Stochastic Subsets for BVH Construction

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Ray Tracing

Use cases: Primary Visibility, NEE, Path Tracing, ...
Bounding Volume Hierarchies (BVHs)
BVH Traversal
BVH Construction

• Tradeoff between build time & quality/traversal efficiency
• General goal: Better quality in less build time
• Targeted for GPUs

[Meister et al. 2021]
Previous Work

• **Top-Down**
  • Binning [Wald 2007]
  • Progressive Refinement [Jakub et al. 2017]

• **Bottom-Up**
  • Agglomerative clustering [Walter et al. 2008]
  • Parallel locally ordered clustering (PLOC) [Meister and Bittner 2017]
  • PLOC++ [Benthin et al. 2022]
Previous Work

• Incremental construction
  • Greedy [Goldsmith and Salmon 1987]
  • Online [Bittner et al. 2015]

• Linear BVH [Lauterbach et al. 2009, Karras 2012]

• Topological optimization
  • Treelet restructuring (TRBVH / ATRBVH)
    [Karras and Aila 2015, Domingues and Pedrini 2015]
  • Parallel reinsertion [Meister and Bittner 2018]
Top-Down Construction

• Superior quality to other build algorithms [Aila et al. 2013]
• Problem: Repeated access of all primitives $O(N \log N)$
Key Concept: Stochastic Subsets

• Primitive subset can preserve high-level structure of a mesh

• Needs to be chosen in a representative fashion (e.g., stochastically)

• Top-levels of BVH show aggregated behavior of the data
Stochastic Subset BVH Construction

Idea: Operate on subset for first levels to achieve speedup
Stochastic Subset BVH Construction

Idea: Operate on subset for first levels to achieve speedup
Subset Sampling

Requirements
• Follow primitive distribution
• Selection proportional to primitive size
• Guaranteed selection of large primitives

→ Combination of Spatial Ordering, Importance Sampling & Stratification
Subset Sampling

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Subset Sampling

In the paper:
- Weight clamping
- Defensive sampling
Varying Subset Size

Colored: Subset Primitives; Color: Spatial Ordering
Stochastic Subset BVH Construction

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Idea: Operate on subset for first levels to achieve speedup
Primitives Insertion

For each primitive, find *best* leaf to insert into
Primitives Insertion

Use approximate neighborhood [Meister et al. 2017]
Leaf node selection
Stochastic Subset BVH Construction

Idea: Operate on subset for first levels to achieve speedup
Evaluation
Environment

• Intel® Alchemist A770 GPU (32 Xe cores).
• Intel® Core i5 9600K @ 3.7 GHz
• 16GB DDR4 RAM
• Ubuntu 20.04 LTS

• oneAPI DPC++ / SYCL

• Subset size of 20%
Scenes

- Crytek Sponza (279K)
- Bistro (1.8M)
- Hairball (2.9M)
- Crown (4.9M)
- Rungholt (6.7M)
- San Miguel (7.9M)
Compared Builders

- GPU implementation of top-down binned SAH builder \[\text{[Wald 2007]}\]
  - Also used as interior builder
- Other state of the art builders:

**LBVH**

**PLOC / PLOC++**

**TRBVH / ATRBVH**
Quality Metric: Binary BVH SAH Cost

Better ↓
Hardware Ray Throughput with AO (GRays/s)

- Additional conversion to hardware-specific BVH format
Discussion
Discussion

• The relative overhead impacts the final speedup
Discussion

• Currently benefits $O(N \log N)$ algorithms
• Not directly applicable to $O(N)$ approaches in its current form
• Higher memory footprint for additional buffers
Conclusion

• New primitive in BVH construction
  • Now possible to importance sample multiple features of the scene
• Retains quality of top-down builder at 1.5x avg. (~1.9x max.) speedup
• Reducing the gap to faster builders (e.g. PLOC++)
  • Untapped theoretical speedup still on the table
Thanks for your attention! Questions?
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Backup
Introduction - Surface Area Heuristic (SAH)

- Quantifies intersection cost through bounding box areas
Subset Sampling - Weight Clamping

Ideal

Reality

→ Duplicates
Subset Sampling - Weight Clamping

Before Weight Clamping

After Weight Clamping
Subset Sampling - Weight Clamping

\[ \text{clamp} \geq \text{stratum} \cdot \sum_{j}^{N} \min(\text{weight}_j, \text{clamp}) \]

\[ \text{clamp} = \text{weight}_k \]

\[ \sum_{j=0}^{k} \text{weight}_j + (N - k) \cdot \text{clamp} \]

Find smallest \( k \) which satisfies \( \text{weight}_k \leq \text{stratum} \cdot \sum_{j}^{N} \min(\text{weight}_j, \text{weight}_k) \)
Subset Sampling - Defensive Sampling

Small, highly tessellated flower in San Miguel.

Forcing some more uniform selection levels the cluster size after insertion.

Cluster size histogram: left max > 35k primitives, right max 500
Primitives Insertion - Metric

Metric: Increase of SAH [Bittner et al. 2013]

• Only need to evaluate leaf and ancestor nodes
  • Search can be parallelized in groups
Throughput

- much fewer primitives in the first levels …
Throughput

- much fewer primitives in the first levels ...
- ... but also less throughput
- there is still a net speedup, but less than anticipated