SRDH : Specializing BVH Construction and Traversal Order Using Representative Shadow Ray Sets

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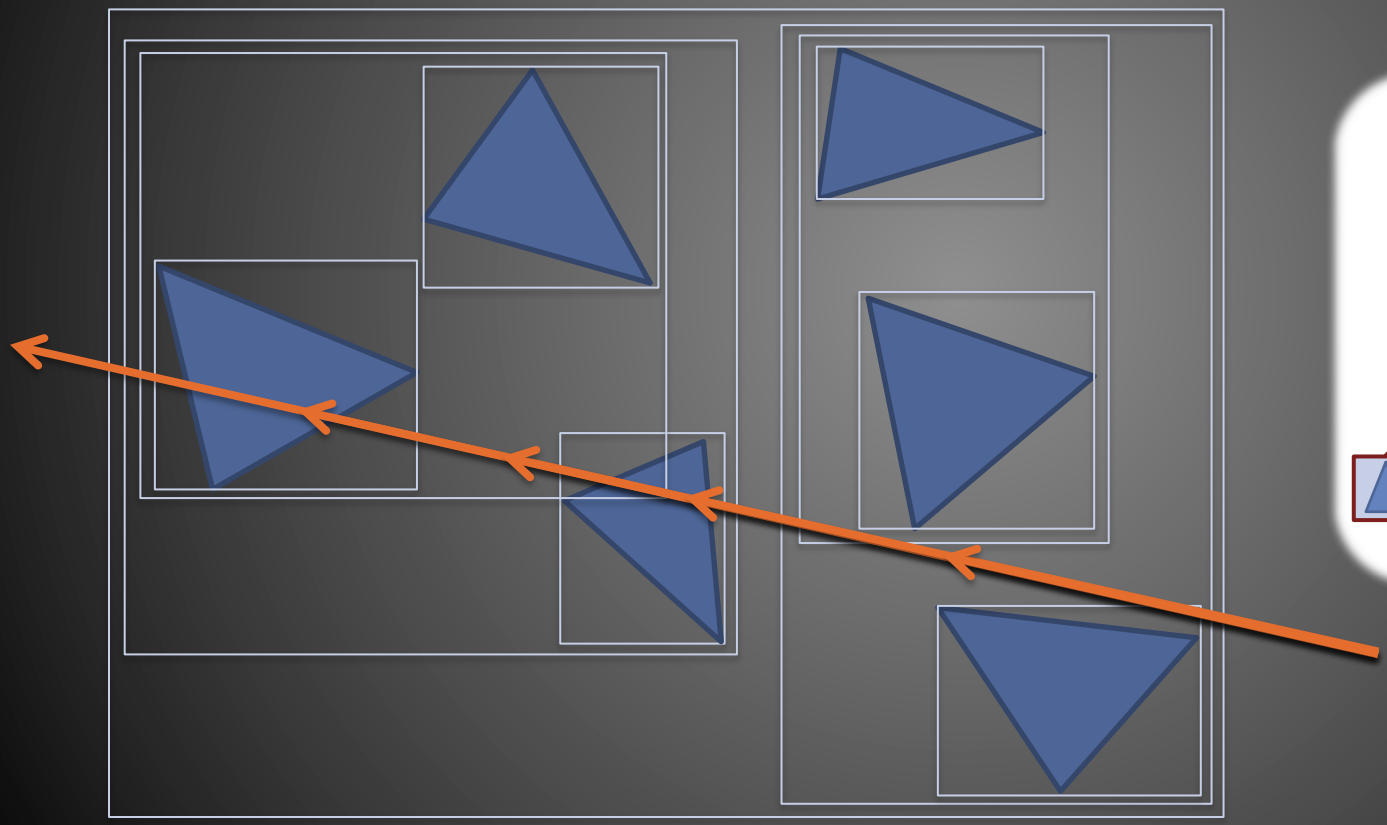
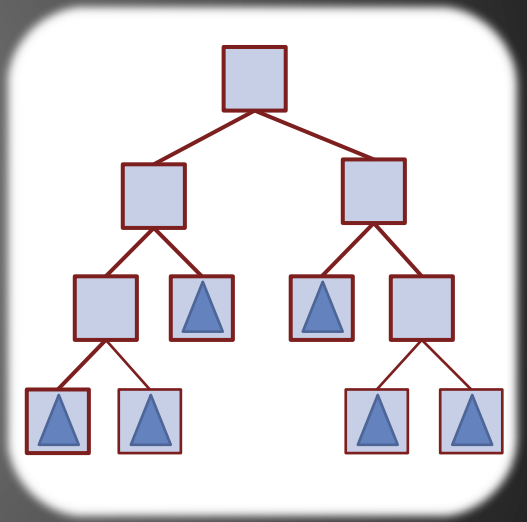
Traversing a BVH (for radiance rays): Find the first hit





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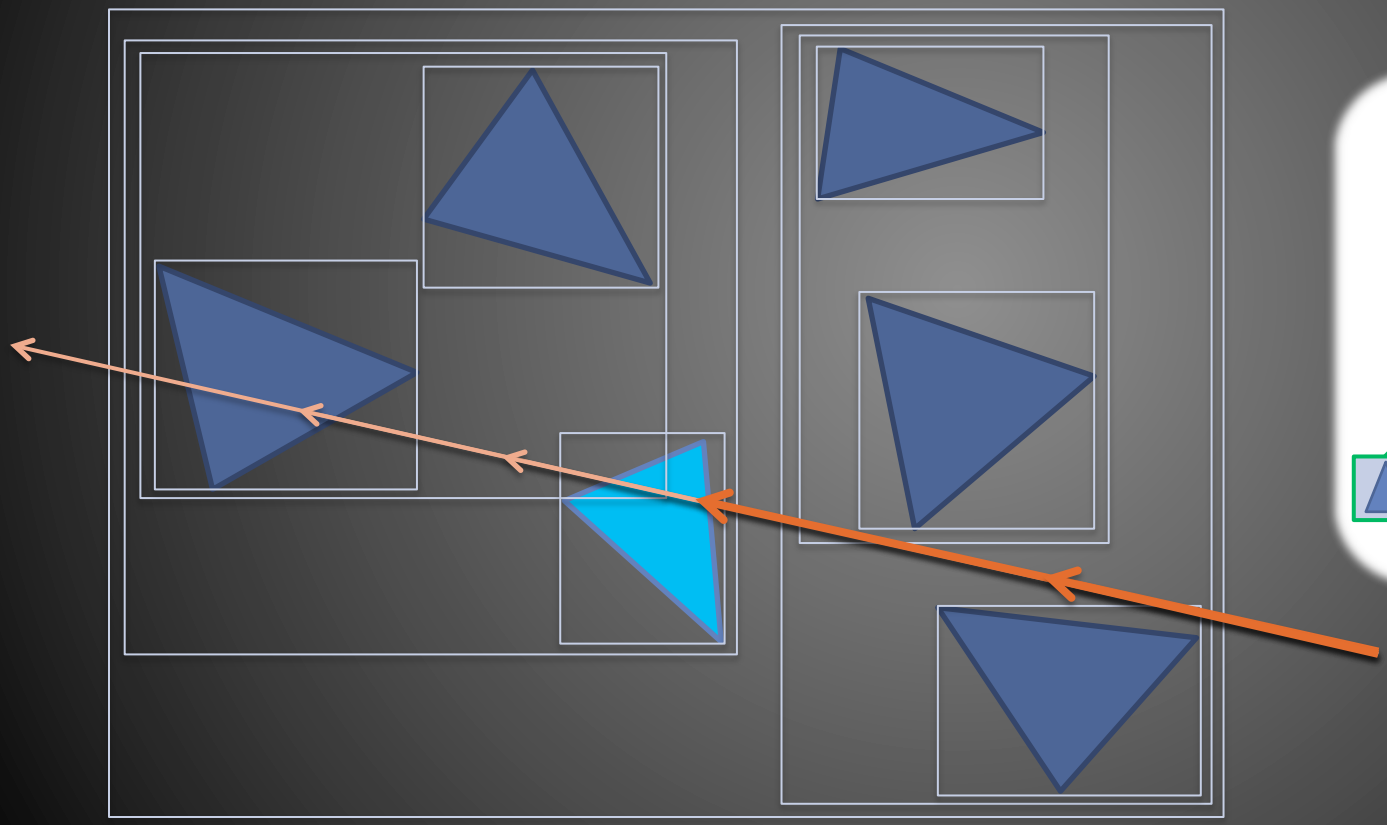
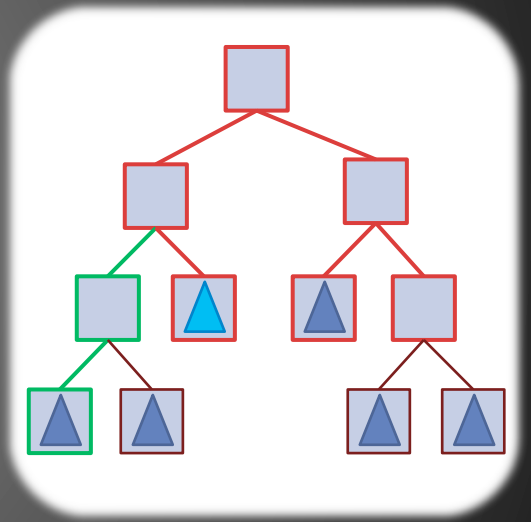
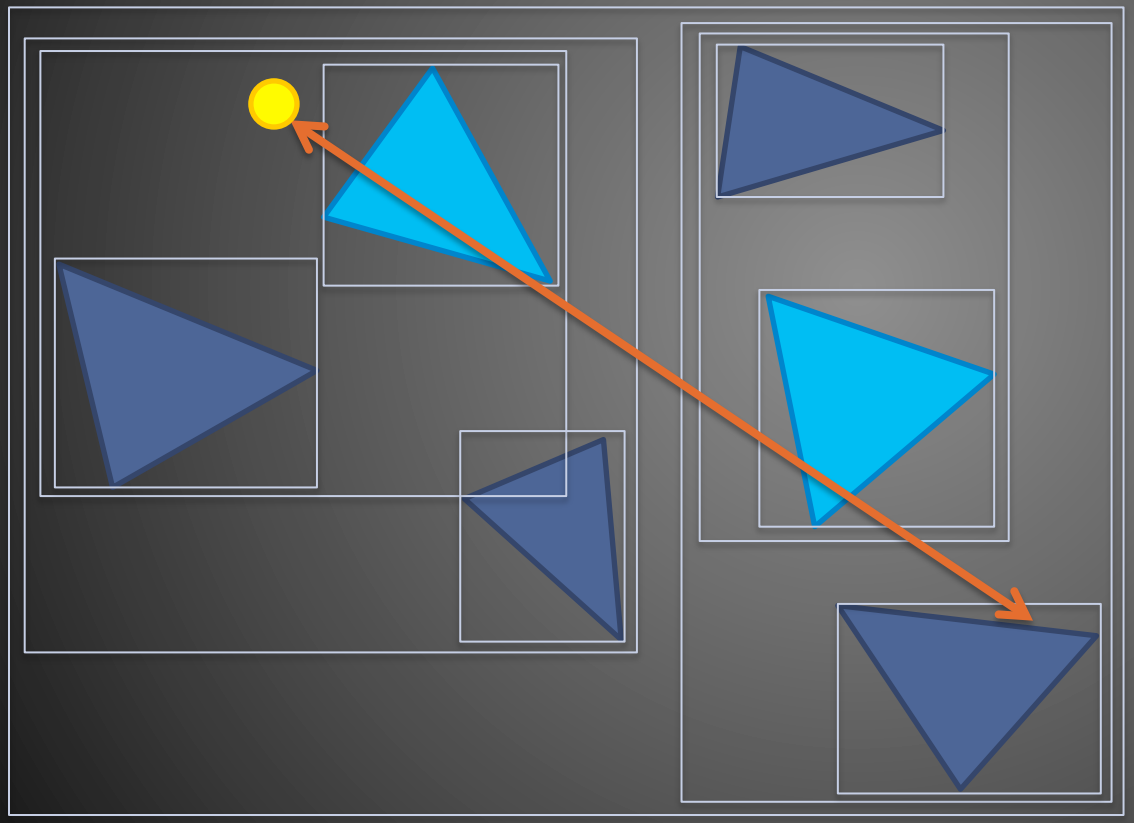
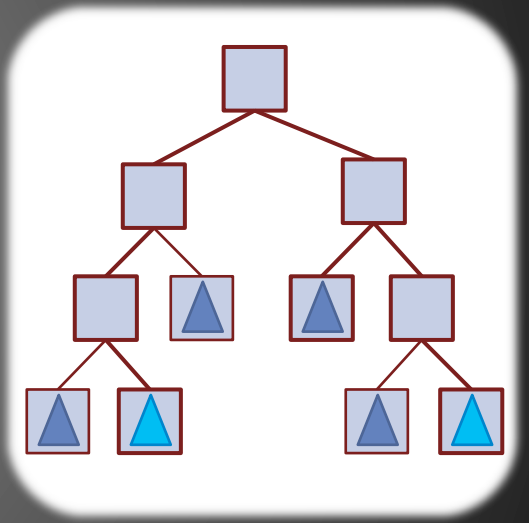


