Integrating Shaders into Your Game Engine

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NVIDIA

Developer Technology

Agenda

- Why shaders?
- What are shaders exactly?
  - Evolution of graphics
- Using Shaders
  - High Level Shading Languages
  - C++ side API and semantics
- Tools

Why Shaders?

- Pixel Shaders are the #1 feature that will visually differentiate next-gen titles
- Distinct materials
  - Great way to show detail without geometry
  - Not everything matte or plastic
  - Moving away from just Blinn/Phong
  - Custom light types
    - Volumetric lights
    - Not limited to OpenGL fixed pipeline

No Shaders vs Shaders

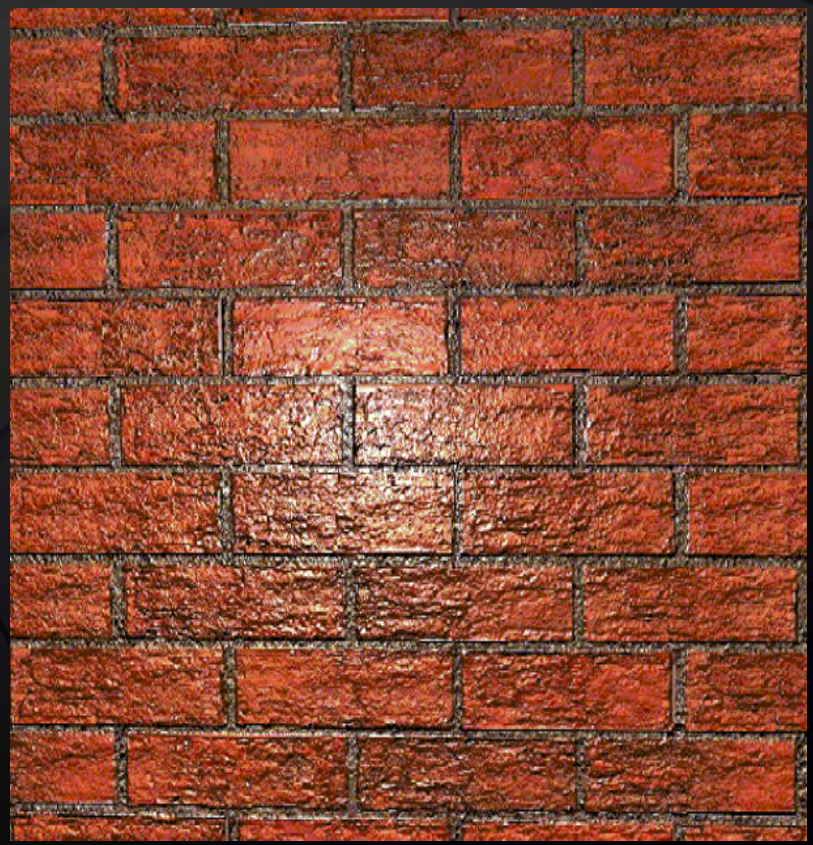
Flat texture, single texture,
vertex lighting, no shadow

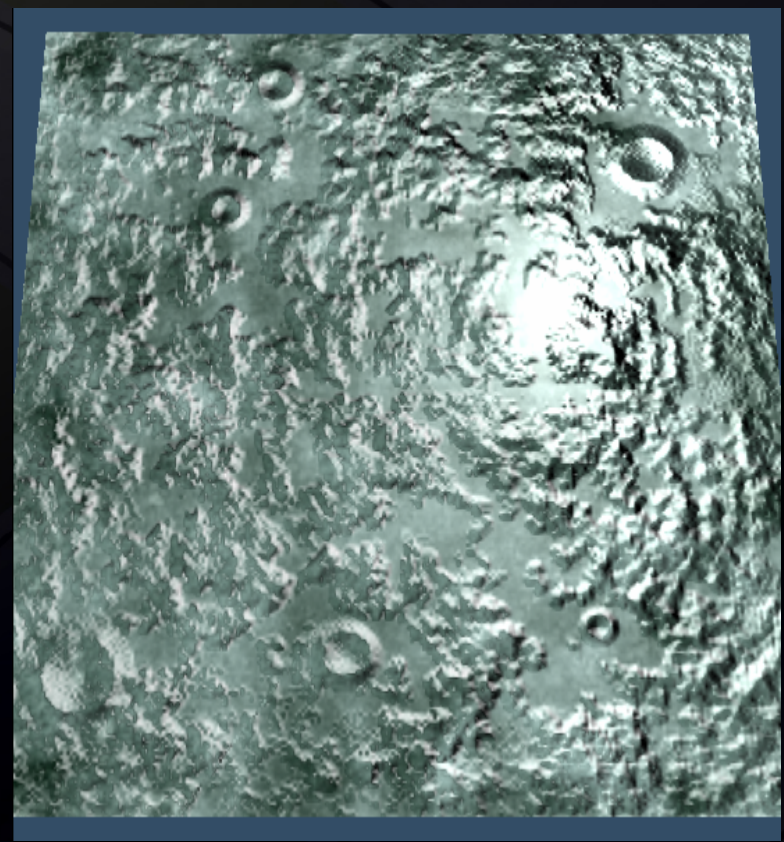
Bump mapped, multi texture,
per pixel lighting, soft shadow

Per Pixel Lighting

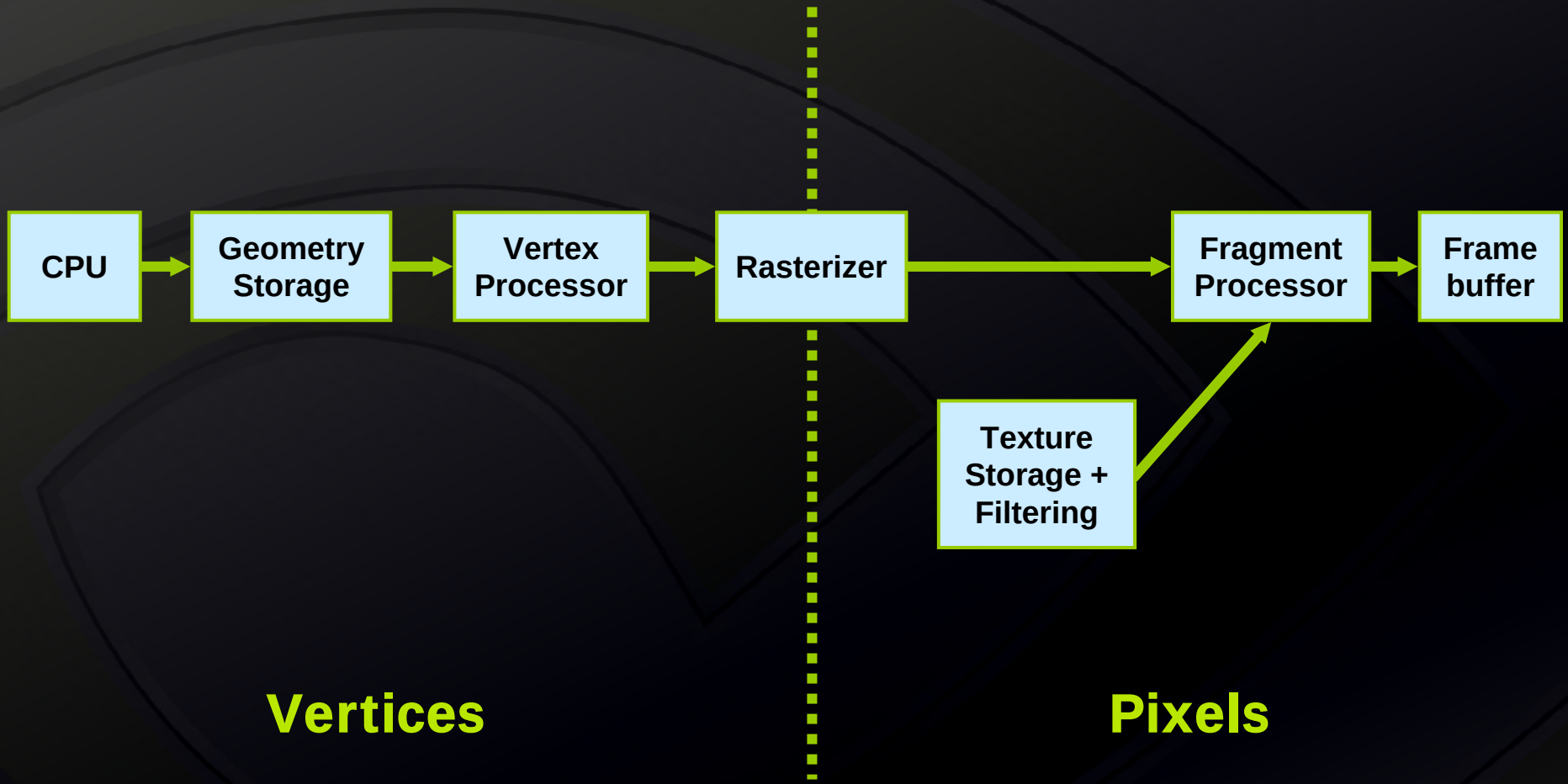
- Bump mapping / Normal Mapping / Per-Pixel Lighting are synonyms
  - Blinn Diffuse Specular lighting
  - With Tangent space Bump mapping
- Instead of calculating lighting on a per-vertex normal, use a per-pixel normal instead

