Graphics Performance Optimization

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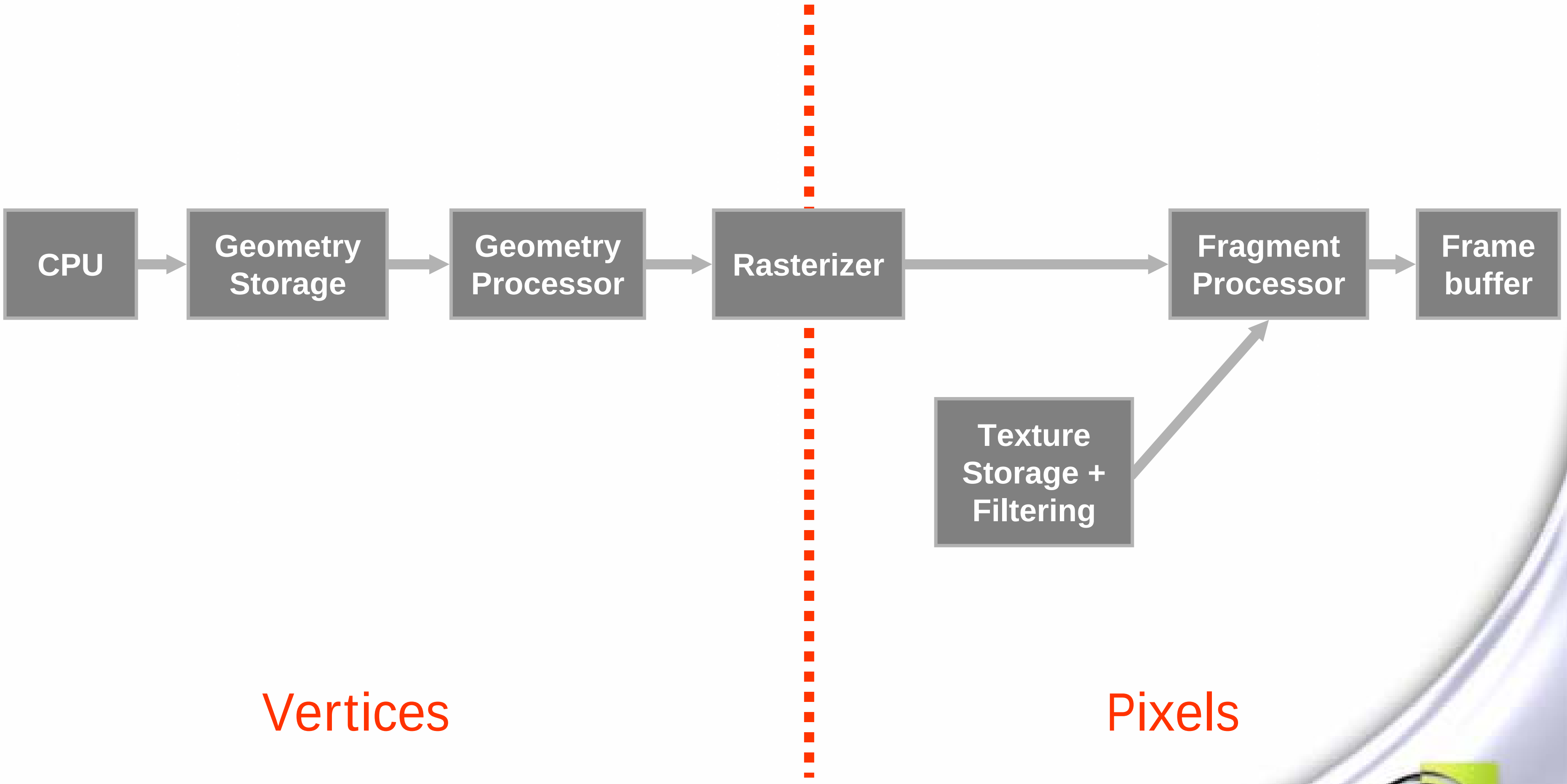
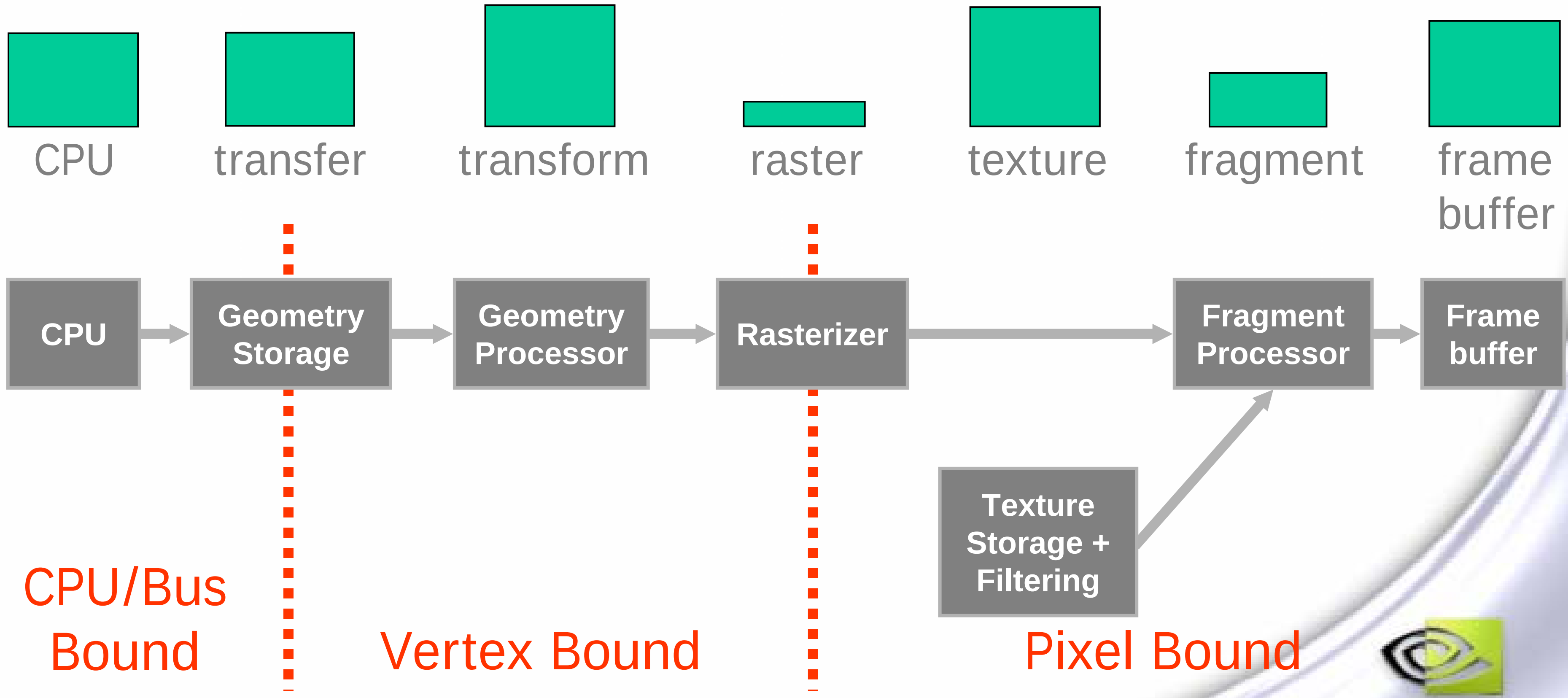
Agenda