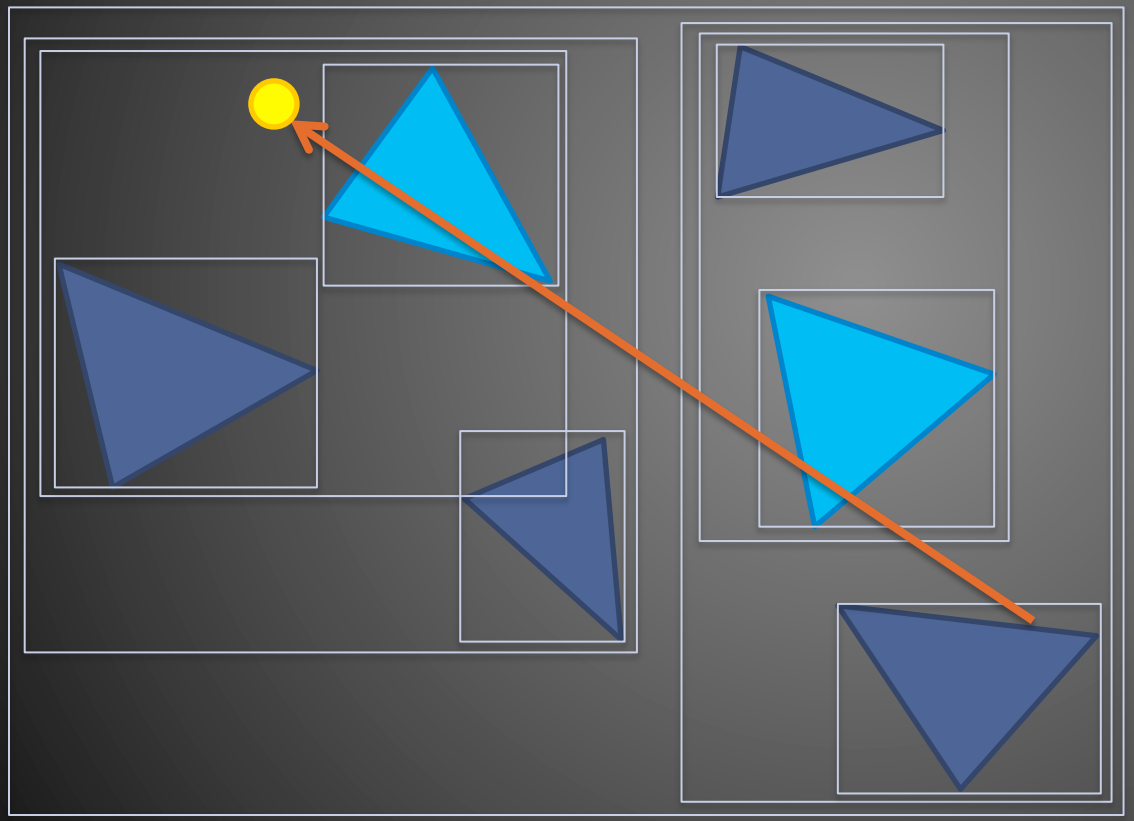


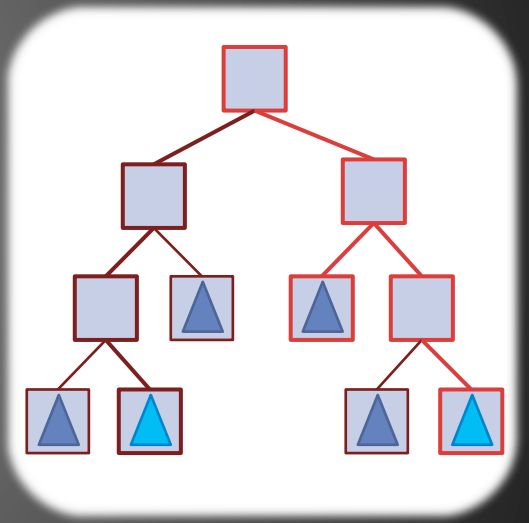
Traversing a BVH (for shadow rays): Find *any* hit



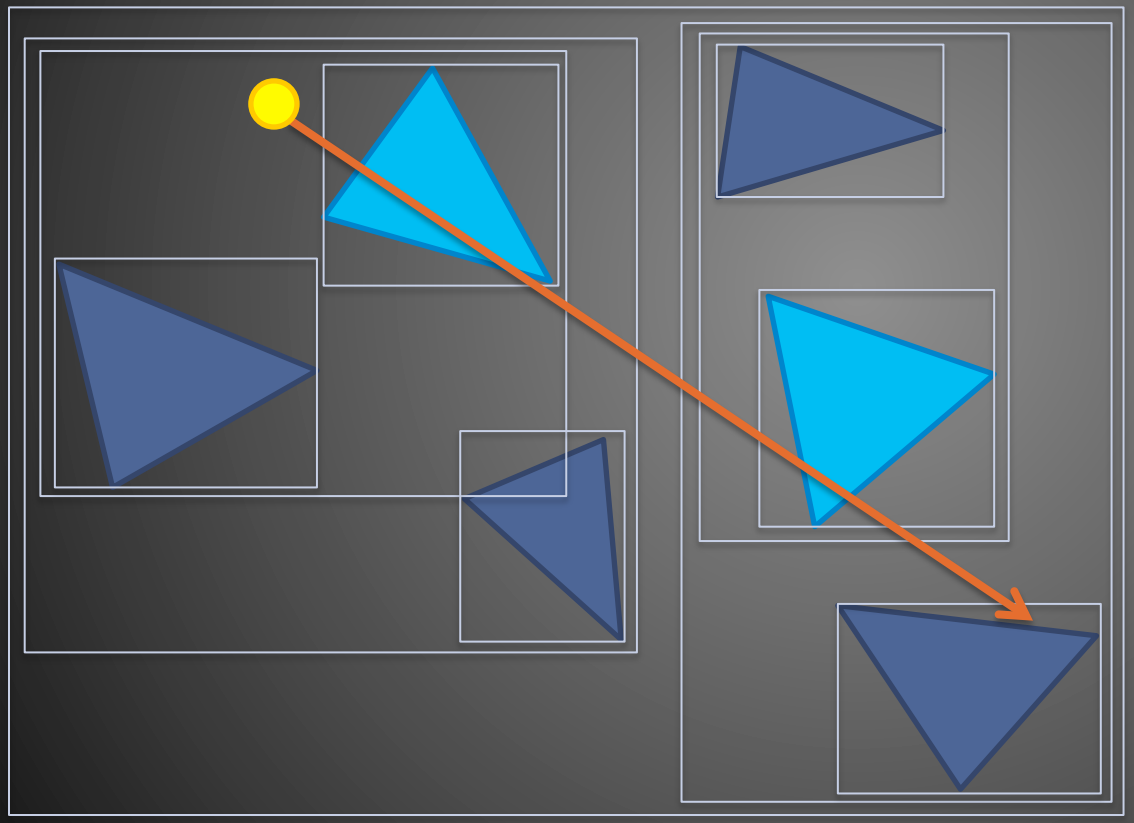


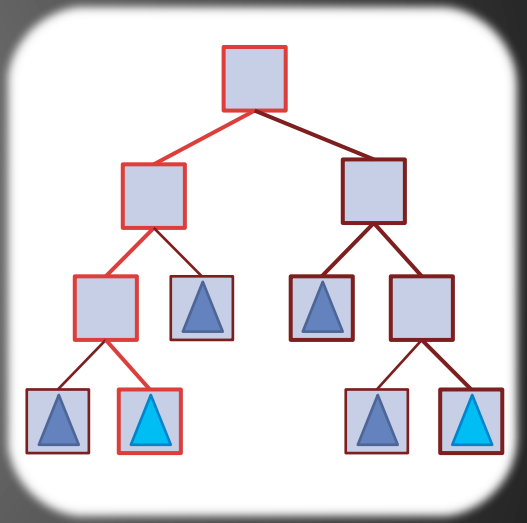
Surface to the light?





Light to the surface?





In Bedroom scene, traverse back to front

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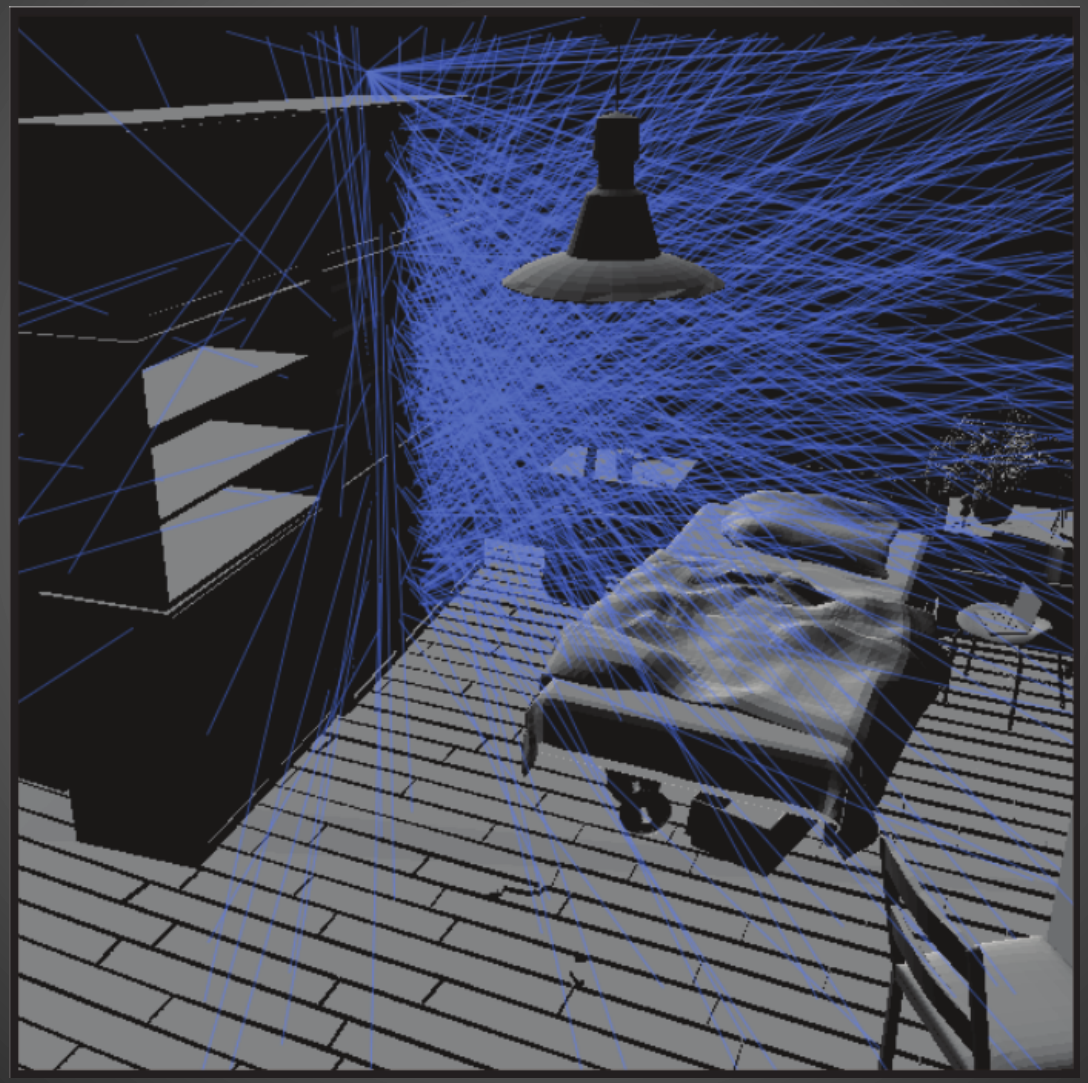
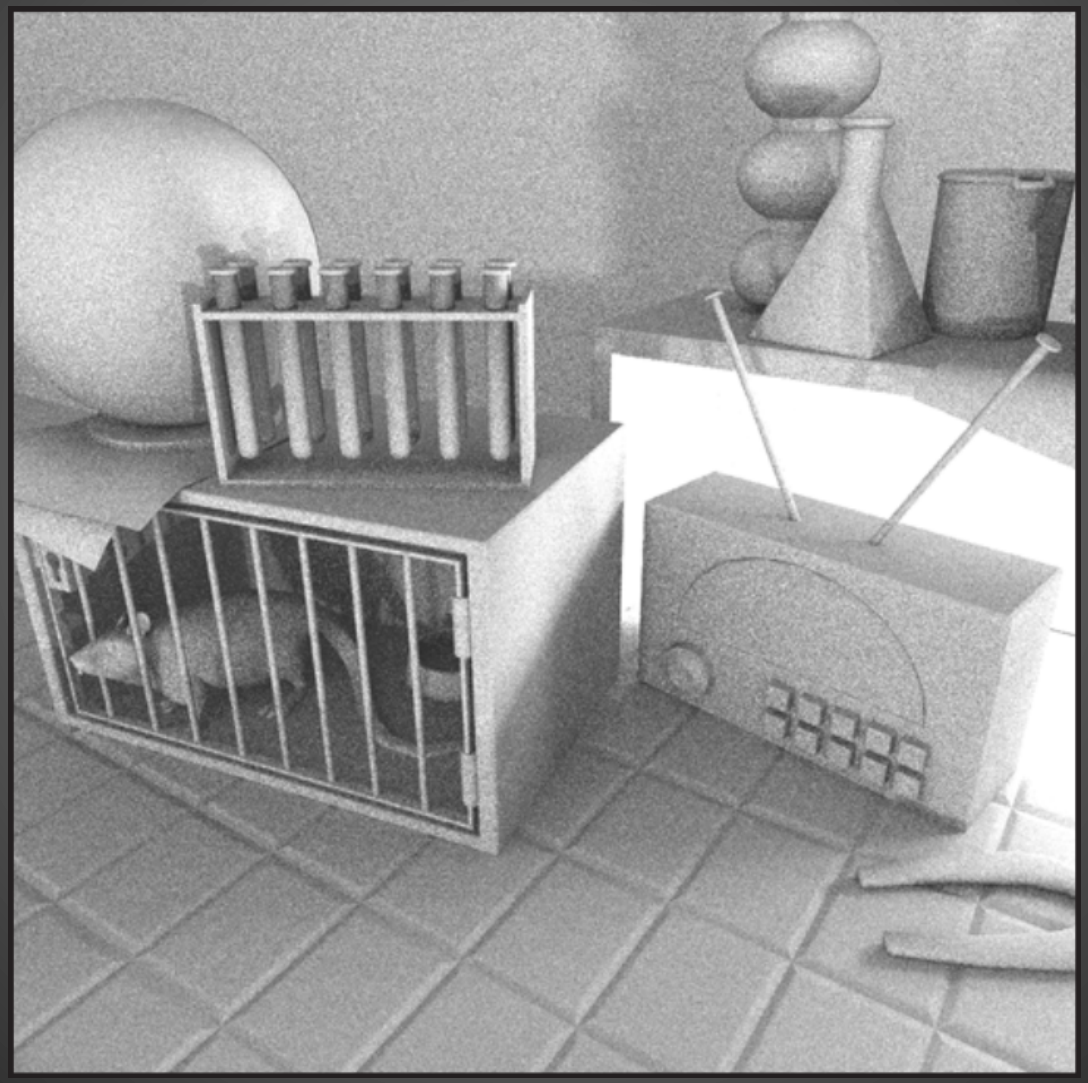
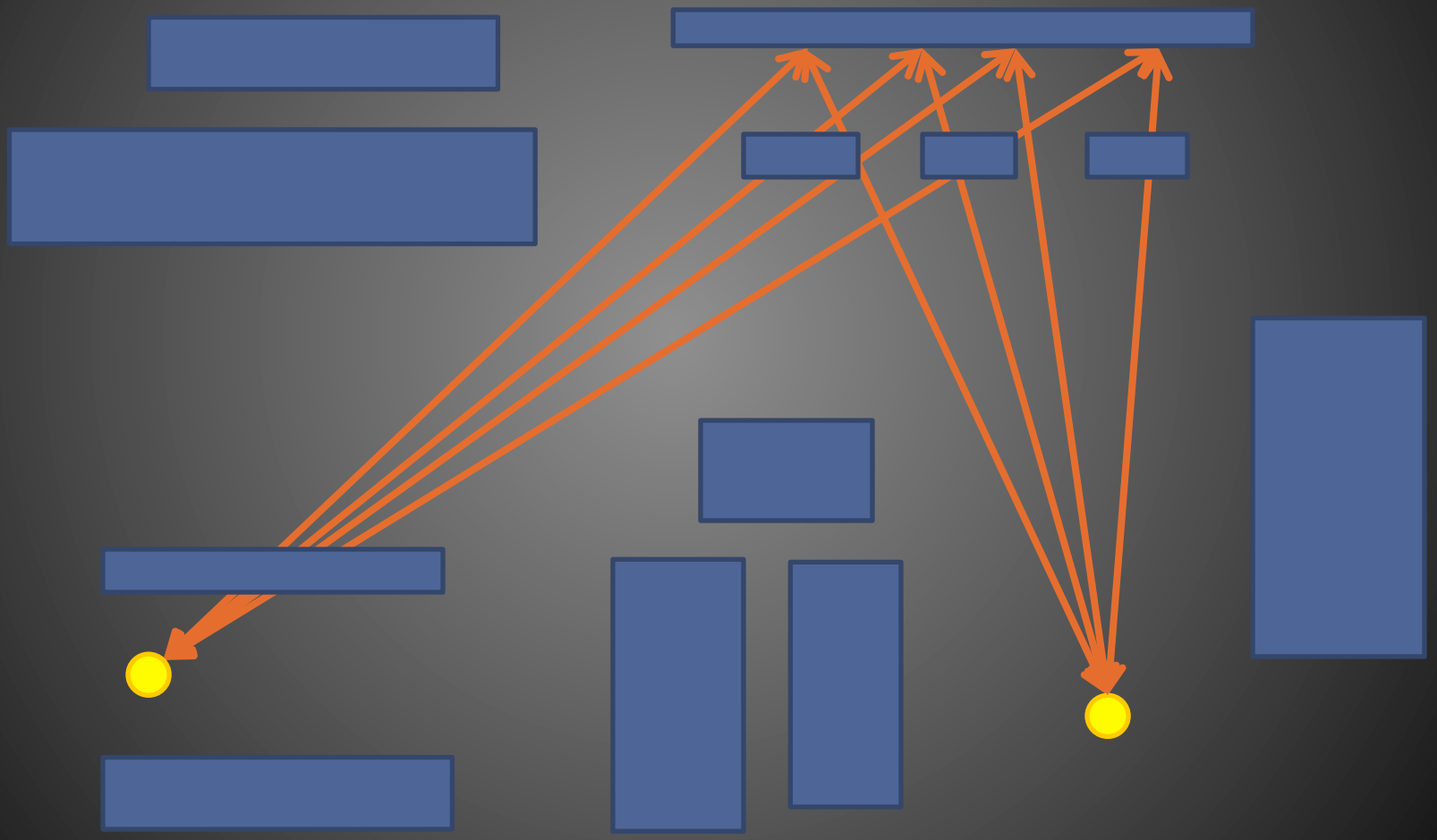


