Practical Performance Analysis and Tuning

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NVIDIA Developer Technology Group

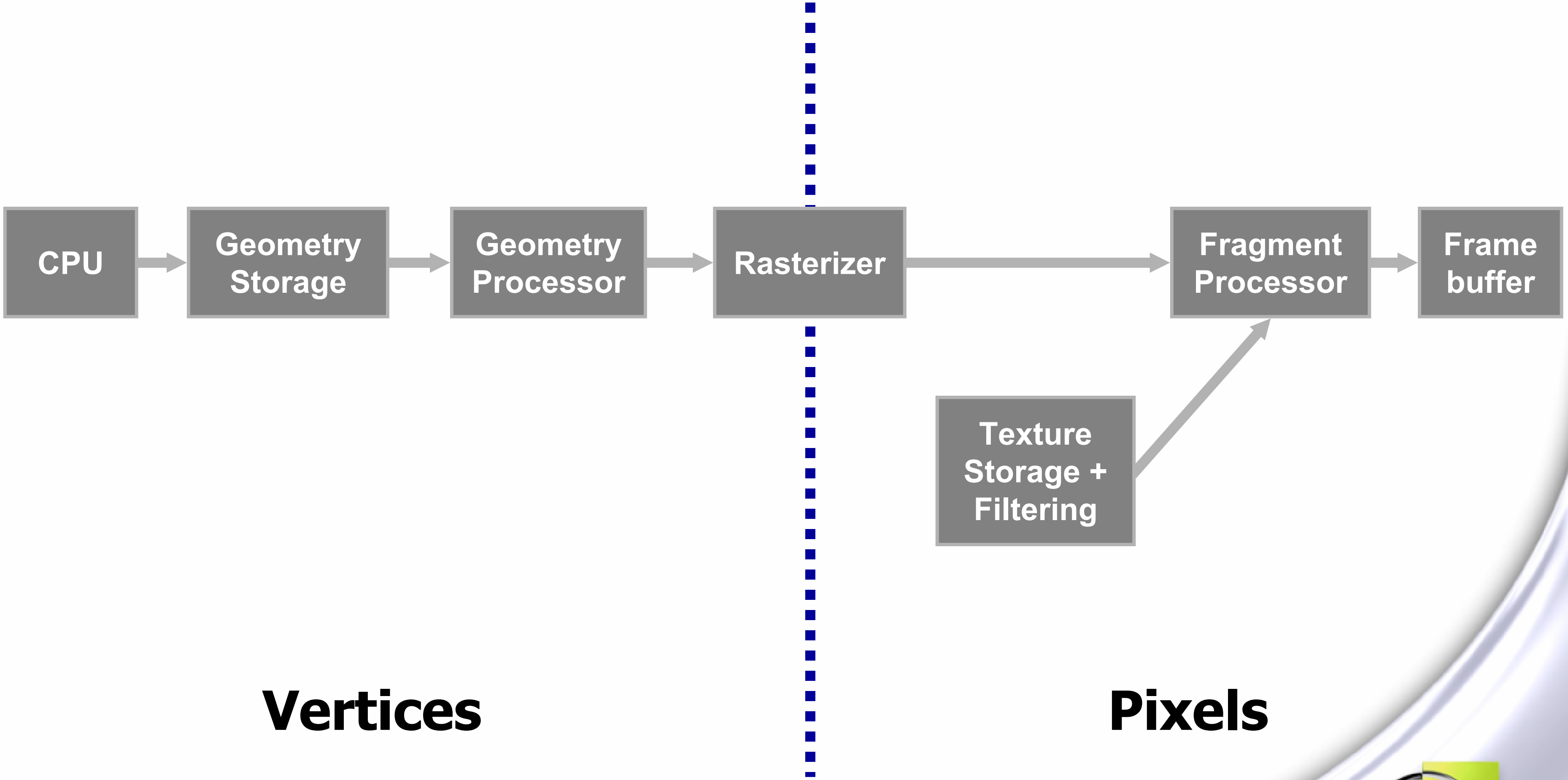
Overview

- Basic principles in practice
- Practice identifying the problems (and win prizes)
- Learn how to fix the problems
- Summary
- Question and Answer
- Performance Lore

Basic Principles

- Pipelined architecture
  - Each part needs the data from the previous part to do its job
- Bottleneck identification and elimination
- Balancing the pipeline

Pipelined Architecture (simplified view)



