NVIDIA OpenGL Update

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Overview

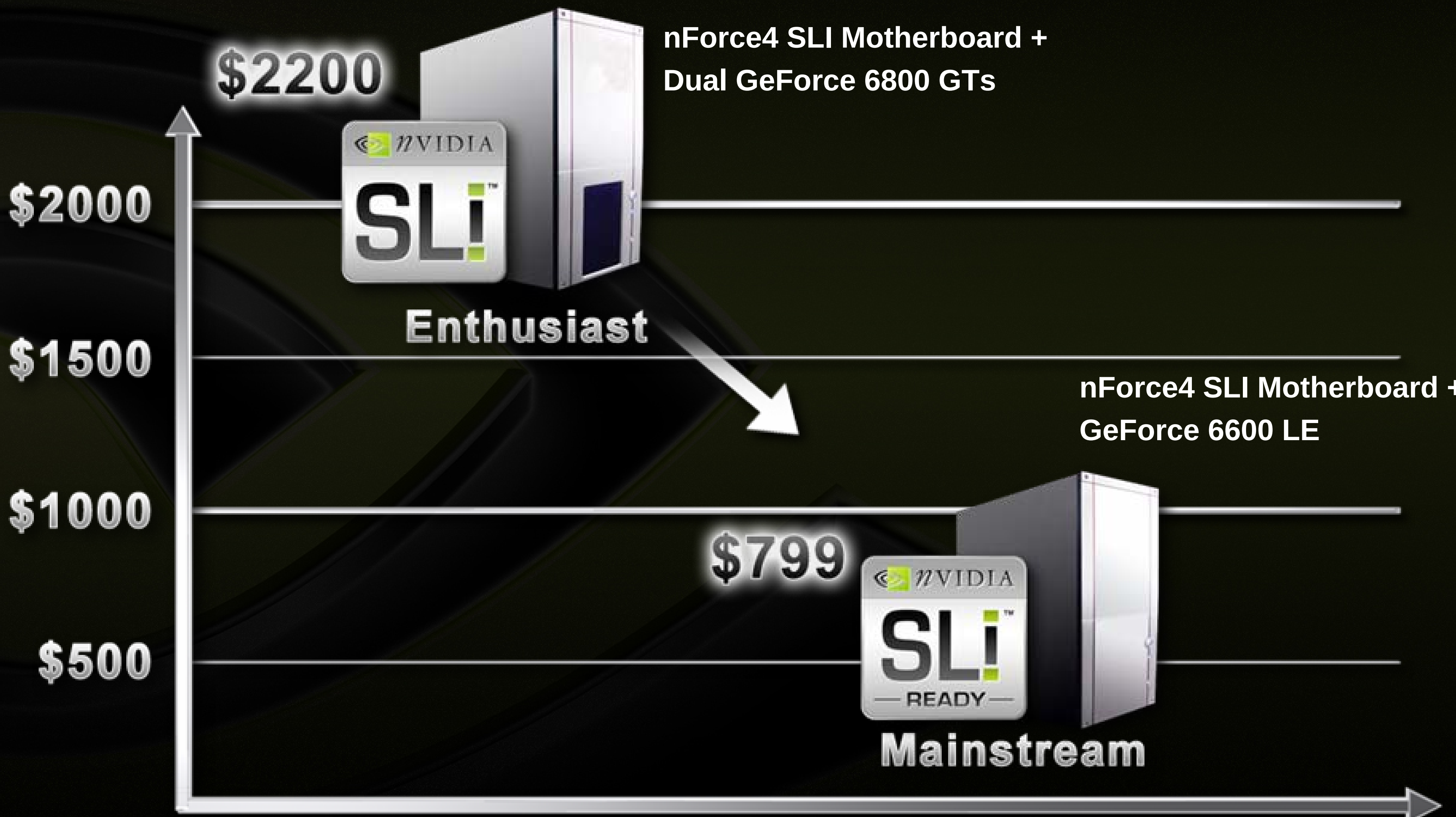
- SLI
  - How it works
  - OpenGL Programming Tips
  - SLI Futures
- New extensions
  - NVX_instanced_arrays – OpenGL instancing!
  - EXT_timer_query


NVIDIA
SLI™

What is SLI?