In Mad Science scene, traverse front to back



Idea: trace towards *occluders*



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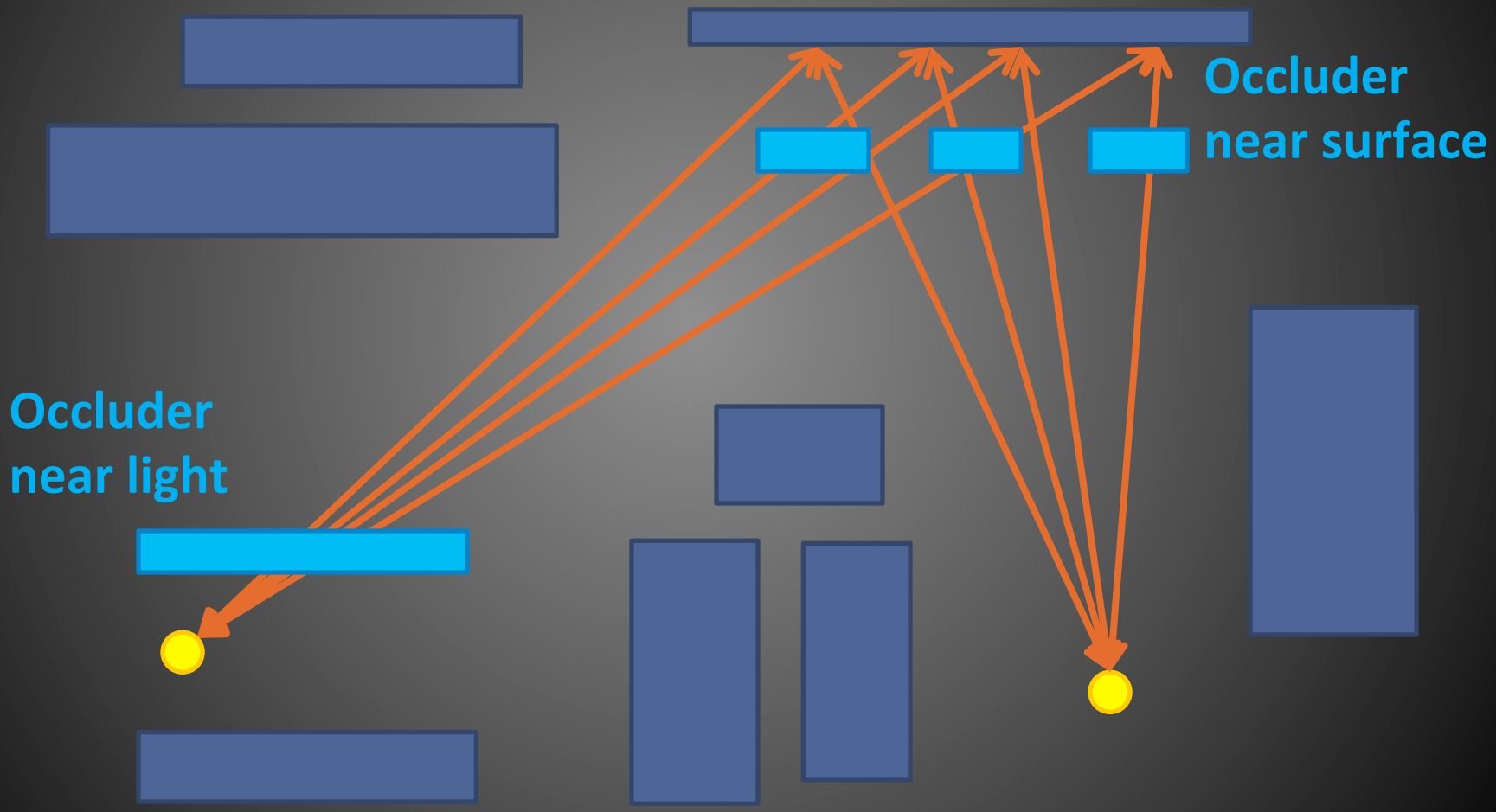
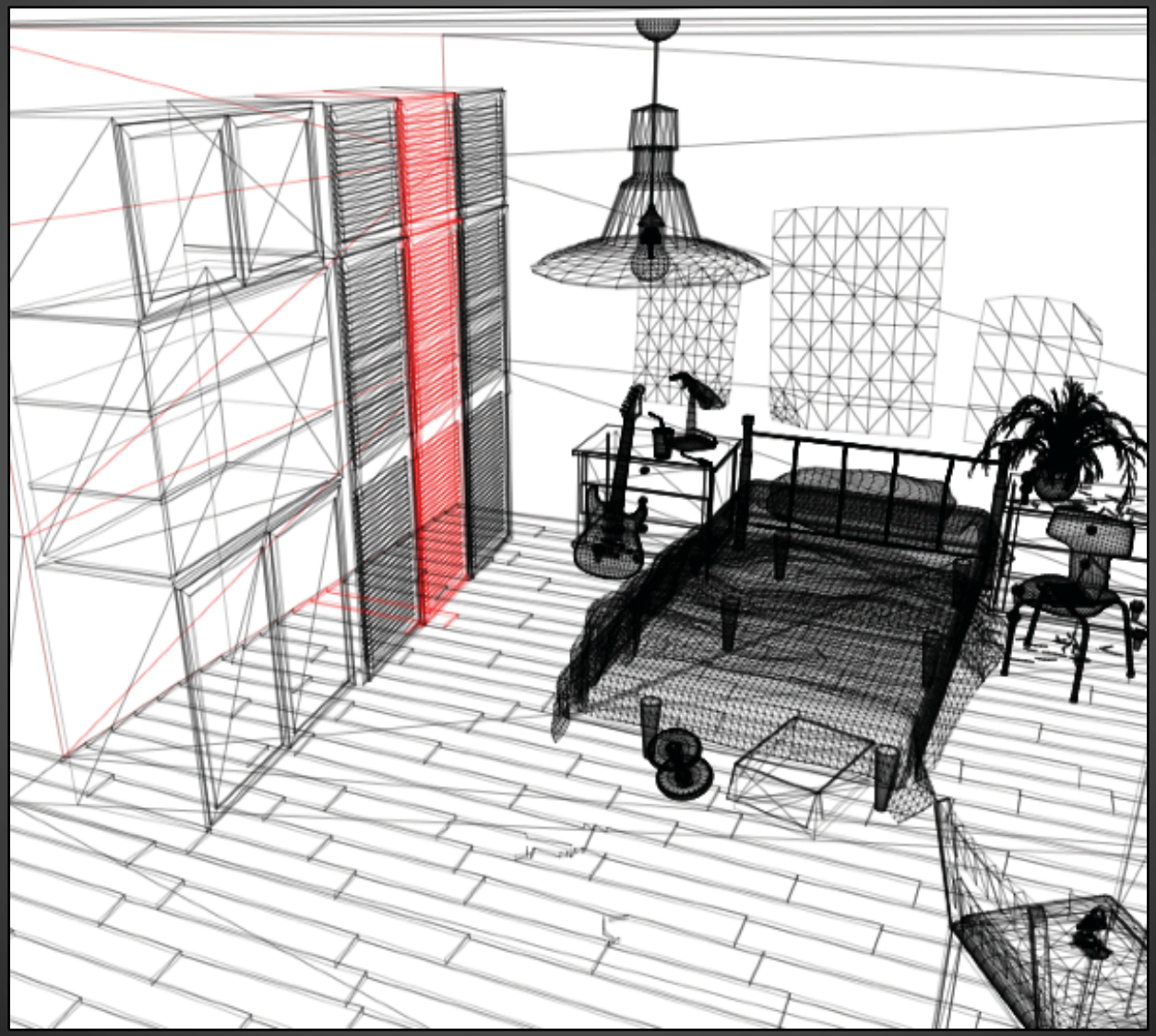
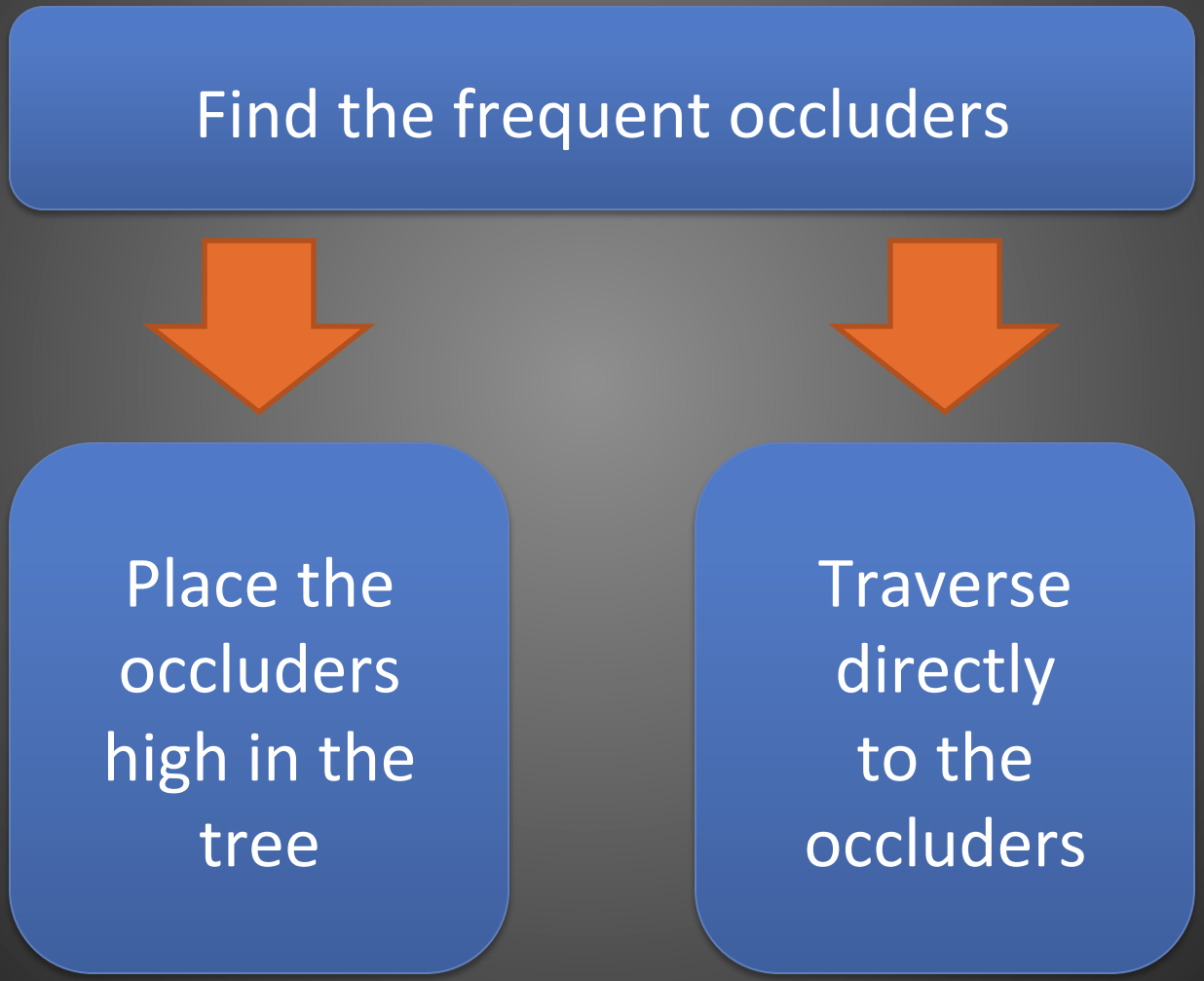