CPU

Geometry Storage

Geometry Processor

Rasterizer

Fragment Processor

Frame buffer

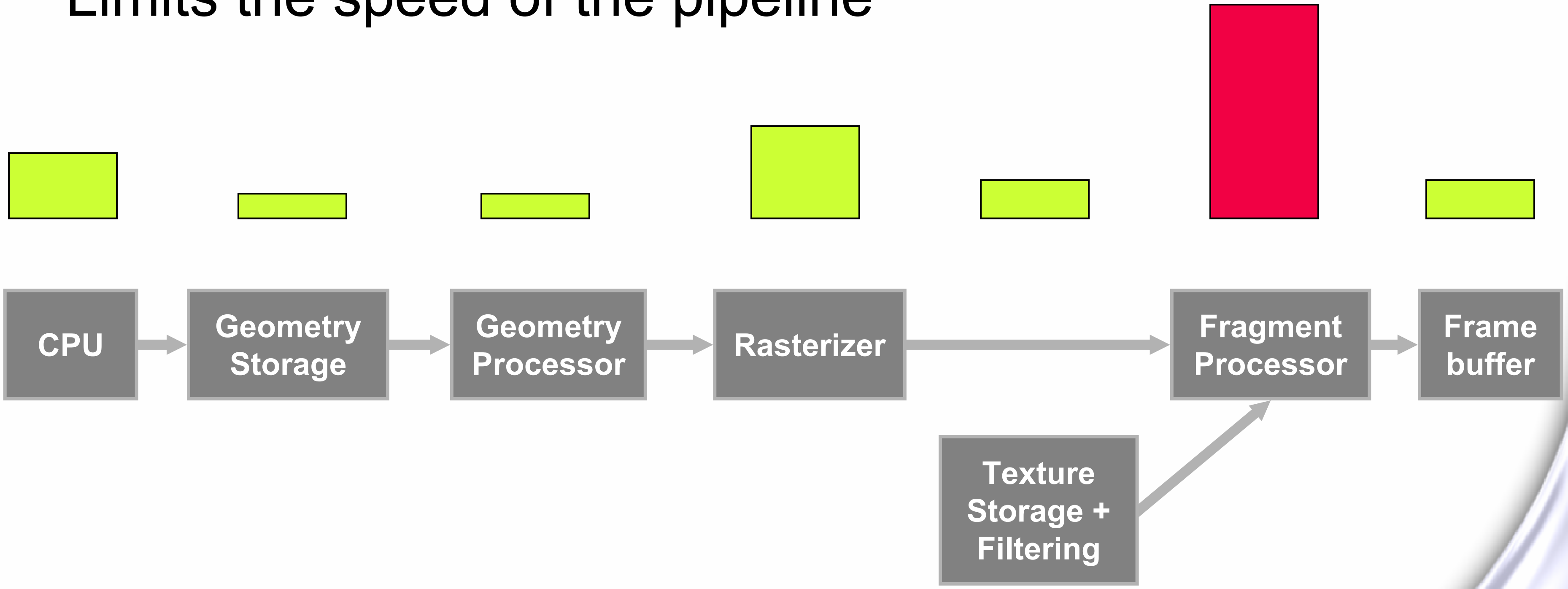
Texture Storage + Filtering

Vertices

Pixels

The Terrible Bottleneck

Limits the speed of the pipeline

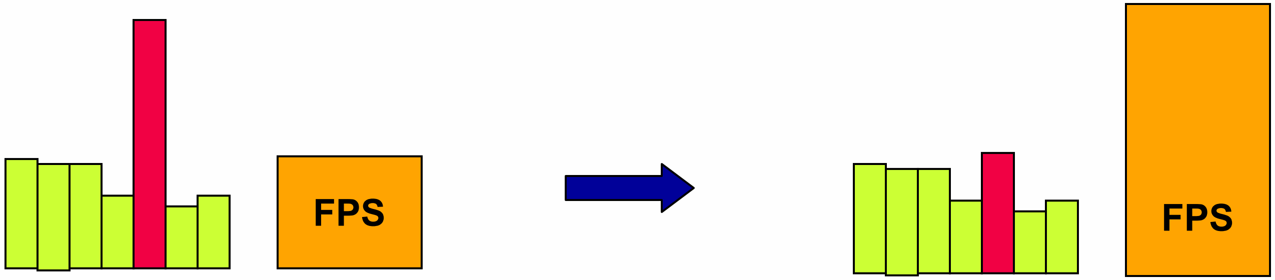


Bottleneck Identification

- Need to identify it quickly and correctly
  - Guessing what it is without testing can waste a lot of coding time
- Two ways to identify a stage as the bottleneck
  - Modify the stage itself
  - Rule out the other stages

Bottleneck Identification

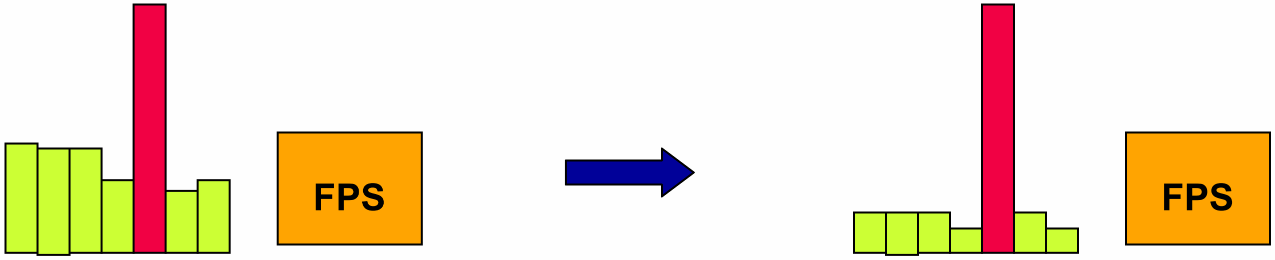
- Modify the stage itself
  - By decreasing its workload



  - If performance improves greatly, then you know this is the bottleneck
  - Careful not to change the workload of other stages!

Bottleneck Identification

- Rule out the other stages
  - By giving all of them little or no work

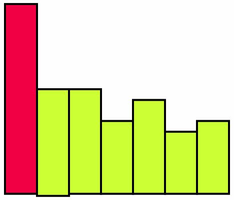


  - If performance doesn’t change significantly, then you know this is the bottleneck
  - Careful not to change the workload of this stage!

Bottleneck Identification

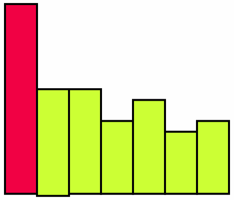
- Most changes to a stage affect other stages as well
- Can be hard to pick what test to do
- Let’s go over some tests

Bottleneck Identification: CPU



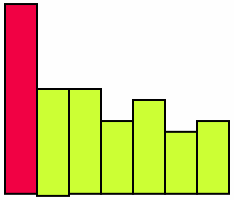
- CPU workload
  - What could the problem be?
    - Could be the game
      - Complex physics, AI, game logic
      - Memory management
      - Data structures
    - Could be incorrect usage of API
      - Check debug runtime output for errors and warnings
    - Could be the display driver
      - Too many batches

Bottleneck Identification: CPU



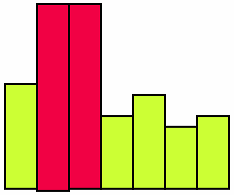
- Reduce the CPU workload
  - Temporarily turn off
    - Game logic
    - AI
    - Physics
    - Any other thing you know to be expensive on the CPU as long as it doesn’t change the rendering workload

Bottleneck Identification: CPU



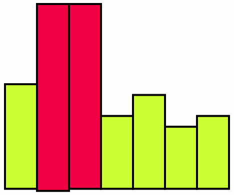
- Rule out other stages
  - Kill the DrawPrimitive calls
    - Set up everything as you normally would but when the time comes to render something, just do not make the DrawPrimitive* call
    - Problem: you don’t know what the runtime or driver does when a draw primitive call is made
  - Use VTUNE or NVPerfHUD (more info later)
    - These let you see right away if the CPU time is in your app or somewhere else

Bottleneck Identification: Vertex



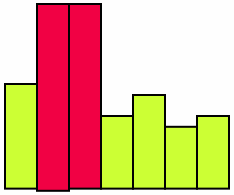
- Vertex Bound
  - What could the problem be?
    - Transferring the vertices and indices to the card
    - Turning the vertices and indices into triangles
    - Vertex cache misses
    - Using an expensive vertex shader

Bottleneck Identification: Vertex



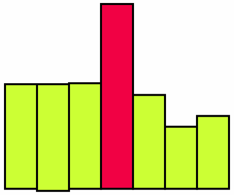
- Reduce vertex overhead
  - Use simpler vertex shader
    - But still include all the data for the pixel shader
  - Send fewer Triangles??
    - Not good: can affect pixel shader, texture, and frame buffer
  - Decrease AGP Aperture??
    - Maybe not good: can affect texture also, depends on where your textures are
    - Use NVPerfHUD to see video memory
      - If it’s full then you might have textures in AGP

Bottleneck Identification: Vertex



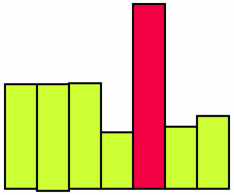
- Rule out other stages
  - Render to a smaller backbuffer; this can rule out
    - Texture
    - Frame buffer
    - Pixel shader
  - Test for a CPU bottleneck
  - Can also render to smaller view port instead of smaller backbuffer. Still rules out
    - Texture
    - Frame buffer
    - Pixel shader