- Allows scaling graphics performance by combining multiple GPUs in a single system
- Works best with NVIDIA nForce motherboards
- Improves rendering performance up to 2x with two GPUs

SLI-Ready PCs affordable for Everyone

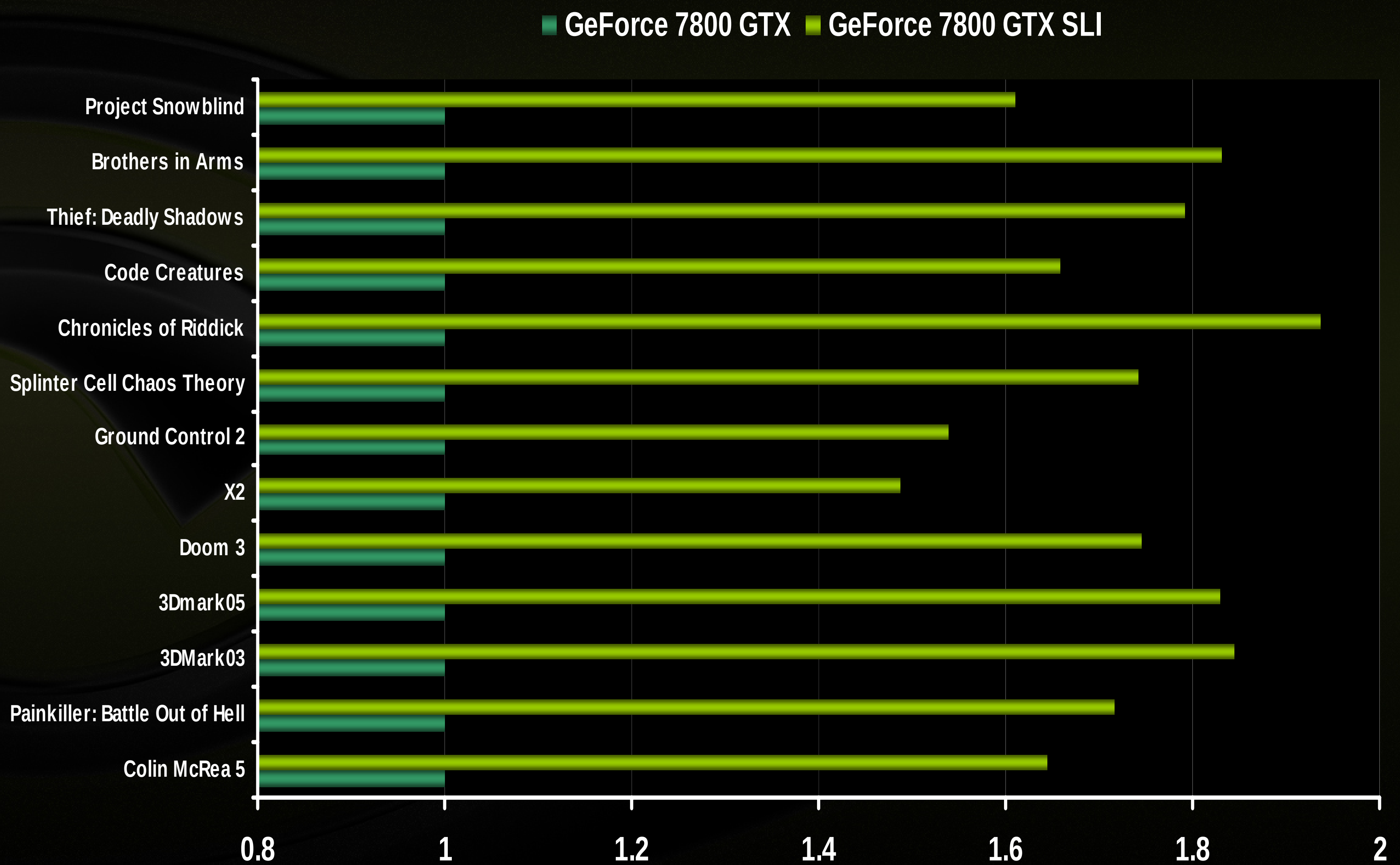


Quad SLI

- 4 GPUs is better than 2!
- 2 cards, each with 2 GPUs

SLI Notebooks

SLI Game Performance Scaling



How SLI Works

- Plug multiple GPUs into motherboard
  - Have to be same model currently
- NVIDIA driver reports as one logical device
  - Video memory does NOT double
- Video scan out happens from one board
  - Bridge connector transmits digital video between boards

