Accelerated Raytracing

Why is Acceleration Important?

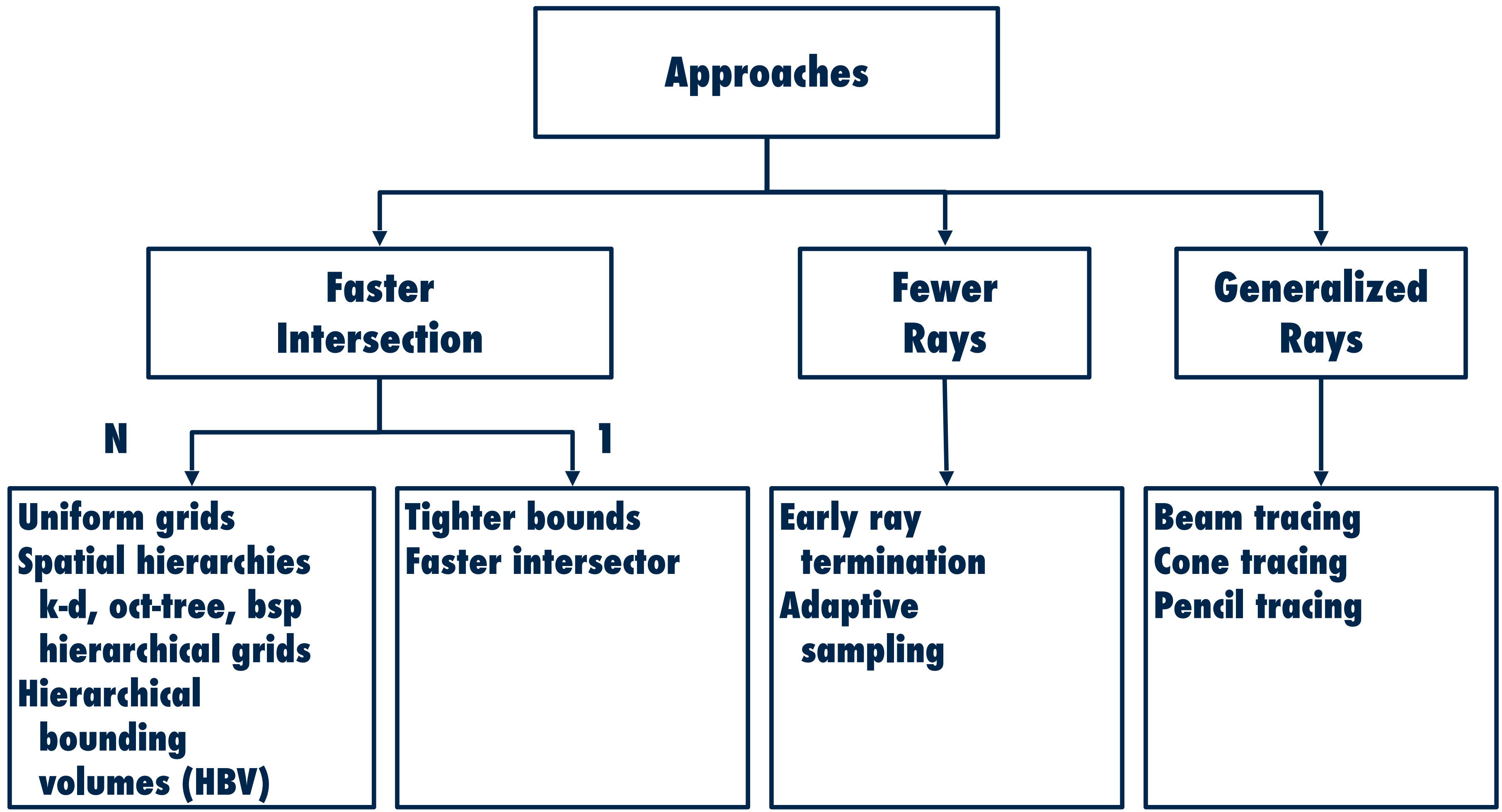
- Vanilla ray tracing is really slow!
- *m*x*m* pixels, *k*x*k* supersampling, *n* primitives, average ray path length of *d*, *l* lights, 2 recursive ray casts per intersection…

- What are some ways to reduce this that we discussed in class?

Reducing These Terms

- Early ray termination
  - Reduce levels of recursion
- Adaptive ray sampling
  - Reduces *k* supersampling term
- Faster intersections
- Generalized rays

Ray Tracing Acceleration Techniques



Faster Intersections

- Optimize the intersection test
- Reduce the number of intersections along *d* to reduce the number of intersection tests

Broad and Narrow Phase Tests

Broadphase refers to the less expensive, less accurate intersection test

- Can have false positives
- Should not have false negatives

Narrowphase refers to the more expensive, more accurate intersection test

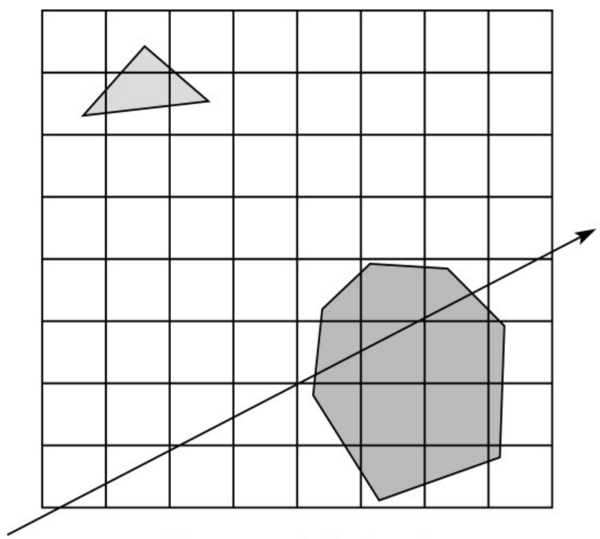
- Should eliminate remaining false positives

Spatial Acceleration Structures

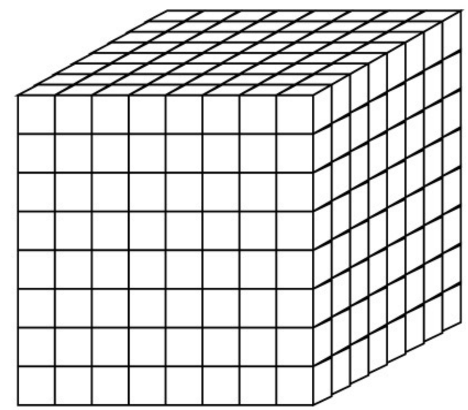
Idea: Index data by spatial location

- Geometry's position in the world affects its likelihood of being seen/intersected
- Fast, approximate queries can eliminate distant or hidden objects

Uniform Spatial Subdivision



Uniform subdivion in 2D

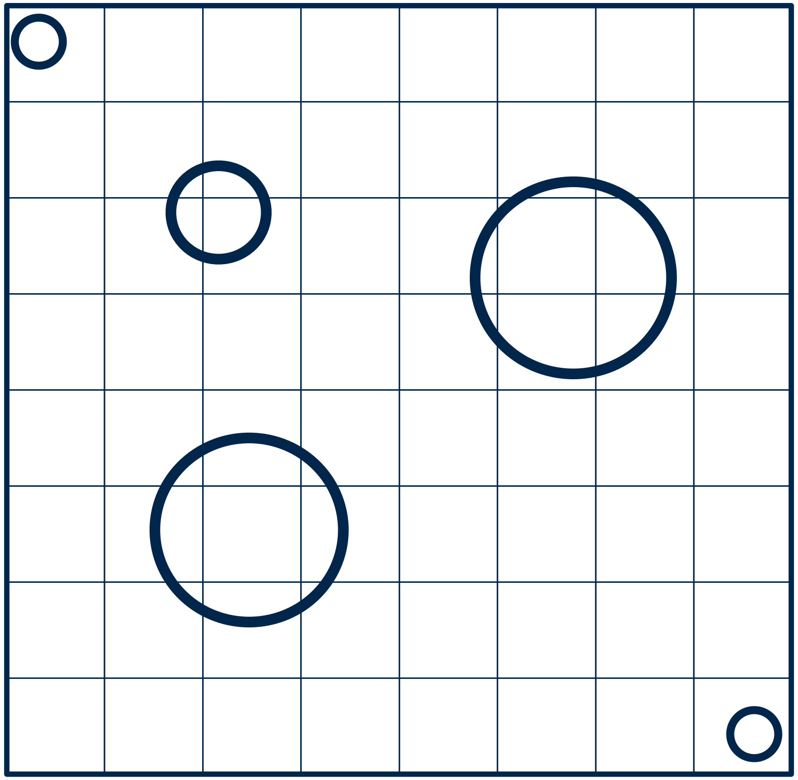


Uniform subdivion in 3D

- Partition space into cells (voxels)
- Associate primitives with all cells it overlaps
- Trace through voxel array using fast incremental arithmetic

