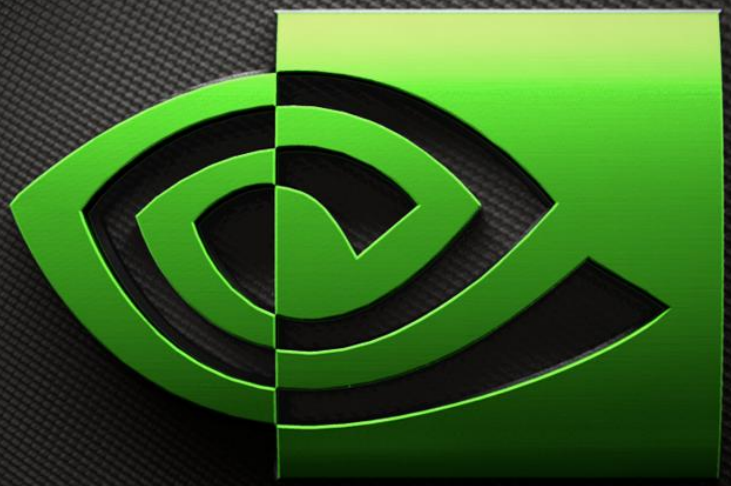


NVIDIA

GPU Ray Tracing

SIGGRAPH 2011 Vancouver

August 8th, 2011

Agenda

1. Brief Introduction
2. Dispelling Myths
3. GPU Ray Tracing Facts
4. Out of Core results
5. mental ray GPU results
6. iray futures (time willing)
7. OptiX 2.5 with David McAllister

Evolving Views on GPU Ray Tracing (it)

4 SIG's ago:	The future is ray tracing and a GPU *can't do it*
3 SIG's ago:	NVIDIA can do it, but *we can't*
2 SIG's ago:	Now *everyone can* do it
Last SIGGRAPH:	*Many companies are* doing it
This SIGGRAPH:	You can do it with most anything
Next year:	You can do it *anywhere*

