EMBREE RAY TRACING KERNELS 3.X: *OVERVIEW AND NEW FEATURES*

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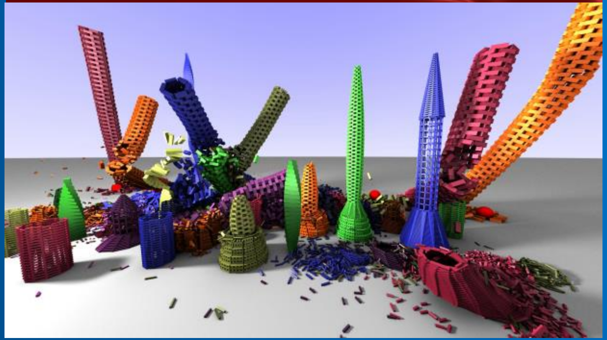

LEGAL

ACRONYM LIST

- Application Programming Interface (API)
- Bounding Volume Hierarchy (BVH)
- Independent Software Vendor (ISV)
- Instruction Set Architecture (ISA)
- Intel® Advanced Vector Extensions (Intel® AVX)
- Intel® Advanced Vector Extensions 2 (Intel® AVX2)
- Intel® Advanced Vector Extensions 512 (Intel® AVX-512)
- Intel® SPMD Program Compiler (Intel® SPC)
- Intel® Streaming SIMD Extensions (Intel® SSE)
- Intel® Threading Building Blocks (Intel® TBB)
- Non-Uniform Rational Basis Spline (NURBS)
- Single Instruction, Multiple Data (SIMD)
- Single Program, Multiple Data (SPMD)
- Surface Area Heuristic (SAH)

EMBREE OVERVIEW
EMBREE API
SELECTED ADVANCED FEATURES
EMBREE PERFORMANCE
SUMMARY & OUTLOOK

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USAGE OF RAY TRACING TODAY

- Movie industry intensively uses ray tracing today (better image quality, faster feedback)
- High-quality rendering for commercials, prints, etc.
- Provides higher fidelity for virtual design (automotive industry, architectural design, etc.)
- Various kinds of simulations (lighting, sound, particles, collision detection, etc.)
- Prebaked lighting in games, starting to go real-time for ray traced lighting and sound effects

FAST RAY TRACING CHALLENGES

- Need to multi-thread
  Easy for rendering but difficult for hierarchy construction
- Need to vectorize
  Efficient use of SIMD & ISAs (Intel® SSE, Intel® AVX, Intel® AVX2, Intel® AVX-512)
- Need to support different CPUs
  Different ISAs/CPUs favor different data structures, data layouts, and algorithms
- Need deep domain knowledge
  Many different data structures and algorithms to choose from
- Different usage scenarios
  Large model visualization favors memory conservative algorithms

EMBREE RAY TRACING KERNELS

- Targets professional rendering applications
- Provides highly optimized ray tracing kernels
  - 1.5–6× speedup reported by users
- Provides rich functionality and flexibility
- Support for latest CPUs and ISAs (e.g. Intel® AVX-512)
- Windows* (64 and 32 bit), macOS* 10.x, Linux*
- API for easy integration into applications
- Open Source under Apache* 2.0 license:
- http://embree.github.com

*Other names and brands may be claimed as the property of others.

