STBVH: A Spatial-Temporal BVH for Efficient Multi-Segment Motion Blur

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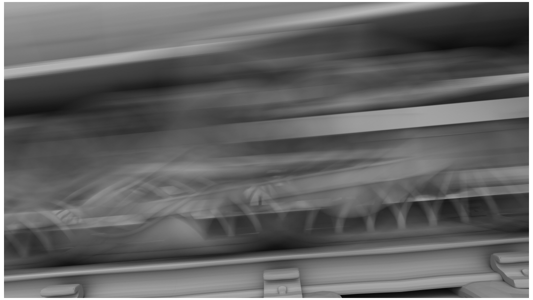
Motion Blur

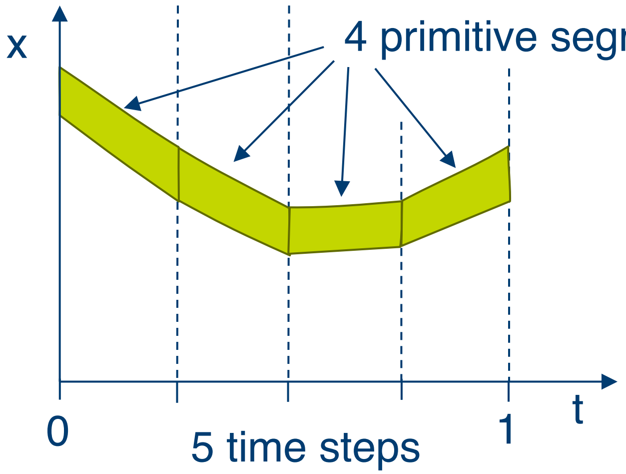
- Fast moving geometry gets blurred for long shutter times
- Often fast moving geometry moves on a straight line (linear motion blur)
- Sometimes fast curved motion (e.g. rotating wheel, fight scenes, spinning dancer, flying bird, etc.)

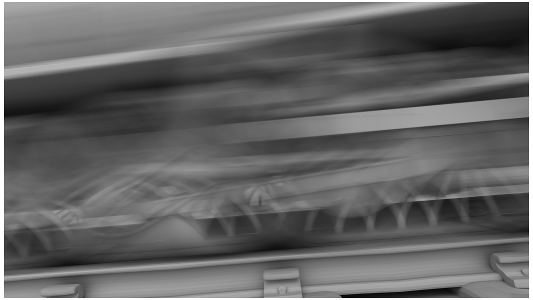
→ Multi Segment Motion Blur required



Multi Segment Motion Blur

- Represent curved motion as sequence of time steps to be linearly interpolated
- Typically equidistant time steps and often different number of time steps per geometry





Previous Work

Linear Motion BVH using OBB Hyper-trapezoids [Hou et al. 2010]

- Works well for linear motion but inefficient for curved motion.

Multiple Linear Motion BVHs for sufficiently large number of time segments [Embree v2.12.0]

- High performance but memory consumption can be arbitrarily bad.

Sequence of AABBs per BVH node [Grünschloß et al. 2011]

- One BVH topology for entire motion, calculate segment to interpolate per traversal step, packet techniques have to gather bounds

4D kd-tree [Olsson 2007]

- Can shrink time range to simplify motion, kd-tree not good at bounding linear motion, no good build algorithm described

4D BVH using 12 fixed slab directions [Glassner 1988]

- Expensive to traverse (24 distance tests to mostly non-axis aligned planes), fixed directions do not align optimally with motion direction

Combining separate renderings for sufficiently many time segments

- No adaptive noise reduction possible, interactive preview not possible

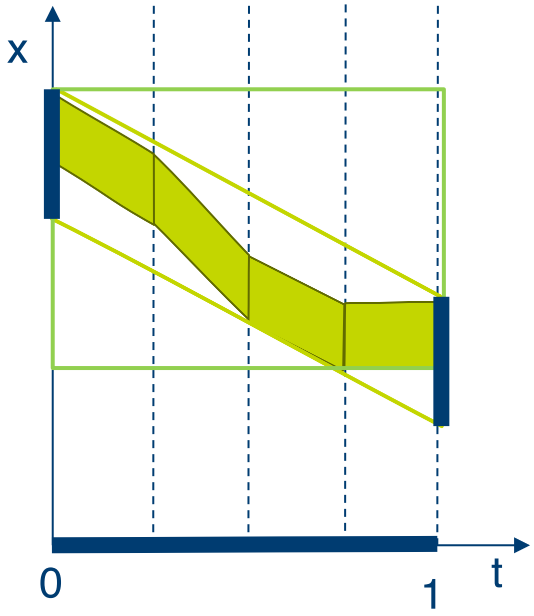
4D Spatial-Temporal BVH (STBVH)

