

# Parallel BVH Construction for Real-Time Ray Tracing

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## ABSTRACT

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The rise in popularity of interactive graphical applications, such as video games, has motivated innovations in rendering 3-dimensional scenes in real time. The ray tracing technique is well-suited for generating realistic images of scenes that feature shadows, reflections, and refractions [3]. Historically, ray tracing has been too slow for real-time applications since it is computationally intensive. However, ray tracing performance can be greatly improved by using an acceleration data structure such as a bounding volume hierarchy (BVH) to store scene information for each frame. Researchers have strived to minimize the combined time of both constructing and using the acceleration data structure. This paper provides a thorough explanation of ray tracing with BVHs and presents a novel method for constructing them in parallel.

## Keywords

thing1, thing2, thing3

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## 1. BACKGROUND

Sources here.

[1] [2] [3]

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In 3D computer graphics, objects are made up of a collection of *primitives*, which are usually simple geometric shapes like triangles. A 3D *scene* consists of all the primitives that construct it. Figure 1 depicts a scene with a dolphin that clearly shows the component triangles. In order to depict a scene on a display, the pixels of the display must be colored to create an image. A technique called *ray tracing* can be used to color the pixels in a way that can accurately portray shadows, reflections, and refractions in a scene. Ray tracing achieves this by determining how light travels in a

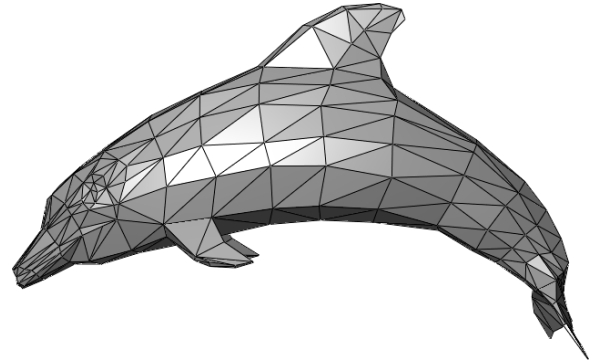


Figure 1: A simple scene containing only a dolphin constructed from triangle primitives.

scene from the light sources, reflecting or refracting off objects, and meeting the viewer. Figure 2 shows the incredible photorealism that ray tracing can achieve.

Since many rays of light from a light source may not ultimately reach the viewer, it is more practical to start from the viewer and trace paths of light backwards. For every pixel on a display, a ray is traced from the viewer through the pixel and into the 3D scene. When a ray intersects with an object in the scene it can recursively generate more rays in directions that will contribute to an appearance of reflections, refractions, or shadows. While ray tracing can create highly realistic images, the process of tracing a large number of rays for a 3D scene with many primitives on a high resolution display can take a very long time.

Ray tracing a single frame of a 3D scene can involve testing for intersections of billions of rays against millions of primitives such as triangles. In order to speed up this process, acceleration data structures can be used to organize the primitives by their location so that only a small subset of them need to be tested for intersection against any given ray. Acceleration data structures usually take the form of a tree: the top node represents the entire 3D volume of the scene and the children of every node divide up the volume of their parent node into subsections. Although these acceleration data structures speed up ray intersection, the time it takes to build these trees can negatively impact performance. This is especially apparent in scenes with moving objects since the acceleration data structures need to be rebuilt or updated to accurately reflect the new locations of objects.

This research addresses methods for building and main-

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UMM CSci Senior Seminar Conference, May 2016 Morris, MN.



Figure 2: A ray traced scene featuring shadows on the wall and beneath the glasses, reflections on the glossy surfaces of the glasses, and refractions through the glass stems and ice cube.

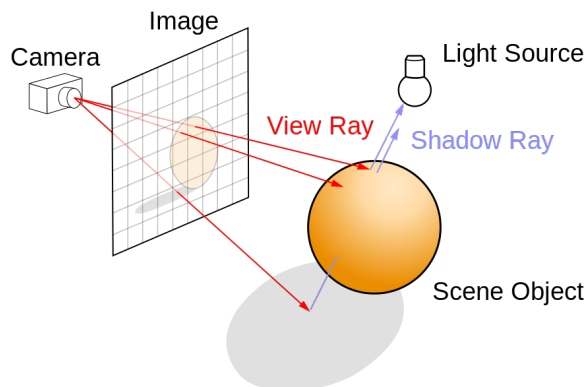


Figure 3: A ray is cast through every pixel of the image plane and tested for intersection with objects in the scene. When intersections occur, the angle of reflection is calculated and a new ray is sent out. Eventually, if a ray intersects with a light source, the color information propagates back to the pixel.

taining acceleration data structures in a way that minimizes the combined time spent constructing the data structure and using it to test for ray intersections. In particular, parallel computing can be effectively utilized to decrease the time spent on an acceleration data structure. More efficient acceleration data structures allow for ray tracing scenes with motion in real time.

