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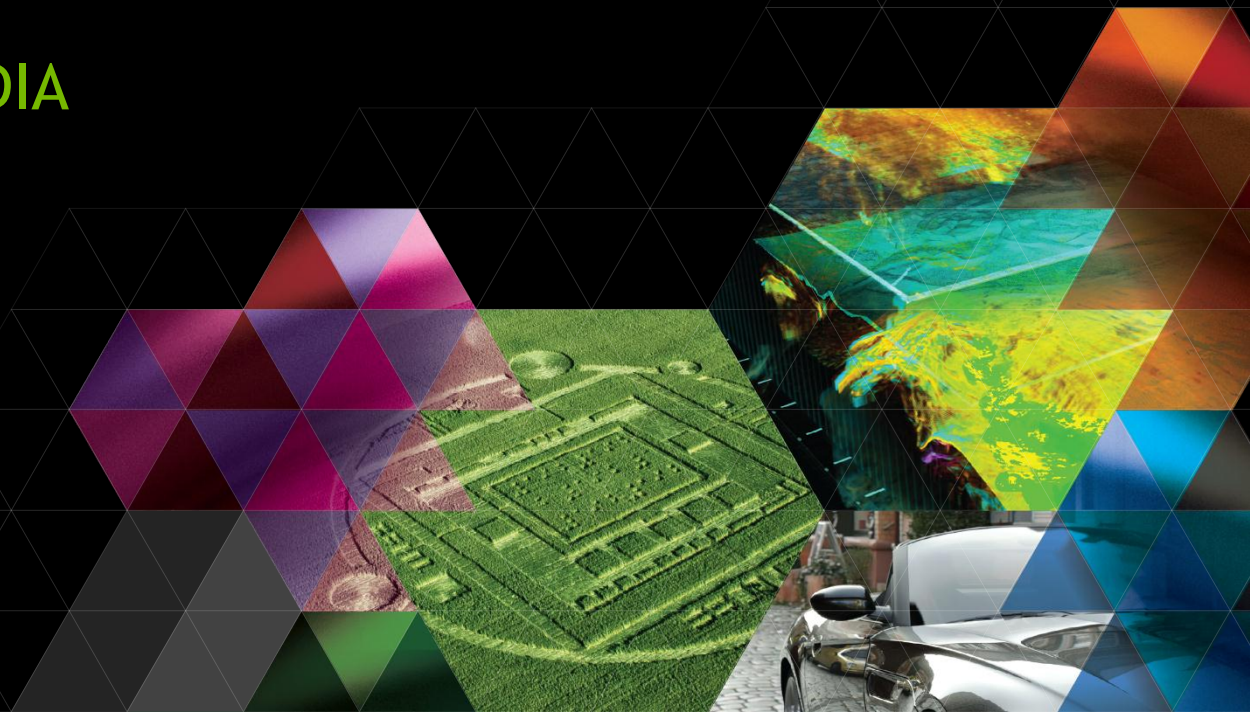
NVIDIA

CRASH, BOOM, BANG!

LEVERAGING GAME PHYSICS AND GRAPHICS APIS FOR SCIENTIFIC COMPUTING

Peter Messmer, NVIDIA



3 WAYS TO ACCELERATE APPLICATIONS

Applications

Libraries	OpenACC Directives	Programming Languages
"Drop-in" Acceleration	Easily Accelerate Applications	Maximum Flexibility

3 WAYS TO ACCELERATE APPLICATIONS

Applications

Middleware

Libraries

OpenACC Directives

Programming Languages

"Drop-in" Acceleration

Easily Accelerate Applications

Maximum Flexibility

MOTIVATION

- Similar algorithms in HPC and Entertainment/Media
- Large ecosystem of software developed for E/M Market

⇒What about leveraging E/M software for HPC applications?

MOTIVATION/OUTLINE

- Similar algorithms in HPC and Entertainment/Media
- Large ecosystem of software developed for E/M Market

⇒What about leveraging E/M software for HPC applications?

Step 1: Understand what's going on in E/M
e.g. PhysX, OptiX

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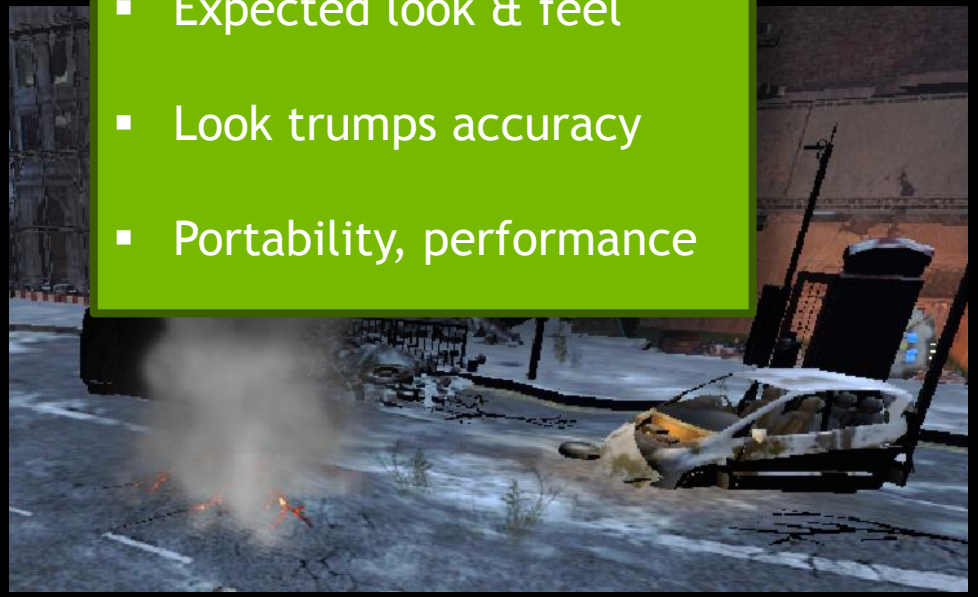
PHYSX

A treasure chest, not only for games

- Fixed, short time budget
- Expected look & feel
- Look trumps accuracy
- Portability, performance



- Limited by scientist's patience
- Predictive capabilities
- Well defined accuracy
- Performance portability