SLI and Game Development

- Developing a game now takes 2 years or more
  - CPU performance doubles (or less)
  - GPU performance quadruples
- CPU / GPU balance shifts
  - Worse: CPU-hungry modules are developed later
  - AI, physics, full game play
- SLI allows you to preview future GPU performance now

SLI Rendering Modes

- Compatibility mode
  - Only uses one GPU
  - No SLI benefits
- Alternate frame rendering (AFR)
- Split frame rendering (SFR)
- SLI AA
- SLI Stereo?

AFR

- GPUs work on alternate frames in parallel

- Scan-out toggles which framebuffer to read from

AFR Advantages

- Advantages
  - All work is parallelized
    - Scales geometry and pixel fill performance
  - Preferred SLI mode
- Disadvantages
  - Requires pushing data to other GPU if frame is not self-contained
  - For example, if application updates a render-to-texture target only every other frame

SFR

- GPUs work on the same frame
- For two GPUs
  - GPU 0 renders top region
  - GPU 1 renders bottom region

- Scan-out combines framebuffer data

SFR Advantages

- Driver load-balances by changing region size
  - Based on time each GPU took to render
- Driver clips geometry to regions
  - Avoids both GPUs processing all vertices
  - But not perfect
- Still requires sharing data between GPUs
  - E.g., render to texture

SFR Compared to AFR

- SFR works even when few frames are buffered
  - Or when AFR otherwise fails
- In general, SFR has more communications overhead
- Applications with heavy vertex load benefit less from SFR

Overview: Things Interfering with SLI

- CPU-bound applications
  - Or vertical-sync enabled
- Applications that limit the number of frames buffered
- Communications overhead

CPU-Bound Applications

- SLI cannot help
- Reduce CPU work
- Move CPU work onto the GPU
  - See http://www.gpgpu.org
- Don't deliberately throttle frame-rate

