NVIDIA®

OpenGL Performance Tools

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Performance Tools Agenda

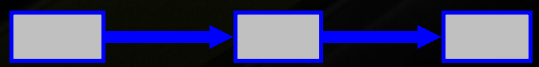
- Problem statement
- GPU pipelined architecture at a glance
- NVPerfKit 2.0: Driver and GPU Performance Data
  - GLExpert: OpenGL API Assistance
  - NVPerfSDK: Integrated into your application
    - NVPerfAPI
    - PDH, NVDevCPL
- Solutions to common bottlenecks
- NVShaderPerf: Shader Performance

What's The Problem?

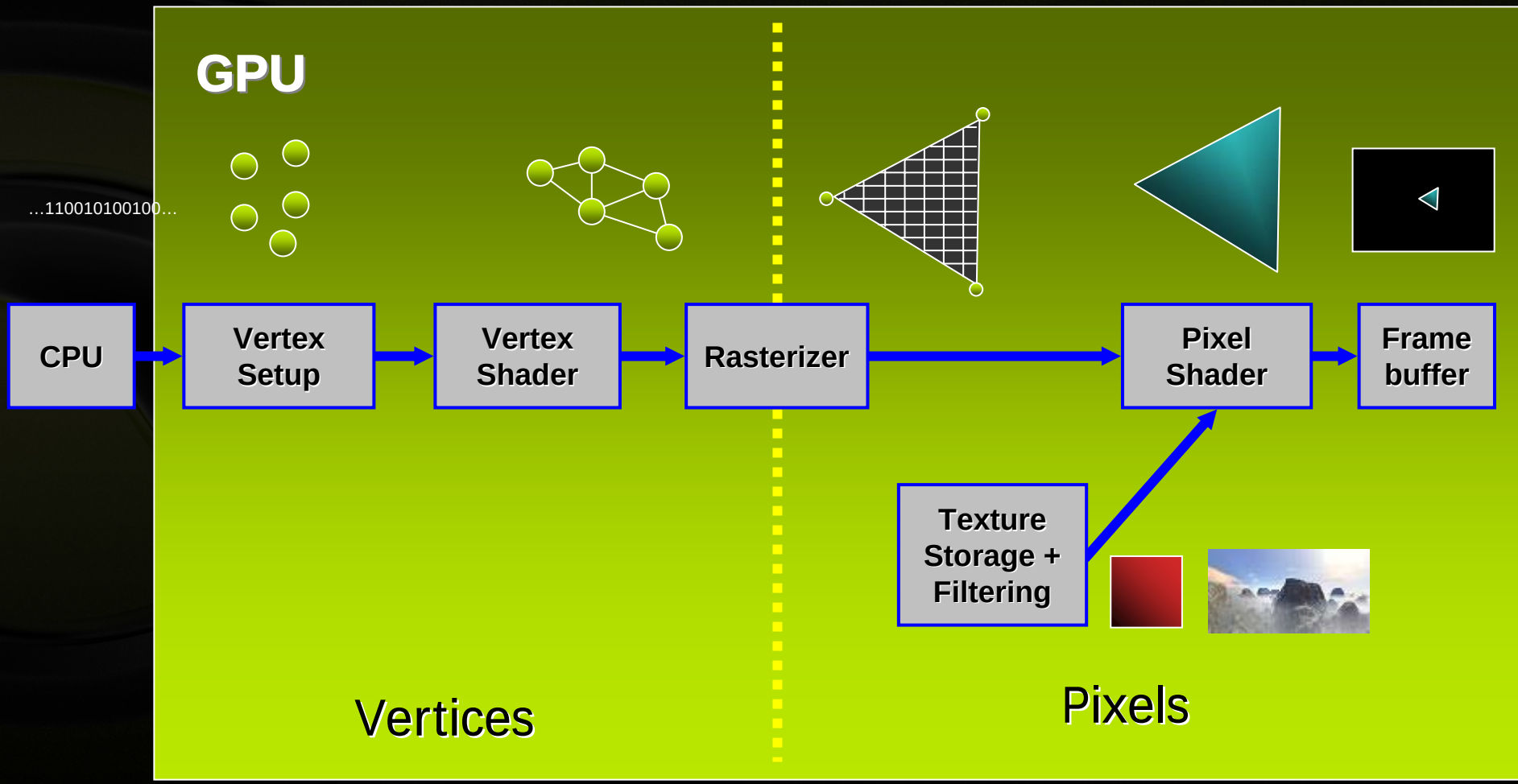
- Why is my app running at 13FPS after CPU tuning?
- How can I determine what is going in that GPU?
- How come IHV engineers are able to figure it out?

GPU architecture at a glance

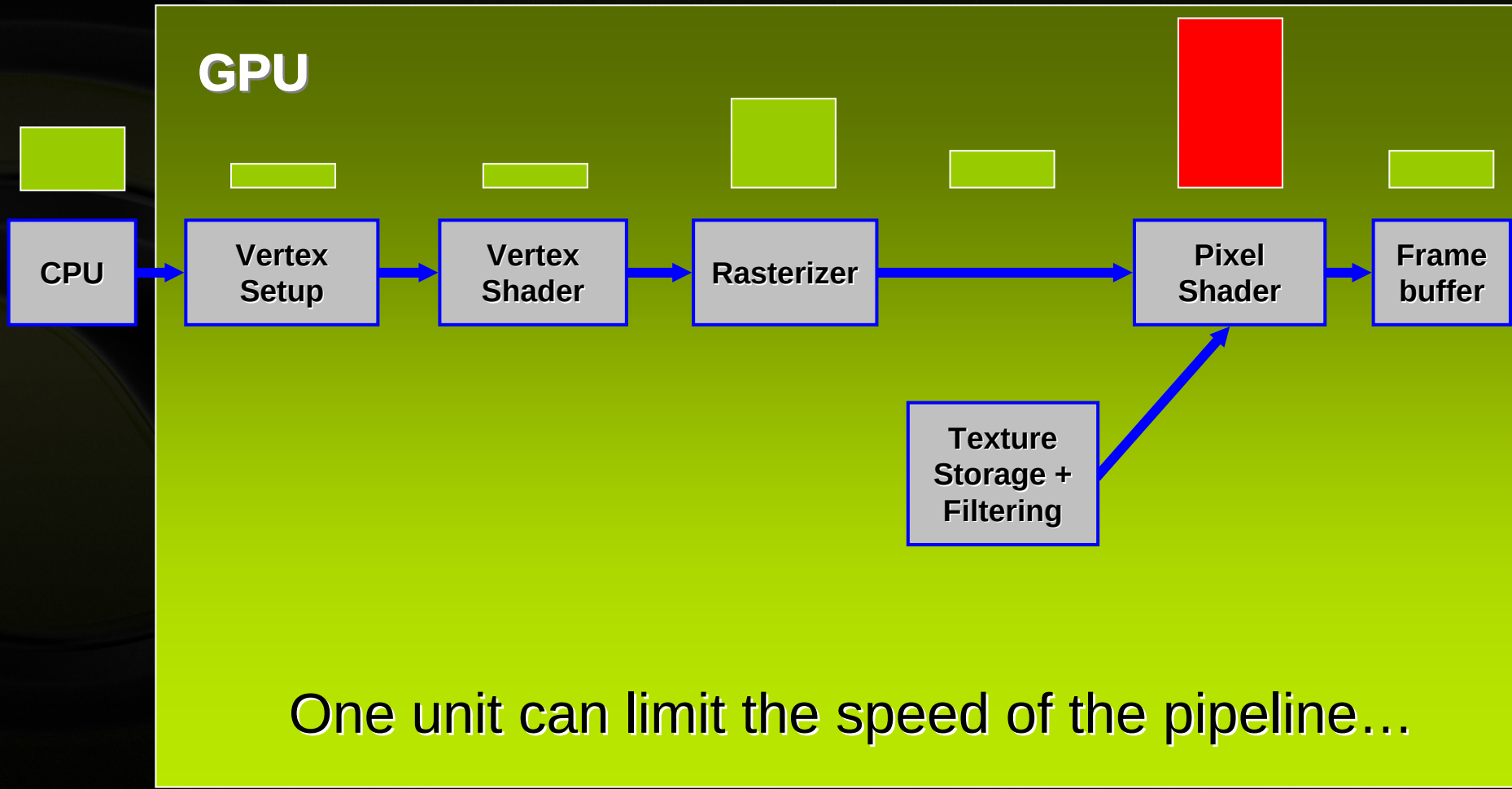
- Pipelined architecture: each unit needs the data from the previous unit to do its job
- Method: Bottleneck identification and elimination
- Goal: Balance the pipeline



