New Features in OptiX 6.0

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NVIDIA

AGENDA

OptiX Overview

New features in OptiX 6

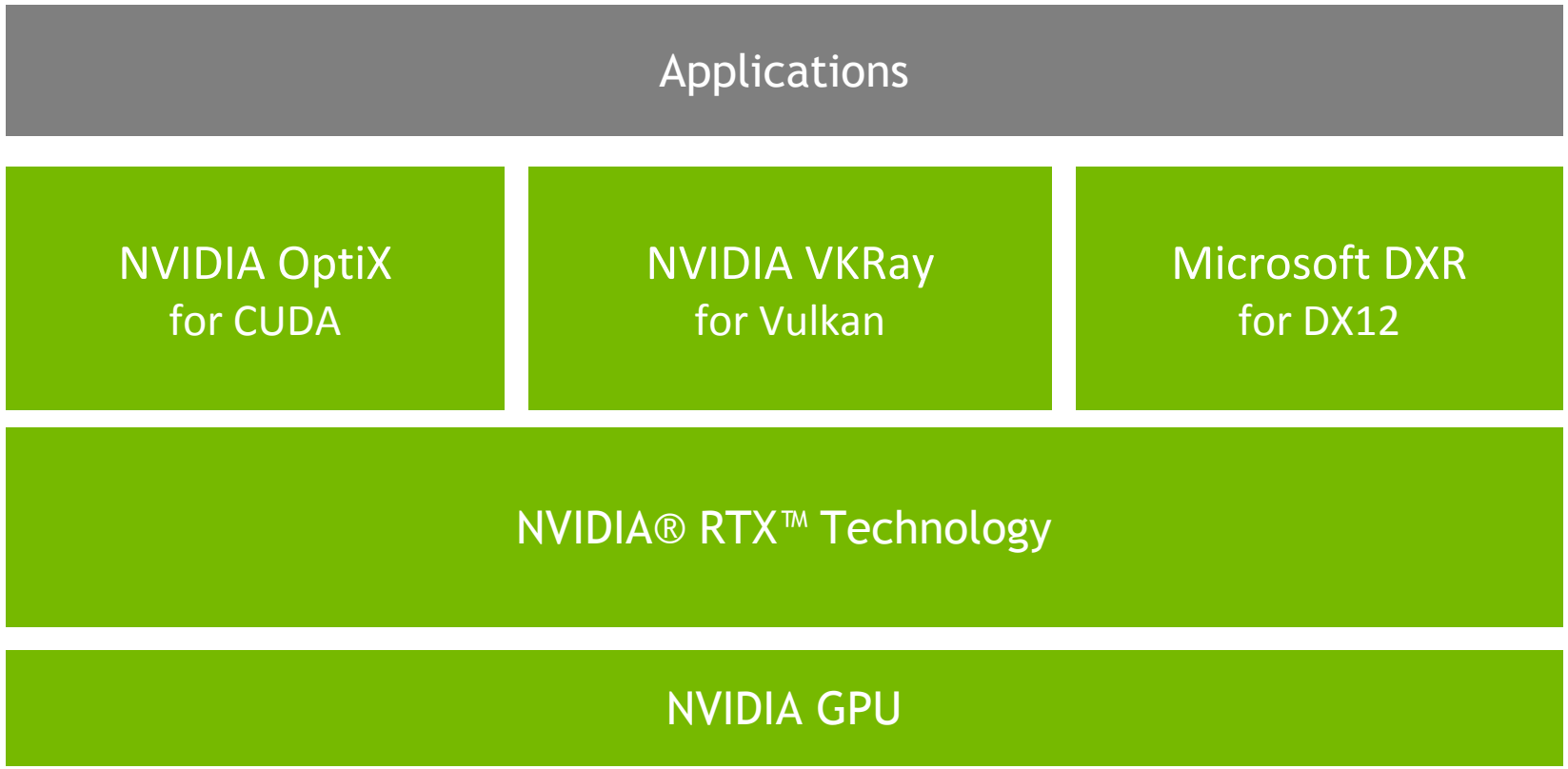
OptiX Performance tips

OptiX Debugging tips

General OptiX improvements

Summary / Q&A

NVIDIA RTX TECHNOLOGY



OptiX: A General Purpose Ray Tracing Engine

Steven G. Parker[1]* James Bigler[1] Andreas Dietrich[1] Heiko Friedrich[1] Jared Hoberock[1] David Luebke[1]
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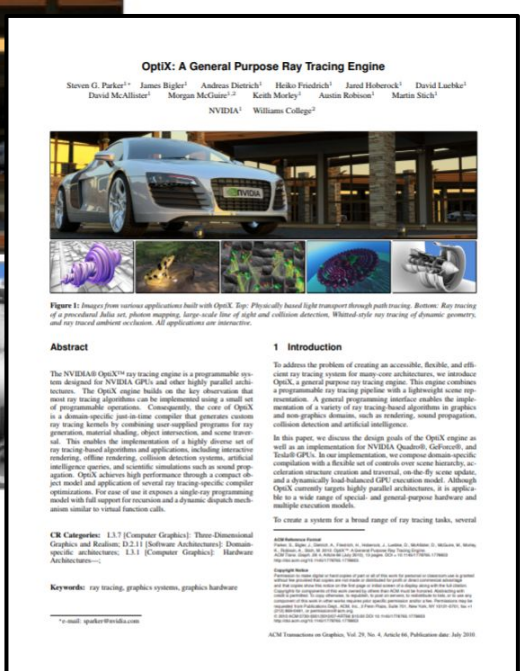

OptiX: A General Purpose Ray Tracing Engine

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Figure 1: *Images from various applications built with OptiX. Top: Physically based light transport through path tracing. Bottom: Ray tracing of a procedural Julia set, photon mapping, large-scale line of sight and collision detection, Whitted-style ray tracing of dynamic geometry, and ray traced ambient occlusion. All applications are interactive.*

Abstract

The NVIDIA® OptiX™ ray tracing engine is a programmable system designed for NVIDIA GPUs and other highly parallel architectures. The OptiX engine builds on the key observation that most ray tracing algorithms can be implemented using a small set of programmable operations. Consequently, the core of OptiX is a domain-specific just-in-time compiler that generates custom ray tracing kernels by combining user-supplied programs for ray generation, material shading, object intersection, and scene traversal. This enables the implementation of a highly diverse set of ray tracing-based algorithms and applications, including interactive rendering, offline rendering, collision detection systems, artificial intelligence queries, and scientific simulations such as sound propagation. OptiX achieves high performance through a compact object model and application of several ray tracing-specific compiler optimizations. For ease of use it exposes a single-ray programming model with full support for recursion and a dynamic dispatch mechanism similar to virtual function calls.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism; D.2.11 [Software Architectures]: Domain-specific architectures; I.3.1 [Computer Graphics]: Hardware Architectures—;

Keywords: ray tracing, graphics systems, graphics hardware

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1 Introduction

To address the problem of creating an accessible, flexible, and efficient ray tracing system for many-core architectures, we introduce OptiX, a general purpose ray tracing engine. This engine combines a programmable ray tracing pipeline with a lightweight scene representation. A general programming interface enables the implementation of a variety of ray tracing-based algorithms in graphics and non-graphics domains, such as rendering, sound propagation, collision detection and artificial intelligence.

In this paper, we discuss the design goals of the OptiX engine as well as an implementation for NVIDIA Quadro®, GeForce®, and Tesla® GPUs. In our implementation, we compose domain-specific compilation with a flexible set of controls over scene hierarchy, acceleration structure creation and traversal, on-the-fly scene update, and a dynamically load-balanced GPU execution model. Although OptiX currently targets highly parallel architectures, it is applicable to a wide range of special- and general-purpose hardware and multiple execution models.

To create a system for a broad range of ray tracing tasks, several

ACM Reference Format
Parker, S., Bigler, J., Dietrich, A., Friedrich, H., Hoberock, J., Luebke, D., McAllister, D., McGuire, M., Morley, K., Robison, A., and Stich, M. 2010. OptiX: A General Purpose Ray Tracing Engine. ACM Trans. Graph. 29, 4, Article 66 (July 2010), 13 pages. DOI = 10.1145/1778765.1778803 http://doi.acm.org/10.1145/1778765.1778803

ACM Transactions on Graphics, Vol. 29, No. 4, Article 66, Publication date: July 2010.

