Dynamic and Implicit Trees for Graphics and Visualization on the GPU

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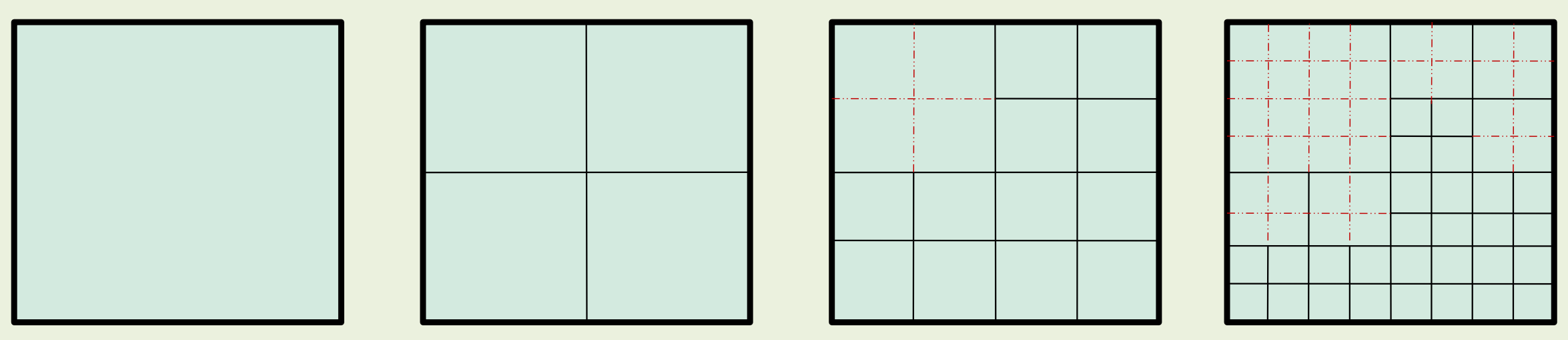
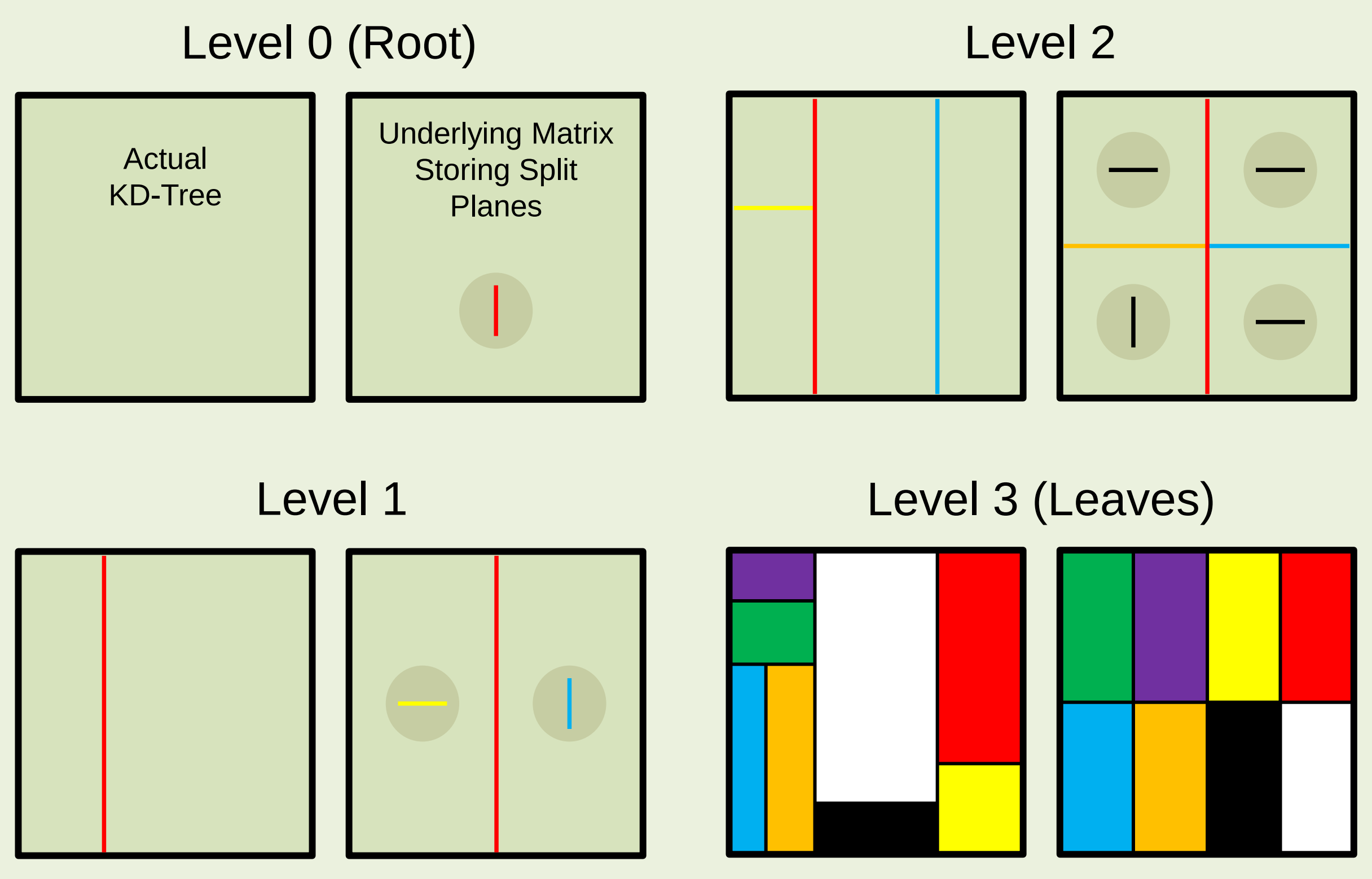
Matrix Trees