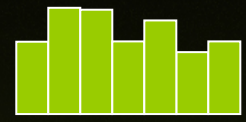
GPU Pipelined Architecture (simplified view)



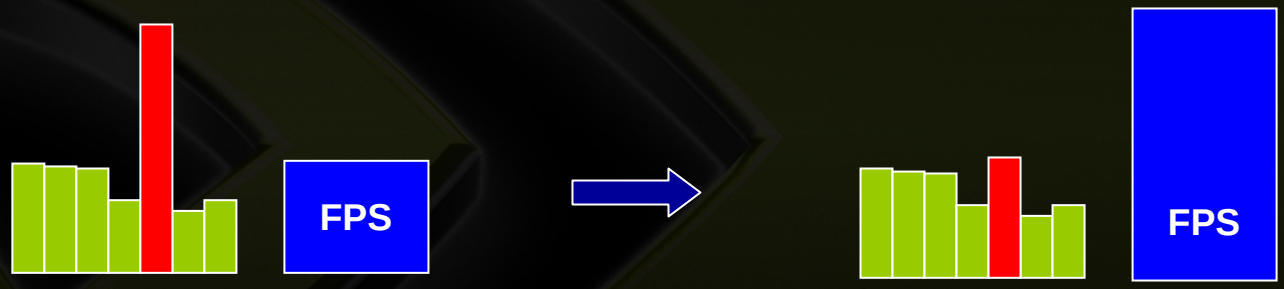
GPU Pipelined Architecture (simplified view)



Classic Bottleneck Identification

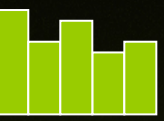


Modify target stage to decrease workload



If performance/FPS improves greatly, this stage is the bottleneck
Careful not to change the workload of other stages!

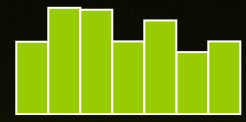
Classic Bottleneck Identification



Rule out other stages, give them little or no work

If performance doesn’t change significantly, this stage is the bottleneck
Careful not to change the workload of target stage!

Ideal Bottleneck Identification



- Sample performance data at different points along the pipeline while rendering
  - Compare amount of work done to maximum work possible
  - Query the GPU for unit bottleneck information
- The answer? NVPerfKit!
  - NVPerfHUD: The GPU Performance Accelerator
  - NVPerfAPI: Integrated in your application

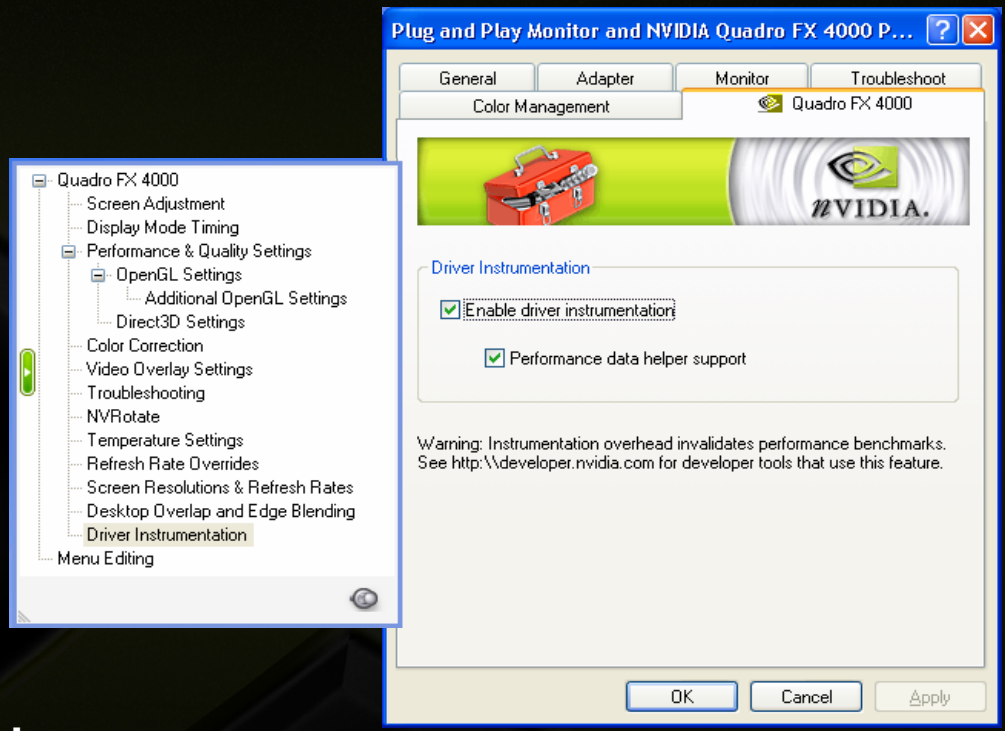
Analyze your application like an NVIDIA Engineer!

NVPerfKit

- What’s new in NVPerfKit 2.0?
- How do I integrate it?
- Associated tools

What is in the NVPerfKit package?

- Instrumented Driver
- GLExpert
- NVPerfHUD
- NVPerfSDK
  - NVPerfAPI
  - Sample Code
  - Helper Classes
  - Documentation
- Tools
  - gDEBugger
  - NVIDIA Plug-In for Microsoft PIX for Windows
  - NVDevCPL



NVPerfKit Instrumented Driver

- Exposes GPU and Driver Performance Counters
- Data exported via NVIDIA API and PDH
- Supports OpenGL and Direct3D
- Simplified Experiments (SimExp)
- Collect GPU and driver data, retain performance
  - Track per-frame statistics
  - Gather and collate at end of frame
  - Typical hit 1-2%

GLExpert: What is it?

- Helps eliminate performance issues on the CPU
- OpenGL portion of the Instrumented Driver
  - Output information to console/stdout or debugger
  - Different groups and levels of information detail
- Controlled using tab in NVDevCPL
- What it can do (today)
  - GL Errors: print when they are raised
  - Software Fallbacks: indicate when the driver is in fall back
  - GPU Programs: errors during compile or link
  - VBOs: show where they reside, mapping details
  - FBOs: print reasons a configuration is unsupported
- Feature list to grow with future drivers

GLExpert: Message Detail

- GLExpert messages are made of a few parts:
  - Category and Message IDs are provided that uniquely tag a message and facilitate parsing
  - A Base Message is category-specific and provides a description of the general issue at hand
  - An Instance Message is situation-specific and details the particular objects, programs, or API usage involved
- Documentation provided for Base Messages

GLExpert: Message Example

- **Example Base Message:**

  ```
  The current FBO state (e.g. attachments, texture
  targets) is UNSUPPORTED.
  ```