10 years of work in computer graphics algorithms and GPU architectures

OptiX Rendering Applications

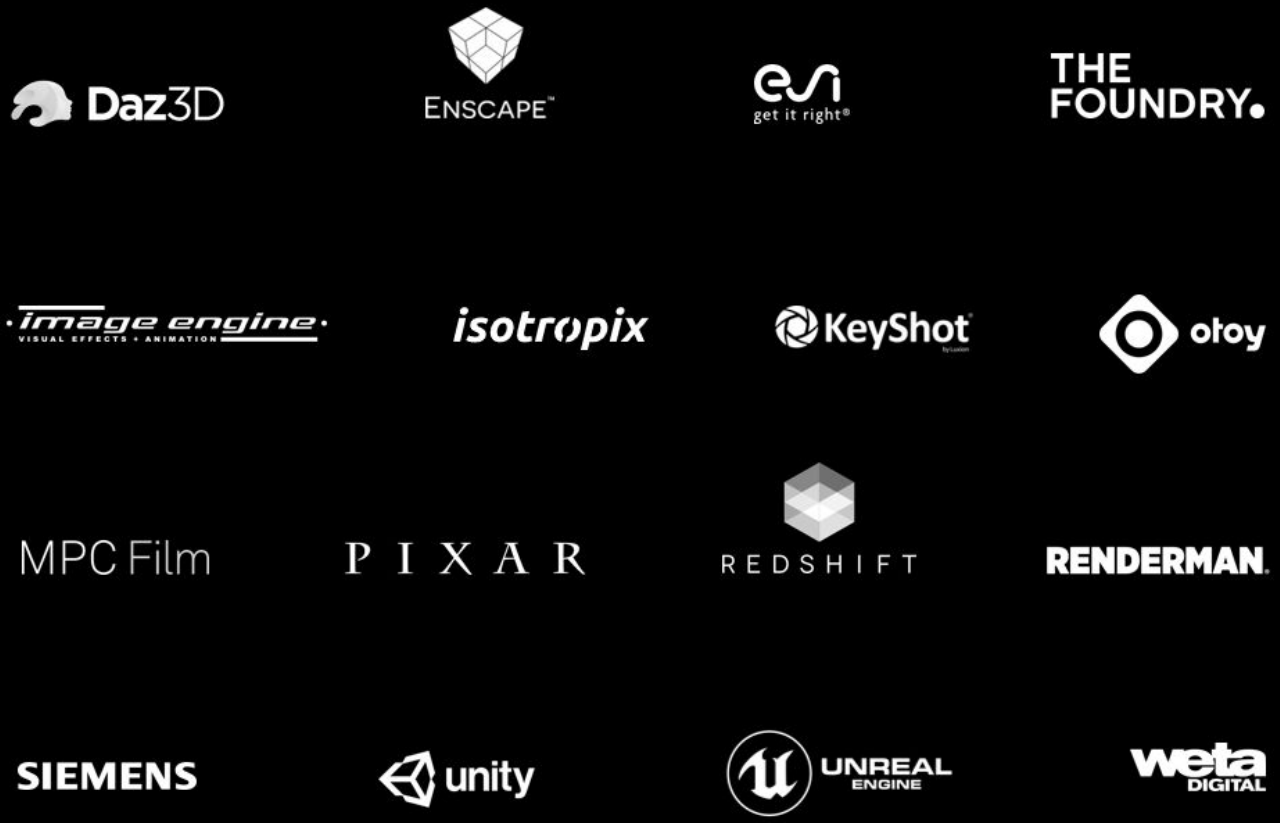
MEDIA & ENTERTAINMENT

PRODUCT DESIGN

ARCHITECTURE

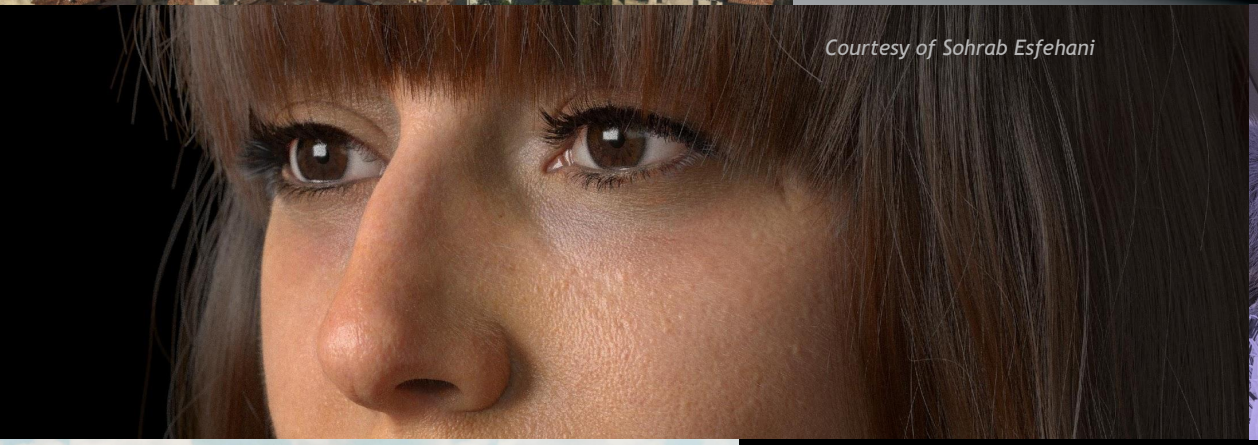
BROAD SUPPORT FOR NVIDIA RTX

RTX COMES TO 9M 3D CREATORS IN 2019




Courtesy of Mickael Riccoitti


Courtesy of Autodesk

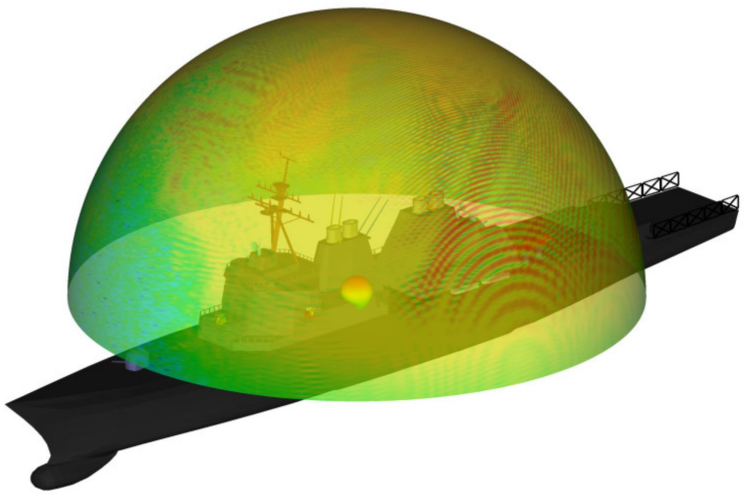

Courtesy of Sohrab Esfehani


Courtesy Vladimir Petkovic

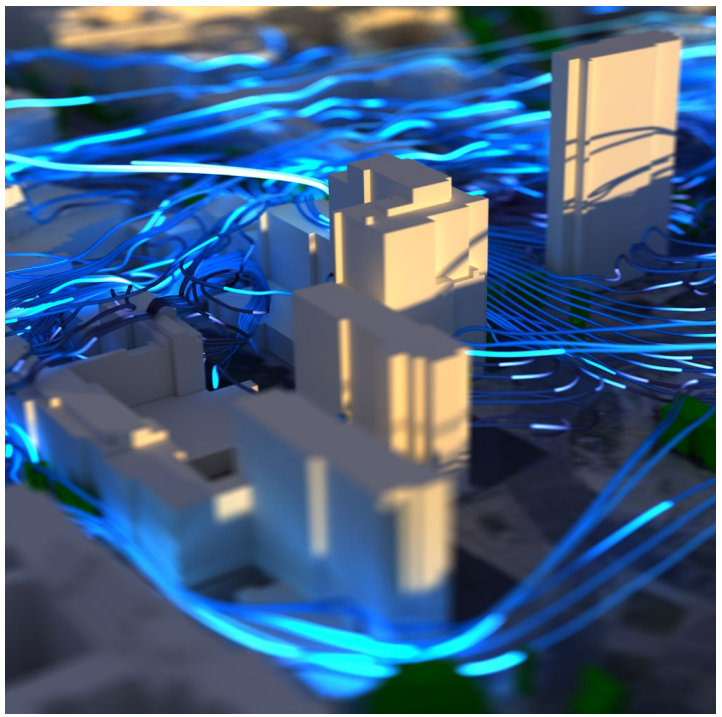

Courtesy *RED* HYDROGEN - Media Machine


Courtesy of Ian Spriggs

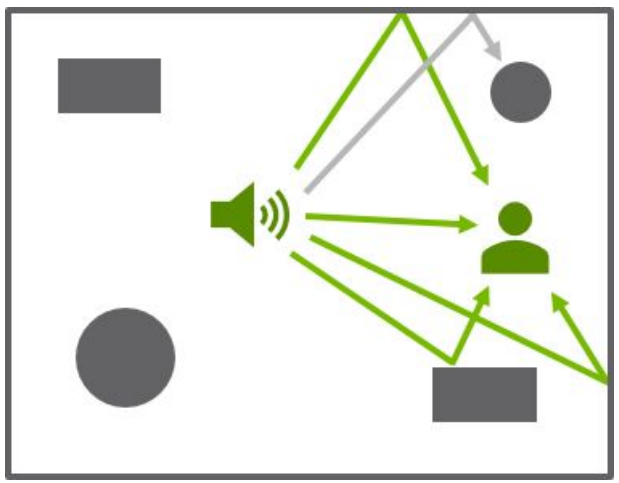
OptiX Scientific Applications



ELECTROMAGNETIC SIMULATIONS



FLUID DYNAMICS



SOUND PROPOGATION [VRWORKS AUDIO]

