Embree: Ray Tracing Kernels

Intel Software

Visualize Create Deliver

SIGGRAPH 2012

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Embree: Ray Tracing Kernels

Motivation

- Ray tracing is used heavily for professional graphics
- Implementing a fast ray tracer is difficult

Goal

- Provide the fastest ray tracing kernels to developers
- Address misconceptions about relative performance of CPUs and GPUs for ray tracing

What is Embree?

- The fastest ray tracing kernels for Intel® CPUs
- Designed for Monte Carlo ray tracing
- Easy to integrate into existing applications
- Published under the Apache 2.0 license on ISN:
  http://software.intel.com/en-us/articles/embree-photo-realistic-ray-tracing-kernels/

Architecture

Professional Graphics Application
CAD, digital content creation, visualization, movie production

Rendering Engine
Distributed ray tracing, path tracing, photon mapping, …

Embree → **Ray Tracing Kernel**
Fast acceleration structure build and traversal

Status

- Version 1.0 released in November 2011
- Broad adoption by developers and researchers
- 2-5x speed-up over existing implementations

- Version 1.1 released … today!

New Features in Embree 1.1

- 2x lower memory consumption during rendering
- 3x lower memory consumption during BVH build
- Up to 2x faster BVH build
- Improved ray/triangle intersection accuracy
- Support for motion blur
- Support for very large scenes

User Feedback

“I had approached my renderer from the GPU aspect. But once I saw Embree it completely shifted my direction. The CPU with extensions is a more viable platform and thanks to your demonstration / research release of Embree this has totally changed my approach which I am thankful for.”

Gary Herbst

The Embree Example Renderer

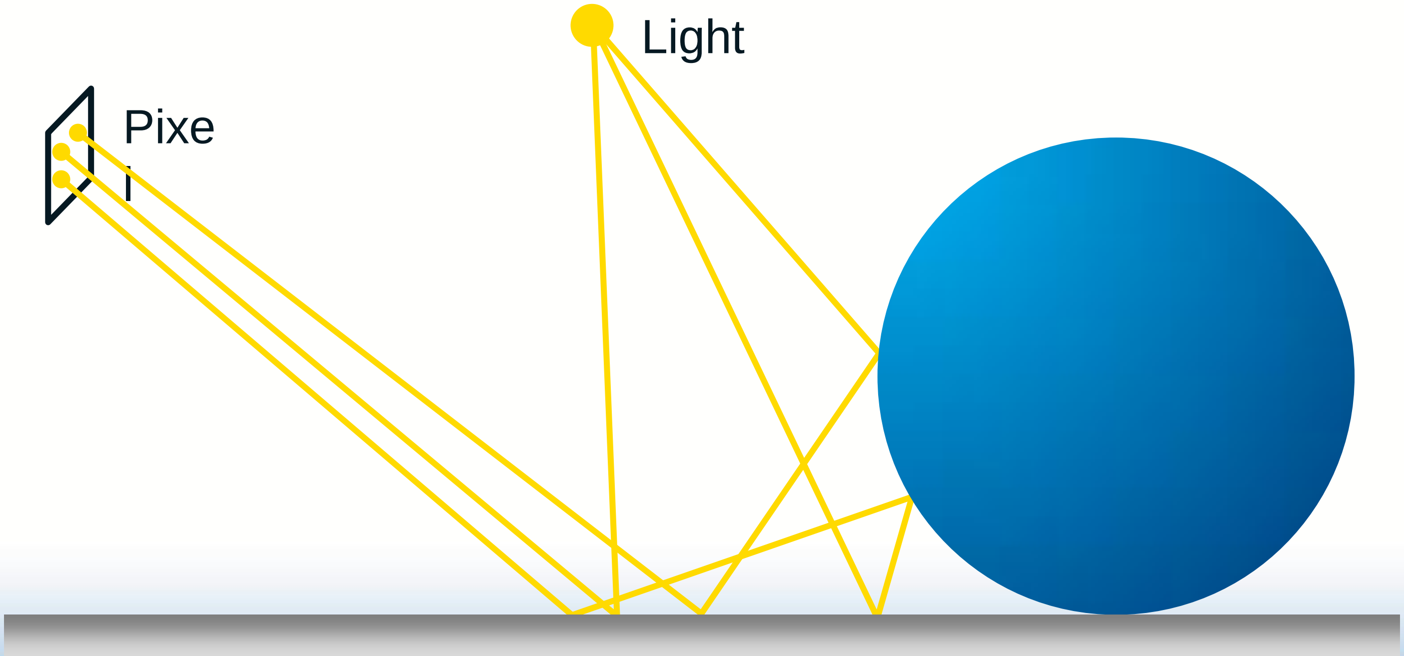
Progressive Path Tracing

1000 x 1200 pixel, rendered on four Intel® Xeon® Processor E7-4860
Model courtesy of Martin Lubich, www.loramel.net