We propose an octree and kd-tree data structure that uses matrices for the underlying data storage. Since we can derive all parent/child locations in memory, instead of explicitly storing pointers, our representation is easily represented on GPU architectures. For regular data structures (i.e. octrees) we also derive spatial information, which helps reduce GPU register pressure since this information does not need to be saved throughout any algorithms. We use a sparse matrix representation to minimize our footprint in memory, while maintaining our regular matrix structure. In this example quadtree, the sparse matrix data structure fills in any "holes" (dotted red lines).

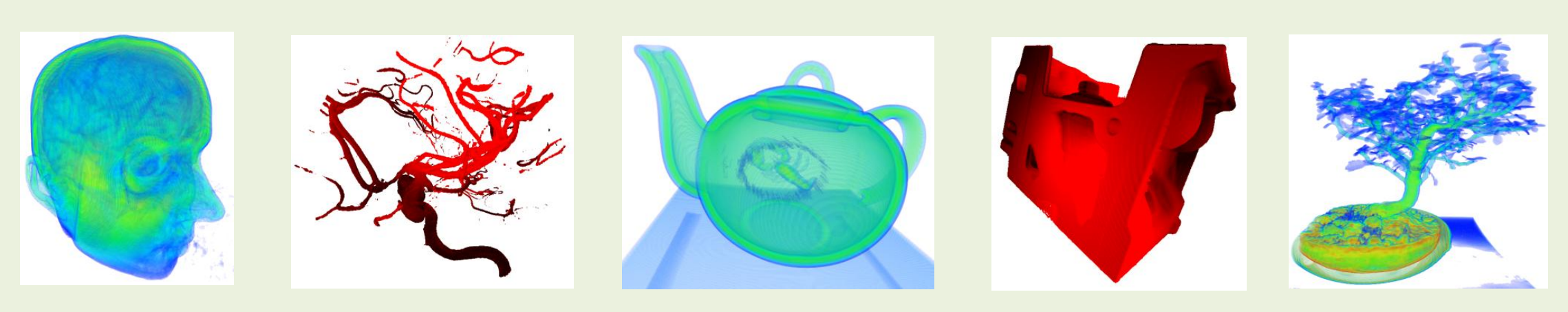


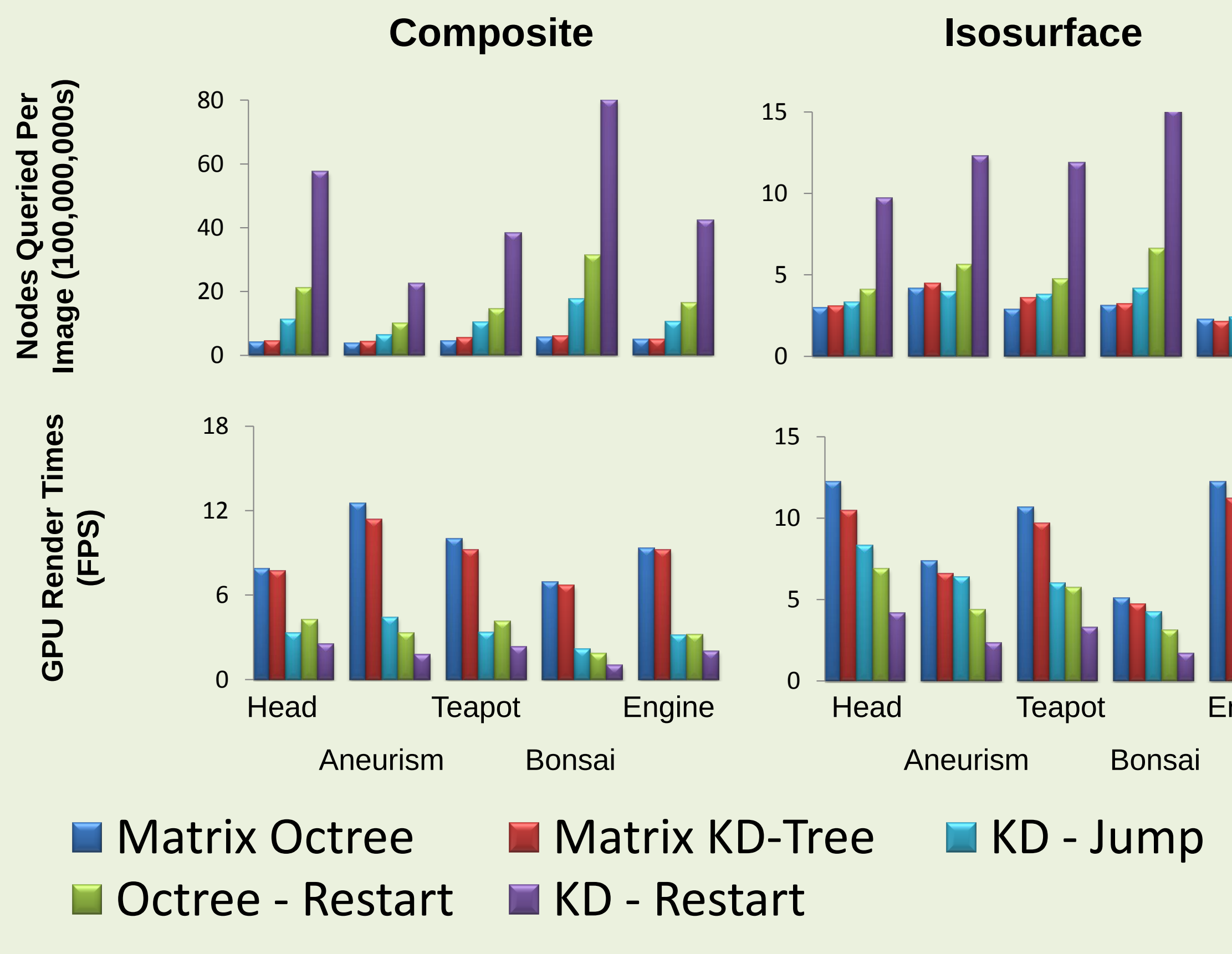
Even for non-regular trees (i.e. BSP-trees), we can use this matrix representation and still derive parent/child information, which can lead to big memory savings over previous representations.