Uniform Grid Preprocessing

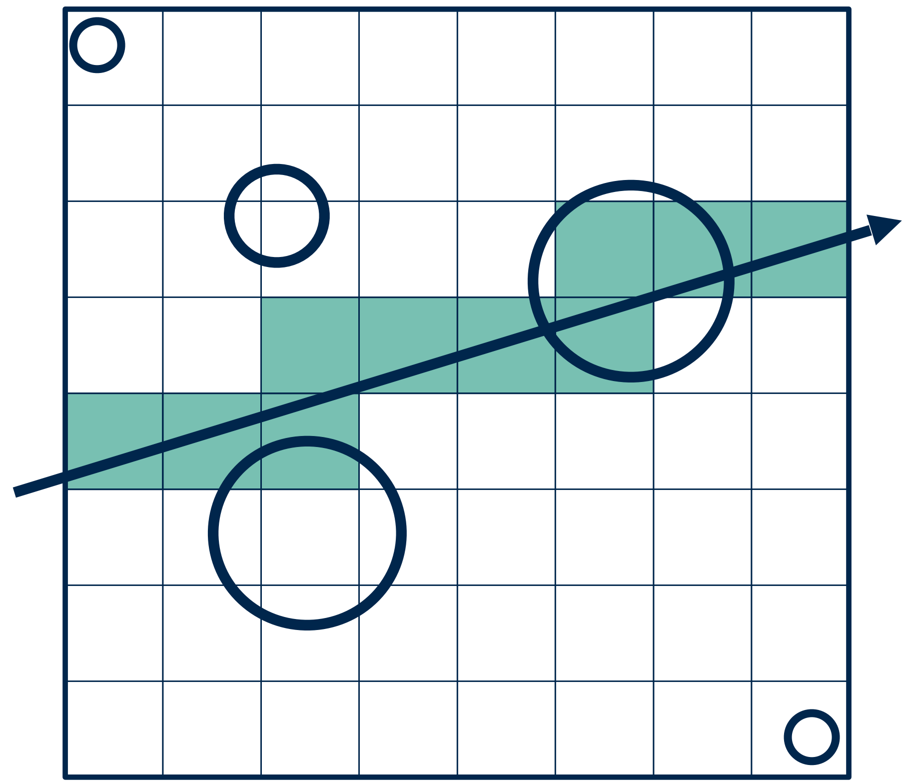
- Find world bounding box
- Determine grid resolution
- Place objects into cells that overlap it



Uniform Grid Traversal

3D Digital Differential Analyzer (3DDDA)

- DDA calculates increment in linear interpolation to touch all cells
- Line segment between start and end position within the grid
- Intersect geometry within visited cells



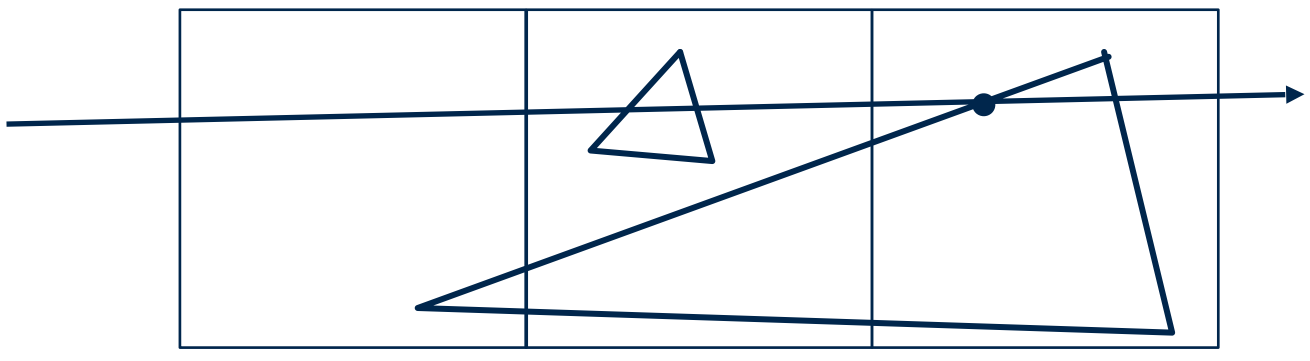
Broad vs Narrow Phase

What is the broadphase of the uniform spatial subdivision traversal?

What is the narrowphase of the uniform spatial subdivision traversal?

What determines the time/memory cost of the broadphase?

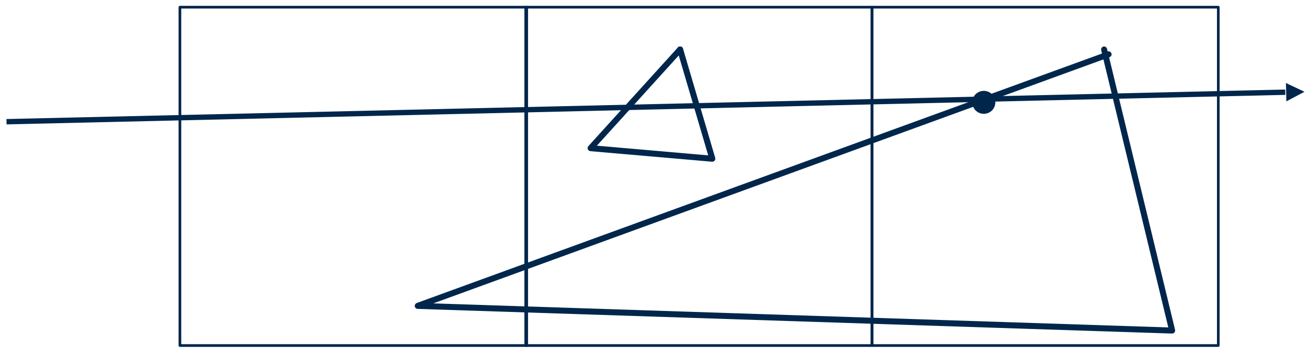
What Happened Here?



Potential Errors in Overlap

Solve redundancy and accuracy issues with mailboxes

- Each object has a mailbox to store intersection results
- Each ray has a distinct number
- Only intersect if ray does not already have an intersection
- Look for intersection only within current voxel



Spatial Hierarchies

- Cells of parent completely contains all cells of children
- If a query fails in a cell, it will fail for all children
- If a query succeeds, try the children
- Only if query reaches a leaf do we perform the expensive intersection test

Non-Uniform Spatial Subdivision

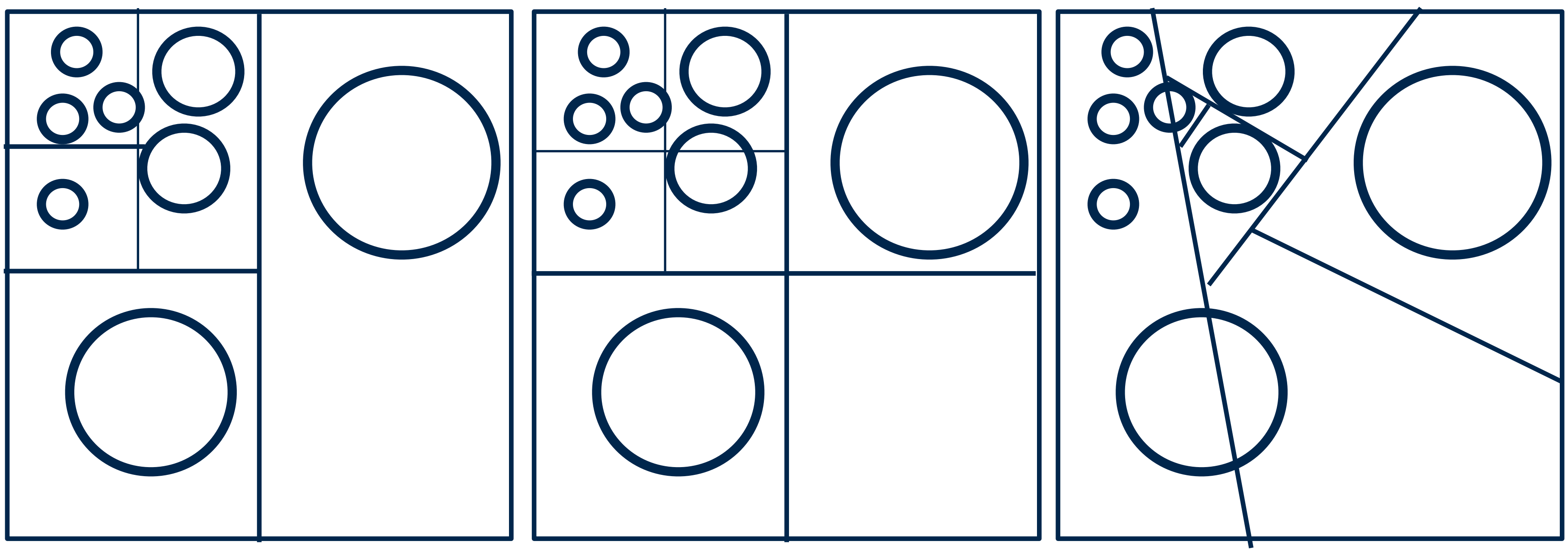
Partitioning Approach:

Octrees, k-d trees, BSP trees

Non-partitioning approach:

Bounding volume hierarchies

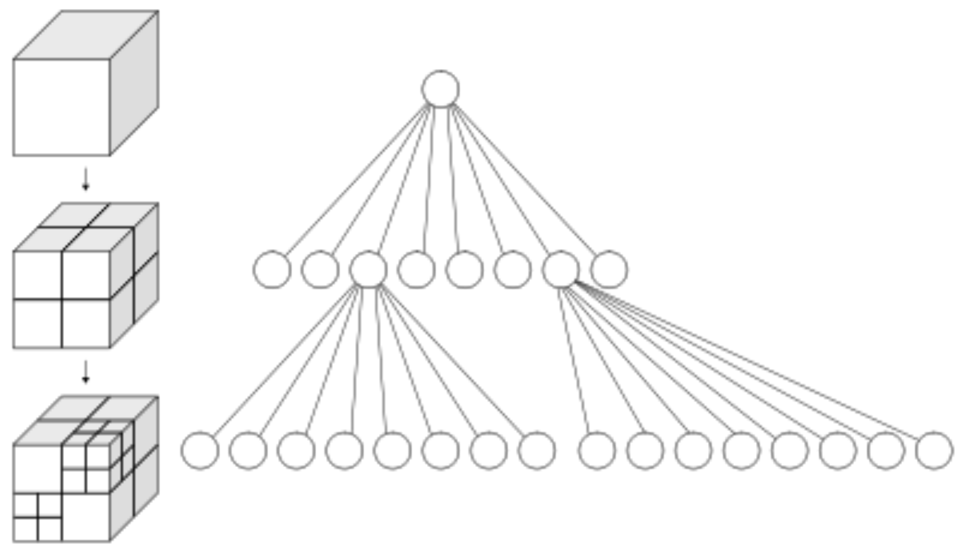
Spatial Partitions



kd-tree oct-tree bsp-tree

Octree

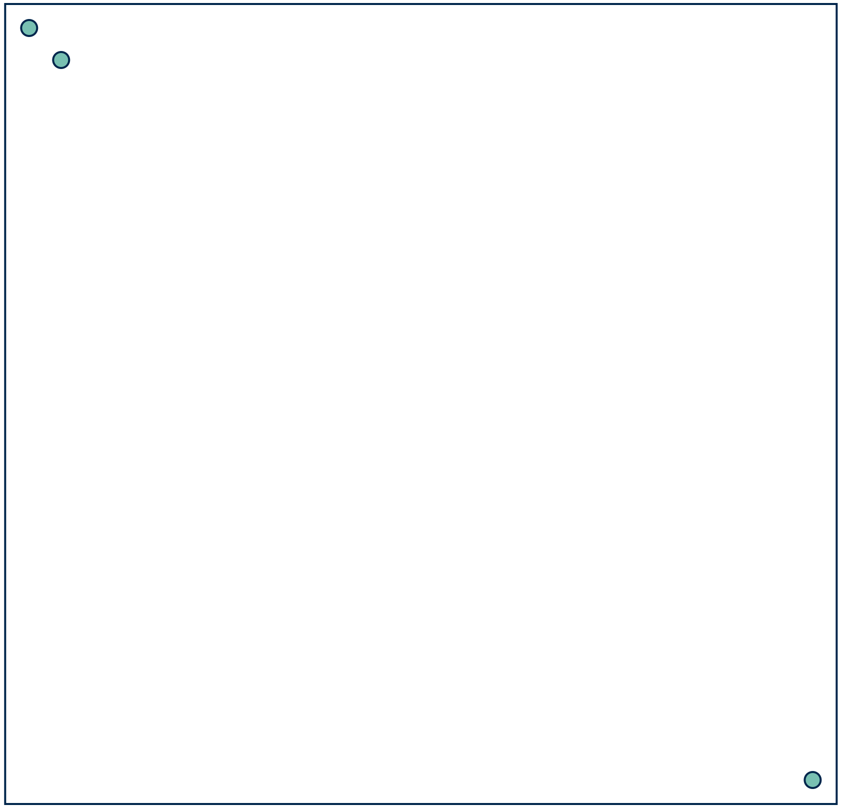
- Eight children per parent
- Objects in leaf nodes
- Extents of cube can be inferred or stored



Octree Problems

Octrees unbalanced if objects aren't uniformly distributed

"Teapot in the stadium"



A bad octree case

k-d Trees

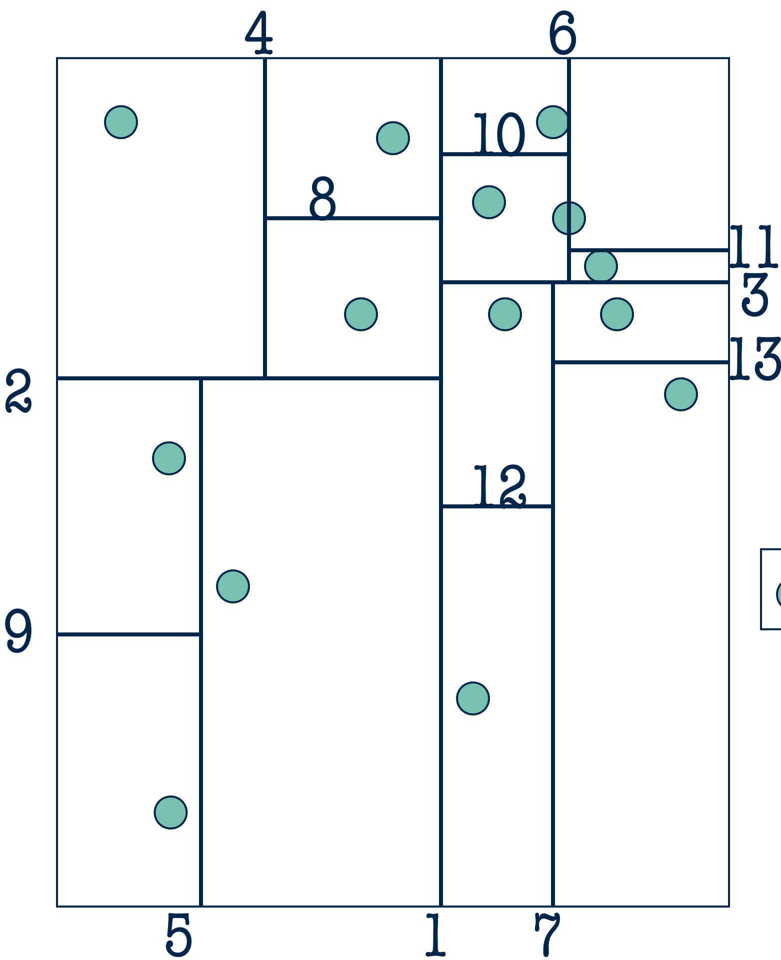
Octree problem: Cube always split evenly between children

