Embree: A Kernel Framework for Efficient CPU Ray Tracing

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Usage of Ray Tracing Today

• Movie industry transitioning to ray tracing (better image quality, faster feedback)
• High quality rendering for commercials, prints, etc.
• Virtual design in automotive industry, architectural design, ...
• Various kind of simulations (lighting, sound, particles, collision detection, etc.)
• Prebaked lighting in games
• etc.
Writing a Fast Ray Tracer is Difficult

- **Need to multi-thread:** easy for rendering but difficult for hierarchy construction
- **Need to vectorize:** efficient use of SIMD units, different ISAs (SSE, AVX, AVX2, AVX-512, Xeon Phi™)
- **Need deep domain knowledge:** many different data structures (kd-trees, octrees, grids, BVH2, BVH4, ..., hybrid structures) and algorithms (single rays, packets, large packets, stream tracing, ...) to choose
- **Need to support different CPUs:** Different ISAs/CPU types favor different data structures, data layouts, and algorithms
Observations

- Ray tracers are often not sufficiently optimized
- Ray traversal consumes a lot of cycles (often over 70%)
- Ray tracing can be expressed by small number of commonly used operations (build and traversal)
- Ray tracing kernel library has potential to speed up many applications
Embree

- Provides highly optimized and scalable Ray Tracing Kernels (data structure build and ray traversal)
- High performance on current (and future) CPUs (1.5x – 6x speedup reported by users)
- Targets application developers in professional rendering environment
- API for easy integration into applications
- Free and Open Source under Apache 2.0 license (http://embree.github.com)
Embree Features

- Find closest hit kernel (**rtcIntersect**)
- Find any hit kernel (**rtcOccluded**)
- Single Ray, Ray Packets (4, 8, 16)
- High quality and high performance hierarchy builders
- Intel® SPMD Program Compiler (ISPC) supported
- Triangles, Instances, Hair
- Extensible (User Defined Geometry, Open Source)
Difficulties Vectorizing Ray Traversal

- Many traversal algorithms not practical for vectorization
  - small number of operations per traversal step
  - many dependent operations

- Need to choose traversal algorithm with many parallel operations per traversal step
Vectorized Ray Traversal in Embree

- Bounding Volume Hierarchy with fanout of 4 (BVH4) for fast single ray traversal
- Packets of rays for 2x faster coherent ray traversal
- Hybrid packet/single ray traversal also fast for incoherent rays
Embree System Overview

**Embree API (C++ and ISPC)**

**Ray Tracing Kernel Selection**

**Accel. structure**
- bvh4.triangle4,
- bvh4.triangle8,
- bvh8.triangle8,
- bvh4aos.triangle1,
- ...

**Builders**
- SAH builder
- Spatial split builder
- Morton code builder
- BVH Refitter

**Traversal**
- Single ray (SSE2), single ray (SSE4.1), single ray (AVX), single ray (AVX2), packet (SSE2), hybrid (SSE4.2), ...

**Intersection**
- Möller Trumbore,
- Plücker Variant,
- Bezier Curve

**Common Vector and SIMD Library**
- (Vec3f, Vec3fa, ssef, avxf, SSE2, SSE4.1, AVX, AVX2)
Embree API

- Compact and easy to use
- Hides implementation details (such as ISA specific optimizations)
- C++ and ISPC version
- Allows data sharing with application

```c
/* create new scene */
RTCSscene scene = rtcNewScene (STATIC);

/* add mesh to scene */
unsigned geomID = rtcNewTriangleMesh (...);
rtcSetBuffer (scene, geomID, INDICES,...);
rtcSetBuffer (scene, geomID, VERTEX,...);

/* commit changes */
rtcCommit (scene);

/* shoot rays */
RTCRay ray = ...
rtcIntersect (scene, ray);
```
Performance Methology

- Models and illumination effects representative for professional rendering environment
- Evaluation on typical Intel® Xeon® rendering workstation* and Intel® Xeon Phi™ Coprocessor**
- Compare against state of the art GPU*** methods (using OptiX™ 3.5.1 and CUDA® 5.5)
- Path tracer with different material types, different light types, about 2000 lines of code
- Identical implementations in C++ (Xeon®), ISPC (Xeon Phi™), OptiX™ (GTX™ Titan)

* Dual Socket Intel® Xeon® E5-2690, 2x 8 cores @ 2.9 GHz  ** Intel® Xeon Phi™ 7120, 61 cores @ 1.238 GHz  *** NVIDIA® GeForce® GTX™ Titan
Build Performance for Static Scenes

- Dual Socket Intel® Xeon® E5-2690, 2x 8 cores @ 2.9 GHz
- Intel® Xeon Phi™ 7120, 61 cores @ 1.238 GHz
- NVIDIA® GeForce® GTX™ Titan

<table>
<thead>
<tr>
<th></th>
<th>Million Triangles/Second</th>
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<tbody>
<tr>
<td>Xeon® * Single Ray (SAH)</td>
<td>18.5, 32.3</td>
</tr>
<tr>
<td>Xeon Phi™ ** ISPC (SAH)</td>
<td>18.9, 31.7</td>
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<td>18.1, 35.1</td>
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Build Performance for Dynamic Scenes

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* Xeon® * Single Ray (Morton)
** Xeon Phi™ ** ISPC (Morton)

Million Triangles/Second

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<th>Xeon Phi™ ** ISPC (Morton)</th>
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<tr>
<td>Million Triangles/Second</td>
<td>76.1</td>
<td>160.1</td>
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<tr>
<td>Million Triangles/Second</td>
<td>81.9</td>
<td>140.4</td>
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<tr>
<td>Million Triangles/Second</td>
<td>56.5</td>
<td>162.1</td>
</tr>
</tbody>
</table>

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Ray Tracing Performance (incl. Shading)

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Million Rays/Second

- Xeon® * Single Ray
- Xeon Phi™ ** ISPC
- Titan*** OptiX™

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Summary

- Embree delivers high ray tracing performance on CPUs
- Embree has potential to speed up many ray tracing applications
- Embree is easy to use through its API
- Free and Open Source (https://embree.github.io)

Demo

- Embree Demo at Exhibition
  Tuesday – Thursday, Intel® Booth 1001 (West Building, Hall B/C)
Questions?

https://embree.github.io
embree@googlegroups.com