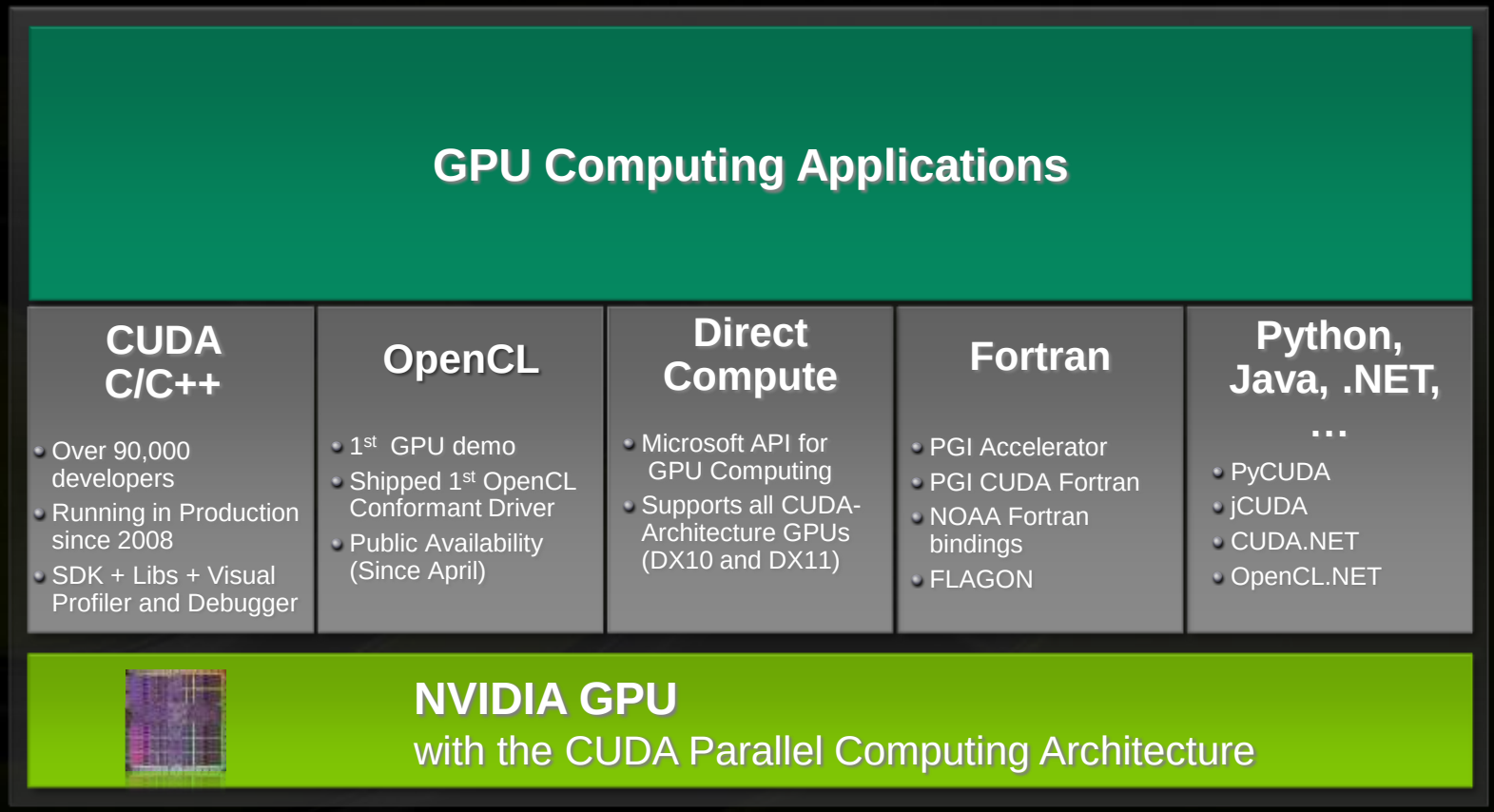
GPU Ray Tracing Myths

1. The only technique possible on the GPU is path tracing
   False: you're techniques are only limited by C
2. You can only use (expensive) pro GPUs
   False: GPU computing languages run on all GPUs
3. A GPU farm is more expensive than a CPU farm
   False: perf/dollar is well in GPUs favor
4. A GPU isn't that much faster than a good CPU
   False: unless you consider 4-12X a quad-core "not much"
5. GPU Ray Tracing is hard
   Can be true: that's why we created OptiX
6. Your scene has to fit into GPU memory – and that's finite
   True: **until now**

Similarities for today's GPU Ray Tracing

- Speed is linear to GPU cores and clock – for a given GPU architecture. Gains between GPU generations will vary per solution, but they're BIG
- Most scale well across system GPUs ("SLI" not needed), but Scaling efficiency will vary per solution and/or technique
- DP an app choice, ECC a user choice – neither usually needed
- GPU Computing (ray tracing) steals from system graphics – care is needed to achieve balanced interaction (or multi GPU)
- GTX GPUs – designed for Ultimate Game performance, and **not** for GPU computing longevity
- Entire scene must fit onto the GPU's memory (geometry, textures, acceleration structures) – to work, or go at top speed

GPU Computing Overview



Broad Adoption

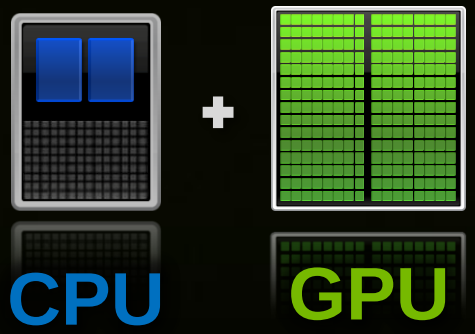
- Over 250,000,000 installed CUDA-Architecture GPUs
- Over 100,000 GPU Computing Developers
- Windows, Linux and MacOS Platforms supported
- GPU Computing spans HPC to Consumer
- 250+ Universities teaching GPU Computing on the CUDA Architecture