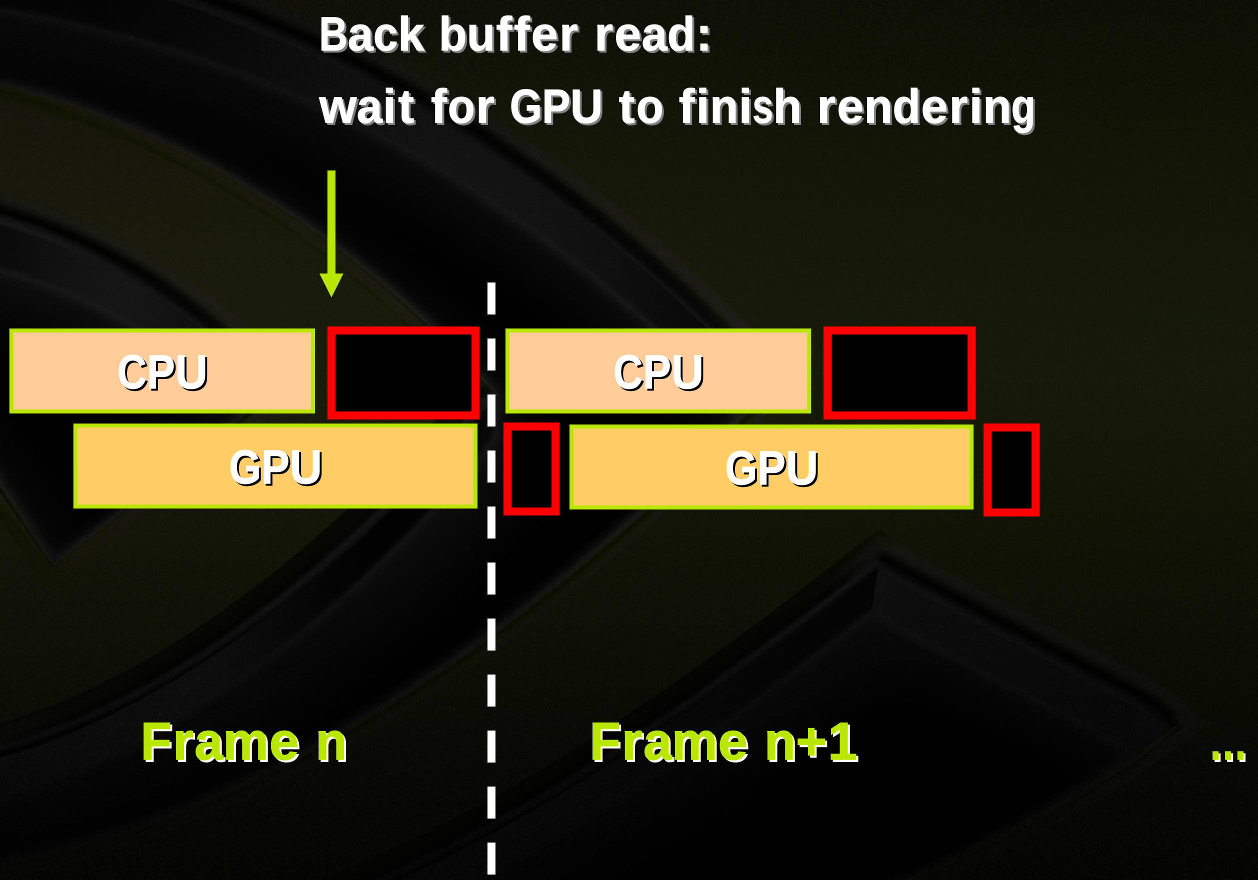
V-Sync

- Enabling vertical-sync limits frame rate to multiples of the monitor refresh rate

Limiting Number of Frames Buffered

- Some apps allow at most one frame buffered
  - To reduce lag
  - Via occlusion queries
  - Don’t read back-buffer - this causes CPU stall
- Breaks AFR SLI
- SLI is faster anyway
  - e.g. 2 GPU SLI systems ~2.0x less lag

Why Reading the Back Buffer Is Bad



OpenGL SLI Tips

- Limit OpenGL rendering to a single window
  - child windows shouldn't have OpenGL contexts
- Request pixel format with PDF_SWAP_EXCHANGE
  - tells driver that app doesn't need the back buffer contents after SwapBuffers()
- Avoid rendering to FRONT buffer
  - use overlays instead on Quadro GPUs

Offscreen Rendering and Textures

- Limit P-buffer usage
  - Often requires broadcasting rendering to both GPUs
- Use render-to-texture rather than glCopyTexSubImage
  - glCopyTexSubImage requires texture to be copied to both GPUs
  - Use FBO or P-buffers instead
- Limit texture working set
  - Textures have to be stored on both GPUs
  - Don’t download new textures unnecessarily

Geometry

- Use Vertex Buffer Objects or display lists to render geometry
  - Don't use immediate mode
  - Reduces CPU overhead
- Render the entire frame
  - Don't use use glViewport or glScissor
  - Disables load balancing in SFR mode, and hurts performance in AFR mode

More OpenGL SLI Tips

- Limit read-backs
  - e.g. glReadPixel, glCopyPixels
  - causes pipeline to stall
- Never call glFinish()
  - doesn't return until all rendering is finished
  - prevents parallelism
- Avoid glGetError() in release code
  - Causes sync point

How Do I Detect SLI Systems?