EMBREE BROAD ADOPTION – 70+ APPS

AUTODESK

DreamWorks

V-ray

3DEXCITE

blender

UBISOFT MOTION PICTURES

corona

FluidRay Physically Based Renderer RT

EasternGraphics visualize your business

pCon PLANNER

4 TERRAGEN

VisIt

ParaView

vtk

Simlab Soft Bringing Art closer

SURVICE ENGINEERING COMPANY

STINGRAY

VMD Visual Molecular Dynamics

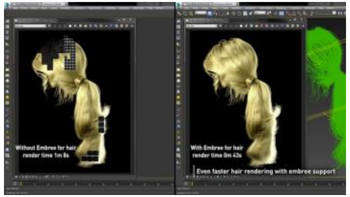
VALVE

REDWAY3D

Cinema4D

THEA RENDER

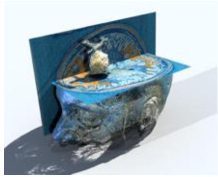
DWA How To Train Your Dragon 2



V-Ray Embree Hair Primitives

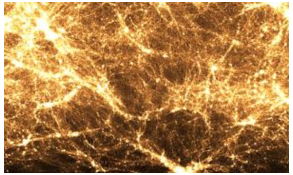
CPU/Embree Only Corona Renderer

ADSK 360 Cloud – >50M Renders



ParaView with OSPRay

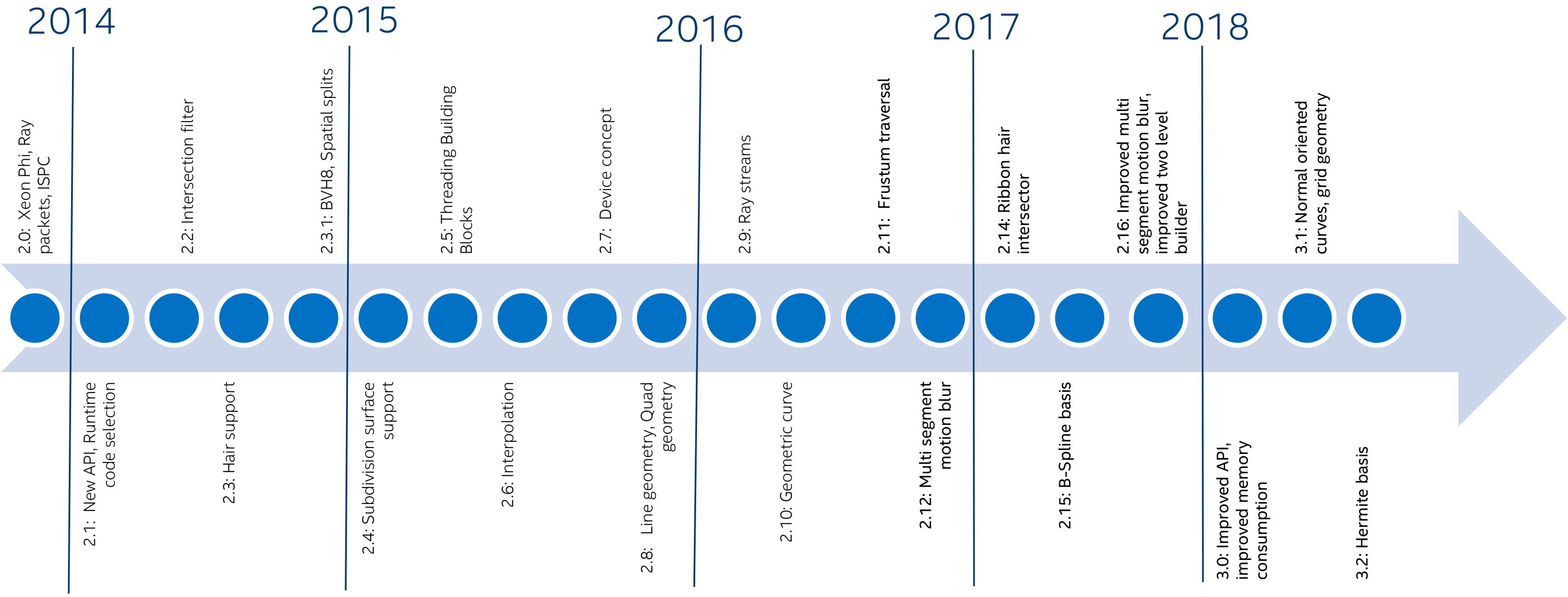
SURVICE StingRay



ANL VL3 Dark Matter - OpenSWR

Rendered with FluidRay RT

EMBREE TIMELINE



GEOMETRY TYPES

- Triangle meshes
- Quad meshes
- Grid meshes (NEW)
- Subdivision meshes
- Flat curves
- Round curves
- Normal-oriented curves (NEW)
- Instances
- User-defined ➔ extensible

Trolls (2016), rendered with MoonRay, DreamWorks Animation*

EMBREE FEATURES

- Find closest hit (rtcIntersect), find any hit (rtcOccluded)
- Single rays, ray packets (4, 8, 16), ray streams (N)
- High-quality and high-performance parallel BVH builders
  - Exploit nested parallelism through Intel® Threading Building Blocks (TBB)
- Multi-segment motion blur, instancing, static/dynamic objects, callback funcs., …
- API support for applications written in:
  - C/C++ and Intel® SPMD Program Compiler (ISPC)
- No dependence on other graphics APIs like DirectX*, OpenGL*, …