Two quads lit per pixel





Pipelined Architecture



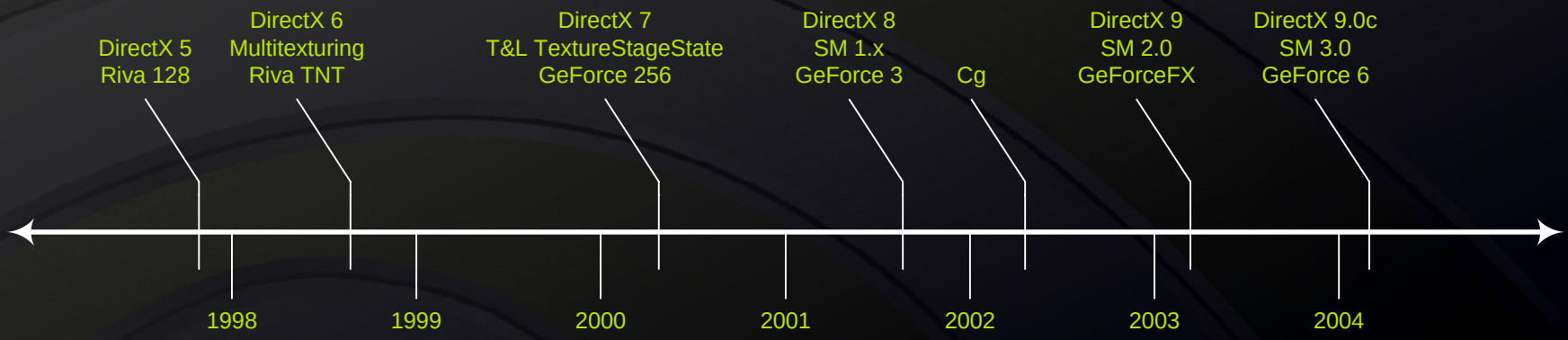
What are Shaders?

- User-defined vertex and fragment processing
  - Custom animation, lighting, image processing, etc.
- Ubiquitous platform & API support
  - PCs, next-generation consoles, cellular phones
  - Direct3D, OpenGL, OpenGL-ES
- Programmed in C-like high level languages
  - HLSL (Direct3D)
  - GLSL (OpenGL)
  - GLSL-ES (OpenGL-ES)
  - Cg (OpenGL, OpenGL-ES)

Shader Taxonomy

- Hardware functionality often described relative to Direct3D shader models 1 – 3
- Newer shader models increase programmability
  - SM 1: Fixed-point color blending, static dependent texturing, <= 16 operations
  - SM 2: Floating-point arithmetic, programmable dependent texturing, <= 64 operations
  - SM 3: Branching & subroutines, 1000s of operations

PC/DirectX Shader Model Timeline



Quake 3

Giants

Halo

Far Cry

UE3

DirectX 8, SM 1.x / OpenGL 1.4

- Programmable vertex shaders
  - Up to 128 floating-point instructions
- Programmable pixel shaders
  - Up to 16 fixed-point vector instructions and 4 textures
  - 3D texture support
  - Up to 1 level of dependent texturing
- Advanced Render-to-Texture support
- Example Hardware
  - GeForce 3, ATI Radeon 8500, XGI Volari V3, Matrox Parhelia

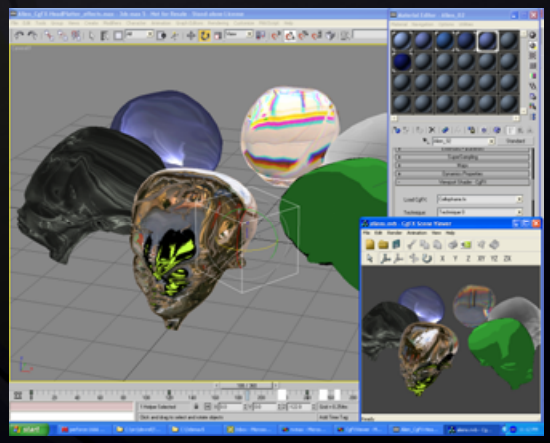
SM 1.x-era Game: Halo

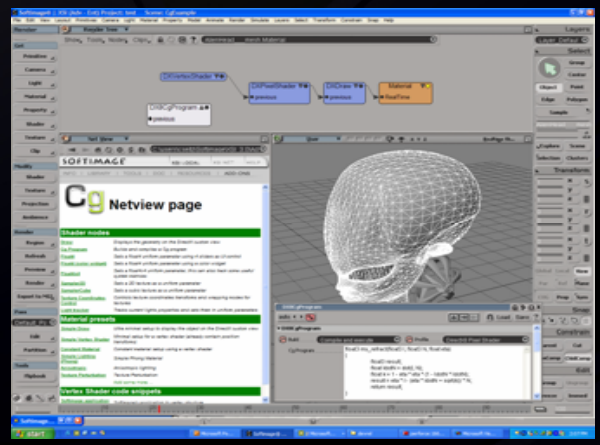
- Vertex shaders used to add fresnel reflection to ice
- Pixel shaders used to add glow to sun
- Render-to-texture used to distort pistol scope
- Dependent texturing used to animate & light water

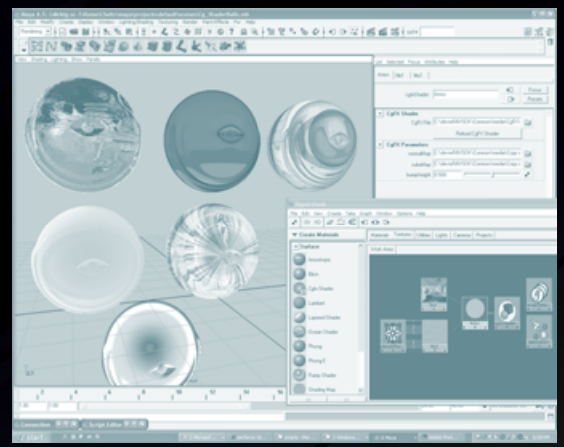
DirectX 7 vs DirectX 8

Cg – C for Graphics

- High-level language designed for real-time shaders
- Supported in major DCC apps (Maya, Max, XSI)
  - What artists see in tool chain matches in-game result





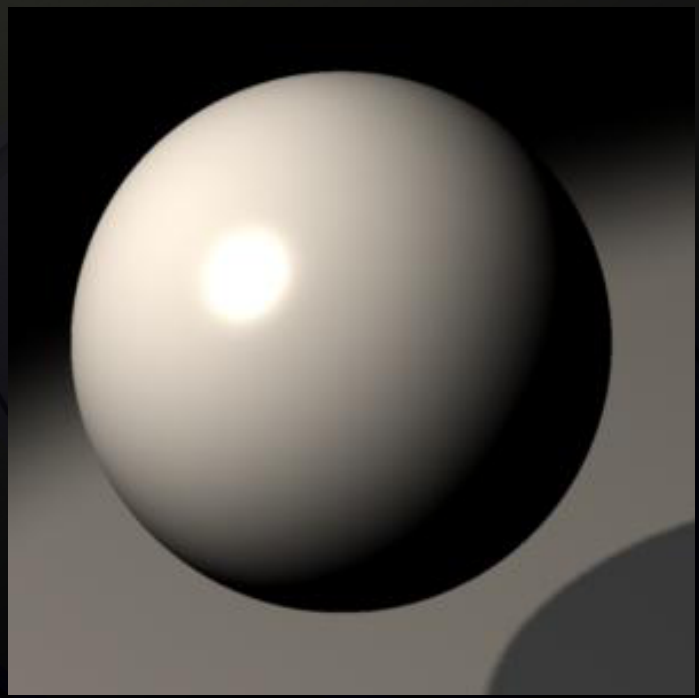


HLL vs Assembly

High-level source code

```
float3 L = normalize(lightPosition – position.xyz);
float3 H = normalize(L + normalize(eyePosition –
                                   position.xyz));

color.xyz = Ke + (Ka * globalAmbient) +
   Kd * lightColor * max(dot(L, N), 0) +
   Ks * lightColor * pow(max(dot(H, N), 0), shininess);
color.w = 1;
```