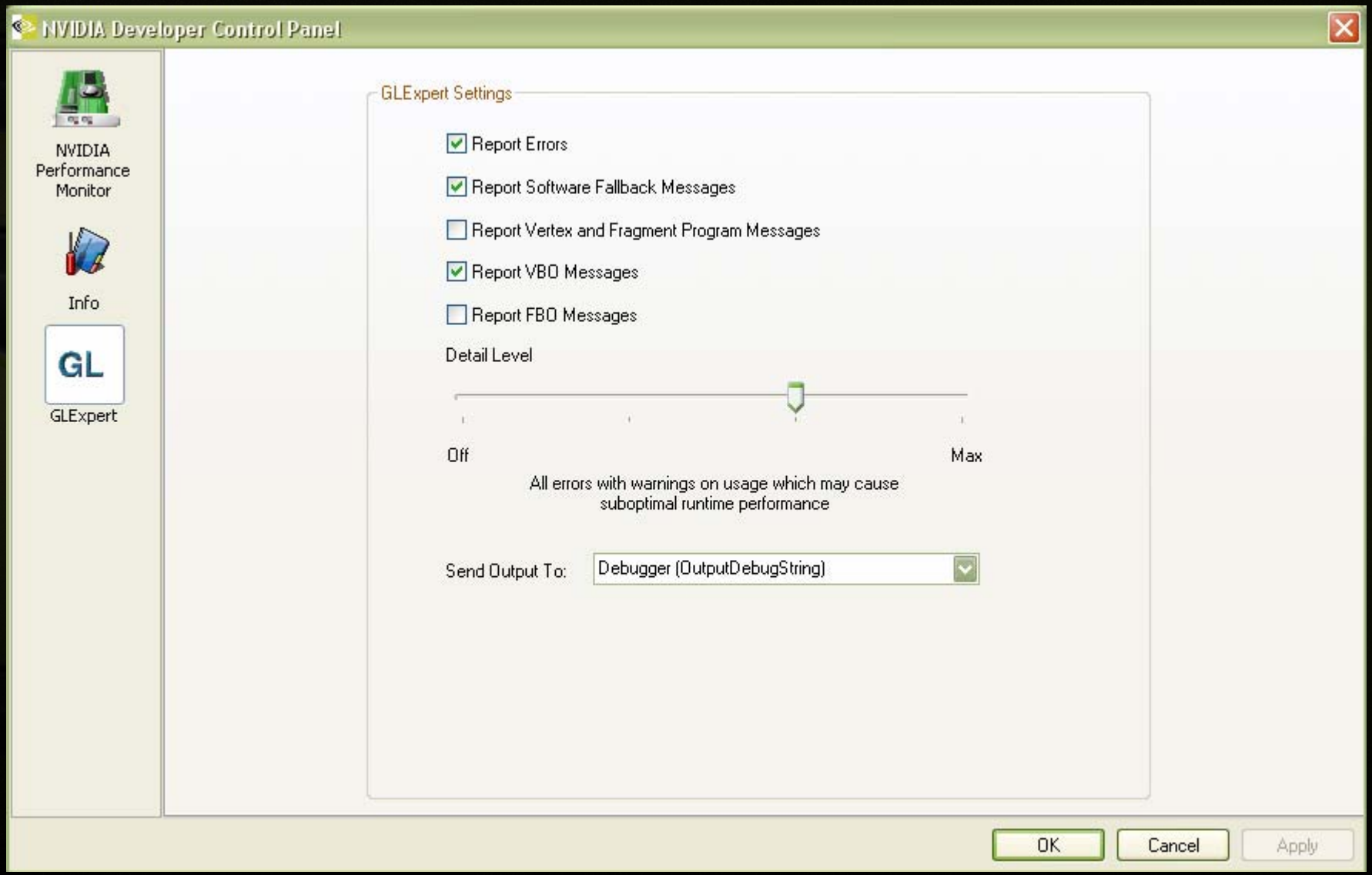
- **Example Instance Message:**

  ```
  Reason: COLOR_ATTACHMENT0 attempting to bind to an
  unsupported texture target.
  ```

- **Example Final Message:**

  ```
  OGLE: CategoryID 0x00000010 MessageID: 0x00840000
        The current FBO state (e.g. attachments,
        texture targets) is UNSUPPORTED. Reason:
        COLOR_ATTACHMENT0 attempting to bind to an
        unsupported texture target.
  ```

GLExpert: NVDevCPL tab

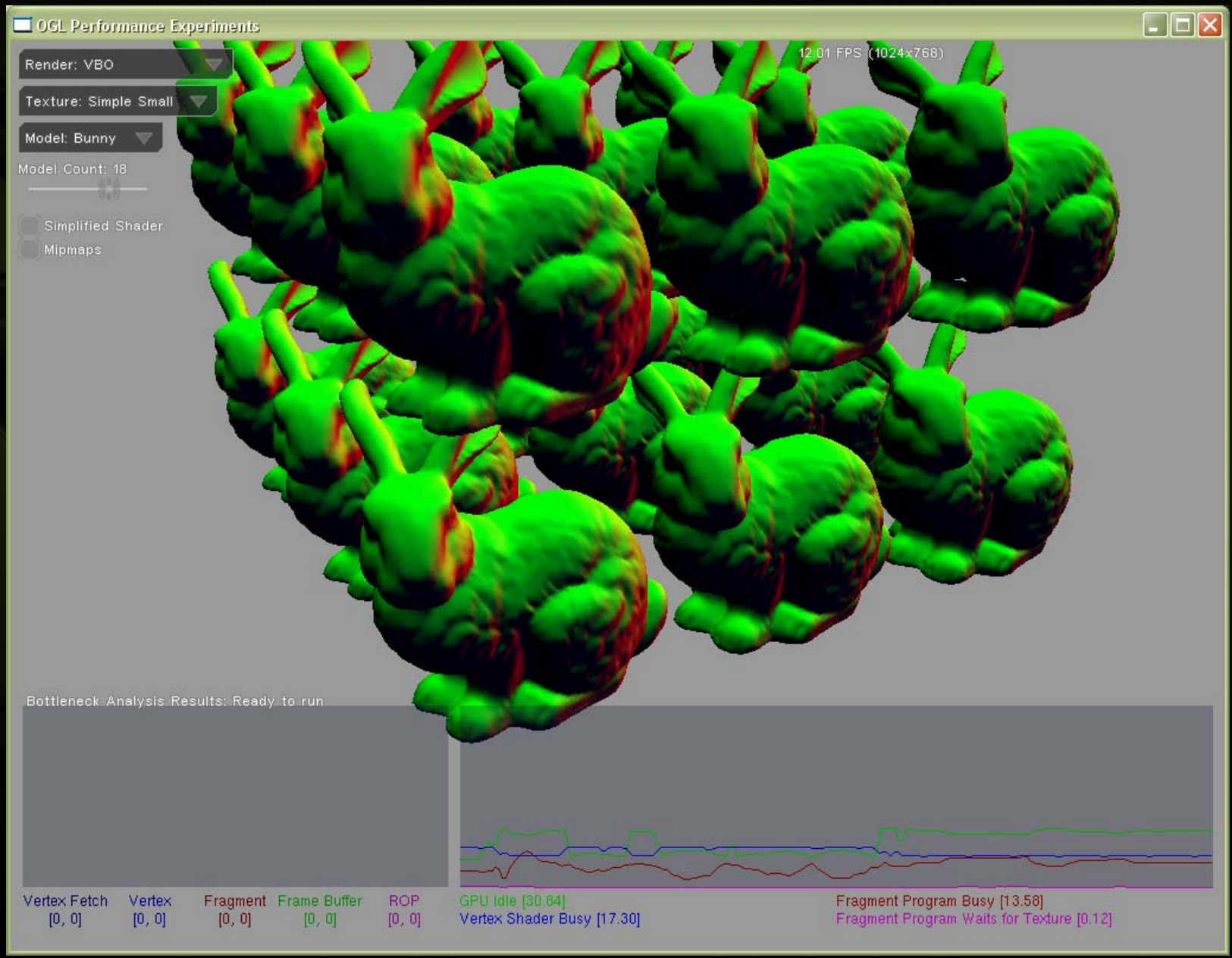


Project Status

- Shipping with NVPerfKit 2.0
- Windows for now, Linux to follow
- Supports NV3x, NV4x, and G7x architectures
- Integrated in Graphic Remedy‘s gDEBugger
- What types of things are interesting?