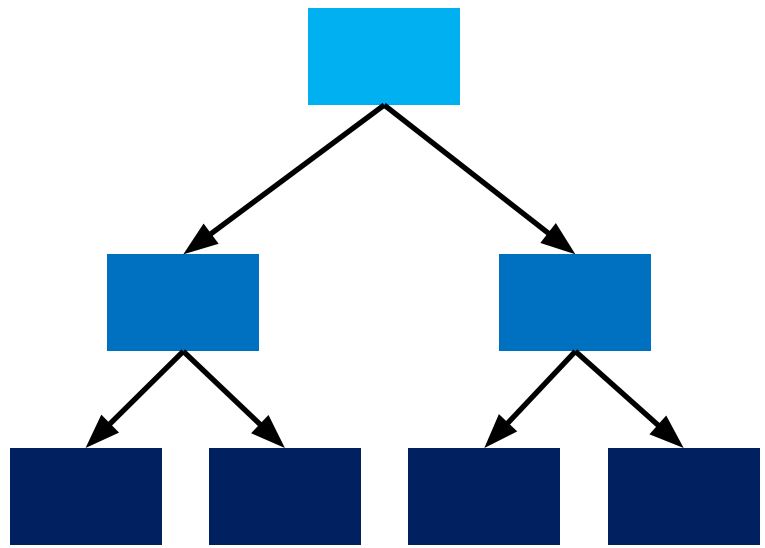
RT Cores

Traversal

- Hardware accelerated with RT Cores
- Includes custom primitives

Triangle intersection

- Only works with triangles
- Requires OptiX triangle API



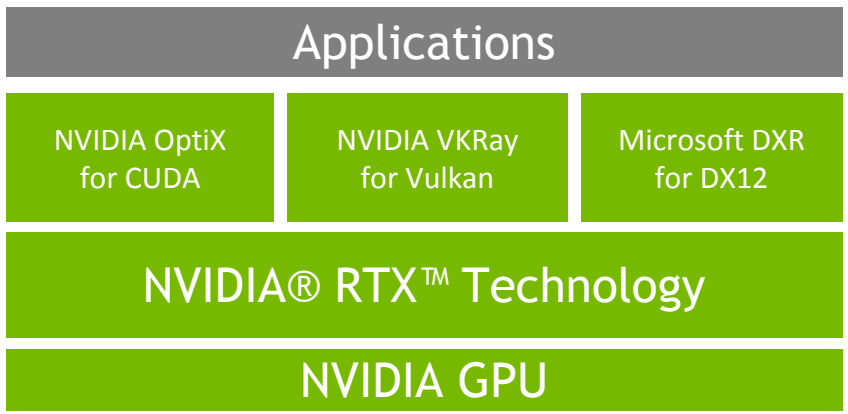
Terminology

RT Cores:

- New in Turing
- Hardware for ray traversal & ray-triangle intersection

RTX Software:

- Technology stack for ray tracing
- Driver software



OptiX delivery

OptiX SDK package contents

- Headers
- Documentation
- Samples
- Libraries
  - optix.51.dll [~40MB]
  - optix.6.0.0.dll [~200KB]

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OptiX in NVIDIA driver

- nvoptix.dll

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Summary / Q&A

OptiX Programming Model

You provide: A renderer

CUDA programs for: Rays, Geometry, Shading, Miss, Exception

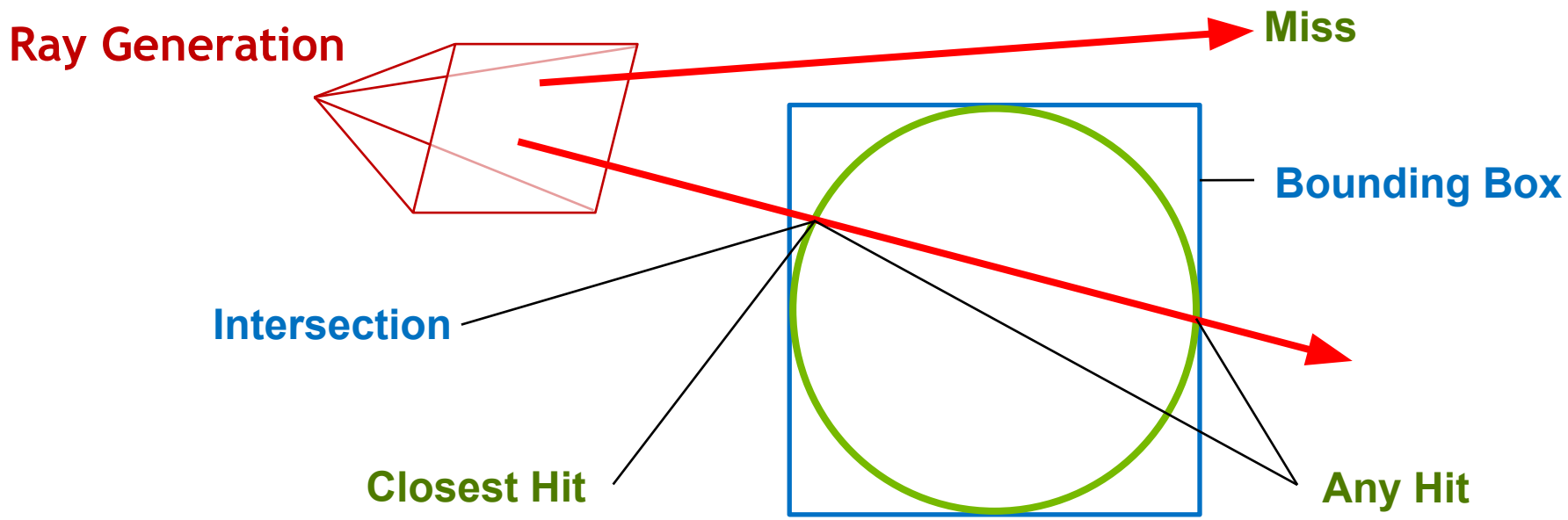
OptiX provides: plumbing

Compilation, scheduling, traversal, memory management, etc.