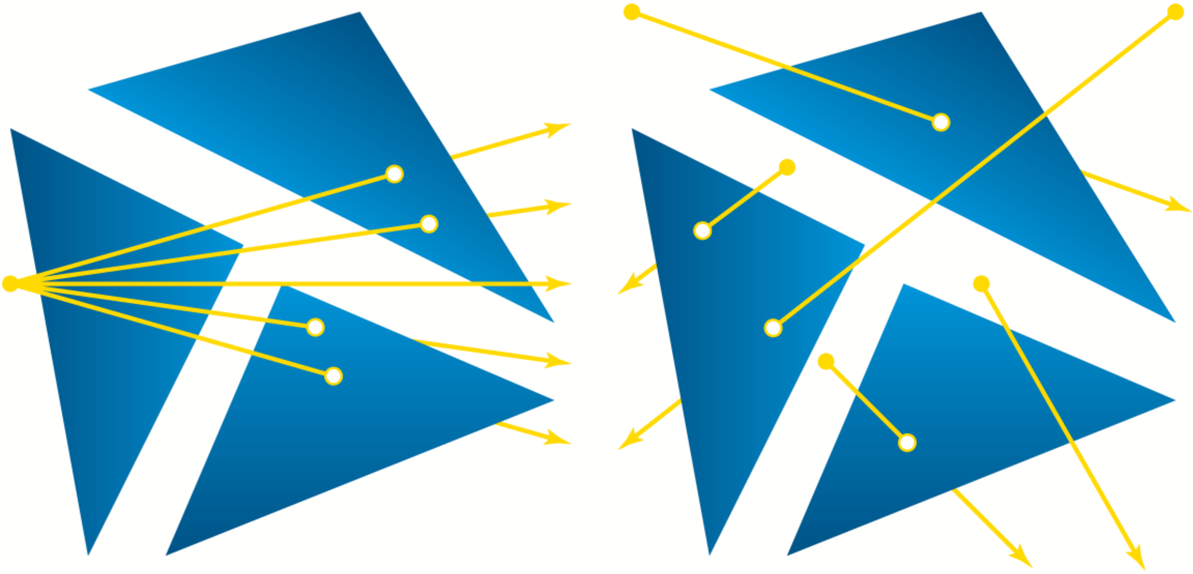
Model courtesy of Martin Lubich
www.loramel.net