- NVCpl API:
  - NVIDIA-specific API supported by all NV drivers
- Function support for:
  - Detecting that NVCpl API is available
  - Bus mode (PCI/AGP/PCI-E) and rate (1x-8x)
  - Video RAM size
  - SLI

NVCpl API SLI Detection

- SDK sample and full documentation available

```
HINSTANCE hLib = ::LoadLibrary("NVCPL.dll");

NvCplGetDataIntType NvCplGetDataInt;
NvCplGetDataInt =
    (NvCplGetDataIntType)::GetProcAddress(hLib,
                                          "NvCplGetDataInt");

long    numSLIGPUs  = 0L;
NvCplGetDataInt(NVCPL_API_NUMBER_OF_SLI_GPUS,
                                          &numSLIGPUs);
```

Forcing SLI Support In Your Game

- Use NVCpl
  - NvCplSetDataInt() sets
    AFR, SFR, Compatibility mode
  - See SDK sample
- Modify or create a profile:
  - http://nzone.com/object/nzone_sli_appprofile.html
  - End-users can create profile as well

SLI Performance Tools

- NVPerfKit has support for SLI
- Provides performance counters for
  - Total SLI peer-to-peer bytes
  - Total SLI peer-to-peer transactions
- Above originating from
  - Vertex/index buffers: bytes and transactions
  - Textures: bytes and transactions
  - Render targets: bytes and transactions

What is Instancing?

- Rendering multiple instances of a given geometry
- Some attributes can vary across instances
  - Transformation matrix
  - Color
- Examples
  - Trees in a forest
  - Characters in a crowd
  - Boulders in a avalanche
  - Screws in an assembly

Instancing Methods in OpenGL

- Send transform as vertex program constants
  - Relatively slow
  - Can also pack several transforms into constant memory and index in vertex program
- Send transform using immediate mode texture coordinates ("pseudo instancing")
  - Usually much faster (glTexCoord calls are inlined)
  - Requires custom vertex program
  - Can use glArrayElement to set current texture coordinates from a vertex array (not efficient on NV hardware)
- NVX_instanced_arrays
  - Single draw call
  - Fastest

NVX_instanced_arrays

- Allows rendering multiple instances of an object with a single draw call
- Similar to Direct3D instancing functionality
- OpenGL draw call cost is lower than Direct3D, but still gives a significant performance benefit
- Combined with render-to-vertex array, can be used for controlling object transformations on the GPU
- Performance is dependent on CPU speed, GPU speed, number of objects and number of vertices per object
  - Will improve on next generation GPU hardware

OpenGL Instancing Performance

Verts/object	Constants (fps)	Texcoords (fps)	Instancing (fps)
8	205	323	560
24	200	266	440
60	183	190	246
120	138	135	155
220	72	77	77

- 8192 objects, Quadro FX 4500, P4 3.4 GHz

NVX_instanced_arrays

- Allows rendering an array of primitives multiple times, while stepping specified vertex attribute arrays only once per N objects
- Only supports generic attribute arrays
- No immediate mode
- Warning – experimental extension -API may change!
- Typically 3 attribute arrays are used to store a 3x4 transformation matrix
  - Attribute divisor is set to 1 for these arrays
  - Custom vertex program transforms geometry from object to world space based on input attributes

NVX_instanced_arrays API

- `void VertexAttribDivisorNVX(uint attrib, uint divisor);`
  - Specifies rate at which to advance attribute per object
  - 0 = disabled
  - Attribute 0 (position) cannot be changed
  - Future – fractional divisor to allow geometry amplification?

- `void DrawArraysInstancedNVX(enum mode, int start, sizei count, sizei primCount);`
- `void DrawElementsInstancedNVX(enum mode, sizei count, enum type, const void *indices, sizei primCount);`
  - Renders primCount instances of specified geometric primitives, using attribute divisors

DrawArraysInstancedNVX Pseudocode

```
for (instance = 0; instance < primCount; instance++) {
            Begin(mode);
            for (vertex = 0; vertex < count; vertex++) {
                for (attrib = 1; attrib < MAX_ATTRIB; attrib++) {
                    if (ArrayAttribEnabled[attrib]) {
                        if (InstanceDivisors[attrib] > 0) {
                            offset = instance / InstanceDivisors[attrib];
                        } else {
                            offset = start + vertex;
                        }
                        offset *= CookedAttribStride[attrib];
                        VertexAttribvFunc[attrib](
                            VertexAttribPointers[attrib] + offset);
                    }
                }
                if (ArrayAttribEnabled[0]) {
                    offset = start + vertex;
                    offset *= CookedAttribStride[0];
                    VertexAttribvFunc[0](
                        VertexAttribPointers[0] + offset);
                }
            }
            End();
        }
```