- Graphics pipeline 101
- Finding the bottleneck
- Resolving the bottleneck
- Tools
  - NVPerfHUD
  - FX Composer
- Conclusion

Simplified Graphics Pipeline

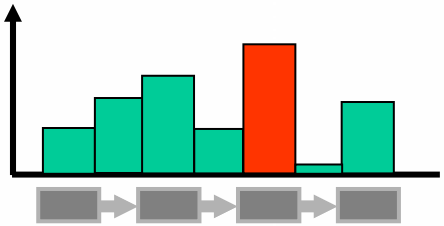


Possible Pipeline Bottlenecks

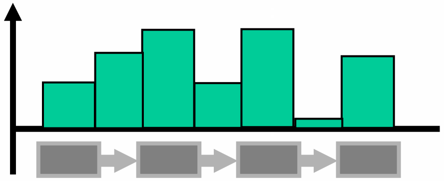


Battle Plan for Better Performance

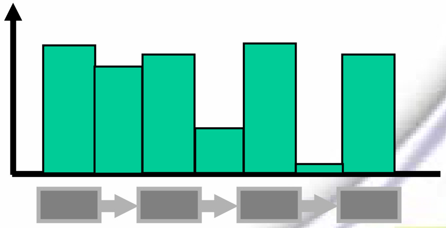
- Locate the bottleneck(s)



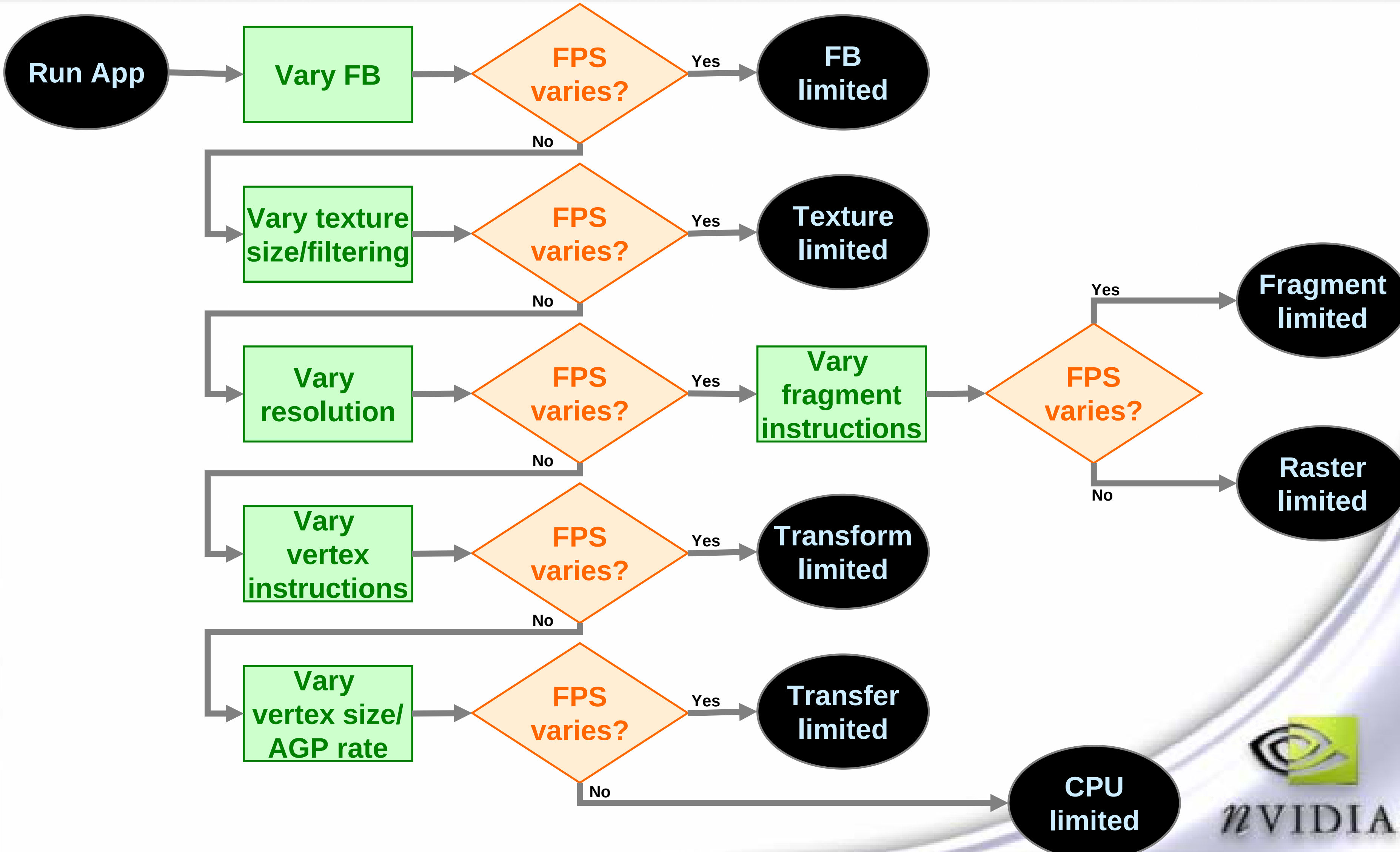
- Eliminate the bottleneck (if possible)
  - Decrease workload of the bottlenecked stage