The Embree Kernels

Monte Carlo Ray Tracing



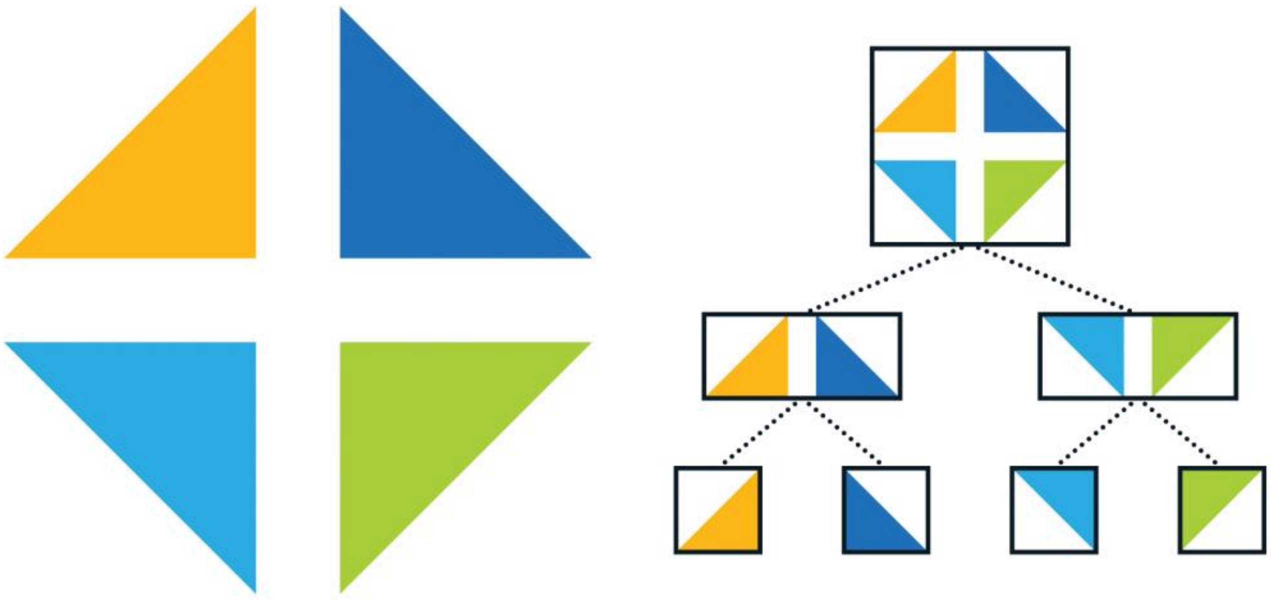
Two Kinds of Ray Distributions



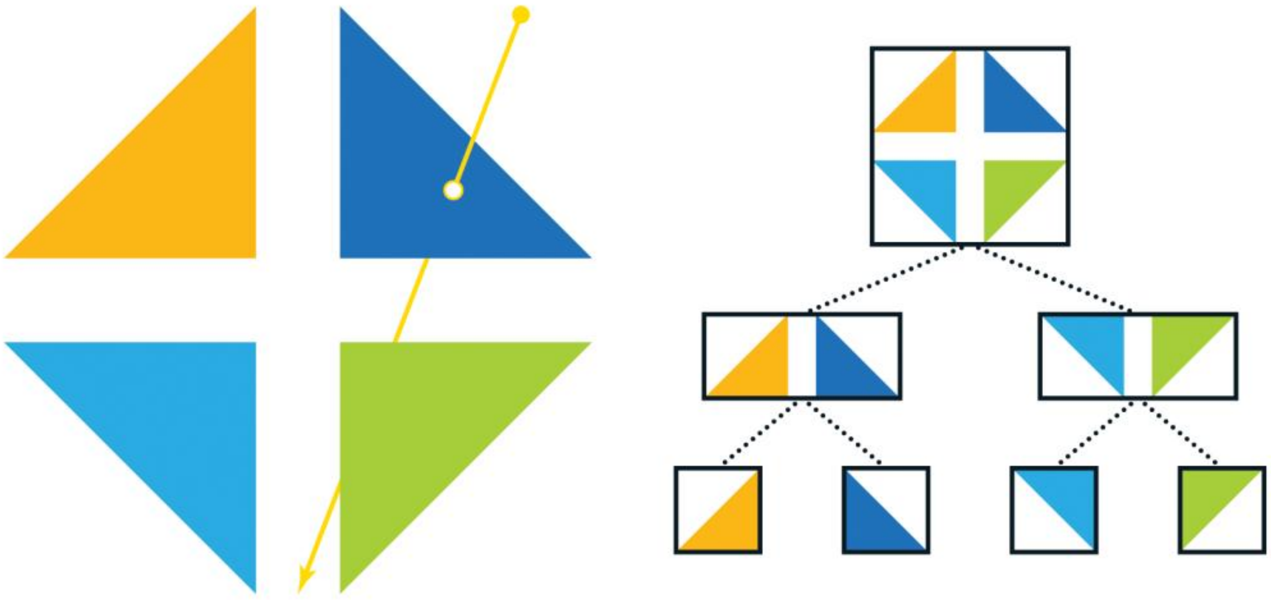
Coherent Rays

Incoherent Rays
(typical for Monte Carlo)