NVPerfKit@nvidia.com

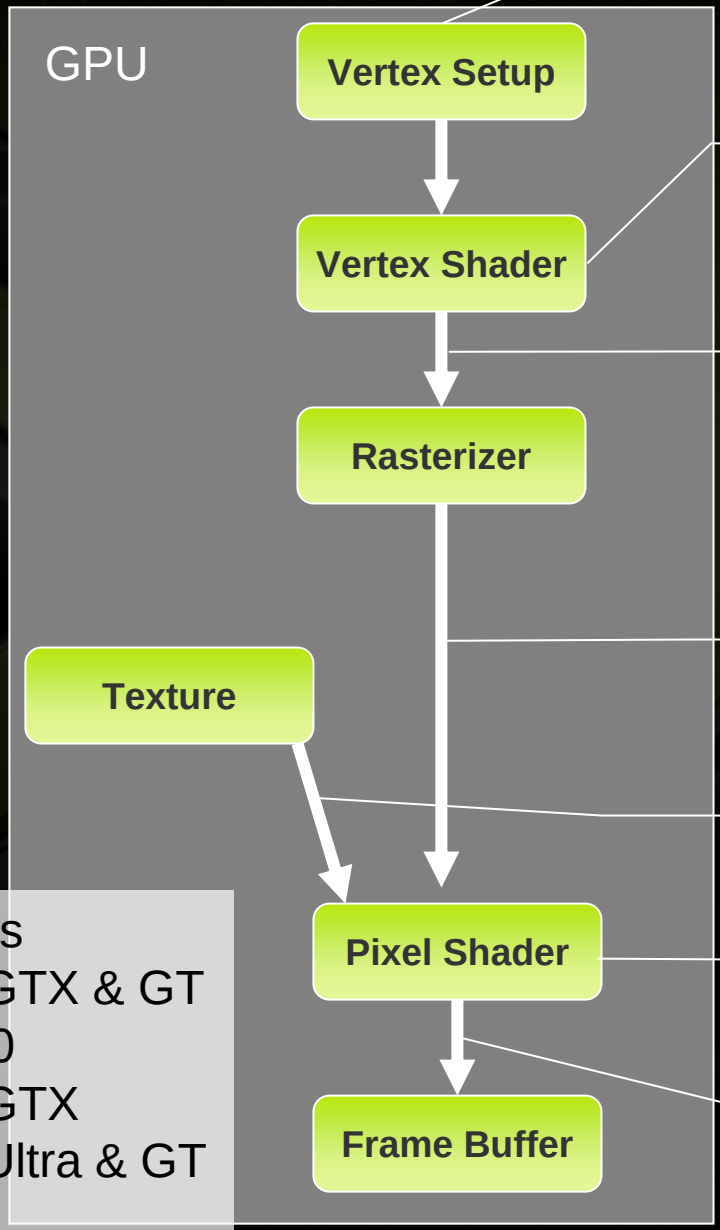
NVPerfKit: What it looks like...



OpenGL Counters

- General
  - FPS
  - ms per frame
- Driver
  - Driver sleep time (waiting for GPU)
  - % of the frame time driver is waiting
- Counts
  - Batches
  - Vertices
  - Primitives
- Memory
  - AGP memory used in MB and bytes
  - Video memory used and total in MB and bytes

GPU Counters



gpu_idle
vertex_attribute_count

vertex_shader_busy

culled_primitive_count
primitive_count
triangle_count
vertex_count

fast_z_count
shaded_pixel_count

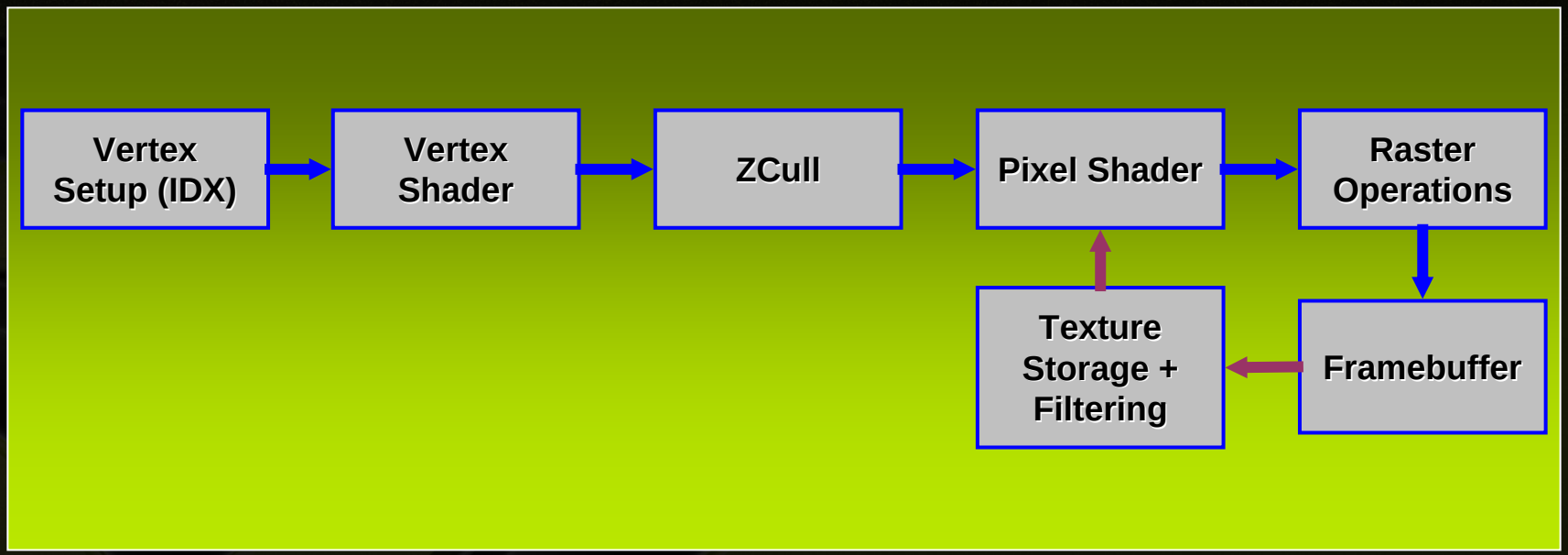
shader_waits_for_texture

pixel_shader_busy

shader_waits_for_rop
rop_busy

Supported GPUs
GeForce 7900 GTX & GT
Quadro FX 4500
GeForce 7800 GTX
GeForce 6800 Ultra & GT
GeForce 6600