Volume Ray Casting

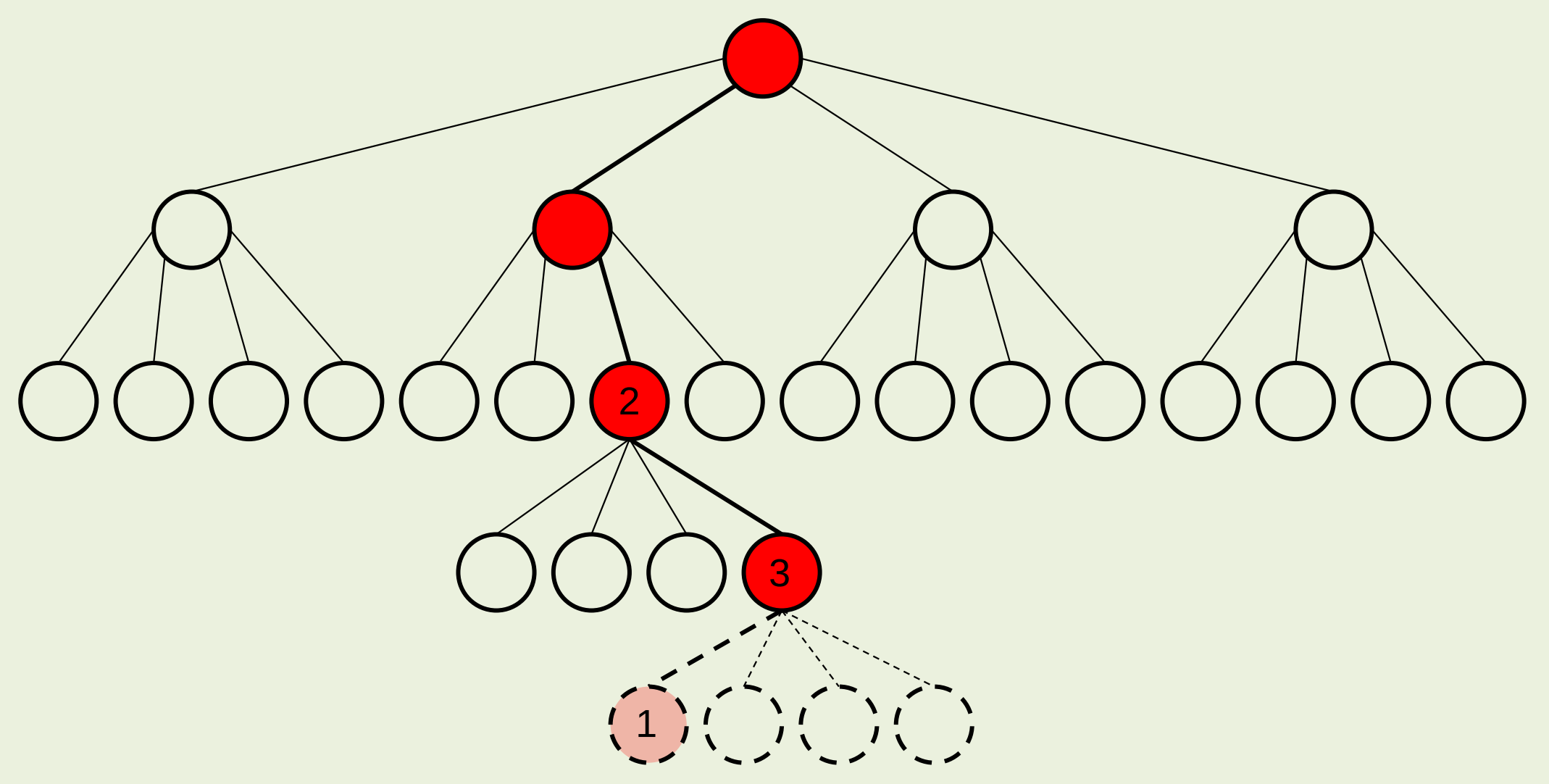
Compared to previous traversal methods, our ray caster visits far fewer nodes. As a result, every single test resulted in faster render times, with a speed-up of nearly 300% in some cases. Additionally, we showed memory savings of nearly 50%.