- N-ary BVH (4 or 8 wide) [Ernst 2008, Dammertz 2008]
  - SOA layout allows efficient use of SIMD instructions during traversal
- Stores spatial *linear bounds* [Qiming Hou et al. 2010]
  - Pair of AABBs that bound the geometry for each time when linearly interpolated to the respective time
  - Efficient support for the common case of linear motion
- Stores temporal bounds as time range [Olsson 2007, Glassner 1988]
  - Efficient support of curved motion through time range reduction
- Two node types for improved performance
  - Spatial-temporal nodes (stores linear bounds and time range)
  - Spatial nodes (stores linear bounds only)

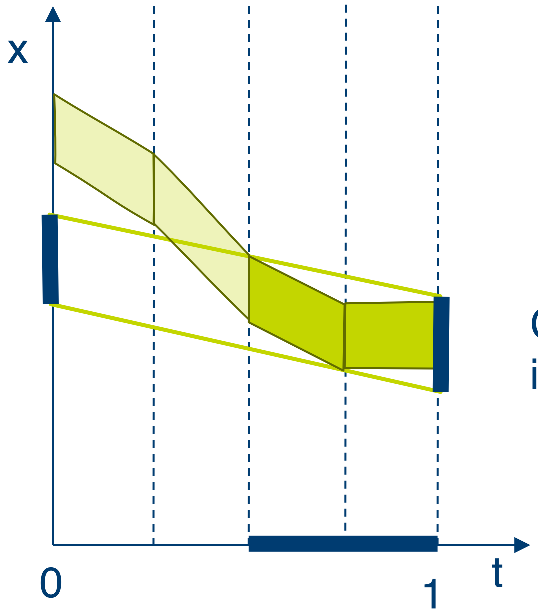
STBVH Advantages

- Efficient handling of different number of time steps per geometry
  - E.g. high temporal resolution possible for main character
  - Large memory savings compared to Embree 2.12.0 implementation
- Efficient handling of longer animations
  - Renderers with large setup times can render multiple frames with one STBVH
- Reduced memory consumption in case of unnecessarily high number of time steps
  - For these parts time ranges do not have to get reduced

Temporal Spatial Bounds Example 1



Temporal Spatial Bounds Example 2



Global linear bounds allow direct interpolation with ray time.

Minimal Traversal Changes

- Ray/box intersection with box interpolated to ray time
- Additional check for time bounds in case of spatial-temporal node

Motion Blur Surface Area Heuristic (MBSAH)

- Motion Blur Surface Area Heuristic
  - $C_{leaf}(X) = |X|_s \cdot C_I$
  - $C_{split}(X, X_0, X_1) = C_T + P(X_0|X) \cdot C_{leaf}(X_0) + P(X_1|X) \cdot C_{leaf}(X_1)$
- Where
  - X is the set of pairs of primitives and time ranges
  - $|X|_s$ is the sum of the number of *primitive segments* active in the time range
  - $P(Y|X) = \frac{SA'(Y)}{SA'(X)} \cdot \frac{T(Y)}{T(X)}$
  - $T(X)$ calculates the size of the merged time bounds over X
  - $SA'(X)$ calculates the surface area of the center time bounds of the linear bounds of X