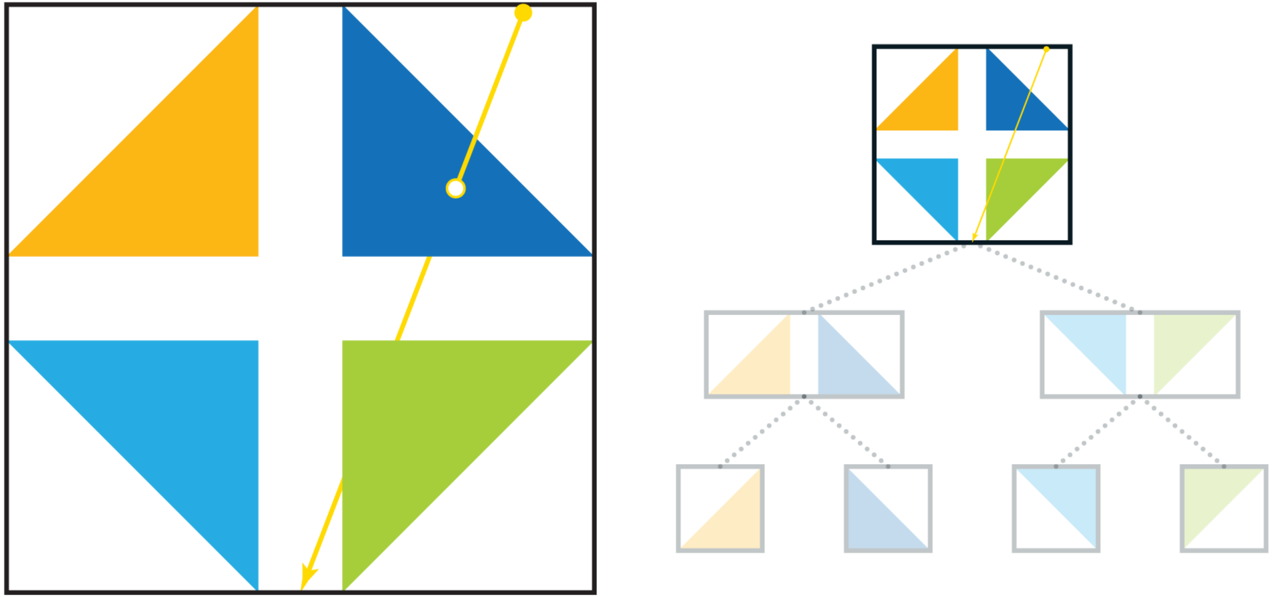
BVH Acceleration Structure



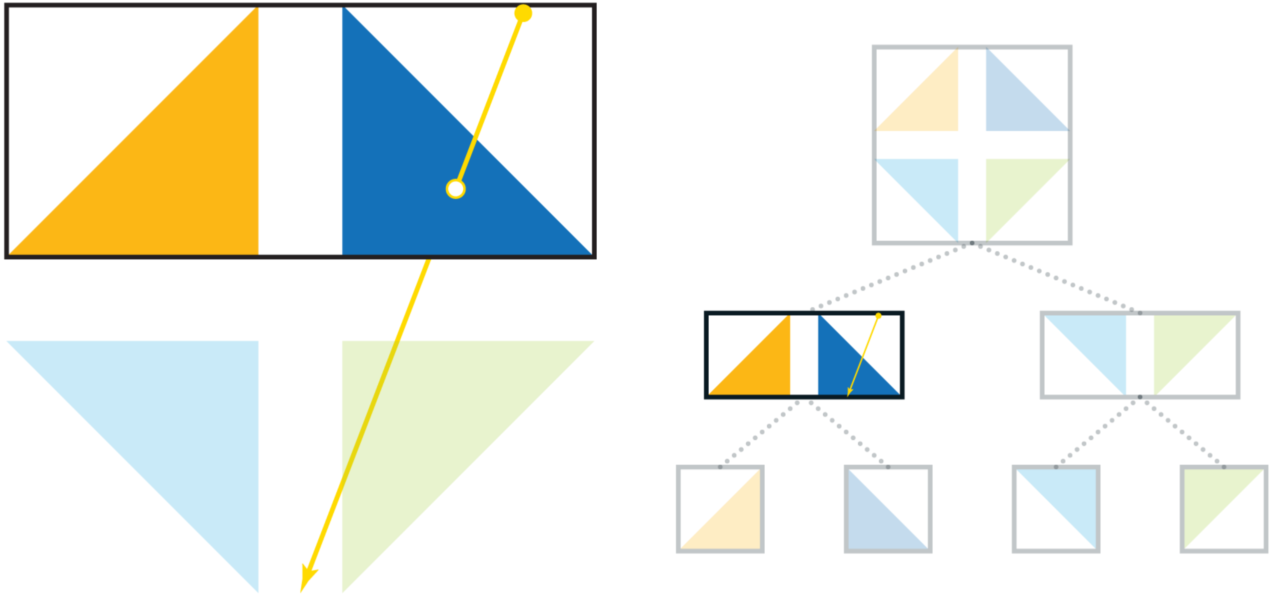
BVH Acceleration Structure



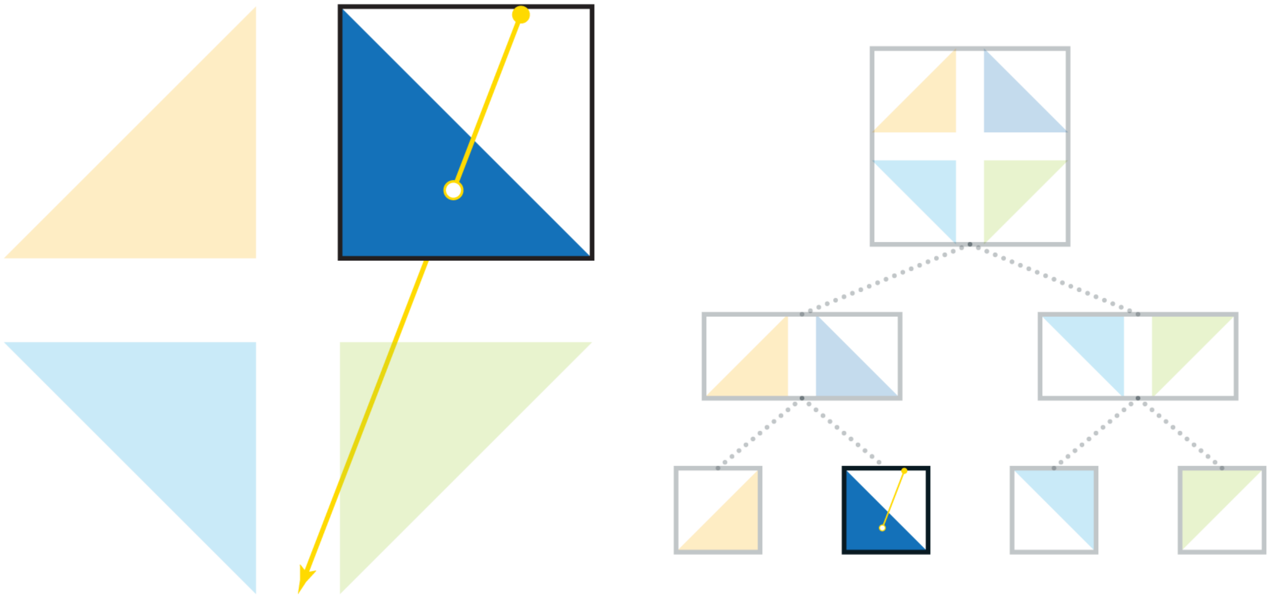
BVH Acceleration Structure



BVH Acceleration Structure



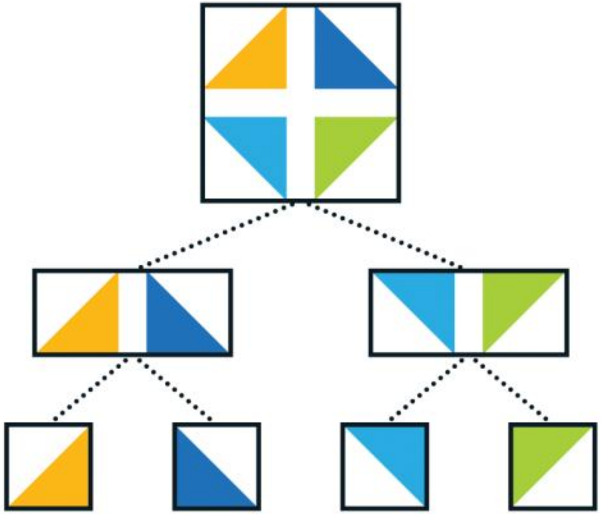
BVH Acceleration Structure