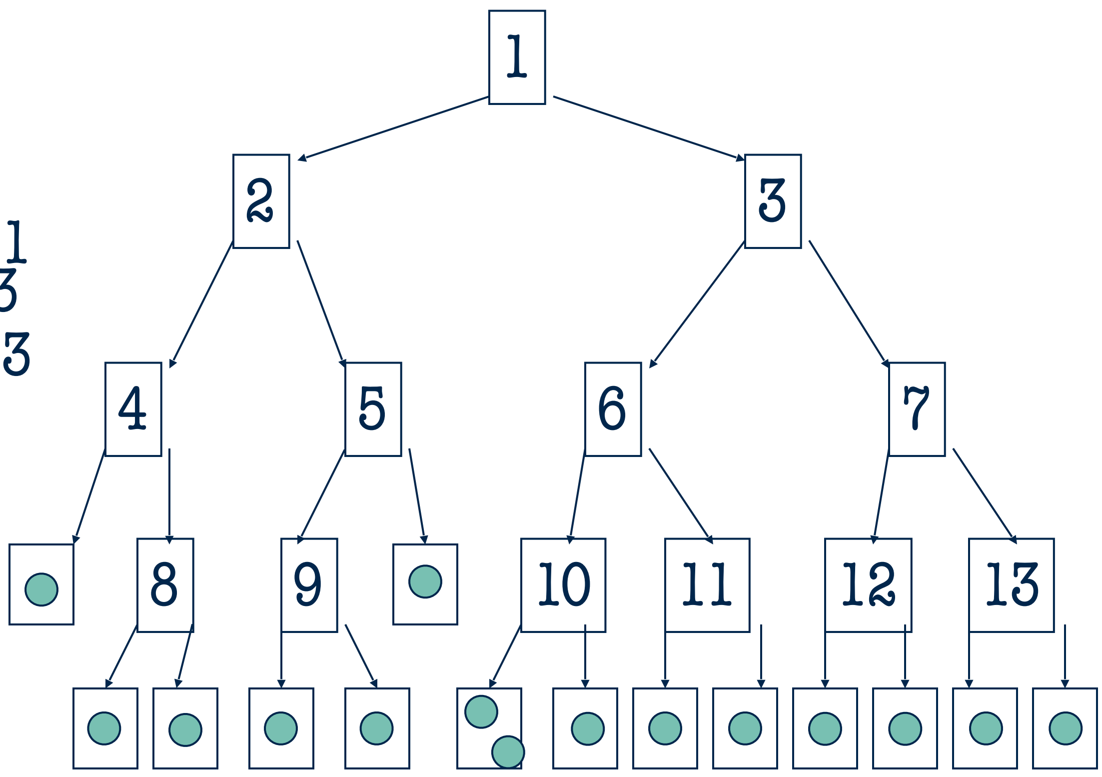
Solution: Allow for splits at variable positions!

k-d Tree Properties

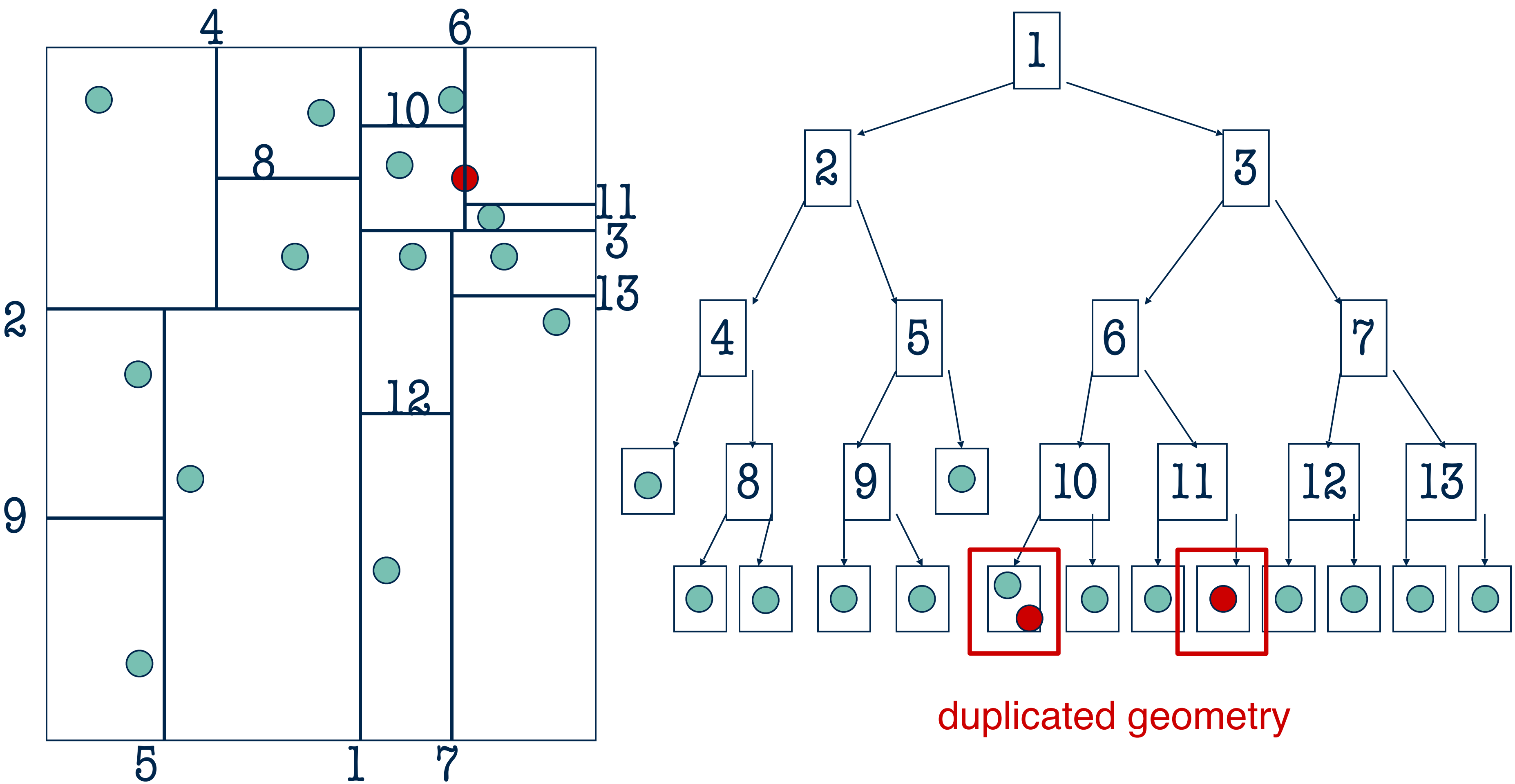
- Node represents rectilinear region (axis-aligned)
- Axis-aligned planes split region into two
- Direction of cutting planes alternate with depth
  - Cut planes in different sub-trees at same sub level not necessarily the same