EMBREE SYSTEM OVERVIEW

Embree API (C99 and ISPC)

Ray Tracing Kernel Selection

Acceleration Structures	Builders	Traversal	Intersection	Subdiv Engine
bvh4.triangle4 bvh8.triangle4 bvh4.quad4v …	SAH Builder MBlur Builder Spatial Split Builder Morton Builder BVH Refitter	Single Ray Packet/Hybrid Ray Stream	Möller-Trumbore Plücker Flat Curve Round Curve Oriented Curve Grid	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)

EMBREE OVERVIEW

EMBREE API

SELECTED ADVANCED FEATURES

EMBREE PERFORMANCE

SUMMARY & OUTLOOK

EMBREE API OVERVIEW

- Version 3 of the Embree API
- Object-oriented
- Reference-counted
- Device concept
- Compact and easy to use
- Hides implementation details (e.g. ISA and acceleration structure selection)
- For details visit https://embree.github.io/api.html

ADVANTAGES AND NEW FEATURES OF 3.X API

- Cleanup of previous API
- Improved flexibility
- Easier to use + API bug fixes
- New primitives, e.g. normal oriented curves, grids, …
- Support for > 4 billion primitives
- More robust intersection computations
- Reduced memory consumption for instances and higher performance
- Conversion script makes adoption easy (included in Embree)

EXAMPLE: SCENE CREATION

- Scene contains a vector of geometries
- Scene geometry changes have to get committed (rtcCommitScene), which triggers BVH build

```
// 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
  ... later slide ...

  // commit changes
  rtcCommitScene(scene);

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

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

EXAMPLE: TRIANGLE MESH CREATION

- Triangle mesh contains vertex and index buffers
- Shared buffers of flexible layout (offset + stride) supported

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

// create triangle mesh
RTCGeometry geom = rtcNewGeometry(device,
    RTC_GEOMETRY_TYPE_TRIANGLE);

// share data buffers
rtcSetSharedGeometryBuffer(geom, RTC_BUFFER_TYPE_VERTEX, 0,
    RTC_FORMAT_FLOAT3, vertexPtr, 0, sizeof(Vertex));
rtcSetSharedGeometryBuffer(geom, RTC_BUFFER_TYPE_INDEX, 0,
    RTC_FORMAT_UINT3, indexPtr, 4, sizeof(Triangle));

// commit geometry
rtcCommitGeometry(geom);

// attach geometry to scene
rtcAttachGeometryByID(scene, geom, user_provided_geomID);

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

EXAMPLE: TRACING SINGLE RAYS

- Context passed to potential callbacks
- Use RTCRayHit for normal rays
- Use RTCRay for occlusion rays
- Hit data and ray.tfar set in case of hit

```
// create intersection context
RTCIntersectContext context;
rtcInitIntersectContext(&context);

// create ray
RTCRayHit query;
query.ray.org_x = 0.0f;
query.ray.org_y = 0.0f;
query.ray.org_z = 0.0f;
query.ray.dir_x = 1.0f;
query.ray.dir_y = 0.0f;
query.ray.dir_z = 0.0f;
query.ray.tnear = eps;
query.ray.tfar = inf;
query.ray.time = 0.0f;
query.hit.geomID = RTC_INVALID_GEOMETRY_ID;
query.hit.primID = RTC_INVALID_GEOMETRY_ID;

// trace ray
rtcIntersect1(scene, &context, query);

// hit data filled on hit
if (query.hit.geomID == RTC_INVALID_GEOMETRY_ID) return;

