MSBVH: An Efficient Acceleration Data Structure for Ray Traced Motion Blur

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August 6, 2011

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Principles of Accelerated Ray Tracing

Hierarchical culling

- object list partitioning $\Rightarrow$ BVH

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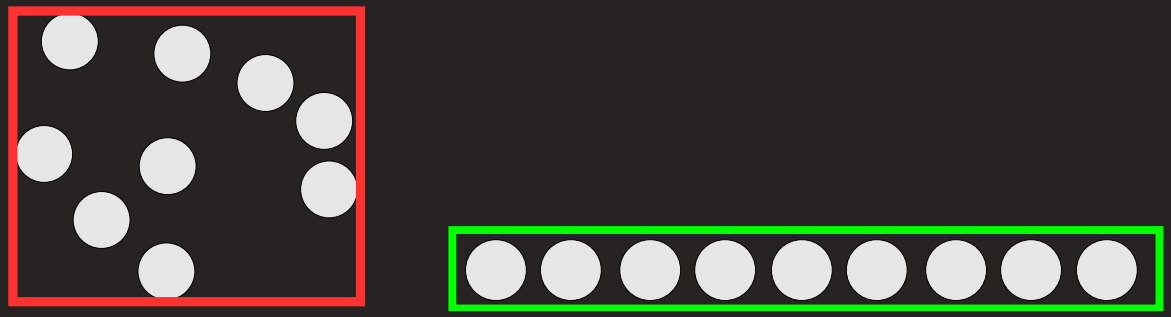

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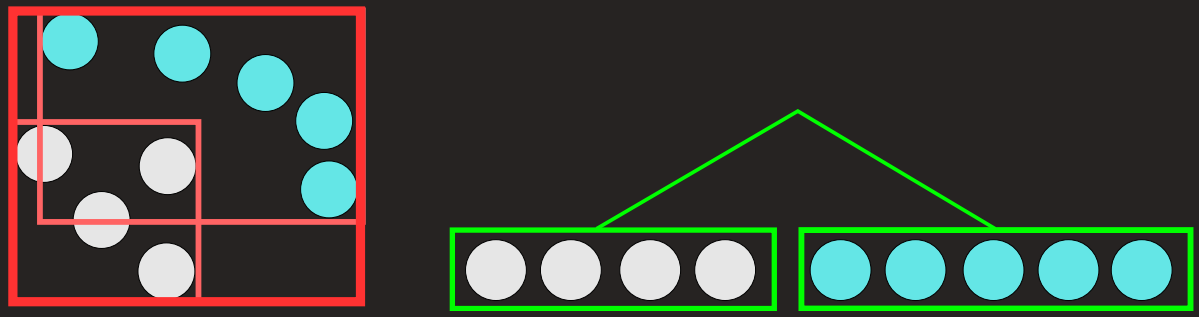

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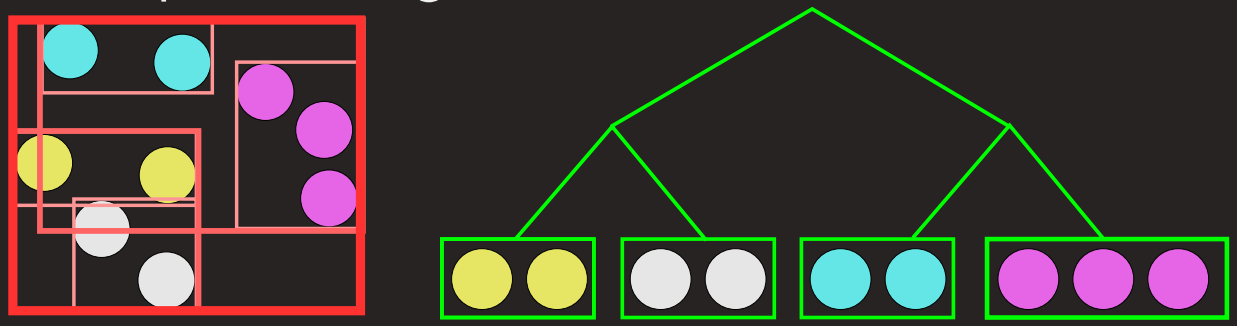

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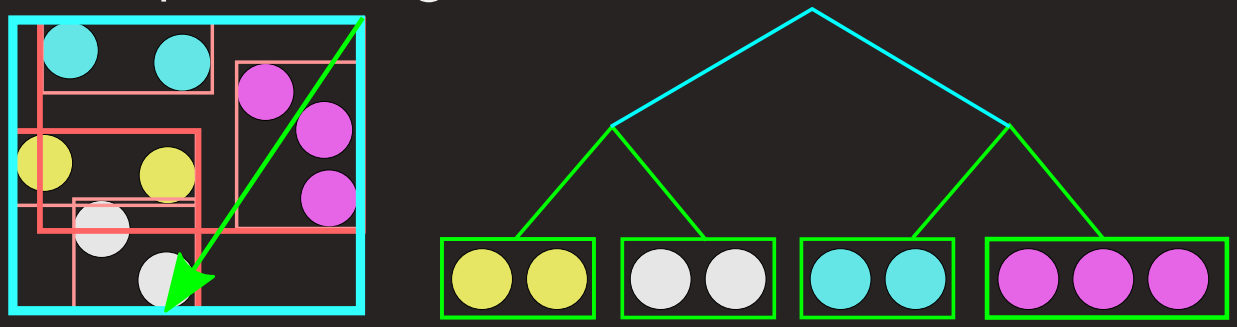

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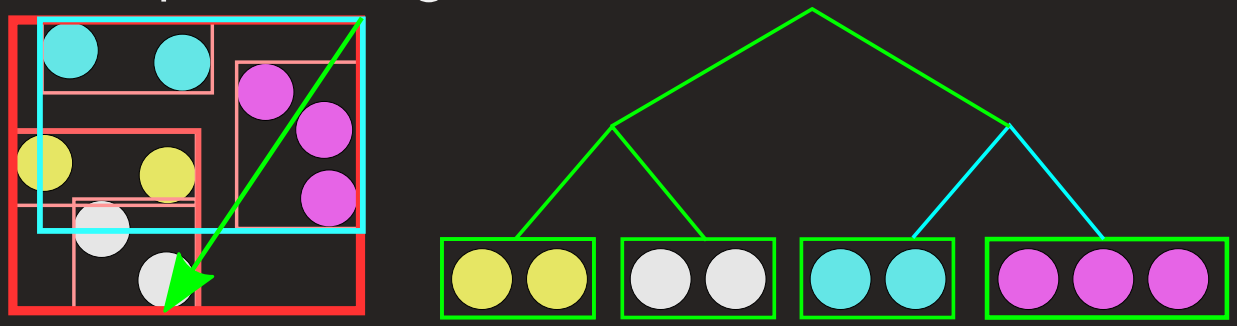

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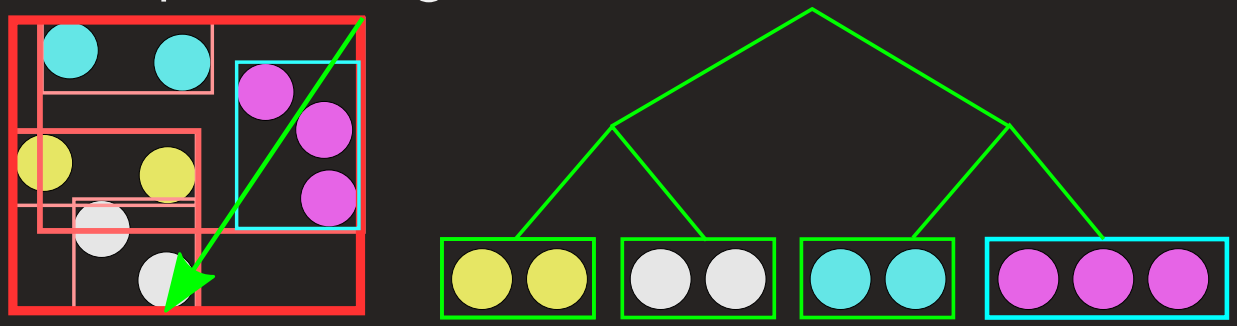

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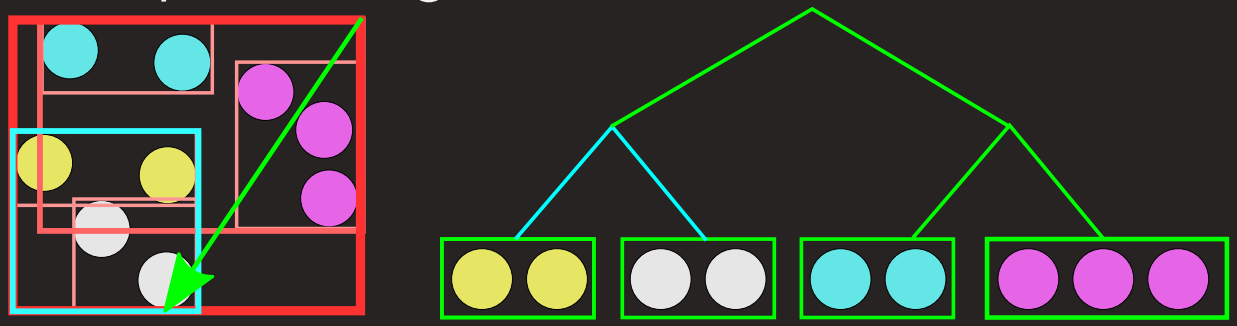

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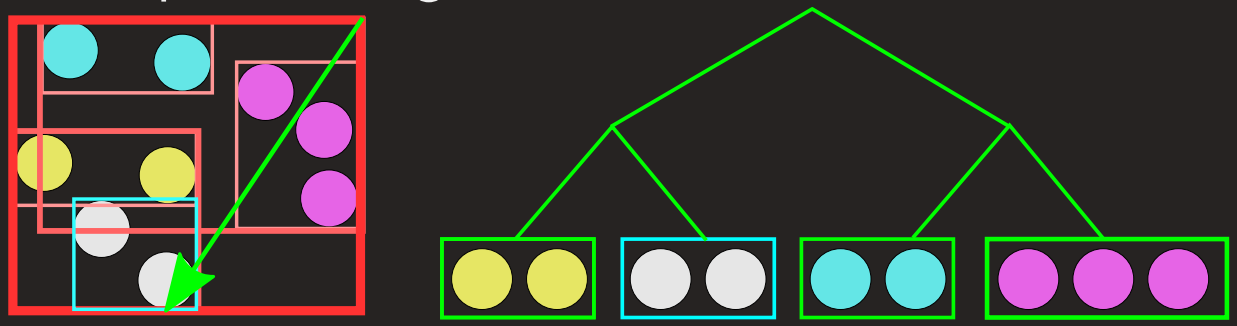

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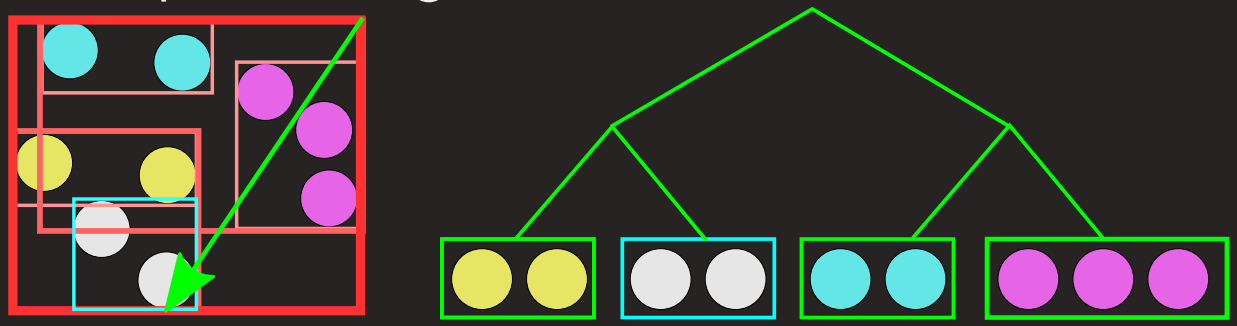

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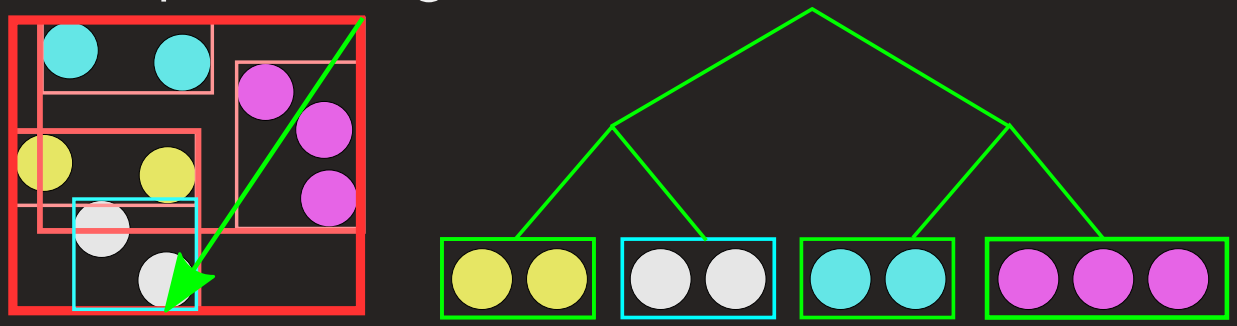

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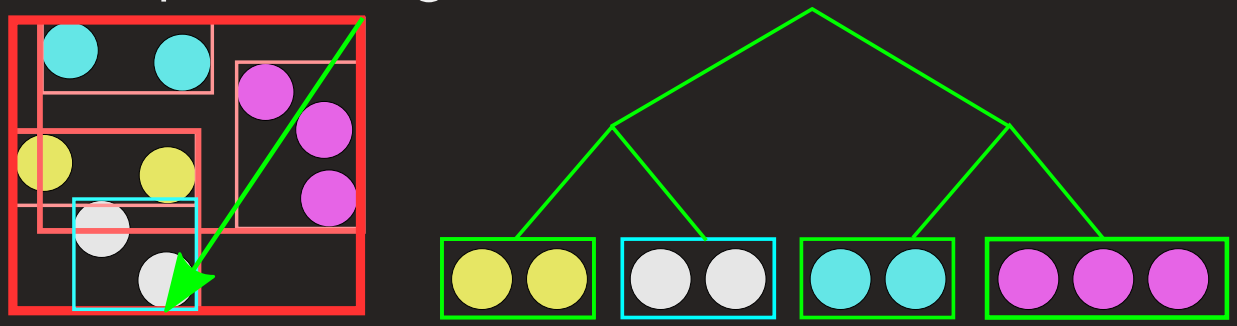