Many Programming Approaches in Use

iray	CUDA C, C Runtime	
finalRender	CUDA C, C Runtime	
Furry Ball	CUDA C, C Runtime	
Arion	CUDA C, driver API	
Octane	CUDA C, driver API	
V-Ray RT (in our booth)	OpenCL	
Brazil	OpenCL	
CentiLeo	CUDA C, driver API	Massive Out of Core
Panta Ray	CUDA C, driver API	Massive Out of Core
OptiX (2.5)	CUDA C, driver API & PTX	(Out of Core)
Adobe Research (in our booth)	CUDA C, OptiX API	" "
Works Zebra, etc. (at our booth)	CUDA C, OptiX API	" "
mental ray	CUDA C, OptiX API	" "

Solutions Vary in their GPU Exploitation

- Speed-ups vary, but a top end Fermi GPU will typically ray trace 6 to 15 times faster than on a quad-core CPU
- A GPGPU programming challenge is to keep the GPU “busy”
  - Gains on complex tasks often greater than for simple ones
  - Particularly evident with multiple GPUs, where data transfers impact simple tasks more
  - Can mean the technique needs to be rethought in how it’s scheduling work for the GPU
  - OptiX 2.1 example – first tuned for simple, now tuned for complex, with a 30-80% speed increase



NVIDIA Goals for Advanced Rendering

- Make the GPU an essential part of ***ALL*** *advanced rendering*
- Create engines and libraries to make it easier for everyone to exploit the GPU (e.g., OptiX); *learning what's needed for future GPU languages and architectures*
- Create compelling commercial offerings to spur GPU adoption (e.g., iray); *learning what's needed for success, so to help other developers and improve the GPU platform for it*
- If you're developing solutions for Advanced Rendering, *NVIDIA wants to help*

NVIDIA ARC: mental ray AO

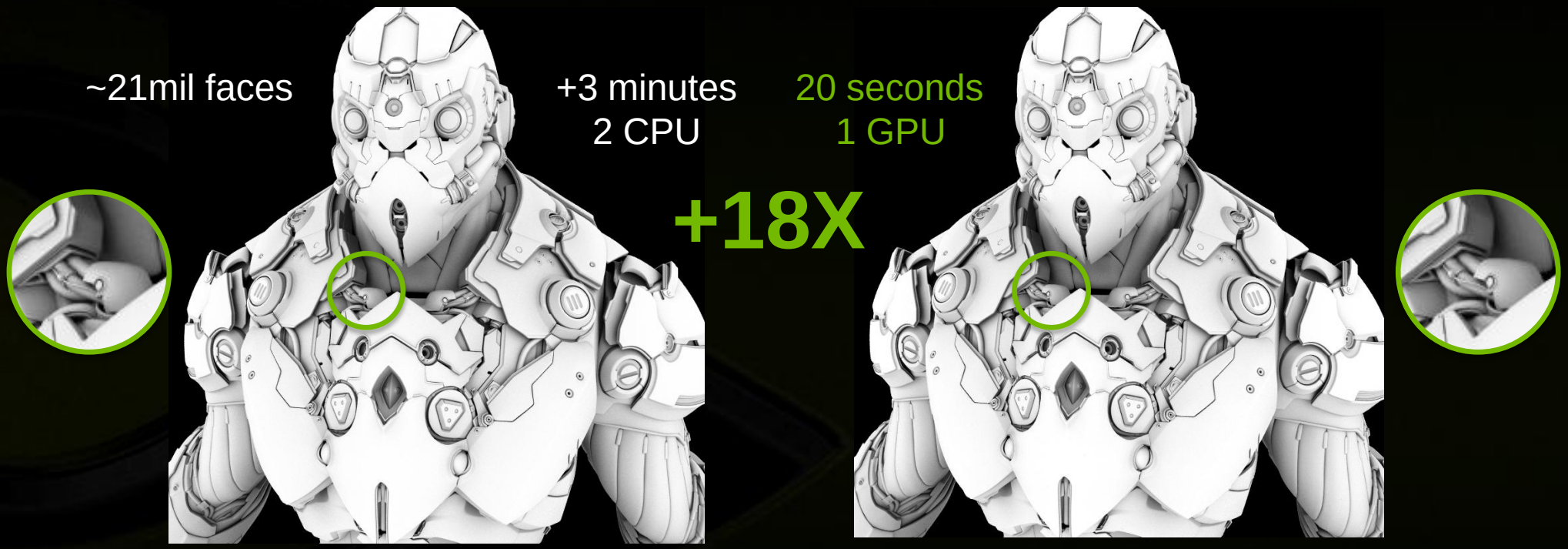
- mental ray 3.9 code & pipeline accelerated w/ OptiX

