Raytracing with Embree

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Content / Agenda

- Raytracing and Embree basics
- Demo1: Ray-Triangle intersection
- Embree’s geometry types
- Demo2: User geometries
- Advanced Embree Features
- Demo3: Point queries
- Q&A
Raytracing with Embree

- Library for raytracing
- Mainly targets professional rendering applications
- High performance (1.5x – 6x speedup)
  - Multithreading using Intel® TBB
  - Heavily utilizes SIMD instructions (e.g. Intel® AVX-512)
- Easy to use API
- Open source (Apache* 2.0 license)
- Cross platform (Windows*, Linux*, macOS*)
Raytracing with Embree

DWA How To Train Your Dragon 2
CPU/Embree Only Corona Renderer
V-Ray Embree Hair Primitives
ADSK 360 Cloud – >50M Renders
ParaView with OSPRay
ANL VL3 Dark Matter - OpenSWR
SURVICE StingRay
Raytracing

- Find intersection of a ray with the virtual scene

- Ray: All points $r(t) = o + t \cdot d$ with $t \in [0, \infty)$
Raytracing

- Find intersection of a ray with the virtual scene

- For all triangles in scene:
  - Intersect ray with triangle \( \text{slow!} \)
Bounding Volume Hierarchies (BVH)

- Hierarchical “clustering” of close-by geometry in boxes

scene

tree structure
Bounding Volume Hierarchies (BVH)

Challenges

- Multi-threaded build
- Vectorization
- Numerical robustness
- Cross-platform availability

Embree solves all of that for you, and more!
# Embree System Overview

## Embree API (C and ISPC)

## Ray Tracing Kernel Selection

### Acceleration Structures
- `bvh4.triangle4`
- `bvh8.triangle4`
- `bvh4.quad4v`

### Builders
- SAH Builder
- MBlur Builder
- Spatial Split Builder
- Morton Builder
- BVH Refitter

### Traversal
- Single Ray
- Packet/Hybrid
- Ray Stream

### Intersection
- Möller-Trumbore
- Plücker
- Flat Curve
- Round Curve
- Oriented Curve
- Grid

### Subdiv Engine
- B-Spline Patch
- Gregory Patch
- Tessellation Cache
- Displ. Mapping

## Common Vector and SIMD Library

(Vec3f, Vec3fa, vfloat4, vfloat8, vfloat16, ..., Intel® SSE2, Intel® SSE4.1, Intel® AVX, Intel® AVX2, Intel® AVX-512)
Demo 1

Ray-Triangle intersection with Embree
A Ray in Embree

- Input parameters:
  - Origin (org) and direction (dir)
  - Ray interval (tnear, tfar)
  - Time (for motion blur, advanced)

```c
struct RTCRay {
    Vec3f org;
    Vec3f dir;
    float tnear;
    float tfar;
    float time;
    Vec3f Ng;
    float u;
    float v;
    int geomID;
    int primID;
    int instID;
};
```
A Ray in Embree

- Output parameters:
  - Hit distance \((tfar)\)
  - Normal \((Ng)\)
  - Local hit coordinates \((u, v)\)
  - Geometry identifier \((geomID)\)
  - Index of primitive of geometry \((primID)\)
  - Geometry identifier of hit instance \((instID, advanced)\)

```c
struct RTCRay {
    Vec3f org;
    Vec3f dir;
    float tnear;
    float tfar;
    float time;
    Vec3f Ng;
    float u;
    float v;
    int geomID;
    int primID;
    int instID;
}
```
Prerequisites

- Embree device encapsulates
  - ISA configuration,
  - number of threads,
  - logging verbosity, ...