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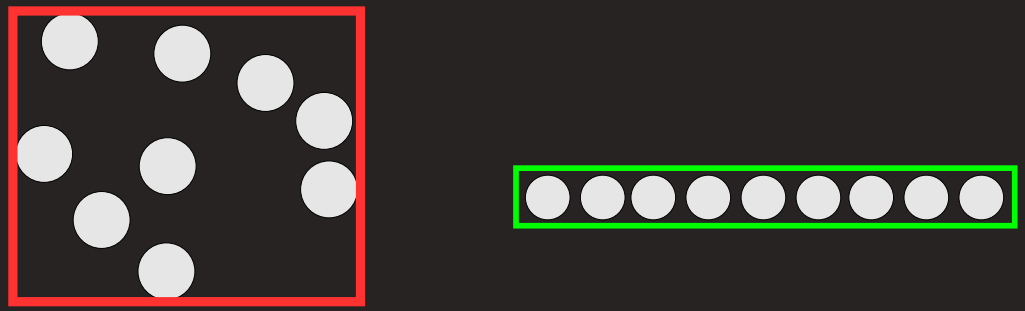

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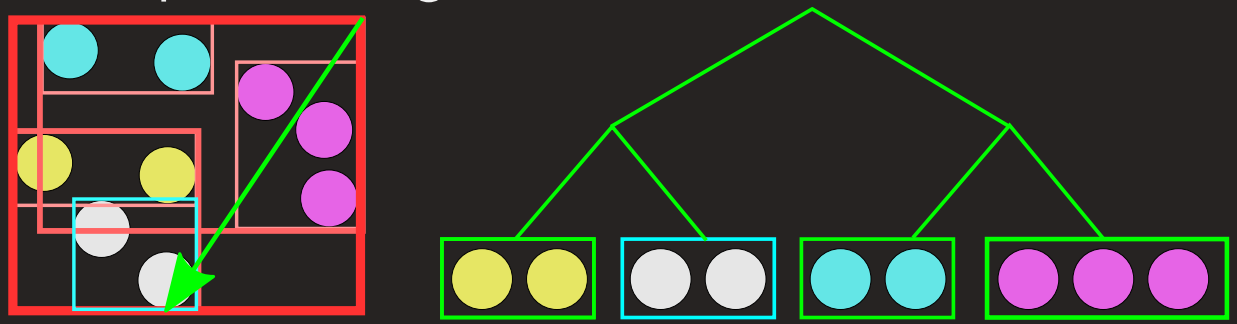

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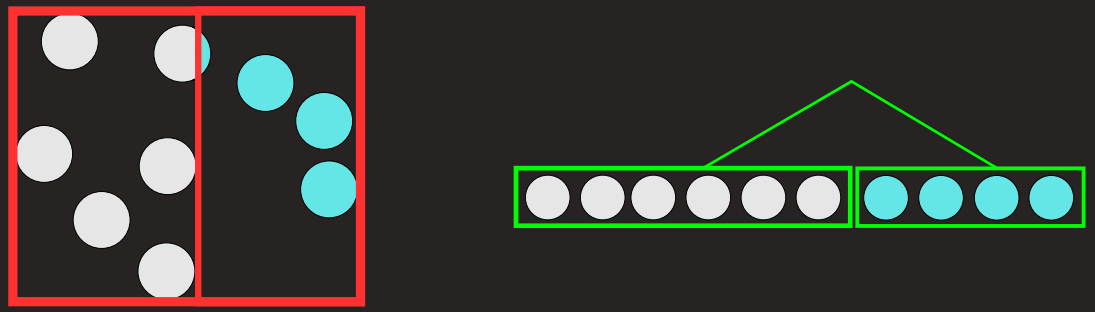

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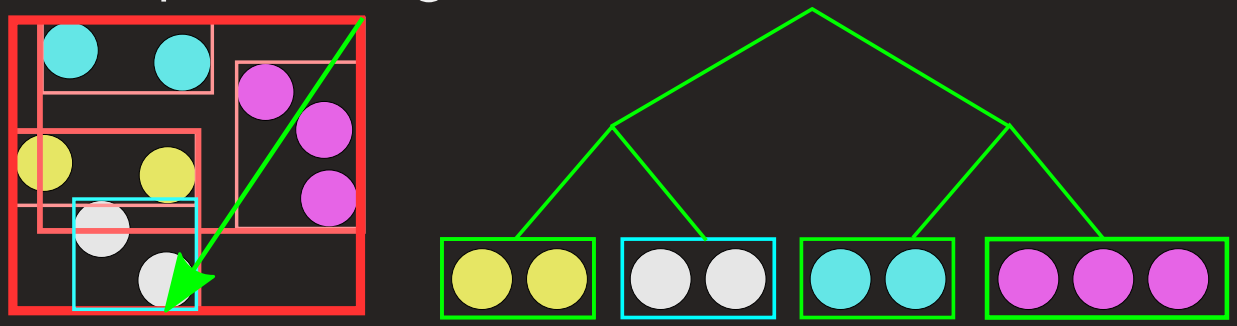

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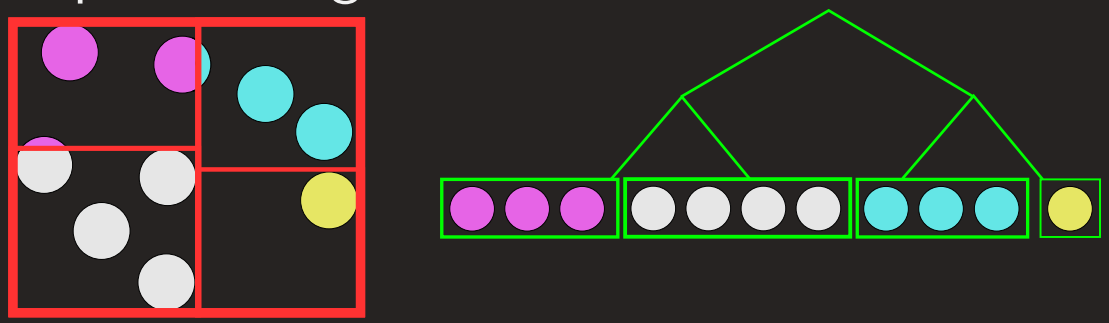

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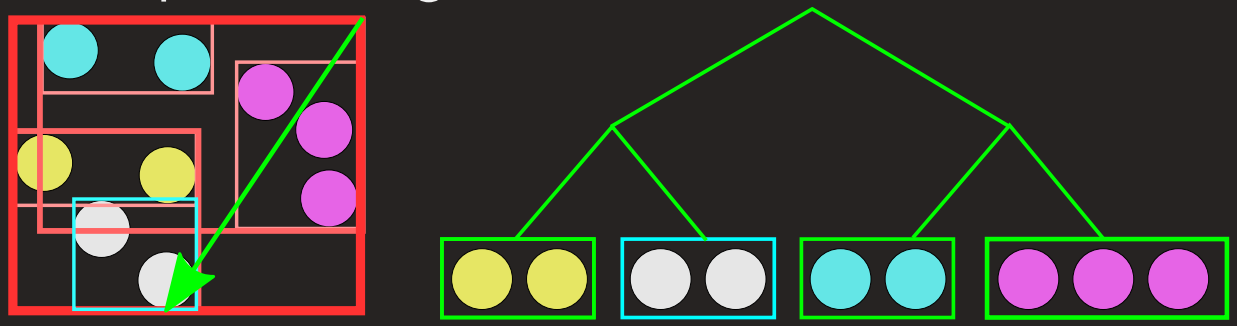

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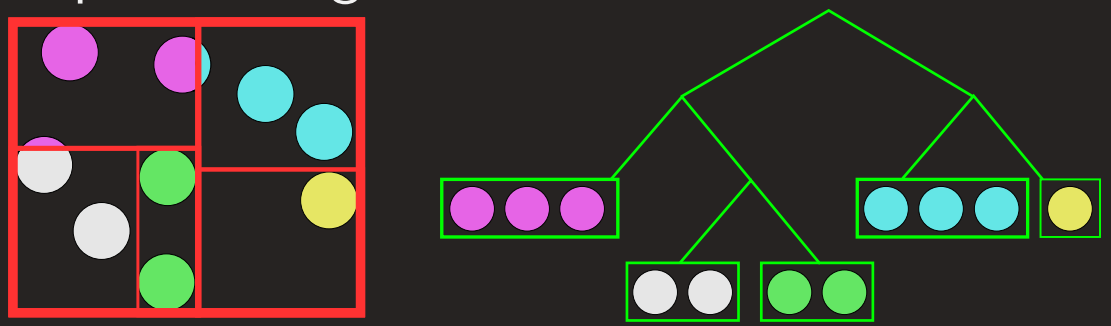

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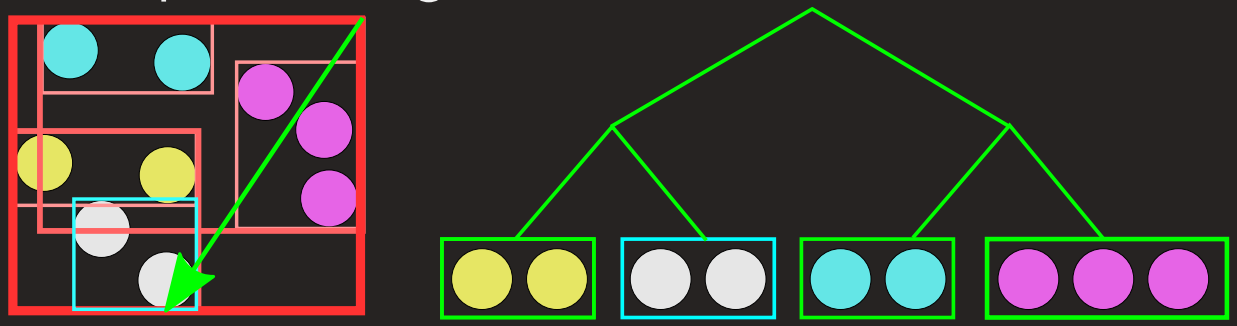

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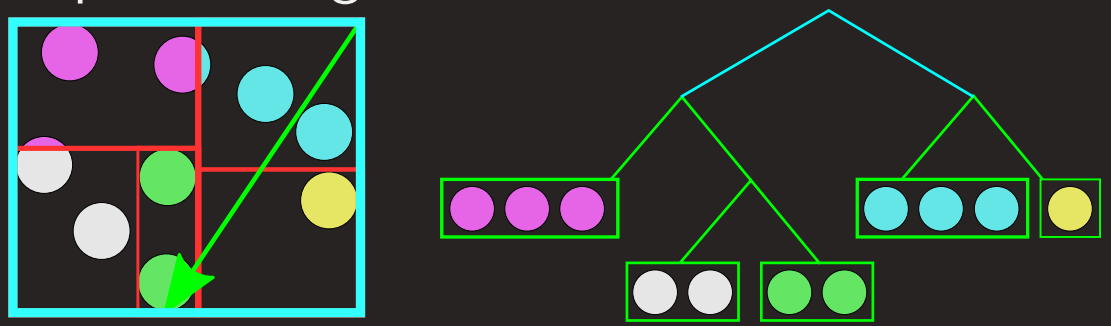

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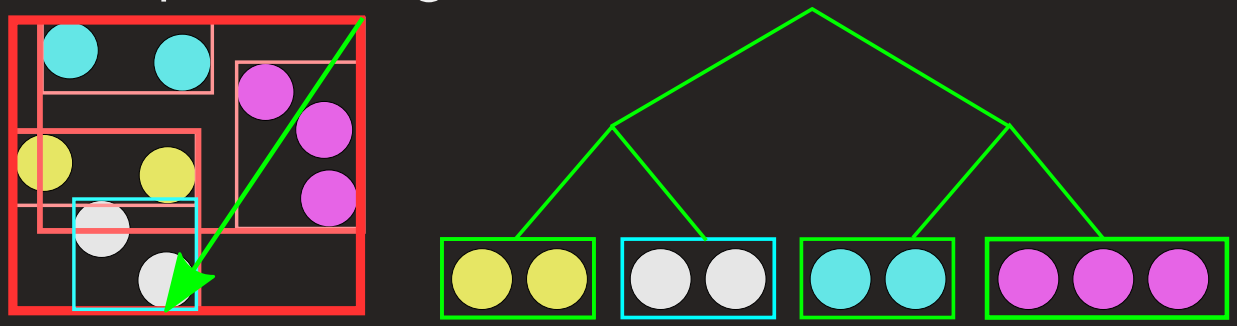

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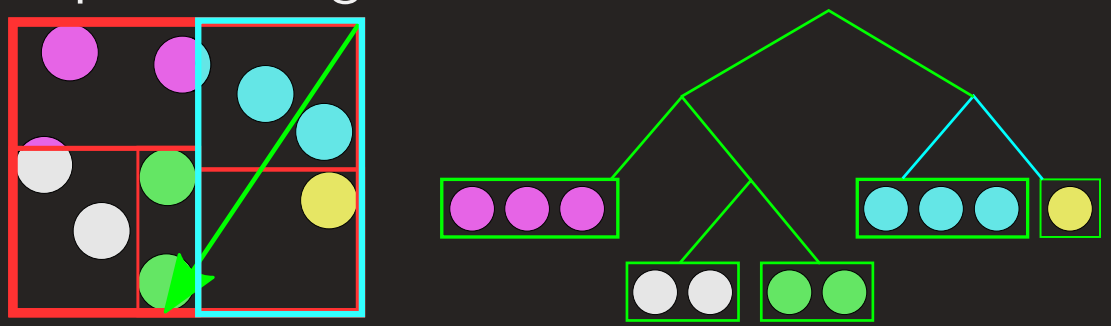

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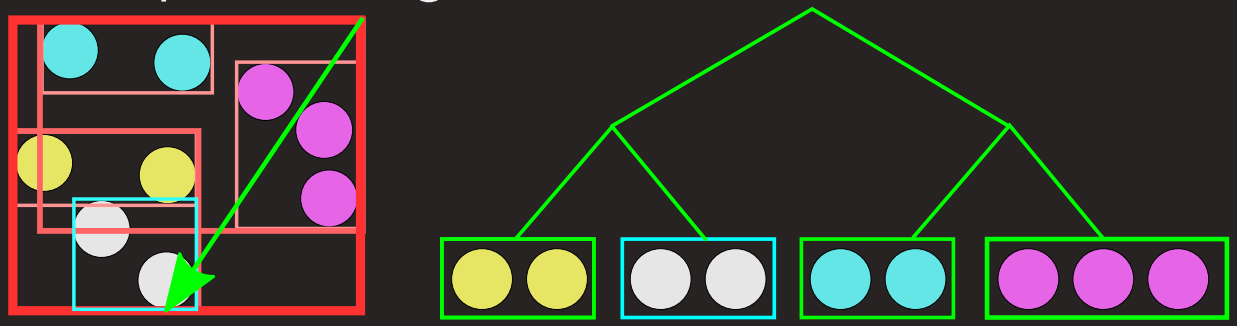