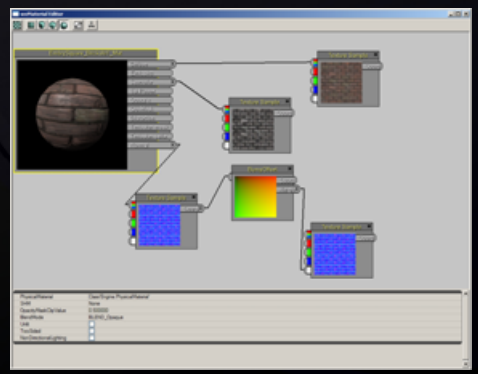


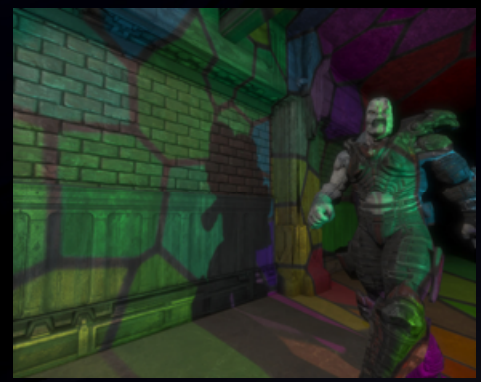
Assembly

```
ADDR R0.xyz, eyePosition.xyzx, -f[TEX0].xyzx;
DP3R R0.w, R0.xyzx, R0.xyzx;
RSQR R0.w, R0.w;
MULR R0.xyz, R0.w, R0.xyzx;
ADDR R1.xyz, lightPosition.xyzx, -f[TEX0].xyzx;
DP3R R0.w, R1.xyzx, R1.xyzx;
RSQR R0.w, R0.w;
MADR R0.xyz, R0.w, R1.xyzx, R0.xyzx;
MULR R1.xyz, R0.w, R1.xyzx;
DP3R R0.w, R1.xyzx, f[TEX1].xyzx;
MAXR R0.w, R0.w, {0}.x;
SLER H0.x, R0.w, {0}.x;
DP3R R1.x, R0.xyzx, R0.xyzx;
RSQR R1.x, R1.x;
MULR R0.xyz, R1.x, R0.xyzx;
DP3R R0.x, R0.xyzx, f[TEX1].xyzx;
MAXR R0.x, R0.x, {0}.x;
POWR R0.x, R0.x, shininess.x;
MOVXC HC.x, H0.x;
MOVR R0.x(GT.x), {0}.x;
MOVR R1.xyz, lightColor.xyzx;
MULR R1.xyz, Kd.xyzx, R1.xyzx;
MOVR R2.xyz, globalAmbient.xyzx;
MOVR R3.xyz, Ke.xyzx;
MADR R3.xyz, Ka.xyzx, R2.xyzx, R3.xyzx;
MADR R3.xyz, R1.xyzx, R0.w, R3.xyzx;
MOVR R1.xyz, lightColor.xyzx;
MULR R1.xyz, Ks.xyzx, R1.xyzx;
MADR R3.xyz, R1.xyzx, R0.x, R3.xyzx;
MOVR o[COLR].xyz, R3.xyzx;
MOVR o[COLR].w, {1}.x;
```

Impact of HLLs

- Dramatic increase in shader adoption
  - Tens of games per year to hundreds
- Shift in game development
  - Shaders become content requirement, not tech feature
  - “What do I want?”, not “what can I do?”
  - Gives control of the look of the game to artists





DirectX 9, SM 2.0 / OpenGL 1.5

- Floating point pixel processing
  - 16/32-bit floating point shaders, render targets & textures
  - Up to 64 vector instructions and 16 textures
  - Arbitrary dependent texturing
- Longer vertex processing – 256 instructions
- Multiple Render Targets – up to 16 outputs per pixel
- Example Hardware
  - GeForce FX 5900, ATI Radeon 9700, S3 DeltaChrome

DirectX 9.0c, SM 3.0 / OpenGL 2.0

- Unified shader programming model
  - Pixel & vertex shader flow control
  - Infinite length vertex & pixel shaders
  - Vertex shader texture lookups
- Floating-point filtering & blending
- Geometry instancing
- Example Hardware
  - GeForce 6800, GeForce 7800 GTX

SM 3.0-era Game: Unreal Engine 3

- 16-bit FP blending for high dynamic range lighting
- 16-bit FP filtering accelerates glow and exposure FX
- Long shaders & flow control for virtual displacement mapping, soft shadows, iridescence, fog, etc.

Using Shaders

“Effects”

- Direct3D FX and CgFX
  - *ID3DXEffect* or *CGeffect*
- Wrapper around pixel and vertex shaders
- Can Configure
  - Target shader version
  - Common case variables
- Can reference a library of shader functions
- Define multi-pass techniques

Semantics

- Define any variable naming you want
  - Semantics make sure constants get set

```
float4x4 wvp      : WorldViewProjection;
```

- D3D SAS is standardized
  - Supported by many applications
    - FX Composer
    - 3D Studio Max
- OpenGL semantics standardized for CgFX in 1.4

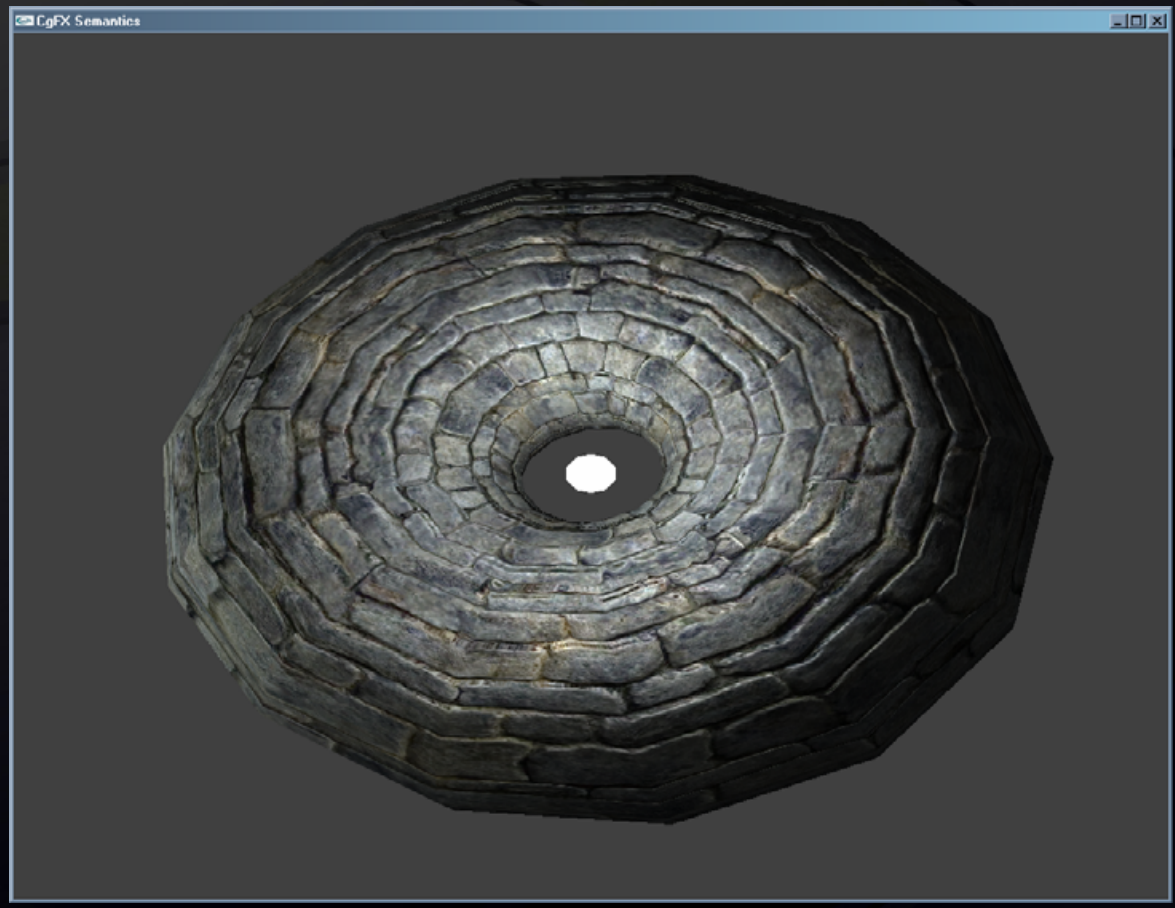
Annotations

- **Custom data associated with any element of your HLSL or CgFX effect**

```
sampler2D anisoTextureSampler <
    string file = "Art/stone-color.png";
> = sampler_state {
        generateMipMap = true;
        minFilter = LinearMipMapLinear;
        magFilter = Linear;
        WrapS = Repeat;
        WrapT = Repeat;
        MaxAnisotropy = 8;
};
```

- **Allows you to provide hooks to set per object data**
  - **E.g. Used extensively by shader tools for UI controls**

CgFX Semantics Demo



Demo Important Bits

- Tangent basis interpolated from vertex shader
- Single fragment shader for lighting
- An unsized array of light structures that is dynamically resized by the C++ side
- A handful of different light types that implement the light interface
  - Point light
  - Spot Light
  - Etc…
- Optional Bump mapping based on a constant

Single Lighting Function

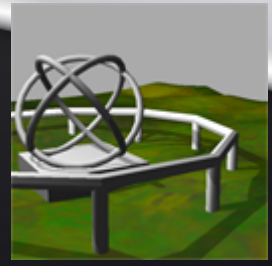
- Sample Albedo map for base color
- Normalize interpolated vectors
  - Tangent space basis vectors
- Optionally perturb our normal based on a normal map
- Iterate over our lights and accumulate diffuse and specular
- Combine color and lighting values to produce final result

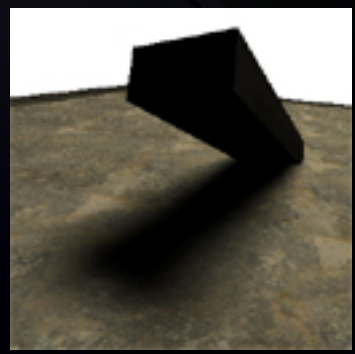
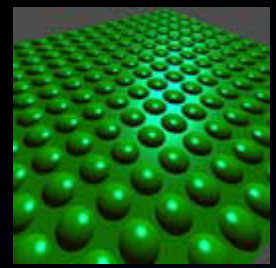
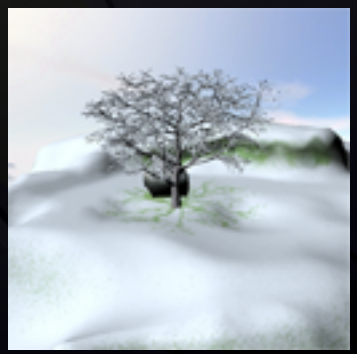
C++ Side

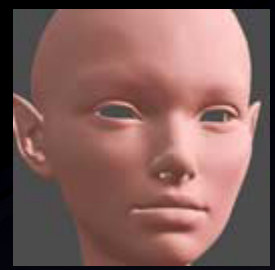
- Assign the light position through the effect given a handle to the variable
- Sets number of lights and light info based on program code dynamically
- Can also pick whether or not to use normal maps
  - When not using it, shader gets faster
- Any dynamic configuration can be represented as a uniform parameter or global constant

Shader Library

- Rather than writing each shader separately
- Code re-use is good!!
- Establish common interpolated values
  - Vertex to Fragment/Pixel program
  - e.g. At a base, COLOR0, TEXCOORD0 off limits
- Create a library of useful functions
  - Break everything out
  - Only costs compile time (can be preprocessed!)