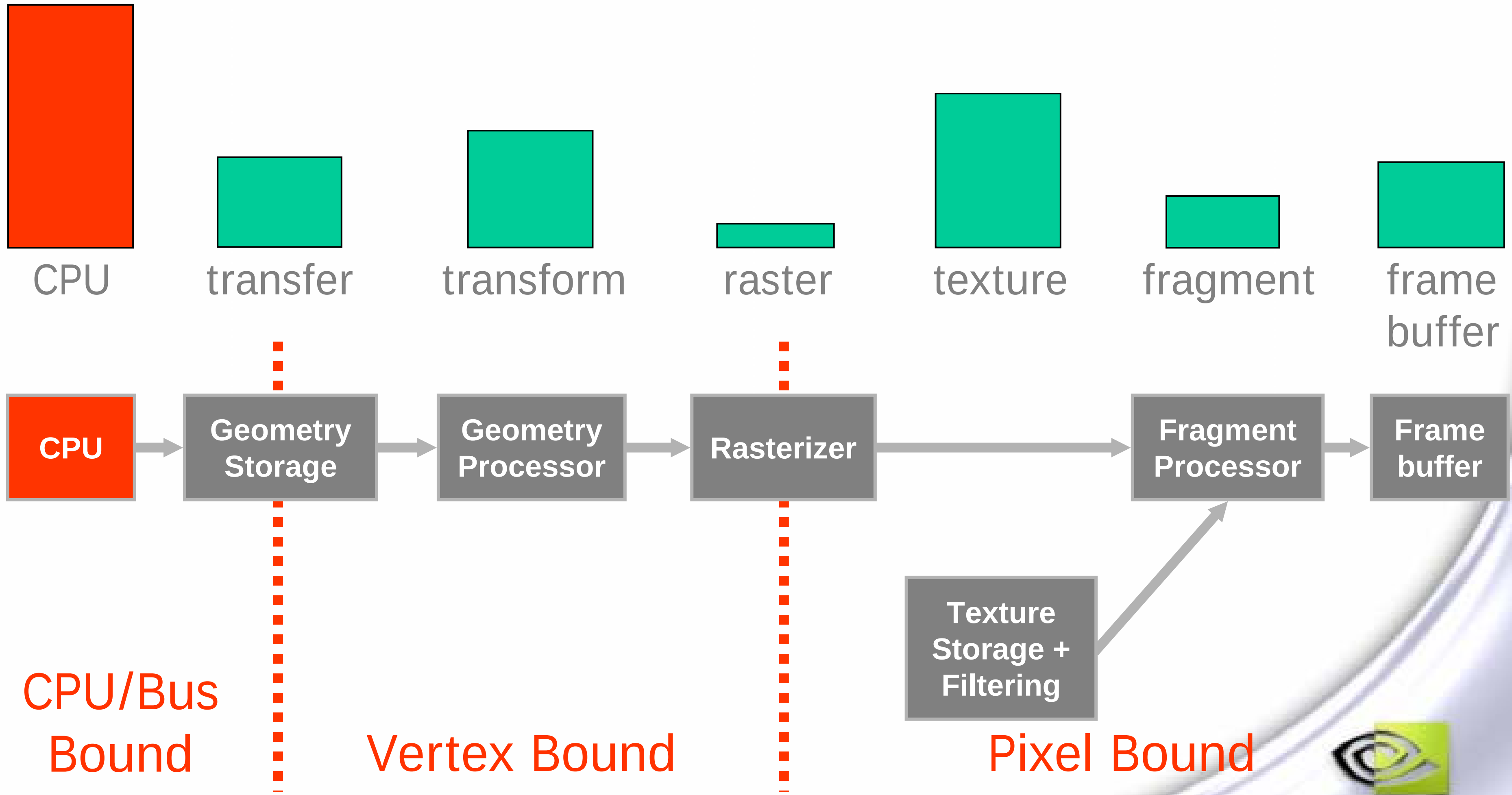
- Otherwise, make it look better
  - Balance pipeline by increasing workload of the non-bottlenecked stages



Bottleneck Identification



CPU Bottlenecks



CPU Bottlenecks

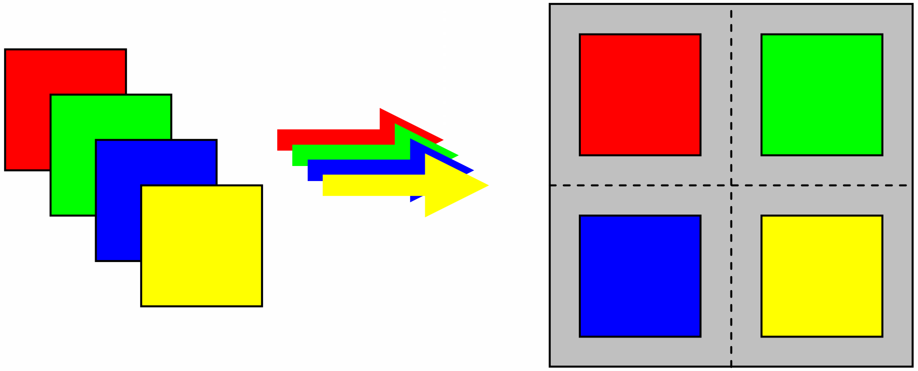
- Application limited (most games are in some way)
- Driver or API limited
  - too many state changes (bad batching)
  - using non-accelerated paths
- Use VTune (Intel performance analyzer)
  - caveat: truly GPU-limited games hard to distinguish from pathological use of API

Consolidate Small Batches

- Each vertex buffer/array preferably has thousands of vertices or more
- Draw as many triangles per call as possible
- ~50K DIPs/s COMPLETELY saturate 1.5GHz Pentium 4
  - 50fps means 1,000 DIPs/frame!
  - Up to you whether drawing 1K tri/frame or 1M tri/frame

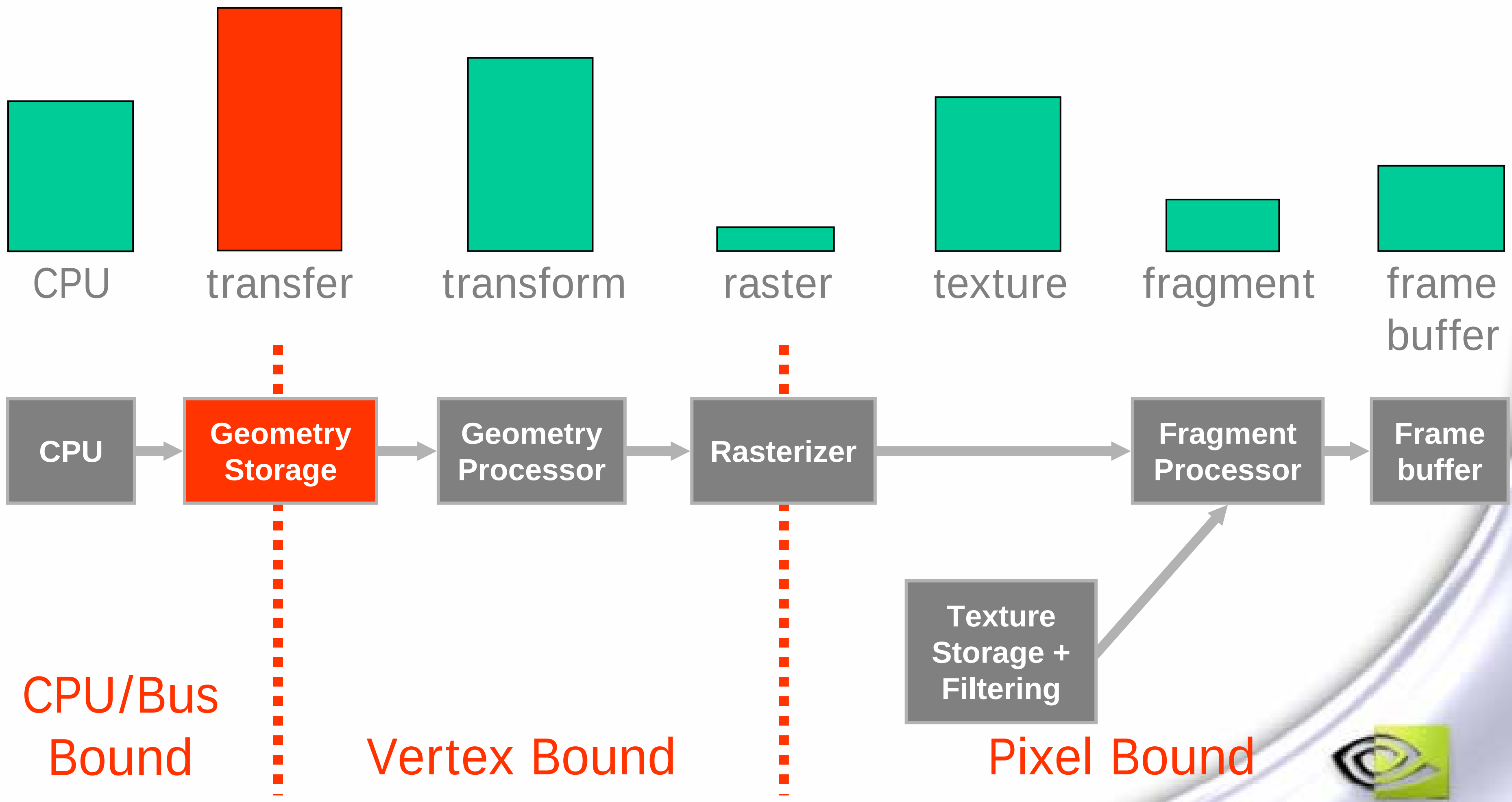
Batch Consolidation Strategies

- Use degenerate triangles to join strips together
  - Hardware culls zero-area triangles very quickly
- Use texture pages