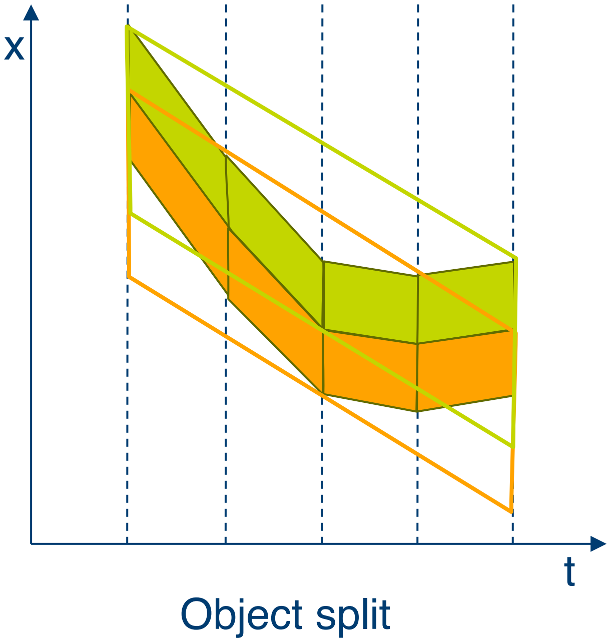
MBSAH Advantages

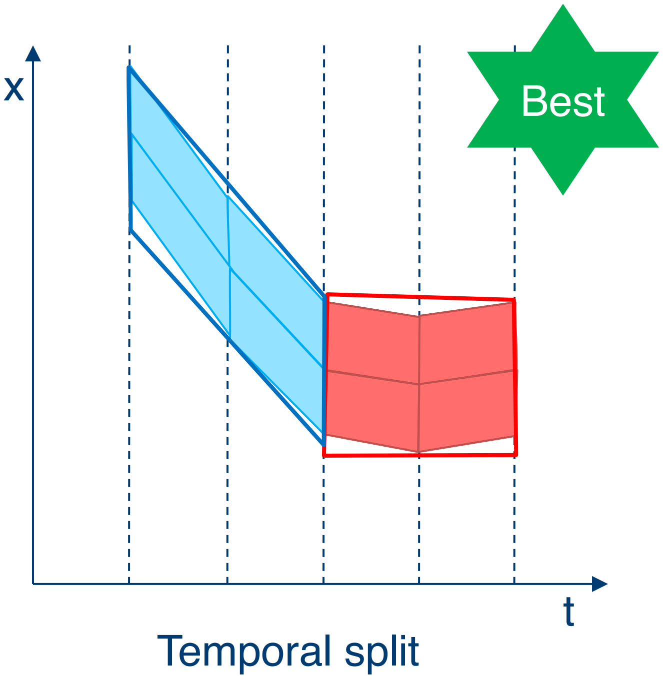
- Handling primitives plus time range
  - Makes time splits of primitives possible
- Counting primitive segments active in time range
  - Increases cost for geometries with many time steps
  - Splitting time at discrete time boundaries produces optimal SAH
- Surface area of linear bounds
  - More accurate than previous approaches
  - Up to 10% render performance improvement for some scenes

STBVH Build

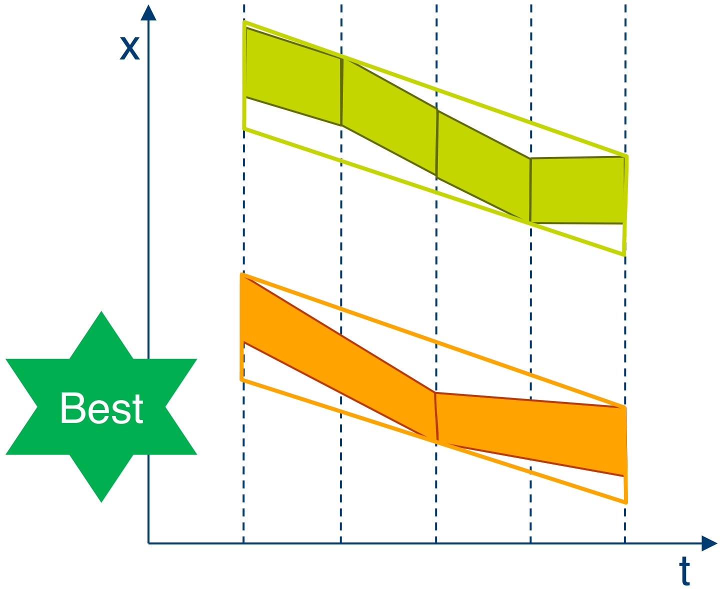
- Top-down construction using MBSAH
- *Build primitive* represents primitive for current time range
  - Stores linear bounds and number of active primitive segments
- Object split
  - Bin build primitives in 3 dimensions using centroid of center time bounds
  - Splits build primitives into two disjoint sets with current time range unchanged
- Temporal split
  - Splits current time range at center time (adjusted to hit discrete time boundary)
  - Generate build primitives for both time ranges (most primitives valid in both time ranges)