// hit data filled on hit
float u = query.hit.u;
float v = query.hit.v;
float t = query.ray.tfar;
```

INTEL® SPMD PROGRAM COMPILER (ISPC)

- C99-based language plus vector extensions
- Simplifies writing vectorized renderer
- Scalar looking code that gets vectorized automatically
- Guaranteed vectorization
- Compilation to different ISAs (Intel® SSE, Intel® AVX, Intel® AVX2, Intel® AVX-512)
- Used for written application/rendering/shading code
- Available as Open Source from http://ispc.github.com

EXAMPLE: RENDERING USING INTEL® ISPC

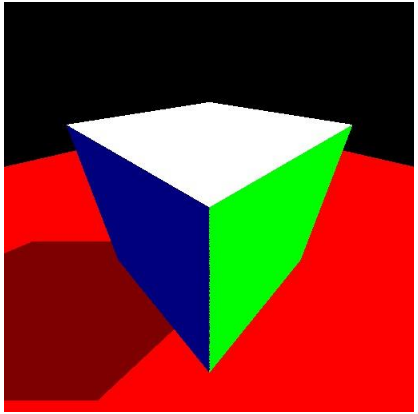
```
// loop over all screen pixels
foreach (y=0 ... screenHeight-1, x=0 ... screenWidth-1) {

    // create and trace primary ray
    RTCRayHit primary = make_RayHit(p, normalize(x*vx + y*vy + vz), eps, inf);
    rtcIntersectV(scene, &context, ray);

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

    // calculate hard shadows
    RTCRay shadow = make_Ray(primary.ray.hitPoint(), neg(lightDir), eps, inf);
    rtcOccludedV(scene, &context, shadow);

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



EMBREE OVERVIEW
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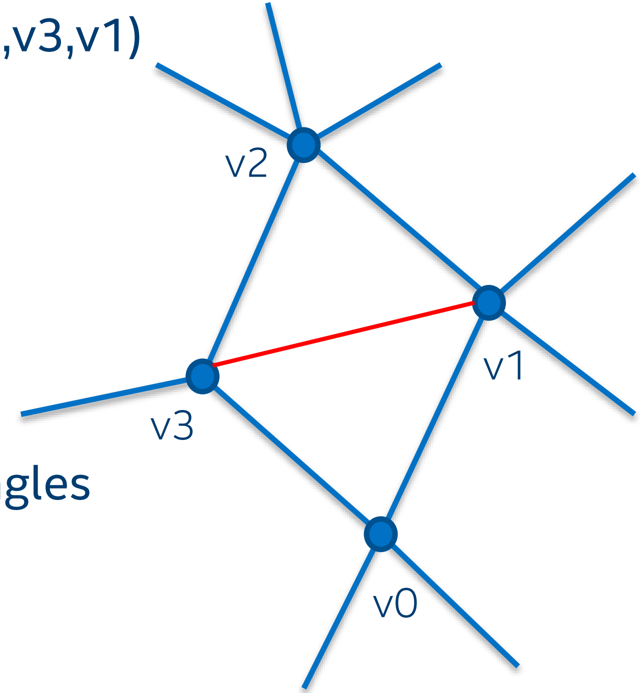
EMBREE PERFORMANCE
SUMMARY & OUTLOOK

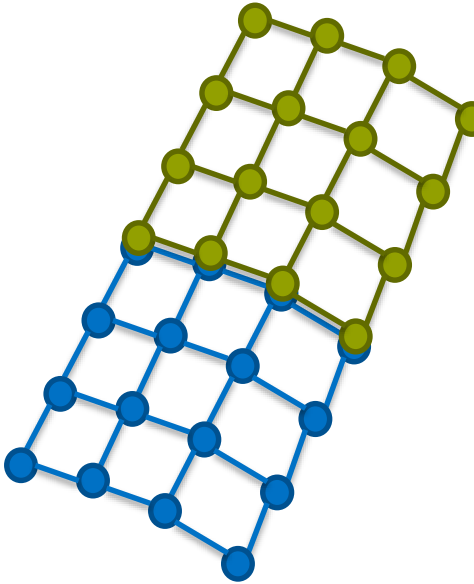
QUAD MESHES

- Quad rendered as pairs of triangles (v0,v1,v3 and v2,v3,v1)
- Mixed triangle/quad mesh supported (v0,v1,v3,v3)
- Most 3D modeling packages produce quad meshes
- Lower memory consumption
- Faster BVH building
- Ray tracing performance slightly lower than for triangles