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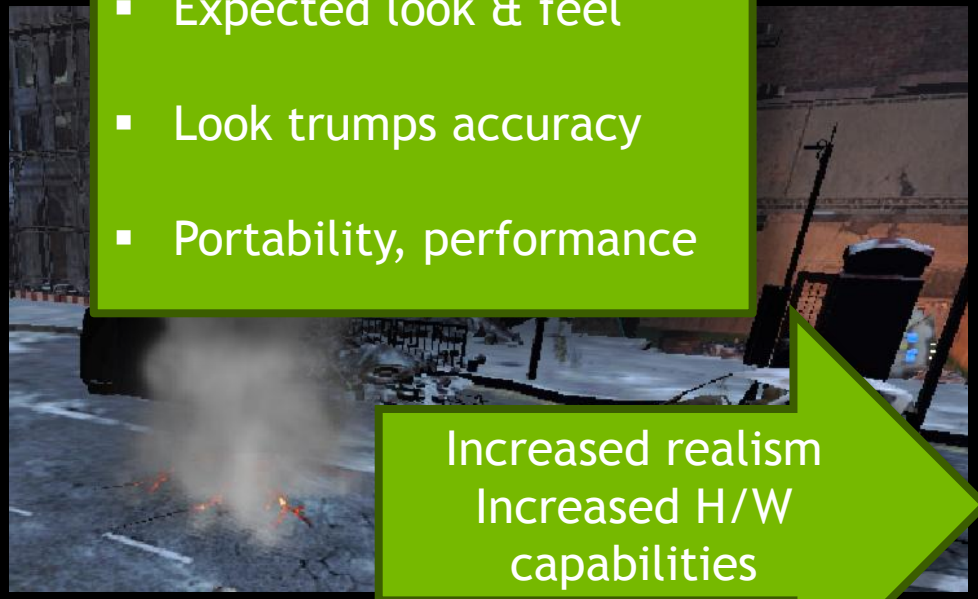

Increased realism
Increased H/W capabilities

- Limited by scientist's patience
- Predictive capabilities
- Well defined accuracy
- Performance portability

Approximate methods
Increased platform spectrum

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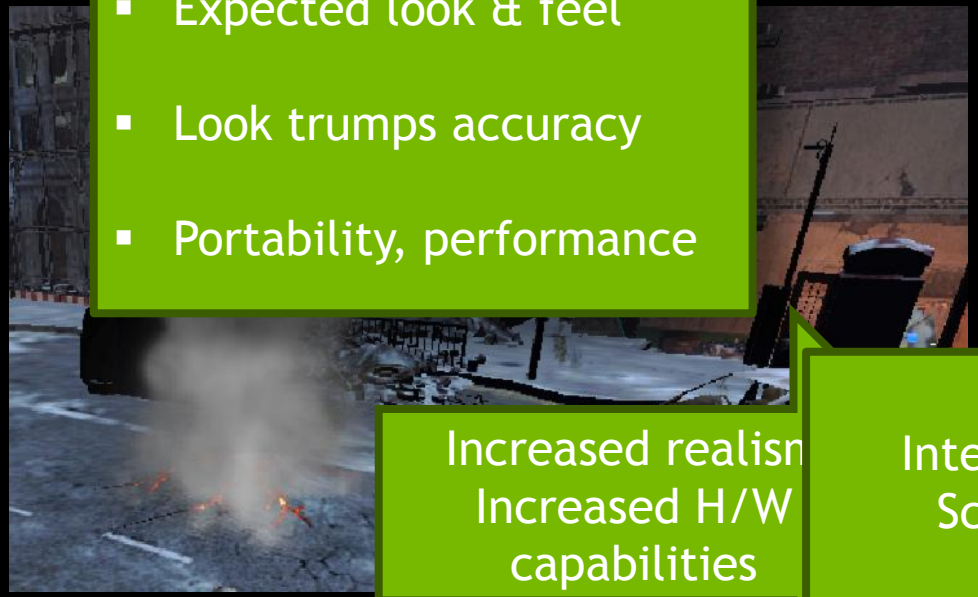


Increased realism
Increased H/W capabilities

Interactive Science

pproximate methods
Increased platform spectrum

- Limited by scientist's patience
- Predictive capabilities
- Well defined accuracy
- Performance portability

PHYSX – NVIDIA'S GAME PHYSICS ENGINE

- Multi-Platform Game Physics Solution
- Collision detection (discrete or continuous)
- Rigid body dynamics
- Ray-Casting, shape sweeps
- Particles, Fluids
- Vehicle & character controllers

PhysX® by NVIDIA

- Available through registered developer program

https://developer.nvidia.com/technologies/physx

PHYSX – SOME COOL FEATURES

- Rigid Body Dynamics
- Particles
- Scene queries

- Cloth
- Vehicles, characters
- …

PHYSX – SOME COOL FEATURES

- Rigid Body Dynamics → Dynamics of shaped objects with collisions, constraints
- Particles → Point particles in complex environment
- Scene queries → Inspection of complex geometries
- Cloth
- Vehicles, characters
- … → Constrained 1D particle systems; Complex objects with internal specifications

PHYSX – SOME COOL FEATURES

- Rigid Body Dynamics
- Particles
- Scene queries
- Cloth
- Vehicles, characters
- …

Dynamics of shaped objects with collisions, constraints

Point particles in complex environment

Inspection of complex geometries

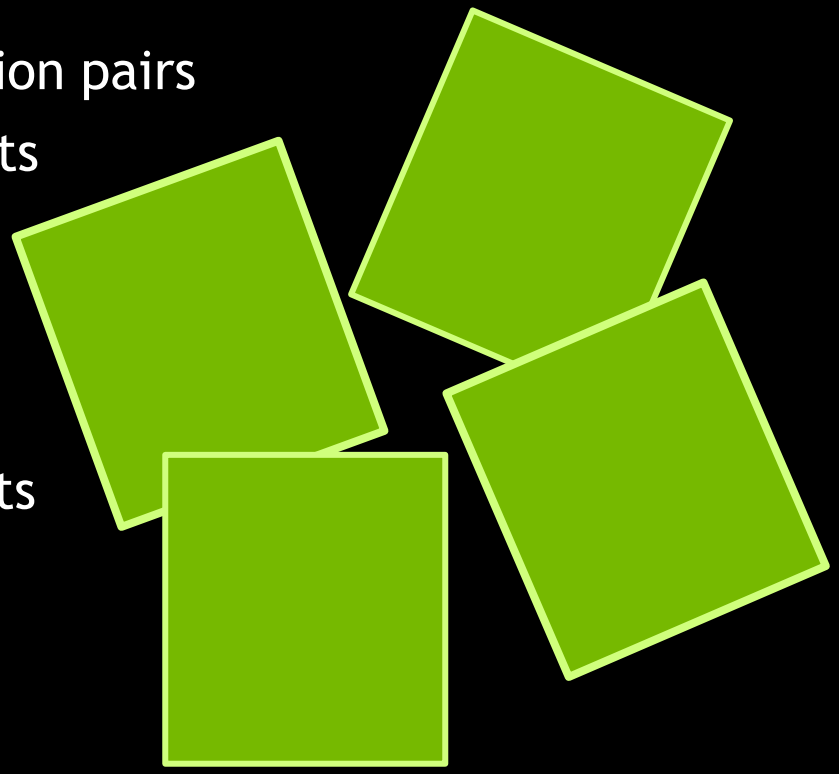
Constrained 1D particle systems

Complex objects with internal specifications

- Discrete Element Method, agent based simulations
- Monte Carlo Methods, particle methods
- Particle-mesh interaction, CAD-mesh interactions