Frequent occluders should be closer to root



Optimizing shadow ray traversal: two simultaneous goals



Contribution:
Shadow Ray Distribution Heuristic (SRDH)

Similar Approaches

- RTSAH [Ize & Hansen '11]
  - Starts with standard SAH tree (without ordering).
  - Uses volumetric density as a proxy for occluder likelihood to assign a shadow traversal scheme
- RDH [Bittner & Havran '09]
  - Uses actual ray information to build BVH
  - For use with radiance rays, so no freedom in traversal order

Similar Approaches

- Occluder caches [Haines & Greenberg ‘86]
- Frequent occluder trees

Shadow Ray Distribution Heuristic (SRDH)

Steps to deriving SRDH:

- Define generalized traversal for shadow rays
- Develop cost metric for our general traversal routine and a *known* ray set
- Use this cost metric to build BVHs

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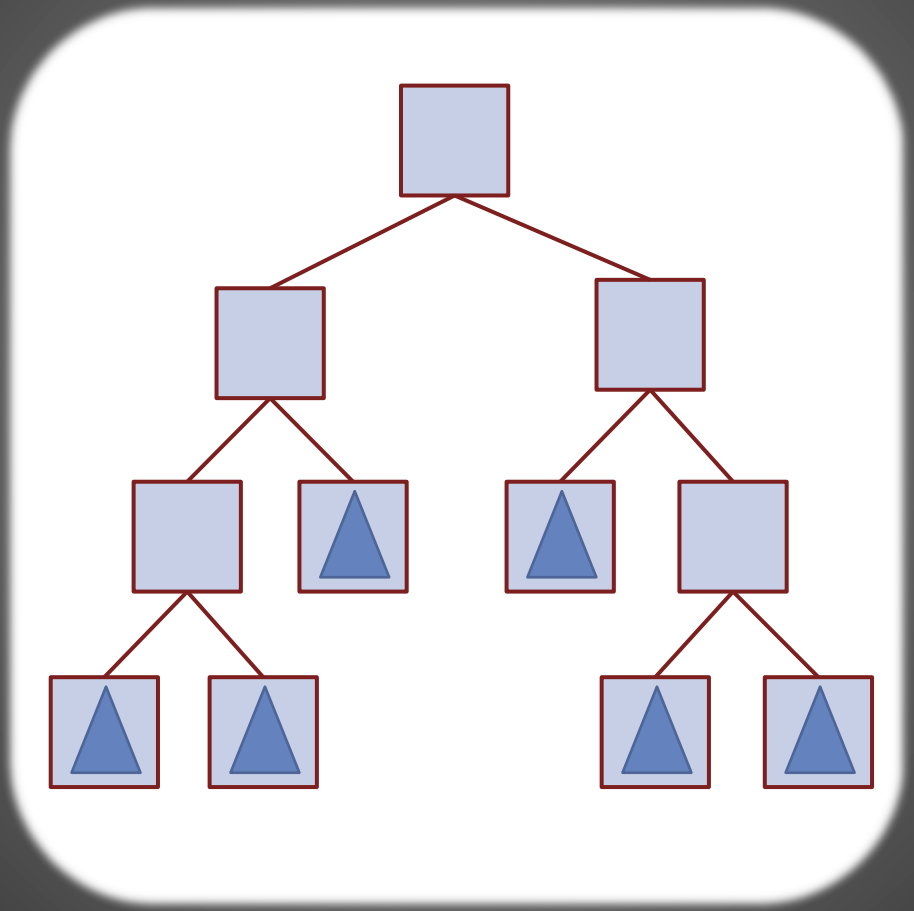
Traversal per node



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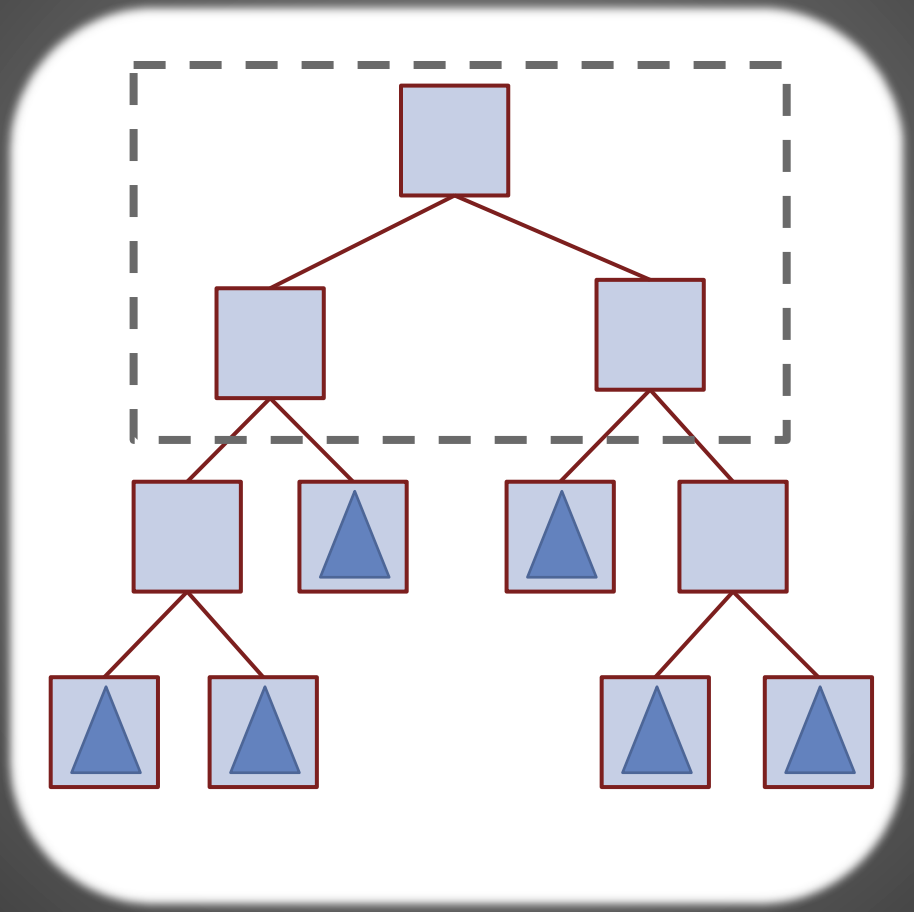
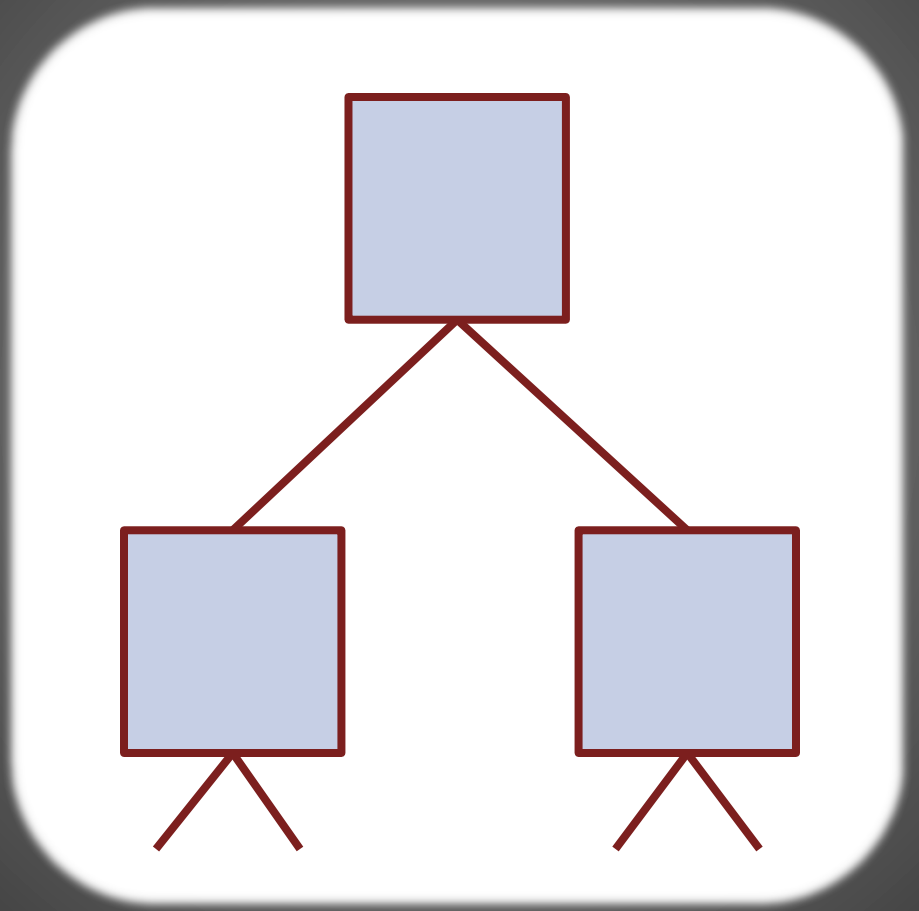


Traversal at a branch



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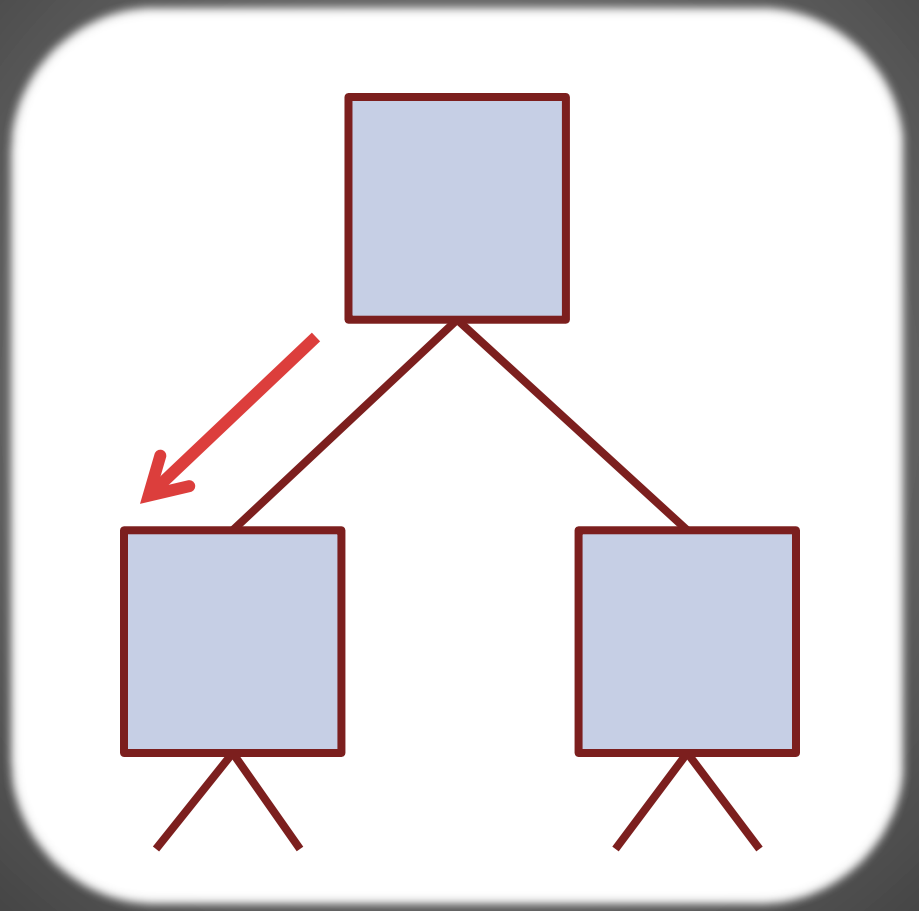

