

EUROGRAPHICS 206

THE 37th ANNUAL CONFERENCE OF THE EUROPEAN ASSOCIATION FOR COMPUTER GRAPHICS

SAH guided spatial split partitioning for fast BVH construction

Per Ganestam and Michael Doggett Lund University

Opportunistic triangle splitting for higher quality BVHs

- Bounding Volume Hierarchies (BVH) are a simple, compact 3D data structure commonly used in Ray Tracing
- Objective is fast construction, fast tracing, and minimal memory
- Traversal cost : Whiter pixels means higher cost



BVH construction

- Focus on a top down approach
- Recursively subdivide triangles
 - Decide where to divide
 - Surface Area Heuristic (SAH) measures cost
 - Sweep SAH is a greedy top down method
- Creating a binary tree



Surface Area Heuristic

$$C_{i}\sum_{n\in I}\frac{A(n)}{A(root)}+C_{l}\sum_{n\in L}\frac{A(n)}{A(root)}+C_{t}\sum_{n\in L}\frac{A(n)}{A(root)}N(n),$$

- A(n) is the surface area
- Find the ratio of current triangle's BB area to parent's
- Consider cost, C, of

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- intersection of internal, *i*, and leaf, *l*, nodes
- t, traversal
- Which partitioning gives the lowest cost?

Bonsai BVH construction algorithm



• From "Bonsai: Rapid Bounding Volume Hierarchy Generation using Mini Trees", Ganestam, Barringer, Doggett, and Akenine-Möller, JCGT, Sep. 2015

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Bonsai Partitioning using triangle mid-points



Guarantees no empty partitions



Bonsai algorithm with pruning

- For mini-trees with large bounds
- Delete node and promote children

Before pruning



Triangle Splitting

- Problem : Big and small triangles don't mix well
- Split clipping splits the bounding box
- Previous algorithms split before construction
 - Early Split Clipping [EG07] and EVH [DHK08]
 - Can result in more triangles and poor splits
 - Also adds to the overall construction time
- Some algorithms need per scene parameters
- Our solution : SAH Spatial Split Partitioning



- Split triangles while partitioning
- Create triangle sets
- Only split triangles when SAH cost is lower than not splitting





• Brown box is mid-point bounds and used to find split plane





Triangle Sets

- Disjoint set
 - D_L, D_R

• Brown box is mid-point bounds and used to find split plane





- **Triangle Sets**
 - Disjoint set
 - D_L, D_R
 - Overlap sets
 - O_L , O_R

- Brown box is mid-point bounds and used to find split plane
- Overlap sets have triangles that overlap the split plane





Triangle Sets

- Disjoint set
 - D_L, D_R
- Overlap sets
 - O_L , O_R
- Split sets
 - S_L , S_R

- Brown box is mid-point bounds and used to find split plane
- Overlap sets have triangles that overlap the split plane
- Split sets contain all overlap triangles

SAH Spatial Split Partitioning algorithm

- Recursively partition using mid-point and SAH cost
 - Take lowest cost of split vs. not split
 - Until mini trees are between 512 and 8K triangles (based on overall scene size)
- Mini trees processed using Sweep SAH



Efficient memory allocation

- Problem : Using separate arrays and merging
- Solution : In place, memory growing
- Memory is allocated for all triangles + 20%
- One half of split triangle overwritten in-place
 - and the other half added to the other side
- What empty space is left is rebalanced
- If split triangles don't fit

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Allocate more memory for right set + 20%

Efficient memory allocation O_L D_L D_R O_R



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- Implemented in Intel's Embree Ray Tracer, version 2.7.1
- Results generated on laptop CPU (MacBook Pro) with AVX2 support
- Consider both build and tracing times
- Compare to algorithms
 - Without splitting
 - SweepSAH
 - Bonsai
 - BinnedSAH (included in Embree)
 - With splitting
 - BonsaiS (Proposed algorithm)

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- SweepPre (Proposed algorithm as a pre splitting pass for Sweep)
- BinnedPre (Pre-split algorithm in Embree)
- BinnedS (Spatial split algorithm in Embree, based on SBVH [SFD09])

	A	rabic City		Crown		Dragon		Fairy Forest		Italian City		Kalabsha	
Triangles	-	416,236	4	,868,924	7	,349,978		174,117		382,029	4	,542,705	
	Build	Trace	Build	Trace	Build	Trace	Build	Trace	Build	Trace	Build	Trace	
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All measurements in ms