k-d Tree Example

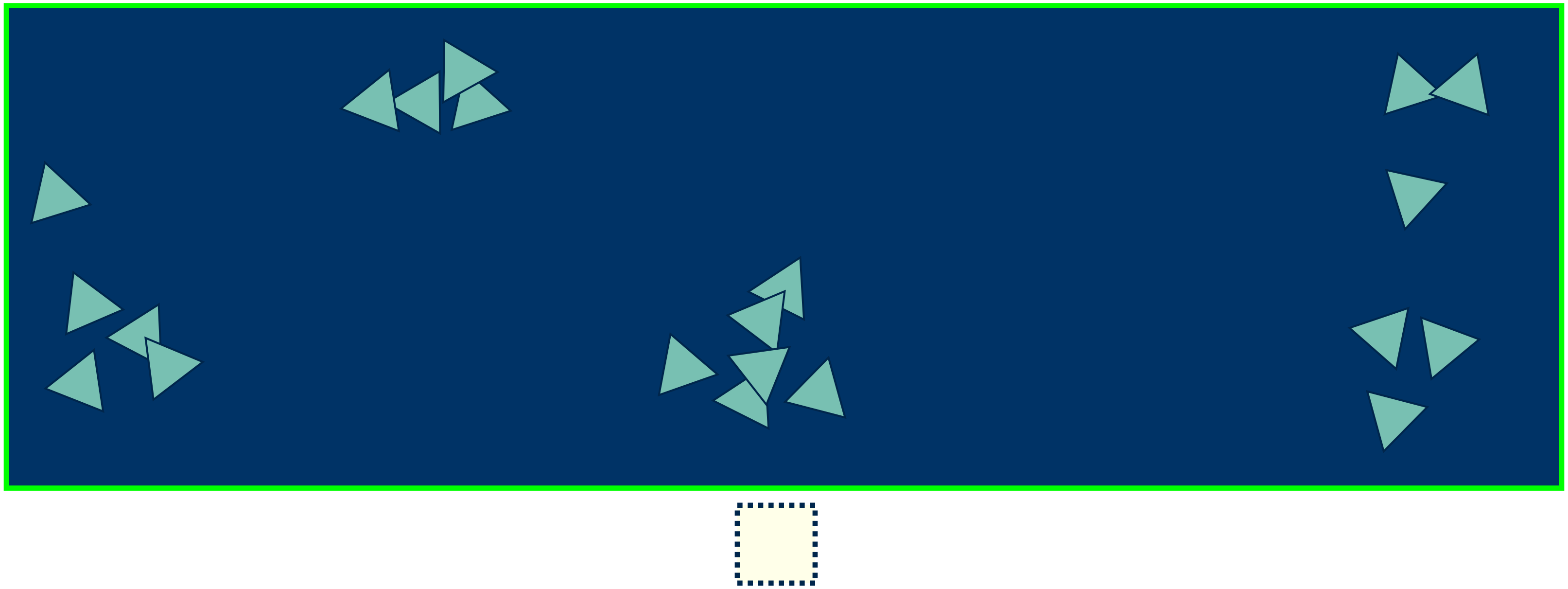


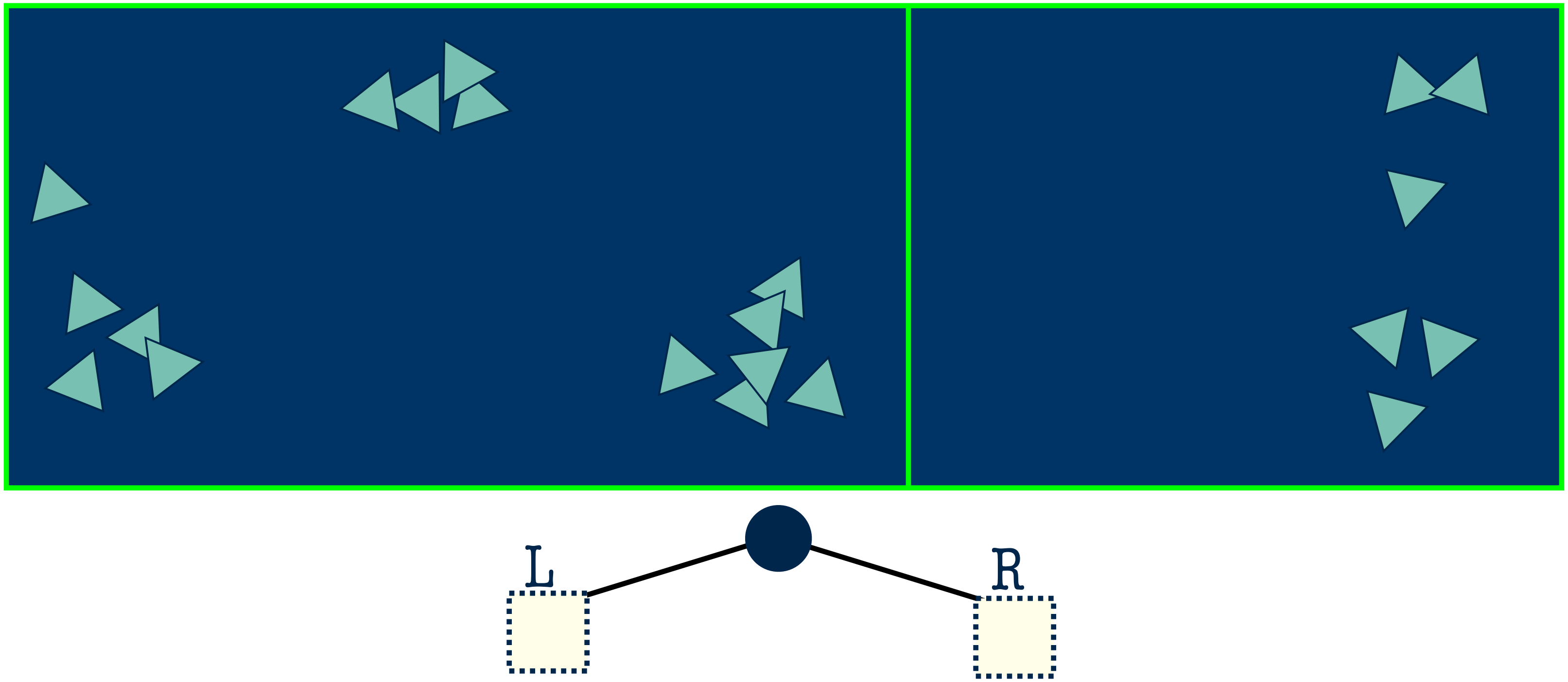


k-d Tree Example



k-d Tree Build

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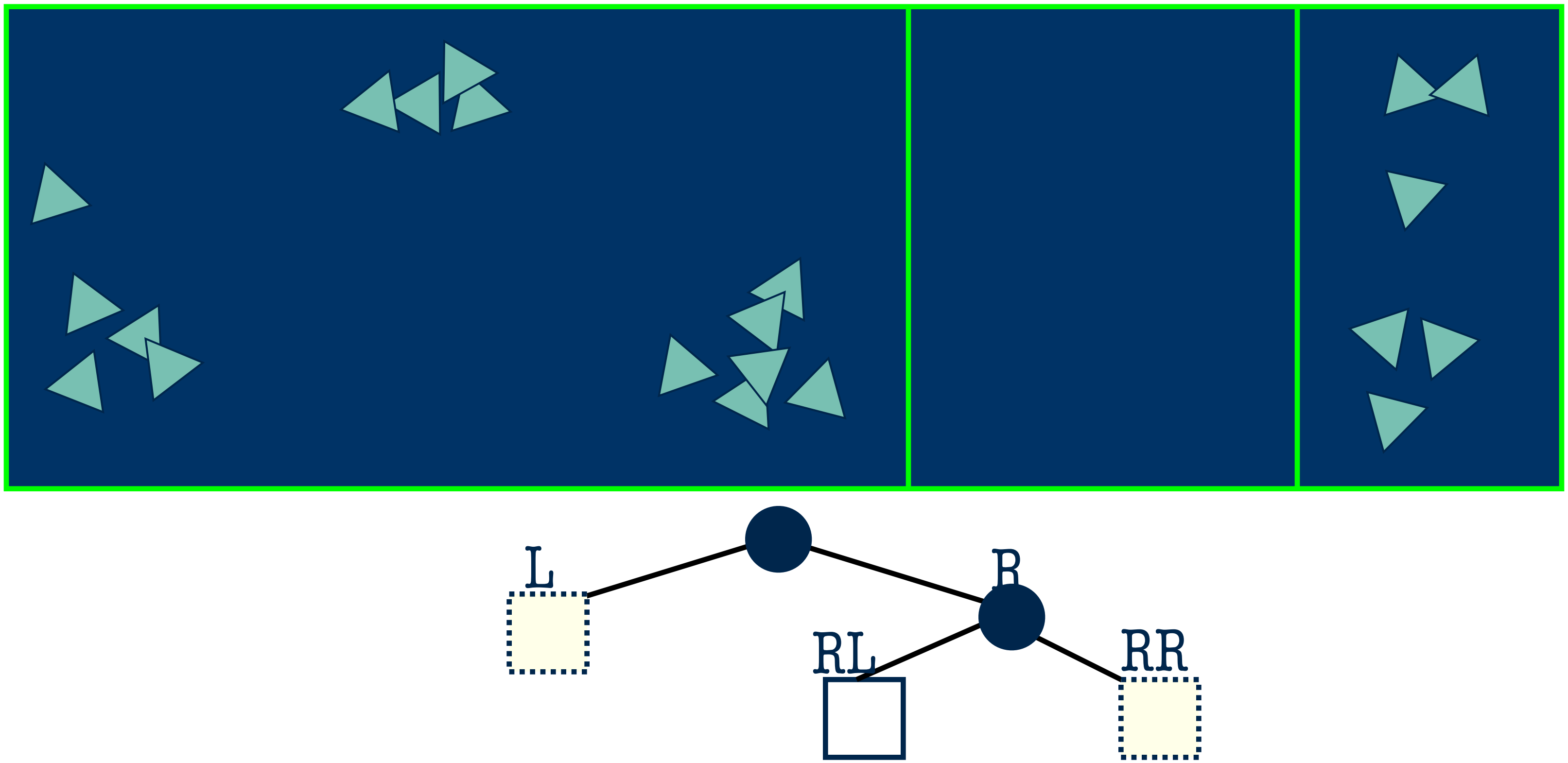