- Use a vertex shader to batch instanciated geometry
  - VS2.0 and VP30 have 256 constant 4D vectors

Geometry Transfer Bottlenecks



Geometry Transfer Bottlenecks

- Vertex data problems
  - size issues (just under or over 32 bytes)
  - non-native types (e.g. double, packed byte normals)
- Using the wrong API calls
  - Immediate mode, non-accelerated vertex arrays
  - Non-indexed primitives (e.g. glDrawArrays, DrawPrimitive)
- AGP misconfigured or aperture set too small

Optimizing Geometry Transfer: OpenGL

- Static geometry – display lists okay, but ARB_vertex_buffer_object is better

- Dynamic geometry - use ARB_vertex_buffer_object
  - vertex size ideally multiples of 32 bytes (compress or pad)
  - access vertices in sequential (cache friendly) pattern
  - always use indexed primitives (i.e. glDrawElements)
  - 16 bit indices can be faster than 32 bit

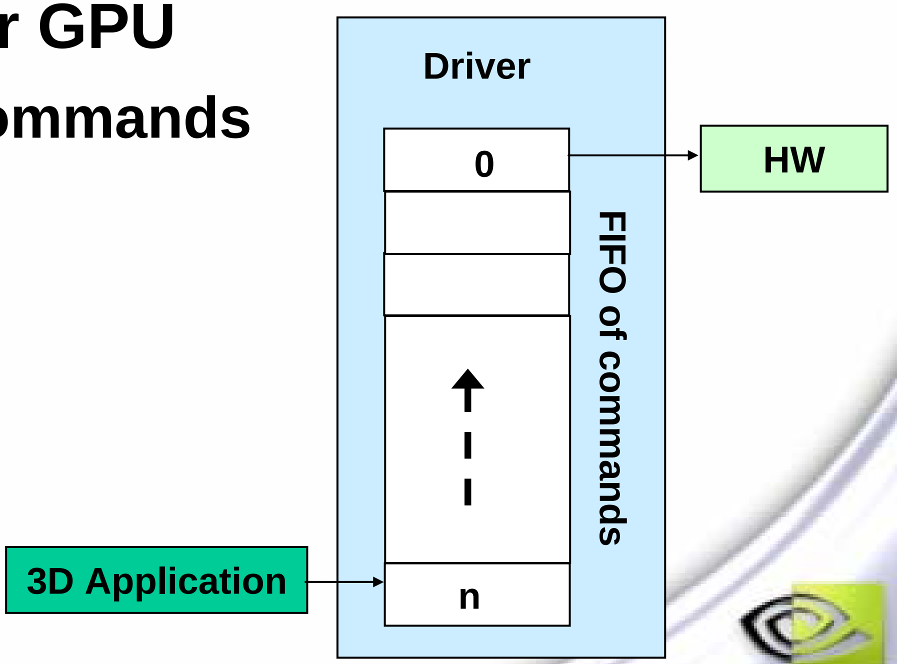
Optimizing Geometry Transfer: Direct3D

- Static geometry:
  - Create a write-only vertex buffer and only write to it once

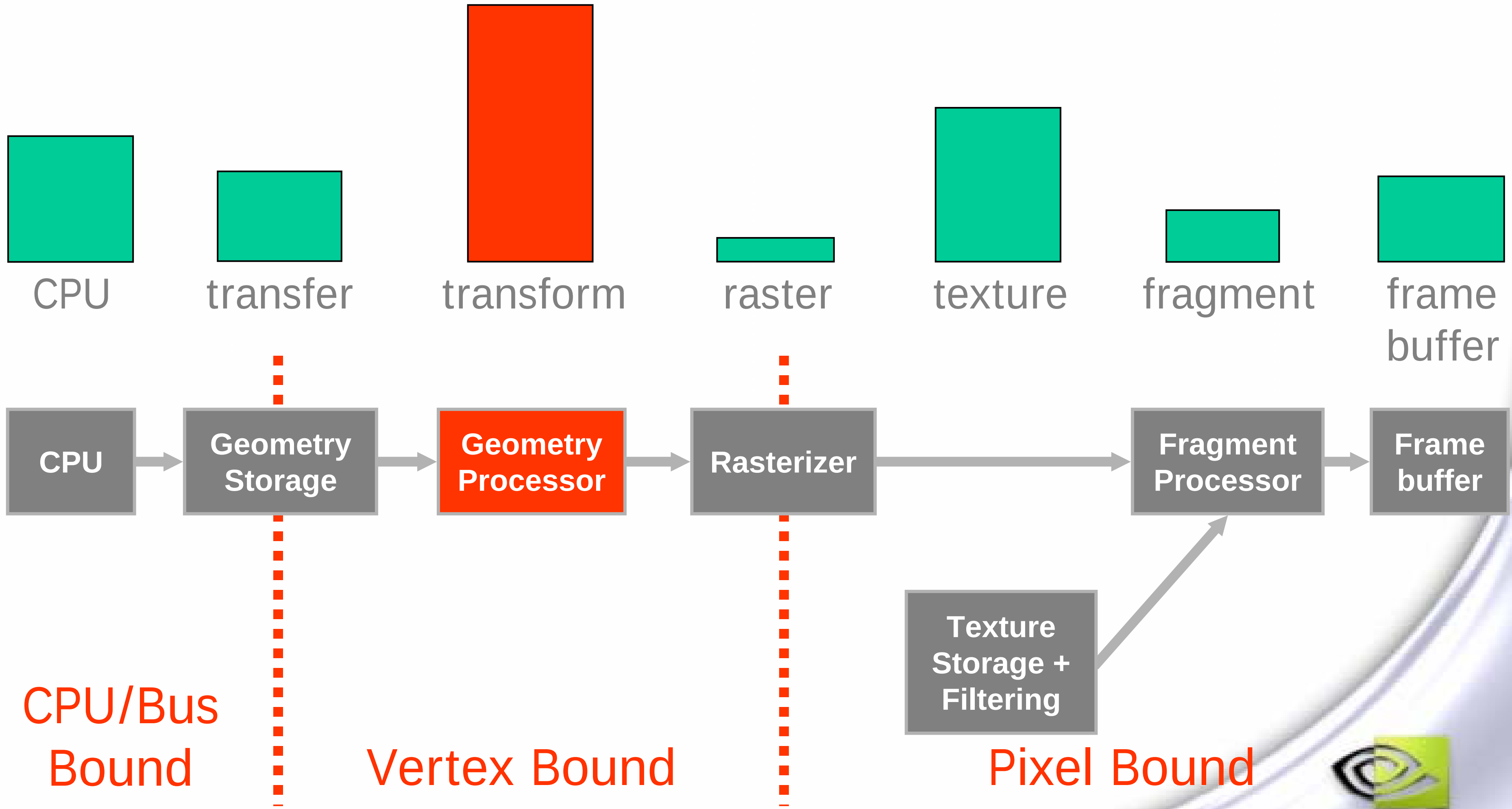
- Dynamic geometry:
  - Create a dynamic vertex buffer
  - Lock with DISCARD at start of frame
    - Then append with NOOVERWRITE until full
  - Use NOOVERWRITE more often than DISCARD
    - Each DISCARD takes either more time or more memory
    - So NOOVERWRITE should be most common
  - Never use no flags