NEW! Simplified Experiments

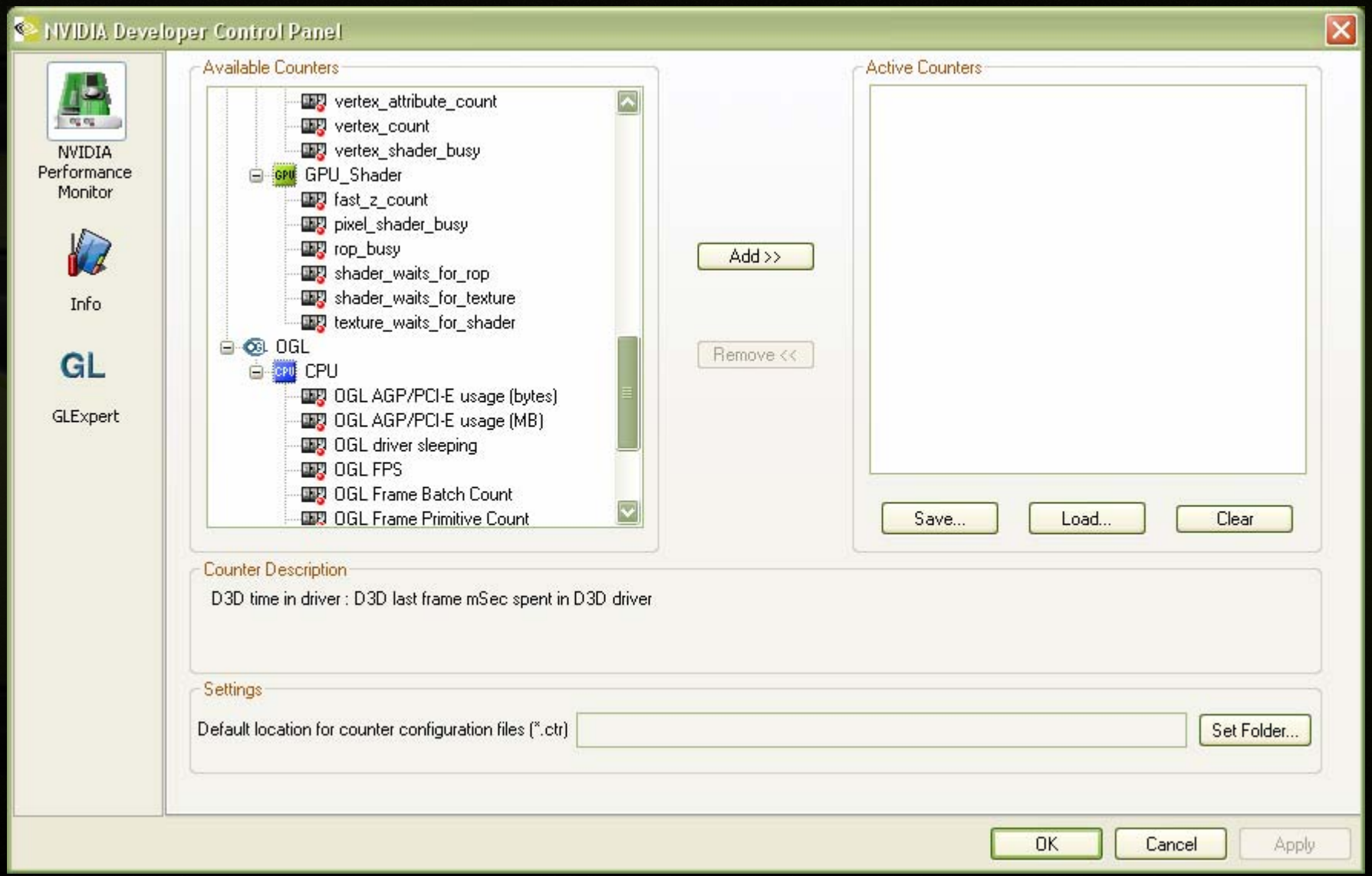


- Unit utilization and bottleneck experiments along the pipeline
- GPU Bottleneck experiment
  - Adds all utilization and bottleneck experiments
  - Expert system analyzes the results
- Exposed via NVPerfAPI

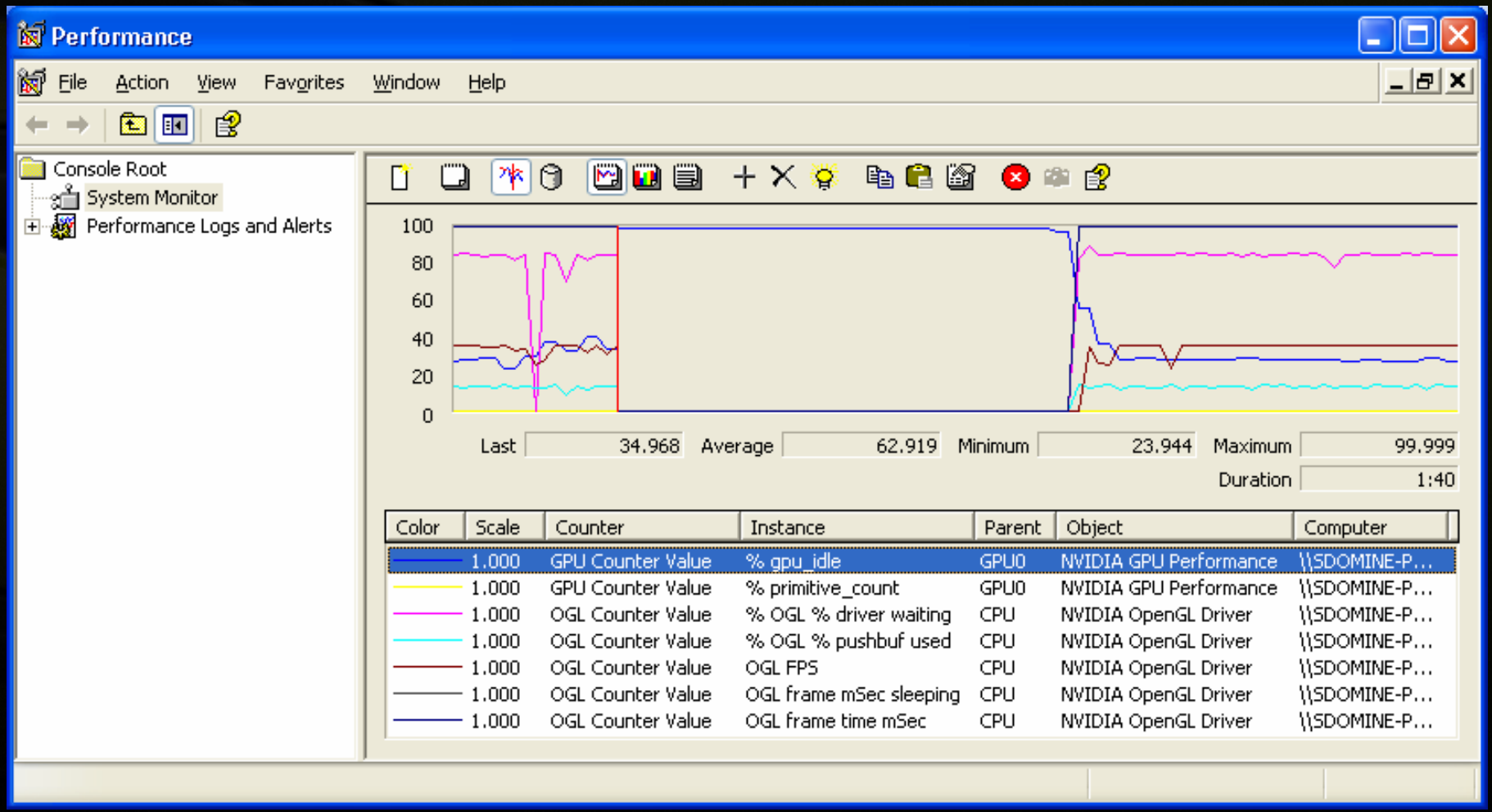
How do I use NVPerfKit counters?

- PDH: Performance Data Helper for Windows
  - Win32 API for exposing performance data to user applications
  - Standard interface, many providers and clients
  - Sample code and helper classes provided in NVPerfSDK
- Perfmon: (aka Microsoft Management Console)
  - Win32 PDH client application
  - Perfmon's sampling frequency is low (1X/s)
  - Displays PDH based counter values:
    - OS: CPU usage, memory usage, swap file usage, network stats, etc.
    - NVIDIA: all of the counters exported by NVPerfKit
- Good for rapid prototyping

Enable counters: NVDevCPL



Graphing results: Perfmon



NEW! NVPerfAPI

- NVIDIA API for easy integration of NVPerfKit
  - No more enable counters in NVDevCPL, run app separately
  - No more lag from PDH
- Simplified Experiments
  - Targeted, multipass experiments to determine GPU bottleneck
  - Automated analysis of results to show bottlenecked unit
- Use cases
  - Real time performance monitoring using GPU and driver counters, round robin sampling
  - Simplified Experiments for single frame analysis