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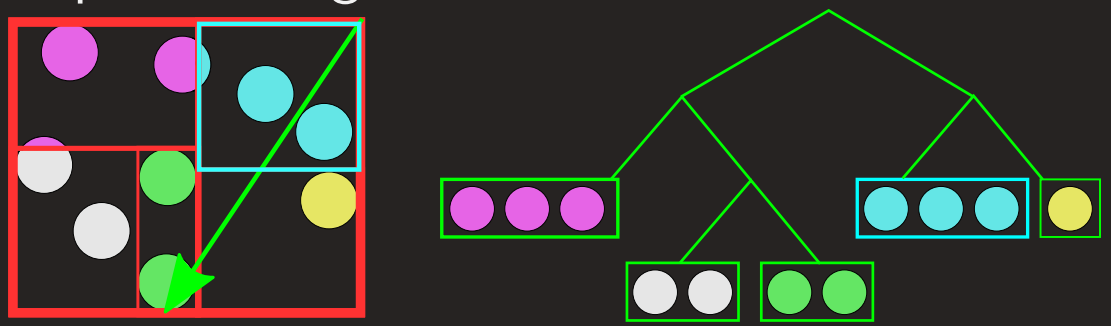

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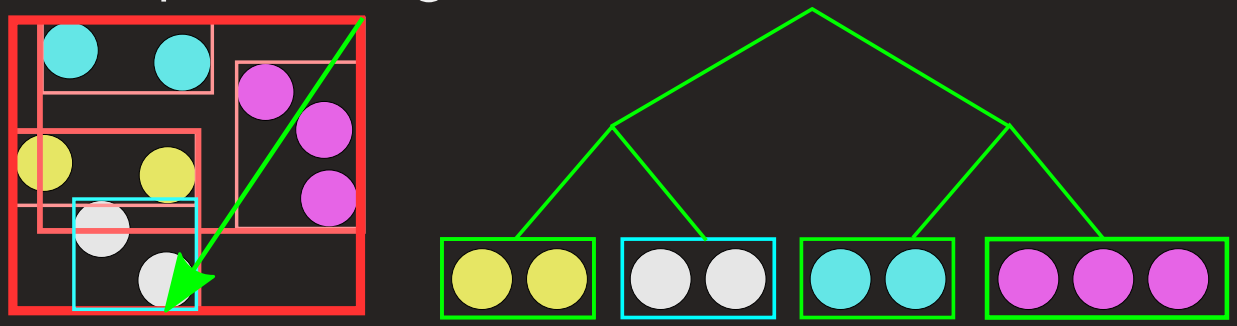

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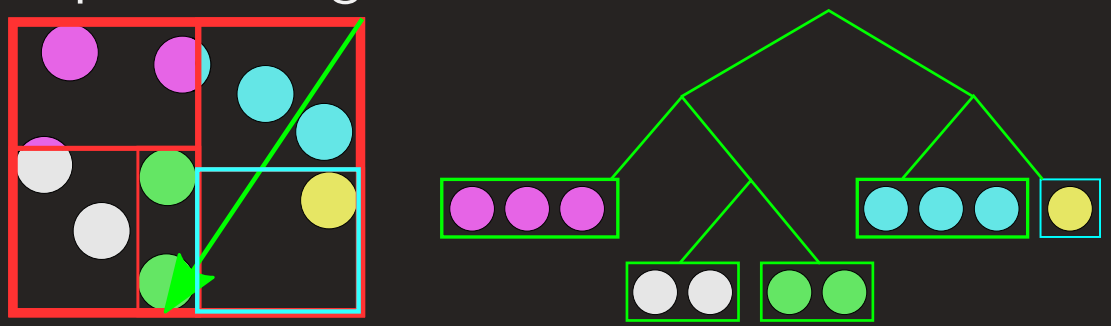

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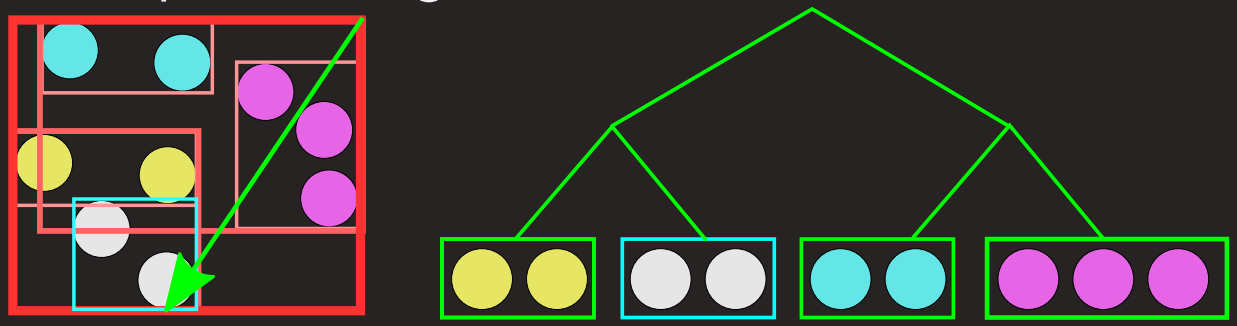

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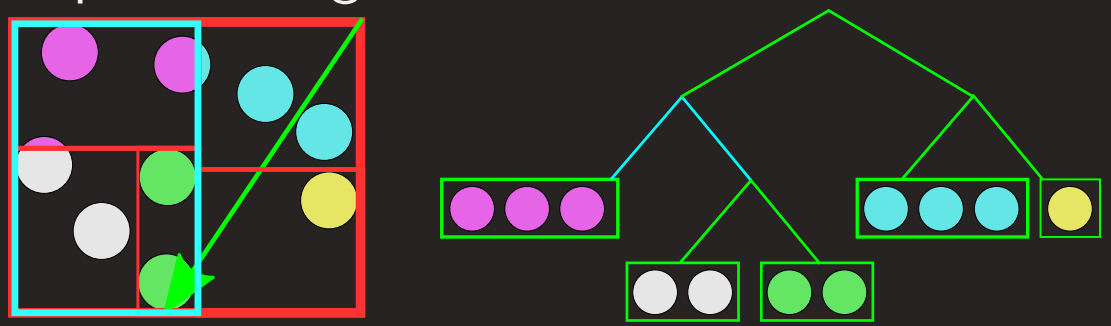

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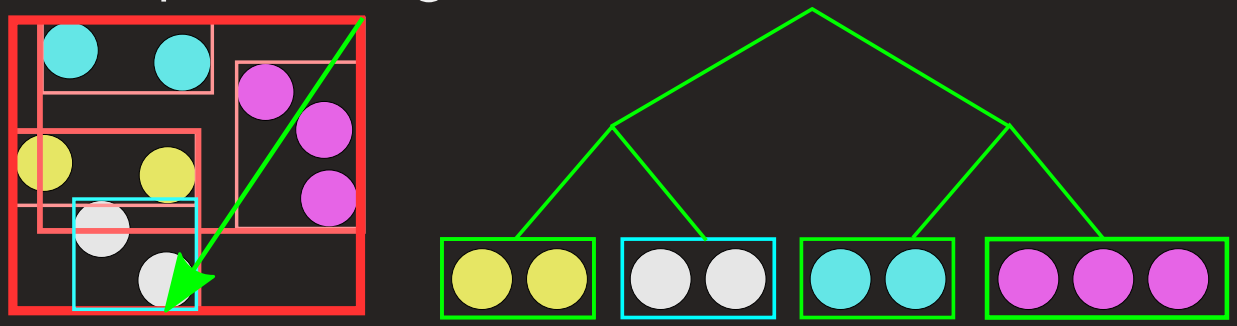

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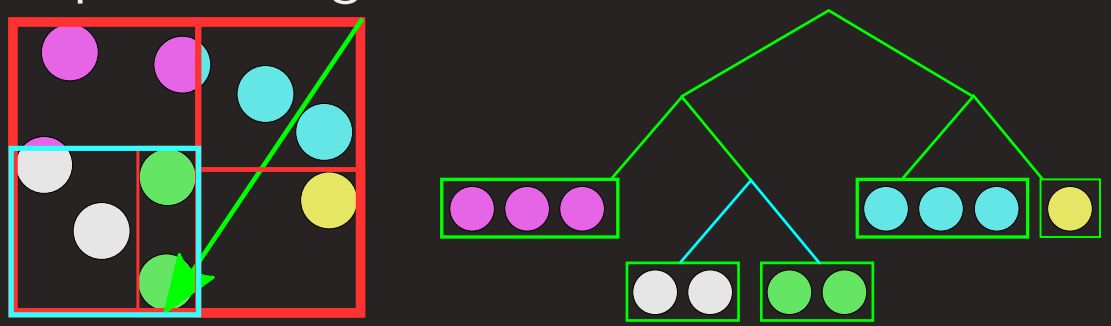

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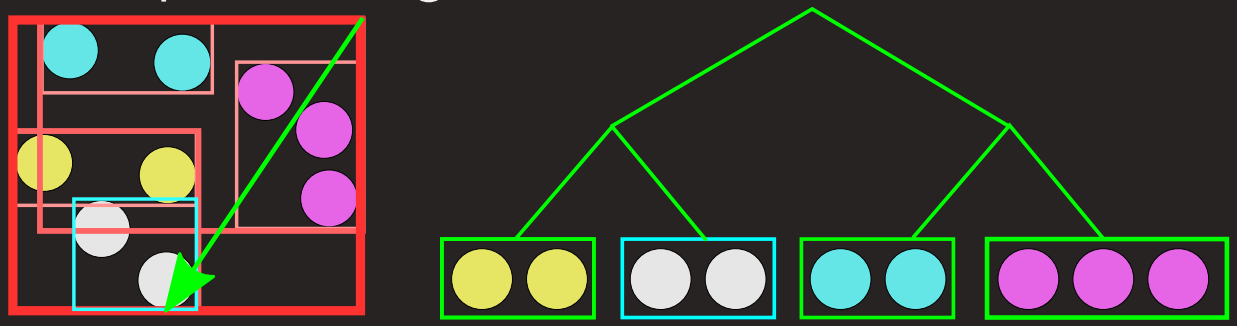

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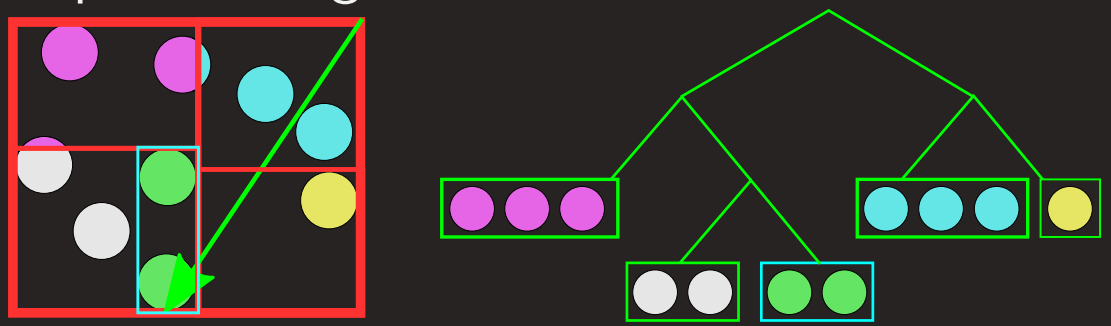

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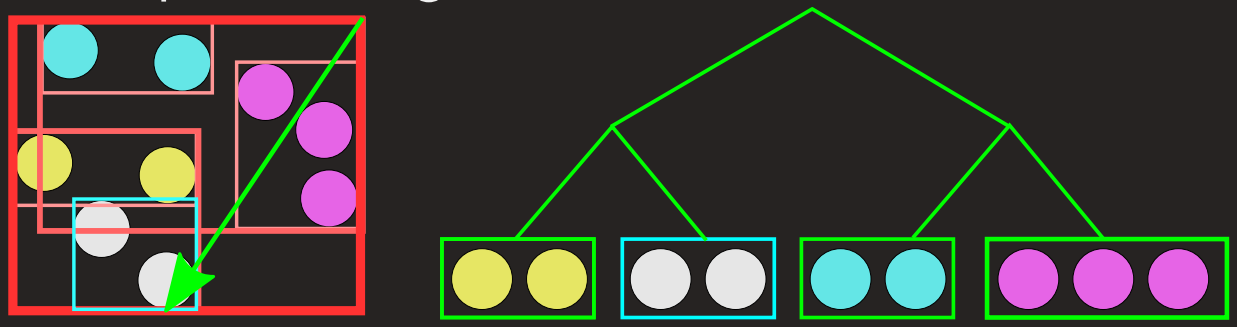

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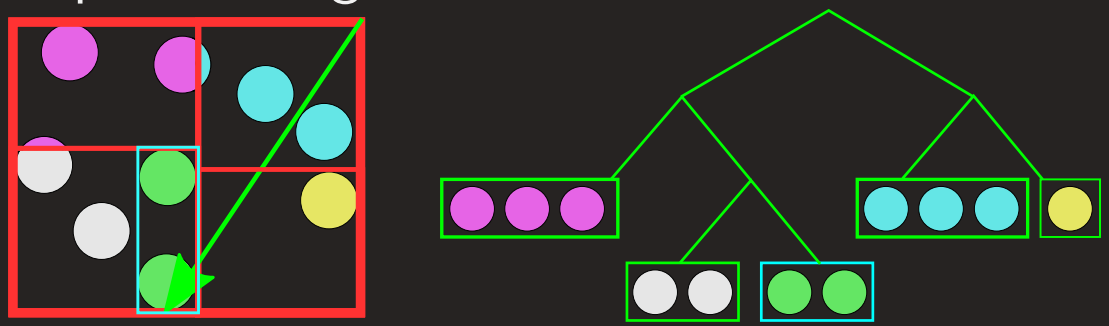

  - nodes do not overlap, but reference duplication

SBVH

Best of both worlds

- object list partitioning whenever overlap is small
- spatial partitioning otherwise

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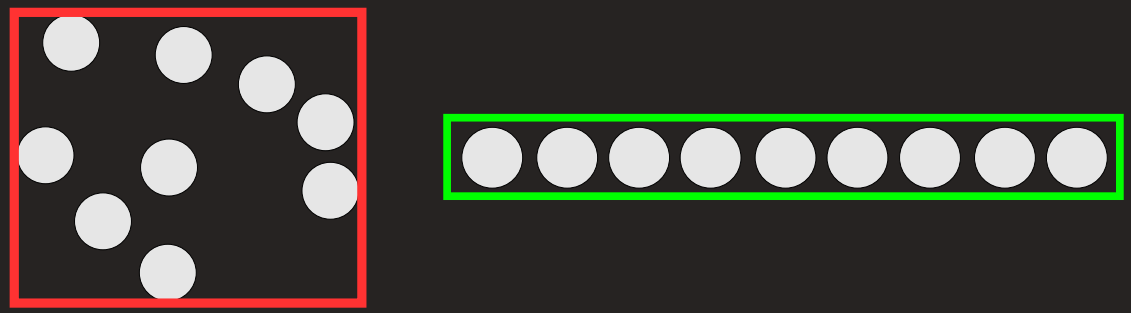