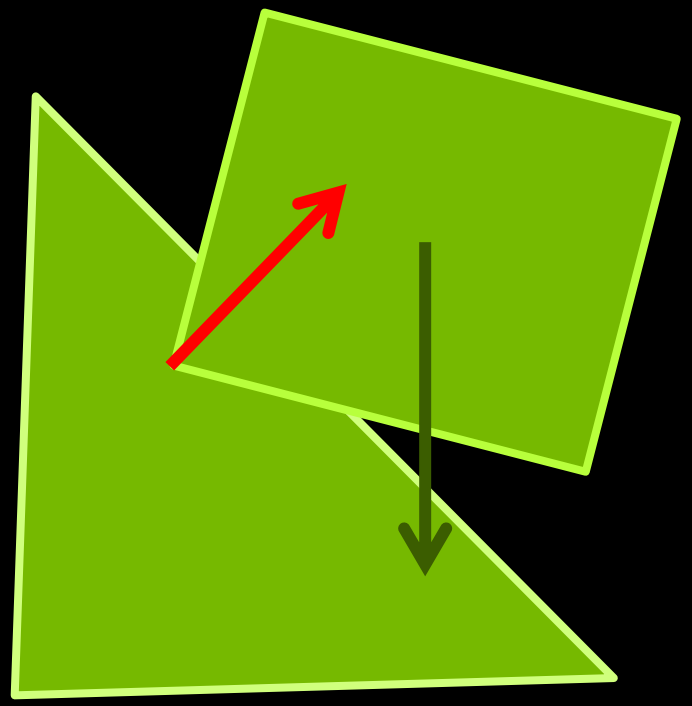
RIGID BODY DYNAMICS COMPONENTS

- Collision detection
  - Broad Phase => Form potential collision pairs
  - Narrow Phase => Identify contact points
- Constraint resolution
  - Compute impulses to resolve contacts
  - Compute impulses to satisfy constraints
    - contacts, joints, friction, ..



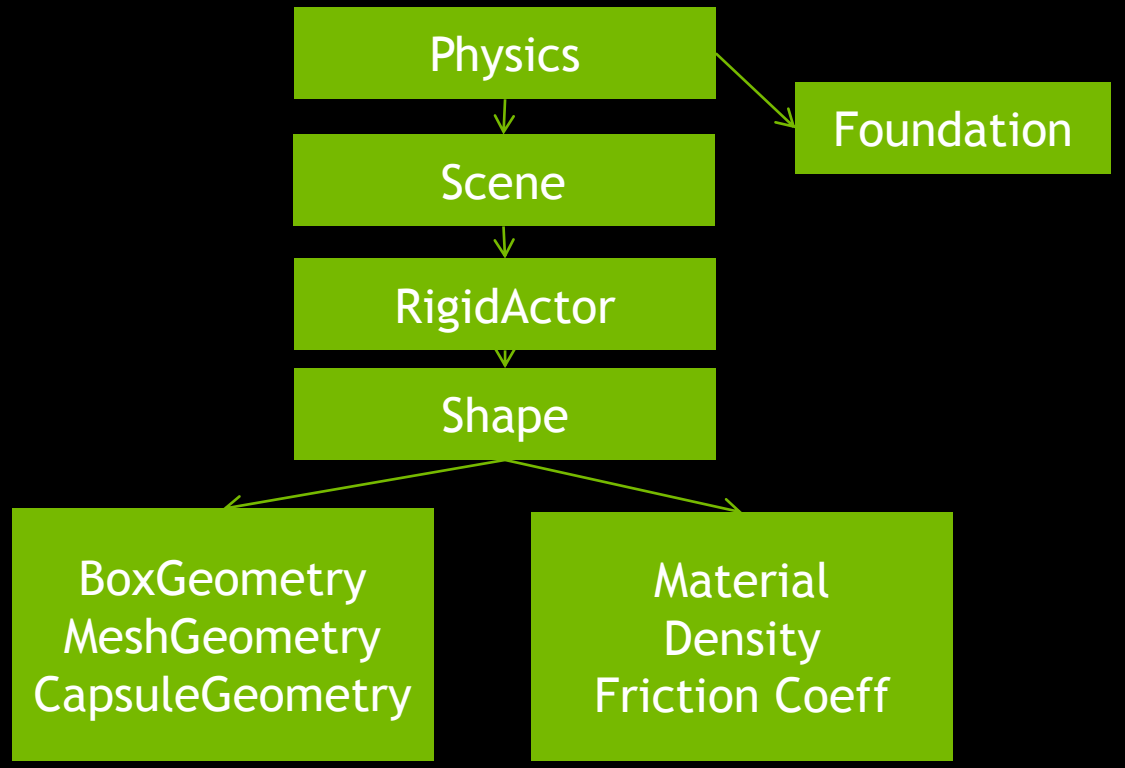
CONSTRAINT RESOLUTION

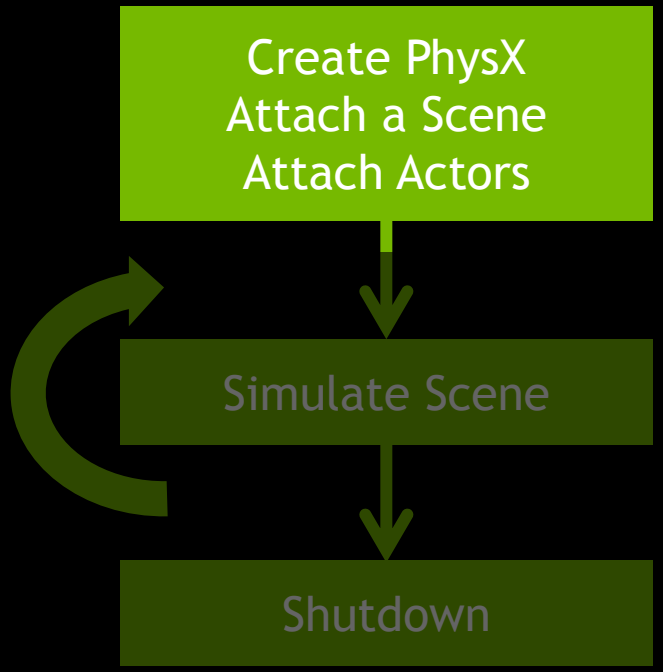
- Linear Complementarity Problem
  - Impulses cannot be negative
- Solve for a single body pair
- Multiple constraint resolution
  - Iterate over all constraint pairs