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## 2. ACCELERATION DATA STRUCTURES

One of the most time-consuming aspects of ray tracing involves testing for intersections between rays and primitives in the scene. This is because there are usually very many primitives in a scene, and an intersection needs to be checked for all of them. However, if the primitives are stored in a data structure that helps identify where they are located in the scene, then a ray only needs to check for intersections with objects located in the parts of the scene the ray is pass-

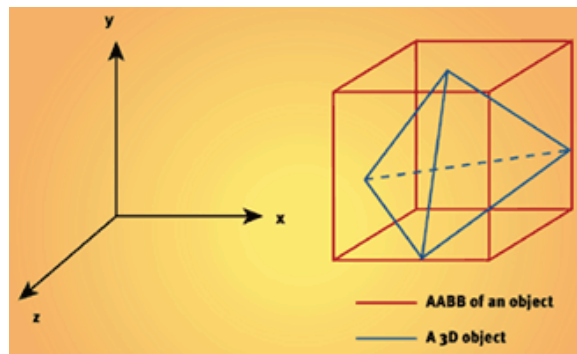


Figure 4: An axis aligned bounding box containing an object constructed from four triangles. Note that the box is fitted as tightly as possible and the edges of the box lie parallel to the axes of the scene.

ing through. This can drastically improve the performance of intersection testing for each ray.

A common way to make intersection tests easier to calculate is to surround primitive with bounding boxes. A bounding box is just a box that completely contains an object as tightly as possible. A common approach is to use *axis-aligned bounding boxes* (AABBs), which are aligned with the axes of the scene as a whole. It is usually much simpler to test for ray intersections with AABBs than with the objects they contain. If a ray does not intersect with an object's AABB, then it cannot intersect with the object itself. However, if it does intersect with the AABB, then a more costly check must be made to test for intersection with the contained object. Overall, the use of AABBs can reduce the cost of testing for intersections since a ray misses many more objects than it hits.

*Bounding volume hierarchies* (BVHs) extend the idea of AABBs to a tree-like data structure. The root node of a BVH is an AABB that contains the entire scene. The child nodes of any parent node subdivide the total volume of the parent node into multiple smaller sub-volumes. By continually separating volumes into smaller volumes, it becomes possible to group close primitives together. The lower nodes on the tree give more precise location information than the higher nodes. As opposed to other types of acceleration data structures, BVHs define the volumes by the objects they contain rather than splitting volumes and then determining which objects should go in each node. Therefore, an object would never be in more than one node.

Searching for a ray intersection with objects in a BVH occurs in a top-down manner. First, the ray is tested against the root of the node to check if it even intersects with the scene. If it does, then each of the root's children is checked for intersection. Any child node that the ray misses can be entirely eliminated from the rest of the search, since the objects contained entirely within the node will also not intersect. Ray tracing with a BVH structure can therefore greatly reduce the number of intersection checks performed per ray.

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### 2.1 A Subsection

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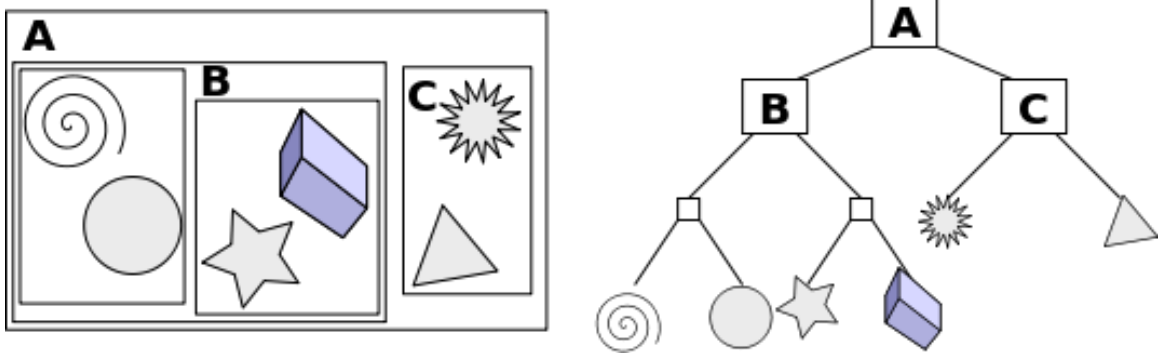


Figure 5: Left: A 2D scene with rectangles as bounding boxes. Right: One possible BVH configuration for the 2D scene. Note that each internal node has exactly two children and that objects that are close in the scene are also close in the BVH tree.