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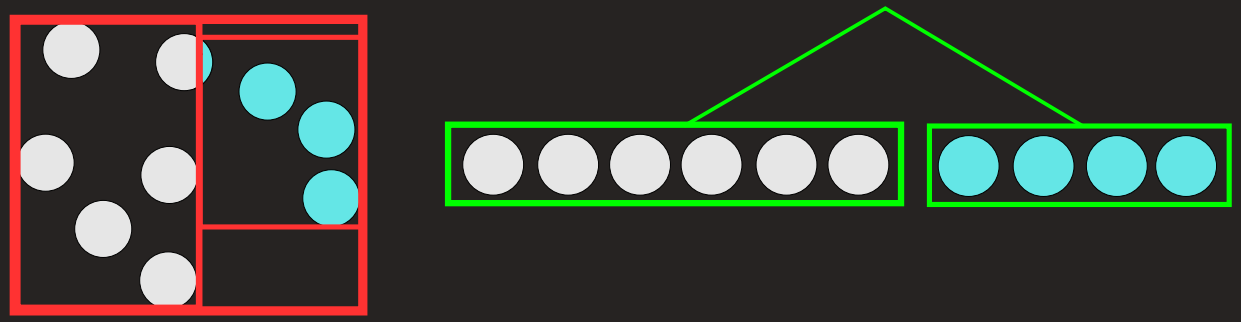

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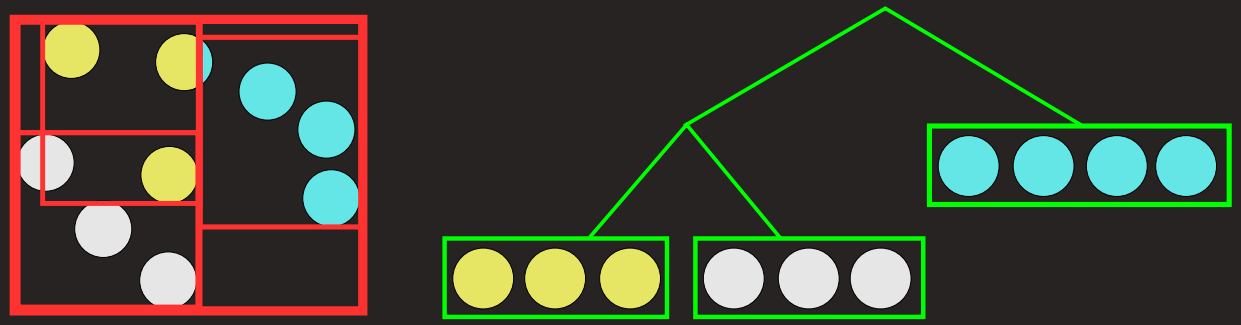

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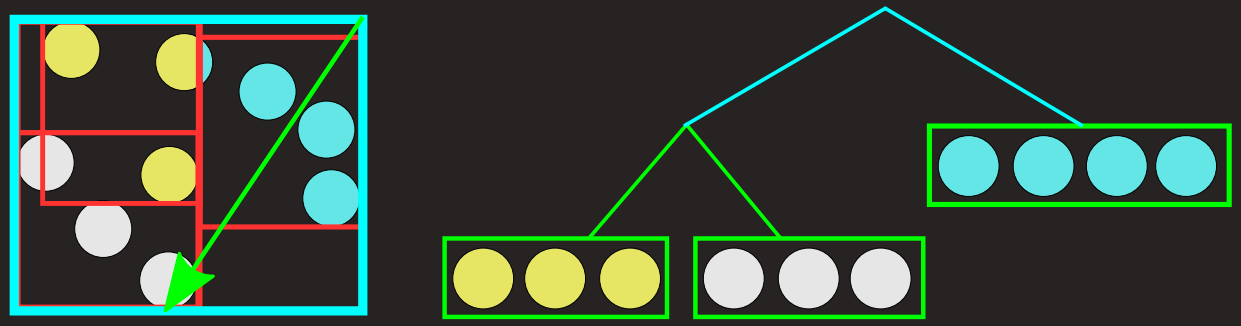

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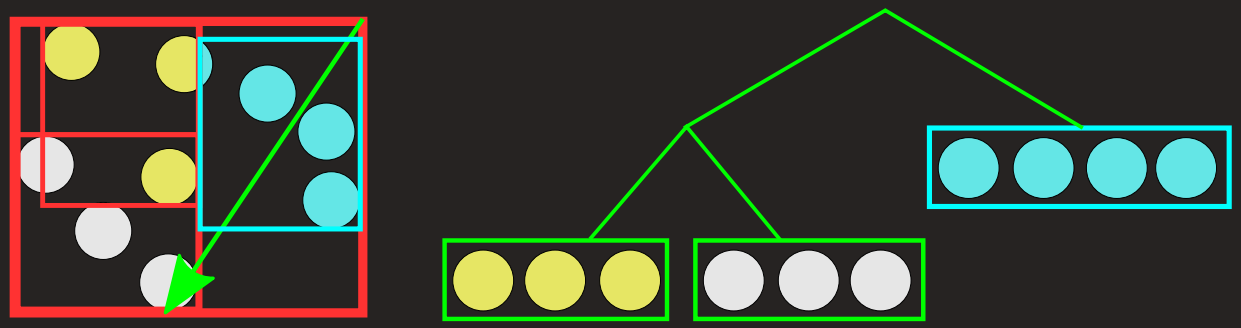

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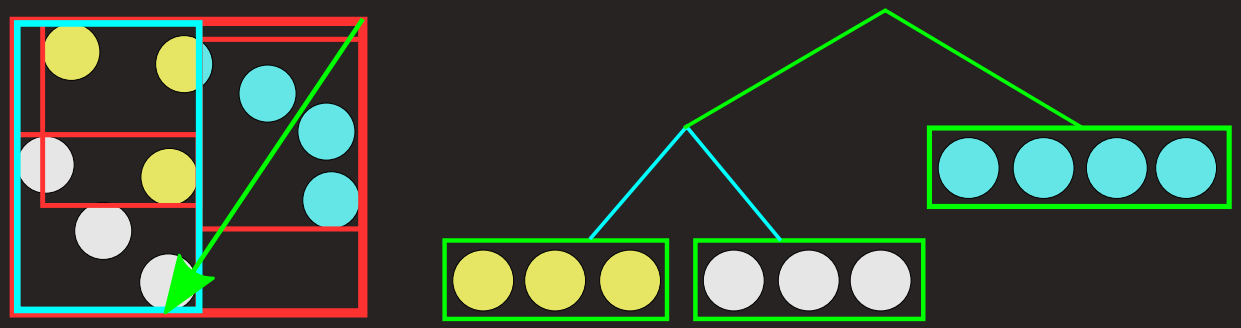

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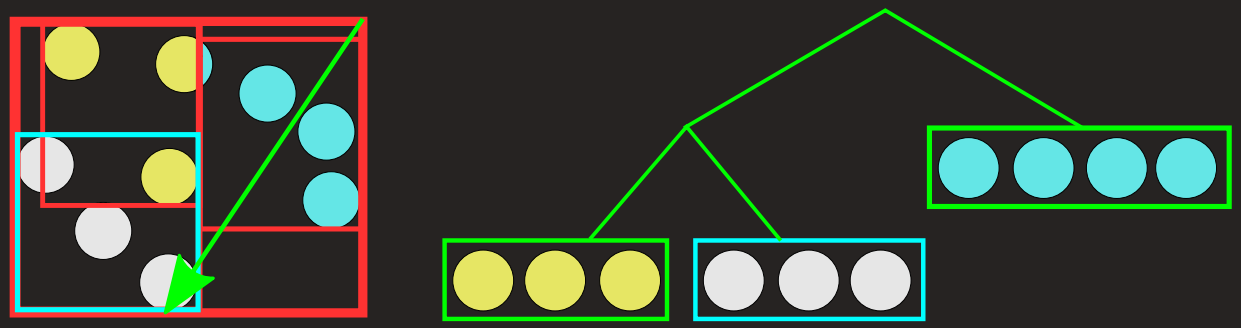

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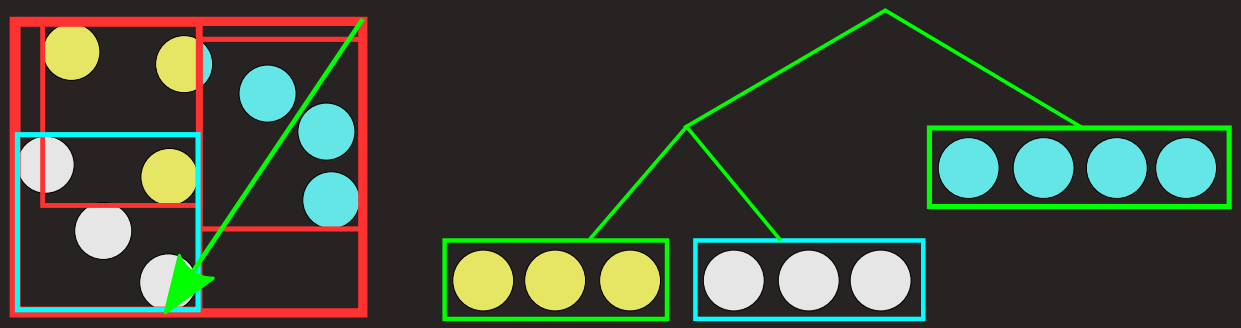
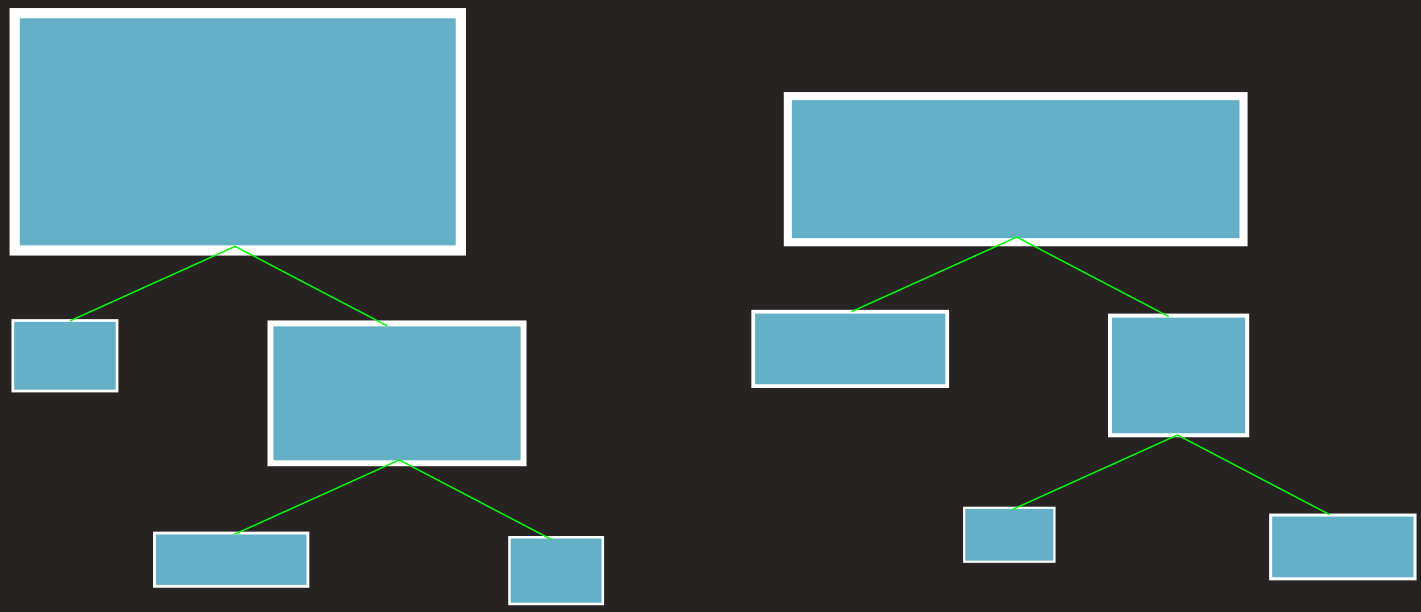


How to support motion blur?

Multiple BVHs Sharing Identical Topology

Convex combination of bounding boxes yields conservative BVH



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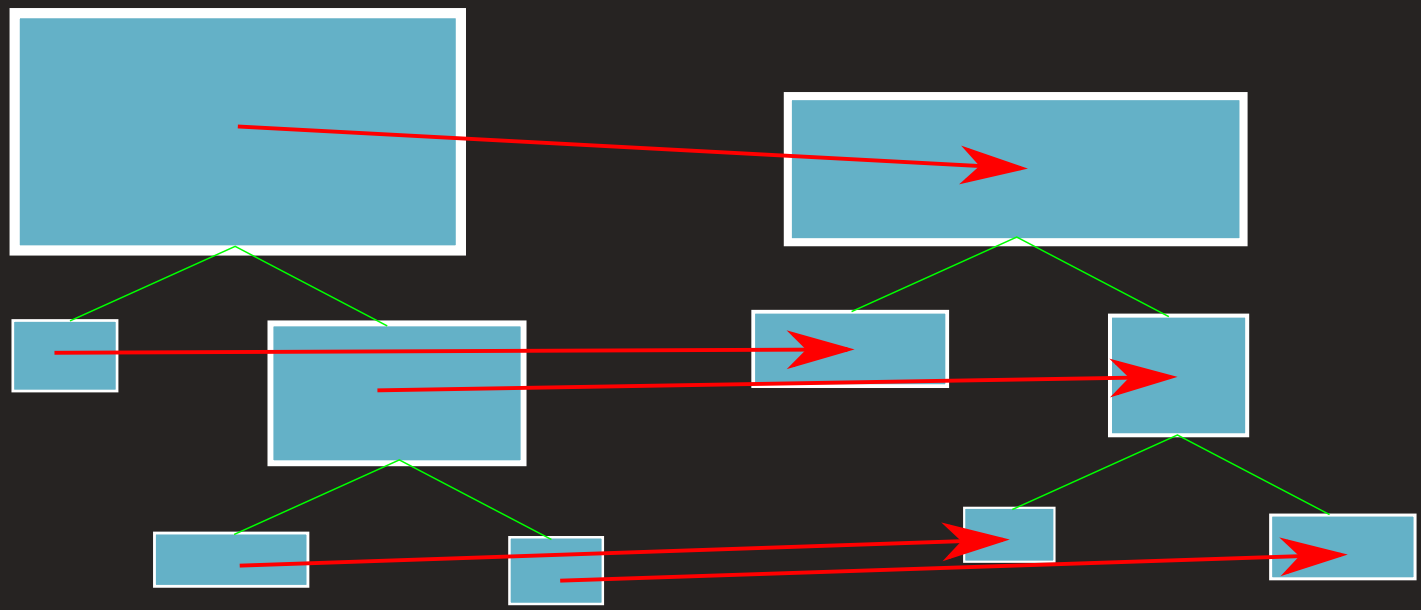

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Example: linear interpolation at leaf level