Bottleneck Identification: Raster



- Rasterization
  - Rarely the bottleneck, spend your time testing other stages first

Bottleneck Identification: Texture

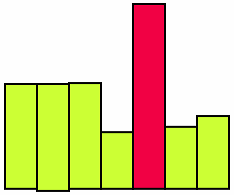


- Texture Bound
  - What could the problem be?
    - Texture cache misses
    - Huge Textures
    - Bandwidth
    - Texturing out of AGP

Bottleneck Identification: Texture

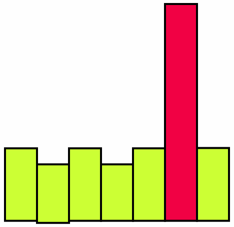
- Reduce Texture bandwidth
  - Use tiny (2x2) textures
    - Good, but if you are using alpha test with texture alpha, then this could actually make things run slower due to increased fill. It is still a good easy test though
  - Use mipmaps if you aren’t already
  - Turn off anisotropic filtering if you have it on

Bottleneck Identification: Texture



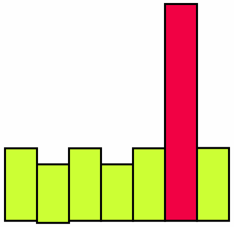
- Rule out other stages
  - Since texture is so easy to test directly, we recommend relying on that

Bottleneck Identification: Fragment



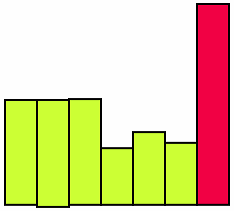
- Fragment Bound
  - What could the problem be?
    - Expensive pixel shader
    - Rendering more fragments than necessary
      - High depth complexity
      - Poor z-cull

Bottleneck Identification: Fragment



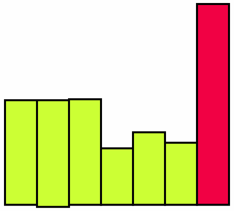
- Modify the stage itself
  - Just output a solid color
    - Good: does no work per fragment
    - But also affects texture, so you must then rule out texture
  - Use simpler math
    - Good: does less work per fragment
    - But make sure that the math still indexes into the textures the same way or you will change the texture stage as well

Bottleneck Identification: FB



- Frame Buffer bandwidth
  - What could the problem be?
    - Touching the buffer more times than necessary
      - Multiple passes
    - Tons of alpha blending
    - Using too big a buffer
      - Stencil when you don’t need it
      - A lot of time dynamic reflection cube-maps can get away with r5g6b5 color instead of x8r8g8b8

Bottleneck Identification: FB



- Modify the stage itself
  - Use a 16 bit depth buffer instead of a 24 bit one
  - Use a 16 bit color buffer instead of a 32 bit one

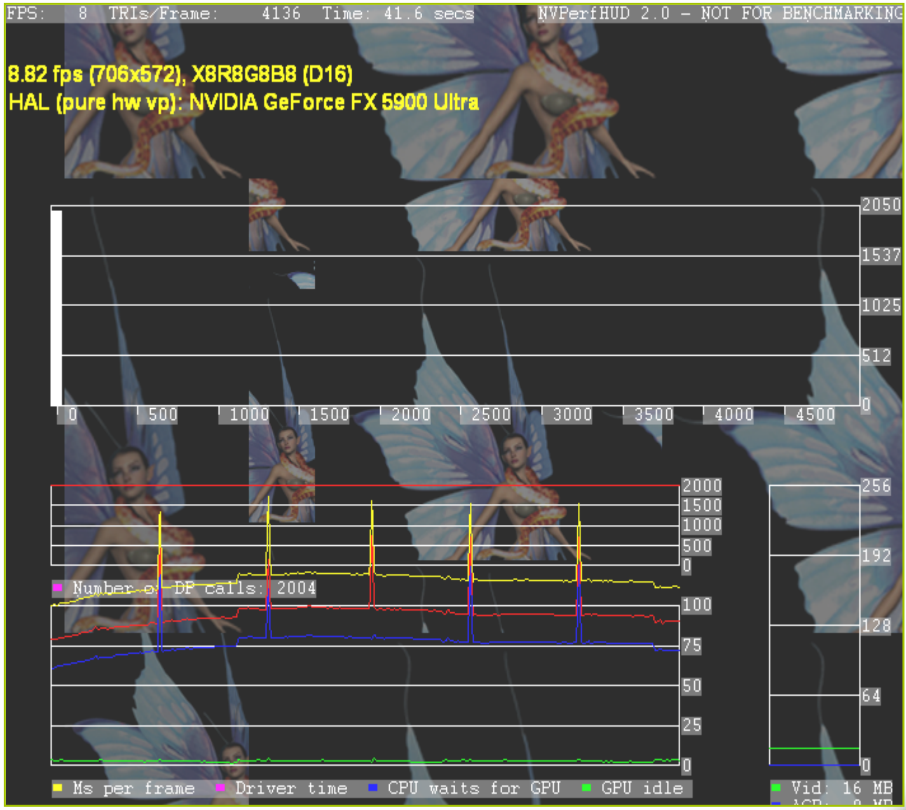
Bottleneck Identification

- Now we have a bunch of practical ideas to find out if each stage is a bottleneck or not

- Questions on Bottleneck Identification?

A Tool: NVPerfHud

- Free tool made to help identify bottlenecks
- Batches
- GPU idle
- CPU waits for GPU
- Driver time
- Total time
- Solid color pixel shaders
- 2x2 textures
- Etc...



```
FPS:   8  TRIs/Frame:     4136  Time: 41.6 secs        NVPerfHUD 2.0 - NOT FOR BENCHMARKING
8.82 fps (706x572), X8R8G8B8 (D16)
HAL (pure hw vp): NVIDIA GeForce FX 5900 Ultra
Number of DP calls: 2004
Vid: 16 MB
```