Solution Space for Vectorized Ray Tracing

	Single Box	Multi Box
Single Ray	**Scalar Traversal**	**Single Ray SIMD Traversal**
Multi Ray	**Packet Traversal**	**Independent Ray Traversal**

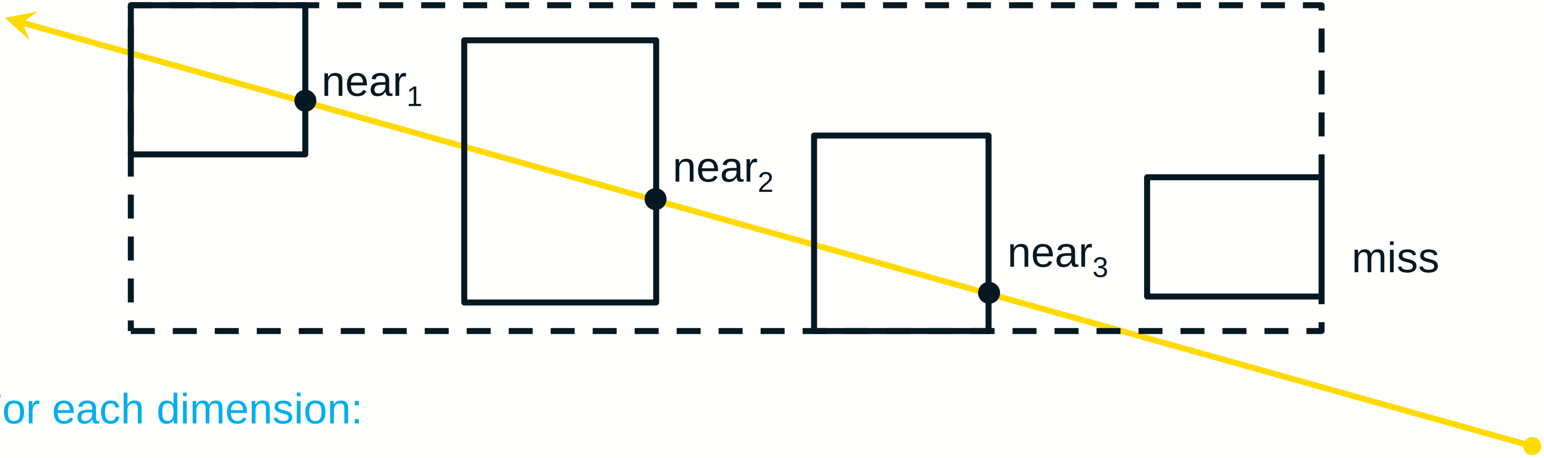
BVH4 Memory Layout



Traditional BVH Layout

BVH4 Layout

BVH4 Traversal



For each dimension:

Intersect ray with near plane of each box in SIMD

Intersect ray with far plane of each box in SIMD

Clip the near and the far parameters

New Features in Embree 1.1

Memory Consumption During Rendering

Embree 1.0: Precomputed SSE triangles (v0, e1, e2, Ng)

55 MB Nodes	319 MB Precomputed Triangles

Additional in Embree 1.1: SSE friendly indexed face set

55 MB Nodes	114 MB Indices	40 MB Vertices	← 44% less data →

Crown (4.8M Triangles)

45% less memory for 10% lower performance

			
Precomputed Triangles	44 Mrps	100 Mrps	68 Mrps
Indexed Face Set	39 Mrps	93 Mrps	61 Mrps
Relative Performance	-11.4 %	-7.0 %	-10.3 %

4x Intel® Xeon® Processor E7-4860

Memory Consumption of BVH Build

- Embree 1.0: *Indices* into Node and Triangle Array
  - Problematic conservative pre-allocations (worst case of 1 out of 4 triangles filled).

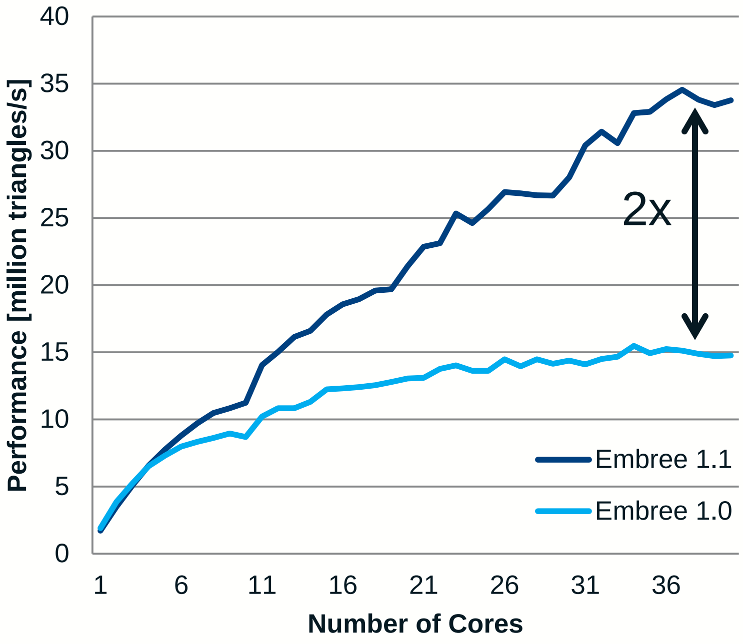
- Embree 1.1: *Pointers* to Nodes and Triangles
  - On-demand allocations possible.

➔ About 3x lower memory consumption compared to Embree 1.0

Up to 2x Faster BVH Builder

Improvements:

- Optimized allocator for nodes, triangles, and primitive lists.
- Single pass to evaluate heuristic and perform split.
- In-place partition also for parallel splits.
- No pre-allocations at build startup.
- Improved parallelization for spatial split builder.



BVH2, SAH binning
4x Intel® Xeon® Processor E7-4860

Ray Triangle Intersection

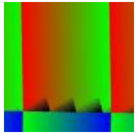
Möller Trumbore

ABC = det(dir,v2-v1,v1-v0)

A = det(dir,org-p0,v1-v0)

B = det(dir,org-p0,v2-v1)

C = ABC – A – B



Improved performance by reducing accuracy of 1 edge test.