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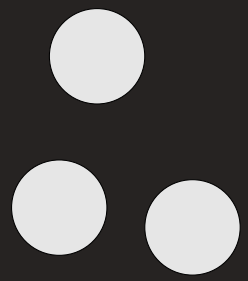

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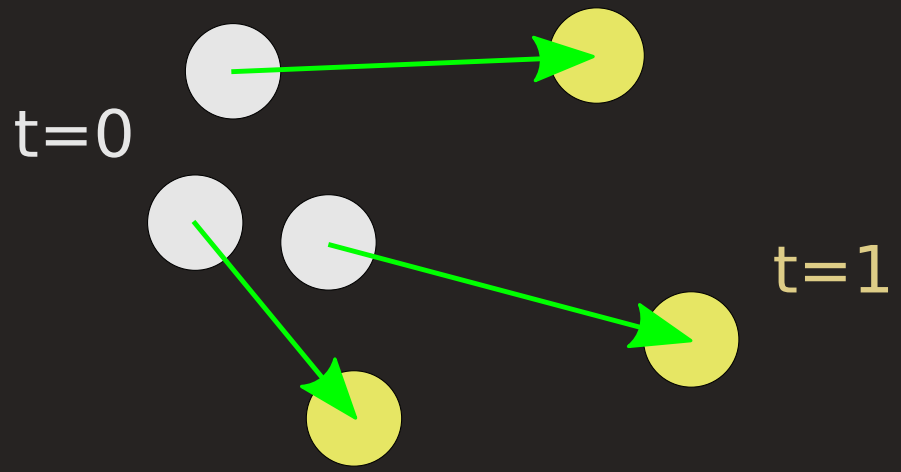

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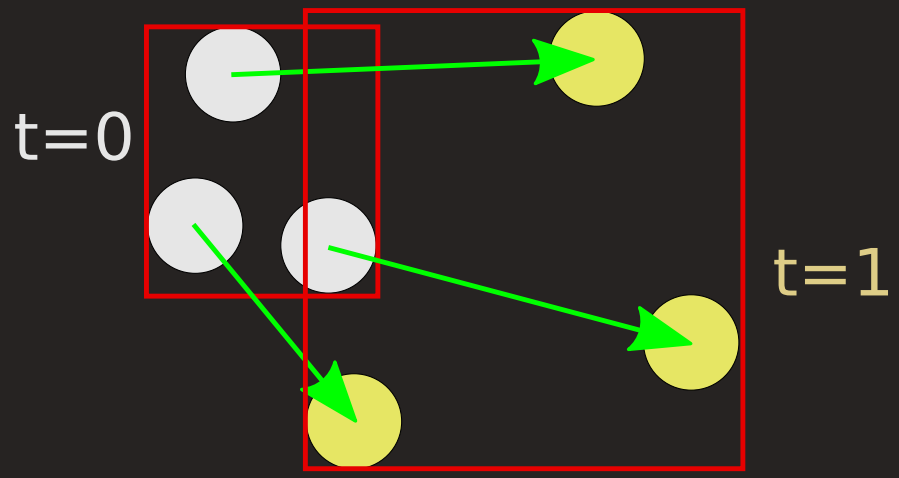

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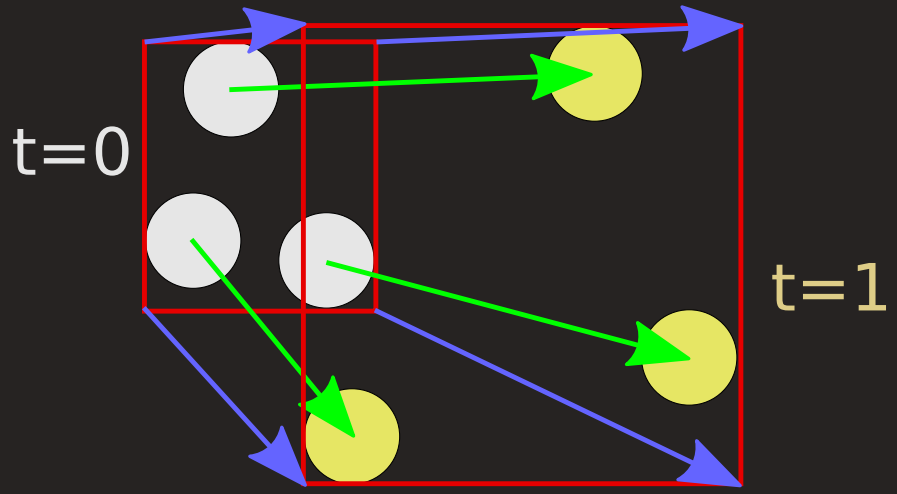

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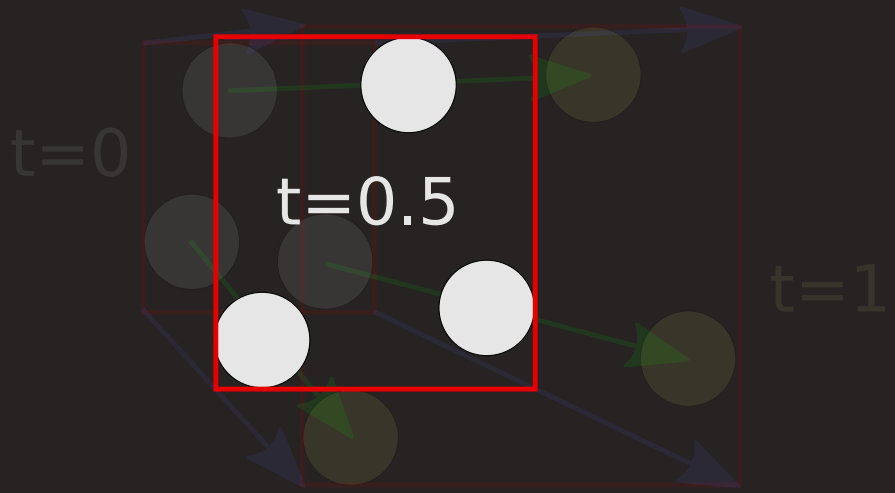

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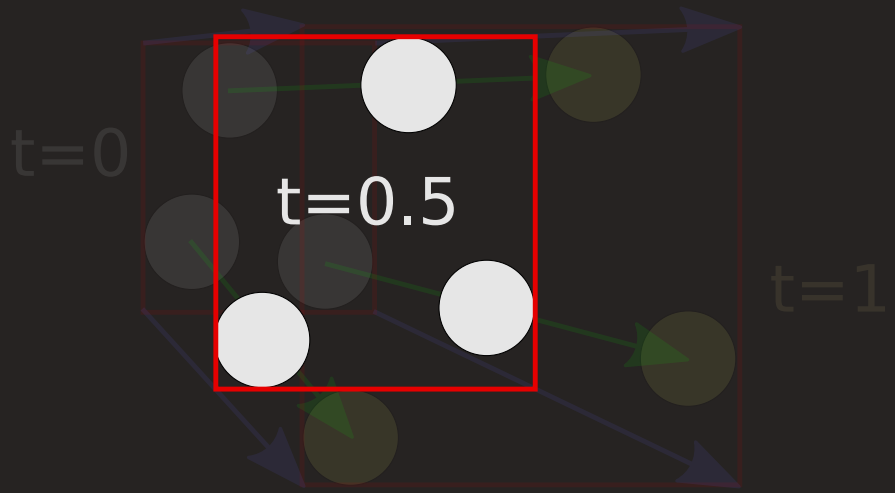
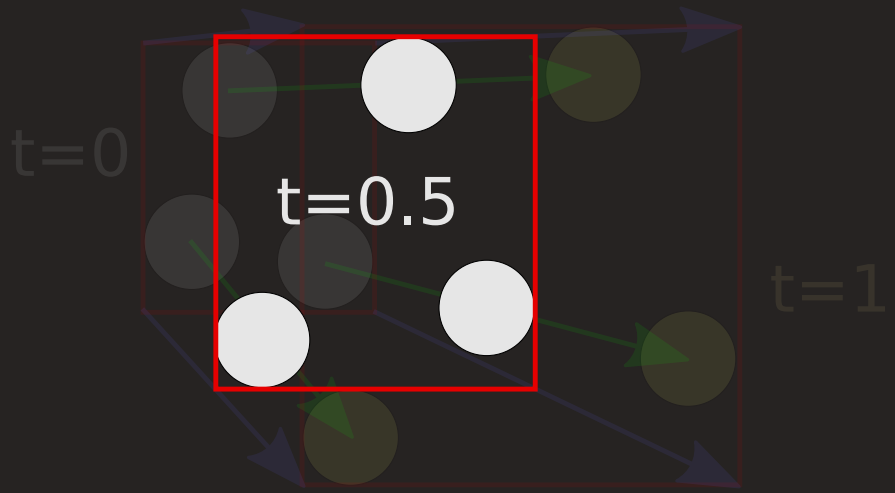


- acceptable memory overhead

Multiple BVHs Sharing Identical Topology

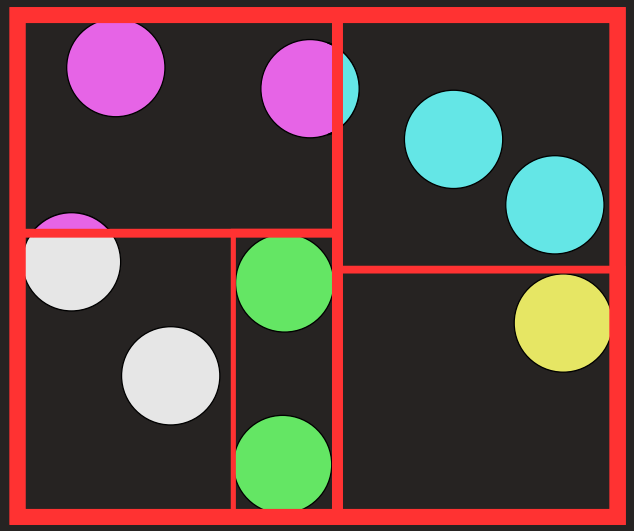
Example: linear interpolation at leaf level



- acceptable memory overhead
- allows for very tight bounding boxes for every ray time t

Interpolation and Spatial Splits

Can a *k*d-tree be interpolated?



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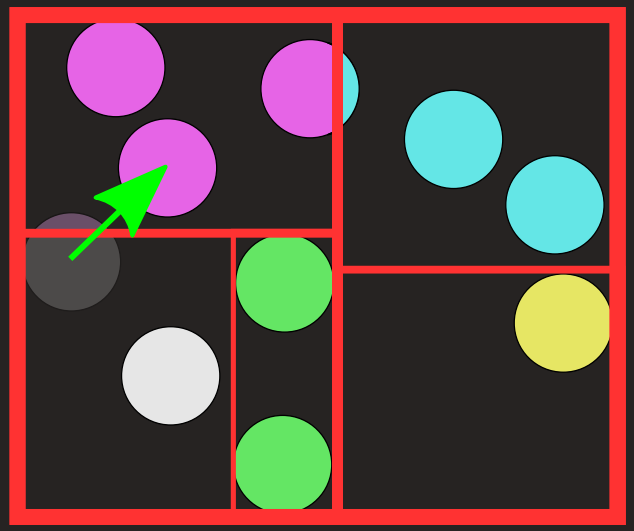

- objects can move across split planes
  - thus node references change!

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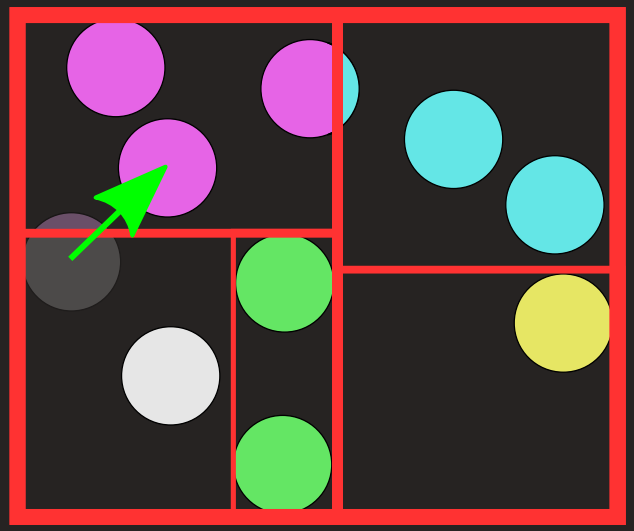

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- hierarchy over convex hulls is inefficient

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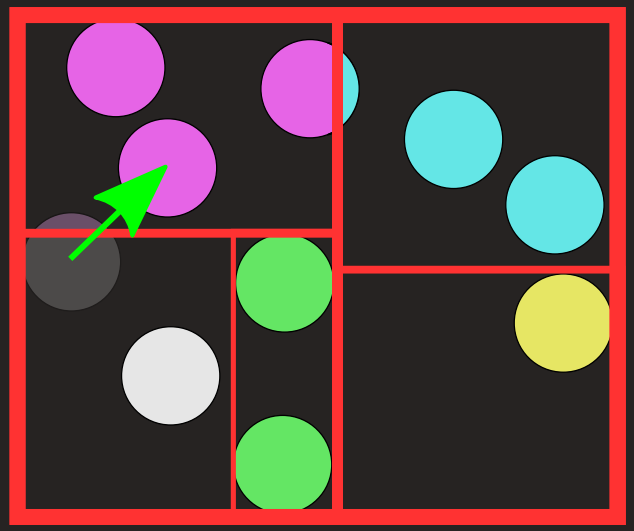

- objects can move across split planes
  - thus node references change!
- hierarchy over convex hulls is inefficient
- splitting along time-axis requires lots of memory

Our Contribution

Extend the SBVH to handle motion blur (MSBVH)

- by computing multiple bounding volumes per node
- using classic bounding volume interpolation traversal

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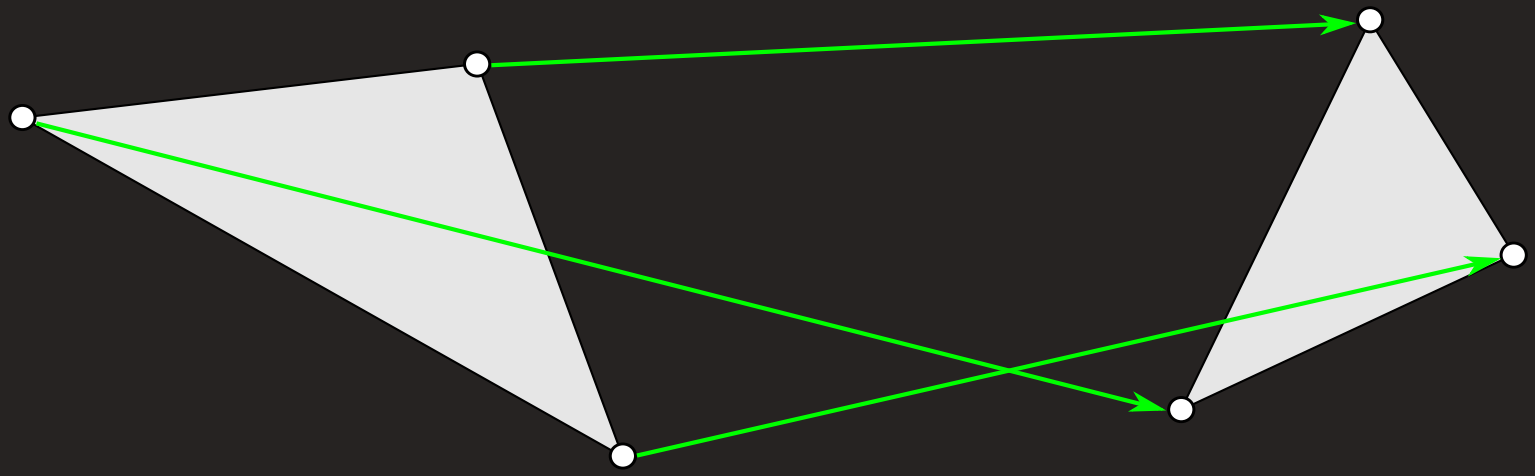
Extend the SBVH to handle motion blur (MSBVH)