A BASIC PHYSX SIMULATION

```
PxFoundation f = PxCreateFoundation(PX_PHYSICS_VERSION,..);
PxPhysics p = PxCreatePhysics(.., *f, .. );
PxScene s = p->createScene(..);
```





A BASIC PHYSX SIMULATION

- Create two rigid bodies

```
PxRigidDynamic* body1 = PxCreateDynamic(p,.., g, m,.);
PxRigidDynamic* body2 = PxCreateDynamic(p,.., g, m,.);
```

- Add bodies to scene

```
s ->addActor(body1);
s ->addActor(body2);
```

- Create joint between bodies

```
PxJoint* joint = PxDistanceCreateJoint(p, body1, .., body2,..)
```

SUMMARY

- Wealth of algorithms relevant to HPC applications
  - Possible uses: discrete element simulations, kinetic simulation, optimization problems, ..
- Portable performance
- Core algorithms GPU accelerated
- Free (see license for details)

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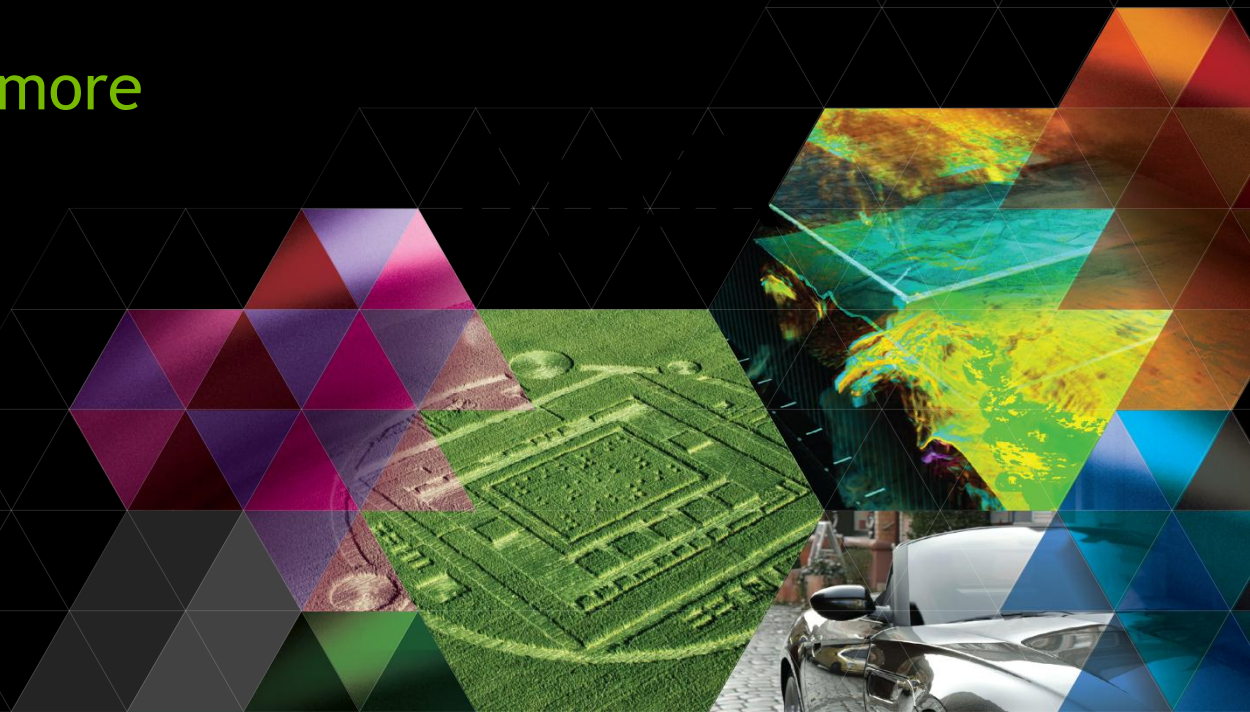
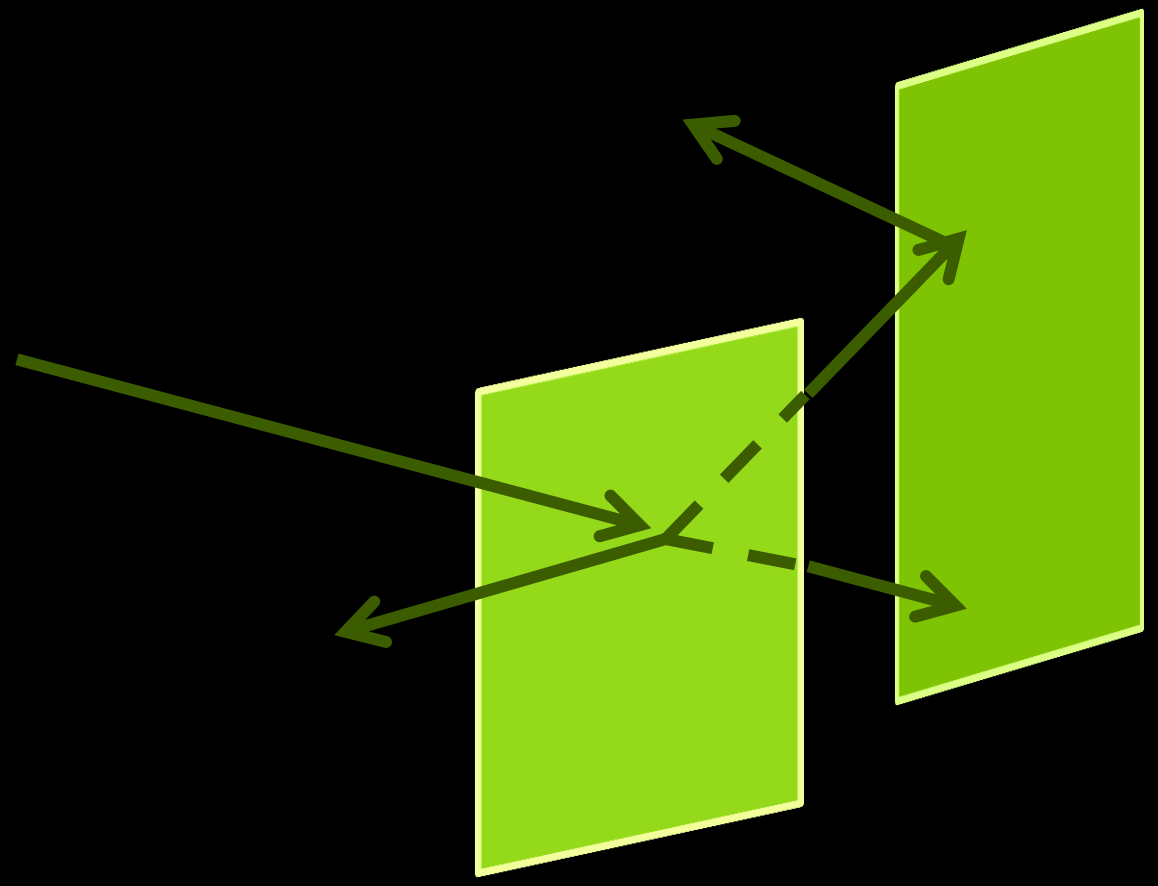
OPTIX