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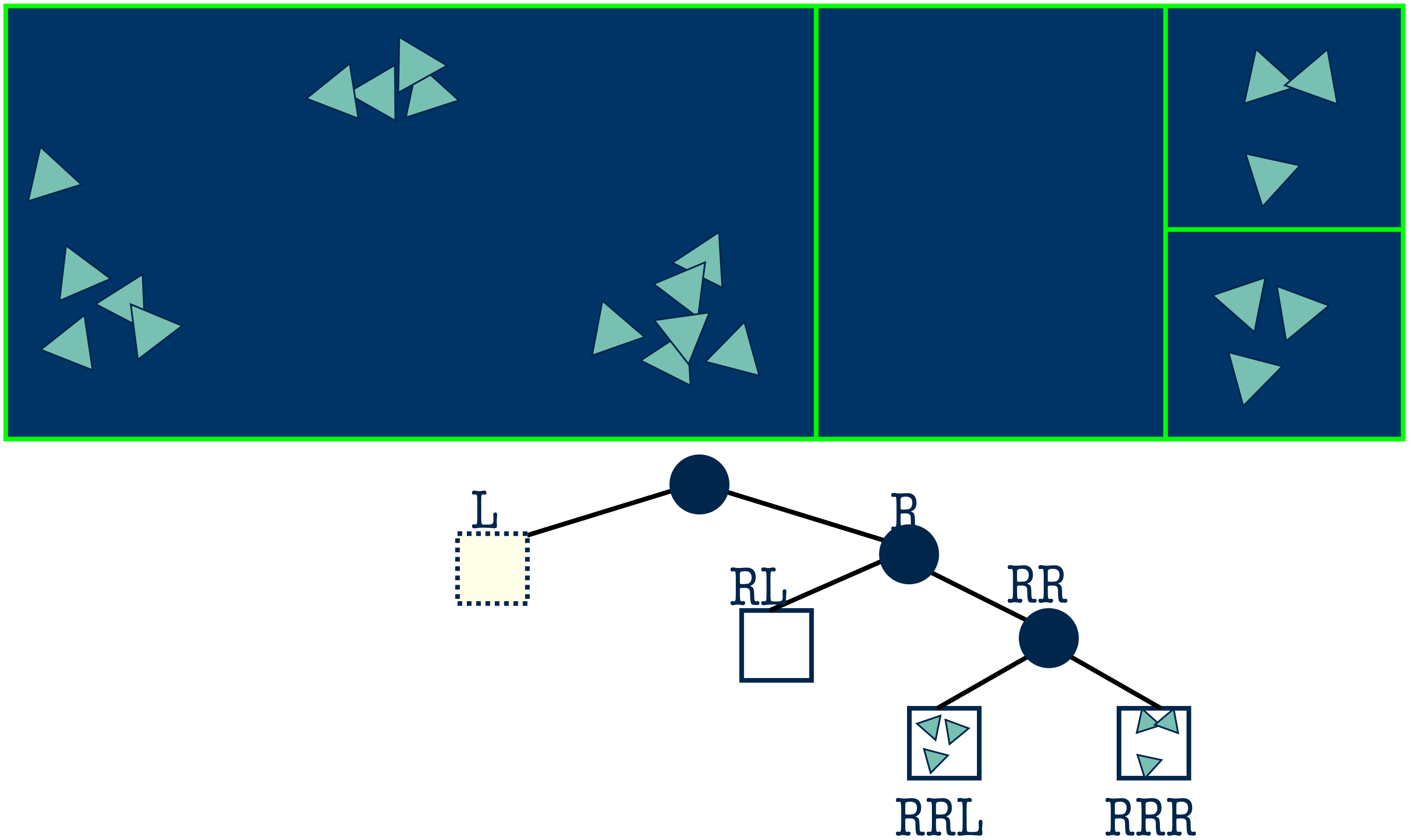
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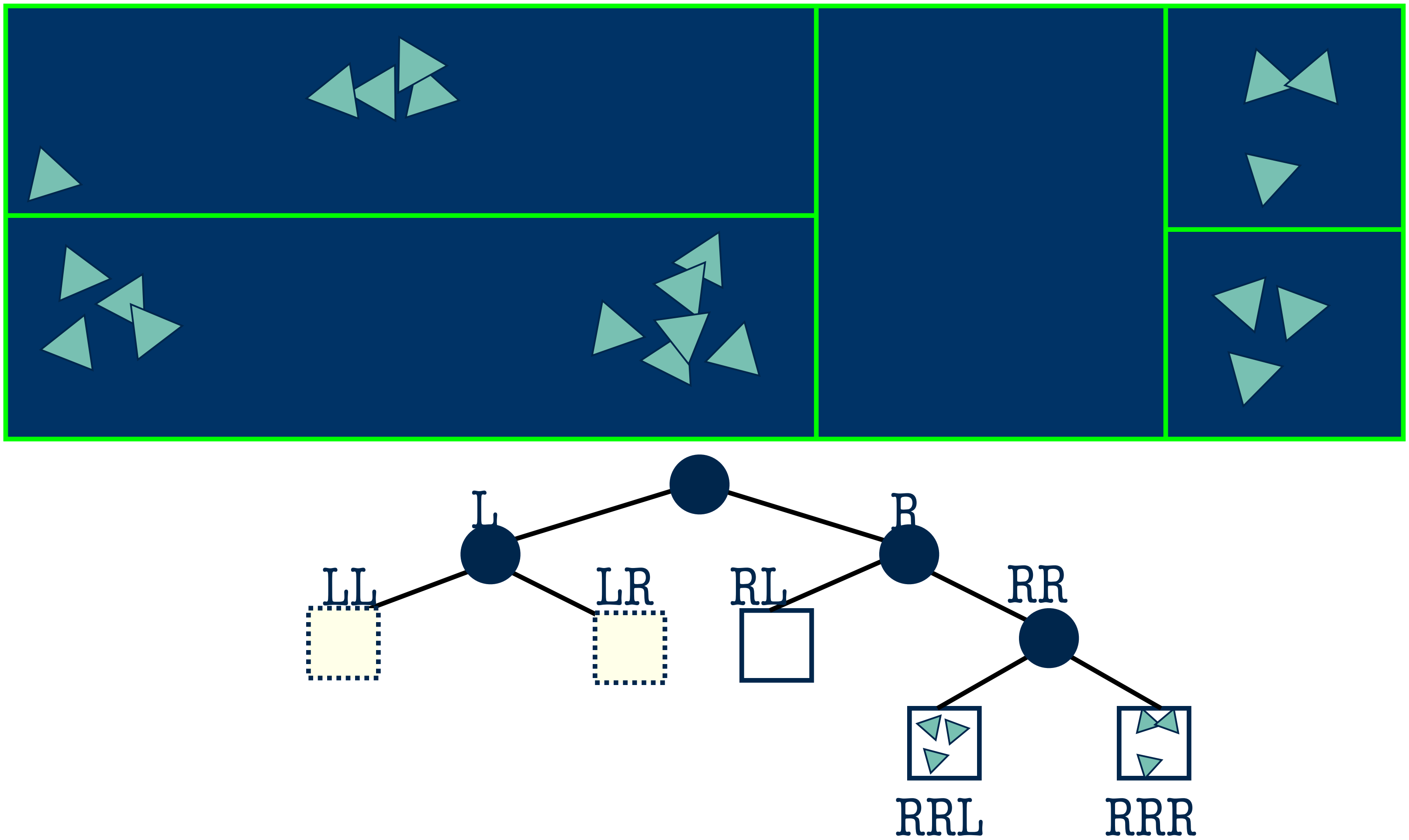
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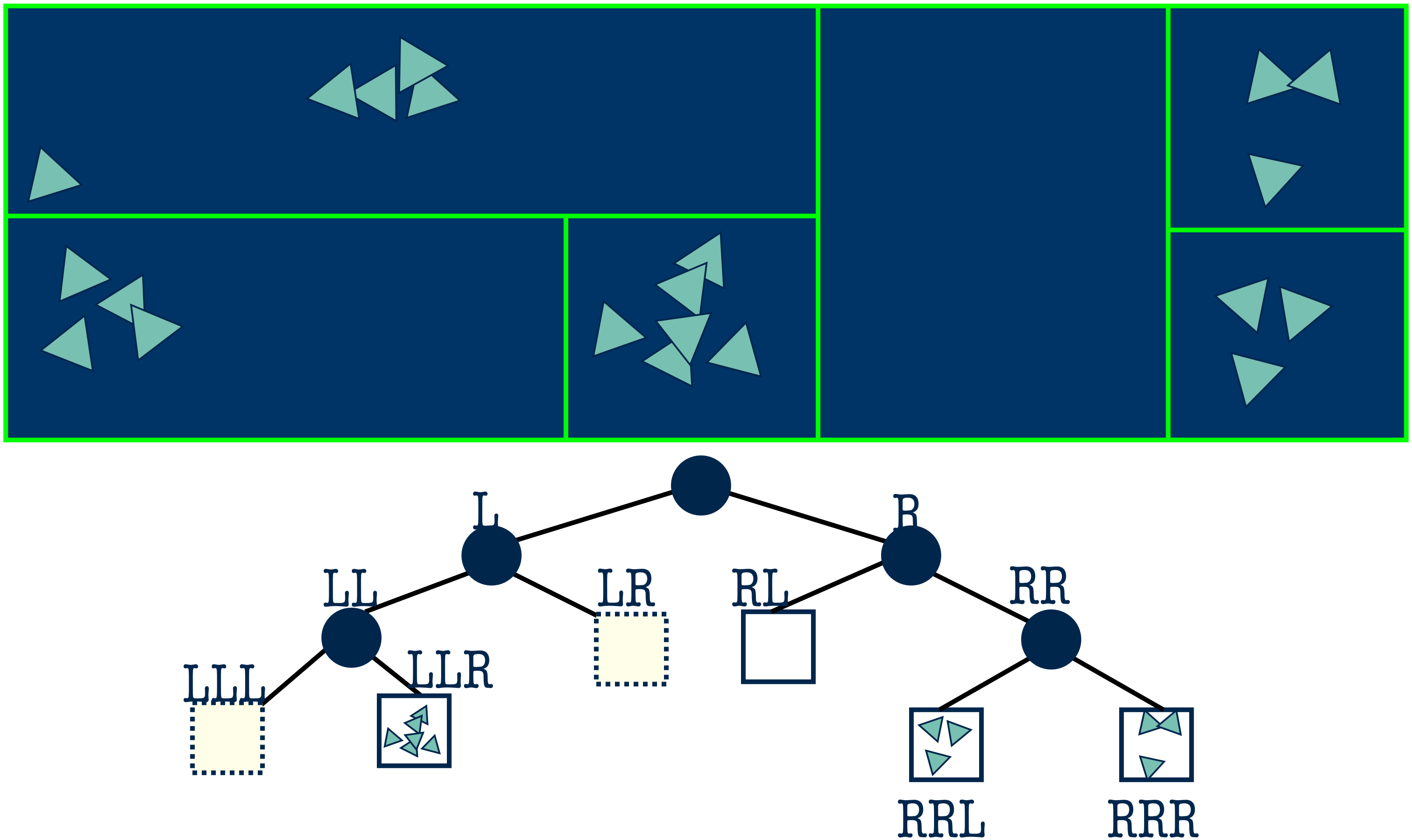