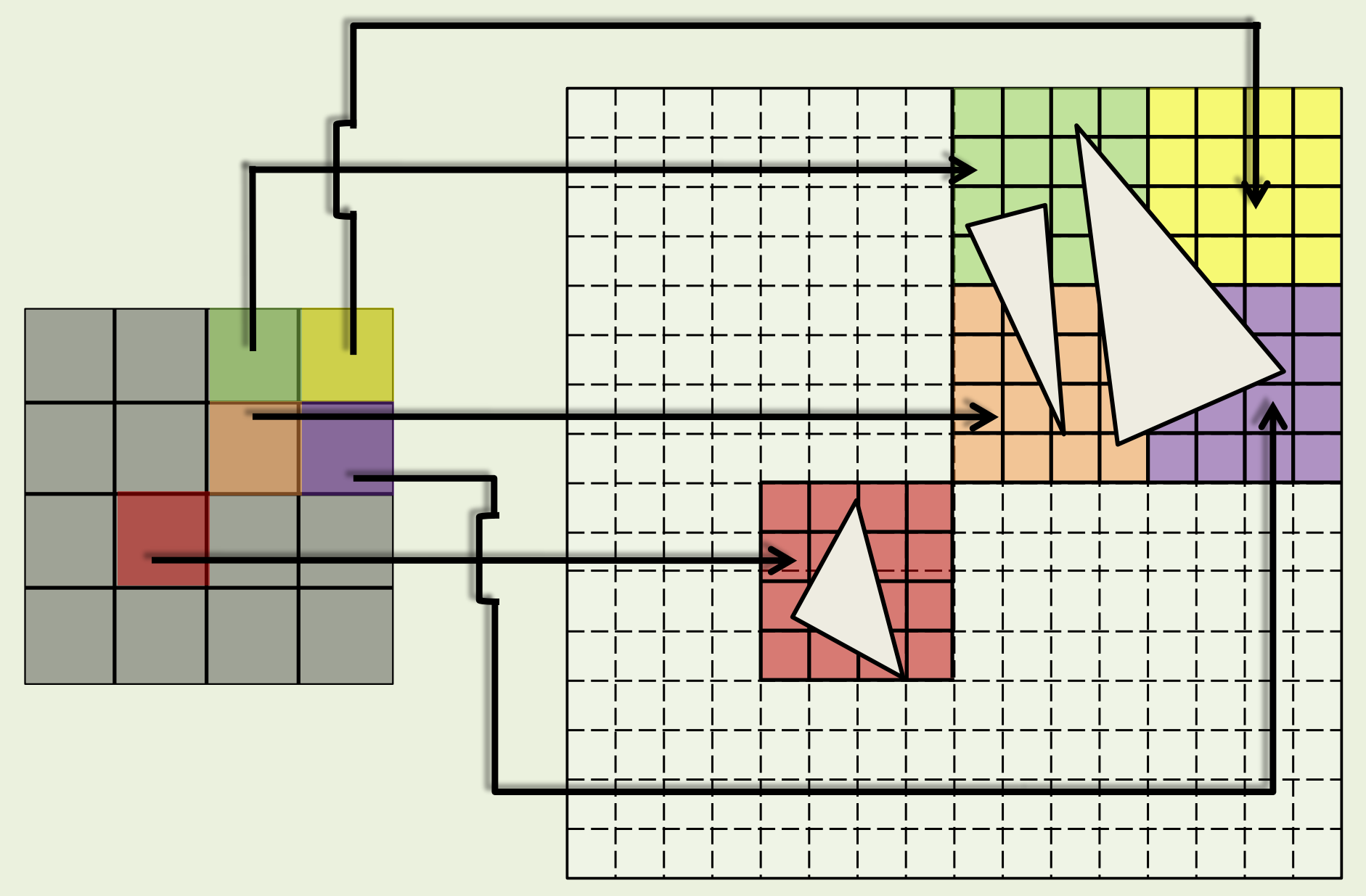
Improved Traversal

Our regular tree structure allows for improved tree operations. First, we are able to spatially hash to any node. We can use this hash to quickly compute any neighbor location. For leaf finding, we can hash directly to the leaf level. If this node does not exist, we can do a binary traversal along the path to the root, giving us a O(*log h*) complexity, where *h* is the height of the tree. The previous state-of-the-art had a O(*log N*), where *N* is the number of nodes in the tree.



