RDH: Ray Distribution Heuristics for Construction of Spatial Data Structures

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1 Introduction

The *Surface Area Heuristics* (SAH) is a widely used technique for the construction of spatial hierarchies for ray tracing [1, 2]. The SAH estimates the probability of rays intersecting a spatial region assuming uniform distribution of rays in space and no occlusion. These estimates are used in a cost model which reflects the expected number of computed intersections as well as the expected number of traversal steps. The major advantage of the SAH is its ability to adapt the constructed hierarchy to irregular distribution of objects in the scene.

In our work we propose a *Ray Distribution Heuristics* (RDH) which discards the assumption of ray uniformity made by the SAH and uses explicit knowledge of ray distribution. Our aim is to analyze the implications of the ray uniformity assumption made by the SAH and evaluate the potential for improving the SAH.

2 Ray Distribution Heuristics

In our analysis we focused on kD-trees. They are built in a standard way using top-down construction and given termination criteria. When creating an interior node of the kD-tree we distribute the objects into two child nodes according to a splitting plane. The major factor influencing the quality of the constructed kd-tree is the positioning of the splitting plane. We select such a position which yields minimum of the cost function:

$$C = c_t + c_i(p_L \cdot |O_L| + p_R \cdot |O_R|), \tag{1}$$

where c_t is the traversal cost through an interior node, c_i is the ray/object intersection cost, $|O_L|$ is the number of objects on the left of the splitting plane, $|O_R|$ is the number of objects on the right of the splitting plane, p_L is the probability of a ray intersecting the spatial region of the left child, and p_R is the probability of a ray intersecting the spatial region of the right child.

Surface Area Heuristics. Traditionally, the probabilities p_L and p_R are computed using the surface area of the box on the left and on the right of the splitting plane, respectively.

Ray Distribution Heuristics. In our new method we have modified only the way how the probability of rays intersecting a spatial region is computed. In order to do so, we use a *representative ray set* (RRS), which models the actual ray distribution. The representative ray set is generally a subset of rays cast in the current frame. Alternatively, it is a subset of rays cast in the previous frame of an animation, assuming sufficient temporal coherence between these frames exists. During the construction of the kd-tree we track all rays of RRS intersecting the current leaves of the subdivision. When the position of the splitting plane is being determined for a given leaf node, we use these rays to estimate the probabilities of rays intersecting the newly established parts of the leaf. As a result the new data structure is adapted to the actual ray distribution.

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3 Estimating Traversal Probabilities from RRS

For each splitting plane candidate we determine the rays which intersect the two fragments of the bounding box of the subdivided node (see Figure 1).

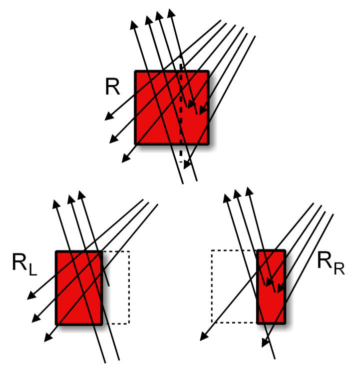

Figure 1: Illustration of the ray distribution heuristics.

Probability of a ray passing through the left and right fragments of the bounding box is then estimated as:

$$p^{RDH}_{\{L|R\}} = \frac{|R_{\{L|R\}}|}{|R|}, \tag{2}$$

where $|R_{L|R}|$ is the number of rays intersecting the left and right fragments respectively, and $|R|$ is the number of rays intersecting the whole box. To avoid degeneracies we blend these probabilities with the probabilities computed with surface area heuristics.

4 Results

In our tests we used 28 scenes in which we specified 52 different view points. We tested the RDH for both ray casting (only primary rays) and ray tracing. For ray casting the number of intersection tests is decreased by 8% and the number of traversal steps by 2% and the achieved speedup is up to 5%. For ray tracing the RDH did not improve the performance, on average we have actually observed a small slowdown.

Our preliminary study of using RDH shows that even if we use more accurate means to estimate the probability of rays than the surface area heuristics, the potential for speedup is only marginal.

References

[1] V. Havran. *Heuristic Ray Shooting Algorithms*. PhD thesis, Faculty of Electrical Engineering, Czech Technical University in Prague, 2000.

[2] J. D. MacDonald and K. S. Booth. Heuristics for ray tracing using space subdivision. *Visual Computer*, 6(6):153–65, 1990.