Allow for CPU/GPU load balancing…

- Interleave your game computation with drawing commands
- The idea is to make sure that your CPU never waits for your GPU
  - Don't send too many commands at once
  - Don't lock VBs
  - Don't do pixel reads
  - Etc…



Geometry Transform Bottlenecks



Geometry Transform Bottlenecks

- Too many vertices
- Too much computation per vertex
- Vertex cache inefficiency

Too Many Vertices

- Favor triangle strips/fans over lists (fewer vertices)
- Use levels of detail (but beware of CPU overhead)
- Use bump maps to fake geometric detail

Too Much Vertex Computation: Fixed Function

- Avoid superflous work
  - >3 lights (saturation occurs quickly)
  - local lights/viewer, unless really necessary
  - unused texgen or non-identity texture matrices
- Consider commuting to vertex program if (and only if) good shortcut exists
  - example: texture matrix only needs to be 2x2
  - not recommended for optimizing fixed function lighting

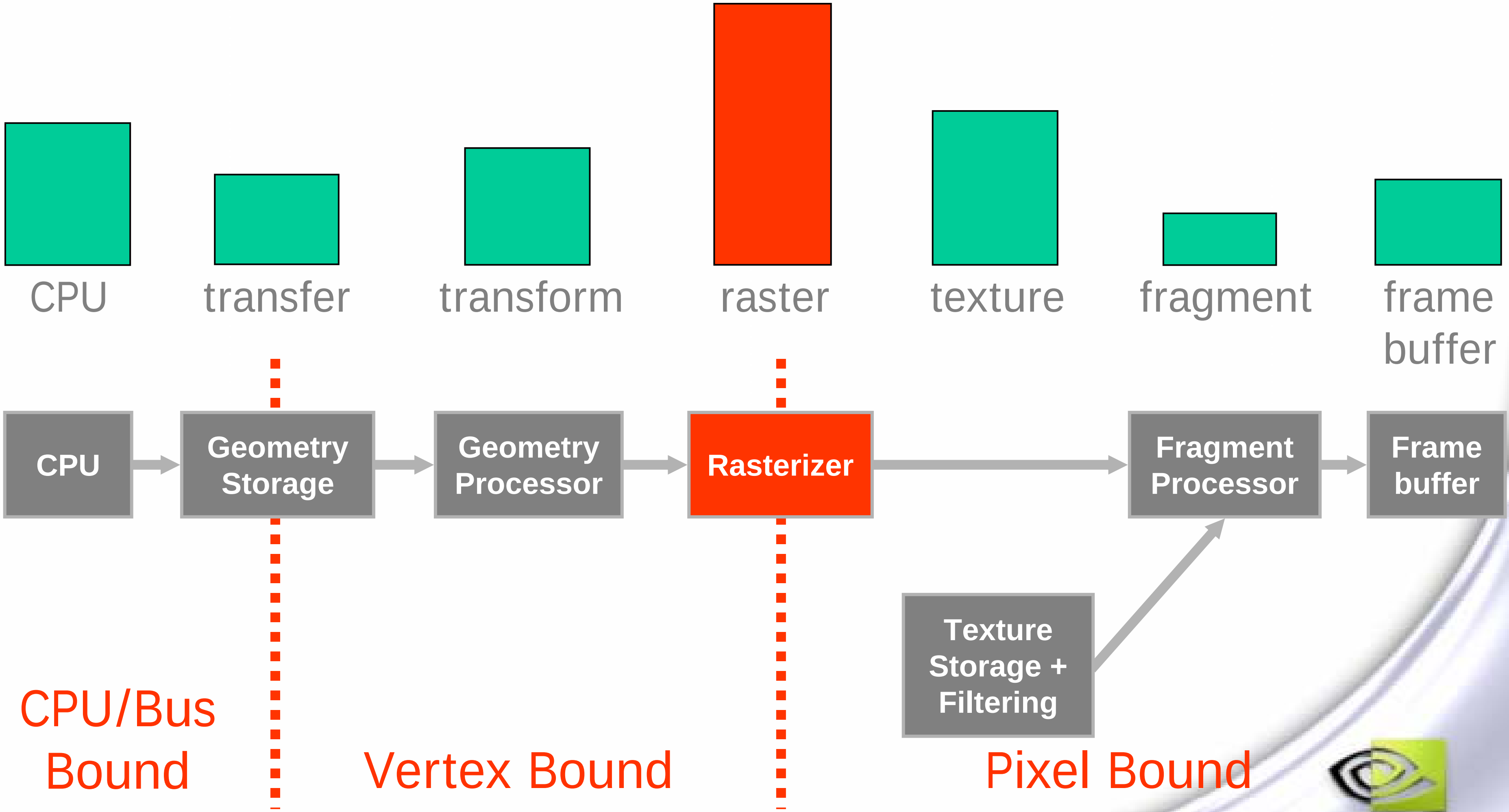
Too Much Vertex Computation: Vertex Programs

- Move per-object calculations to CPU, save results as constants
- Leverage full spectrum of instruction set (LIT, DST, SIN,...)
- Leverage swizzle and mask operators to minimize MOVs
- Consider using shader levels of detail

Vertex Cache Inefficiency

- **Always use indexed primitives on high-poly models**
- **Re-order vertices to be sequential in use (e.g. NVTriStrip)**
- **Favor triangle fans/strips over lists**