~21mil faces

+3 minutes
2 CPU

20 seconds
1 GPU

+18X



Rendered with mental ray 3.9

Model courtesy NVIDIA Creative

- Subsequent frames can be *far* faster yet…

NVIDIA iray: roadmap

- **iray 2** now
  - Layered Material Model
    (car paint, subsurface scattering, decals, etc.)
  - Increased Performance & Interactivity, Daylight Portals, Clipping Planes, more…
- **iray 3** next year
  - Better convergence for more difficult lighting conditions
  - Increased interactivity…
  - Increased flexibility for production use cases…
  - Much more in the works…

Agenda

1. What is OptiX
2. Why OptiX
3. What's New

NVIDIA ARC: OptiX ray tracing engine

- A ray tracing framework for developers
  - Similar to OpenGL in doing the “heavy lifting” of ray tracing and leaving capability and technique to the developers
  - Very general and applicable to many markets
  - Proven to speed development as well as performance
- Being used by Adobe in our booth
- Being used internally in our commercial software

The Beauty of OptiX as Middleware

The Beauty of OptiX as Middleware

- *We do the heavy lifting for you.*

The Beauty of OptiX as Middleware

- *We handle acceleration structure build and traversal.*

The Beauty of OptiX as Middleware

- *We handle multiple GPUs transparently.*

The Beauty of OptiX as Middleware

- *We handle thread scheduling and reconvergence.*

The Beauty of OptiX as Middleware

- We automatically page datasets too large for GPU memory.