Practice

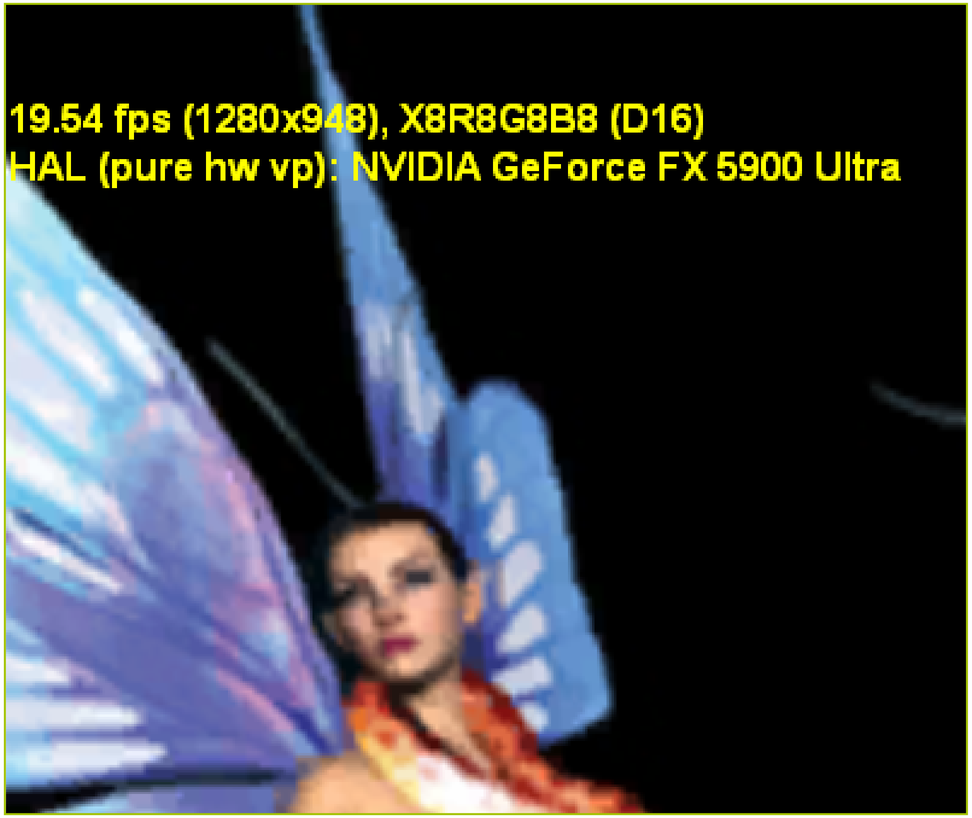
- Now lets look at some sample problems and see if we can find out where the problem is
- Use NVPerfHUD to help

Practice: Clean the Machine

- Make sure that your machine is ready for analysis
  - Make sure you have the right drivers
  - Use a release build of the game (optimizations on)
  - Check debug output for warnings or errors but.....
  - Use the release d3d runtime!!!
  - No maximum validation
  - No driver overridden anisotropic filtering or anti-aliasing
  - Make sure v-sync is off

Practice: Example 1

- A seemingly simple scene runs horribly slow
  - Narrow in on the bottleneck



```
19.54 fps (1280x948), X8R8G8B8 (D16)
HAL (pure hw vp): NVIDIA GeForce FX 5900 Ultra
```

Practice: Example 1

- Dynamic vertex buffer
  - BAD creation flags

```
HRESULT hr = pd3dDevice->CreateVertexBuffer(
               6* sizeof( PARTICLE_VERT ),
               0,      //declares this as static
               PARTICLE_VERT::FVF,
               D3DPOOL_DEFAULT,
               &m_pVB,
               NULL );
```

Practice: Example 1

- Dynamic vertex buffer
  - GOOD creation flags

```
HRESULT hr = pd3dDevice->CreateVertexBuffer(
                        6* sizeof( PARTICLE_VERT ),
                        D3DUSAGE_DYNAMIC |
                        D3DUSAGE_WRITEONLY,
                        PARTICLE_VERT::FVF,
                        D3DPOOL_DEFAULT,
                        &m_pVB,
                        NULL );
```

Practice: Example 1

- Dynamic Vertex Buffer
  - BAD Lock flags

```
m_pVB->Lock(0, 0,(void**)&quadTris, 0);
```

- No flags at all!?
  - That can’t be good....

Practice: Example 1

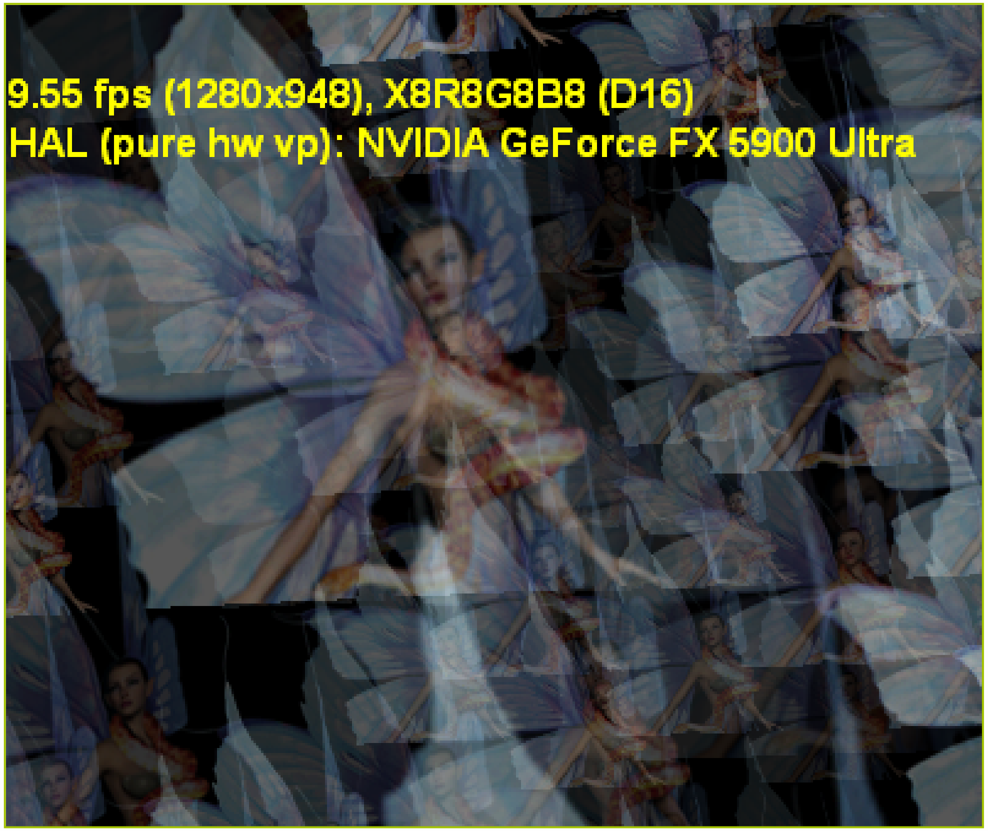
- **Dynamic Vertex Buffer**
  - **GOOD Lock flags**

```
m_pVB->Lock(0, 0,(void**)&quadTris,
D3DLOCK_NOSYSLOCK | D3DLOCK_DISCARD);
```

- **Use D3DLOCK_DISCARD the first time you lock a vertex buffer each frame**
  - **And again when that buffer is full**
  - **Otherwise just use NOSYSLOCK**

Practice: Example 2

- Another slow scene
  - What’s the problem here



9.55 fps (1280x948), X8R8G8B8 (D16)