MBSAH: Temporal Split

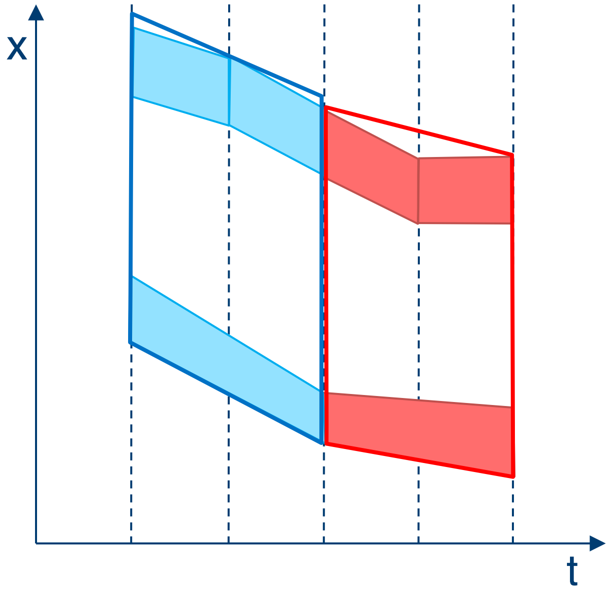




MBSAH: Spatial Split



Object split



Temporal split

Results

Llama
3 time steps: 7M primitives
9 time steps: 1.7M primitives

Barbershop
3 time steps: 1.4M primitives
5 time steps: 2.8M primitives
9 time steps: 3.9M primitives

Train
3 time steps: 0.3M primitives
17 time steps: 2.0M primitives

Turtle Barbarian Crowd
2 time steps: 7.5M primitives
6 time steps: 2.8M primitives
15 time steps: 0.1M primitives

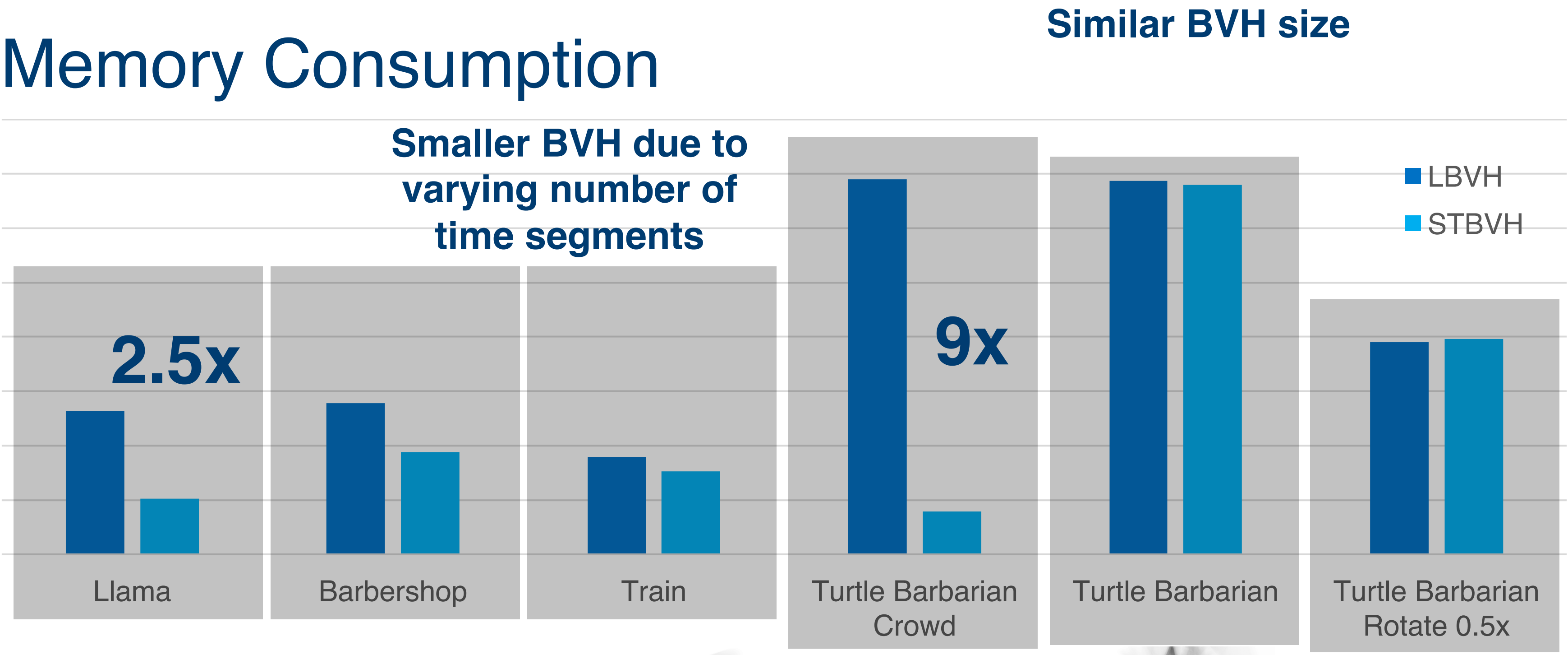
Turtle Barbarian
15 time steps: 0.1M primitives