Rasterization Bottlenecks



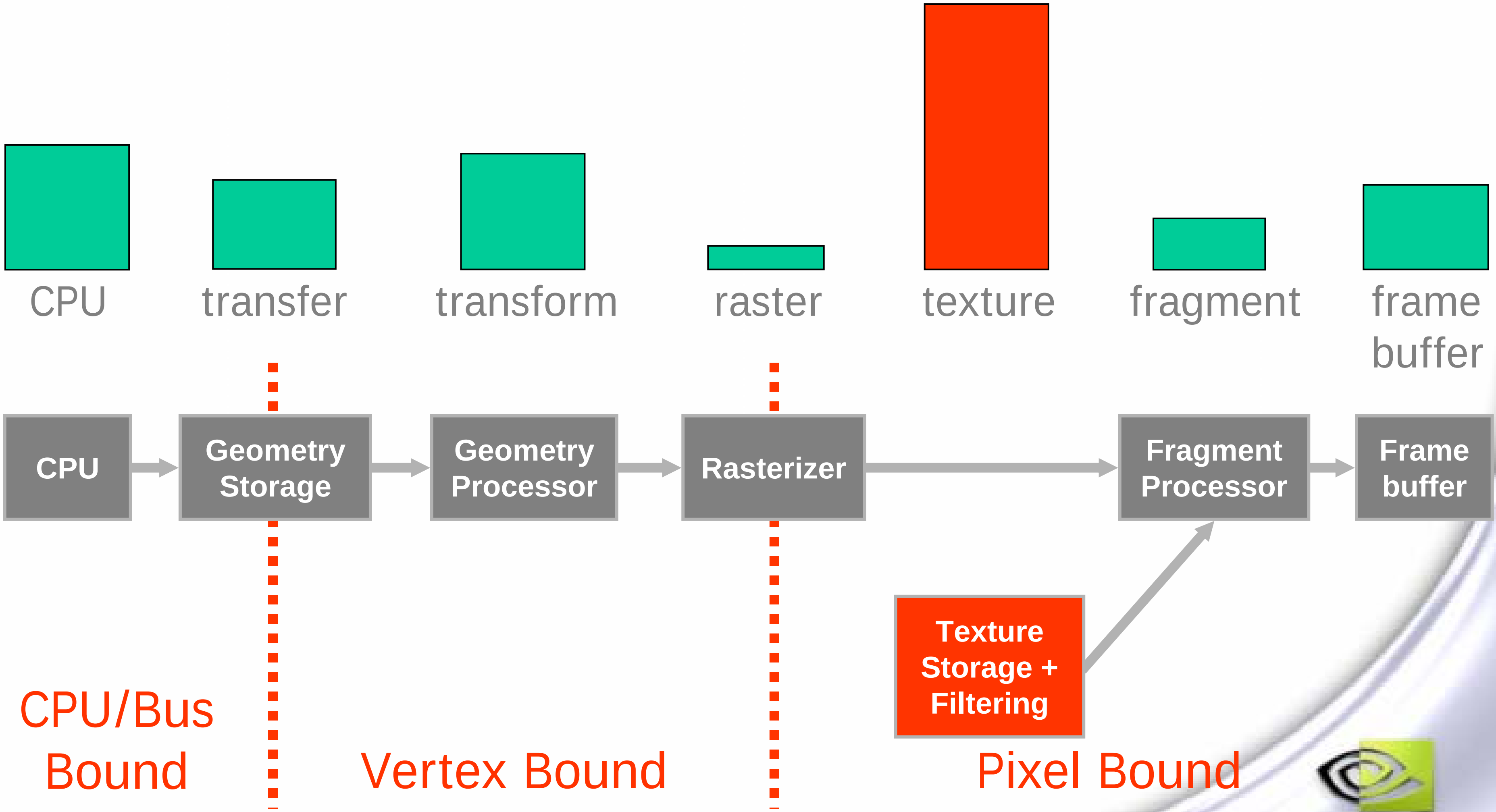
Rasterization

- Rarely the bottleneck (exception: stencil shadow volumes)
- Speed influenced primarily by size of triangles
- Also, by number of vertex attributes to be interpolated
- Be sure to maximize depth culling efficiency

Maximize Depth Culling Efficiency

- Always clear depth at the beginning of each frame
  - clear with stencil, if stencil buffer exists
  - feel free to combine with color clear, if applicable
- Coarsely sort objects front to back
- Don't switch the direction of the depth test mid-frame
- Constrain near and far planes to geometry visible in frame
- Use scissor to minimize superfluous fragment generation for stencil shadow volumes
- Avoid polygon offset unless you really need it
- NVIDIA advice
  - use depth bounds test for stencil shadow volumes

Texture Bottlenecks



Texture Bottlenecks

- Running out of texture memory
- Poor texture cache utilization
- Excessive texture filtering
- Minimize Texture bandwidth

Conserving Texture Memory

- Texture resolutions should be only as big as needed
- Avoid expensive internal formats
  - New GPUs allow floating point 4xfp16 and 4xfp32 formats
- Compress textures:
  - Collapse monochrome channels into alpha
  - Use 16-bit color depth when possible (environment maps and shadow maps)
  - Use DXT compression

Poor Texture Cache Utilization

- Localize texture accesses
  - beware of dependent texturing
  - beware of non-power of 2 textures
  - ALWAYS use mipmapping
  - use trilinear/aniso only when necessary (more later!)
- Avoid negative LOD bias to sharpen
  - texture caches are tuned for standard LODs
  - sharpening usually causes aliasing in the distance
  - opt for anisotropic filtering over sharpening