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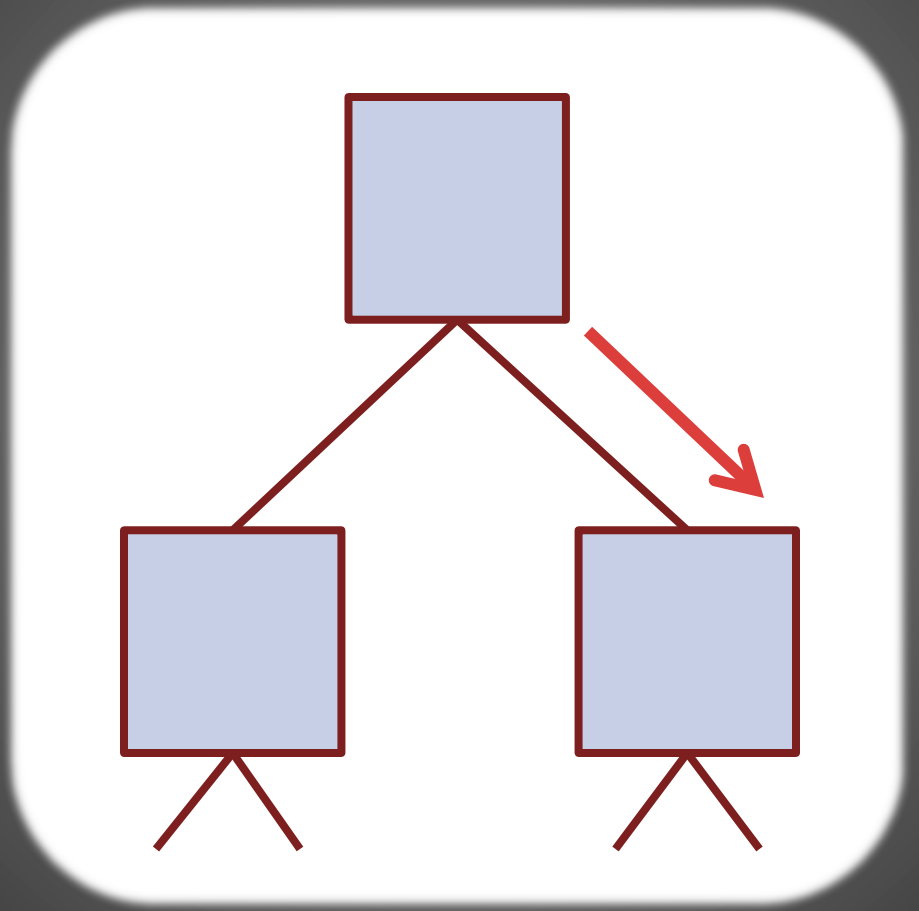

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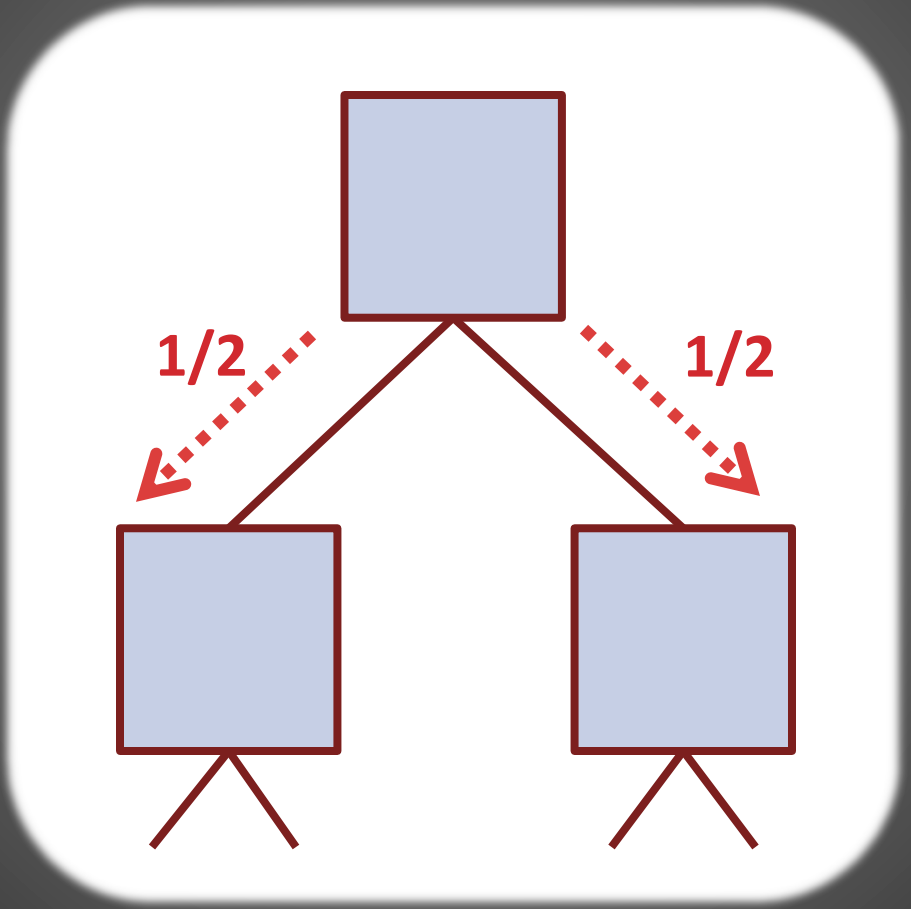

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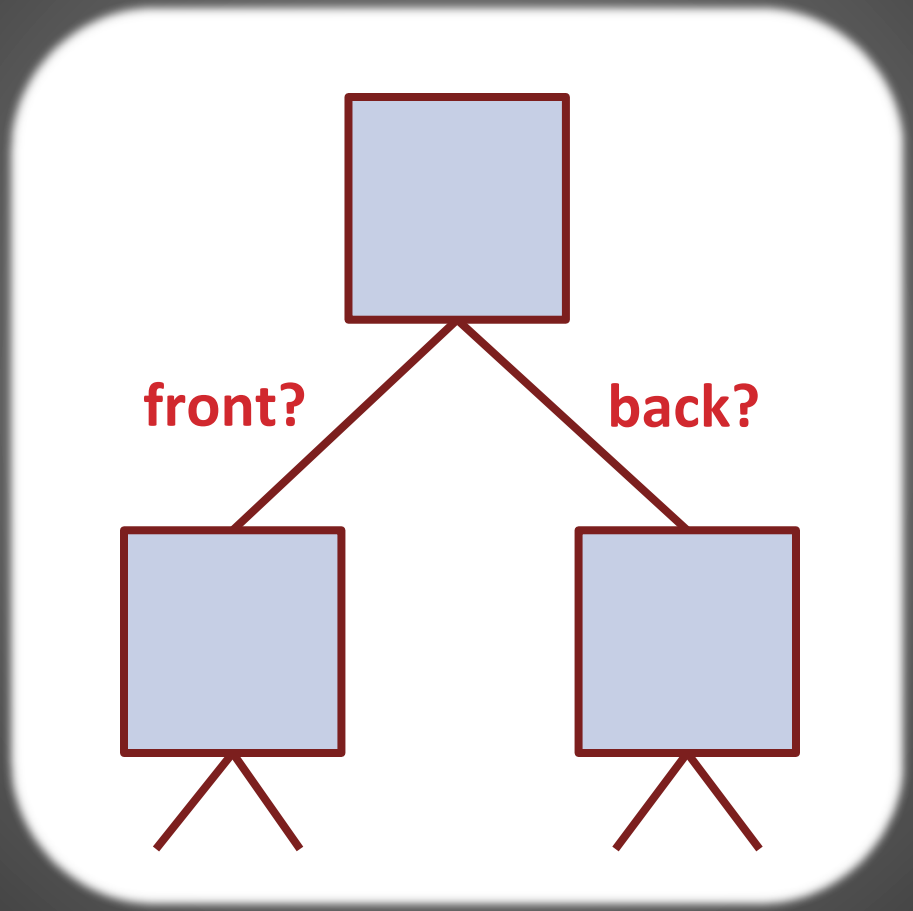
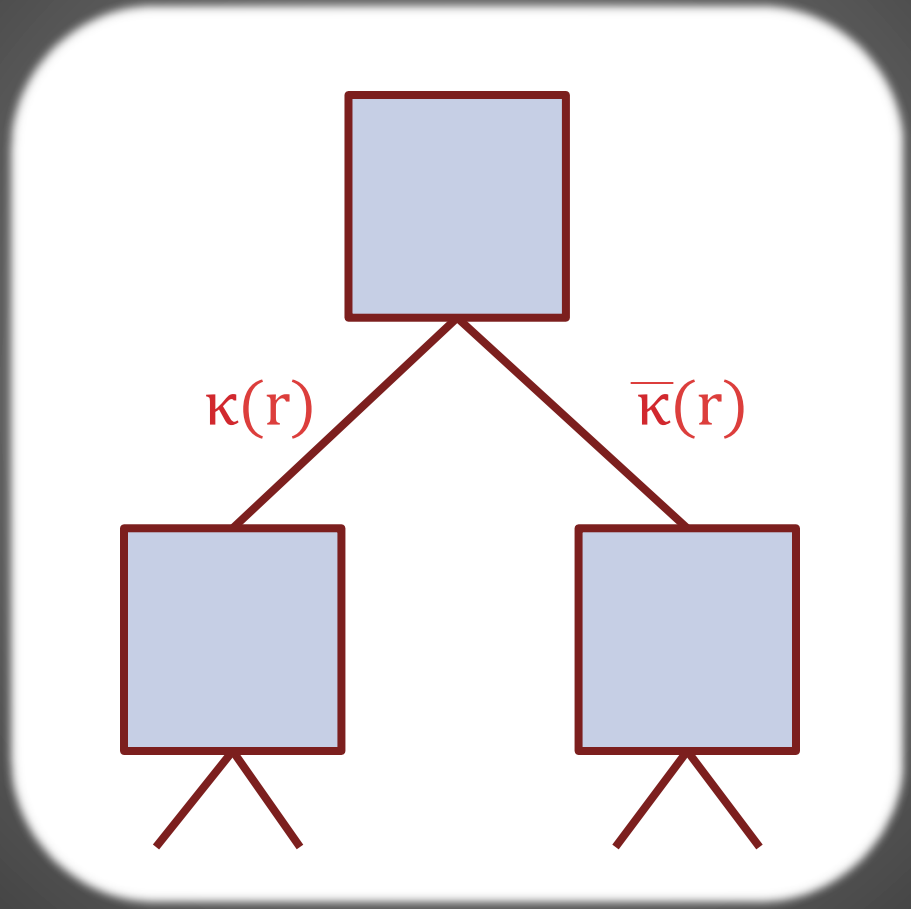


Traversal per node



$\overline{\kappa}(r) = 1 - \kappa(r)$

Specify traversal policy for each node

Left First: $\kappa(r) = 1$

Right First: $\kappa(r) = 0$

Random: $\kappa(r) = 0.5$

Back to front: $\kappa(r) = \begin{cases} 1 & \text{if r...} \\ 0 & \text{if r...} \end{cases}$

Front to back: $\kappa(r) = \begin{cases} 0 & \text{if r...} \\ 1 & \text{if r...} \end{cases}$

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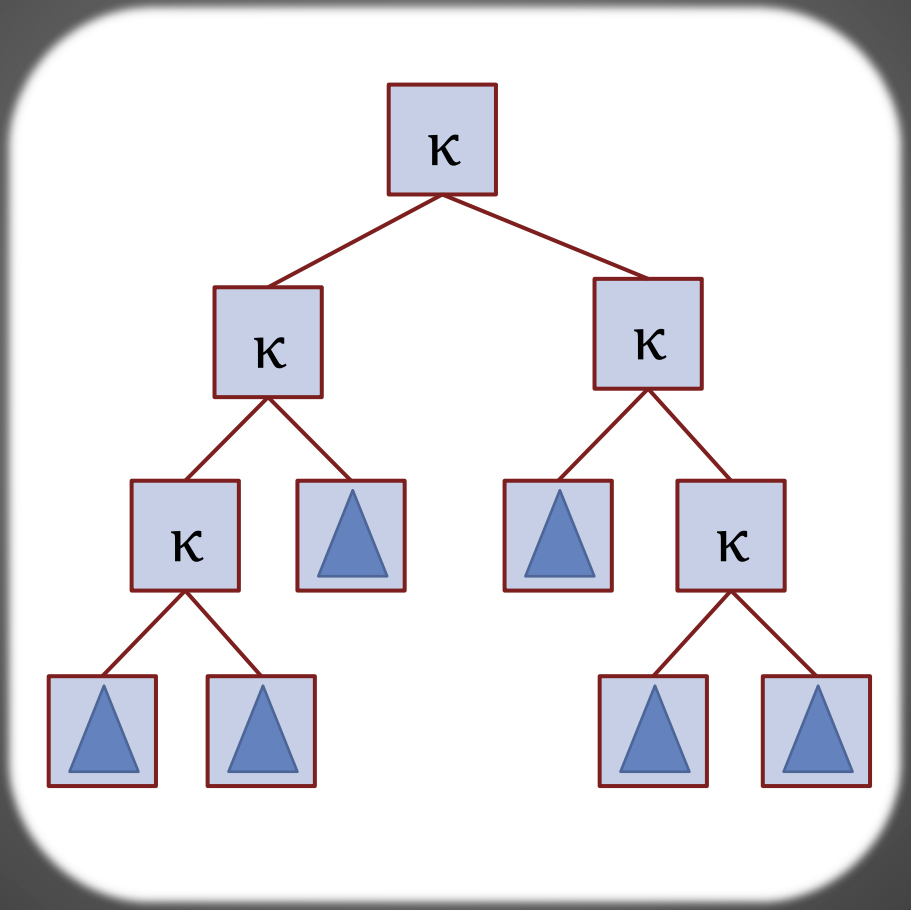