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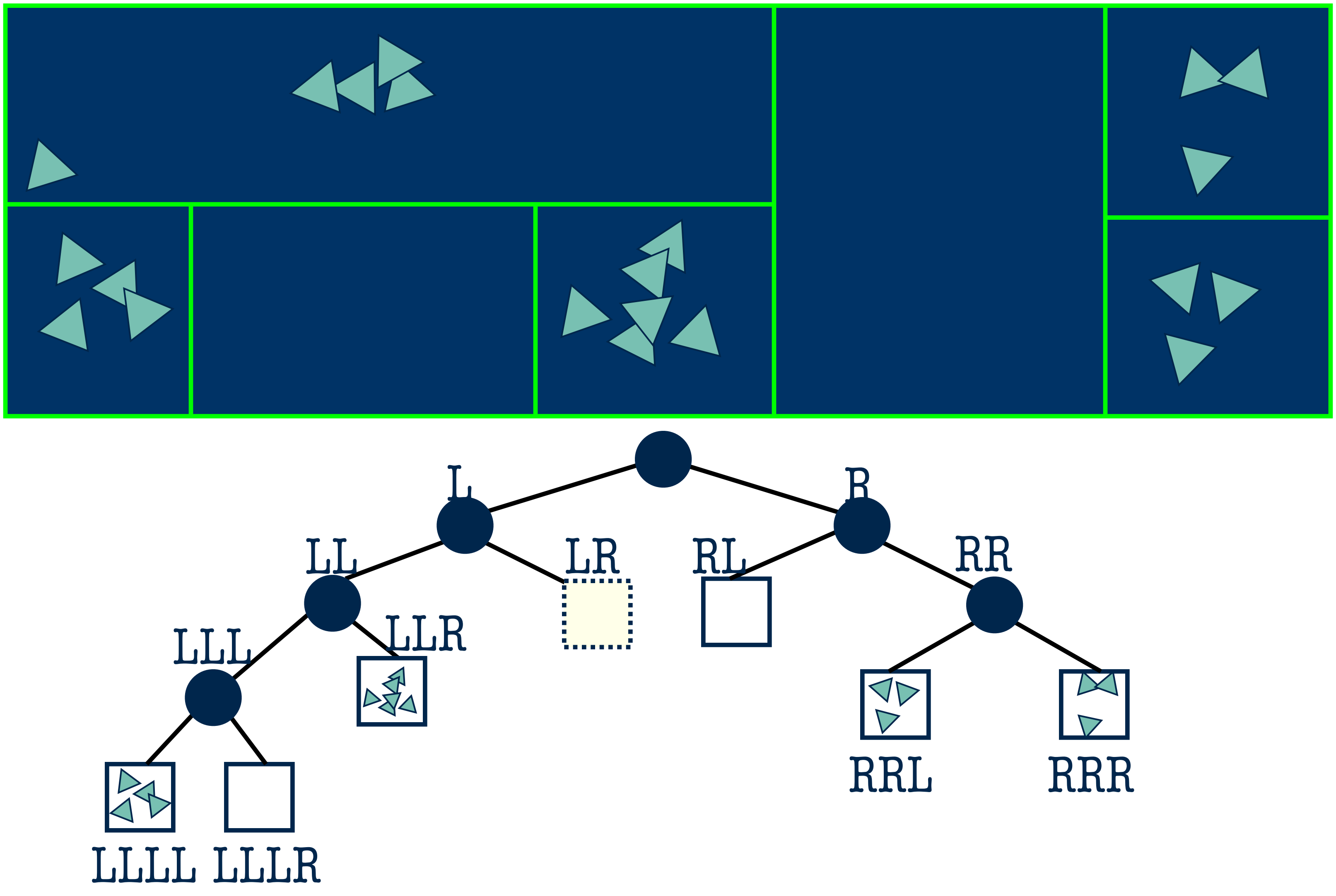
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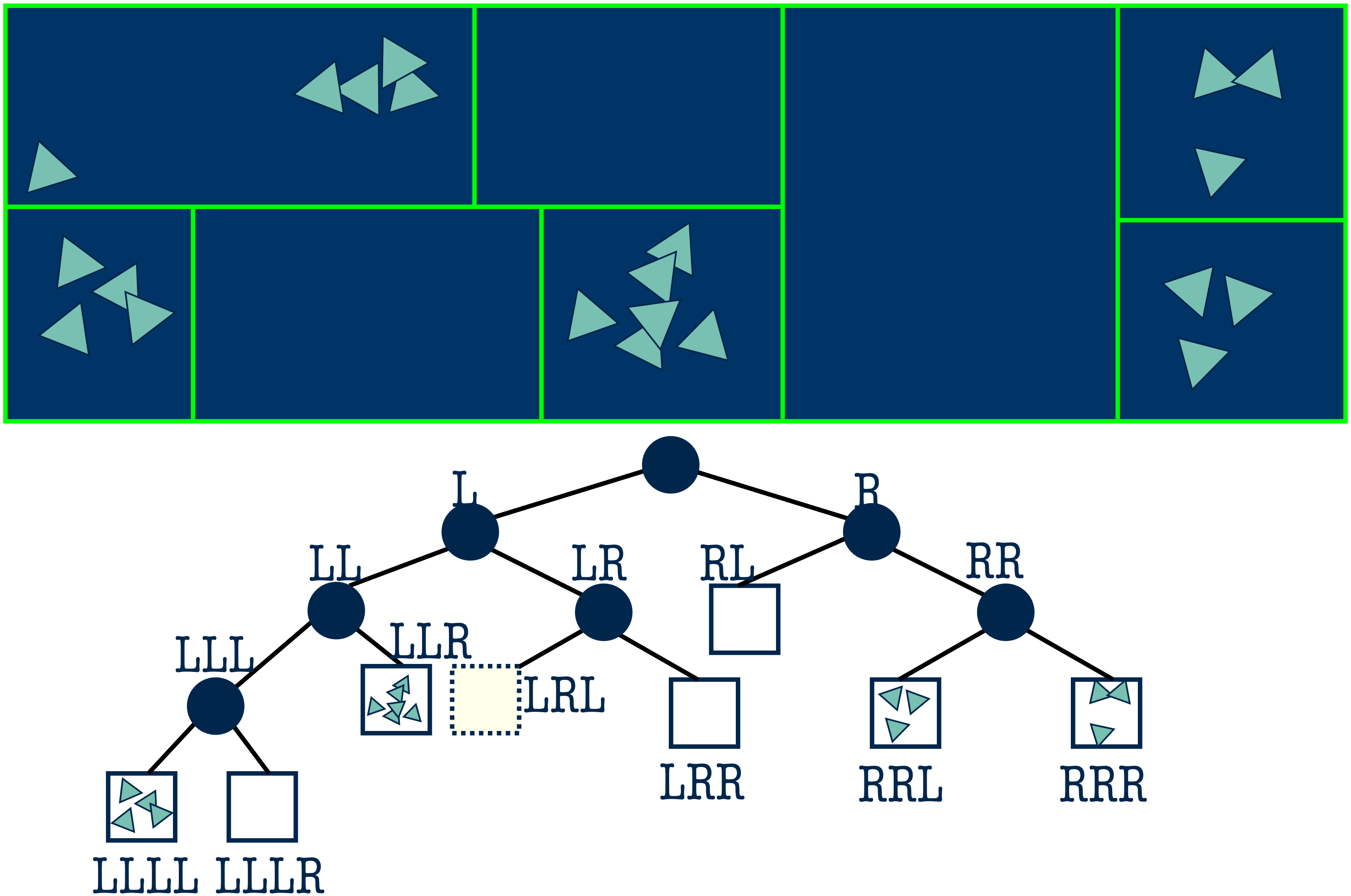