Pretty pictures and more



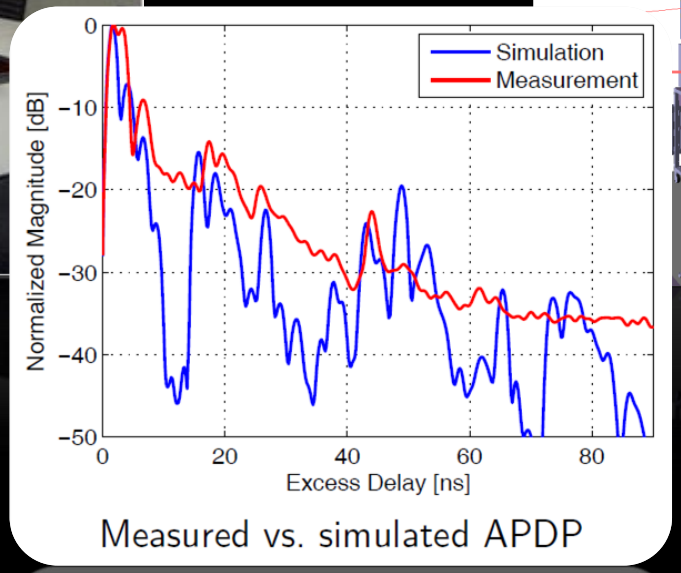
IF YOUR APPLICATION LOOKS LIKE THIS..



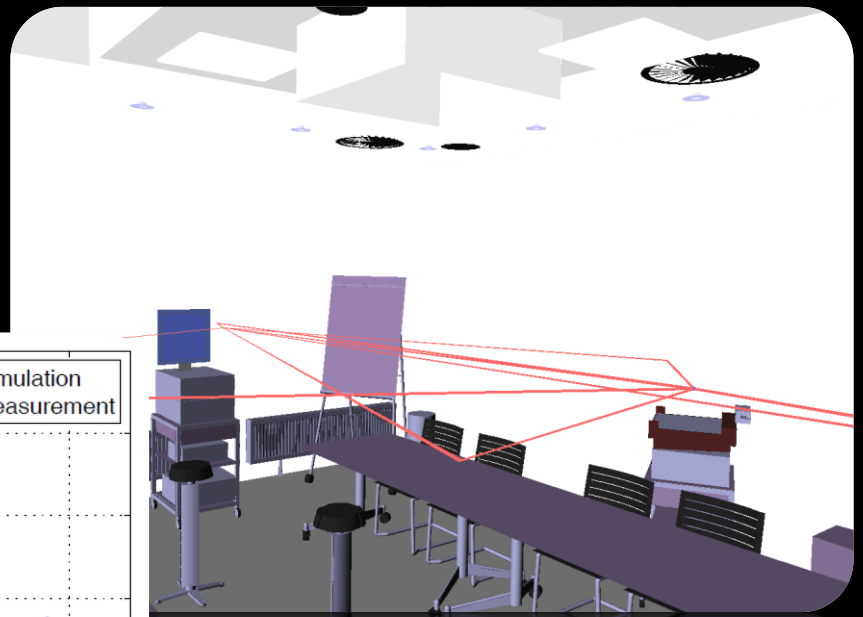
.. YOU MIGHT BE INTERESTED IN OPTIX

- Ray-tracing framework
  - Build your own RT application
- Generic Ray-Geometry interaction
  - Rays with arbitrary payloads
- Multi-GPU-support