OptiX does not make assumptions about your

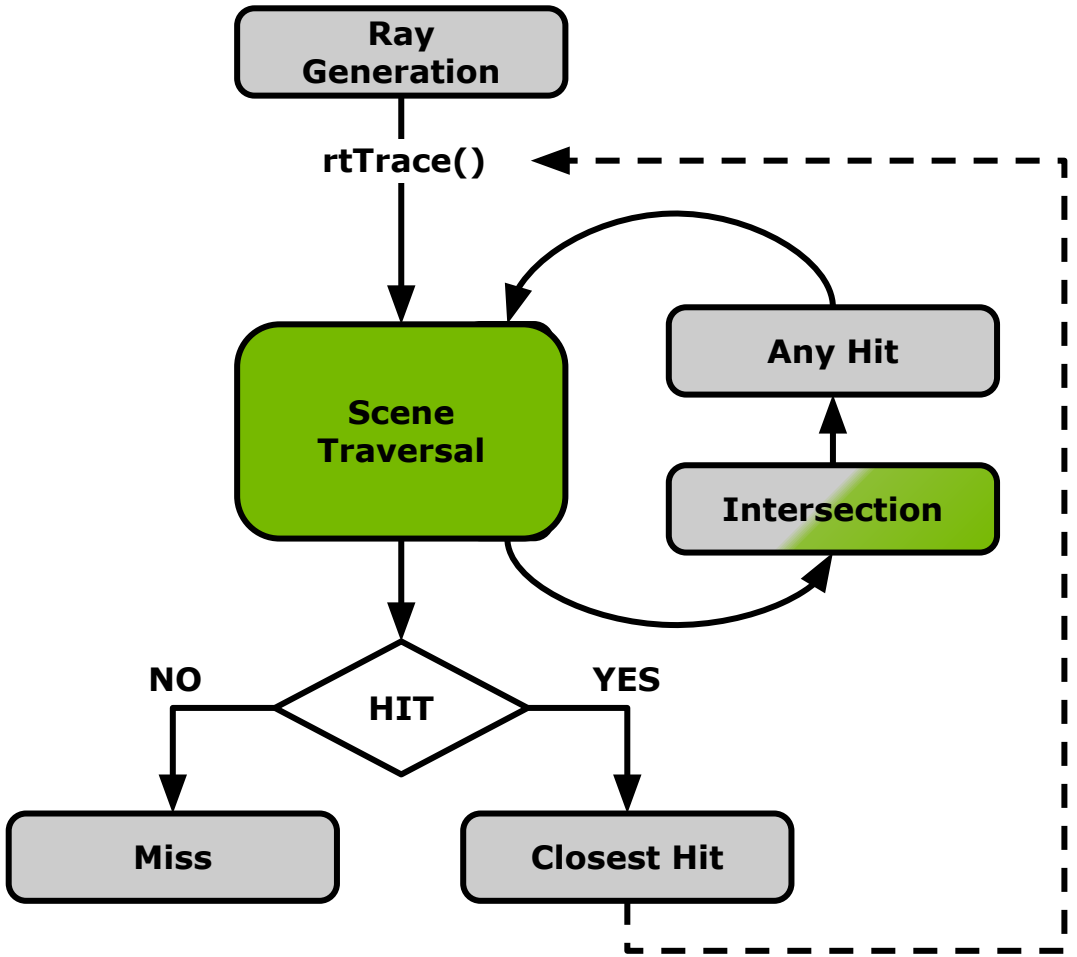
input data, output data, or algorithms

OptiX Programs



* per geometric primitive type
* per entry point
* per ray type

OptiX Program Model



Getting Started with OptiX

developer.nvidia.com/optix

Tutorial (“Introduction to NVIDIA OptiX”, GTC 2018)

OptiX 6 Programming Guide

SDK samples

OptiX advanced samples (github)

Forum developer.nvidia.com/optix-forums

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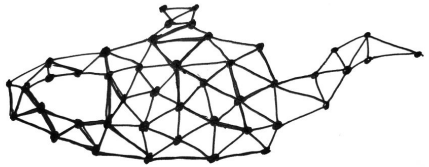
New in OptiX 6

=> Support for RT Cores

RTX API: Maxwell+
RT Cores: Turing+
New Triangle API for hardware accelerated meshes
New attribute programs
New API for stack sizes, rtTrace, and more
rtTrace from bindless callable programs
Separate & parallel compilation of shaders
Multi-GPU improvements
Denoiser is Turing accelerated



Triangle API

OptiX interface to RTX (built-in) triangle intersection

No bounds program or intersection program needed

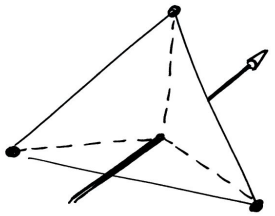
New “attribute program” lets you compute attributes for shading

Attribute Programs

Compute intersection data for shaders

There is a default attribute program that produces U & V

You get barycentrics, then compute your own attributes
shading normals, etc…



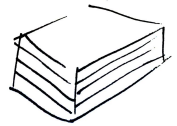
See:

[host] *rtGeometryTrianglesSetAttributeProgram()*
[device] *rtGetPrimitiveIndex()*
[device] *rtGetTriangleBarycentrics()*

Triangle API Example: OptiXMesh.cpp

```
optix::GeometryTriangles geom_tri = ctx->createGeometryTriangles();
geom_tri->setPrimitiveCount( mesh.num_triangles );
geom_tri->setTriangleIndices( buffers.tri_indices, RT_FORMAT_UNSIGNED_INT3 );
geom_tri->setVertices( mesh.num_vertices, buffers.positions, buffers.positions->getFormat() );

geom_tri->setAttributeProgram( createAttributesProgram( ctx ) );

size_t num_matls = optix_materials.size();
geom_tri->setMaterialCount( num_matls );
geom_tri->setMaterialIndices( buffers.mat_indices, 0, sizeof( unsigned ), RT_FORMAT_UNSIGNED_INT );

optix_mesh.geom_instance = ctx->createGeometryInstance();
optix_mesh.geom_instance->setGeometryTriangles( geom_tri );

// Set the materials
optix_mesh.geom_instance->setMaterialCount( num_matls );
for( size_t idx = 0; idx < num_matls; ++idx )
{
    optix_mesh.geom_instance->setMaterial( idx, optix_materials[idx] );
}
```

Stack sizes



New API calls:

rtContextSetMaxTraceDepth()

rtContextSetMaxCallableProgramDepth()

Default is 5. Reduce them when you can. Max. is 31

In RTX Mode, *rtContextSetStackSize()* has no effect

rtTrace from bindless callables

You can now call rtTrace() from inside a bindless callable program

They cost a little bit more than inline code

so balance your usage

Details are covered in the OptiX Programming Guide

“Calling rtTrace from a bindless callable program”

rtTrace flags

Two new optional flags

```
rtTrace( topNode, ray, prd,
    RTvisibilitymask mask=RT_VISIBILITY_ALL,
    RTrayflags flags=RT_RAY_FLAG_NONE )
```

rtTrace: 8 bit visibility mask

Hide/show geometry -- hardware support for skipping sub-trees

Allows for up to 8 visibility sets, replaces selectors & visit programs

See:

rtGroupSetVisibilityMask()
rtGeometryGroupSetVisibilityMask()

To use:

rtTrace(top_object, ray, per_ray_data, mask=0xFF)

rtTrace: ray flags

```
rtTrace( topNode, ray, prd,
    RTvisibilitymask mask=RT_VISIBILITY_ALL,
    RTrayflags flags=RT_RAY_FLAG_NONE )
```

RT_RAY_FLAG_DISABLE_ANYHIT
RT_RAY_FLAG_FORCE_ANYHIT
RT_RAY_FLAG_TERMINATE_ON_FIRST_HIT
RT_RAY_FLAG_DISABLE_CLOSESTHIT
RT_RAY_FLAG_CULL_BACK_FACING_TRIANGLES
RT_RAY_FLAG_CULL_FRONT_FACING_TRIANGLES
RT_RAY_FLAG_CULL_DISABLED_ANYHIT
RT_RAY_FLAG_CULL_ENABLED_ANYHIT

New geometry flags

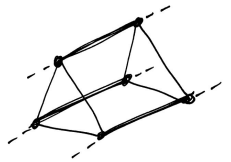
RTgeometryflags

- rtGeometrySetFlags()
- rtGeometryTrianglesSetFlagsPerMaterial()
  - RT_GEOMETRY_FLAG_DISABLE_ANYHIT
  - RT_GEOMETRY_FLAG_NO_SPLITTING

RTinstanceflags

- rtGeometryGroupSetFlags()
  - RT_INSTANCE_FLAG_DISABLE_TRIANGLE_CULLING
  - RT_INSTANCE_FLAG_FLIP_TRIANGLE_FACING
  - RT_INSTANCE_FLAG_DISABLE_ANYHIT
  - RT_INSTANCE_FLAG_FORCE_ANYHIT

Triangle API + Motion Blur



Use *rtGeometryTrianglesSetMotionVertices()*
instead of *rtGeometryTrianglesSetVertices()*

Motion blur currently requires SM traversal
in the motion BVH & parent BVH

You can mix motion BVHs and static BVHs
The static BVHs will use RT Core traversal
Try not to mix in the same Geometry Group