- Embree scene
  - Collection of geometries that can be intersected

- Create/Release pairs

```c
// include Embree headers
#include <embree3/rtcore.h>

int main()
{
    // create Embree device at application startup
    RTCDevice device = rtcNewDevice();

    // create scene
    RTCScene scene = rtcNewScene(device);

    // attach geometries ...

    // commit changes
    rtcCommitScene(scene);

    // trace rays ...

    // release objects
    rtcReleaseScene(scene);
    rtcReleaseDevice(device);
}
```
Geometry Types

- Triangle meshes
- Quad meshes
- Grid meshes
- Subdivision meshes
- Curves
- User-defined → extensible
Demo 2

User-Defined Geometries
User-Defined Geometries

- Enables implementing custom primitives and features
- User provides
  - Bounding function
  - Intersect and occluded functions

Example: Implementing analytical spheres
- Sphere: all points where \((x - c)^2 - r^2 = 0, x \in \mathbb{R}^3\)
- Intersections: solve \((o + t \cdot d - c)^2 - r^2 = 0\) for \(t\)
Selected Advanced Features
Catmull-Clark Subdivision Surfaces

- Converts coarse mesh into smooth surface (subdivision)
- Established as standard in movie production
- Embree implementation compatible with OpenSubdiv 3.0
- Evaluation of surface supported
- Walking mesh topology supported
Grid Meshes

- Primitives are grids of vertices with regular triangulation
- For displaced surfaces with higher tessellation levels
- Use quad meshes for low tessellation levels
- Extremely low memory consumption
- Down to 4 bytes per triangle
- Can use grid with displacement function instead of subdiv mesh
Curve Geometries

- Curve bases
  - Linear (for very distant curves)
  - Cubic Bézier (widely used representation)
  - Cubic B-spline (most compact)
  - Cubic Hermite (compact and interpolating)

- Curve types
  - Flat curves (for distant geometry)
  - Round curves for close-ups (swept circle)
  - Normal-oriented curves (for grass)
Intersection Filter Functions

- **Per-geometry callback**
  - Called during traversal for each primitive intersection
- **Callback can accept or reject hit**
- **Can be used for:**
  - Trimming curves (e.g. modeling tree leaves)
  - Transparent shadows (reject and accumulate)
  - Find all hits (reject and collect)
  - Advanced self-intersection avoidance
Collision Detection

- Fast parallel collision detection implementation
- Callback invoked with potentially colliding primitive pairs
- Coarse phase only, narrowing needs to be done by application
- Performance of up to 50 M pairs/s/core

Measured on a single core of an Intel® Xeon® Platinum 8180 CPU
Point Queries

- Allows the traversal of the BVH with a point instead of a ray
  - Can be used for nearest neighbor lookups in point clouds or
  - Find the closest point on the geometry with respect to the query position

- User provides Primitive-Point distance computation in callback function
Demo 3

Point Queries
Embree Timeline and Outlook

2014
- 2.0: Intel® Xeon Phi® Ray packets, SPC
- 2.2: Interaction list
- 2.3.1: BVH8, Spiky spheres
- 2.5: Threading Building Blocks
- 2.7: Device concept
- 2.9: Ray streams
- 3.0: Improved API, improved memory consumption
- 3.1: Normal oriented curves, grid geometry
- 3.2: Hermite basis
- 3.3: Time range per motion blur object
- 3.4: Point primitives
- 3.5: Quaternion motion blur
- 3.6: Multi-level intersecting point queries, Catmull-Rom Basis
- 3.7: Quaternion motion blur

2015
- 2.1: New API, runtime code optimization
- 2.3: 1X, Ray parallelism
- 2.4: Subdivision surface support
- 2.6: BV8, Area Release
- 2.8: Line geometry, Quad geometry
- 2.10: Motion blur
- 2.11: Frustum traversal
- 2.12: Multi-segment motion blur
- 2.13: Subdivision surface support
- 2.14: Ray tracer

2016
- 2.15: B-Spline basis
- 2.16: Improved multi-segment motion blur, improved two level builders
- 2.17: Improved BVH8, spatial splits

2017
- 2.18: Improved BVH8, spatial splits
- 2.19: Improved BVH8, spatial splits
- 2.20: Improved BVH8, spatial splits
- 2.21: Improved BVH8, spatial splits

2018
- 3.0: Improved API, improved memory consumption
- 3.1: Normal oriented curves, grid geometry
- 3.2: Hermite basis
- 3.3: Time range per motion blur object
- 3.4: Point primitives
- 3.5: Quaternion motion blur
- 3.6: Multi-level intersecting point queries, Catmull-Rom Basis
- 3.7: Quaternion motion blur

2019
- 3.8: Collision detection

2020
- 3.9: Collision detection
Q&A
Raytracing with Embree
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