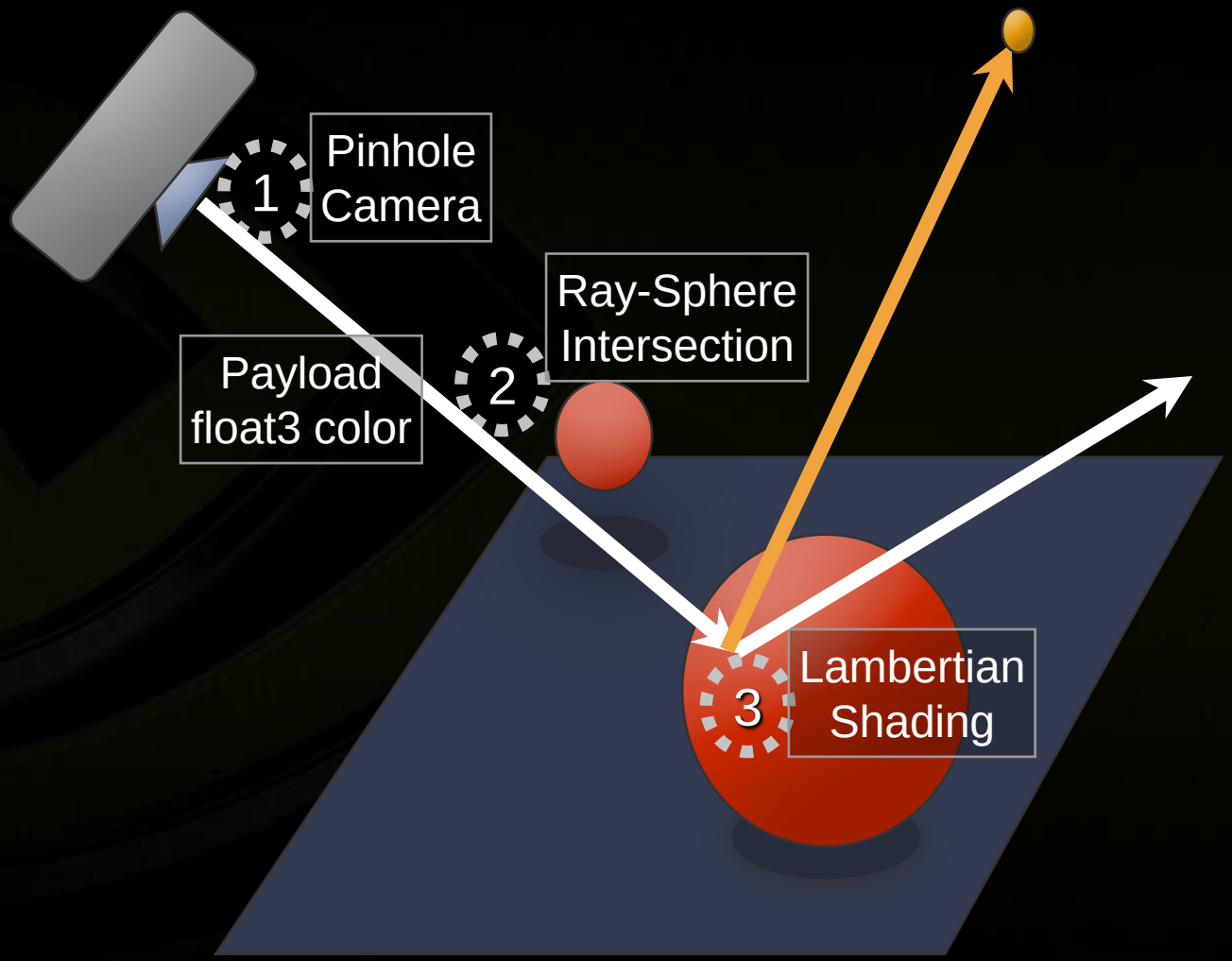
The Beauty of OptiX as Middleware

- We enable interactive scene editing via fast rebuilds

The Beauty of OptiX as Middleware

- We virtualize texture resources and use software texturing as needed.

Life of a ray



1 Ray Generation

2 Intersection

3 Shading

Life of a ray

1 Pinhole Camera

```
RT_PROGRAM void pinhole_camera()
{
  float2 d = make_float2(launch_index) / make_float2(launch_dim) * 2.f -
1.f;
  float3 ray_origin = eye;
  float3 ray_direction = normalize(d.x*U + d.y*V + W);

  optix::Ray ray = optix::make_Ray(ray_origin, ray_direction,
    radiance_ray_type, scene_epsilon, RT_DEFAULT_MAX);

  PerRayData_radiance prd;
  rtTrace(top_object, ray, prd);
  output_buffer[launch_index] = make_color( prd.result );
}
```

2 Ray-Sphere Intersection

```
RT_PROGRAM void intersect_sphere()
{
  float3 O = ray.origin - center;
  float3 D = ray.direction;
  float b = dot(O, D);
  float c = dot(O, O)-radius*radius;
  float disc = b*b-c;
  if(disc > 0.0f){
    float sdisc = sqrtf(disc);
    float root1 = (-b - sdisc);
    bool check_second = true;
    if( rtPotentialIntersection( root1 ) ) {
      shading_normal = geometric_normal = (O +
root1*D)/radius;
      if(rtReportIntersection(0))
        check_second = false;
    }
    if(check_second) {
      float root2 = (-b + sdisc);
      if( rtPotentialIntersection( root2 ) ) {
        shading_normal = geometric_normal = (O +
root2*D)/radius;
        rtReportIntersection(0);
      }
    }
  }
```