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Performance with RT Cores

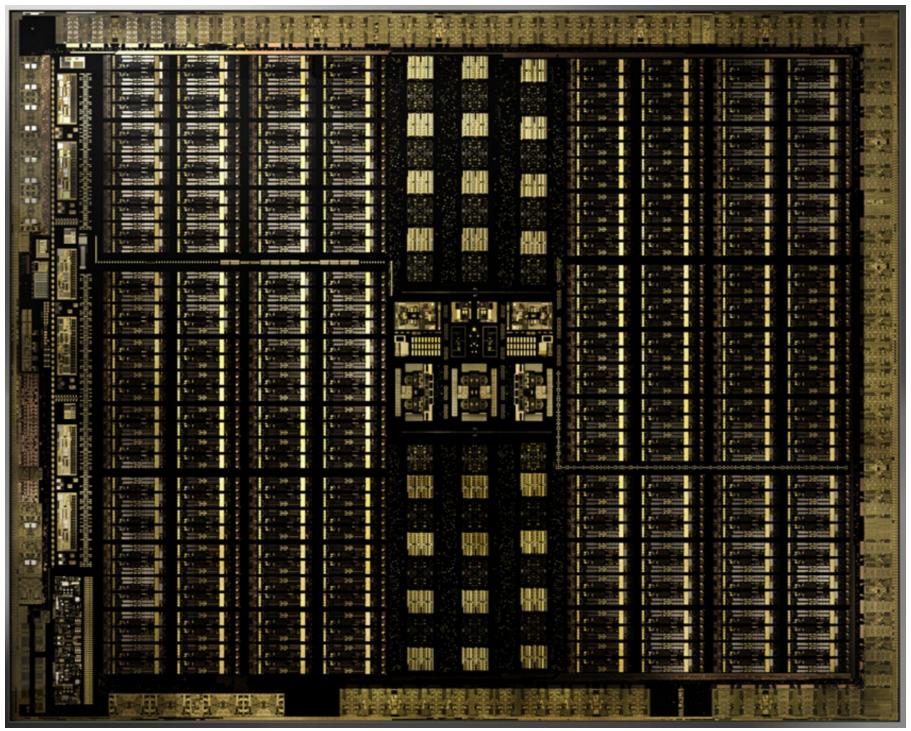
Don’t forget **Amdahl's Law** $S_{\text{latency}}(s) = \frac{1}{(1-p) + \frac{p}{s}}$

For RT Core speedup to be big, you need to be traversal bound

Both obvious and easy to forget

Imagine 50-50 shade vs traverse+intersect

RT Cores



- Workload
- Scene Hierarchy
- Memory Traffic
- Round Trips

Highest Performance Workloads

Coherent rays are better
- Primary rays

Short rays are better
- AO / small t_max

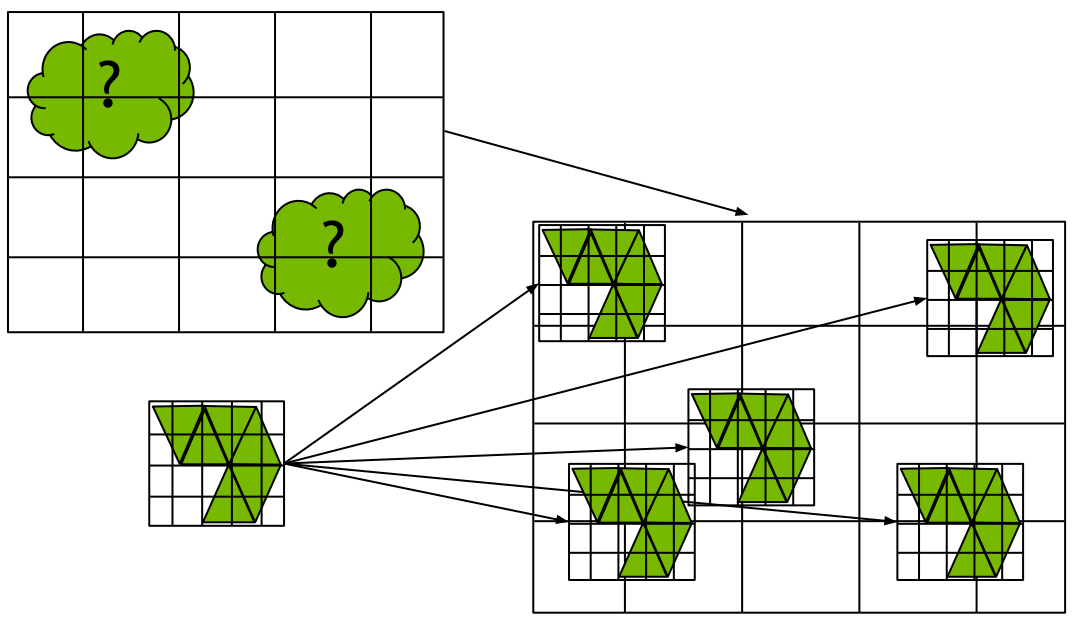
Simple shading
- trivial shading, e.g., diffuse or normal

Big batches

Scene hierarchy

Hardware support for 1 level of instancing

You get 1 for free!



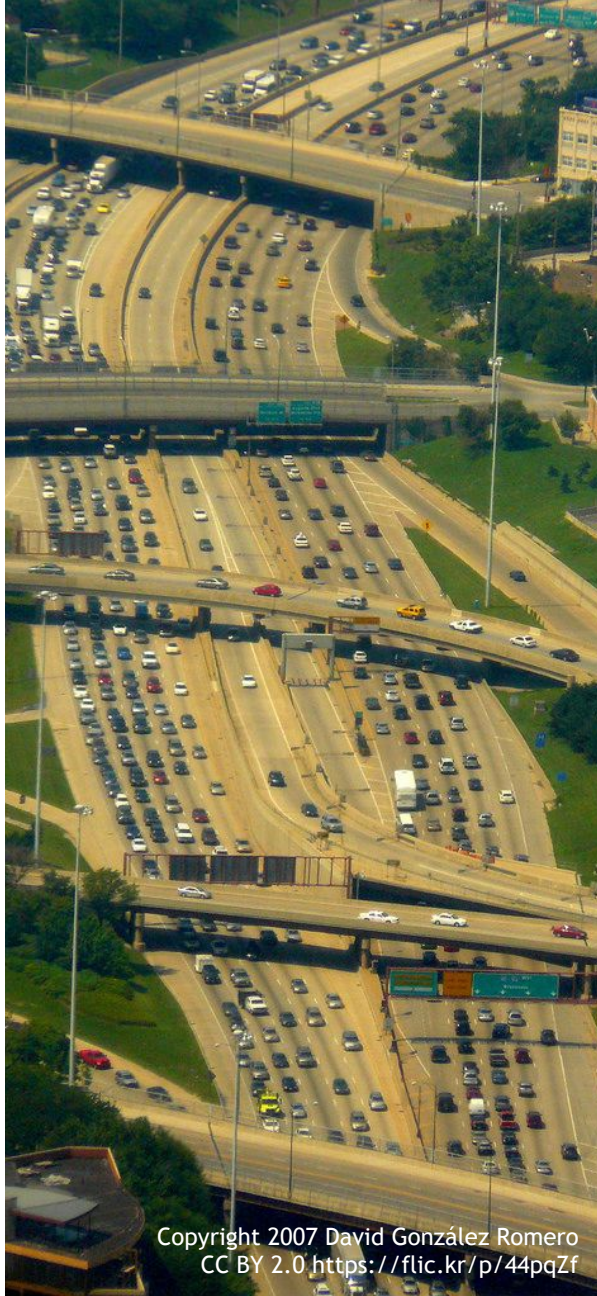
Memory Traffic

RTX 6000 memory bandwidth: 672 GB/sec

672 GB/sec ÷ 10 GRays/sec = 67.2 bytes / ray

Includes traversal

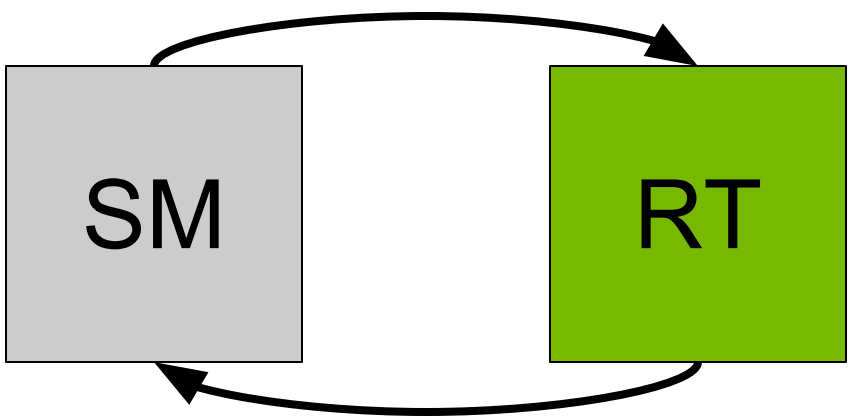
It’s easy to exceed this budget in shaders