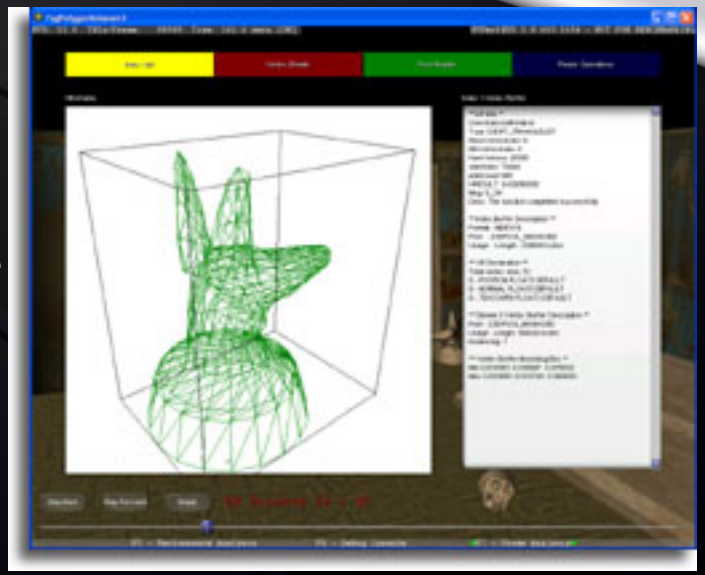



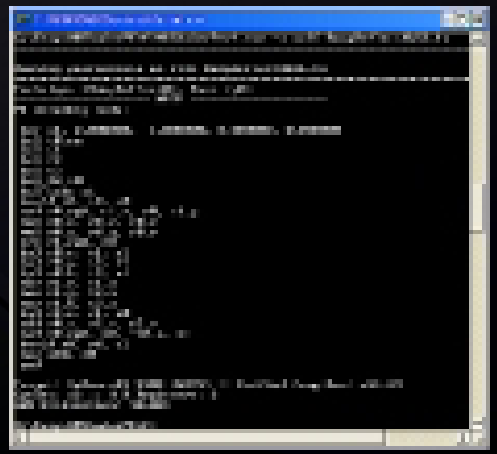

Write with extensibility in Mind

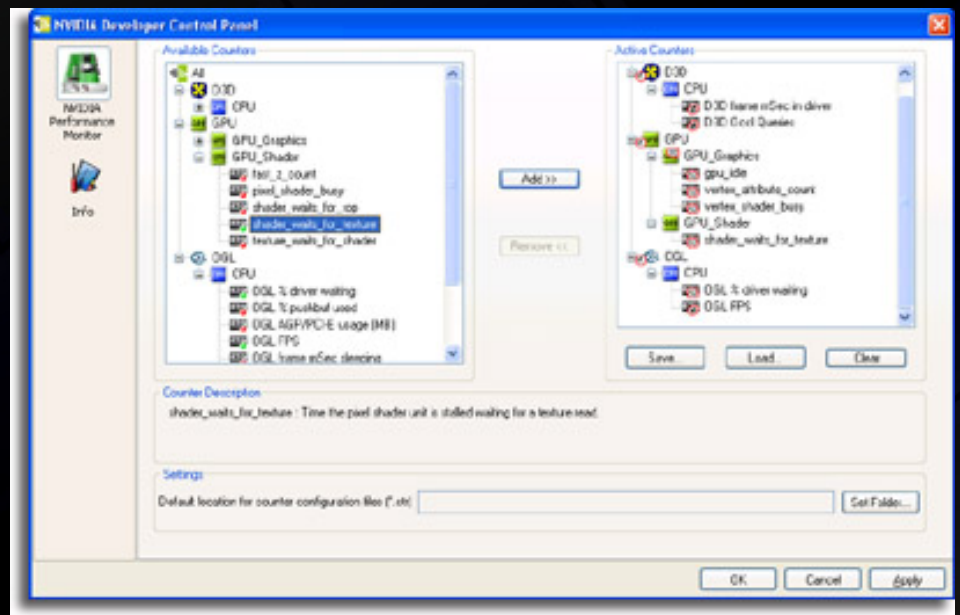
- Quick hacks are for prototyping
- Same as regular code
- Establish guidelines for style
- Full preprocessor support
  - #ifdef #define etc
- Naming convention for techniques
- No Assembly!

Performance

- CPU bound, or Pixel Shader
- NVIDIA's GPU Programming Guide
- NVIDIA provides a number of handy performance analysis tools
  - NVShaderPerf
  - NVPerfHUD
  - NVPerfKit







NVPerfHUD

- What is NVPerfHUD?
- How does it work?
- Schedule

What is NVPerfHUD?

- Stands for: PERFormance Heads Up Display
  - Overlays graphs and dialogs on top of your application
  - Interactive HUD

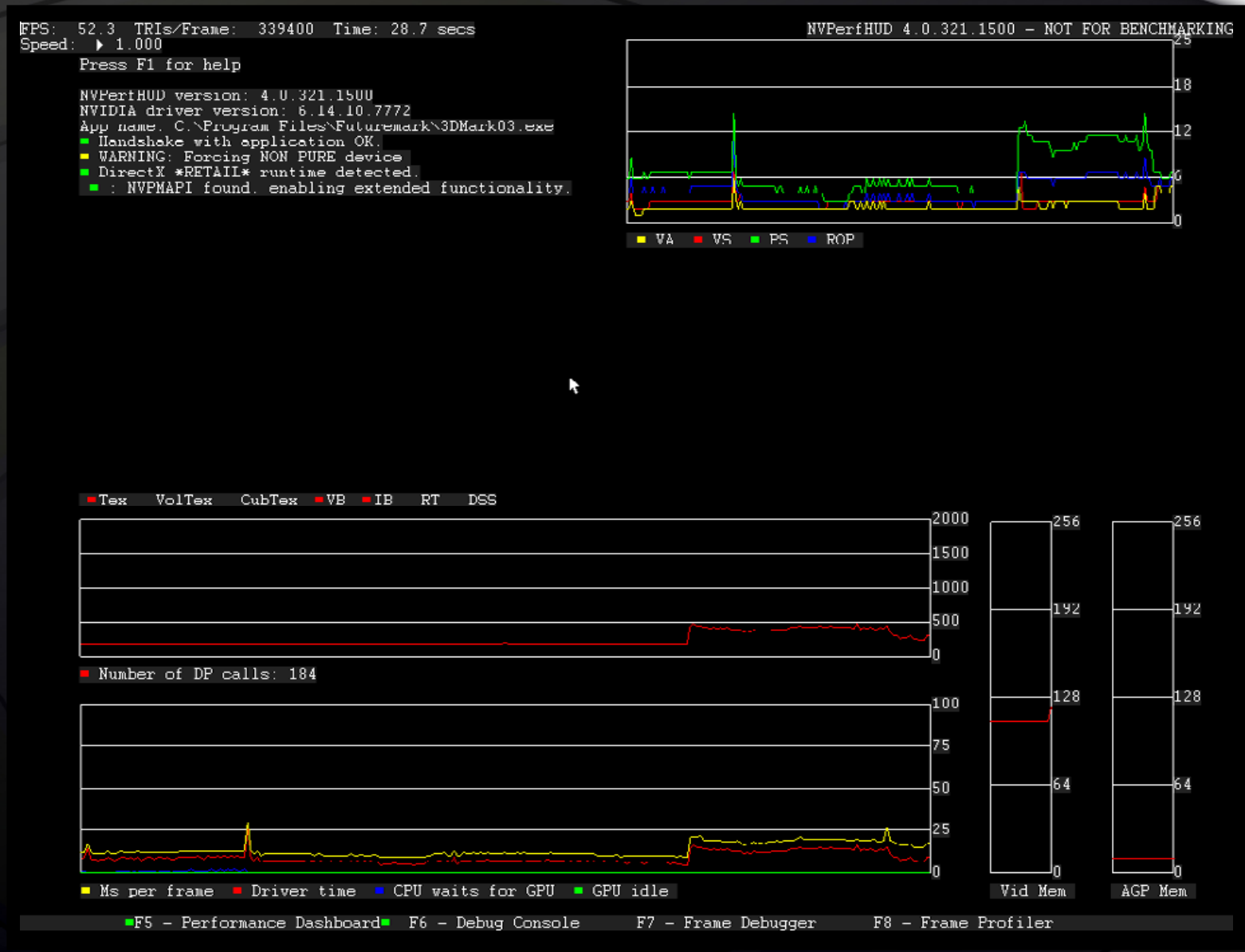
What is NVPerfHUD?