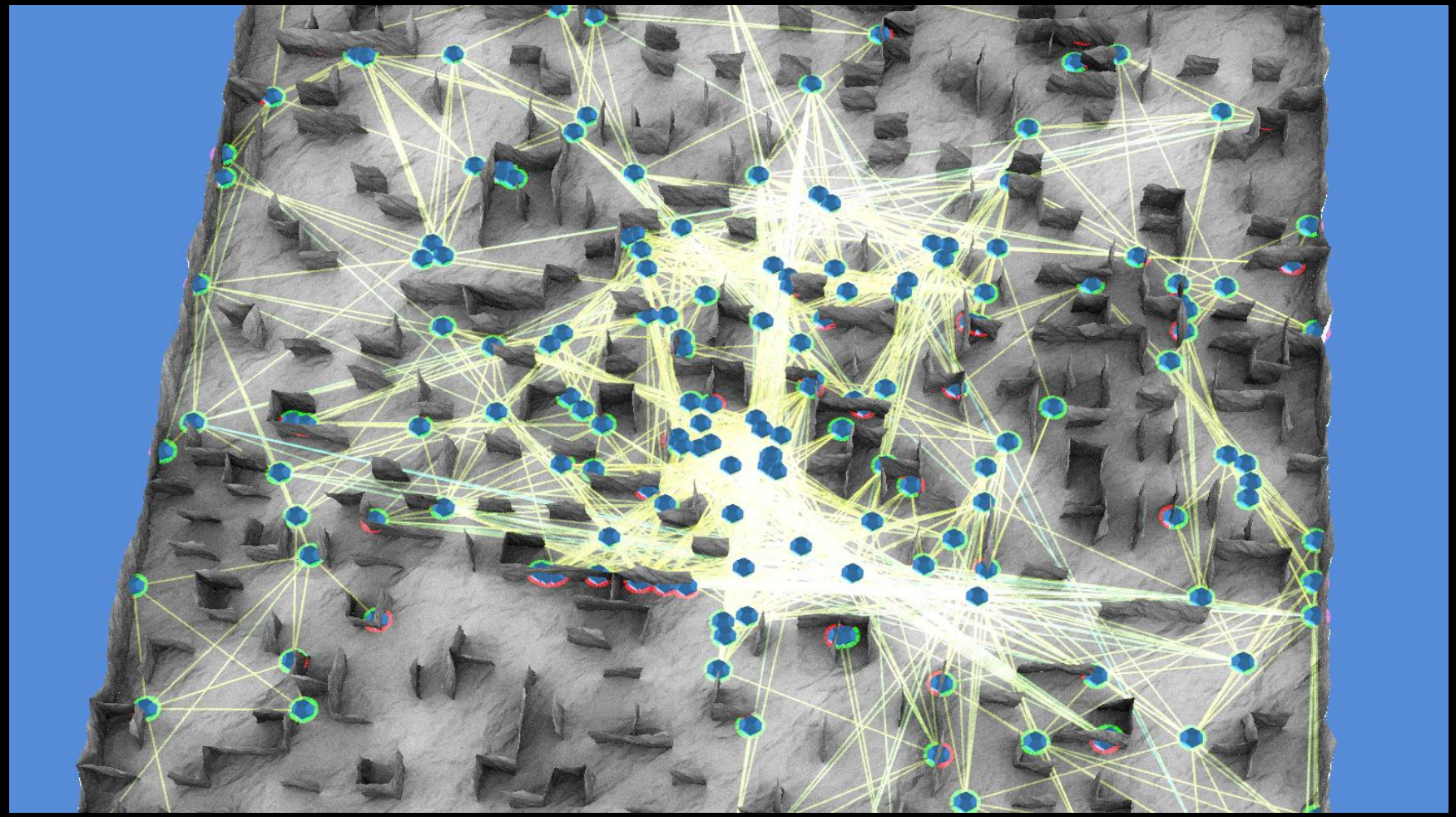
60GHZ ELECTROMAGNETIC PROPAGATION



Measured vs. simulated APDP



COLLISION DETECTION / PATH PLANNING



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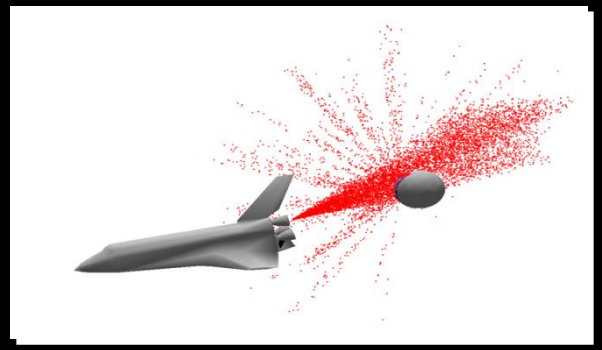
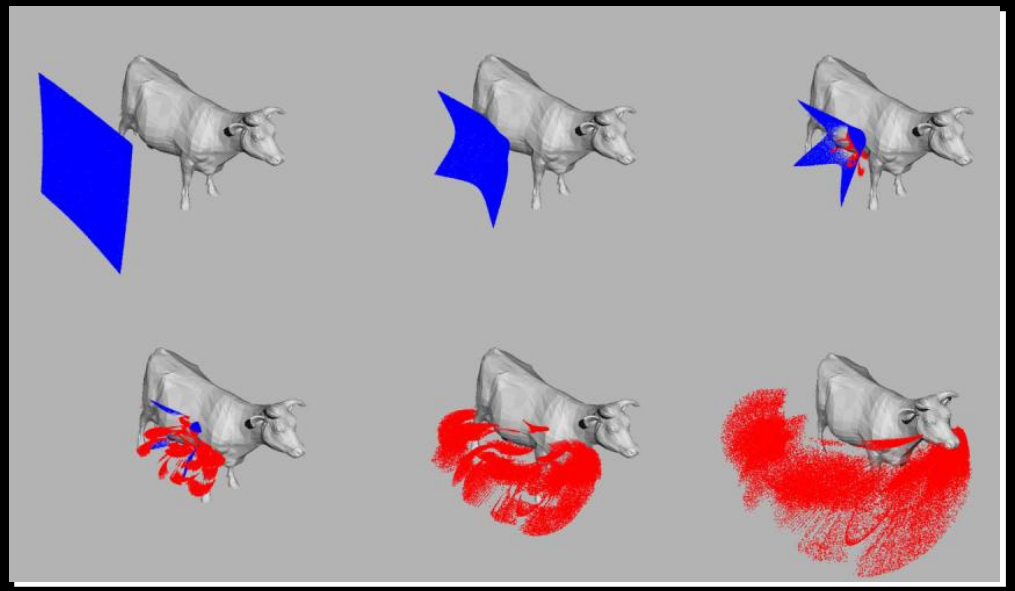
PARTICLE TRACKING WITH OPTIX

- GPU accelerated particle-geometry interaction
- Ultimate use: Simulation of spacecraft engines
- Particle-geometry interaction, change in species, complex dynamics