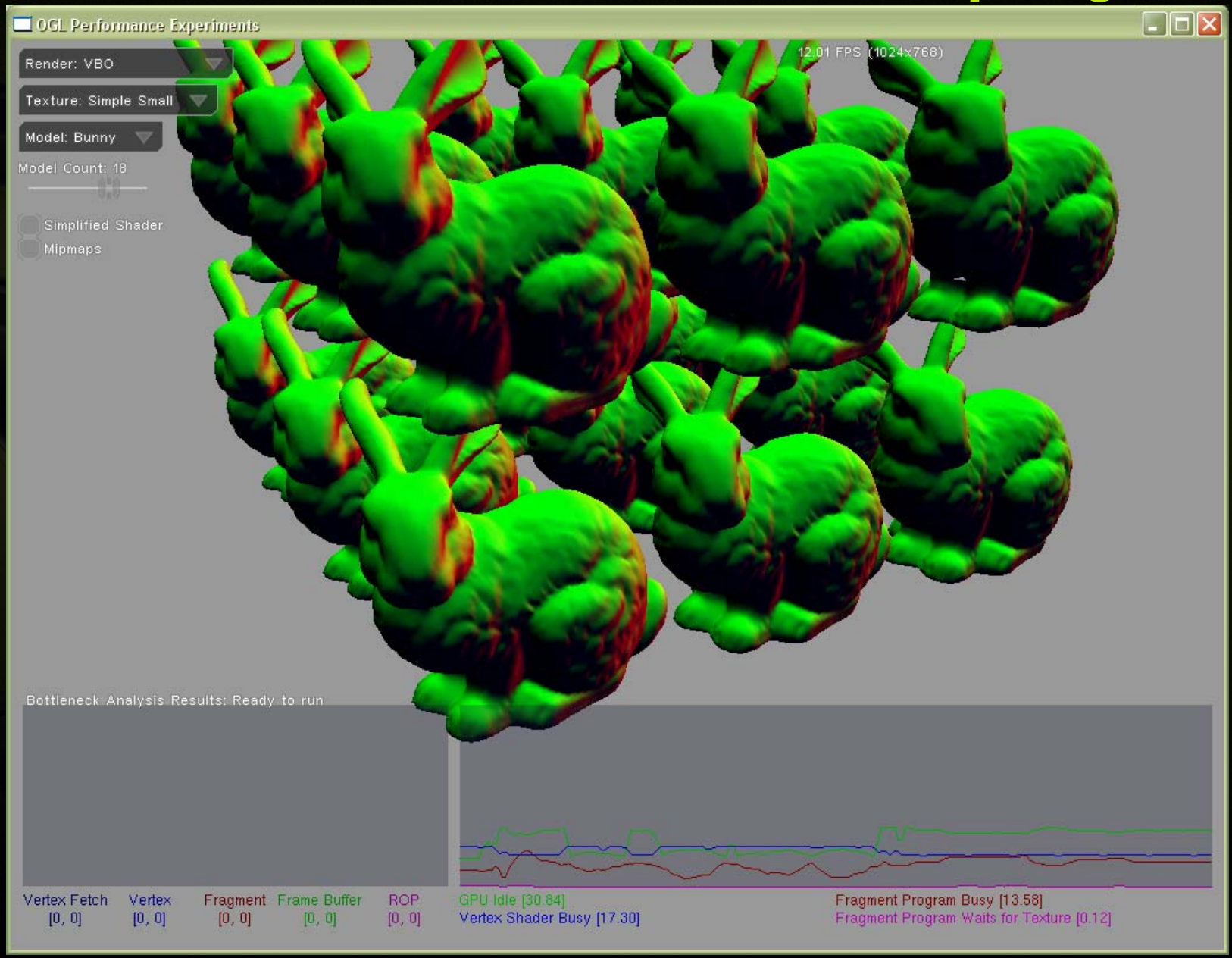
NVPerfAPI: Real Time

```
// Somewhere in setup
NVPMAddCounterByName(“vertex_shader_busy”);
NVPMAddCounterByName (“pixel_shader_busy”);
NVPMAddCounterByName (“shader_waits_for_texture”);
NVPMAddCounterByName (“gpu_idle”);

// In your rendering loop, sample using names
NVPMSample(NULL, &nNumSamples);
NVPMGetCounterValueByName(“vertex_shader_busy”, 0, &nVSEvents, &nVSCycles);
NVPMGetCounterValueByName(“pixel_shader_busy”, 0, &nPSEvents, &nPSCycles);
NVPMGetCounterValueByName(“shader_waits_for_texture”, 0, &nTexEvents,
    &nTexCycles);
NVPMGetCounterValueByName(“gpu_idle”, 0, &nIdleEvents, &nIdleCycles);
```

NVPerfAPI: Real Time

```
// Somewhere in setup
nVSBusy = NVPMGetCounterByName(“vertex_shader_busy”);
NVPMAddCounter(nVSBusy);
nPSBusy = NVPMGetCounterByName(“pixel_shader_busy”);
NVPMAddCounter(nPSBusy);
nWaitTexture = NVPMGetCounterByName(“shader_waits_for_texture”);
NVPMAddCounter(nWaitTexture);
nGPUIdle = NVPMGetCounterByName(“gpu_idle”);
NVPMAddCounter(nGPUIdle);


// In your rendering loop, sample using IDs
NVPMSample(aSamples, &nNumSamples);
for(ii = 0; ii < nNumSamples; ++ii) {
    if(aSamples[ii].index == nVSBusy) {
    }
    if(aSamples[ii].index == nPSBusy) {
    }
    if(aSamples[ii].index == nWaitTexture) {
    }
    if(aSamples[ii].index == nGPUIdle) {
    }
}
```

NVPerfAPI Demo: Real time sampling



NVPerfAPI: Simplified Experiments

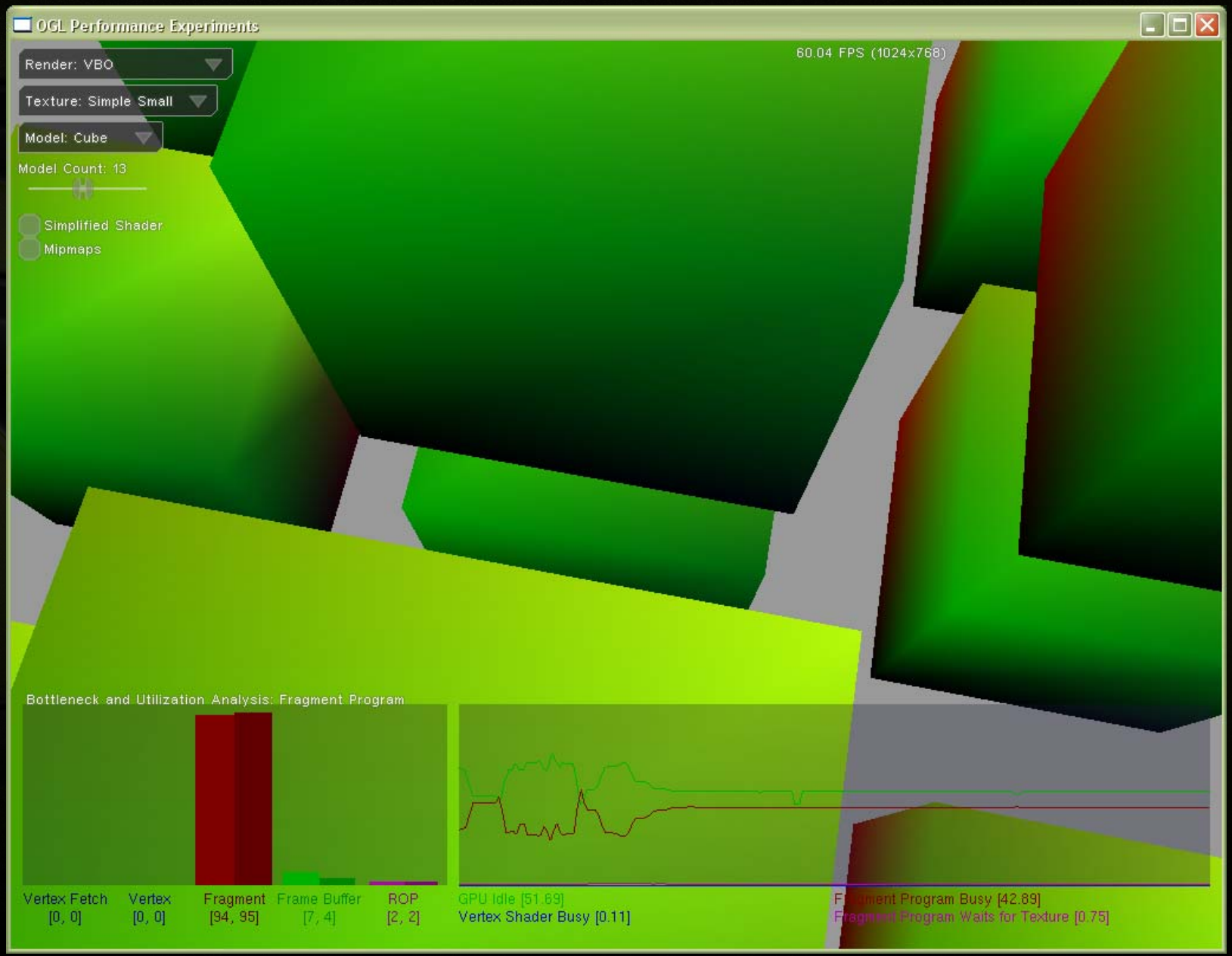
```
NVPMAddCounter(“GPU Bottleneck”);
NVPMAllocObjects(50);

NVPMBeginExperiment(&nNumPasses);
for(int ii = 0; ii < nNumPasses; ++ii) {
     // Setup the scene, clear Zbuffer/render target

     NVPMBeginPass(ii);

     NVPMBeginObject(0);
     // Draw calls associated with object 0 and flush
     NVPMEndObject(0);

     NVPMBeginObject(1);
     // Draw calls associated with object 1 and flush
     NVPMEndObject(1);

     // ...

     NVPMEndPass(ii);
}

NVPMEndExperiment();
NVPMGetCounterValueByName(“GPU Bottleneck”, 0, &nGPUBneck, &nGPUCycles);
NVPMGetGPUBottleneckName(nGPUBneck, pcString); // Convert to name

// End scene/present/swap buffers
```