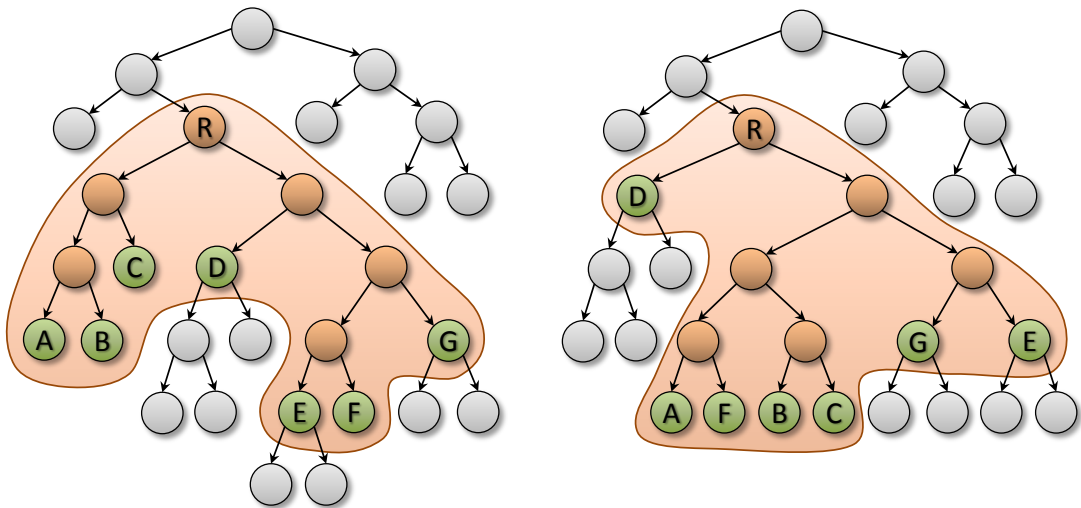


Figure 6: A treelet rotation that decreases the ray tracing cost of the BVH.

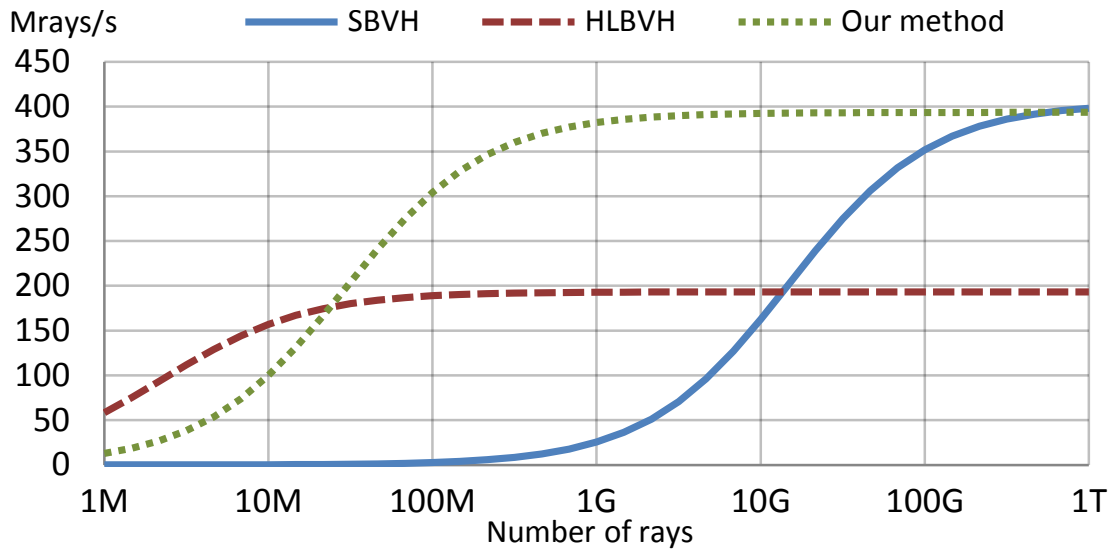


Figure 7: Performance comparison from primary source.

### 3. PERFORMANCE COMPARISONS

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### 4. CONCLUSION

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### Acknowledgments

Thanks to Nic McPhee, Elena Machkasova, and Emma Sax for their time, feedback, and constructive comments.

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