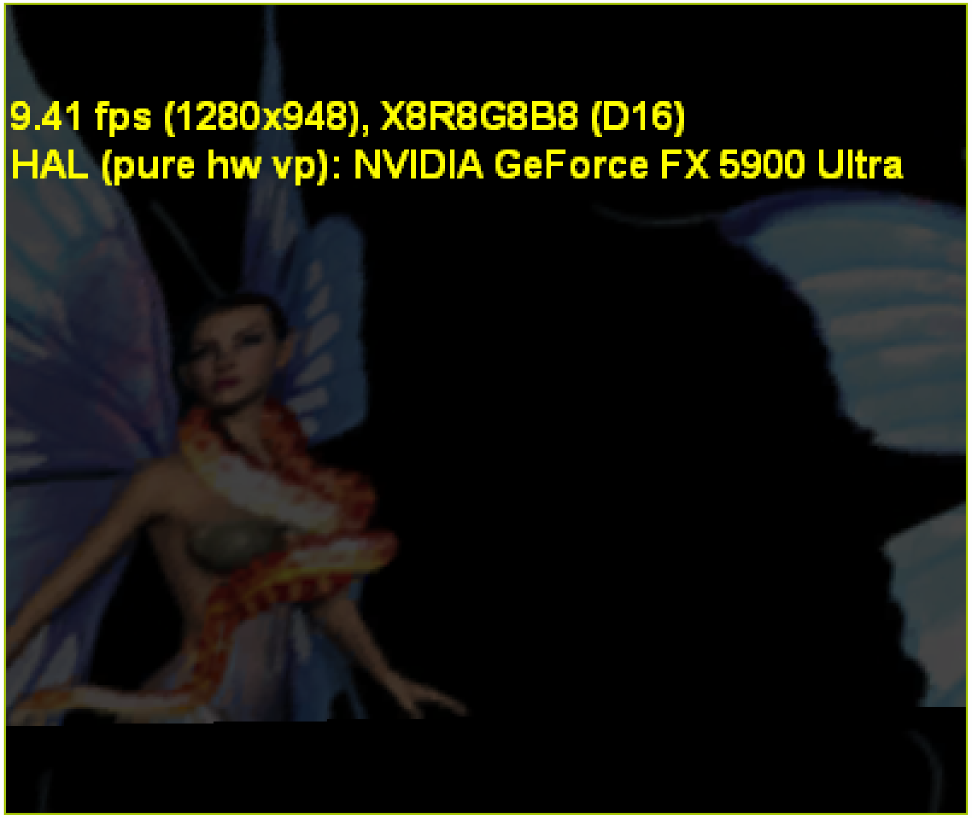
HAL (pure hw vp): NVIDIA GeForce FX 5900 Ultra

Practice: Example 2

- Texture bandwidth overkill
  - Use mipmaps
  - Use dxt1 if possible
    - Some cards can store compressed data in cache
  - Use smaller textures when they are fine
    - Does the grass blade really need a 1024x1024 texture?
      - Maybe

Practice: Example 3

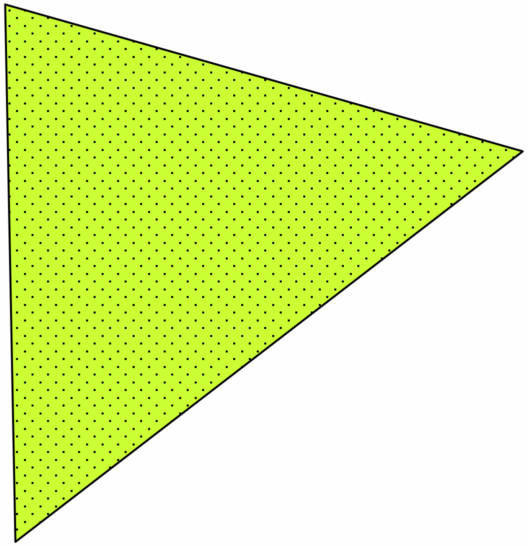
- Another slow scene
  - Who wants a prize?



9.41 fps (1280x948), X8R8G8B8 (D16)
HAL (pure hw vp): NVIDIA GeForce FX 5900 Ultra

Practice: Example 3

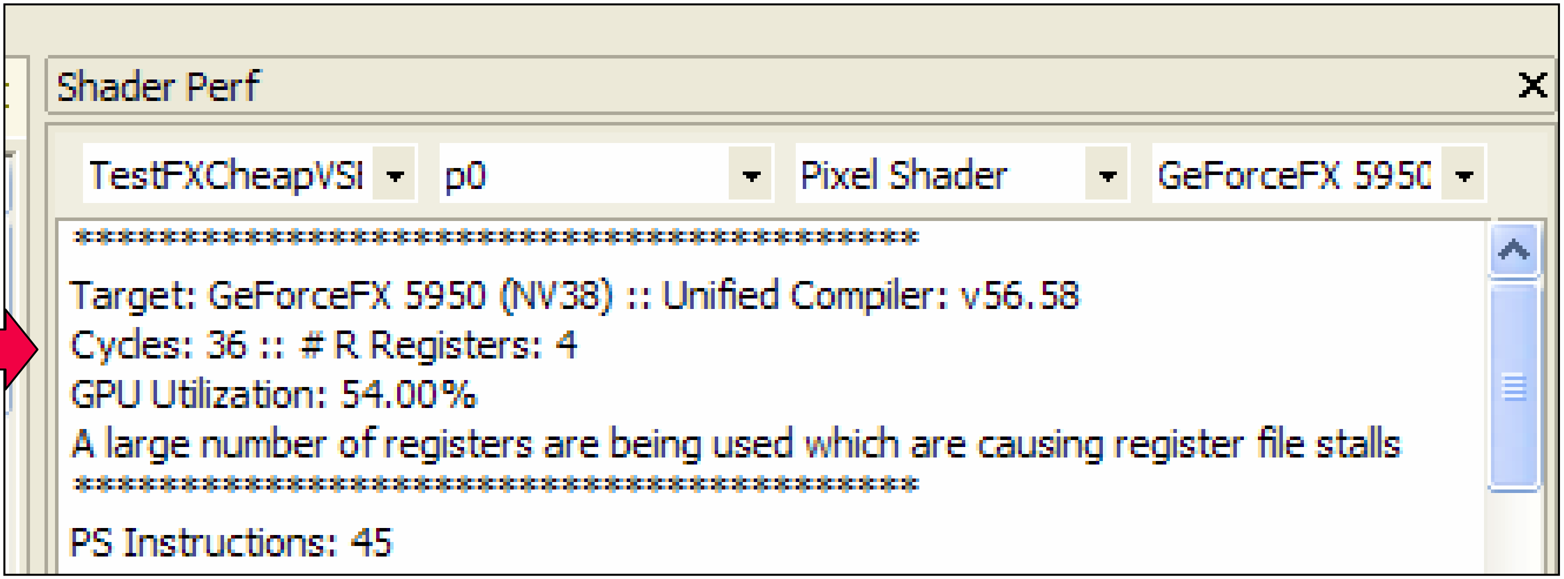
- Expensive pixel shader
  - Can have huge performance effect
  - Only 3 verts, but maybe a million pixels
    - That's only 1024x1024



Look at all the pixels!!