- 4 different types of HUD
  - Performance Dashboard
  - Debug Console
  - Frame Debugger
  - Frame Profiler (New in 4.0)

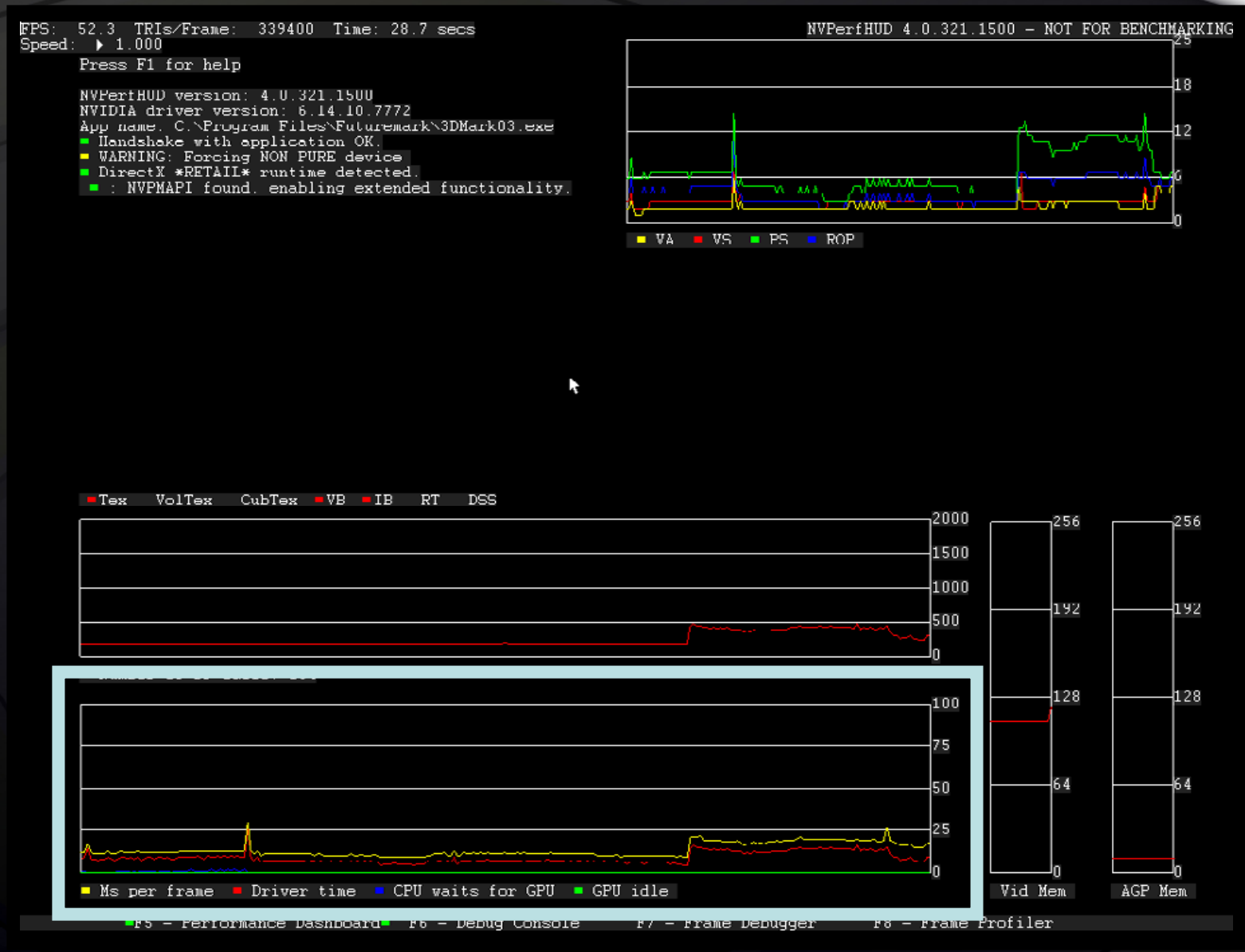
How to use it

- Run your application with NVPerfHUD
- Use it as you normally do until you find:
  - Functional problem: use the debugger
  - Low FPS: use the profiler

Performance Dashboard



Performance Dashboard



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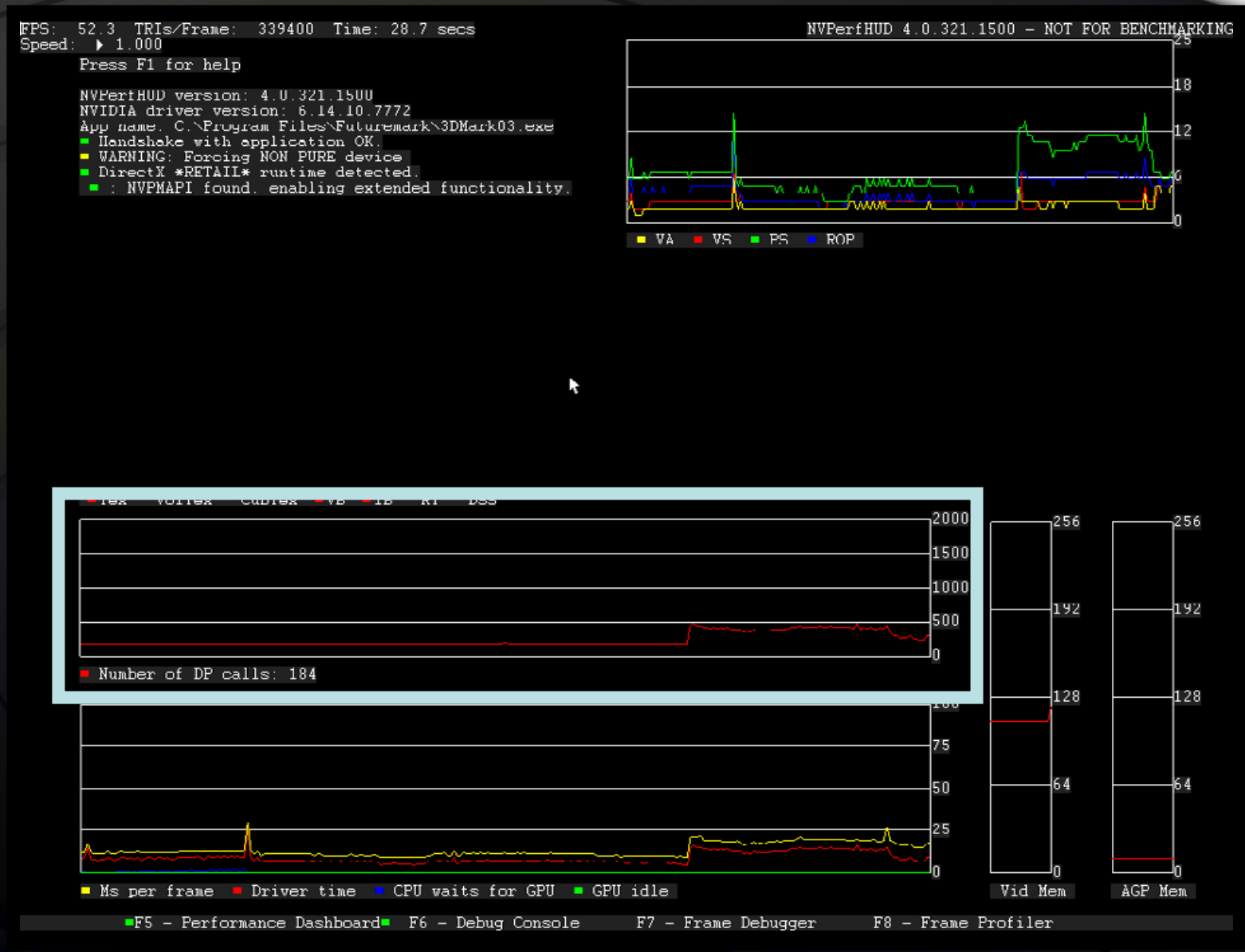