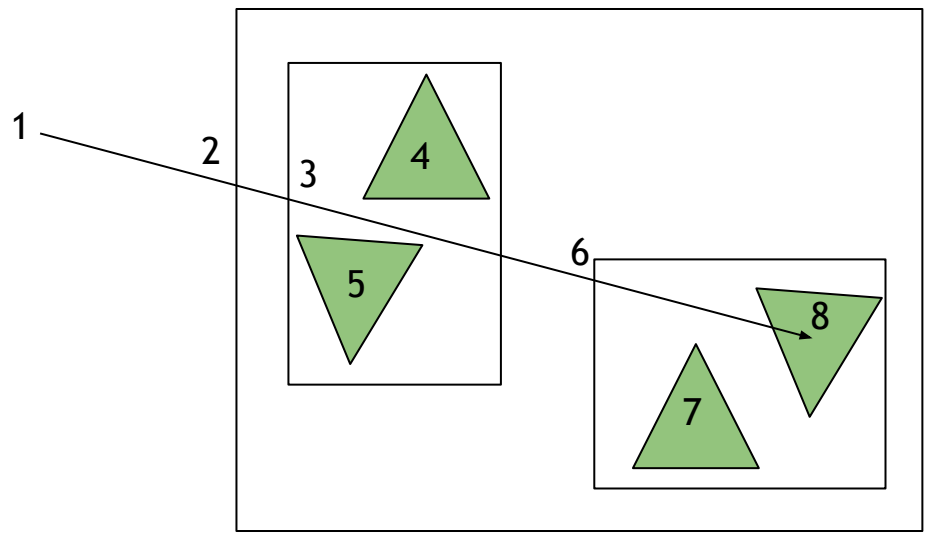
SM + RT Core round-trips

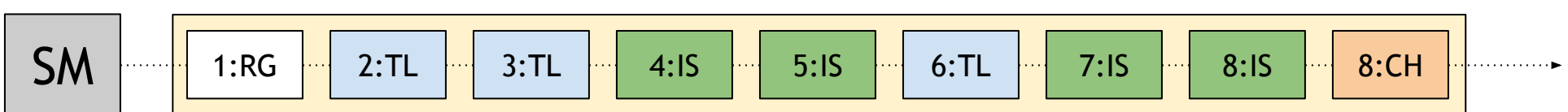
Some features run CUDA code mid-traversal