- by computing multiple bounding volumes per node
- using classic bounding volume interpolation traversal
  - *which includes spatial splits*
- memory-efficient (MSBVH)
- reduced bounding volume overlap (MSBVH)

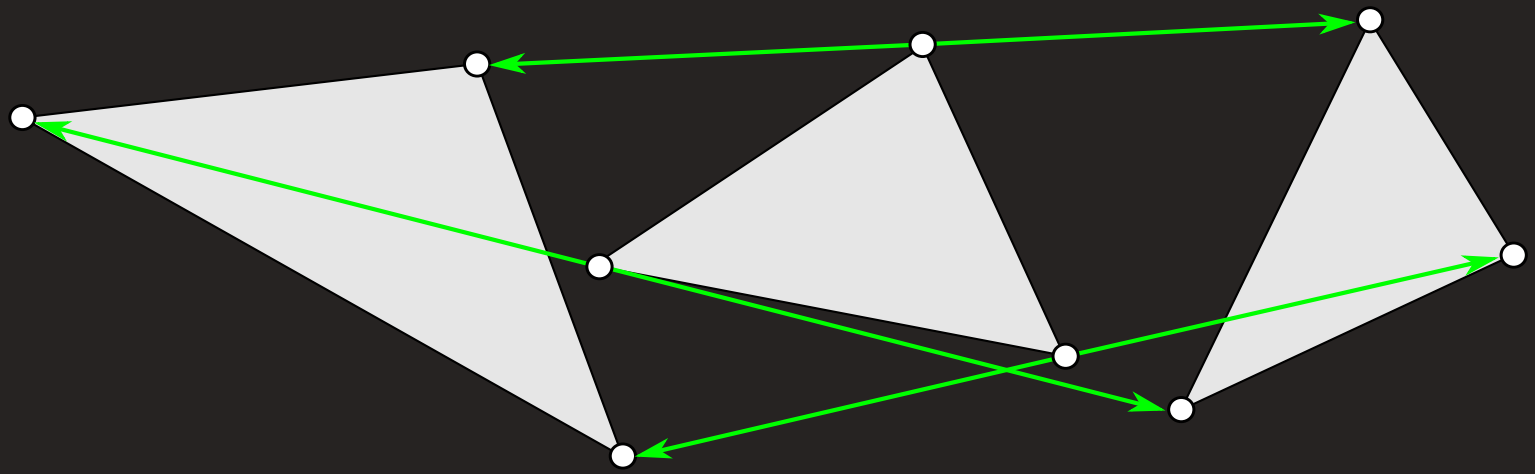
Note: we assume the hierarchy is rebuilt per frame

Algorithm



t=0 t=1

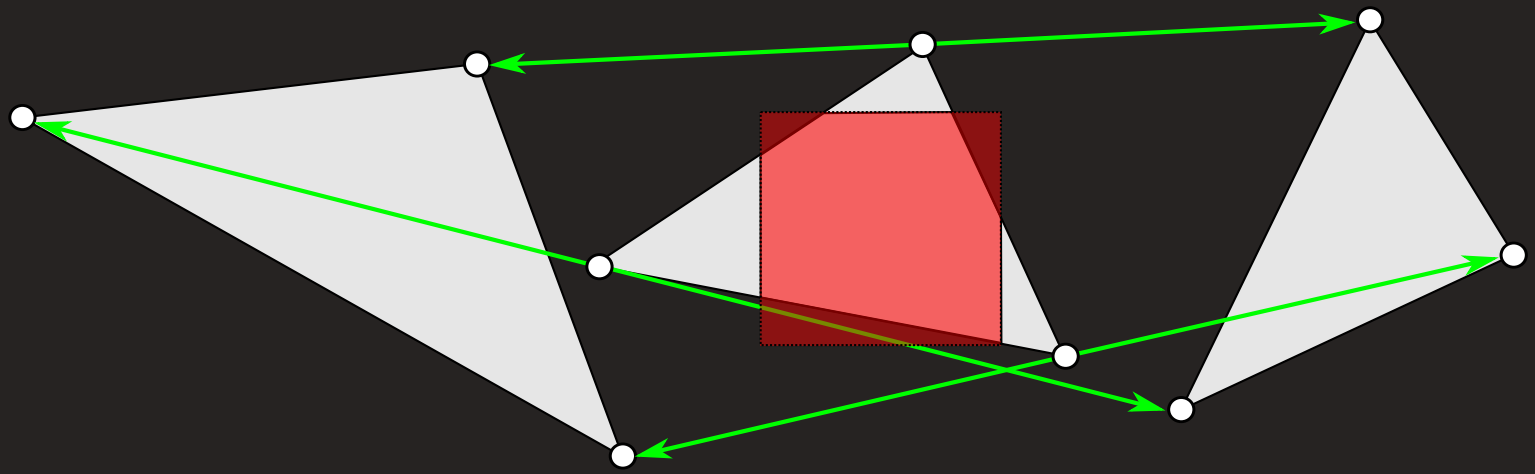
Algorithm



t=0 t=0.5 t=1

1. Build the SBVH for $t = 0.5$ to determine topology

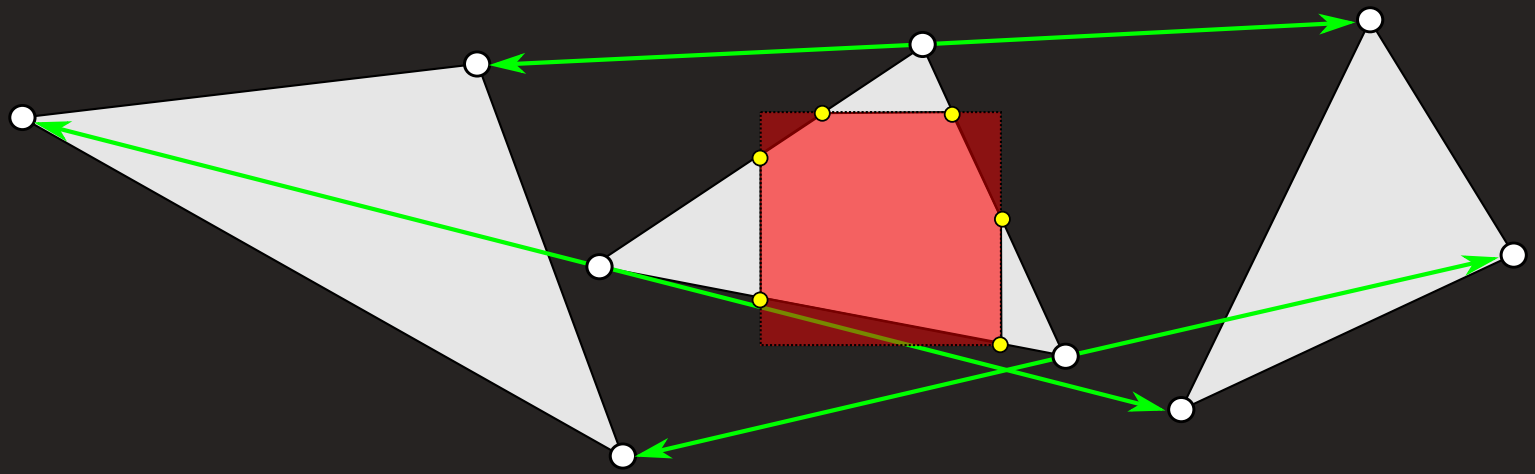
Algorithm



t=0 t=0.5 t=1

1. Build the SBVH for $t = 0.5$ to determine topology
2. Compute partial primitives in leaf nodes

Algorithm



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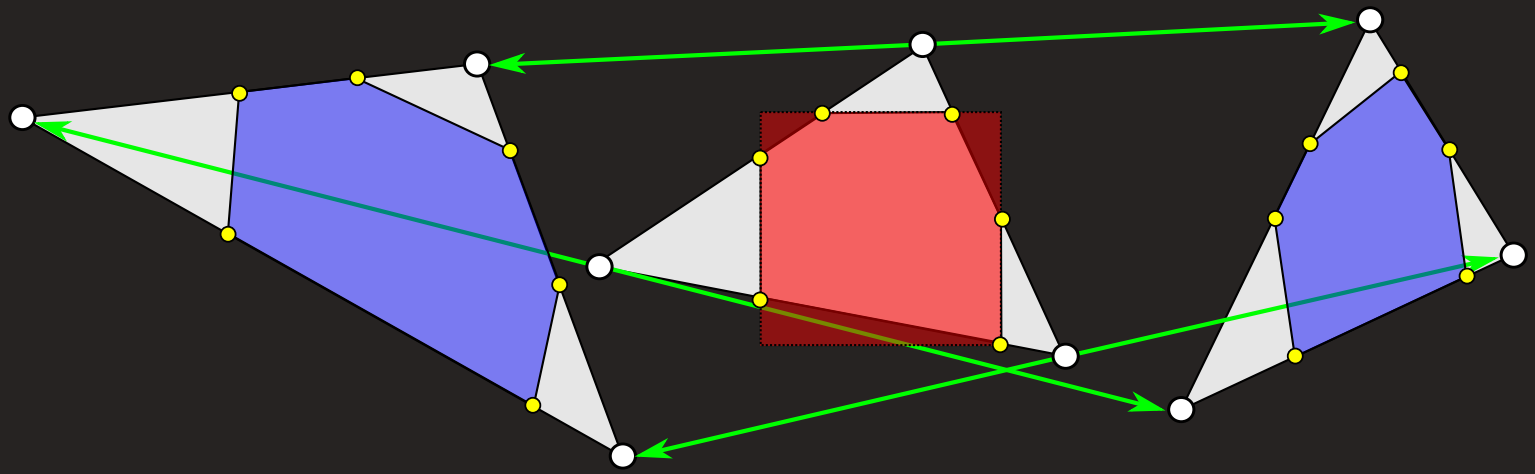

1. Build the SBVH for $t = 0.5$ to determine topology
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3. Compute corresponding bounds for $t = 0$ and $t = 1$

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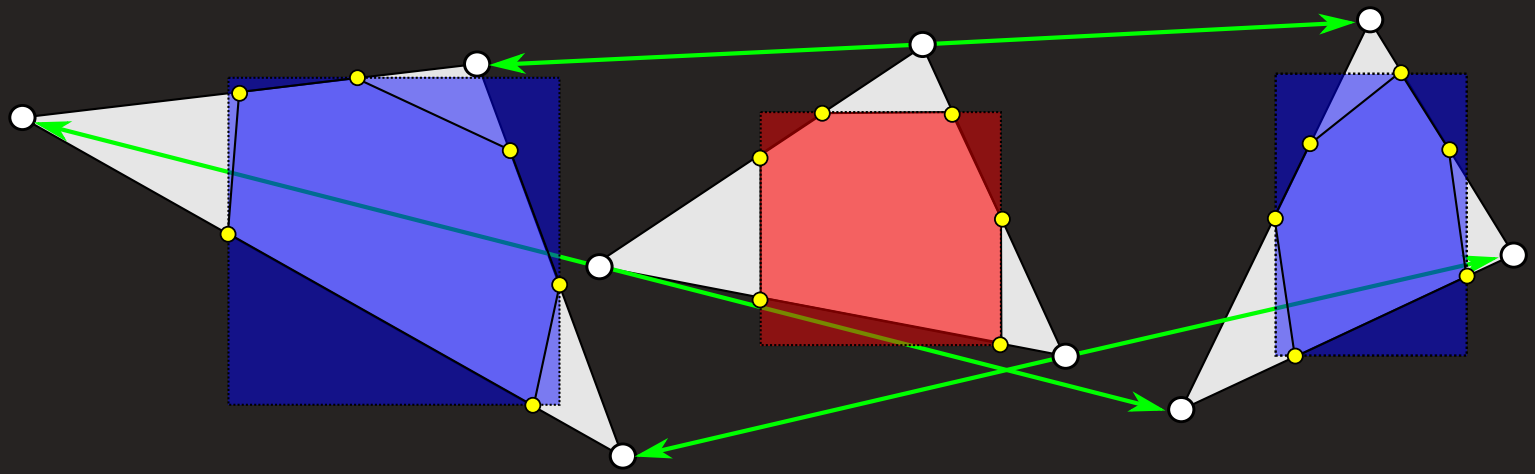

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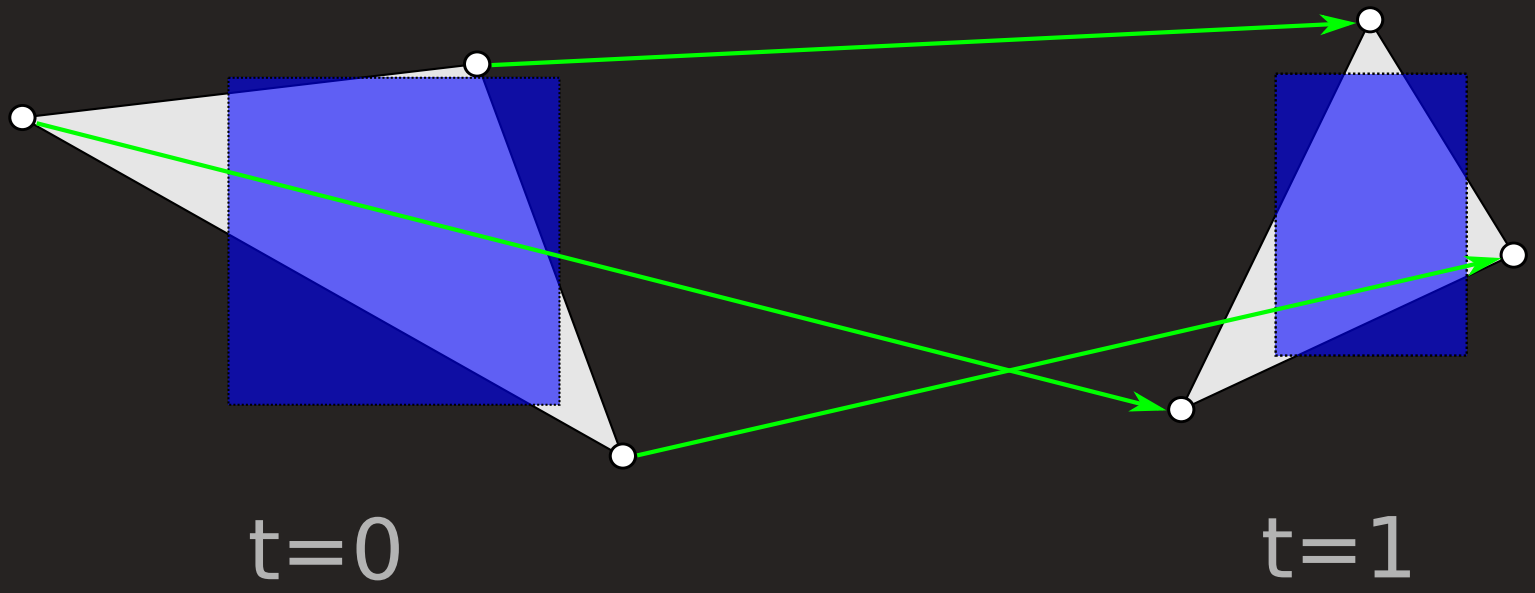