Turtle Barbarian Rotate 0.5x
9 time steps: 0.1M primitives

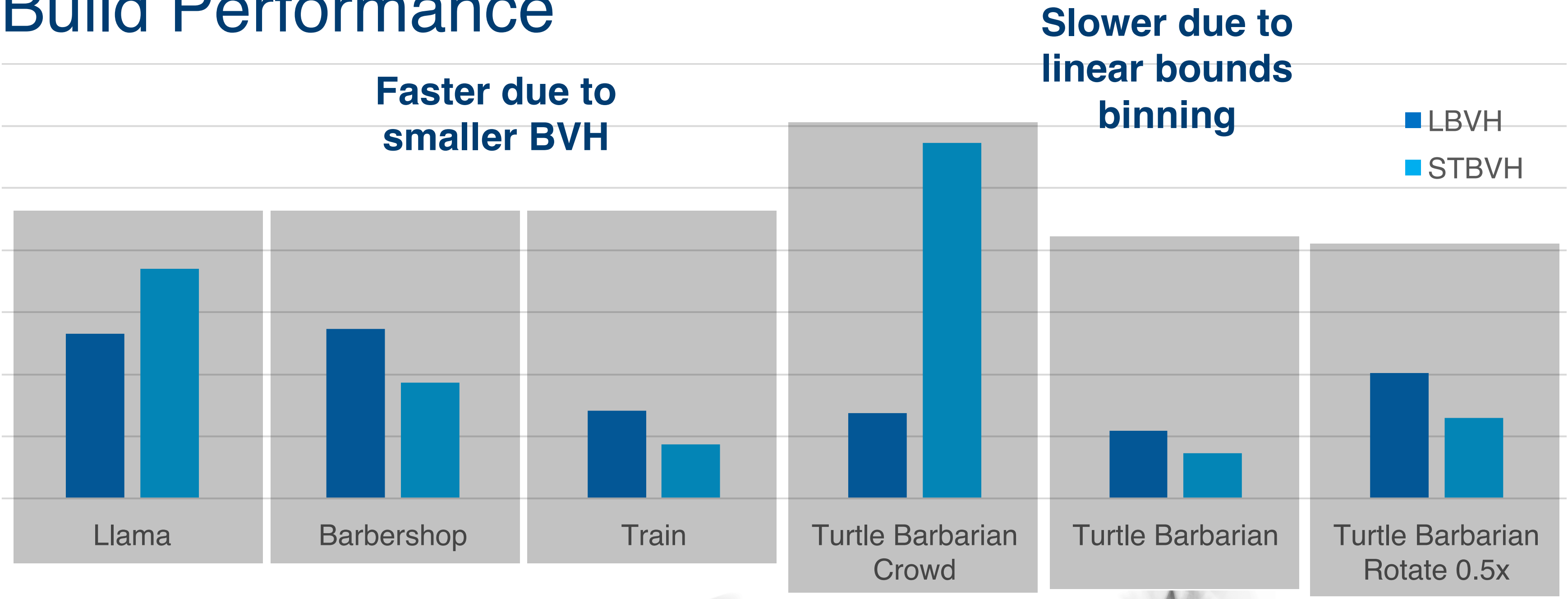
Results

- Comparing against LBVH of Embree 2.12.0
  - Separate Linear Motion BVHs for maximal number of linear time segments
  - We integrated our STBVH into Embree thus share algorithmic details of traversal and build