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BonsaiS is one of 2 best tracing 10/12 times

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SWEEPPRE	374	243 [82%]	5414	322 [99%]	8087	134 [104%]	147	301 [100%]	322	239 [80%]	6098	550 [100%]
BONSAIS	53	247 [84%]	535	316 [97%]	827	132 [102%]	24	297 [99%]	47	231 [77%]	765	513 [93%]
BINNEDPRE	91	267 [91%]	980	317 [98%]	1577	134 [104%]	40	305 [102%]	77	254 [85%]	811	572 [104%]
BINNEDS	404	237 [80%]	4130	304 [94%]	2205	124 [96%]	129	289 [97%]	316	229 [76%]	4646	505 [92%]
											N. C.	
Trionales		Mini	Power Plant		Sala		San Miguel		Sibenik		Sponza	
Triangles	Build	712,411 Trace	Build	.,739,240 Trace	Build	400,037	/ Build	,000,512	Build	79,360 Trace	Build	202,207 Trace
SWEEPSAH	719	593 [100%]	14347	617 [100%]	283	298 [100%]	8208	394 [100%]	49	222 [100%]	178	1210 [100%]
BONSAL	74	581 [98%]	1261	606 [98%]	34	298 [100%]	711	363 [92%]	9	225 [101%]	22	1137 [94%]
BINNEDSAH	83	592 [100%]	1311	700 [113%]	35	332 [111%]	798	386 [98%]	7	222 [100%]	22	1393 [115%]
SWEEPPRE	952	548 [92%]	17603	469 [76%]	359	296 [100%]	9301	359 [91%]	53	222 [100%]	213	1224 [101%]
BONSAIS	106	538 [91%]	1881	437 [71%]	47	286 [96%]	835	339 [86%]	11	218 [98%]	29	1057 [87%]
BINNEDPRE	166	617 [104%]	3625	606 [98%]	90	339 [114%]	2168	388 [98%]	14	229 [103%]	56	1244 [103%]
				~ ~								
BINNEDS	739	572 [96%]	13835	441 [71%]	342	292 [98%]	7118	341 [87%]	53	213 [96%]	168	1113 [92%]

- For 4 scenes BonsaiS traces faster than BinnedS (considered to be the HQ builder)
- SweepPre is twice in the top two tracers
 - and is typically between BinnedS and BinnedPre (Embree builders)
- BinnedS always improves tracing performance of BinnedSAH, but at much longer build times
- BinnedS allocated 34x more memory compared to BonsaiS (measured with Valgrind)
- For Arabic City BonsaiS allocated 735MB, BinnedS 25GB



Parallel scaling



EUROGRAPHICS 2016

- Intel E5-2643V3 dual socket 12 core CPU
- Powerplant scene
- Per frame tracing performance on the 12 core CPU
 - BonsaiS 105ms
 - BinnedSAH 162ms

Conclusion

- Simple top down triangle splitting and BVH construction algorithm
- Integrated or preprocess triangle splitter
- Fast BVH construction and fast ray tracing
- Source code will be available in Embree and on paper web page

• Acknowledgements : Thanks to ELLIIT and the Intel Visual Computing Institute for funding.





Bonus slides



Binary Trees

- GPU (Intel Iris Pro 5200) traversal, CPU shading
- BonsaiS improves tracing performance compared to SweepSAH for all scenes
- Similar tracing improvement to [KA13], but with fewer split triangles

	Arabic City	Crown	Italian City	Kalabsha	San Miguel	Sponza
SWEEPSAH	240 [100%]	191 [100%]	129 [100%]	455 [100%]	667 [100%]	630 [100%]
BONSAIS	155 [65%]	183 [96%]	86 [67%]	330 [73%]	499 [75%]	380 [60%]



Triangle Counts and SAH costs

- BonsaiS creates fewer additional triangles than the two triangle split methods available in Embree
- BonsaiS can split far fewer triangles and get the same and faster tracing
- BonsaiS consistently produces lower SAH costs





- **Triangle Sets**
 - Disjoint set
 - D_L, D_R
 - Overlap sets
 - O_L, O_R
 - Split sets
 - S_L, S_R

- Brown box is mid-point bounds and used to find split plane
- Overlap sets have triangles that overlap the split plane
- Split sets contain all overlap triangles

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