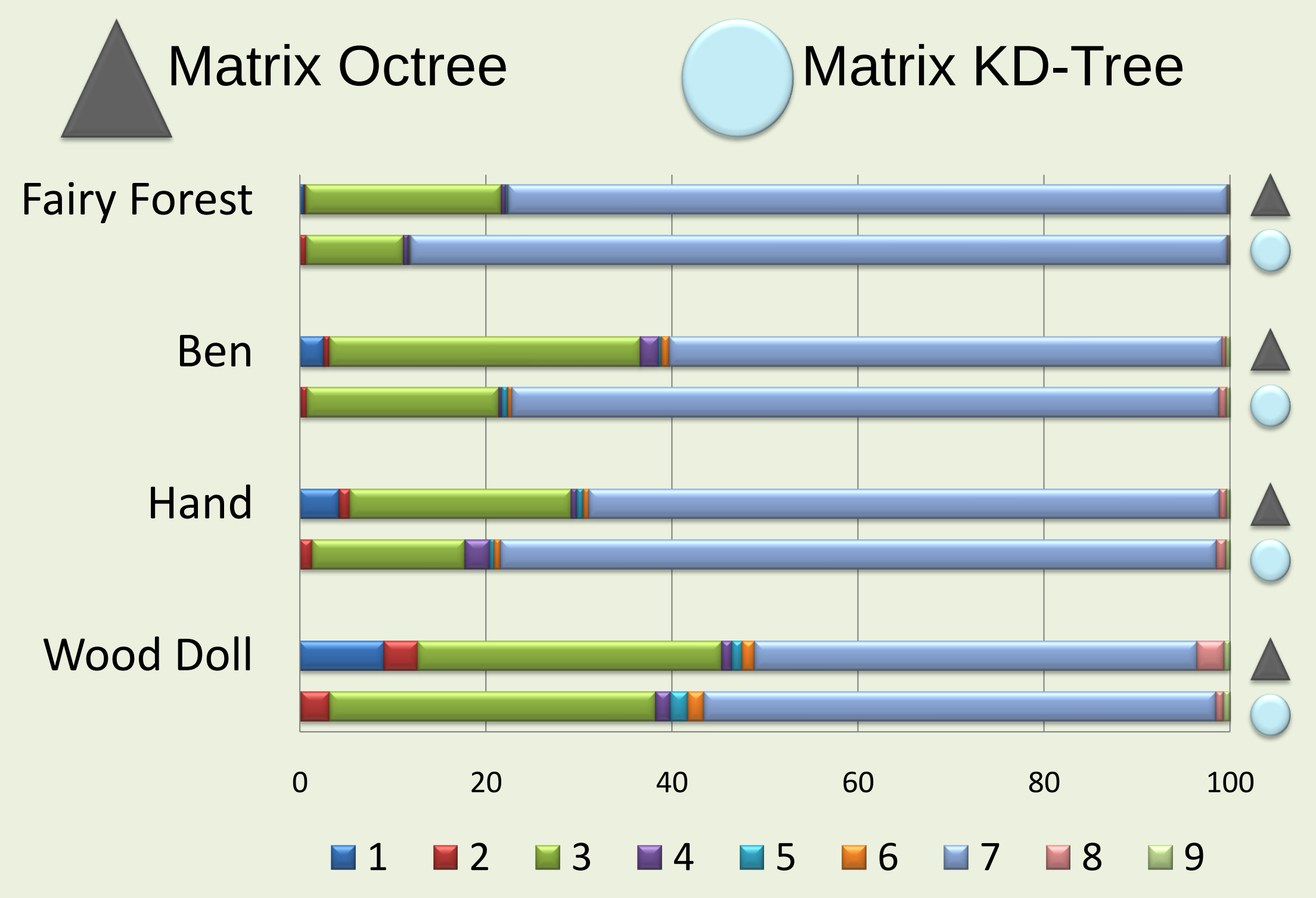
Sparse Matrix Data Structure

Unlike previous pointerless tree representations, our data structure can adapt its sparsity to the tree's shape. Though any sparse matrix data structure can be used, we recommend the use of the following block based one. In this data structure, we only allocate a block if data is contained within it. We use an auxiliary matrix to maintain references to our allocated blocks. This sparse matrix representation has O(1) access and insertion time, which means global memory accesses on the GPU is minimized.