3 Lambertian Shading

```
RT_PROGRAM void closest_hit_radiance3()
{
  float3 world_geo_normal   = normalize( rtTransformNormal( RT_OBJECT_TO_WORLD, geometric_no
  float3 world_shade_normal = normalize( rtTransformNormal( RT_OBJECT_TO_WORLD, shading_norm
  float3 ffnormal     = faceforward( world_shade_normal, -ray.direction, world_geo_normal );
  float3 color = Ka * ambient_light_color;

  float3 hit_point = ray.origin + t_hit * ray.direction;

  for(int i = 0; i < lights.size(); ++i) {
    BasicLight light = lights[i];
    float3 L = normalize(light.pos - hit_point);
    float nDl = dot( ffnormal, L);

    if( nDl > 0.0f ){
      // cast shadow ray
      PerRayData_shadow shadow_prd;
      shadow_prd.attenuation = make_float3(1.0f);
      float Ldist = length(light.pos - hit_point);
      optix::Ray shadow_ray( hit_point, L, shadow_ray_type, scene_epsilon, Ldist );
      rtTrace(top_shadower, shadow_ray, shadow_prd);
      float3 light_attenuation = shadow_prd.attenuation;

      if( fmaxf(light_attenuation) > 0.0f ){
        float3 Lc = light.color * light_attenuation;
        color += Kd * nDl * Lc;

        float3 H = normalize(L - ray.direction);
        float nDh = dot( ffnormal, H );
        if(nDh > 0)
          color += Ks * Lc * pow(nDh, phong_exp);
      }

    }
  }
  prd_radiance.result = color;
}
```

Program objects (shaders)

```
RT_PROGRAM void pinhole_camera()
{
  float2 d = make_float2(launch_index) /
    make_float2(launch_dim) * 2.f - 1.f;
  float3 ray_origin = eye;
  float3 ray_direction = normalize(d.x*U + d.y*V + W);

  optix::Ray ray = optix::make_Ray(ray_origin, ray_direction,
    radiance_ray_type, scene_epsilon, RT_DEFAULT_MAX);

  PerRayData_radiance prd;
  rtTrace(top_object, ray, prd);
  output_buffer[launch_index] = make_color( prd.result );
}
```

- Input “language” is based on CUDA C/C++
  - No new language to learn
  - Powerful language features available immediately
  - Can also take raw PTX as input
- Interconnection of programs defines the outcome
- Data associated with ray is programmable
- Caveat: still need to use it responsibly to get performance

Programmable Operations

Rasterization	Ray Tracing
Fragment	Closest Hit
	Any Hit
Vertex	Intersection
Geometry	Selector
Hull/Domain (Tesselation)	
	Ray Generation
	Miss
	Exception

Acceleration Structure Choices

Sbvh	Splits slivery triangles	*Fastest ray tracing*
Bvh	Standard CPU build	
MedianBvh	Fast CPU build	
Lbvh	Built on GPU	*Fastest build time*

Fast BVH Build on GPU

- Fairy Forest (174K triangles) – 4.8ms
- Turbine Blade (2M triangles) – 10.5ms
- Power Plant (12M triangles) – 62ms

Large Dataset Paging

- App is not written to be paging aware
- Handles models somewhat larger than GPU memory
- Modest slowdown vs. in-core

- App is written for large datasets
- Handles models 3X size of GPU memory
- More substantial slowdown but fast vs. CPU

