Embree Ray Tracing Kernels: *Overview and New Features*

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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)
- 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

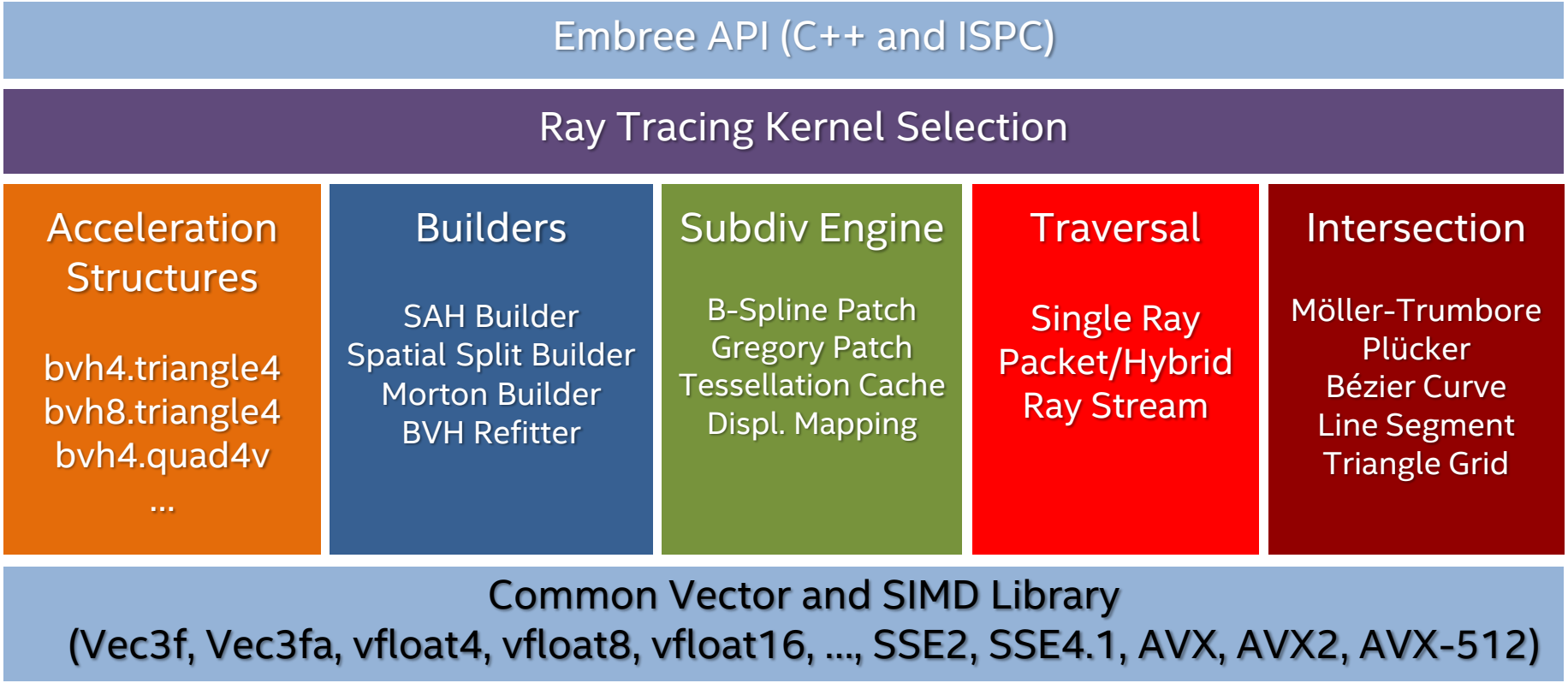
Embree ray tracing kernels

- Provides highly optimized and scalable ray tracing kernels
  - Acceleration structure build and ray traversal
- Targets professional rendering applications
- Highest ray tracing performance on CPUs
  - 1.5–6× speedup reported by users
- Support for latest CPUs
  - Intel® Xeon Phi™ Processor (codenamed *Knights Landing*)
- API for easy integration into applications
- Free and open source under Apache 2.0 license
  - http://embree.github.com

Embree features

- Find closest hit, any hit
  - rtcIntersect, rtcOccluded
- Single rays, ray packets (4, 8, 16), ray streams (N)
- High-quality and high-performance BVH builders
- Intel® SPMD Program Compiler (ISPC) support
- Triangles, quads, subdivs, instances, hair, linear motion blur
- Extensible
  - User defined geometry, intersection filter functions, open source
- Support for Intel® Threading Building Blocks (TBB)

Embree system overview



Embree API

How to use Embree?