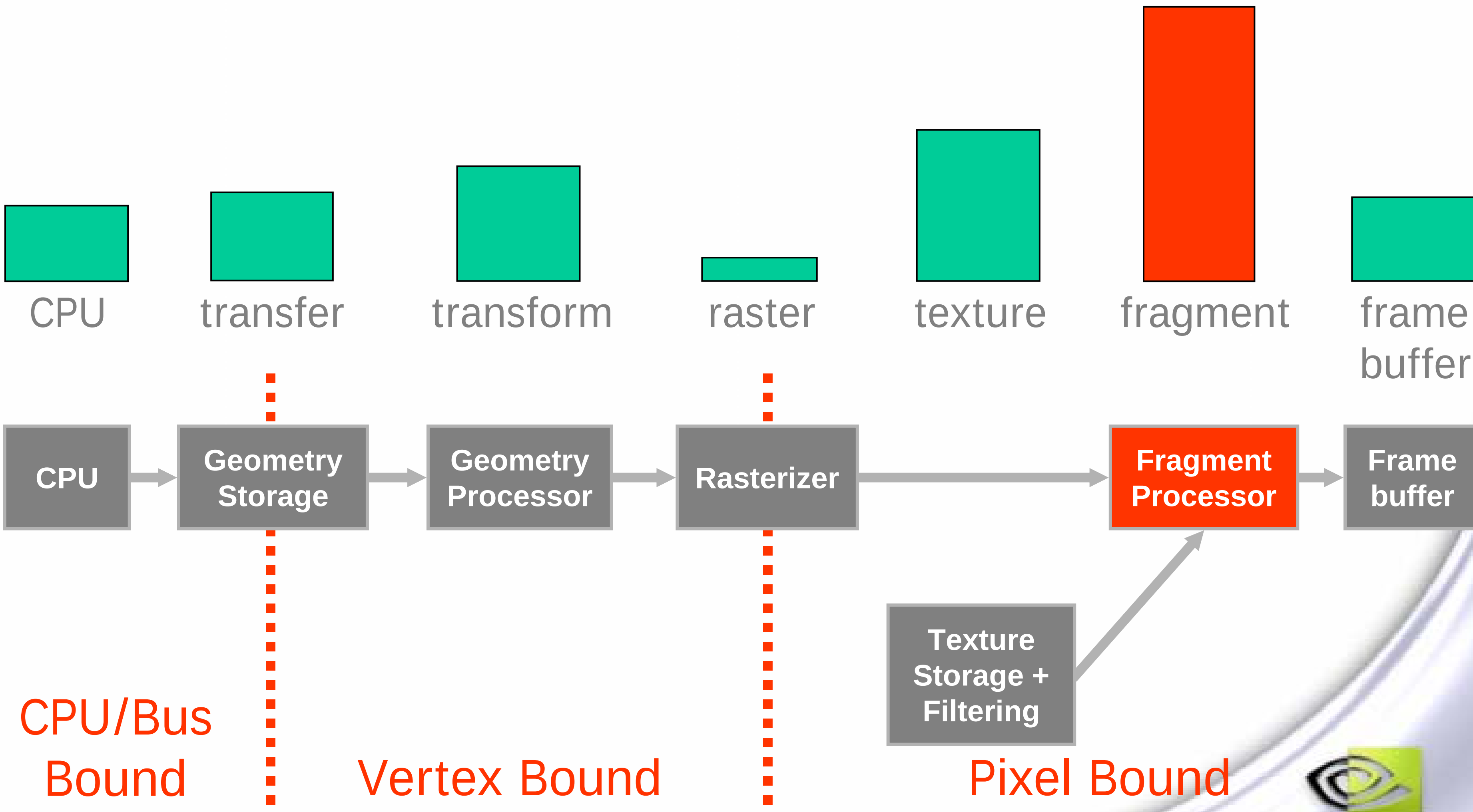
Excessive Texture Filtering

- Use trilinear filtering only when needed
  - trilinear filtering can cut fillrate in half
  - typically, only diffuse maps truly benefit
  - light maps are too low resolution to benefit
  - environment maps are distorted anyway
- Similarly use anisotropic filtering judiciously
  - Set the right anisotropic level for each texture
    - Lower level of aniso for low frequency textures
  - More expensive than trilinear
  - not useful for environment maps (again, distortion)

Minimize Texture bandwidth

- Pack multiple textures into one
  - Minimize amount of data to transfer
- Use DXT
- Lower your level of anisotropic filtering
  - Use appropriate level of aniso on a per texture basis:
    - High frequency texture -> High Aniso
    - Low frequency texture -> low Aniso – wasted perf is set too high and no visual differences

Fragment Bottlenecks



Fragment Bottlenecks

- Too many fragments
- Too much computation per fragment
- Unnecessary fragment operations

Too Many Fragments

- Follow prior advice for maximizing depth culling efficiency
- Consider using a depth-only first pass
  - shade only the visible fragments in subsequent pass(es)
  - improve fragment throughput at the expense of additional vertex burden (only use for frames employing complex shaders)

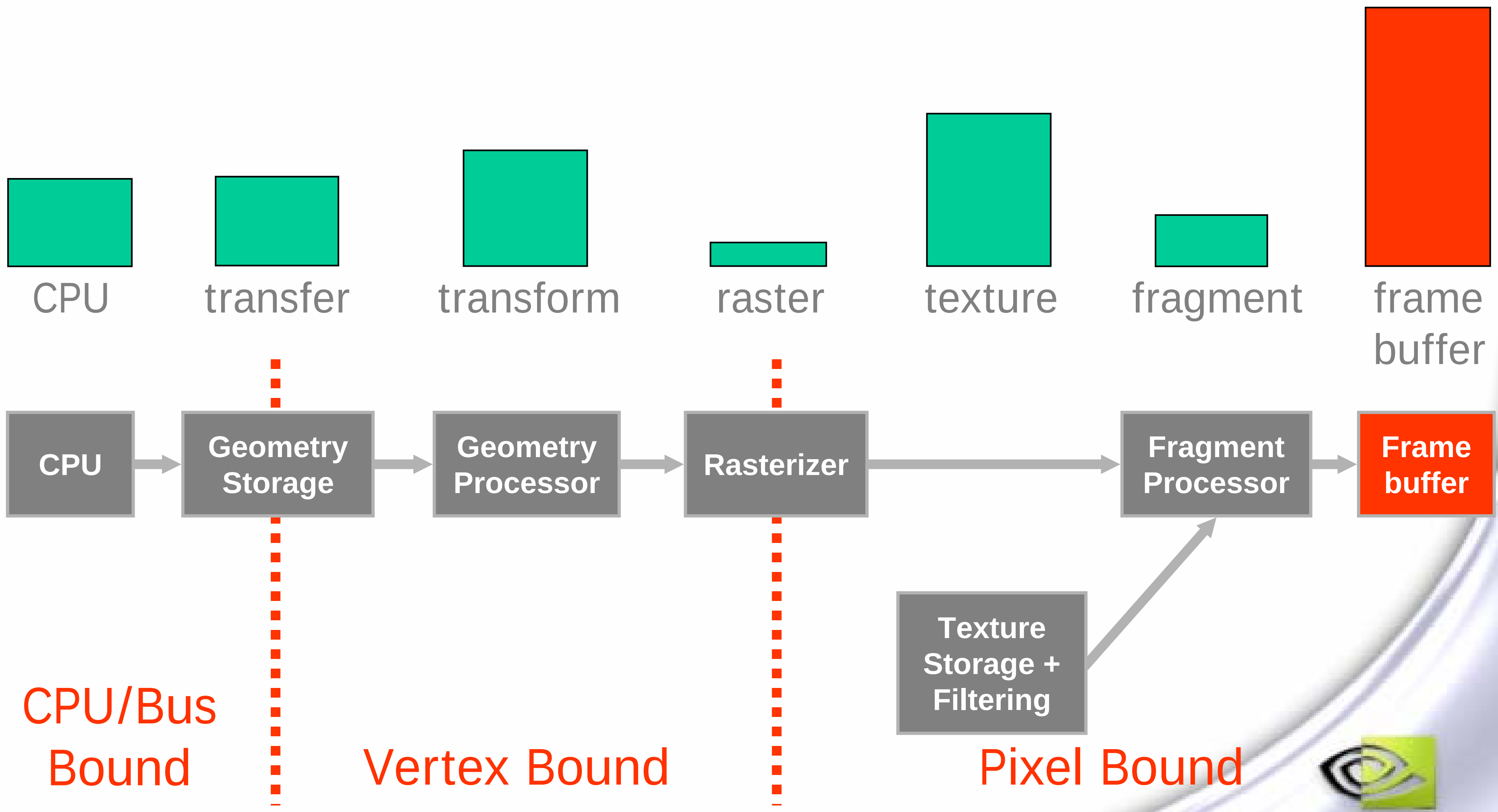
Too Much Fragment Computation

- Use a mix of texture and math instructions (they often run in parallel)
- Move constant per-triangle calculations to vertex program, send data as texture coordinates
- Do similar with values that can be linear interpolated (e.g. fresnel)
- Use lowest pixel shader version you can until you start loosing visual quality
- Consider using shader levels of detail

GeForceFX-specific Optimizations

- Use even numbers of texture instructions
- Use even numbers of blending (math) instructions
- Use normalization cubemaps to efficiently normalize vectors
- Leverage full spectrum of instruction set (LIT, DST, SIN,...)
- Leverage swizzle and mask operators to minimize MOVs
- Minimize temporary storage
  - Use 16-bit registers where applicable (most cases)
  - Use all components in each (swizzling is free)
- Use ps_2_a profile in HLSL
- Check out FX Composer on our developer website

Framebuffer Bottlenecks



Minimizing Framebuffer Traffic

- Collapse multiple passes with longer shaders (not always a win)
- Turn off Z writes for transparent objects and multipass
- Question the use of floating point frame buffers
- Use 16-bit Z depth if you can get away with it
- Reduce number and size of render-to-texture targets
  - Cube maps and shadow maps can be of small resolution and at 16-bit color depth and still look good
  - Try turning cube-maps into hemisphere maps for reflections instead
    - Can be smaller than an equivalent cube map
    - Fewer render target switches
  - Reuse render target textures to reduce memory footprint
- Do not mask off only some color channels unless really necessary