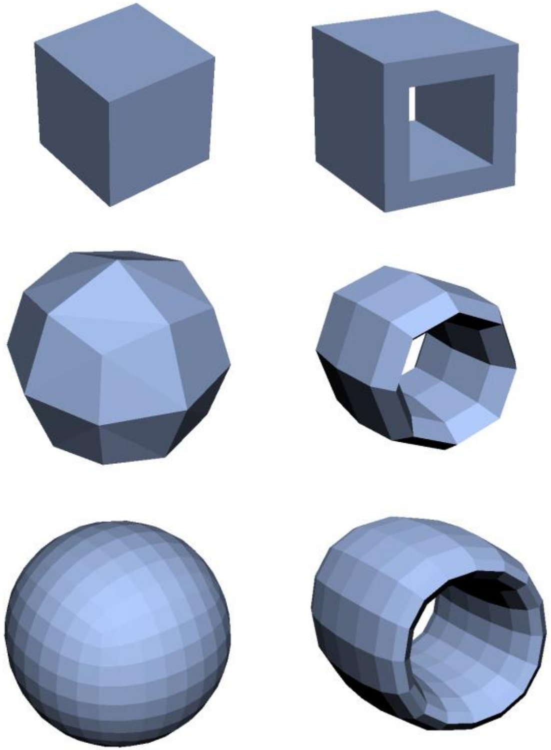
GRID MESHES

- 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
- Use instead of subdiv mesh **with** displacement function



CATMULL-CLARK SUBDIVISION SURFACES

- Converts coarse mesh into smooth surface (subdivision)
- Support for arbitrary topology
- Established as standard in movie production
- Embree implementation compatible with OpenSubdiv 3.0 (creases, boundary modes, etc.)
- Evaluation of surface supported
- Walking mesh topology supported



CURVE GEOMETRIES

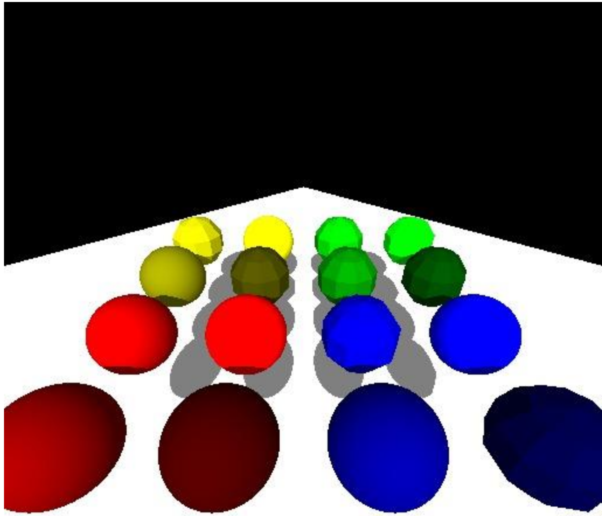
- Curve bases
  - Linear (for very distant curves)
  - Cubic Bézier (widely used representation)
  - Cubic B-spline (most compact)
  - Cubic Hermite (compact and interpolating)
- Curve types
  - Flat curves (for distant geometry)
  - Round curves for close-ups (swept circle)
  - Normal-oriented curves (for grass)

CURVE GEOMETRIES

- Supports varying radius along the curve
- High performance through use of oriented bounding boxes [Woop et al. 2014]
- Low memory consumption through direct ray/curve intersection (new algorithm)

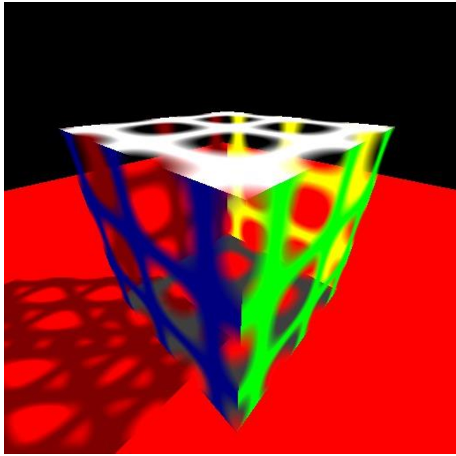
USER-DEFINED GEOMETRIES

- Enables implementing custom primitives and features
  - Sphere, disk, multi level instancing, rotation motion blur, etc.
- User provides:
  - Bounding function
  - Intersect and occluded functions



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



MULTI-SEGMENT MOTION BLUR

- Important to render fast curved motion (e.g. rotating wheels, fight scenes, spinning dancers, etc.)
- Sequence of time steps to be piecewise-linearly interpolated
- Typically equidistant time steps and often different number of time steps per geometry
- 4D-BVH which stores linear spatial and temporal bounds
  - BVH can spatially separate geometries
  - BVH can reduce time ranges where required