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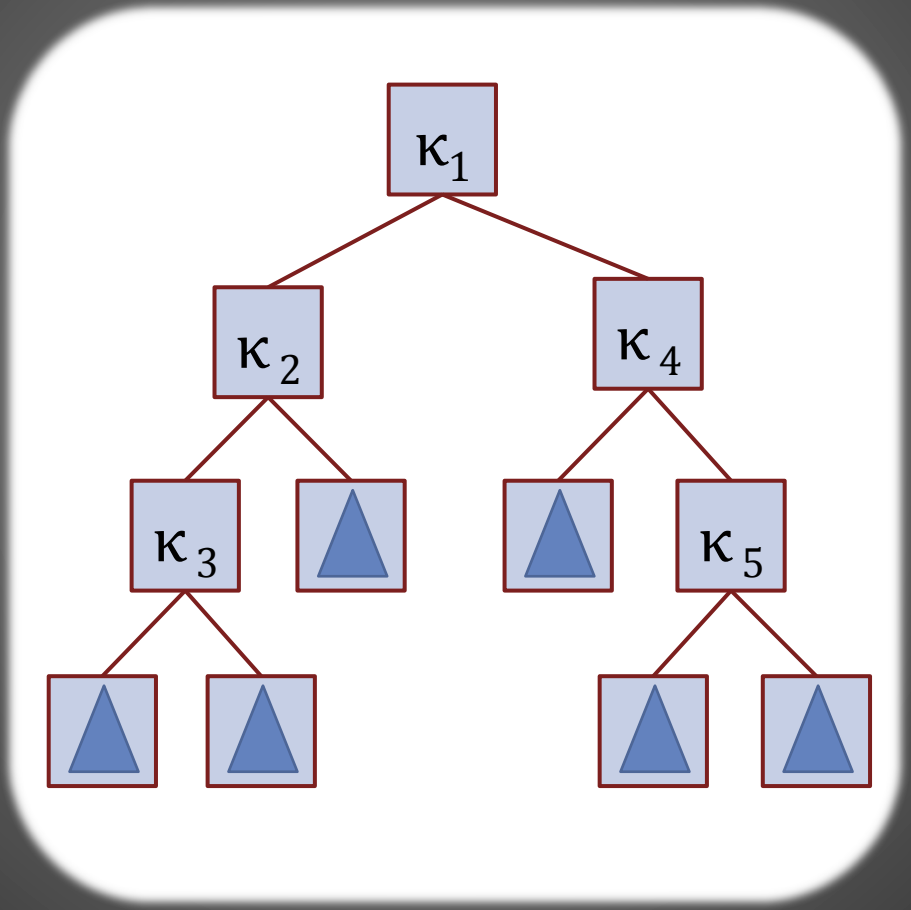

Generalized Kernel Traversal

```
function traverse(node, ray)

   if(ray misses the node's bounds)
      return MISS;

   if(node is a leaf)
      test with n's primitives
        and return the result;

   if(node is a branch)
      evaluate κ_N(r) to determine
        traversal order;
      if(the first child is a hit)
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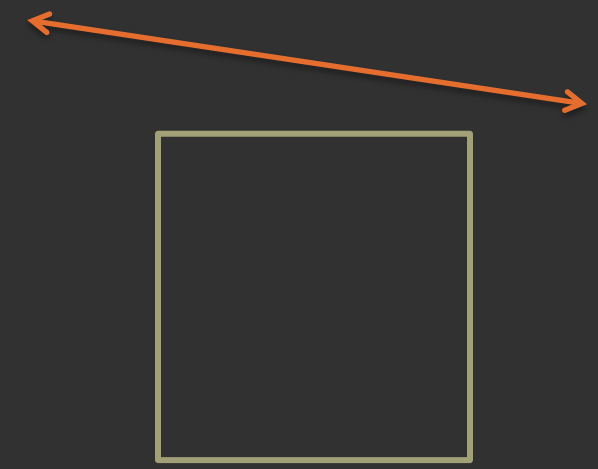

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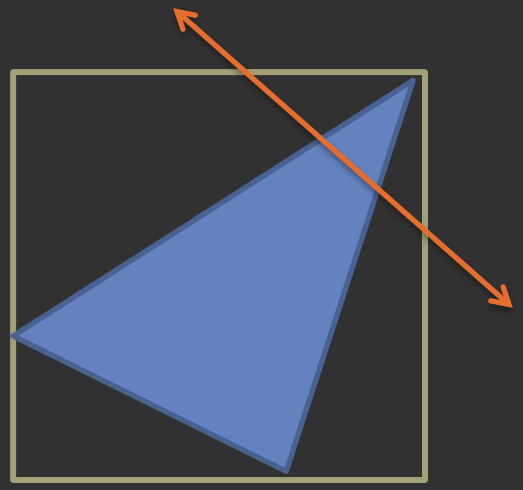

Full Kernel Traversal

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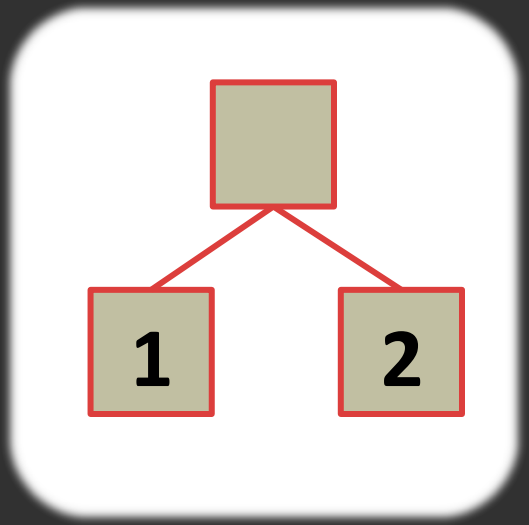

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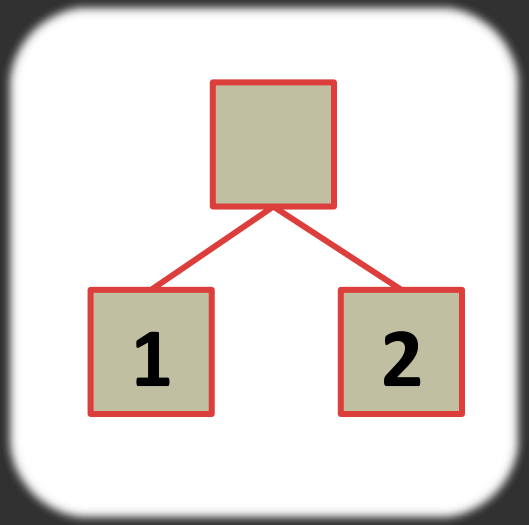

Steps to deriving SRDH:

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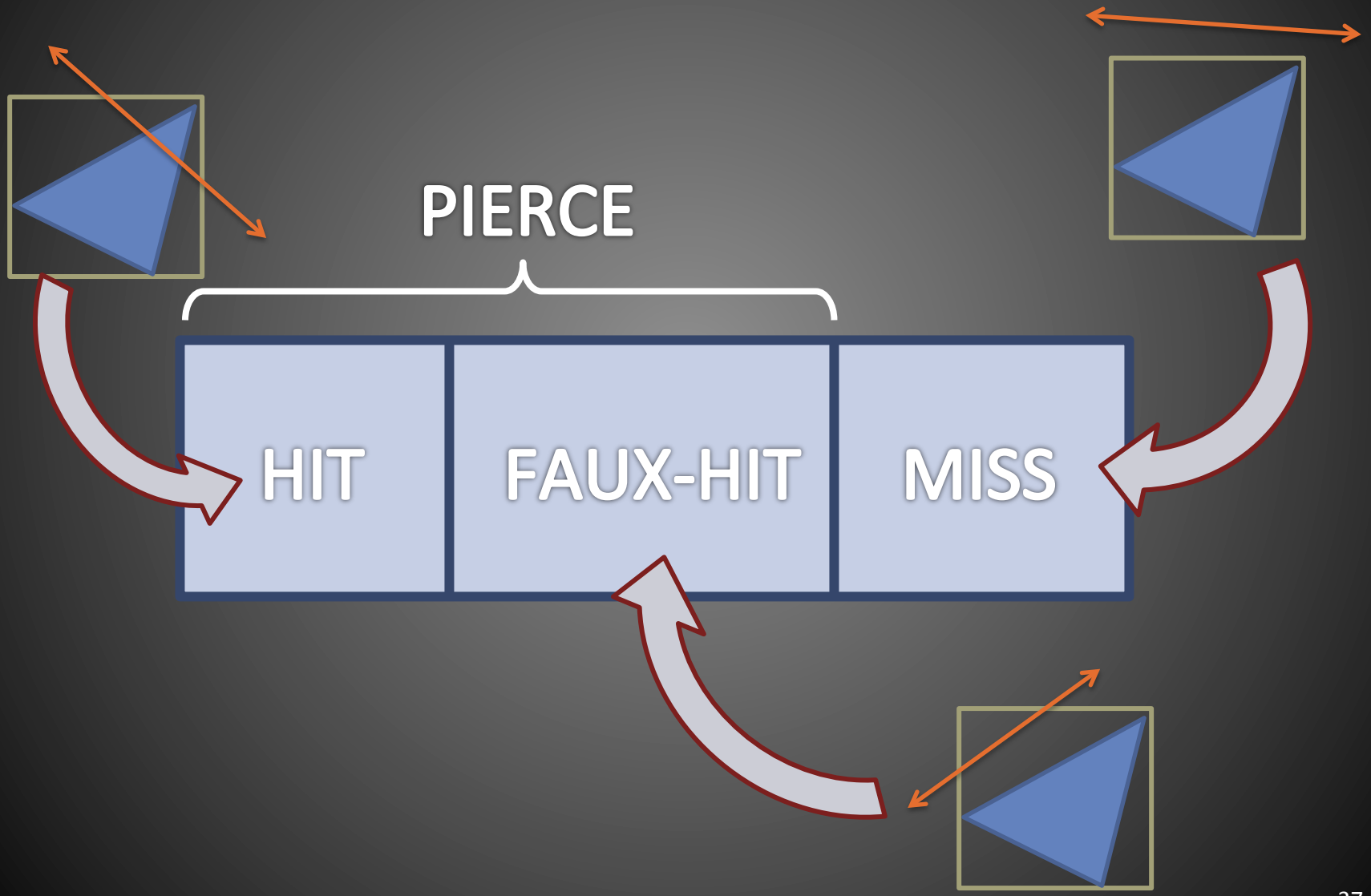
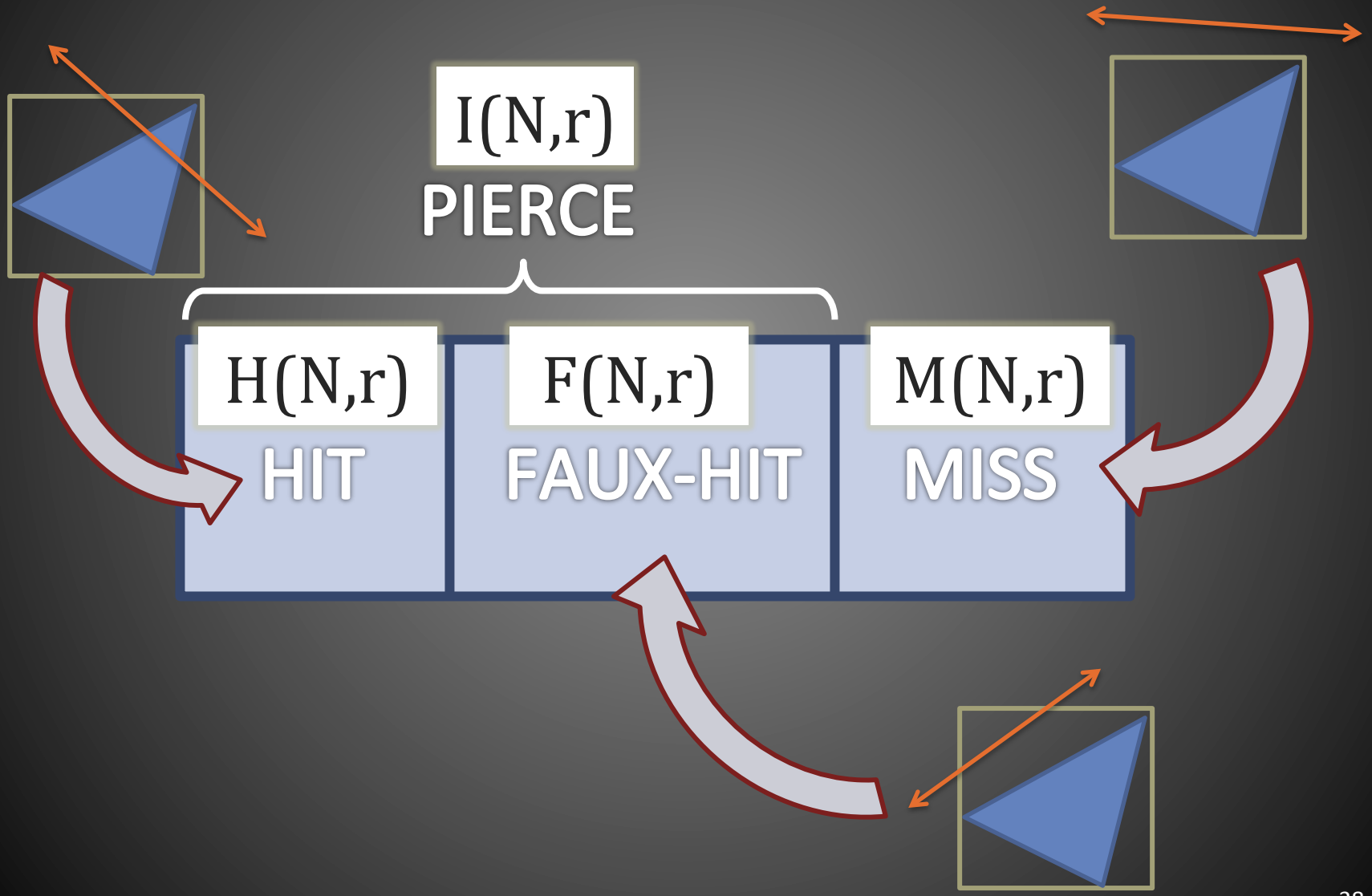
- Use this cost metric to build BVHs.

Rays and nodes interact in three ways



Encode states with binary indicator functions



The cost metric follows from the traversal algorithm

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Leaf case:

$$C(N,r)=c_b+I(N,r)c_p$$

The cost metric follows from the traversal algorithm

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Branch case:

$$C(N,r)=c_b+I(N,r)C'(N,r)$$

$$C'(N,r)=\kappa(r)Ord(L,R) + \ldots$$

$$Ord(L,R)=C(L,r) + (1-H(L,r))C(R,r)$$

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$$C'(N,r)=\kappa(r)\mathrm{Ord}(L,R) + \ldots$$

$$\mathrm{Ord}(L,R)=C(L,r)+(1-H(L,r))C(R,r)$$

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Branch case:

$$C(N,r)=c_b+I(N,r)C'(N,r)$$

$$C'(N,r)=\kappa(r)Ord(L,R)+\bar{\kappa}(r)Ord(R,L)$$

$$Ord(L,R)=C(L,r)+(1-H(L,r))C(R,r)$$

Branch case: canonical recursive form

$$C(N,r)=c_b+I(N,r)C'(N,r)$$

$$C'(N,r)=(1-\bar{\kappa}(r)H(R,r))C(L,r)$$
$$+(1-\kappa(r)H(L,r))C(R,r)$$

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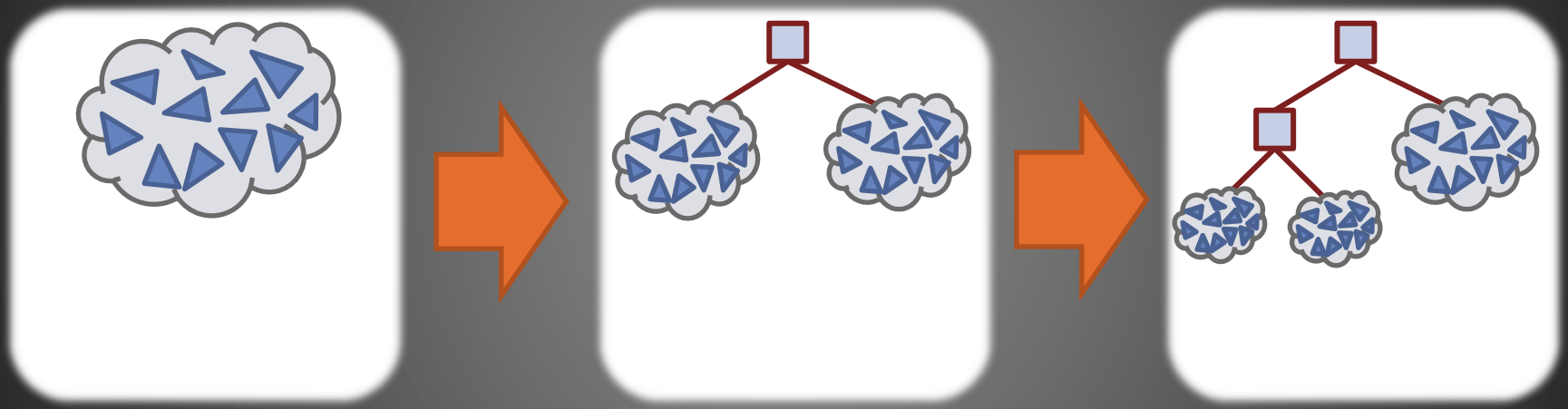
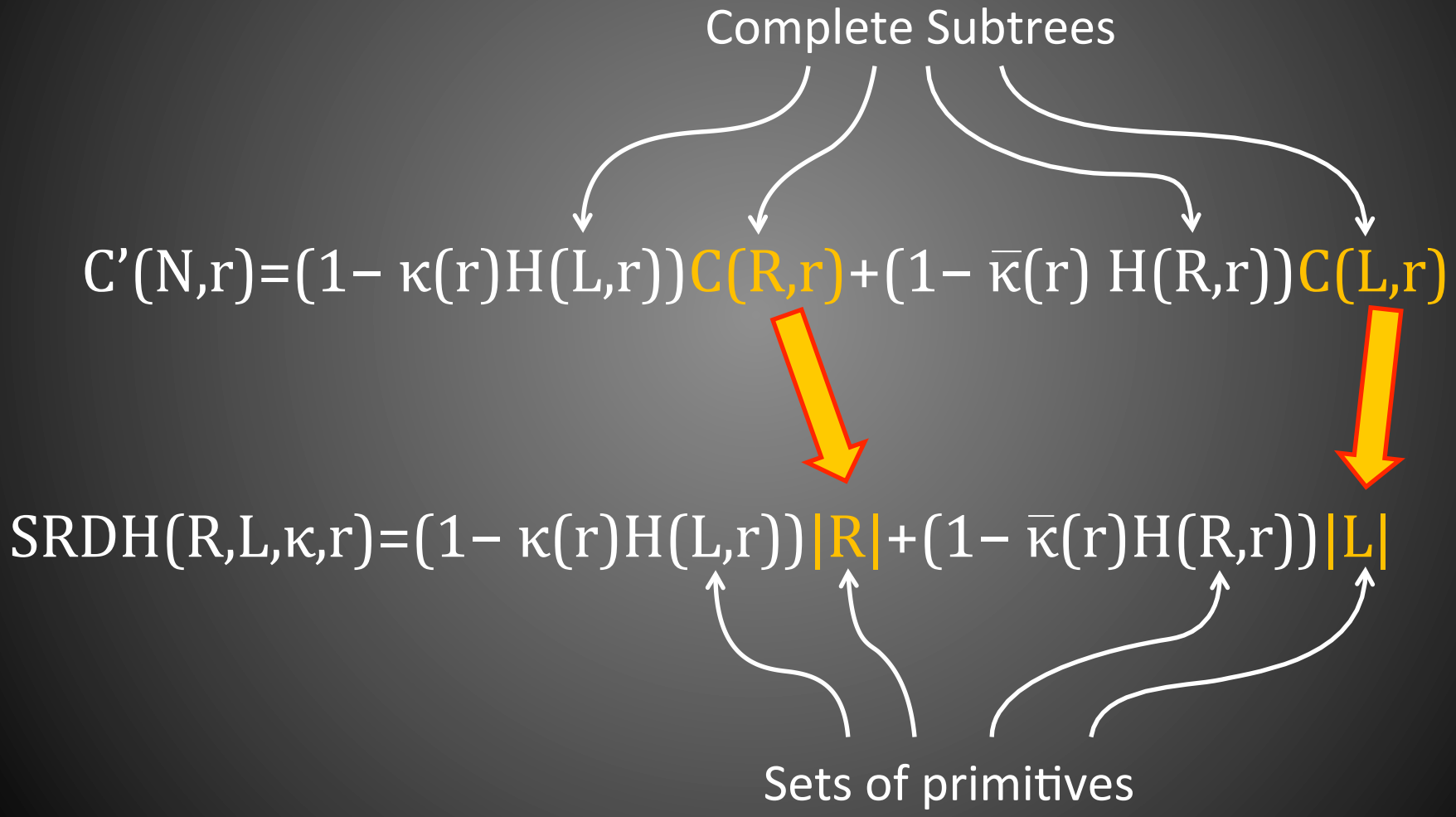
Top-down and greedy BVH build



A heuristic estimates the cost metric



Greedy SRDH build optimizes over partitions and traversal policies

SAH:

```
forall(partitions in set-of-partitions)
        …evaluate SAH and pick min…
```

SRDH:

```
forall(partitions in set-of-partitions)
        forall(traversalKernels in set-of-kernels)
                …evaluate SRDH and pick min…
```

Greedy SRDH build optimizes over partitions and traversal policies

SAH:

```
forall(partitions in set-of-partitions)
        …evaluate SAH and pick min…
```

SRDH:

```
forall(partitions in set-of-partitions)
        forall(traversalKernels in set-of-kernels)
                …evaluate SRDH and pick min…
```

$$SRDH(R,L,\kappa,r)=(1-\kappa(r)H(L,r))|R|+(1-\kappa(r)H(R,r))|L|$$

Greedy SRDH build optimizes over partitions and traversal policies

SAH:

```
forall(partitions in set-of-partitions)
        …evaluate SAH and pick min…
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SRDH:

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forall(partitions in set-of-partitions)
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                …evaluate SRDH and pick min…
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$$SRDH(R,L,\kappa,r)=(1-\kappa(r)H(L,r))|R|+(1-\kappa(r)H(R,r))|L|$$

Putting it all together: three stage build

- STEP 1: Build a BVH with SAH (BVH can also be used for radiance rays too)
- STEP 2: Do full trace of the whole representative ray set, finding EVERY hit for each ray.
- STEP 3: Use representative ray set to build a specialized BVH with the SRDH.

Results

Two key questions:

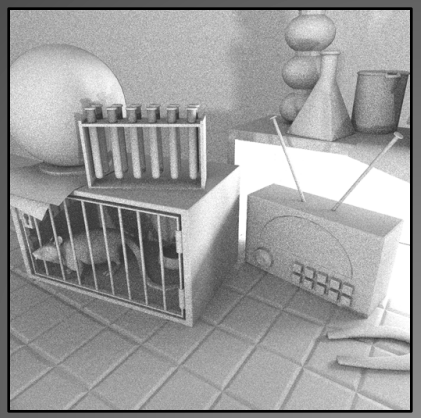
- How much does SRDH improve traversal cost when perfect information about shadow rays is present?

- How does the benefit of the SRDH decrease as less shadow ray information is known a priori? (Is a practical implementation possible?)

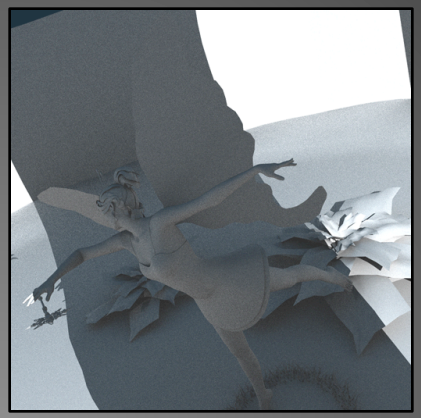
Test Scenes / Experimental Setup

Bedroom
(93% occluded)

Mad Science
(80% occluded)



Fairy
(56% occluded)



Sponza
(14% occluded)

Arcade
(38% occluded)

- 1024x1024 renderings
- Four possible traversal kernels:
  - back-to-front, front-to-back, left-first, right-first
- BVH build: up to 32 partitioning buckets in each dimension
- Use count of nodes traversed as a proxy for traversal cost

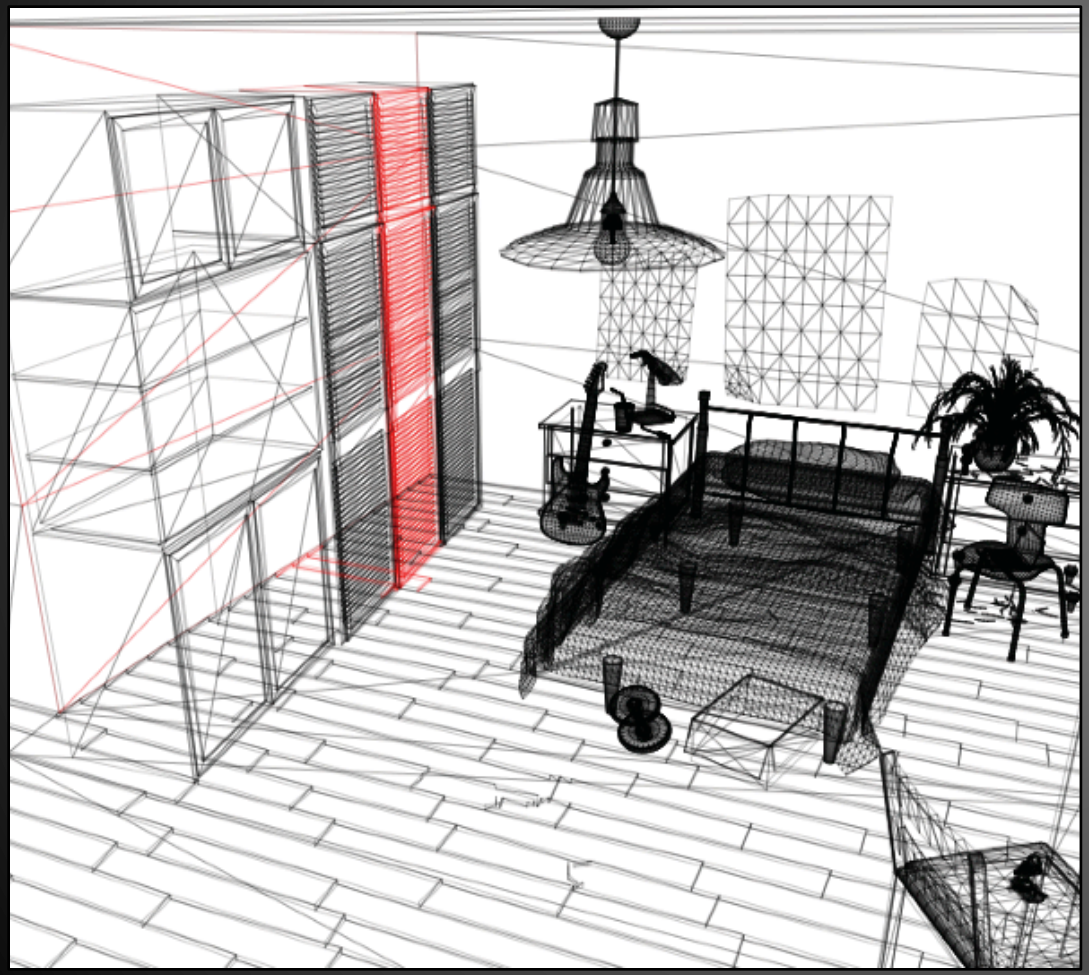
How much does SRDH improve traversal cost when perfect information about shadow rays is present?