Finally... Use Occlusion Query

- Use occlusion query to minimize useless rendering
- It's cheap *and* easy!
- Examples:
  - multi-pass rendering
  - rough visibility determination (lens flare, portals)
- Caveats:
  - need time for query to process
  - can add fillrate overhead

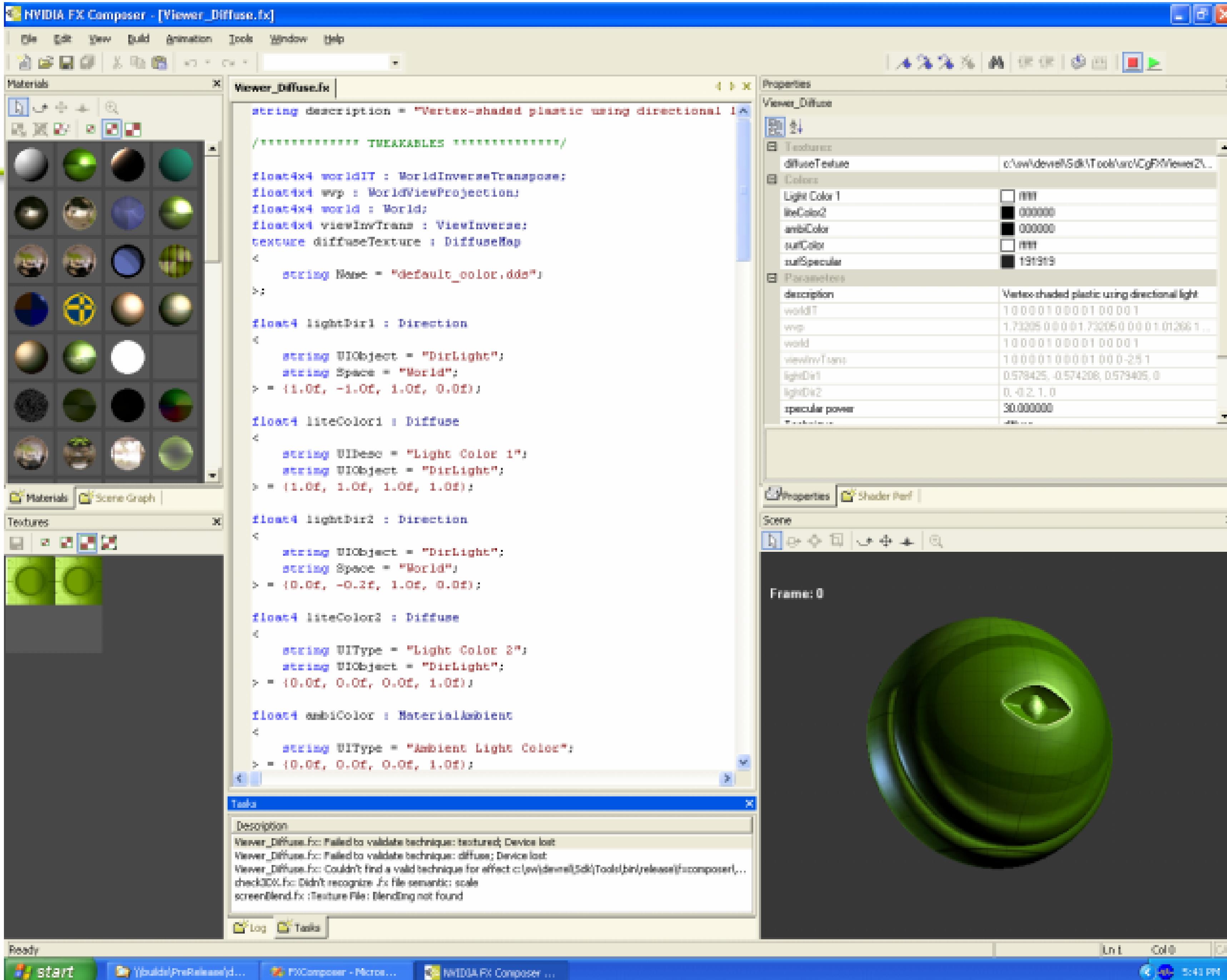
Tools: NVPerfHUD

- Drivers now support NVPerfHUD
- Overlay that shows vital various statistics as the application runs
- Top graph shows :
  - Number of API calls – Draw*Prim*, render states, texture states, shader states
  - Memory allocated – AGP and video
- Bottom graph shows :
  - GPU Idle – Graphics HW not processing anything
  - Driver Time – Driver doing work (state and resource management, shader compilation)
  - Driver Idle – Driver waiting for GPU to finish
  - Frame Time – Milliseconds per frame time


fps: 014
tris/frame: 69215
AQUAMARK
2000
1500
1000
500
0
Number of batches
100 ms
75 ms
50 ms
25 ms
256 Mb
192 Mb
128 Mb
64 Mb
Complex Multimaterial Shader

Tools: FX Composer

- Integrated IDE for HLSL FX development
- Simulated shader scheduling on nv3x family
- Disassembly of vertex and pixel shaders
- Bakes textures from HLSL code
- Allows render to texture effects
- HLSL Intellisense
- Allows scene import from .x and .nvb files
- Supports animation, lights, skinned meshes, etc...
- Allows pluggable geometry modifiers (fins, ...)
- Project files .fxcomposer
- Fxmapping.xml – custom semantic/annotation mapping


NVIDIA FX Composer - [Viewer_Diffuse.fx]
File Edit View Build Animation Tools Window Help
Materials
Viewer_Diffuse.fx
string description = "Vertex-shaded plastic using directional l
/************* TWEAKABLES **************/
float4x4 worldIT : WorldInverseTranspose;
float4x4 wvp : WorldViewProjection;
float4x4 world : World;
float4x4 viewInvTrans : ViewInverse;
texture diffuseTexture : DiffuseMap
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string Name = "default_color.dds";
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float4 lightDir1 : Direction
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string UIObject = "DirLight";
string Space = "World";
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float4 lightDir2 : Direction
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string UIType = "Ambient Light Color";
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Properties
Viewer_Diffuse
Textures
diffuseTexture
Colors
Light Color 1
liteColor2
ambiColor
surfColor
surfSpecular
Parameters
description
Vertex-shaded plastic using directional light
specular power
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Properties
Shader Perf
Materials
Scene Graph
Textures
Scene
Frame: 0
Tasks
Description
Viewer_Diffuse.fx: Failed to validate technique: textured; Device lost
Viewer_Diffuse.fx: Failed to validate technique: diffuse; Device lost
check3DX.fx: Didn't recognize .fx file semantic: scale
screenBlend.fx :Texture File: Blending not found
Log
Tasks
Ready
start
NVIDIA FX Composer ...

Conclusion

- Complex, programmable GPUs have many potential bottlenecks
- Rarely is there but one bottleneck in a game
- Understand what you are bound by in various sections of the scene
  - The skybox is probably texture limited
  - The skinned, dot3 characters are probably transfer or transform limited
- Exploit imbalances to get things for free

Questions, comments, feedback?

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