Let’s build a mental model of how the SMs & RT Cores interact



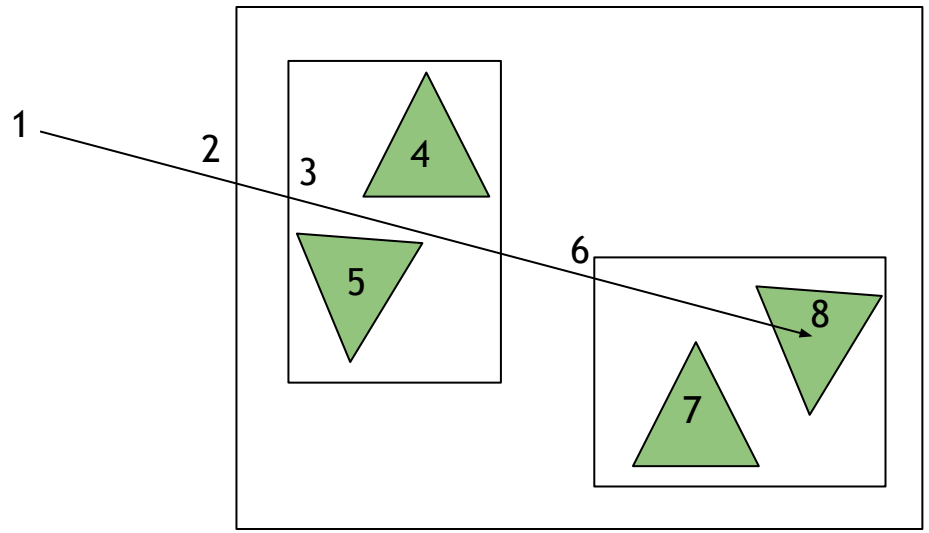
OptiX 5 traversal

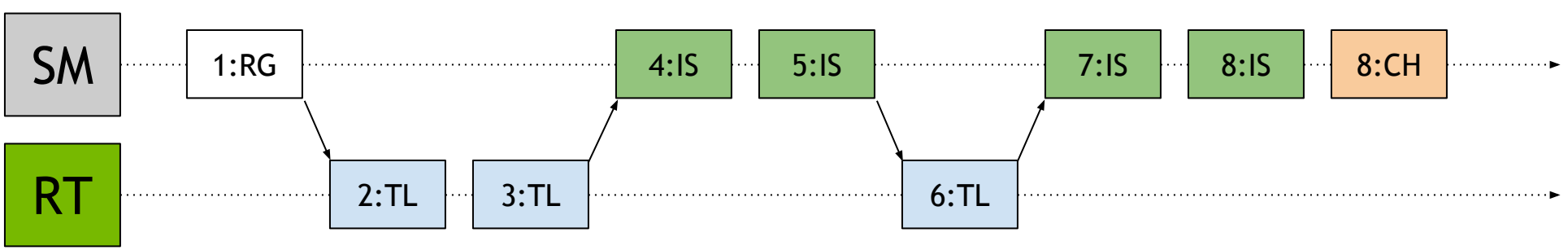




“Mega” Kernel

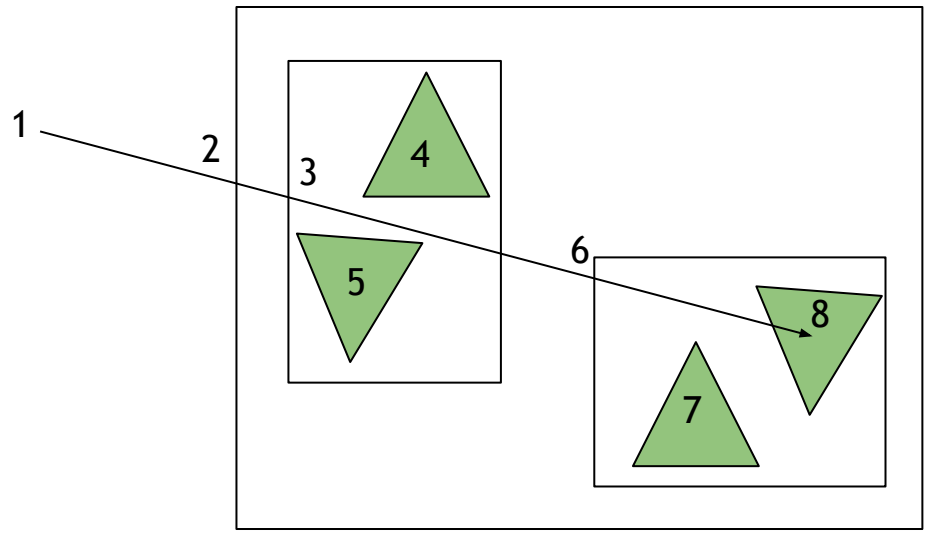
RTX traversal: custom primitives

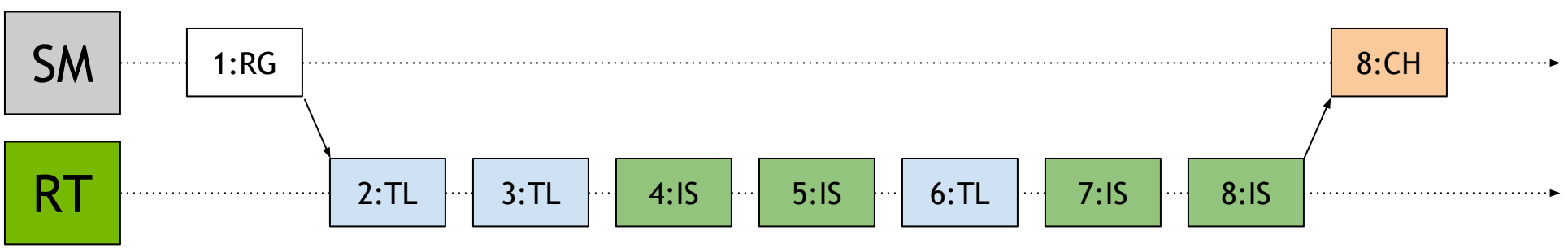




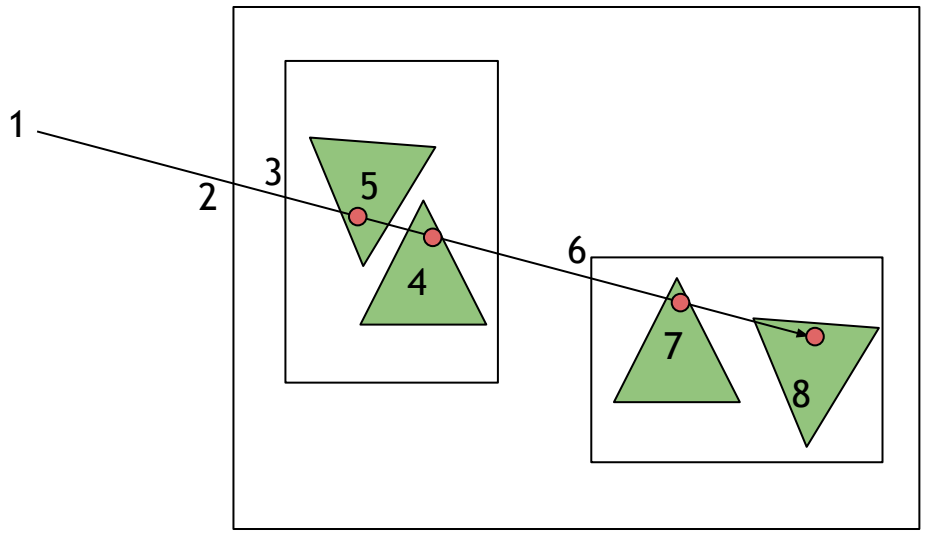
*NB: conceptual model of execution, not timing.

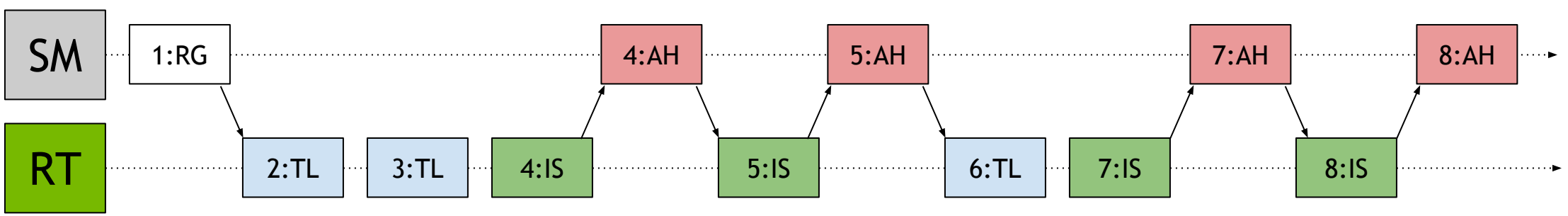
RTX traversal: hardware triangles



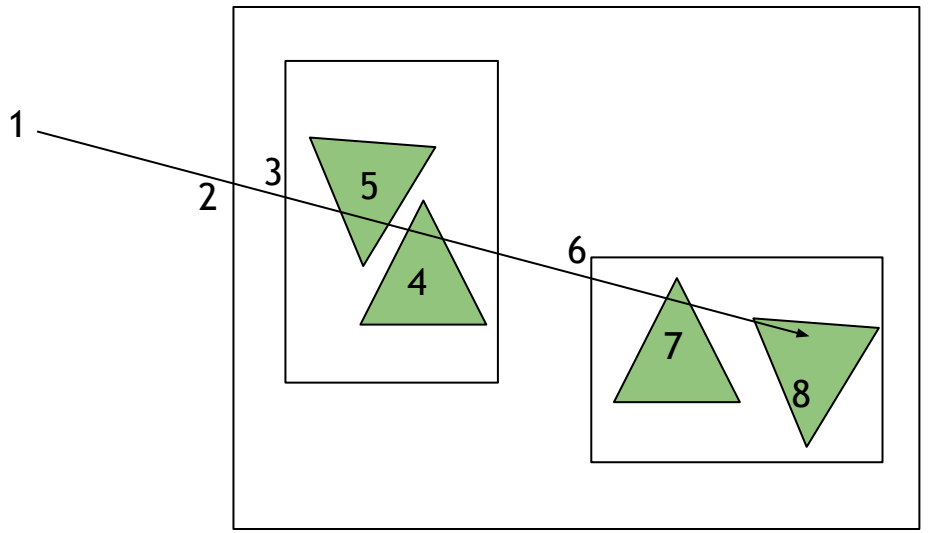


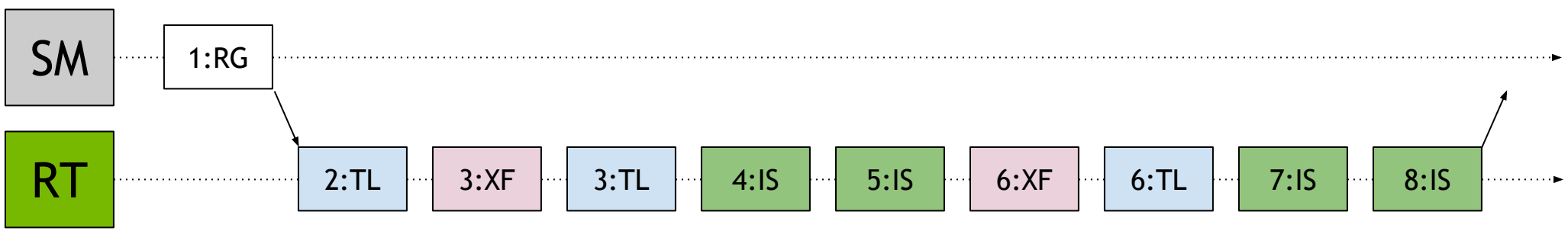
RTX traversal: any-hit



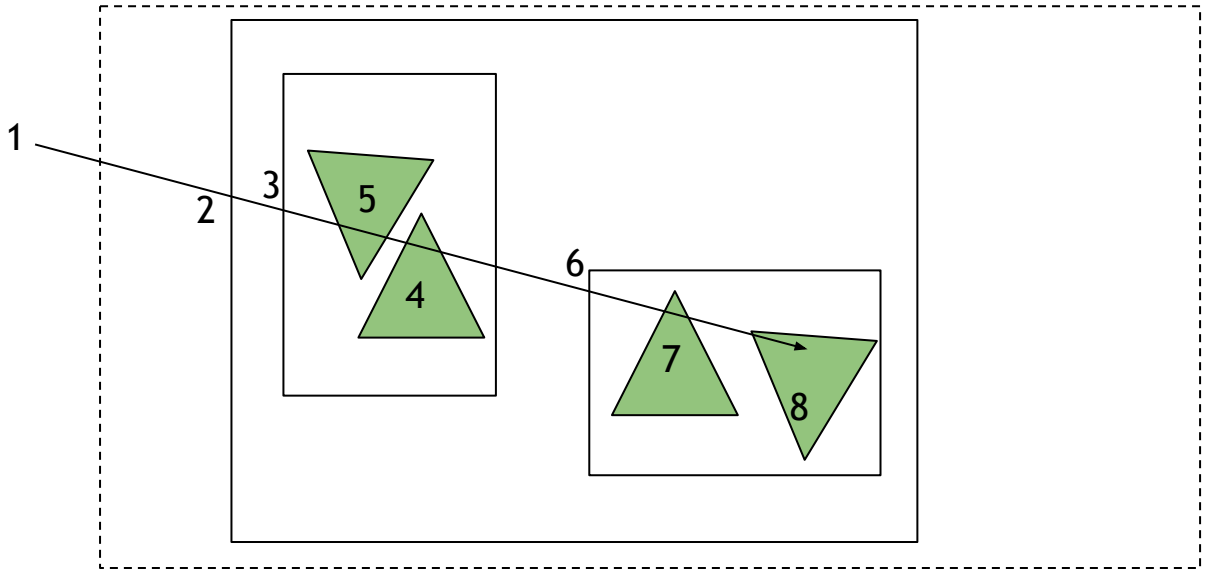


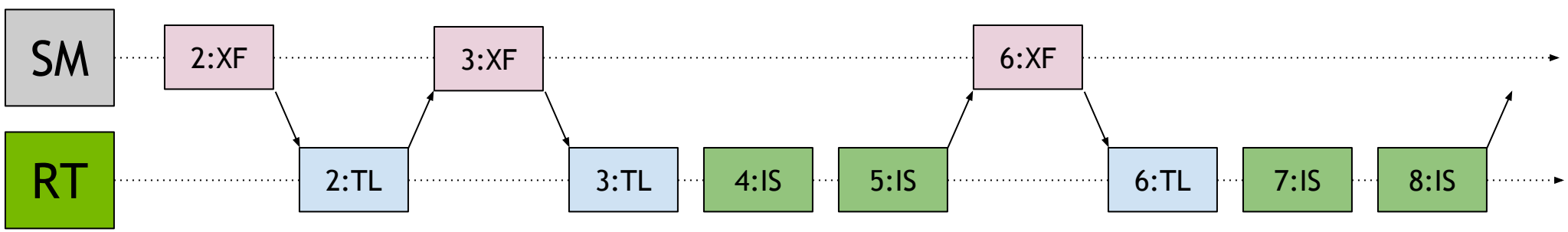
RTX traversal: 1 level instancing (2 lvl scene)