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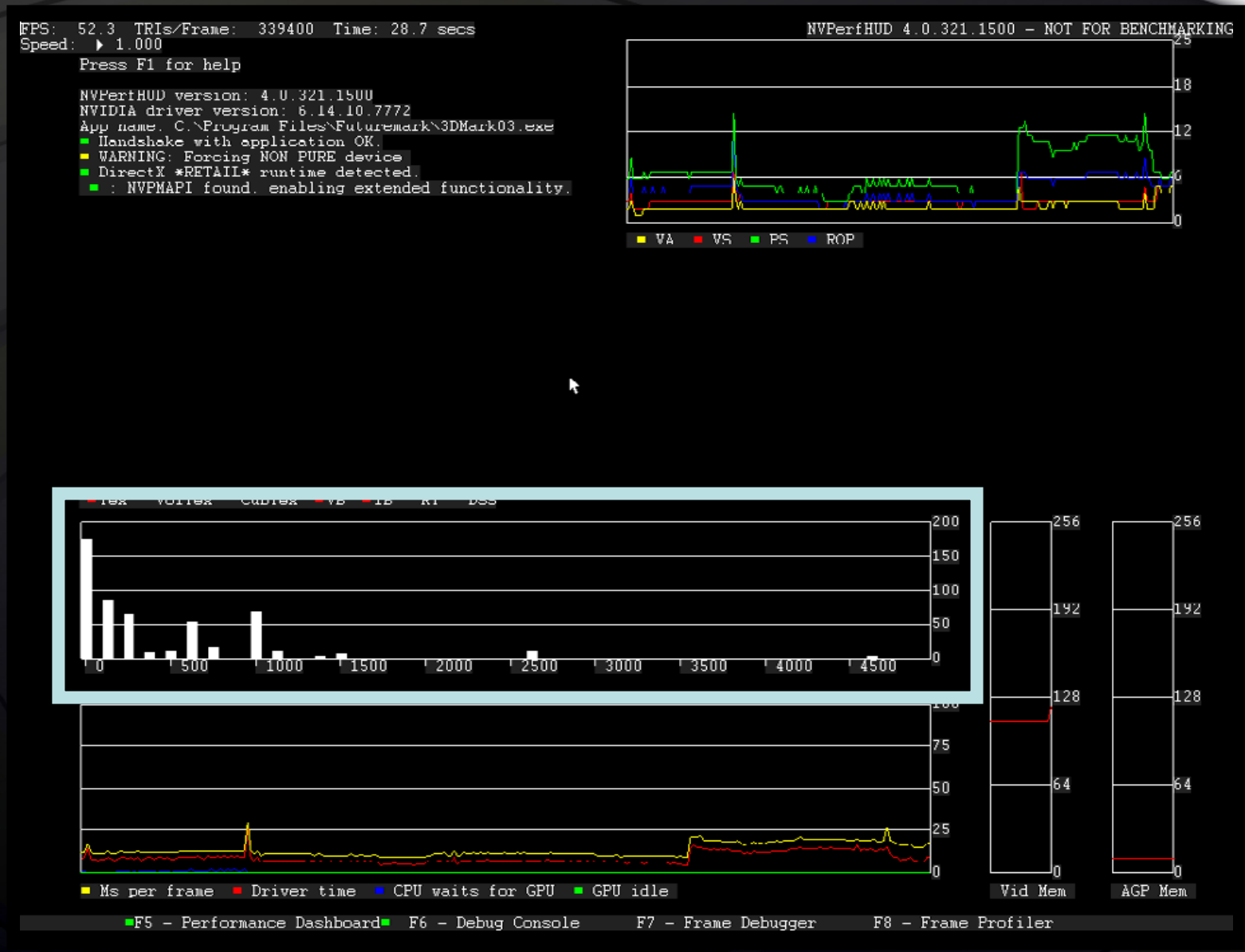
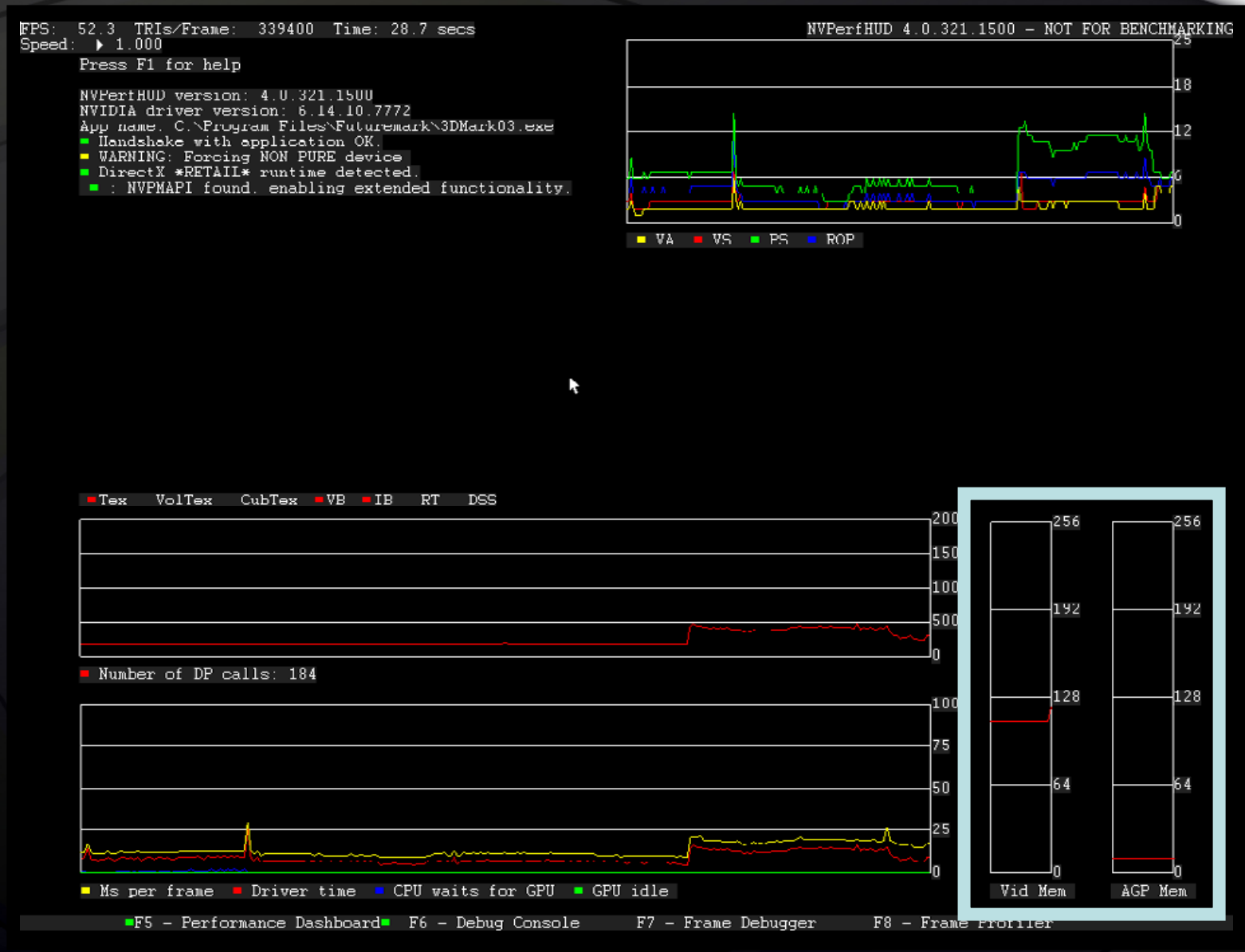