NVPerfAPI: Simplified Experiments

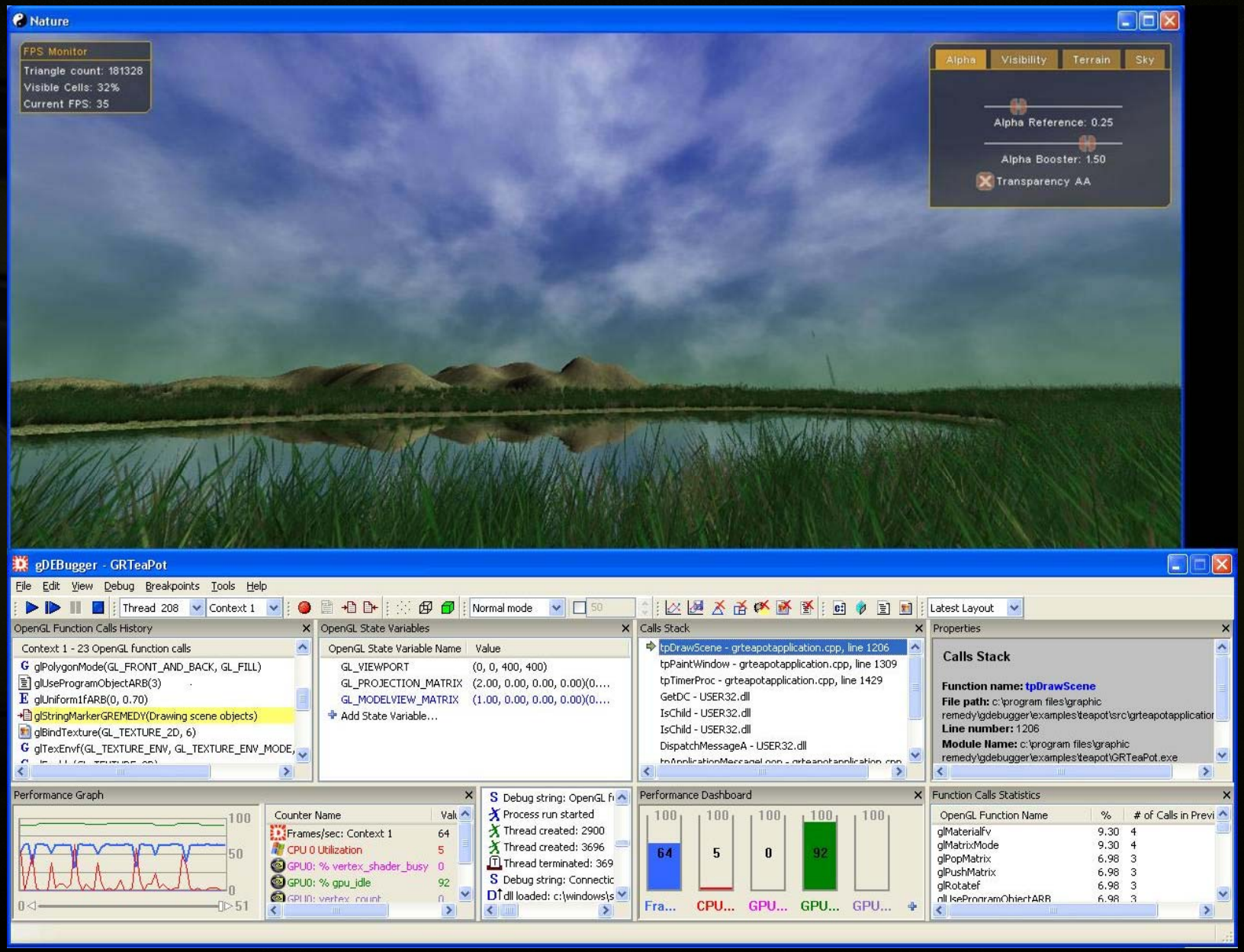
- GPU Bottleneck experiment
  - Run bottleneck and utilization experiments on all units
  - Process results to find bottlenecked unit
- Individual unit information can be queried
- Can run individual unit experiments
- Events: % utilization or % bottleneck…best way to visualize data
- Cycles: microseconds that the experiment ran, helps recompute the numerator for sorting

```
NVPMGetCounterValueByName(“IDX BNeck”, 0, &nIDXBneckEvents, &nIDXBNeckCycles);
NVPMGetCounterValueByName(“IDX SOL”, 0, &nIDXSOLEvents, &nIDXSOLCycles);
```

NVPerfAPI Demo: SimExp



Graphic Remedy's gDEBugger



Solutions to common bottlenecks

- CPU Bound?
  - In your code:
    - VTune…VTune…VTune… Don't assume!
    - LOD all calculations: Physics, animation, AI, you name it!
  - In driver code:
    - Create all resources up front: textures, VBOs, FBOs, GPU programs
    - Reduce locking resources on the fly (don't write to a surface the GPU is reading from, etc.)
    - Create bigger batches: texture atlas, stitch strips together with degenerates
    - Vertex shader constants = lookup table for matrices
    - Instancing
  - Transferring data to GPU
    - Smallest vertex format possible
      - Remove unnecessary data
      - Use smallest data type possible
    - Derive attributes in vertex shader
    - 16 bit indices

Solutions to common bottlenecks

- IDX Bound, Vertex Program Bound?
  - Reduce vertex attribute count
    - Compute some attributes
    - Combine attributes (2 2D tex coords per attribute)
  - Use geometry LOD
  - Move invariant calculations to the CPU
  - Use indexed primitives, more cache friendly
  - Don’t do unnecessary matrix multiplies
  - Use vertex shader branching to bypass expensive calculations
  - Use NVShaderPerf!

Solutions to common bottlenecks

- Fragment Program Bound?
  - Render depth first (no color writes = 2X speed)
  - Prebake complex math into textures
  - Move per pixel calculations to the vertex shader
  - Use partial precision where possible, try it you may like the result
  - Avoid unnecessary normalizations
  - Use LOD specific pixel shaders
  - Use NVShaderPerf!

Solutions to common bottlenecks

- Texture bound?
  - Prefilter textures to reduce size
  - Mipmap on any texture/surface that might be minified
  - Compressed textures
  - Use float textures only when needed

Solutions to common bottlenecks

- Frame buffer bound?
  - Render depth first (no color writes = 2X speed)
  - Only use alpha blending when necessary
  - Use alpha test
  - Disable depth writes when possible
  - Avoid clearing the color buffer (sky box?)
  - Render front to back to get better z culling
  - Use float textures only when needed

NVShaderPerf

- What is NVShaderPerf?
- What's new with version 1.8?
- What's coming with version 2.0?