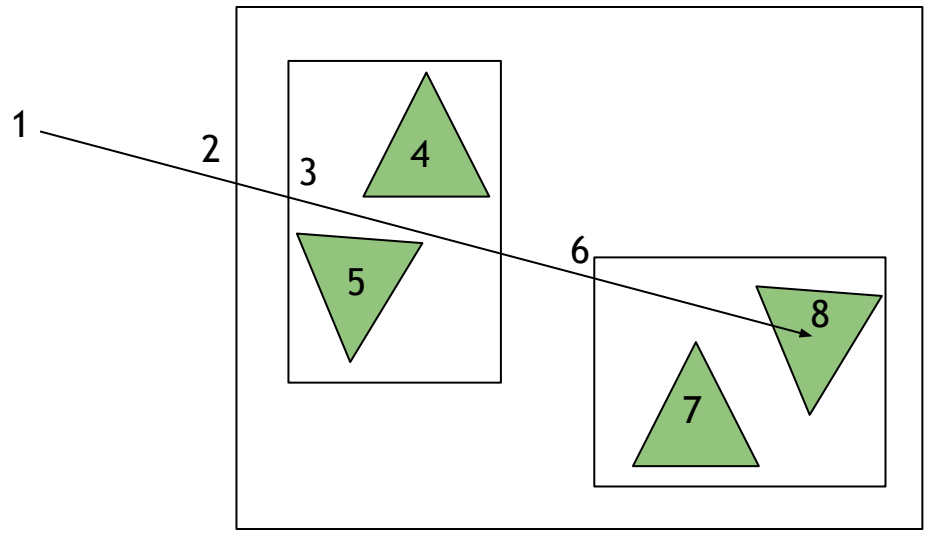


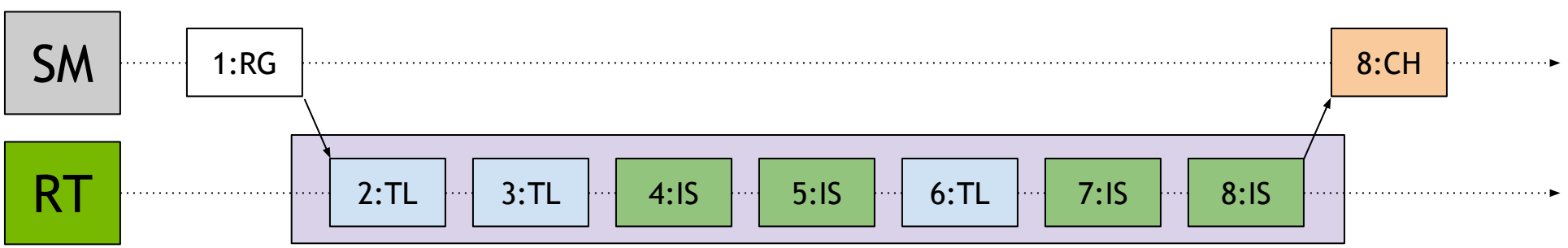
RTX traversal: 2 level instancing (3 lvl scene)





RTX traversal: the ideal





The goal: uninterrupted traversal on RT core

RTX Traversal: summary

Triangle API + RTX => 2x-10x faster -- first step to gigarays

Things that can impact RT Core traversal:

- intersection program
- any-hit program
- 2 or more levels of instancing
- motion blur

Shadow rays tend to be faster. (re-evaluate balance of shadow rays)

Any-hit & early termination

Disable any-hit if you don’t need it!

Use one of the *_DISABLE_ANYHIT instance or ray flags

For shadow-like rays and built-in triangles, we now recommend

closest-hit & rtTrace(,,,, RT_RAY_FLAG_TERMINATE_ON_FIRST_HIT)

For shadow-like rays and custom intersection

continue to use any-hit & call rtTerminateRay()

Continuations: callables & rtTrace

The compiler wraps callable program & rtTrace invocations in *continuations*, which take longer to compile, and consume registers.

Seize the opportunity if you see ways to trim

Calls very early or very late are better than right in the middle
    goal: less live state, think about tail-recursion

Achieving High Performance in OptiX

Peak RT Core throughput depends on your workload

Be judicious with:

- traversal depth
- complex shading
- use of any_hit for cut-outs
- motion blur

NB: # of polygons is less relevant!

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Common pitfalls in OptiX

Crash?

Stack overrun
- Increase stack size

Indexing user data out of bounds
- Enable exceptions & add bounds checks*

Common pitfalls in OptiX

Slow start?

shader compilation
- avoid dynamic program selection

large number of instances / scene graph
- merge meshes, flatten scene

Common pitfalls in OptiX

Slow trace?

deep instancing: flatten / merge / bake, when you can
large ray payload: trim payload
large any-hit program: trim / remove any-hit
    use closest-hit w/ flags
large number of variable updates:
    use a buffer instead
shader re-compilation
shader complexity
move callable programs to inline code*
memory traffic & payload size

OptiX debugging tips

Turn on exceptions	*rtContextSetExceptionEnabled()*
Add an exception program	*rtContextSetExceptionProgram()*
Print exception details	*rtPrintExceptionDetails()*
Turn on usage report	*rtContextSetUsageReportCallback()*

OptiX 6 Known Issues

- Motion blur is not supported with no-accel enabled in RTX Mode
- Selectors not implemented in RTX Mode, use visibility masks instead.
- Nsight can not (yet) profile OptiX in RTX Mode. Coming soon.

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OptiX Overview

New features in OptiX 6

OptiX Performance tips

OptiX Debugging tips

General OptiX improvements

Summary / Q&A

General OptiX improvements

Behind the scenes, OptiX 6 improved:

- Separate & parallel shader compilation
- BVH build times
- BVH memory
- Denoiser perf

RTX Acceleration Structures

They are faster, ~80Mtris/sec build

Re-fit is usually >= 10x faster than build

BVH format is set automatically when using RTX Mode

BVH compaction: may save 1.5x-2x on memory

in return for ~+10% build time

To disable: rtAccelerationSetProperty(accel, "compact", "0");

Multi-GPU

OptiX 6 adds RTX support for multiple GPUs

Geometry & BVH replicate
Textures replicate until memory gets tight,
=> N GPUs are usually ~N x faster, but usually not N x memory

Simplified load balancing
No mixing Turing and pre-Turing devices
For best performance: Use NVLINK & homogeneous GPUs
- Slow GPUs bottleneck fast GPUs
- Heterogeneous GPUs can trigger multiple compiles.

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Best practices in OptiX

When possible…

- Use built-in triangles, instead of AABB & intersect programs
- Flatten your scene to zero or one level of instancing
- Share bottom level structures / merge meshes to a single bottom level structure
- Use BVH refit instead of rebuilding
- Distribute accel refits over multiple frames / update lazily, only when needed
- Minimize payload size, attribute size, and trace recursion depth
- Use closest-hit instead of any-hit with built-in triangles
- Do use any-hit for cut-outs. (NB any-hit is out of order, may not be closest)
- Pay attention to dependent memory access when reading vertex & material data.

Summary

- RT Core support

- For fast trace, “Feed The RT Cores”
  - Triangle api, one level of instancing
  - Use sparingly: any-hit, deep hierarchy, motion blur

- New API: attribute programs, stack sizes, callable programs
- Improvements to: BVH, compilation, multi-GPU, denoiser
- OptiX runtime in the driver

Questions?