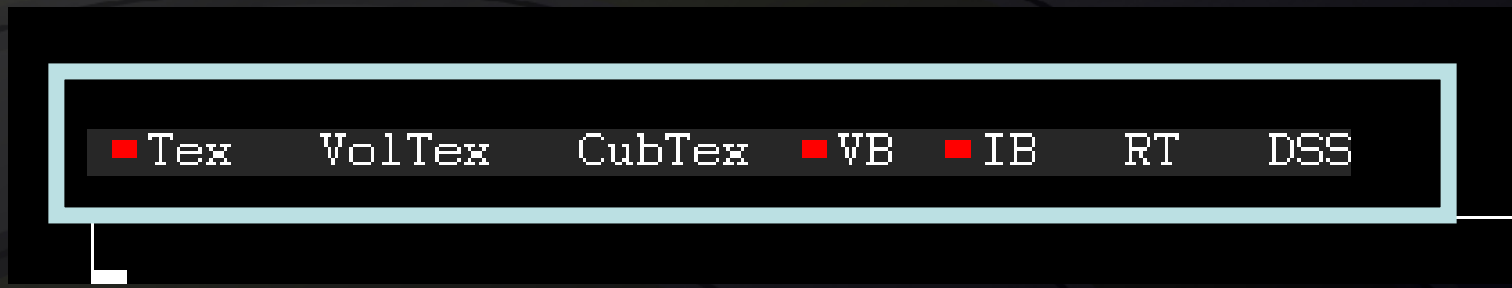
Performance Dashboard



Performance Dashboard

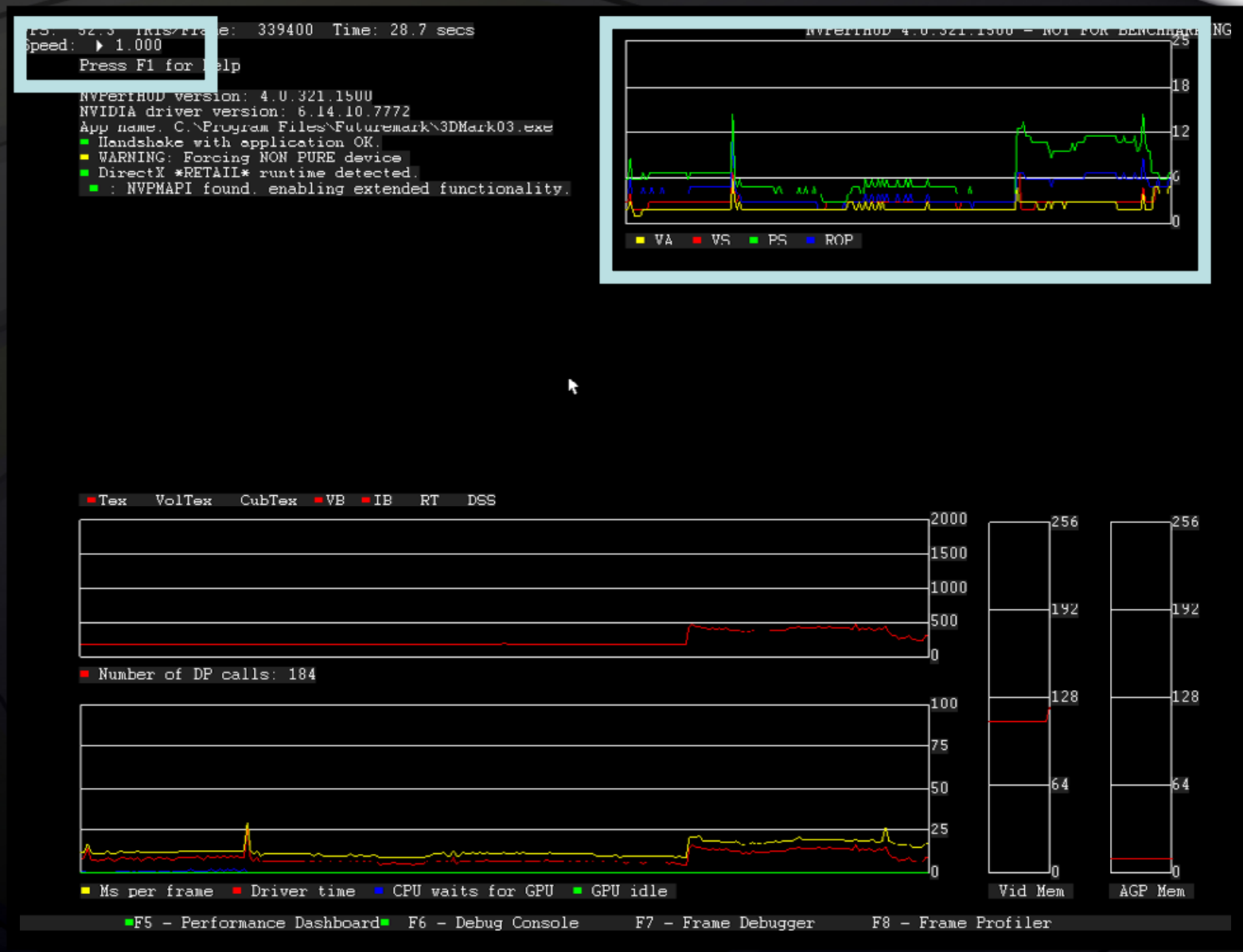
Performance Dashboard

- Resource monitor



- Resources monitored
  - Textures
  - Volume Textures
  - Cube textures
  - Vertex Buffers
  - Index buffers
  - Stencil and depth surfaces

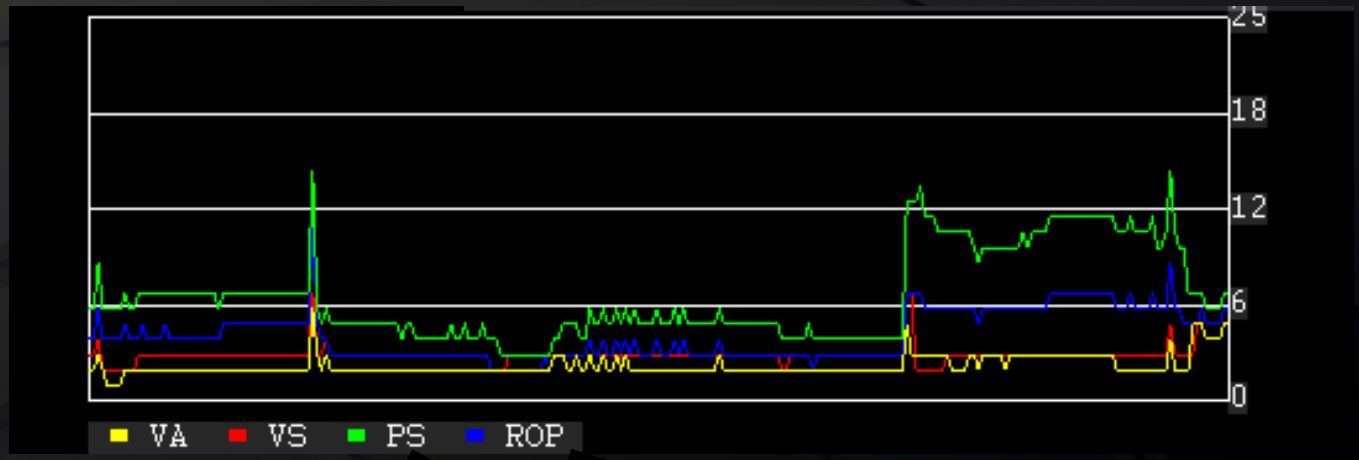
Performance Dashboard



Performance Dashboard

- Speed control

The simplified graphics pipeline



Schedule

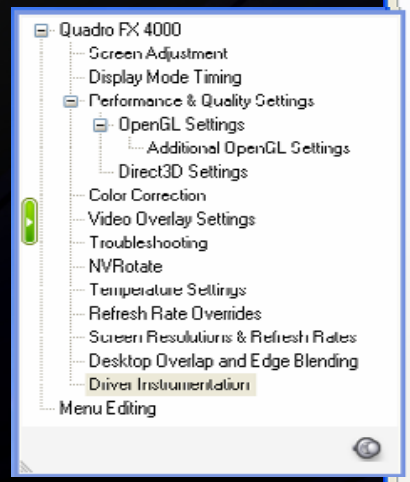
- Beta: August
- Release : September

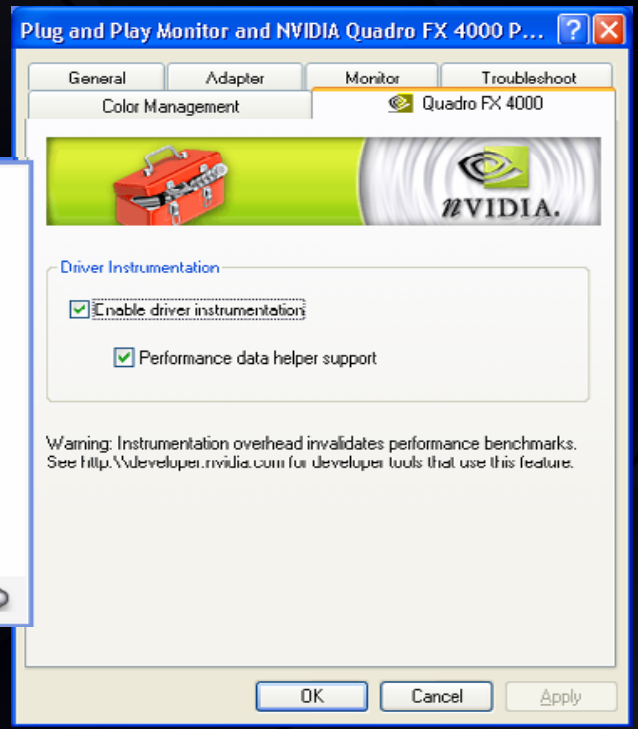
NVPerfKit Performance Analysis Toolkit

- Complete Performance Instrumentation Solution
  - Instrumented Driver
  - NVIDIA Developer Control Panel (NVDevCPL)
  - NVIDIA Plug-in for Microsoft PIX for Windows
  - Direct access to performance counters via PDH
    - Support for PerfMon, Intel® VTune™, gDEBugger, and more
    - Access to performance signals inside your applications
  - Includes code samples for OpenGL and Direct3D
  - Opt-in security mechanism prevents unauthorized analysis