Scene

- Scene is a container for set of geometries
- Scene flags passed at creation time
  - Static scene
  - Dynamic scene
  - etc.
- Scene geometry changes have to get commited (rtcCommit), which triggers BVH build

```
// include Embree headers
#include <embree2/rtcore.h>

int main()
{
  // initialize at application startup
  rtcInit();

  // create scene
  RTCScene scene = rtcNewScene
    (RTC_SCENE_STATIC, RTC_INTERSECT1);

  // add geometries
  ... later slide ...

  // commit changes
  rtcCommit(scene);

  // trace rays
  ... later slide ...

  // cleanup at application exit
  rtcExit();
}
```

Triangle mesh

- Contains vertex and index buffers
- Number of triangles and vertices set at creation time
- Linear motion blur supported
  - 2 vertex buffers

```
// application vertex and index layout
struct Vertex { float x, y, z, s, t; };
struct Triangle { int materialID, v0, v1, v2; };

// add mesh to scene
unsigned int geomID = rtcNewTriangleMesh
  (scene, numTriangles, numVertices, 1);

// set data buffers
rtcSetBuffer(scene, geomID, RTC_VERTEX_BUFFER,
  vertexPtr, 0, sizeof(Vertex));
rtcSetBuffer(scene, geomID, RTC_INDEX_BUFFER,
  indexPtr, 4, sizeof(Triangle));

// add more geometries
...

// commit changes
rtcCommit(scene);
```

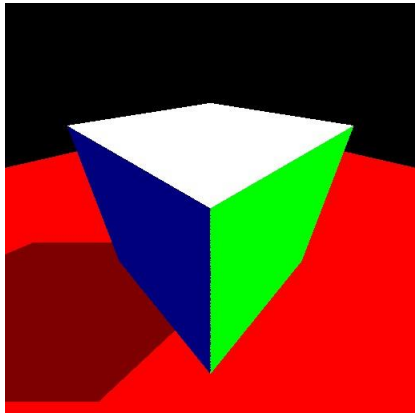
Rendering (ISPC)

```
// loop over all screen pixels
foreach (y=0 ... screenHeight-1, x=0 ... screenWidth-1) {
```

```
    // create and trace primary ray
    RTCRay ray = make_Ray(p, normalize(x*vx + y*vy + vz), eps, inf);
    rtcIntersect(scene, ray);
```

```
    // environment shading
    if (ray.geomID == RTC_INVALID_GEOMETRY_ID) {
      pixels[y*screenWidth+x] = make_Vec3f(0.0f); continue;
    }
```

```
    // calculate hard shadows
    RTCRay shadow = make_Ray(ray.org+ray.tfar*ray.dir, neg(lightDir), eps, inf);
    rtcOccluded(scene, shadow);
```



```
    if (shadow.geomID == RTC_INVALID_GEOMETRY_ID)
      pixels[y*width+x] = colors[ray.primID]*(0.5f + clamp(-dot(lightDir, normalize(ray.Ng)), 0.0f, 1.0f));
    else
      pixels[y*width+x] = colors[ray.primID]*0.5f;
}
```

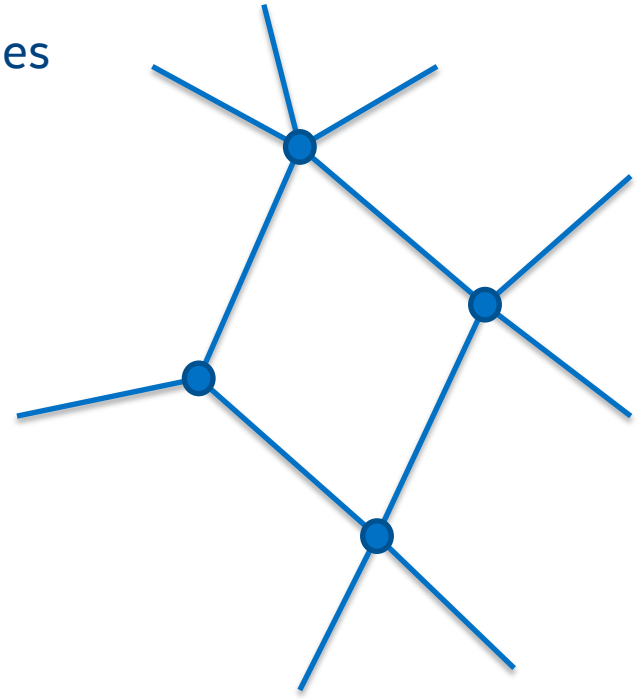
New/Advanced Features

Since the initial publication of Embree [Wald et al. 2014]

Quad meshes (Embree 2.8)