Practice: Example 3

- 36 cycles BAD

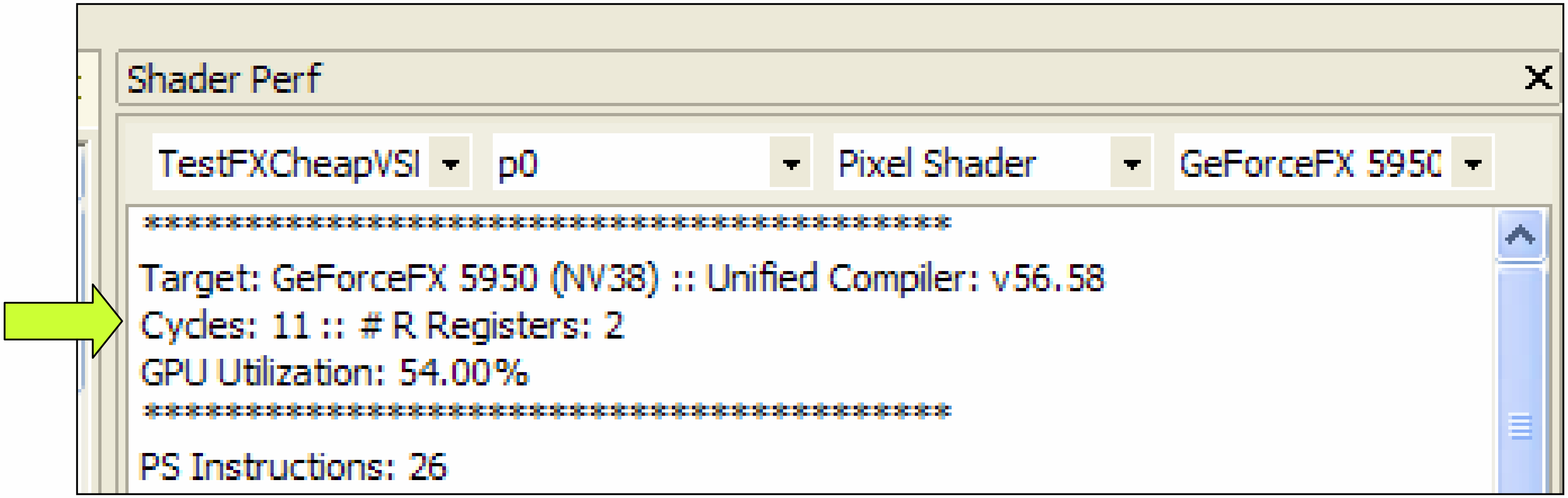


```
*************************************************
Target: GeForceFX 5950 (NV38) :: Unified Compiler: v56.58
Cycles: 36 :: # R Registers: 4
GPU Utilization: 54.00%
A large number of registers are being used which are causing register file stalls
*************************************************

PS Instructions: 45
```

Practice: Example 3

- 11 cycles GOOD



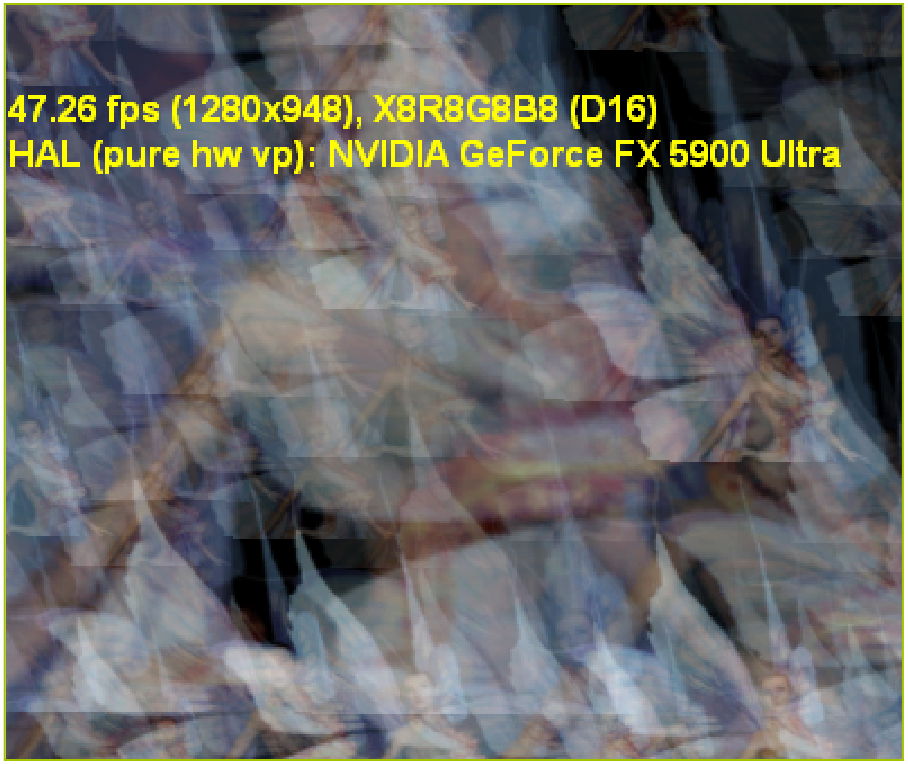
```
******************************************************
Target: GeForceFX 5950 (NV38) :: Unified Compiler: v56.58
Cycles: 11 :: # R Registers: 2
GPU Utilization: 54.00%
******************************************************
PS Instructions: 26
```

Practice: Example 3

- What changed?
  - Moved math that was constant across the triangle into the vertex shader
  - Used ‘half’ instead of ‘float’
  - Got rid of normalize where it wasn’t necessary
    - See Normalization Heuristics
    - http://developer.nvidia.com

Practice: Example 4

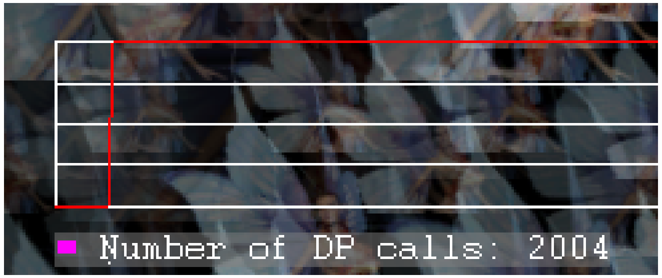
- The last one
  - Audience: there are no more prizes, but we’ve locked the doors



```
47.26 fps (1280x948), X8R8G8B8 (D16)
HAL (pure hw vp): NVIDIA GeForce FX 5900 Ultra
```