GPU Build Algorithm

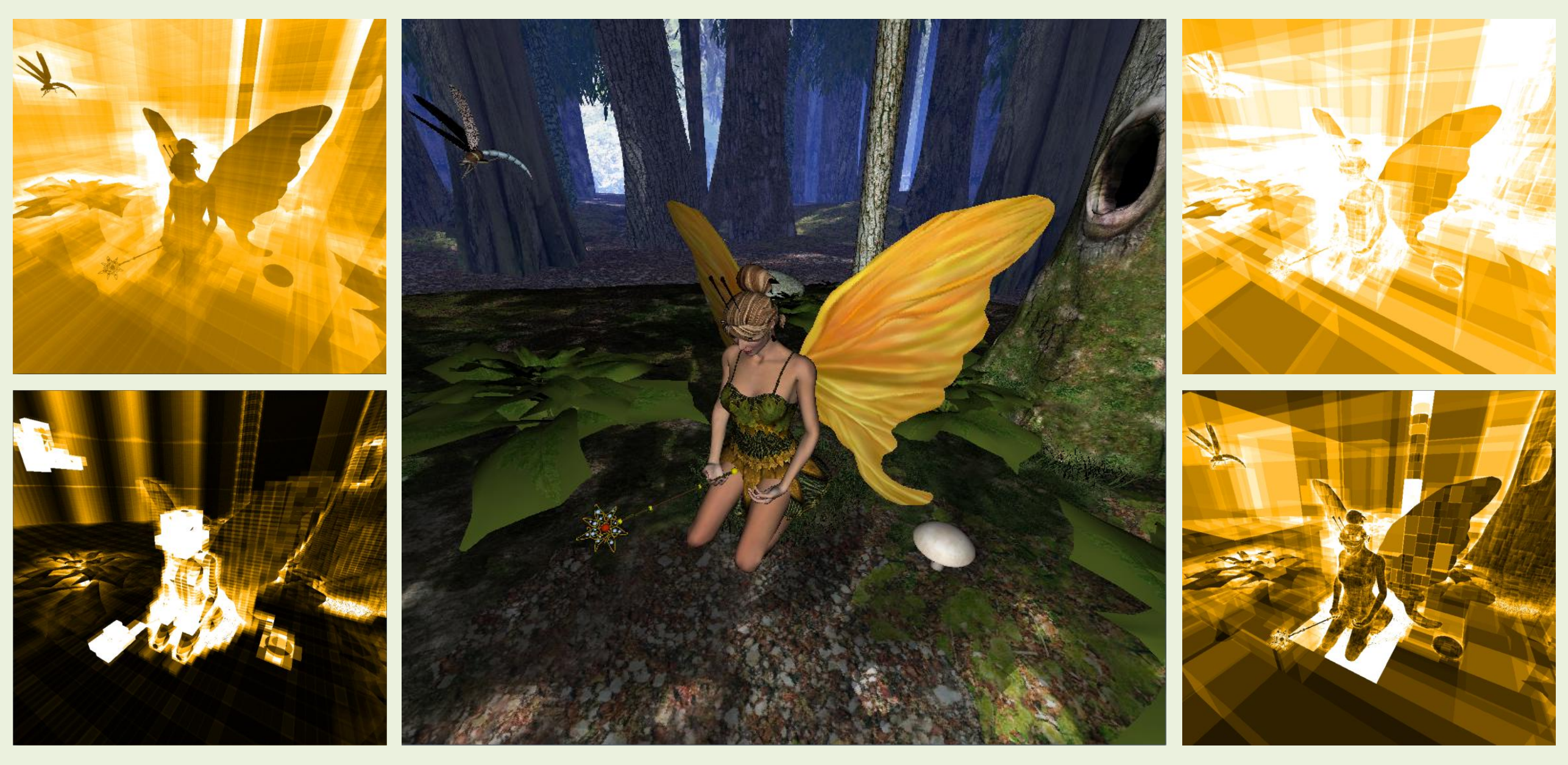
The following algorithm is used to build our regular tree data structure on the GPU. The data type we are storing in the trees is triangles, but the algorithm is easily adjusted to other primitives. Except for the initial step (1), which has a minimal amount of iterations and is more quickly executed on CPU, each step is executed in parallel as its own GPU kernel. The scans and sort can efficiently be done using CUDPP. The graph below shows how much time is spent in each part of the algorithm. The build is both less theoretically complex and simpler to implement than the surface area heuristic tree builds used in ray tracing. Combined with faster render times, our trees outperform the previous state-of-the-art on the GPU for all ray tracing stages.