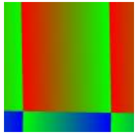
Stable Plücker (Additional in Embree 1.1)

ABC = det(dir,v2-v1,v1-v0)

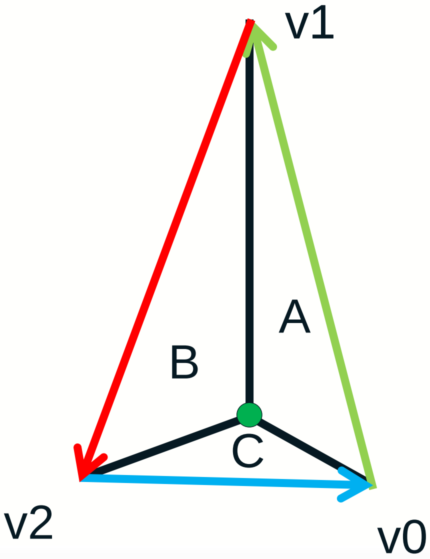
A = det(dir,org-p0,v1-v0)

B = det(dir,org-p0,v2-v1)

C = det(dir,org-p0,v0-v2)



Improved accuracy by performing all 3 tests at high precision.



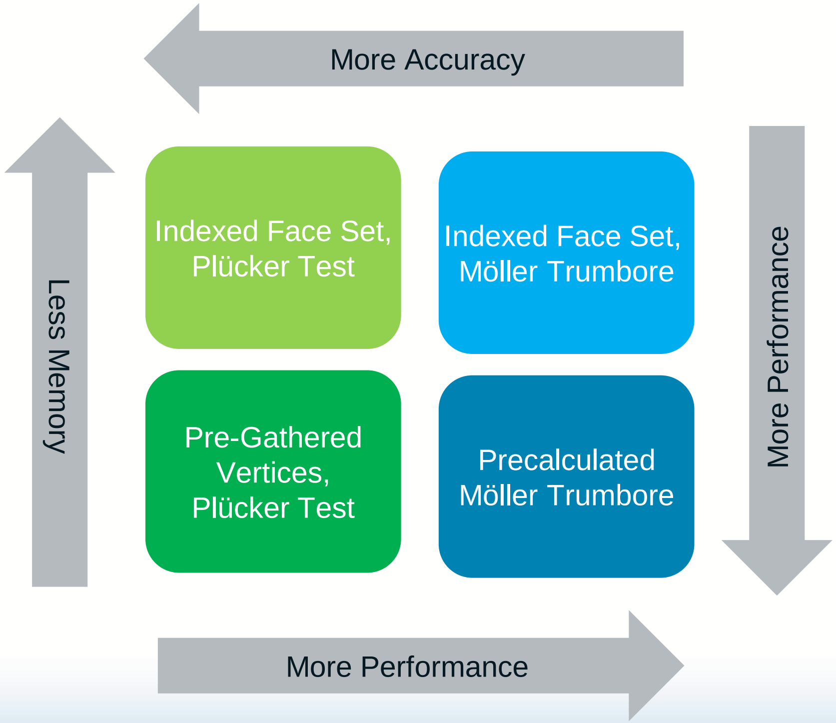
Performance Impact of Plücker Test



Möller Trumbore	44 mrps	100 mrps	68 mrps
Plücker	41 mrps	98 mrps	65 mrps
Relative Performance	-6.8 %	-2.0 %	-4.4 %

4x Intel® Xeon® Processor E7-4860

Combining Memory and Accuracy Optimizations



Support for Linear Motion Blur

Linear motions:

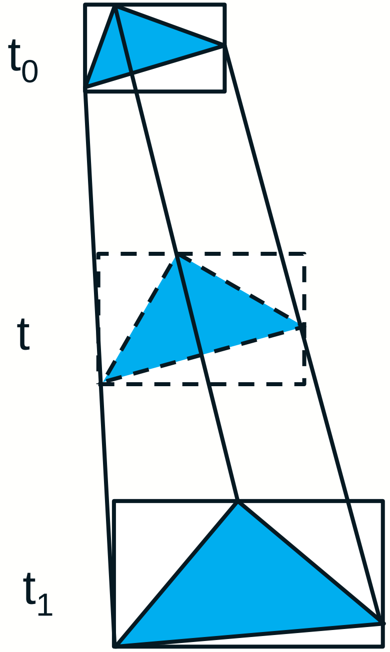
- Good approximation for short shutter times.
- Approximated curved motion by piecewise linear motion.

Key Idea:

- Linearly interpolated geometry can be bounded by linearly interpolated bounds.

Algorithm:

- Interpolate bounds at time t during traversal.
- Interpolate triangle vertices at time t during intersection.