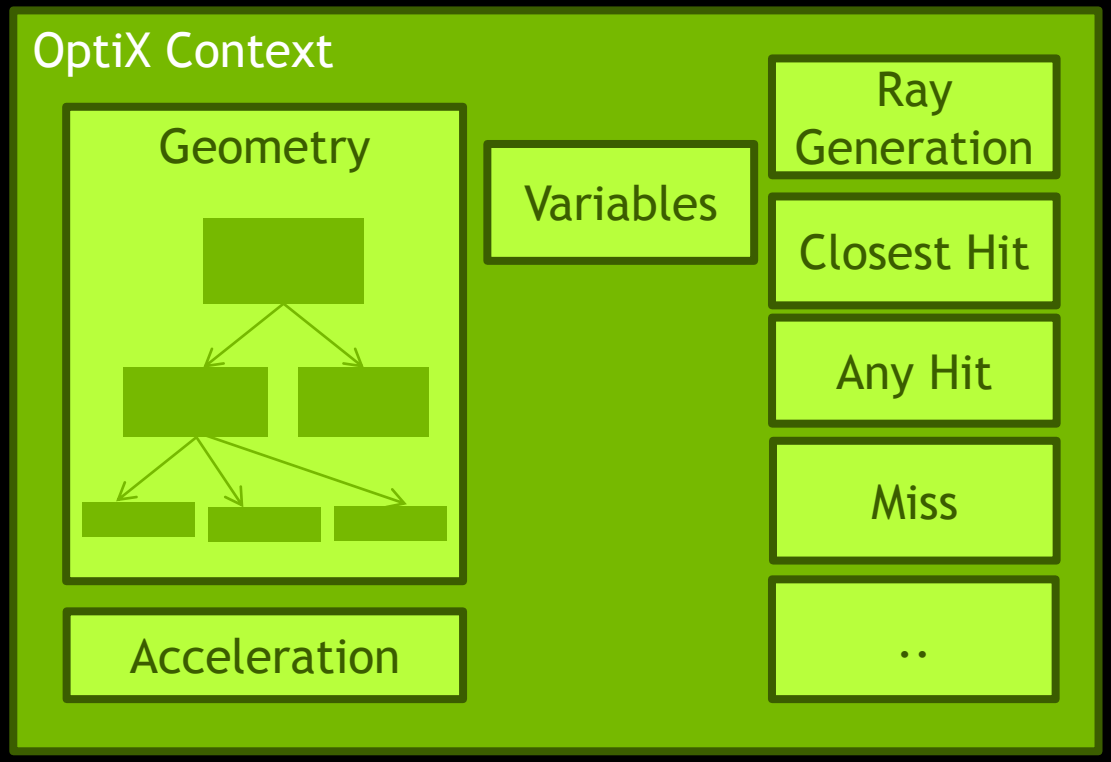


TECH-X
SIMULATIONS EMPOWERING YOUR INNOVATIONS

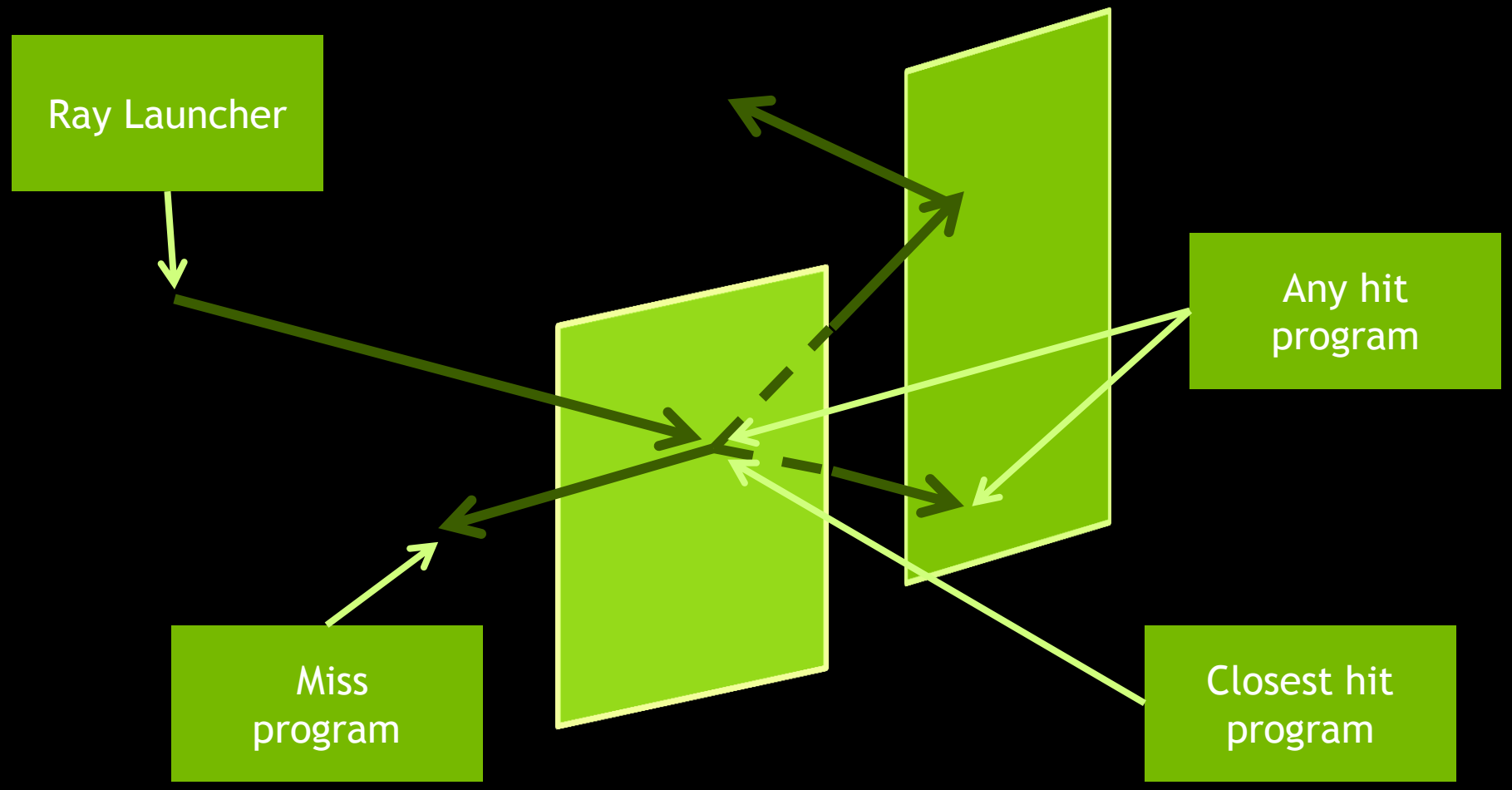


OPTIX PROGRAMMING MODEL

- Context: One instance of the RT engine
  - Host interface
- Geometries
- Acceleration structures
- Programs: Specific tasks executed on GPU



DIFFERENT PROGRAMS GET INVOKED FOR DIFFERENT RAYS



HOW DO OPTIX PROGRAMS LOOK LIKE?

```
RT_PROGRAM void miss()
{
  prd_radiance.result = bg_color;
}
```

The miss program

HOW DO OPTIX PROGRAMS LOOK LIKE?

```
struct PerRayData_radiance
{
 float3 result;
};

rtDeclareVariable(PerRayData_radiance, prd_radiance, rtPayload, );
rtDeclareVariable(float3, bg_color, , );

RT_PROGRAM void miss()
{
  prd_radiance.result = bg_color;
}
```

Ray's payload

Define the ray's payload with semantic variable

The miss program

RAY LAUNCHER: PROGRAM EXECUTED FOR EACH RAY

```
RT_PROGRAM void pinhole_camera()
{
  size_t2 screen = output_buffer.size();
  float2 d = make_float2(rtLaunchIndex) / make_float2(screen) * 2.f - 1.f;
  float3 ray_origin = eye;
  float3 ray_direction = normalize(d.x*U + d.y*V + W);

  optix::Ray ray(ray_origin, ray_direction, radiance_ray_type, scene_eps);

  PerRayData_radiance prd;
  prd.importance = 1.f;
  prd.depth = 0;

   rtTrace(top_object, ray, prd);

  output_buffer[rtLaunchIndex] = make_color( prd.result );
}
```