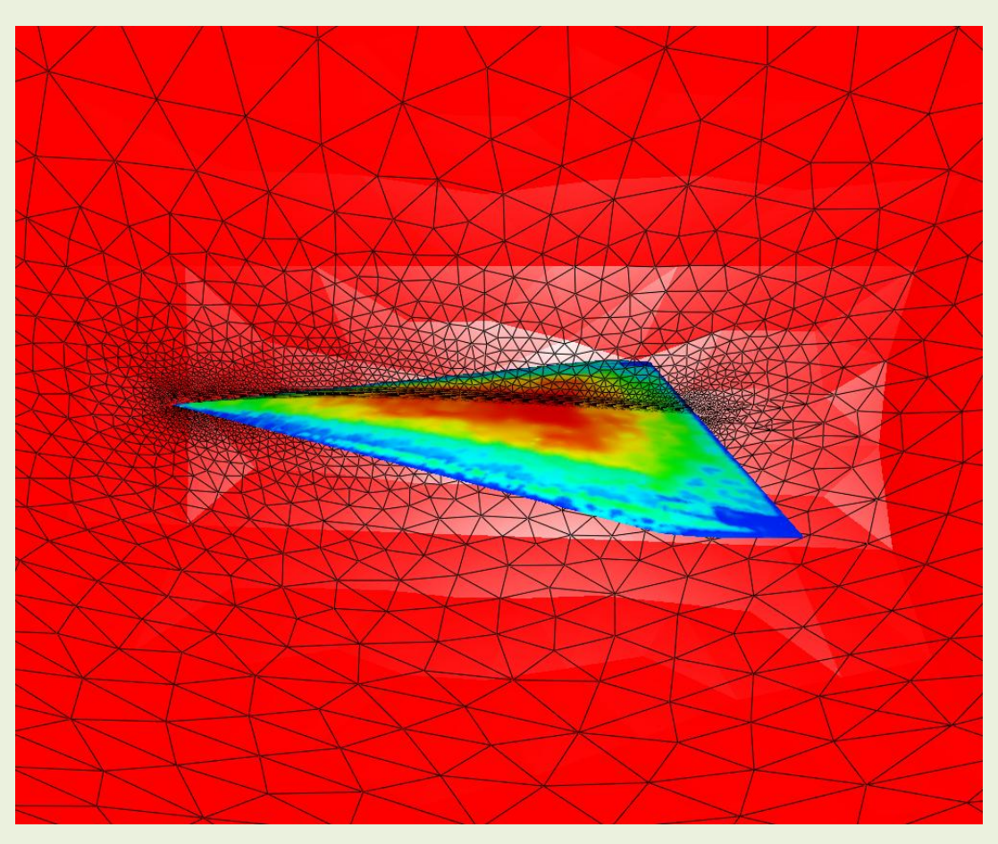
```
1) for level ← 0 to max_tree_level do
       compute regular tree properties
2) foreach triangle do
       counter intersecting nodes
       mark intersecting blocks
3) scan (triangle-node counter)
4) scan (marked block counter)
5) foreach marked block do
       assign index pointer to allocated block
6) foreach triangle do
       foreach intersecting node do
           output triangle-node pair
7) sort (triangle-node pair vector)
8) foreach sorted triangle-node pair do
       if next pair in vector has different node then
           update these nodes' offsets into triangle vector
9) foreach leaf level node do
       mark parents as non-null
```

Ray Tracing

Using the matrix tree data structure results in faster build times and quicker rendering on the GPU than previous state-of-the-art methods. Not only do our trees require fewer node traversals, but we also perform fewer ray-primitive intersection tests. The image to the left demonstrates this property, where we compare a regular matrix kd-tree (left) to a surface area heuristic built kd-tree (right). Black indicates a low number of traversals/tests and white indicates high. Overall, we achieved a 50% speed increase for this scene, with other test scenes showing similar improvements.



Future work



We wish to represent very large data sets on the GPU. One such data set type is the unstructured meshes used in fluid dynamic simulations. In preliminary tests, we show promising results in representing this type of data using the matrix tree representation.