1. Build the SBVH for $t = 0.5$ to determine topology
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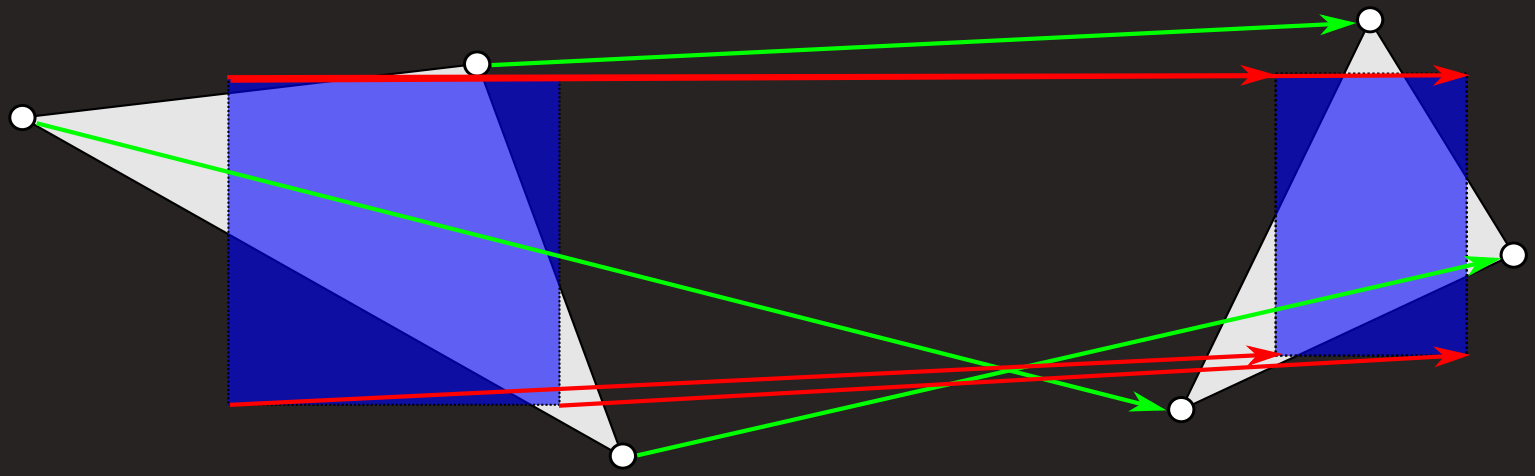

1. Build the SBVH for $t = 0.5$ to determine topology
2. Compute partial primitives in leaf nodes
3. Compute corresponding bounds for $t = 0$ and $t = 1$
4. Propagate bounds to the parent nodes
5. Interpolate these bounds during traversal

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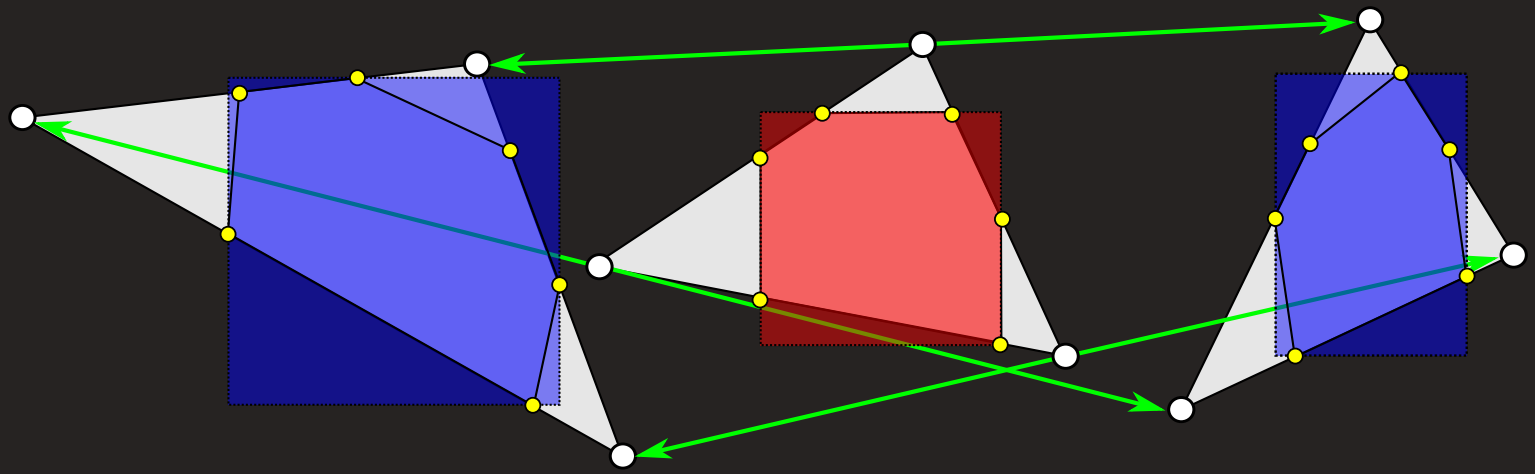
Triangles and AABB-Hierarchies under Linear Motion



1. Use Sutherland-Hodgman to clip against leaf AABB
2. Results in barycentric coordinates of polygon vertices

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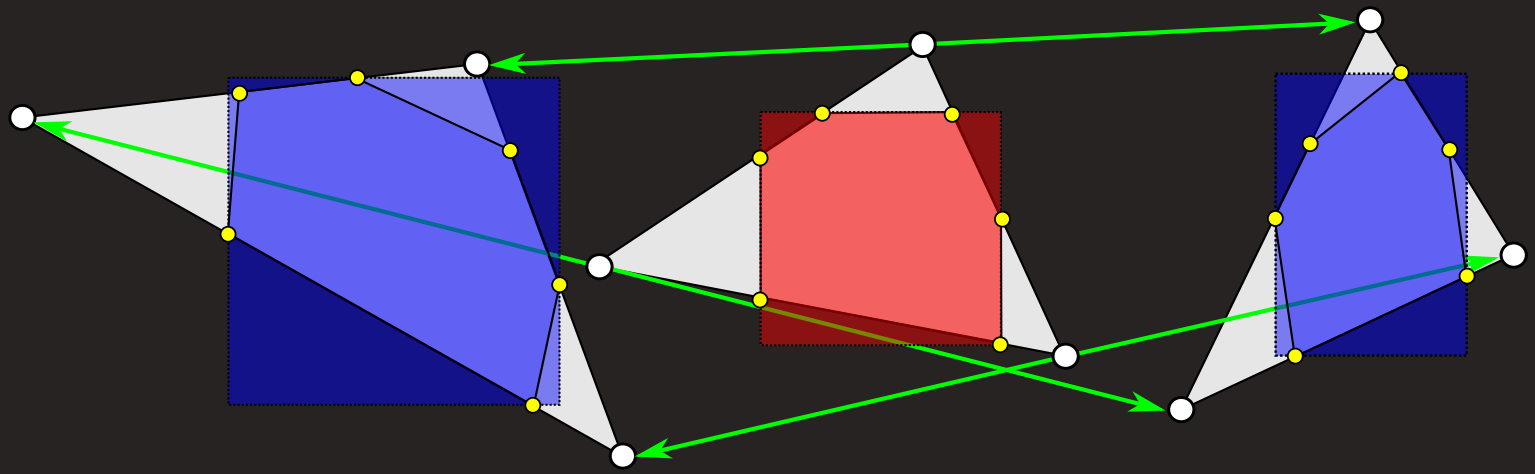

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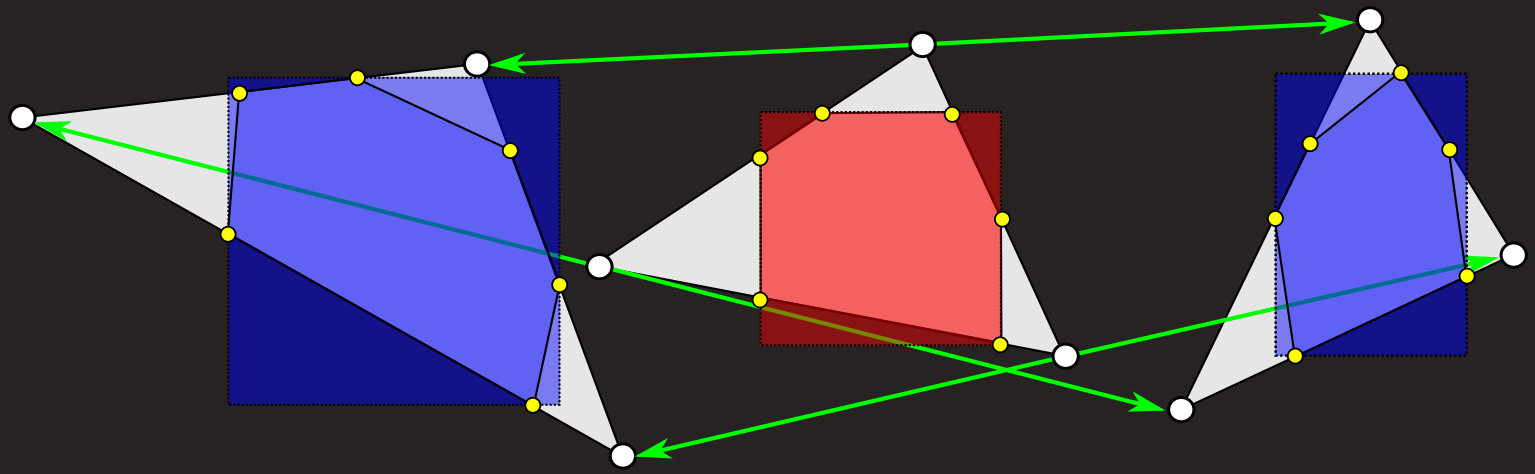

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4. Bound the transformed polygon

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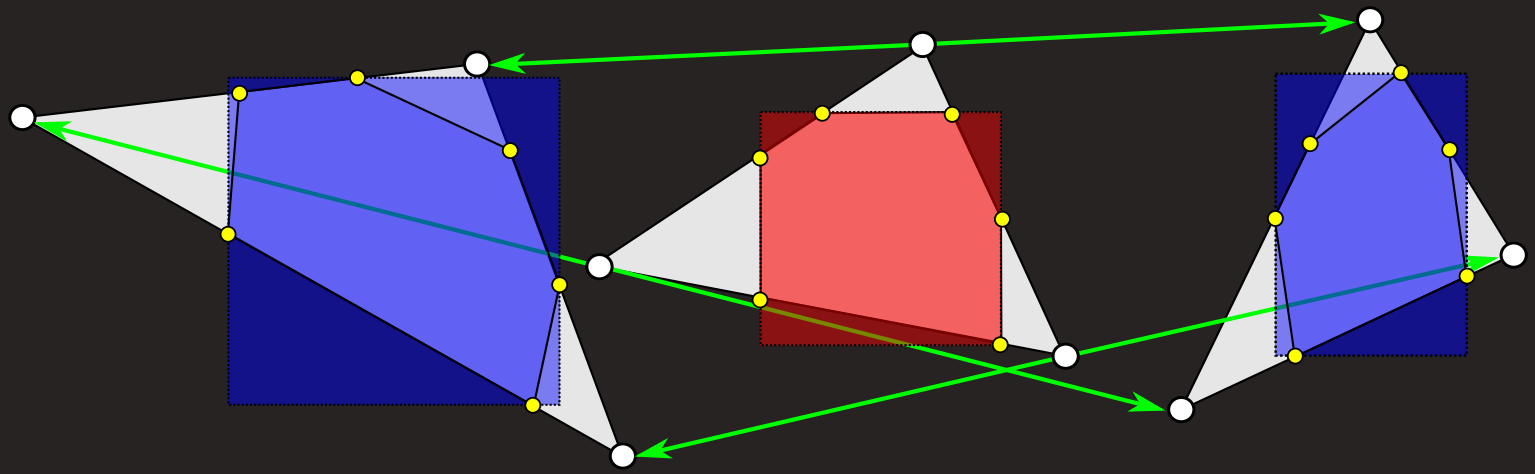
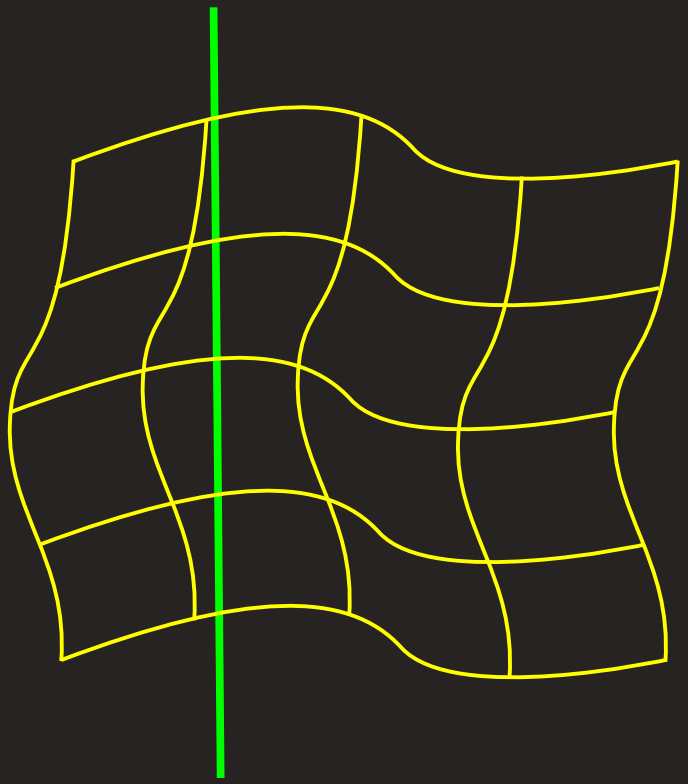