Determine per ray direction

Create the ray

Launch the ray

Store result into result buffer

RAY LAUNCHER: PROGRAM EXECUTED FOR EACH RAY

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RT_PROGRAM void pinhole_camera()
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  opt                                                  e_ray_type, scene_eps);

  Per
  prd
  prd

   rtTrace(top_object, ray, prd);

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}
```

Determine per ray direction

Create the ray

Not limited to planar launcher!

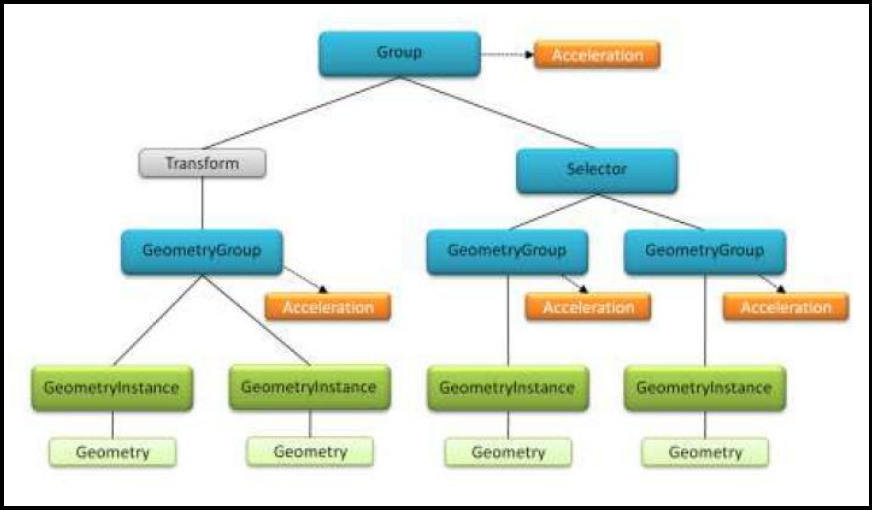
Launch the ray

Store result into result buffer

GEOMETRY

- Tree structure of geometry instances
- Association geometry-programs
  - Different programs for different parts of the geometry possible

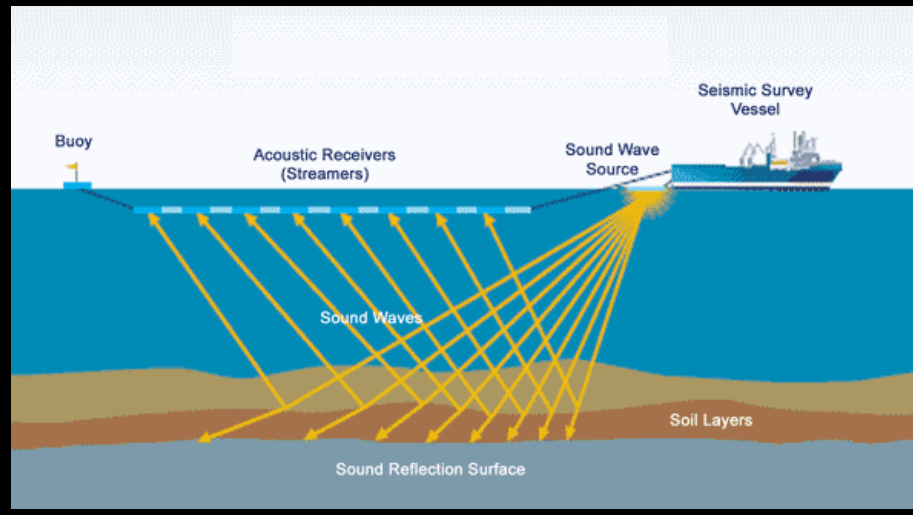
- Acceleration structures
  - Enable quick scene queries
  - Requires BoundingBox program



SOMETIMES NOT ALL BELLS AND WHISTLES NEEDED

- Seismic wave propagation code

- Challenge: Find unstructured mesh cell corresponding to a surface position



=> Scientists don’t want to spend their time writing geometry query codes

OPTIX PRIME: LOW-LEVEL RAY TRACING API

- OptiX simplifies implementation of RT apps
  - Manages memory, data transfers etc
- Sometimes all you need are visibilities
  - E.g. just need visibility of triangulated geometries
- OptiX Prime: Low-Level Tracing API
  - User provides geometry, rays, OptiX returns hits

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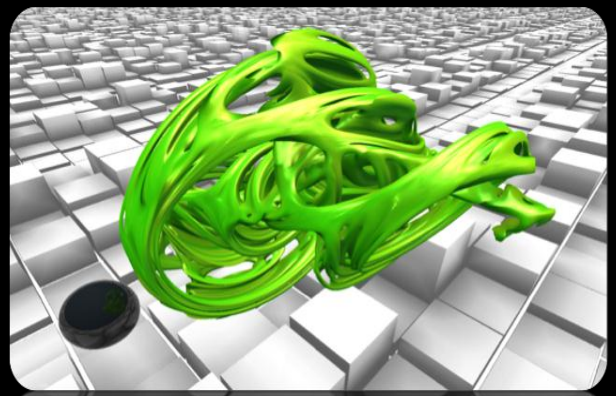
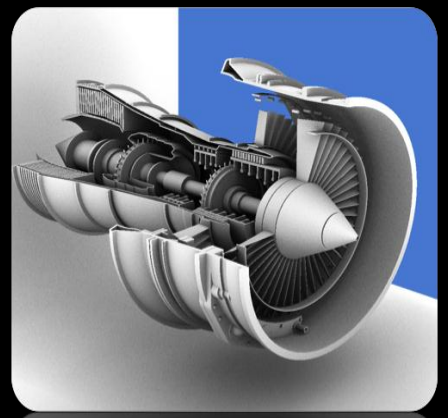
OPTIX SDK

- Available for free: Windows, Linux, Mac
- http://developer.nvidia.com





SUMMARY

- Overlap of algorithms used in E/M and HPC
- PhysX
  - Examples: Rigid body dynamics, particles
- OptiX
  - GPU accelerated ray-tracing
  - OptiX Prime for basic ray-geometry intersection tests

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ABSTRACT (FOR REFERENCE ONLY)

In this talk, you will learn how to use the game and visualization wizard's tool chest to accelerate your scientific computing applications. NVIDIA's game physics engine PhysX and the ray tracing framework OptiX offer a wealth of functionality often needed in scientific computing application. However, due to the different target audiences, these frameworks are generally not very well known to the scientific computing communities. High-frequency electromagnetic simulations, particle simulations in complex geometries, or discrete element simulations are all examples of applications that could immediately benefit from these frameworks. Based on examples, we will talk about the basic concepts of these frameworks, introduce their strengths and their approximation, and how to take advantage of them from within a scientific application.