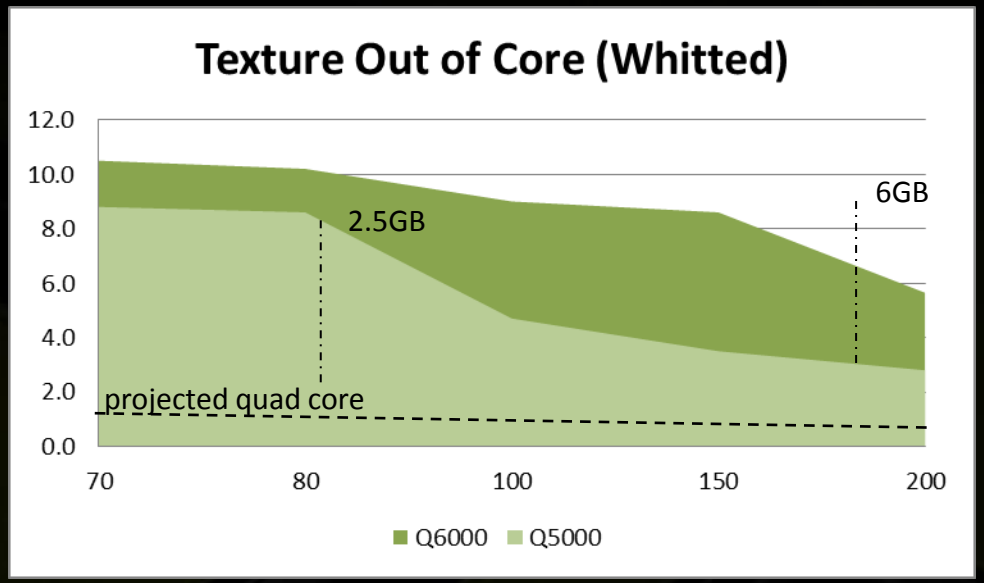
- Create SW page table
- Rewrite LD/ST instructions to virtualize
- On page hit, translate virtual address and load it
- On page miss save thread state to GPU memory and pause ray, grab a new ray
- Copy requested pages from CPU to GPU on page fault
- Restart kernel, restore state, resume rendering

OptiX Roadmap

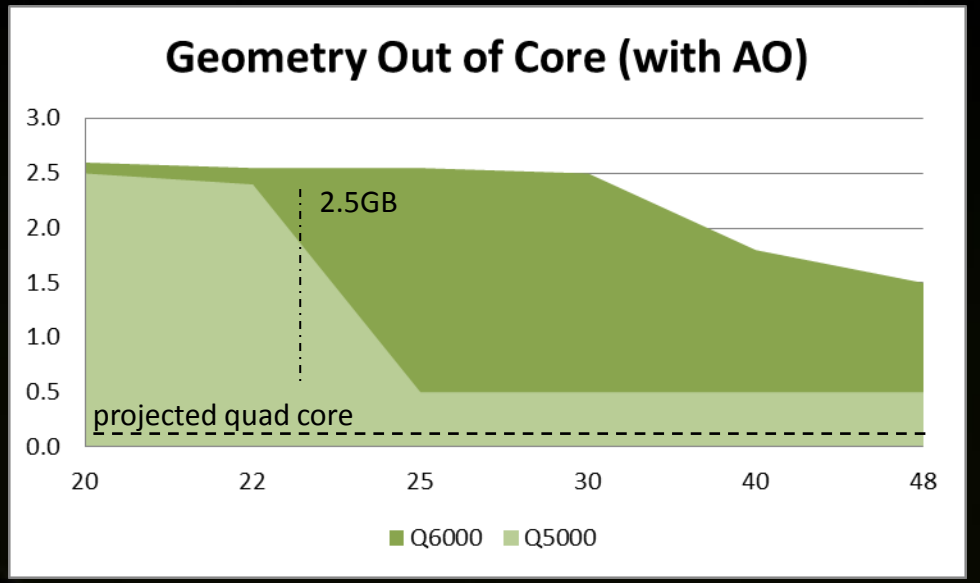
- Version 2.5 later this year
  - Out-of-core support, paging to system RAM
  - Unlimited number of textures
  - Very fast device-side BVH builds
  - Speedups!

- Version 3 first half of next year
  - Optimized for Kepler GPU Architecture
  - CPU fallback (for interactive rendering)
    - Why? - required by major commercial products (including NVDIA ARC's)

Preliminary tests with OptiX 2.5



# of 4k Images



Millions of Textured & Smoothed Faces

Quadro 6000 = 6GB on board memory

Quadro 5000 = 2.5GB on board memory


Questions?
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