Practice: Example 4

- Too many batches
  - Was sending every quad as it's own batch
  - Instead, group quads into one big VB then send that with one call



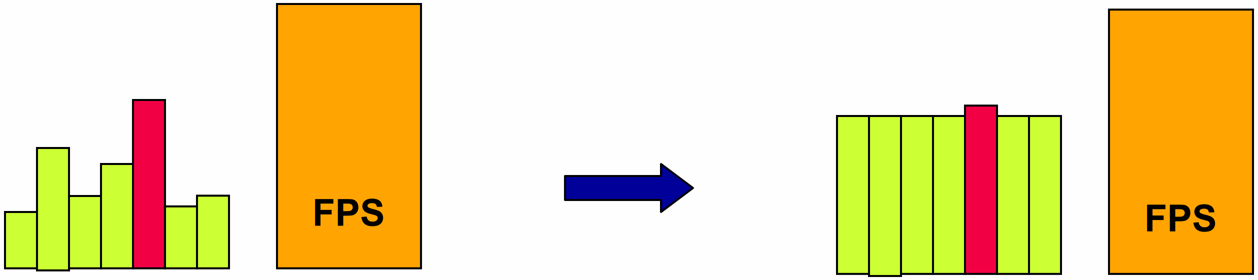
🟪 Number of DP calls: 2004

Practice: Example 4

- What if they use different textures?
  - Use texture atlases
  - Put the two textures into a single texture and use a vertex and pixel shader to offset the texture coordinates

Balancing the Pipeline

- Once satisfied with performance
  - Balance the pipeline by making more use of un-bottlenecked stages
  - Careful not to make too much use of them



Summary

- Pipeline architecture is ruled by bottlenecks
- Don’t waste time optimizing stages needlessly
- Identify bottlenecks with quick tests
- Use NVPerfHUD to analyze your pipeline
- Use Fxcomposer to help tune your shaders
- Check your performance early and often
  - Don’t wait until the last week!

NVIDIA.

Questions?

Ashu Rege (arege@nvidia.com)

Clint Brewer (cbrewer@nvidia.com)

Other NVIDIA programming talks

- GPU Gems Showcase
  Wed 5:30 – 6:00
- Real-time Translucent Animated Objects
  Fri 2:30 – 3:30

Performance Lore

- We collected some advice from various developers and include it here so you don’t have to discover it the hard way

Performance Lore

- Use low resolution (<256x256) 8-bit normalization cube-maps. Quality isn't reduced since 50% of texels in high resolution cube-map are identical you are only getting nearest filtering
- Use oblique frustum clipping to clip geometry for reflection instead of a clip plane
- Re-use vertex buffers for streaming geometry. Don't create and delete vertex buffers every frame if they could be re-used
- Use multiples of 32 byte sized vertices for transfer over AGP

Performance Lore

- Use Occlusion Query and render object’s bounding box this frame. Then use the result next frame to decide whether or not you need to draw the real object
- For ARB fragment programs use ARB_precision_hint_fastest
- Use 16-bit 565 cube-maps for dynamic reflections on cars. Don’t need 32-bit reflections
- Blend out small game objects and don’t render them when they are far away. cuts down on batches

Performance Lore

- use half instead of float optimizations early in development
- If rendering multiple passes, lay down Depth first then render your expensive pixel shaders. Cuts out depth complexity problems when shading
- If rendering multiple passes, on later additive passes you can set alpha to r + g + b, then use alpha test to cut on fill
- Terrain was rendered in 4 passes in ps1.1 due to texture limits. Render it in 1 pass in ps2.0

Performance Lore

- Communicate with IHVs about your problem, sometimes it really isn’t your code and we can fix the bugs!
- Use texture pages / atlases to combine objects into a single batch
- Use anisotropic filtering only on textures that need it. Don’t just set it to default on
- Don’t lock static vertex buffers multiple times per frame. make them dynamic
- Sorting the scene by render target gave a large perf boost

Performance Lore

- When locating the bottleneck, divide and conquer. Lower resolution first, cuts the problem almost in half. rules out just about everything fill and pixel related
- Use float4 to pack multiple float2 texture coordinates
- Optimize your index and vertex buffers to take advantage of the cache
- Move per object calculations out of the vertex shader and onto the cpu
- Move per triangle calculations out of the pixel shader and into the vertex shader