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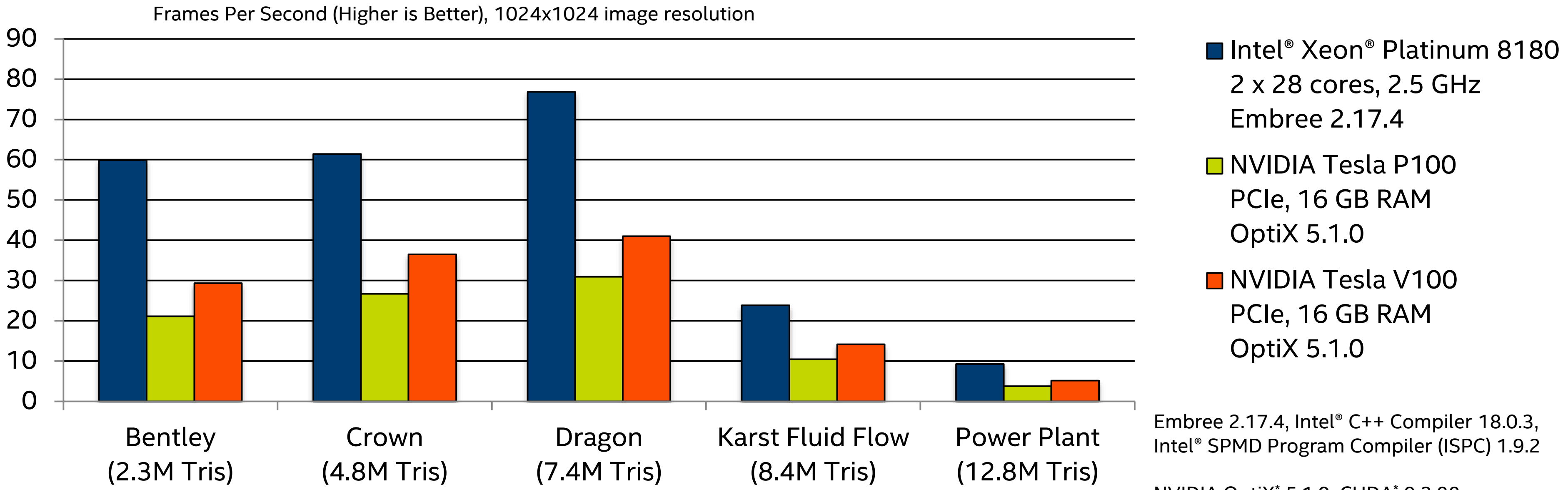
BENCHMARK OVERVIEW

- Path tracer with different material types, different light types, ~2k lines of code
- Similar implementation for CPU (ISPC + Embree) and GPU (CUDA* + OptiX*)
- Highest quality BVH build settings for all platforms
- Evaluation on typical Intel® Xeon® rendering workstation†
  - Dual-socket Intel® Xeon® Platinum 8180 Processor (2x28 cores @ 2.5 GHz)
- Compare against state-of-the-art GPU methods
  - OptiX 5.1.0 and CUDA 9.2.88
  - NVIDIA Tesla* V100 Coprocessor (5120 CUDA cores @ 1.37 GHz, Volta)

PERFORMANCE: EMBREE VS. NVIDIA OPTIX*



Embree 2.17.4, Intel® C++ Compiler 18.0.3, Intel® SPMD Program Compiler (ISPC) 1.9.2

NVIDIA OptiX* 5.1.0, CUDA* 9.2.88

Source: Intel

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SUMMARY

- Embree provides optimized and scalable ray tracing kernels for the CPU
- Latest state-of-the-art feature set
  - Lots of ray tracing research goes directly into Embree ☺
- Actively developed and completely open-source
- Easy to integrate into existing applications
- Lots of ISVs using it as their core ray tracing engine

OUTLOOK

- Denoising
- Quaternion interpolation for transformation motion blur
- Non-uniform motion blur
- New primitive types (disk, sphere, bilinear patch)
- Improve ray/geometry masking and instancing performance
- Point projection onto geometry (robust manifold next event estimation)
- Partial double support

QUESTIONS?

Check out the Embree/OSPRay demos at booth #1300 West Hall

https://embree.github.io

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