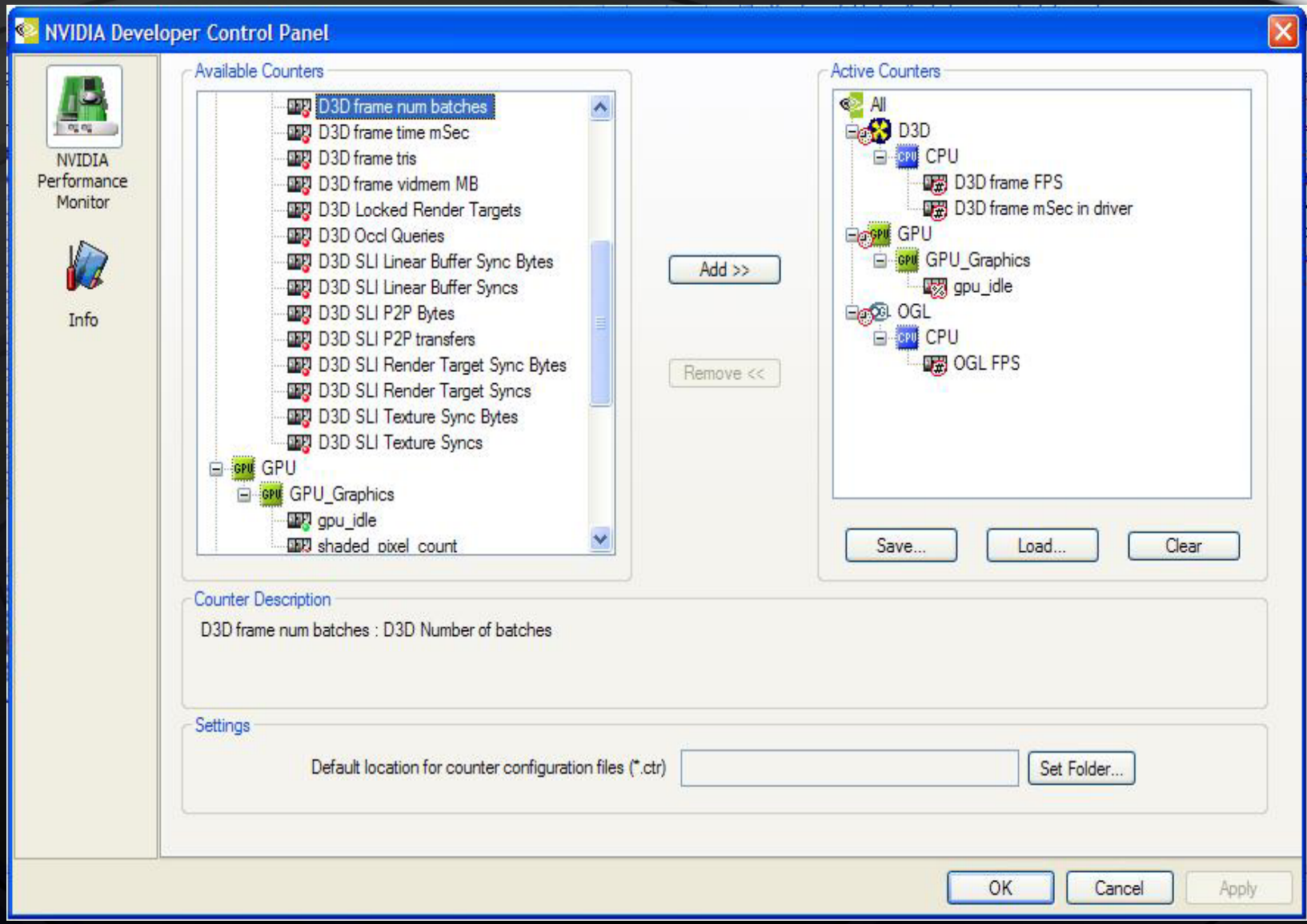
NVPerfKit Instrumented Driver

- Provides GPU and Driver Performance Counters
- Supports OpenGL and Direct3D
- Supports SLI Counters
- Requires GeForce FX or later
  - Significantly more counters available on GeForce 6 Series and later...

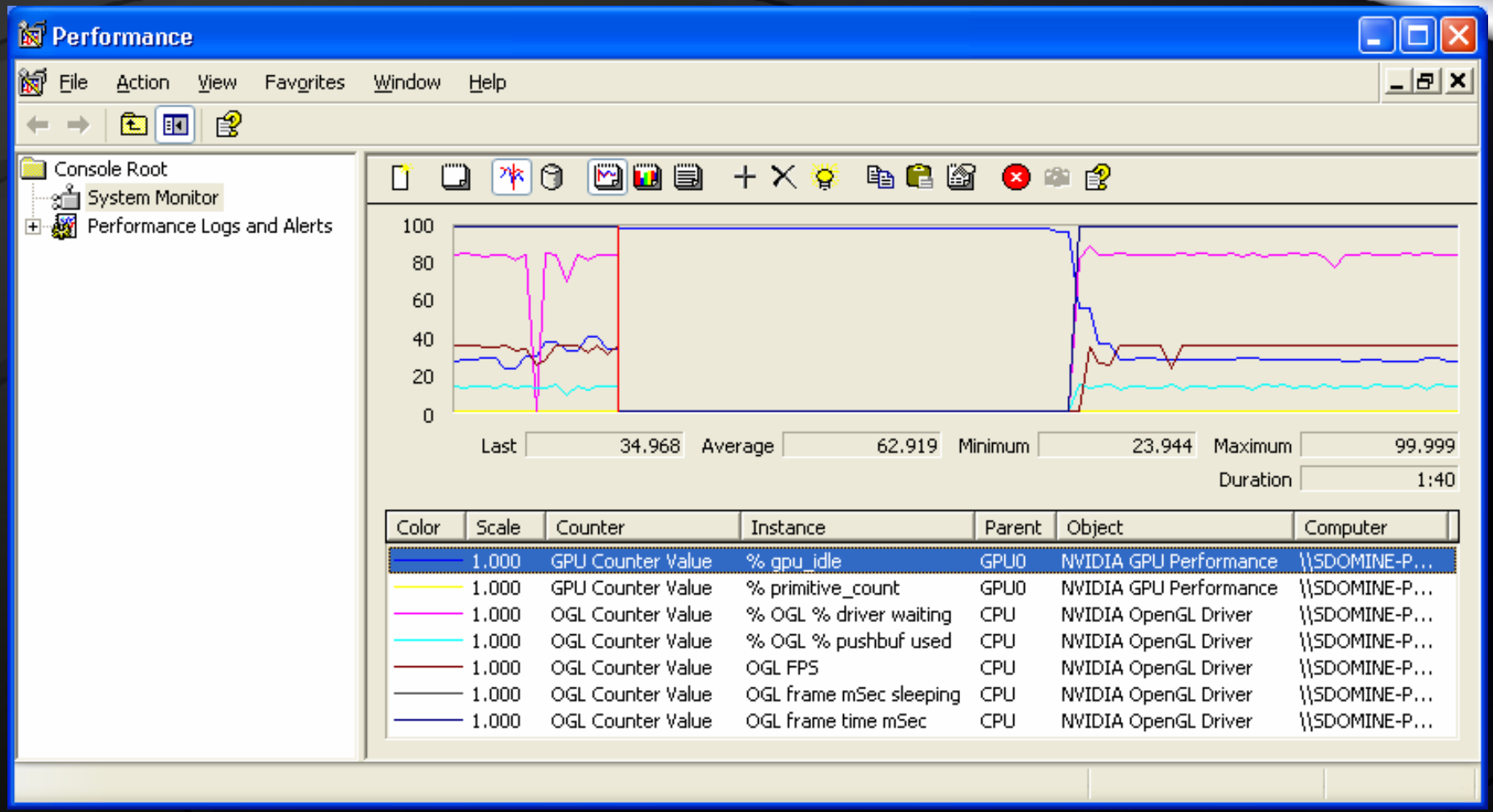




NVPerfKit NVIDIA Developer Control Panel



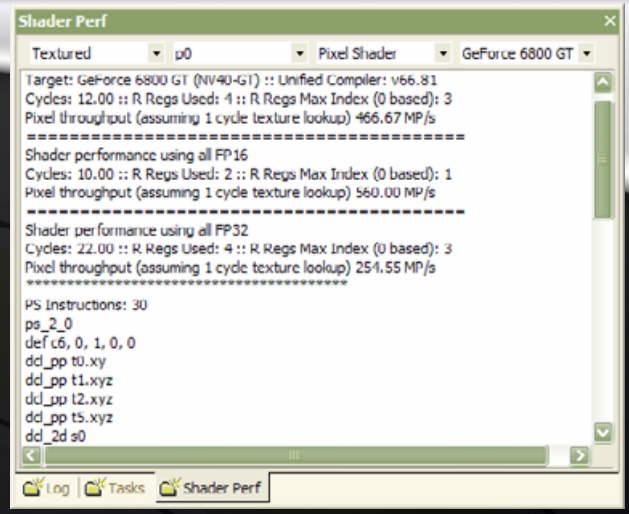
NVPerfKit PDH Counters in PerfMon



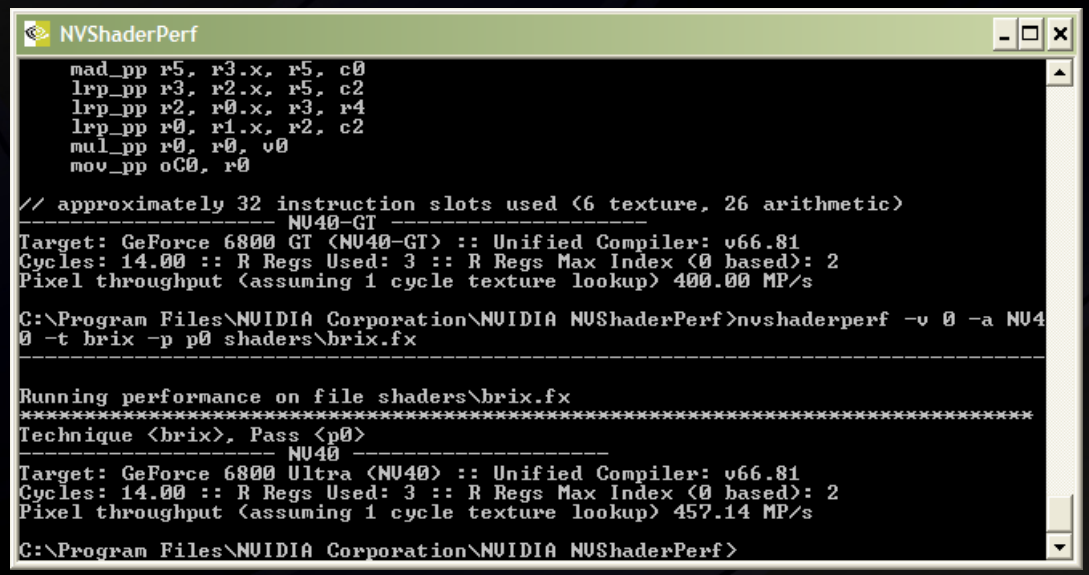
PerfMon already shows [illegible]
reported by the [illegible]

Add NVPerfKit counters
Direct3D Driver.

NVShaderPerf



- Same technology as Shader Perf panel in FX Composer
- Analyze DirectX and OpenGL Shaders
  - HLSL, GLSL, Cg, !!FP1.0, !!ARBfp1.0, VS1.x, VS2.x, VS3.x, PS1.x, PS2.x, PS3.x, etc.
- Shader performance regression testing on the entire family of NVIDIA GPUs, without rebooting!



Conclusion

- Use high-level shading languages
- Use FX files and Semantics
  - Either CgFX or D3D FX
- Use our tools
  - Tons of free tools
  - Tons of free examples
- Treat Shaders like C++ code
  - Good design can save tons of time in making your game look amazing!

Questions

- http://developer.nvidia.com
- http://developer.nvidia.com/CgTutorial
- **Email:** bdudash@nvidia.com