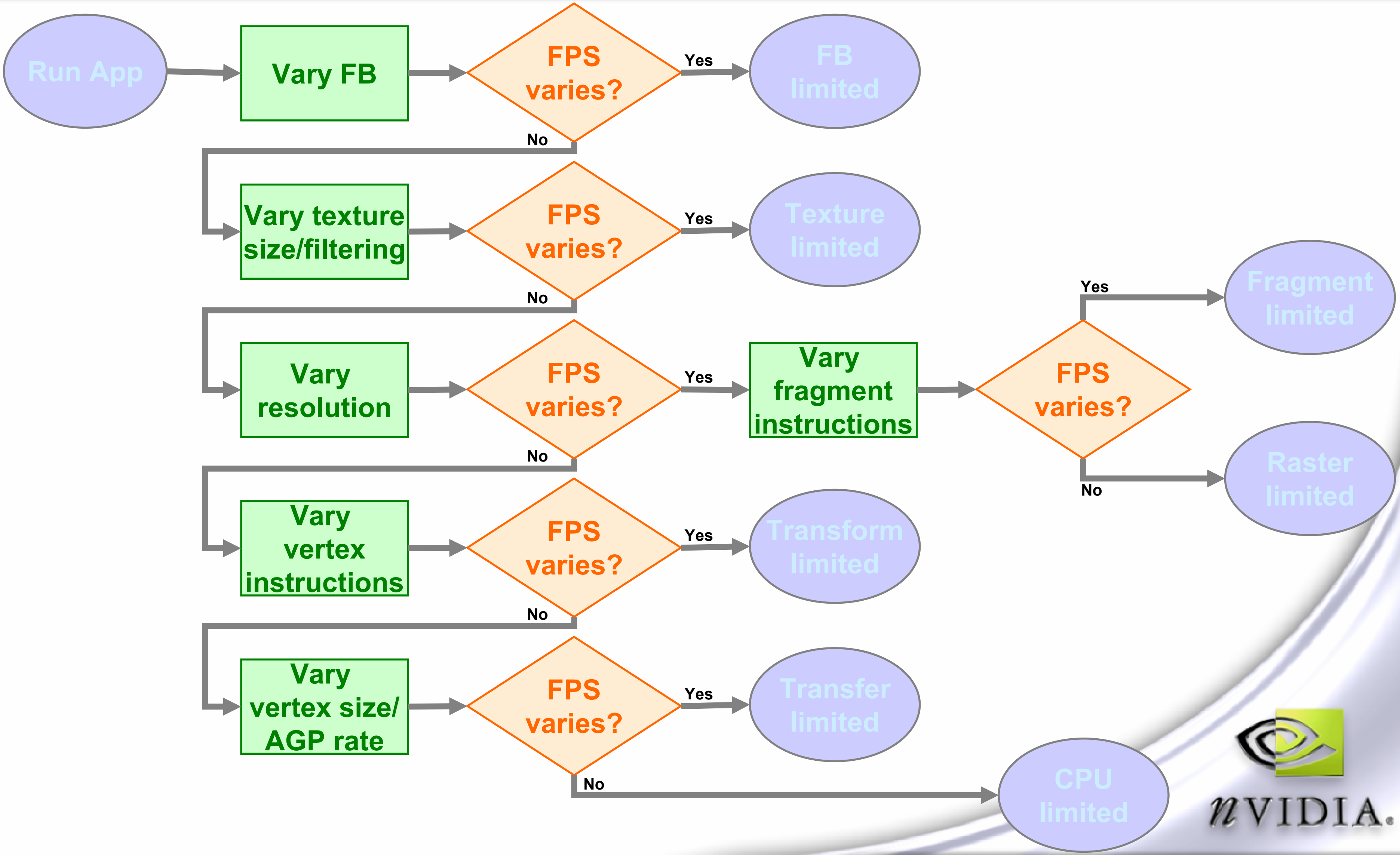
Performance Lore

- Use swizzles and masks in your vertex and pixel shaders: Value.xy = blah
- Use the API to clear the color and depth buffer
- Don’t change the direction of your z test mid frame, going from > ...to... >= ...to... = should be fine, but don’t go from > ...to... <
- Don’t use polygon offset if something else will work
- Don’t write depth in your pixel shader if you don’t have to

Performance Lore

- Use Mipmaps. If they are too blurry for you, use anisotropic and/or trilinear filtering: that gives better quality than LOD bias
- Rarely is there a single bottleneck in a game. If you find a bottleneck and fix it, and performance doesn’t improve more than a few fps. Don’t give up. You’ve helped yourself by making the real bottleneck apparent. Keep narrowing it down until you find it

Bottleneck Identification

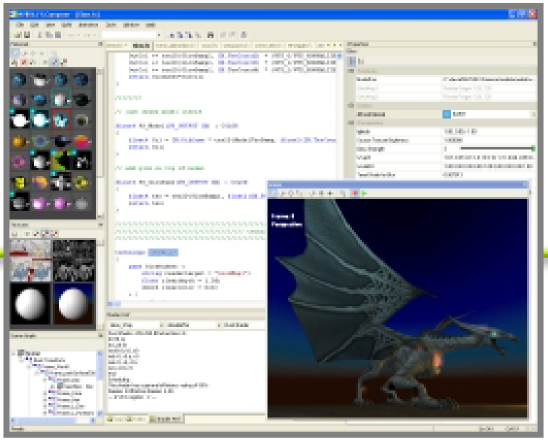


references

- **http://developer.nvidia.com/object/GDC_2004_Presentations.html**
- Tomas Akenine-Moller and Eric Haines, **Real-Time Rendering**, second edition
- http://developer.nvidia.com/object/GDCE_2003_Presentations.html, Has other presentations on finding and locating the bottleneck

developer.nvidia.com

The Source for GPU Programming



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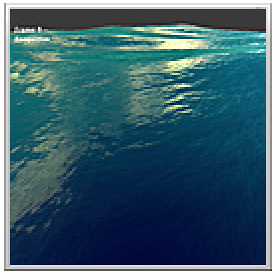
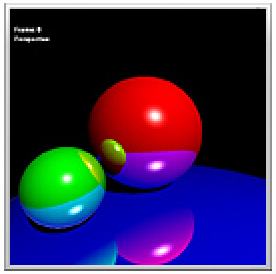
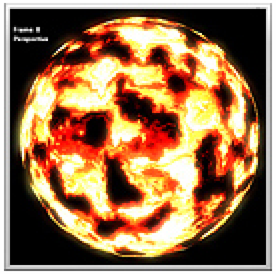
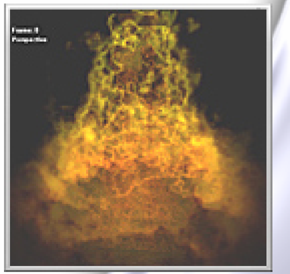
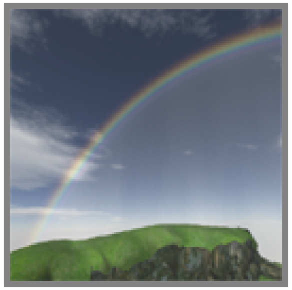
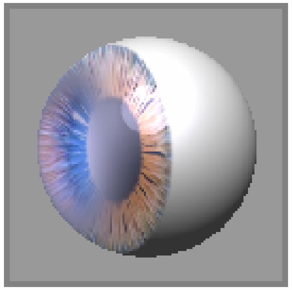




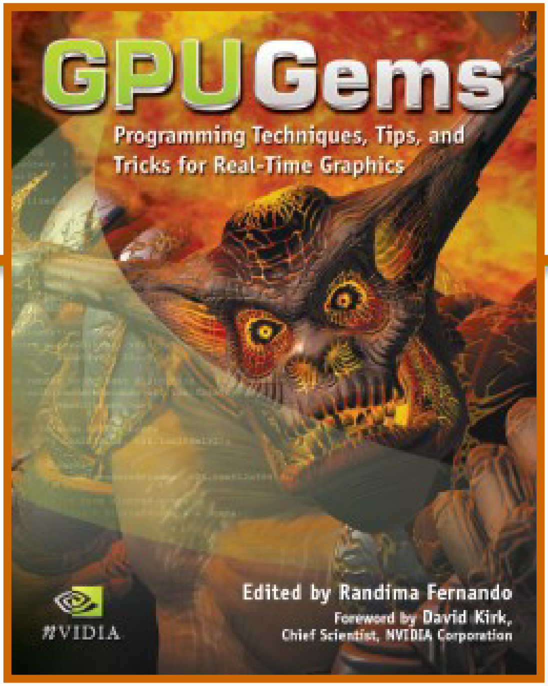








GPU Gems: Programming Techniques, Tips, and Tricks for Real-Time Graphics


GPU Gems
Programming Techniques, Tips, and Tricks for Real-Time Graphics
NVIDIA
Edited by Randima Fernando
Foreword by David Kirk, Chief Scientist, NVIDIA Corporation

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- Great value:
  - Contributions from industry experts
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Tim Sweeney

Lead programmer of *Unreal* at Epic Games

"This collection of articles is particularly impressive for its depth and breadth. The book includes product-oriented case studies, previously unpublished state-of-the-art research, comprehensive tutorials, and extensive code samples and demos throughout."

Eric Haines

Author of *Real-Time Rendering*