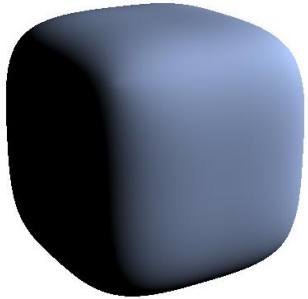
- Most 3D modeling packages produce quad meshes
- No need to convert them to triangles anymore!
- rtcNewQuadMesh

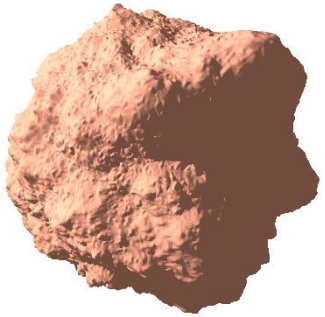
- Up to 2× lower memory usage
- Faster BVH building
- Higher ray intersection throughput



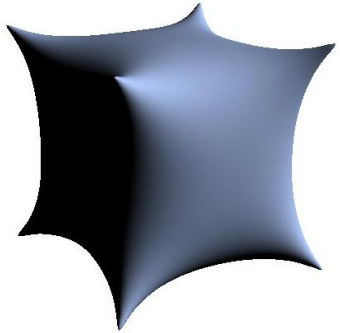
Subdivision surfaces (Embree 2.4)

- Catmull-Clark subdivision surfaces
- Compatible with OpenSubdiv 3.0
- Displacement mapping



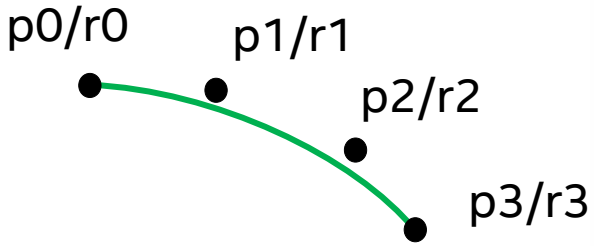


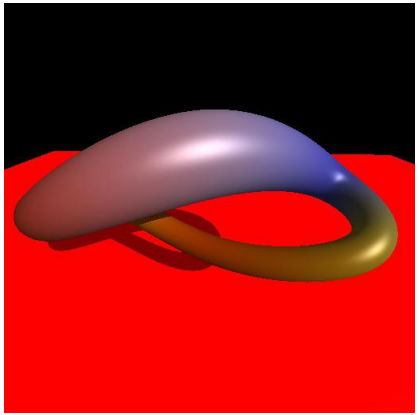
- Tessellation cache [Benthin et al. 2015]
  - Low memory usage
  - Real-time rendering performance



Hair

- Three hair geometry types:
  - Cubic Bézier hair (Embree 2.3)
  - Line segment (Embree 2.8)
  - Cubic Bézier curve (Embree 2.10)
    - Sweep surface of a circle along a Bézier curve

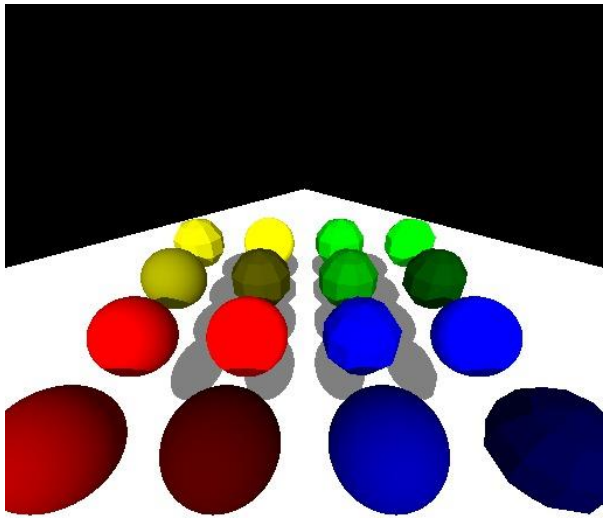




- High performance through use of oriented bounding boxes [Woop et al. 2014]
- Low memory consumption through direct ray/curve intersection

User defined geometries

- Enables implementing custom primitives not provided by Embree
  - e.g., point, disk
- User provides:
  - Bounding function
  - Intersect and occluded functions
- Linear motion blur support (Embree 2.8)



Ray streams (Embree 2.9)

- Intersect many rays together
  - e.g., 1K-4K
- rtcIntersect1M, rtcIntersectNM, rtcIntersectNp
- Enables better coherence extraction than packets
  - Improves both traversal and shading [Áfra et al. 2016] performance
- Novel stream traversal algorithm
  - Based on hiding memory access latency
- Improves performance by 10-30% depending on coherence