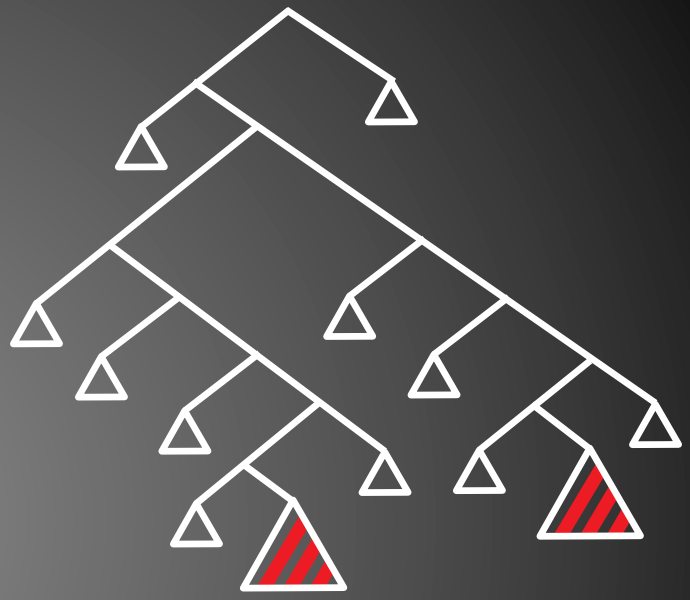
- Optimize over all traversal kernels
  - Left-first, right-first, front-to-back, back-to-front
- Representative ray set includes all shadow rays (best-case scenario)

Bedroom: SRDH reduces traversal steps by 56%

Bedroom
(93% occlusion)

SRDH groups occluders and places them high in the BVH

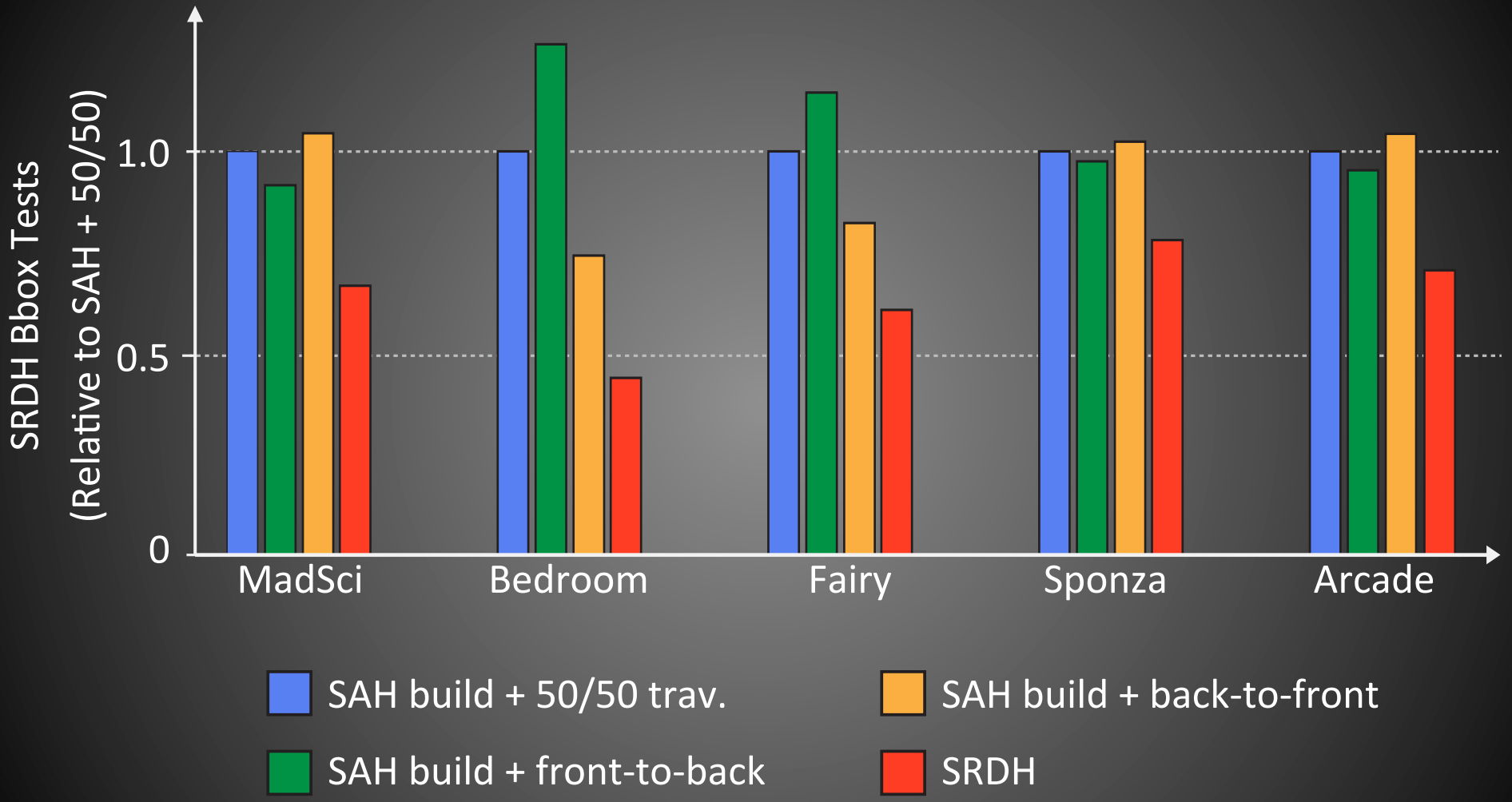




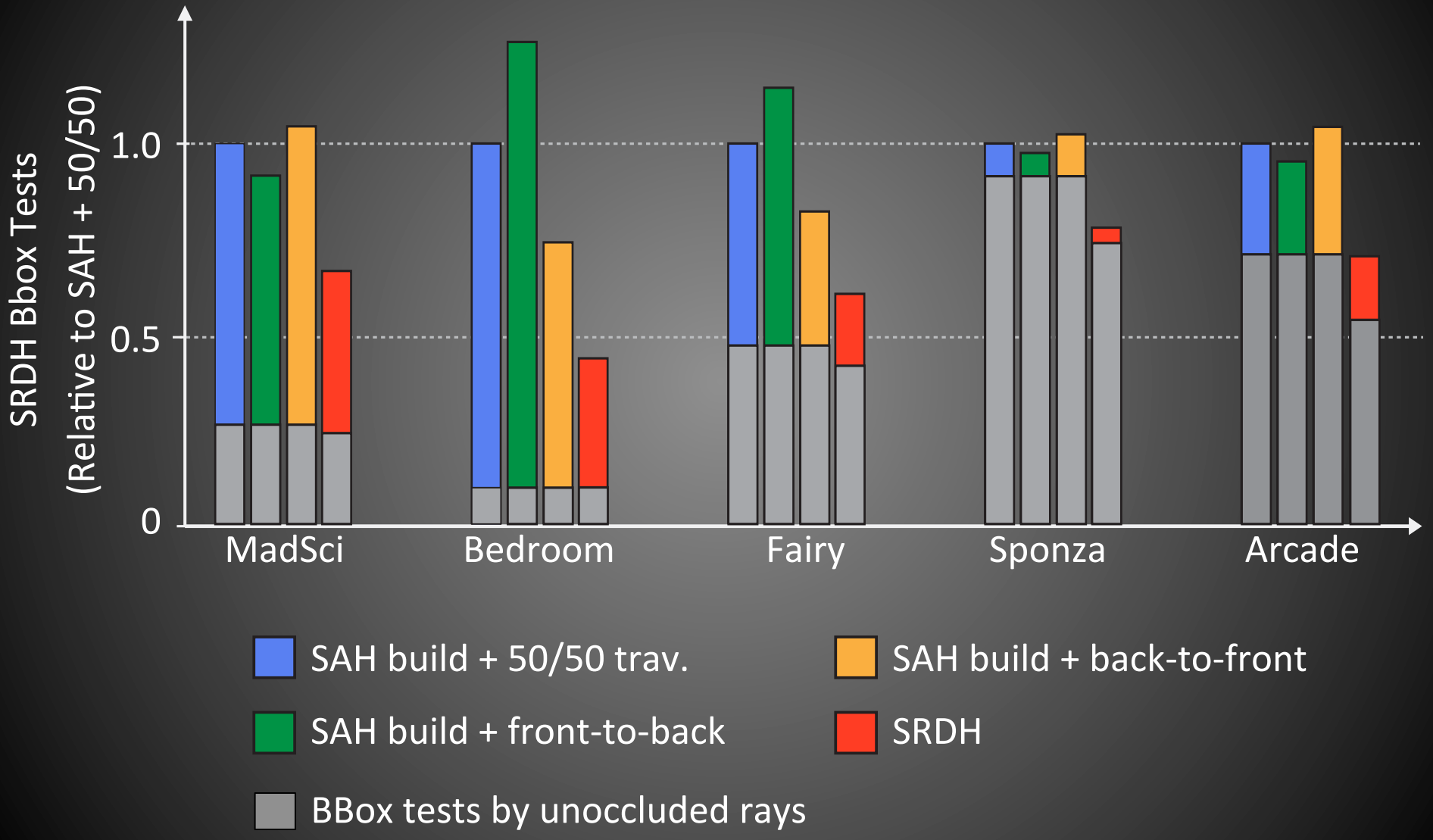
SAH-built BVH

SRDH-built BVH

SRDH reduces traversal steps 22% to 56%

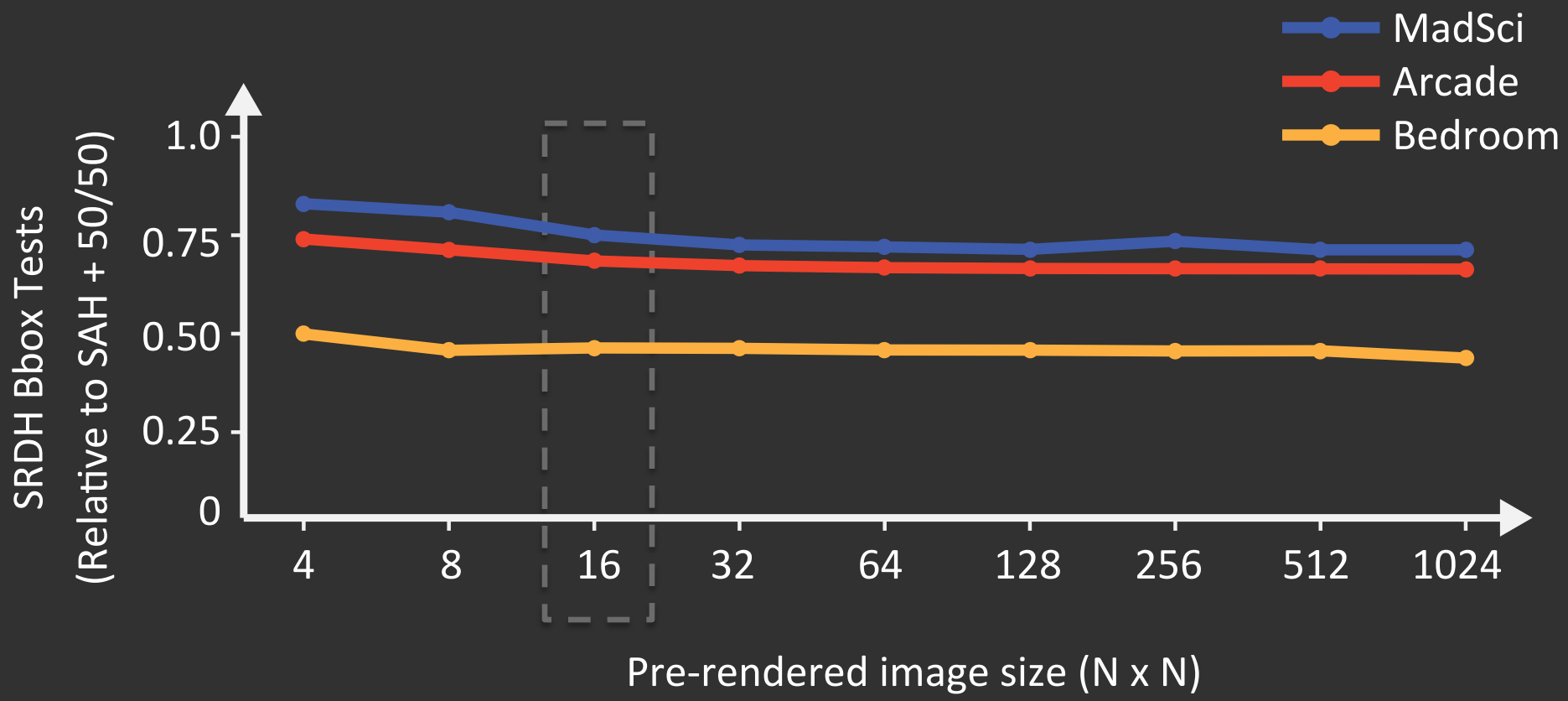


Smallest benefit in low occlusion conditions



How does the benefit of the SRDH decrease as less shadow ray information is known a priori? (Is a practical implementation possible?)

SRDH is robust to sparse representative ray sets



Representative ray set from 16x16 pre-rerendering always within 6% of optimal
(ray set is less than 1% size of all shadow rays)

Bottom Line

- SRDH increases preprocessing costs (it builds two BVHs)
  - SRDH tree build (with a 16x16 ray set) takes 1.6x time of simple SAH build
  - Overall preprocessing 2.6x that of SAH build
- SRDH reduces shadow ray traversal costs 22% to 56%
  - Benefit greatest in scenes with high occlusion
- We found that only employing the always-left and always-right kernels was sufficient for our kernel choices
  - No runtime overhead to implement traversal policy

SRDH Summary

- The SRDH simultaneously determines BVH structure and traversal order based on knowledge of shadow rays and scene geometry

- Enabled by new cost metric for a generalized model of traversal

Final Thoughts

- By dreaming up data structures with greater freedom, we can minimize over the freedoms during build, and create better algorithms

- Rendering algorithms can do better to specialize themselves to specific machines and workloads