- Only motion blur geometry for benchmarks
- Intel® Xeon® E5-2699 v4 workstation (Broadwell 22 cores, 2.2 GHz)

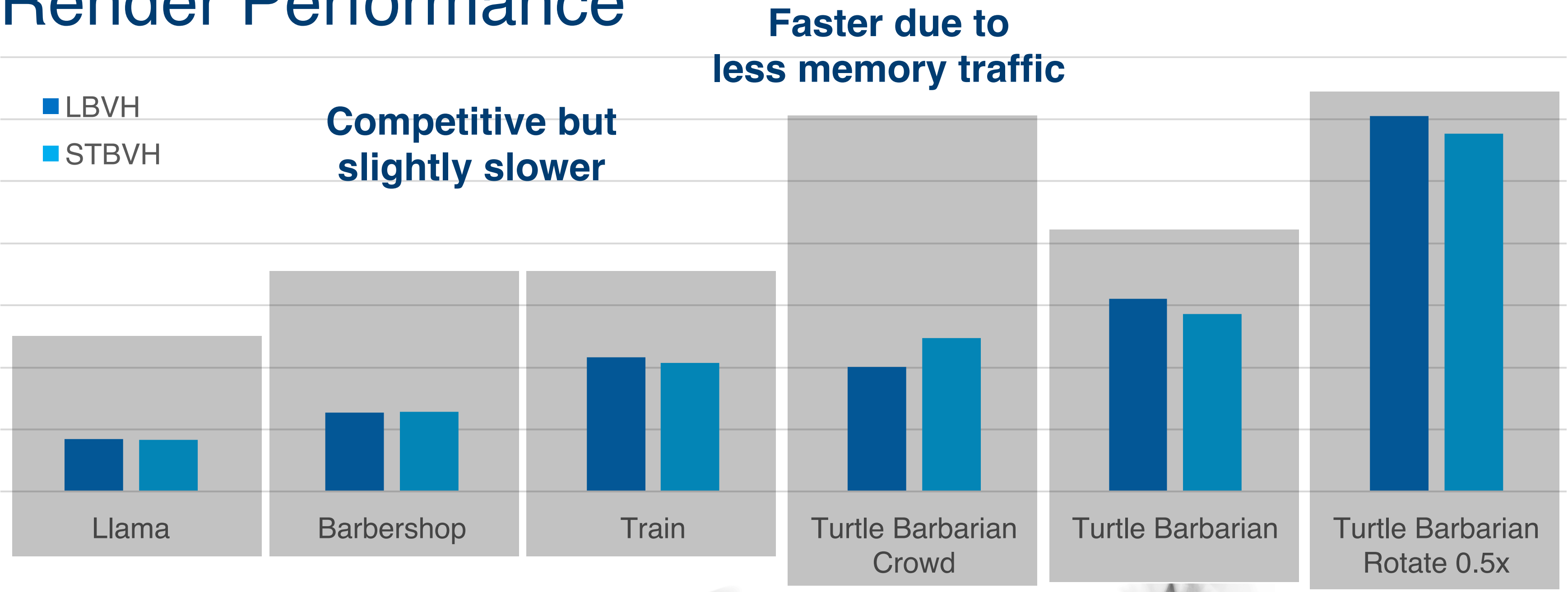
Memory Consumption



Build Performance



Render Performance



Questions?

“High Performance Rendering Appliance” demo
at Intel booth #807 at SIGGRAPH