Embree 2.10.0 Performance

Ray tracing performance

Test setup

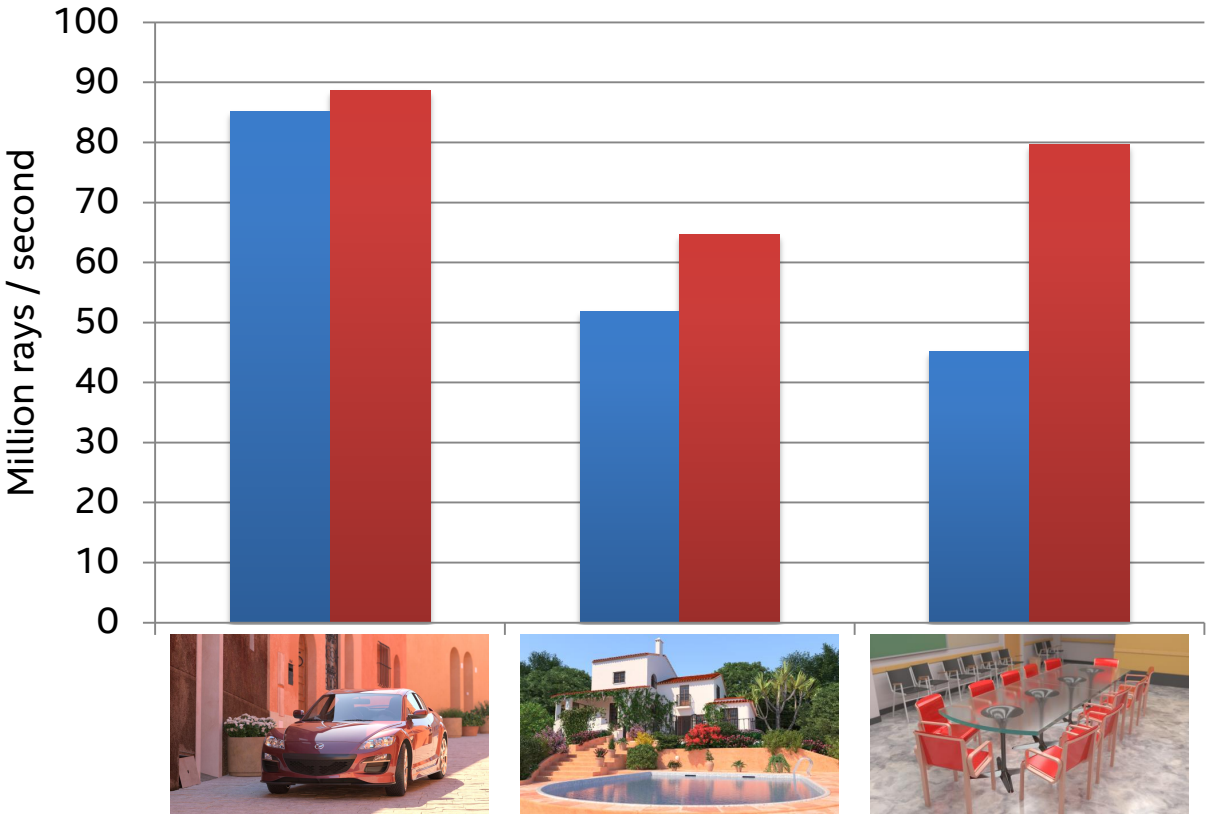
- Path tracer with complex materials and shaders (including procedural)
- Ray stream tracing with local shading coherence extraction [Áfra et al. 2016]
- Hardware:
  - Dual-socket Intel® Xeon® E5-2699 v3 (*Haswell*, 2×18 cores, 2.3 GHz, AVX2), 64 GB DDR4
  - Intel® Xeon Phi™ 7210 (*Knights Landing*, 64 cores, 1.3 GHz, AVX-512), 96 GB DDR4

Mazda / 5.7M triangles

Villa / 37.7M triangles

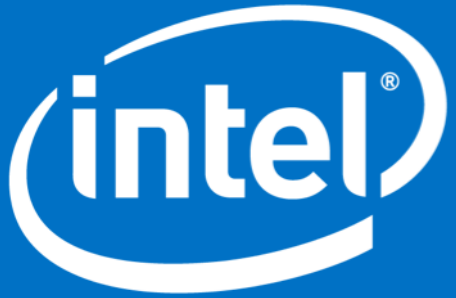
Conference / 0.3M triangles

Ray tracing performance (including shading)



Q&A

Visit the Intel booth for a live Embree demo running on Intel® Xeon Phi™!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