NVShaderPerf

Inputs:
- GLSL (fragments)
- !!FP1.0
- !!ARBfp1.0
- Cg
- HLSL
- PS1.x,PS2.x,PS3.x
- VS1.x,VS2.x, VS3.x

NVShaderPerf

GPU Arch:
- GeForce 7X00
- GeForce 6X00
- Geforce FX series
- Quadro FX series

C:\WINDOWS\system32\cmd.exe

```
dp3 r0.x, r1, r1
rsq r0.w, r0.x
nrm r0.xyz, t1
mad r1.xyz, r1, r0.w, r0
nrm r2.xyz, r1
nrm r1.xyz, t2
dp3 r2.x, r2, r1
max r1.w, r2.x, c9.x
pow r0.w, r1.w, c5.x
add r1.w, r0.w, -c7.x
mov r2.w, c6.x
add r2.w, r2.w, -c7.x
rcp r2.w, r2.w
mul_sat r2.w, r1.w, r2.w
mad r1.w, r2.w, c9.y, c9.z
mul r2.w, r2.w, r2.w
mul r1.w, r1.w, r2.w
mov r2.x, c9.w
add r2.w, r2.x, -c8.x
mad r1.w, r1.w, r2.w, c8.x
dp3 r0.x, r0, r1
mul r0.w, r0.w, r1.w
```

Outputs:
- Resulting assembly code
- # of cycles
- # of temporary registers
- Pixel throughput
- Test all fp16 and all fp32

```
Shader performance using all FP32
Cycles: 21.00 :: R Regs Used: 3 :: R Regs Max Index (0 based)
Pixel throughput (assuming 1 cycle texture lookup) 304.76 MP

C:\Temp\NVShaderPerf_61_77>
```

NVShaderPerf: In your pipeline

- Test current performance
  - against shader cycle budgets
  - test optimization opportunities
- Automated regression analysis

New in NVShaderPerf 1.8

- Support for GeForce 7X00 series, Quadro FX
- Unified Compiler from ForceWare Rel 80 driver
- Better support for branching performance
  - Default computes maximum path through shader
  - Use –minbranch to compute minimum path

NVShaderPerf 1.8

```
////////////////////////////////////////////////////////////////////
 // determine where the iris is and update normals, and lighting parameters to simulate iris geometry
 ////////////////////////////////////////////////////////////////////

 float3 objCoord = objFlatCoord;
 float3 objBumpNormal = normalize( f3tex2D( g_eyeNermel, v2f.UVtex0 ) * 2.0 - float3( 1, 1, 1 ) );
 objBumpNormal = 0.350000 * objBumpNormal + ( 1 - 0.350000 ) * objFlatNormal;
 half3 diffuseCol = h3tex2D( g_irisWhiteMap, v2f.UVtex0 );
 float specExp = 20.0;
 half3 specularCol = h3tex2D( g_eyeSpecMap, v2f.UVtex0 ) * g_specAmount;

 float tea;

 float3 centerToSurfaceVec = objFlatNormal; // = normalize( v2f.objCoord )
 float firstDot = centerToSurfaceVec.y; // = dot( ce
 if( firstDot > 0.805000 )
 {
  // We hit the iris.  Do the math.

  // we start with a ray from the eye to the surface
  float3 ray_dir = normalize( v2f.objCoord - objEy
  float3 ray_origin = v2f.objCoord;

  // refract the ray before intersecting with the iris
  ray_dir = refract( ray_dir, objFlatNormal, g_refra

  // first, see if the refracted ray would leave the e
  float t_eyeballSurface = SphereIntersect( 16.0, r
  float3 objPosOnEyeBall = ray_origin + t_eyeball
  float3 centerToSurface2 = normalize( objPosOn

  if( centerToSurface2.y > 0.805000 )
  {
   // Display a blue color
   diffuseCol = float3( 0, 0, 0.7 );
   objBumpNormal = objFlatNormal;
   specularCol = float3( 0, 0, 0 );
   specExp = 10.0;
  }
  else
  {
   // transform into irisSphere space
   ray_origin.y -= 5.109000;

   // intersect with the Iris sphere
   float t = SphereIntersect( 9.650000, ray_origin, ray_dir );
   float3 SphereSpaceIntersectCoord = ray_origin + t * ray_dir;
   float3 irisNormal = normalize( -SphereSpaceIntersectCoord );
```

Eye Shader from Luna
Maximum branch takes 674 cycles
Minimum branch takes 193 cycles.

```
C:\WINDOWS\System32\cmd.exe

T:\tmp>t:\sw\devrel\sdk\tools\bin\release_pdb\nvshperf\nvshaderperf -a NV40 corn
ea2.txt
----------------------------------------------------------------------------

Running performance on file Cornea2.txt
--------------------- NV40 ---------------------
Target: GeForce 6800 Ultra (NV40) :: Unified Compiler: v77.72
Cycles: 674.25 :: R Regs Used: 12 :: R Regs Max Index (0 based): 11
Pixel throughput (assuming 1 cycle texture lookup) 9.50 MP/s

T:\tmp>t:\sw\devrel\sdk\tools\bin\release_pdb\nvshperf\nvshaderperf -minbranch -
a NV40 cornea2.txt
----------------------------------------------------------------------------

Running performance on file Cornea2.txt
--------------------- NV40 ---------------------
Target: GeForce 6800 Ultra (NV40) :: Unified Compiler: v77.72
Cycles: 192.82 :: R Regs Used: 12 :: R Regs Max Index (0 based): 11
Pixel throughput (assuming 1 cycle texture lookup) 33.33 MP/s

T:\tmp>_
```

NVShaderPerf – version 2.0

- Vertex throughput
- GLSL vertex program
- Multiple driver versions from one NVShaderPerf
- Much smaller footprint
- New programmatic interface
- What else do you need?

NVShaderPerf@nvidia.com

Questions?

- Developer tools DVDs available at our booth
  - NVPerfKit 2.0
  - NVPerfHUD 4.0 Materials
  - User Guides
- Online:
  - http://developer.nvidia.com/NVPerfKit
  - http://developer.nvidia.com/NVPerfHUD

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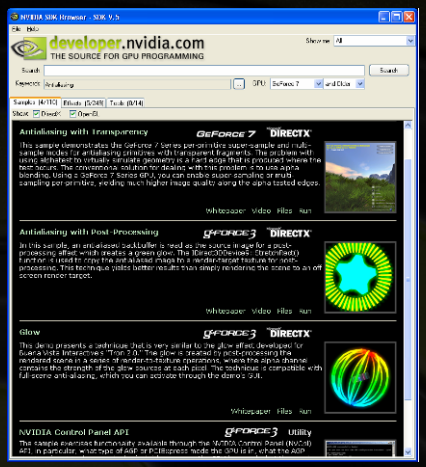
NVPerfHUD@nvidia.com
NVShaderPerf@nvidia.com
FXComposer@nvidia.com

NVIDIA SDK

The Source for GPU Programming



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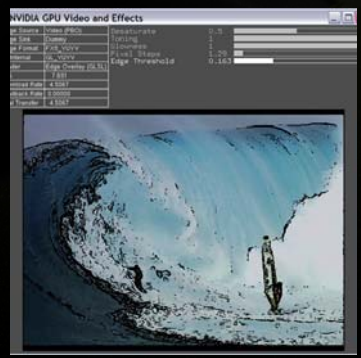
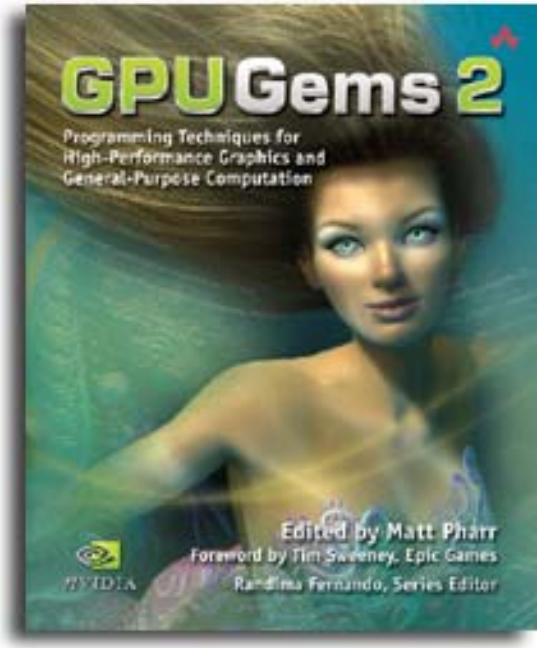


GPU Gems 2

Programming Techniques for High-Performance Graphics and General-Purpose Computation



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