Performance Impact of Motion Blur

			
Static	44 mrps	100 mrps	68 mrps
Motion Blur	29 mrps	71 mrps	25 mrps
Relative Performance	-34.1 %	-29.0 %	-63.2 %

4x Intel® Xeon® Processor E7-4860

Outlook: Embree for Intel® Xeon Phi™

Intel® Xeon® Brand Family

Intel Xeon® Processors E5-1600/2600 Product Family

- High performance computing for mainstream applications
- Accelerating your innovation with exponential performance gains over previous generations

Intel® Xeon® Phi™

- Parallel performance to power breakthrough innovation
- Delivering extremely scalable performance for parallel applications (e.g. simulation, ray tracing and analytics)

Intel® Xeon® Phi™ Architecture

Optimized for highly parallel performance

Groundbreaking differences

- > 50 Smaller, less power consuming cores
- High Memory Bandwidth
- Highly parallel architecture
- Wider vector processing units for greater floating point performance/watt

Embree 2.0 Design Goals

- Two primary goals
  - Goal #1: As easy to use and extend as Embree 1.x
  - Goal #2: High performance on Intel® Xeon Phi™
- Problem: Requires more than just new single-ray kernels for Intel® Xeon Phi™

Traditional Embree 1.x Architecture

User Code

Application (C++, scalar)
E.g. visualization, lighting simulation, …

Rendering Engine (C++, scalar)
E.g. path tracer (Embree path tracer but one example)

Embree

Ray Tracing Kernels (Intrinsics, SIMD)
E.g., BVH with single ray traversal

Embree 1.x Issues with wide SIMD

- Intel® Xeon Phi™ : 16-wide SIMD, focus on throughput performance

  → Causes two issues with Embree 1.x Architecture

Problem #1: Harder to use wide SIMD in *single*-ray kernels

- E.g.: “16-wide BVH” not 4x as efficient as “4-wide BVH”
- Instead, prefer working on “packets” of 16 rays in parallel where possible
- Problem: can’t *traverse* 16 rays if scalar renderer only produces 1 at a time

Problem #2: “Scalar Renderer” doesn’t make use of vector units

- Large scalar portion of runtime = diminishing return of wider SIMD (→ Amdahl’s law)

Embree 2.x Approach for wide SIMD

- Solution: Use SPMD compiler to vectorize renderer as well (→ISPC)

Embree 1.x: Scalar Renderer

Application (C++, scalar)
E.g. visualization, lighting simulation, …

Rendering Engine (C++, scalar)
E.g. path tracer

User Code

Ray Tracing Kernels (Intrinsics)
E.g., BVH with single ray traversal

Low-level
RT kernels

Embree 2.x Approach for wide SIMD

- Solution: Use SPMD compiler to vectorize renderer as well (→ISPC)

Embree 1.x: Scalar Renderer		Embree 2.0 : SPMD Renderer
Application (C++, scalar) E.g. visualization, lighting simulation, …	User Code	Application (C++, scalar) E.g. visualization, lighting simulation, …
Rendering Engine (C++, scalar) E.g. path tracer		
Ray Tracing Kernels (Intrinsics) E.g., BVH with single ray traversal	Low-level RT kernels	Ray Tracing Kernels (Intrinsics) E.g., hybrid packet/single-ray traversal

Embree 2.x Approach for wide SIMD

- Solution: Use SPMD compiler to vectorize renderer as well (→ISPC)

Embree 1.x: Scalar Renderer		Embree 2.0 : SPMD Renderer
Application (C++, scalar) E.g. visualization, lighting simulation, …	User Code	Application (C++, scalar) E.g. visualization, lighting simulation, …
Rendering Engine (C++, scalar) E.g. path tracer		Rendering Engine (SPMD → vector!) E.g. path tracer
Ray Tracing Kernels (Intrinsics) E.g., BVH with single ray traversal	Low-level RT kernels	Ray Tracing Kernels (Intrinsics) E.g., hybrid packet/single-ray traversal

Embree 2.x Approach for wide SIMD

- Implemented as new Embree "device"
  - Same scalar interface for apps as Embree 1.x
- Use "Intel SPMD Program Compiler (ISPC)" for SPMD renderer *
  - SPMD: User "sees" scalar code (→ code as easy to write/maintain as scalar code) ….
  - … but vectorized (one program per SIMD lane) throughout renderer (→ performance)
- Use low-level intrinsics kernel for (16-wide!) ray traversal
  - Benthin et al, "Combining Single and Packet Ray Tracing for Arbitrary Ray Distributions on the Intel® MIC Architecture", IEEE TVCG 2012
  - Of course, can also implement one's own (SPMD-)traversers in ISPC

* The Intel SPMD Program Compiler, http://ispc.github.com

Embree 2.x Summary

- Fully optional SPMD extension (scalar version on Xeon® still available)
- Uses the right tool for each application layer
- Excellent performance and high programmer productivity
- Code is portable between Xeon® and Intel® Xeon Phi™
- Optional integration of hand-optimized kernels

Features	Embree 1.x	Embree 2.x
Intel® Core™	Yes	Yes
Intel® Xeon®	Yes	Yes
Intel® Xeon® Phi™	No	Yes

Demo!