1. Use Sutherland-Hodgman to clip against leaf AABB
2. Results in barycentric coordinates of polygon vertices
3. Compute transformed polygon for $t = 0$ and $t = 1$
4. Bound the transformed polygon
5. No extra storage necessary

Clipping Displaced Subdivision Surfaces



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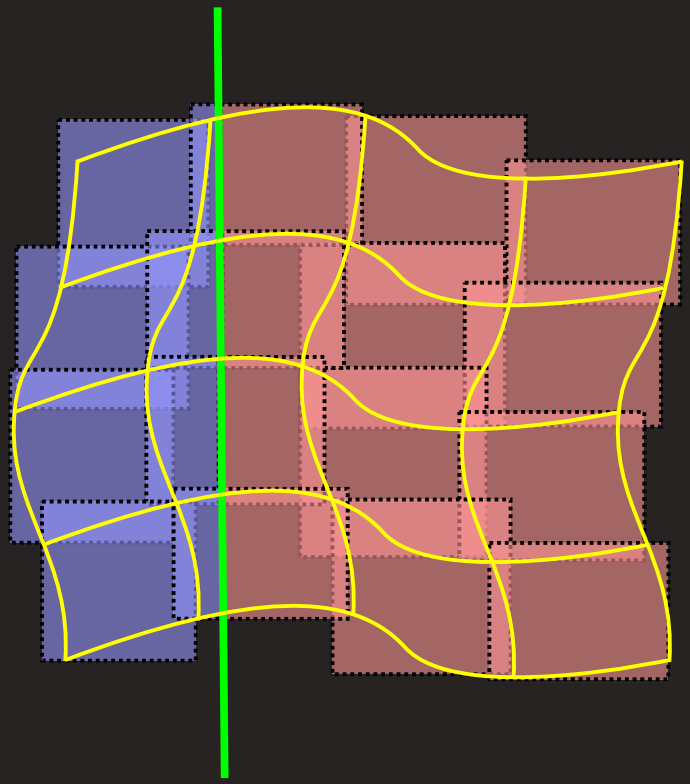

1. Subdivide along surface parametrization
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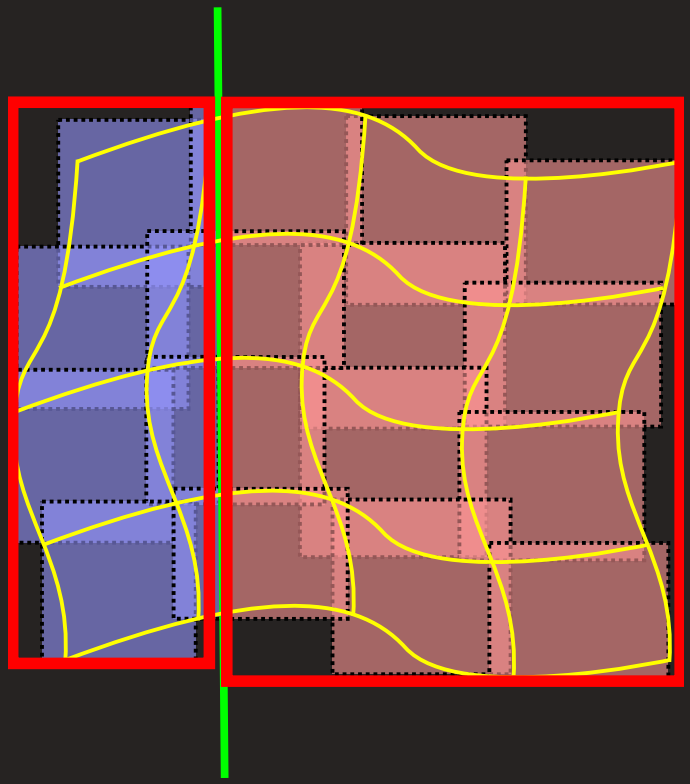

1. Subdivide along surface parametrization
2. Bound individual elements, e.g. using interval arithmetic
3. Clip resulting bounding boxes
4. The union conservatively bounds the clipped primitive

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Extensions

- two-level hierarchy: animated instances

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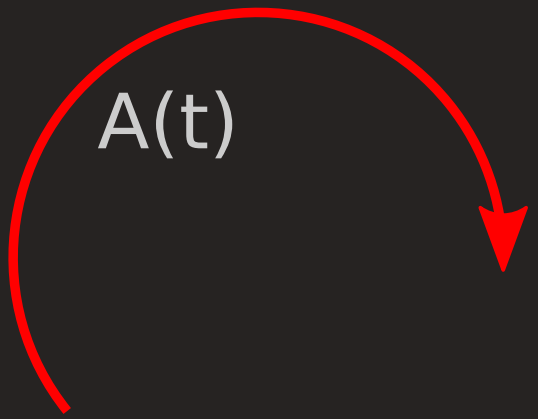
- interpolate transformation matrix *elements* to force linear motion



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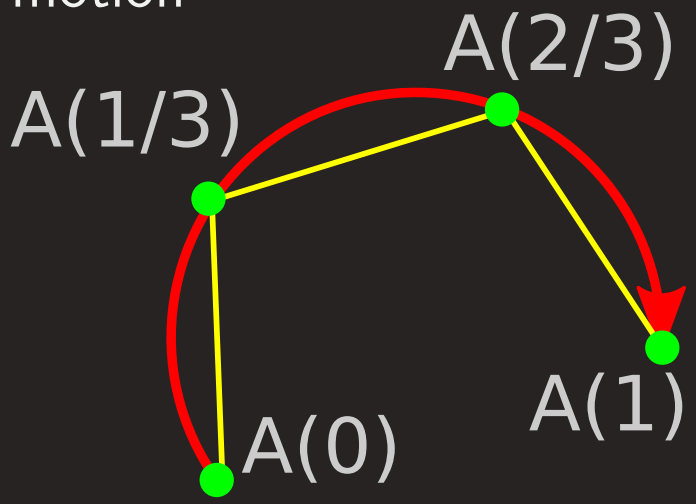

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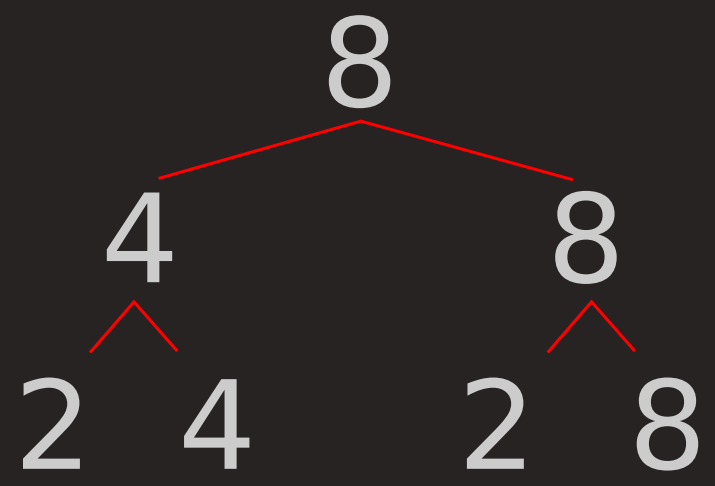
  - restricted to powers of two for propagation up the hierarchy



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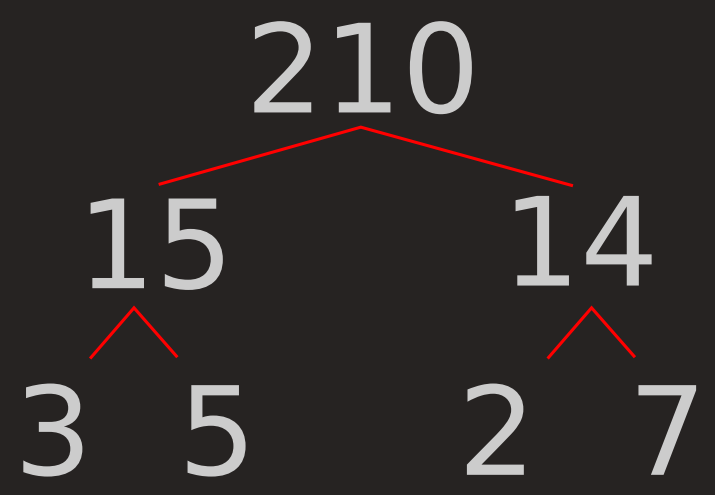

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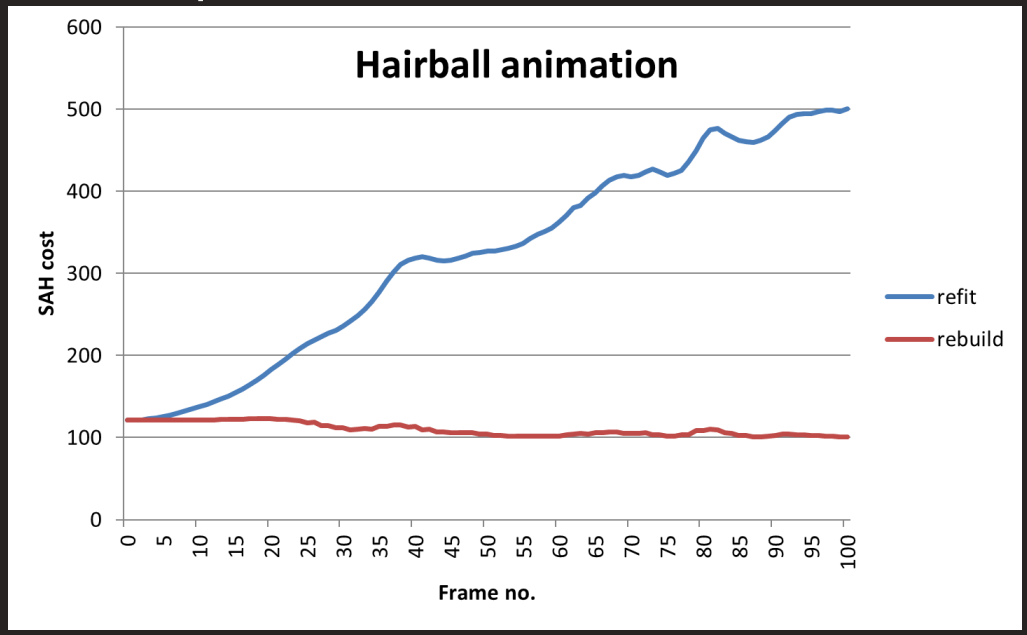
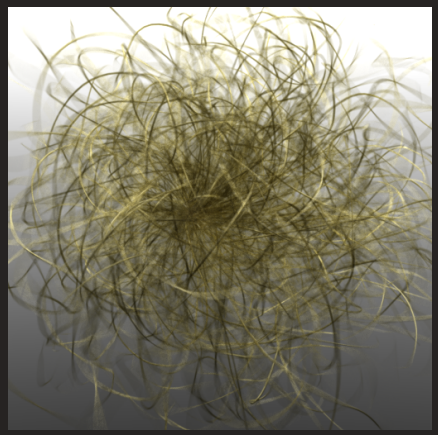
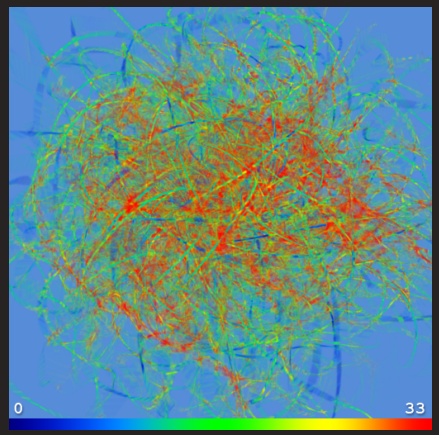
- higher-order interpolation
- refitting over multiple frames

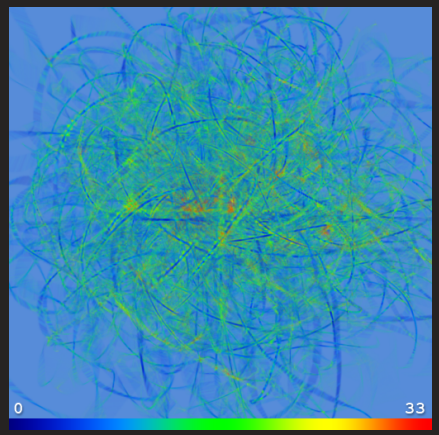


Results

BVH traversal with linear interpolation

- reduced SAH cost
- significantly less intersection tests



$\Rightarrow$ Video

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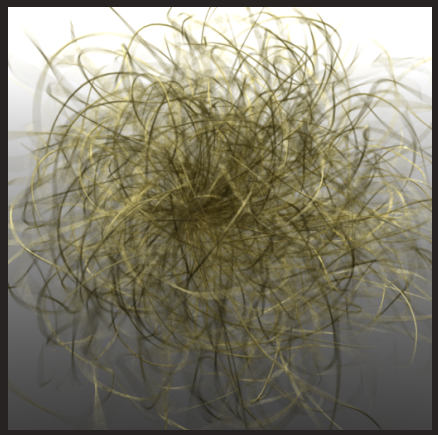
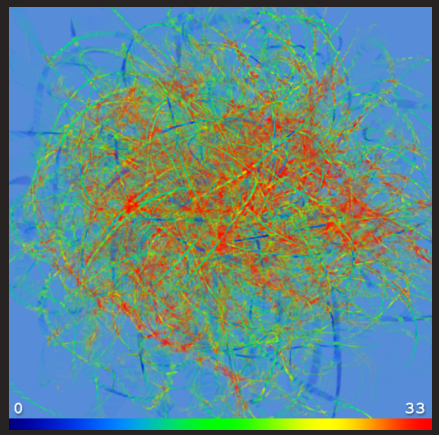

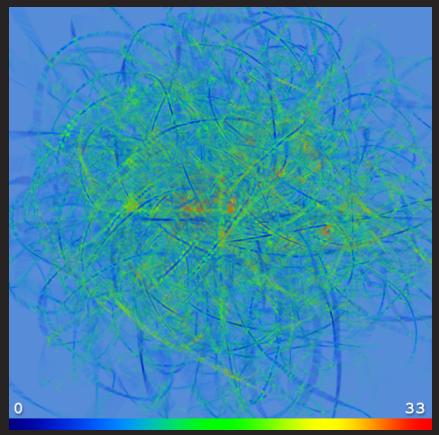

- often less traversal steps
- about 20% rendering speed-up for many scenes

Summary

In practice, works well for single frames

- helps well whenever SBVH helps
- increased build times (between BVH and kd-tree)
- prototype implemention in OptiX

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Summary

In practice, works well for single frames

- helps well whenever SBVH helps
- increased build times (between BVH and kd-tree)
- prototype implemention in OptiX
- spatial splits only avoid overlap for $t = 0.5$
  - topology determined for $t = 0.5$
  - problematic for incoherent motion

Weta Digital is hiring!

http://wetafx.co.nz/siggraph2011

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