Standard Rendering Loop

```
// load vertex arrays and transform data
…

for(int i=0; i<nobjects; i++) {
    // send transformation as texture coordinates
    glMultiTexCoord4fv(GL_TEXTURE0, &transform_data[0][i*4]);
    glMultiTexCoord4fv(GL_TEXTURE1, &transform_data[1][i*4]);
    glMultiTexCoord4fv(GL_TEXTURE2, &transform_data[2][i*4]);

    // draw instance
    glDrawElements(GL_TRIANGLES, nindices, GL_UNSIGNED_SHORT, indices);
}
```

Using Instancing

```
// set vertex array pointers
…

// enable transform attribute arrays and set divisors
glEnableVertexAttribArrayARB(8);   // texcoord0
glVertexAttribDivisorNVX(8, 1);
glEnableVertexAttribArrayARB(9);   // texcoord1
glVertexAttribDivisorNVX(9, 1);
glEnableVertexAttribArrayARB(10);  // texcoord2
glVertexAttribDivisorNVX(10, 1);

// draw all instances at once
glDrawElementsInstancedNVX(GL_TRIANGLES, nindices,
                           GL_UNSIGNED_SHORT, indices, nobjects);

glDisableVertexAttribArrayARB(8);
glVertexAttribDivisorNVX(8, 0);
glDisableVertexAttribArrayARB(9);
glVertexAttribDivisorNVX(9, 0);
glDisableVertexAttribArrayARB(10);
glVertexAttribDivisorNVX(10, 0);
```

HavokFX Instancing Results

	Readback (fps)	Instancing (fps)	Instancing / Readback
4096 bricks	240	280	1.17
8000 bricks	130	150	1.15
27000 bricks	40	46	1.15
5000 boulders	173	223	1.29
10000 boulders	90	114	1.27
30000 boulders	31	41	1.32

GPU Timing

- Timing is important for performance tuning
  - How can you improve something if you can't measure it accurately?
- Problem with timing the GPU is that it is asynchronous and has a deep pipeline
  - There's no way to know if a particular command has completed before reading the timer
- Usual solution is to insert glFinish() commands
  - Guarantees that all rendering commands have completed, but stalls pipeline and changes performance!

EXT_timer_query

- Provides a method for timing a sequence of OpenGL commands, without stalling the pipeline
- Based on the query object mechanism introduced by the occlusion query extension
- `glBeginQuery()`
  - Timer starts when all prior commands have completed
- `glEndQuery()`
  - Timer stops when all prior commands have completed
- Measures total time elapsed (driver + hardware)
  - Measured in nanoseconds (10^{-9} seconds)
  - 32 bit counter can represent about 4 seconds maximum
- Introduces GLuint64 type to allow 64 bit counters

Code Example

```
GLint queries[N];
glGenQueries(N, queries); // generate query objects

for(int i=0; i<N; i++) {
    glBeginQuery(GL_TIME_ELAPSED_EXT, queries[i]); // Start query
    // Draw object i
    glEndQuery(GL_TIME_ELAPSED_EXT);               // End query
}

// Wait for all results to become available
// (should really only wait for previous frame's results)
int available = 0;
while (!available) {
    glGetQueryObjectiv(GL_QUERY_RESULT_AVAILABLE, queries[N-1],
    &available);
}

// See how much time the rendering of object i took in nanoseconds
GLuint64EXT timeElapsed;
for (i = 0; i < N; i++) {
    glGetQueryObjectui64vEXT(queries[i], GL_QUERY_RESULT, &timeElapsed);
    // do something with result
}
```

Questions?

- GPU Programming Guide:
  http://developer.nvidia.com/object/gpu_programming_guide.html
- http://developer.nvidia.com
- Thanks: Matthias Wloka, Jason Allen, Michael Gold