  - Effectively a 25-bit depth buffer
- Changing to [0-256] is no better
  - [128 – 256] has the same 24-bits

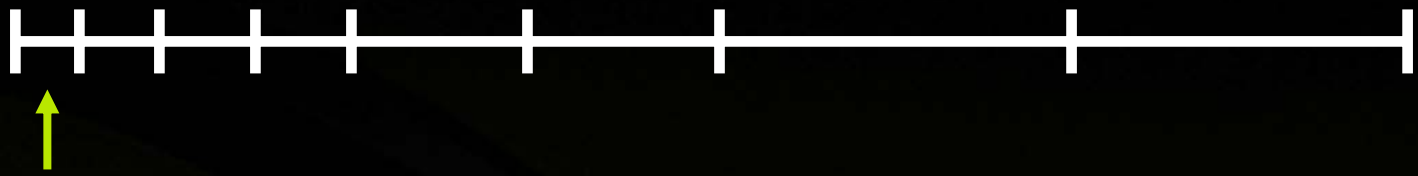
Depth Precision Distribution



The Solution

- Reverse the depth mapping
  - Far = 0.0
  - Near = 1.0 (or higher)
- Precision bunching now reversed
  - Compression and expansion line up
  - Results in essentially linear depth buffering

A Caveat



- Small precision cliff near 0
  - FP numbers often use denormals to fill it
  - Graphics hardware typically avoid it
    - Often CPU's too, denorms are slow
- Problem is minimal due to exponent range
  - Infinite far plane completely fixes it

EXT_draw_buffers2

- Provides per draw buffer control of
  - Blend Enable
  - Color mask
- Does not provide independent control of
  - Blend Function
  - Blend Equation
  - Blend Color

EXT_framebuffer_sRGB

- Allows framebuffer to be stored in sRGB space
  - Provides perceptual color compression
    - 8 bits sRGB is similar to 10 bits linear RGB
  - Converts to/from sRGB on access to framebuffer
  - Implements a gamma of 2.2
    - This matches most monitors relatively well
- Controlled via a simple enable
  - Not available on all formats (>8 bit per component)

CSAA

- Coverage Sample Anti-Aliasing
  - GL_NV_framebuffer_multisample_coverage
- Decouples primitive coverage from depth/color
  - Increases edge quality with little cost
  - Memory and bandwidth overhead scale with # depth samples
  - Worst case is as good as # of depth samples

CSAA usage

- Extremely simple
- MSAA

```
glRenderbufferStorageMultisampleEXT(
  GL_RENDERBUFFER_EXT, 4, GL_RGBA8, width,
   height)
```

- CSAA

```
glRenderbufferStorageMultisampleCoverageNV(
  GL_RENDERBUFFER_EXT, 16, 4, GL_RGBA8, width,
   height)
```

CSAA Modes

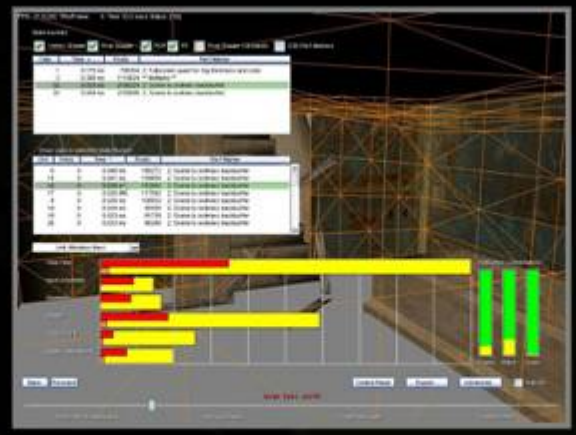
Name	Coverage Samples	Color/Depth Samples
2x	2	2
4x	4	4
8x	8	4
8xQ	8	8
16x	16	4
16xQ	16	8

Thanks

- Simon Green
- Samuel Gateau
- Henry Moreton
- NVIDIA DevTech team

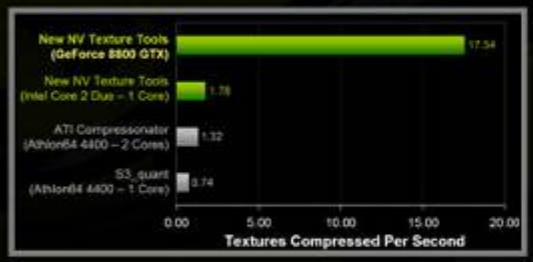
New Developer Tools at GDC 02007

SDK 10



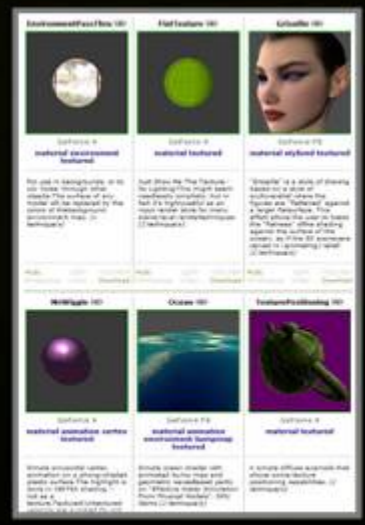
PerfKit 5

FX Composer 2



GPU-Accelerated Texture Tools

ShaderPerf 2



Shader Library