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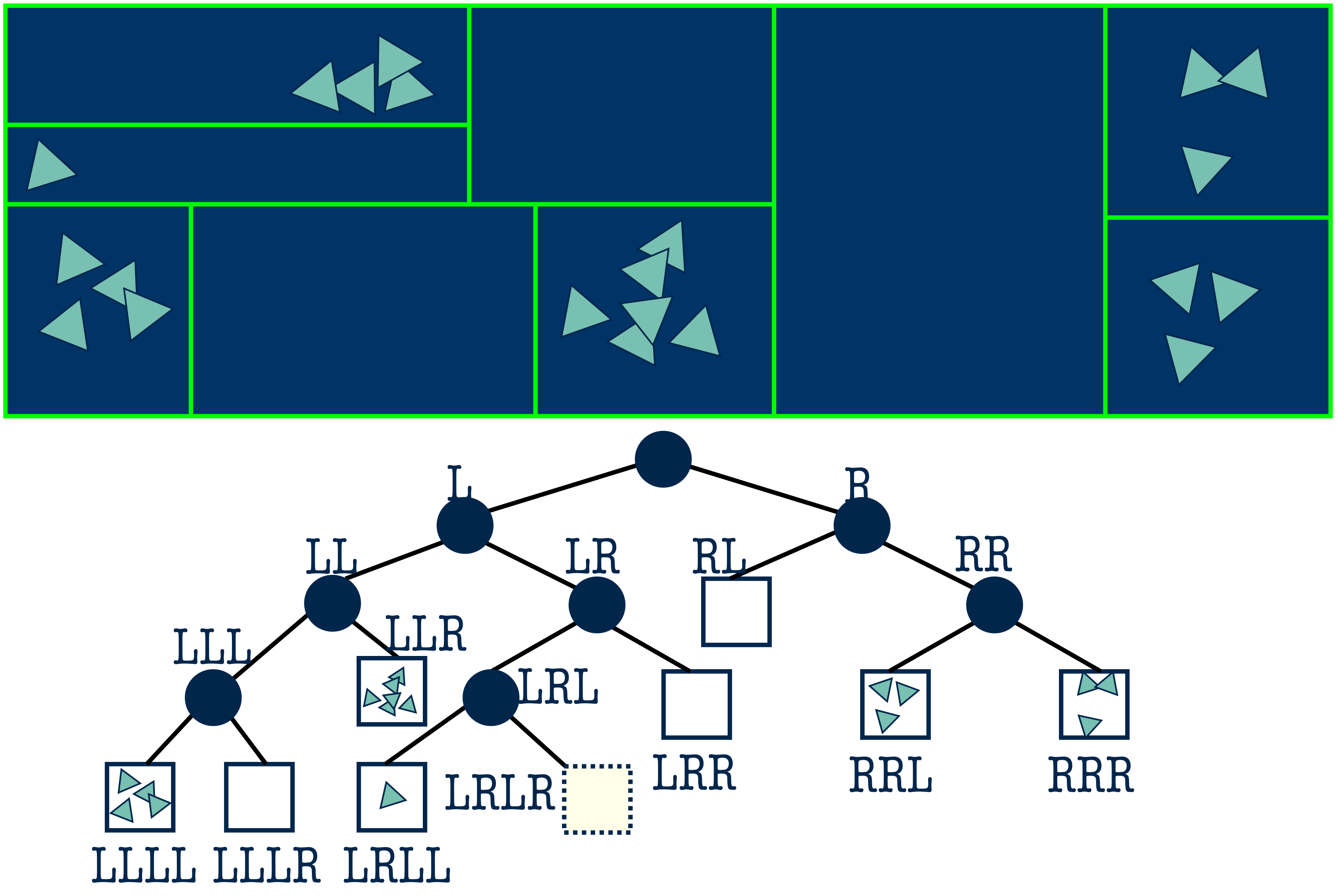

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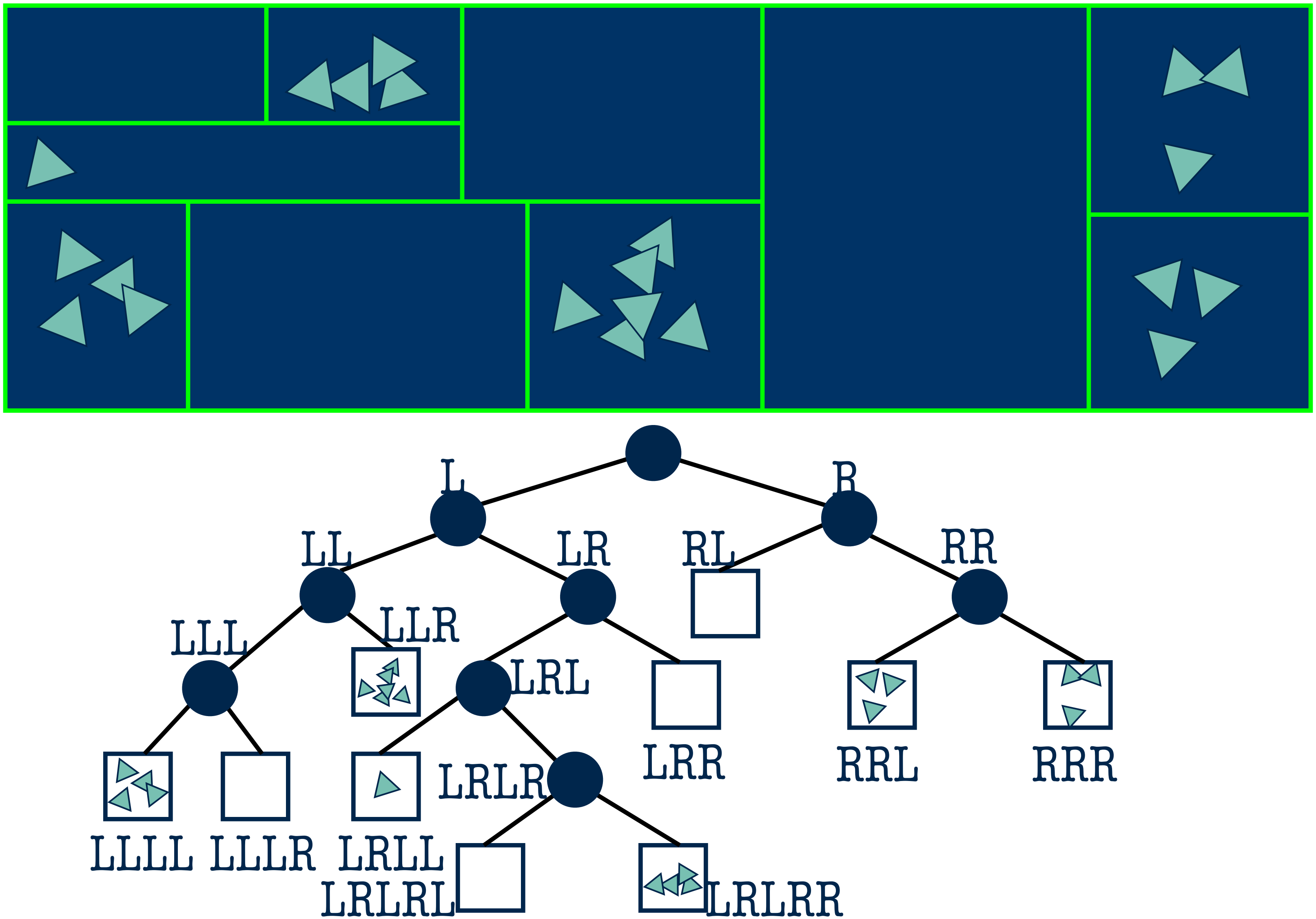

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Where to Split Nodes?

How to decide which split plane to use in a given node? What are some possible criteria?

Split Plane Criteria

Balance cost of building k-d tree with cost of traversal (number of steps) and intersection test

Spatial Median Splitting

- Simplest “naive” method
- Dimension of sub-tree’s split plane *p* chosen in round robin fashion
- Plane positioned at spatial median of voxel
- Terminate recursion when number of triangles in node are below a threshold, or tree depth exceeds maximum depth

Spatial Median Issues

- Does not consider geometry of scene
- Can gain speed ups by maximizing empty space toward root node

Surface Area Metric

Representation of ray traversal cost for a split:

$\text{Cost(split)} = C_s + P_L C_L + P_R C_R$

C_s is cost of node traversal (constant)

C_L and C_r are costs of left and right children (based on number of primitives on that side)

P_L and P_r are probabilities of ray hitting that child (assumes uniform ray distribution, so surface area ratio of child to parent)

Surface Area Heuristic

Greedy, top down approach to tree construction

1. Consider candidate splits for scene partitioning
2. Evaluate candidates using SAM
3. Partition along best candidate and recurse to left and right child

How to Choose Candidates?

Infinite number of potential split plane candidates but not all of them are reasonable choices

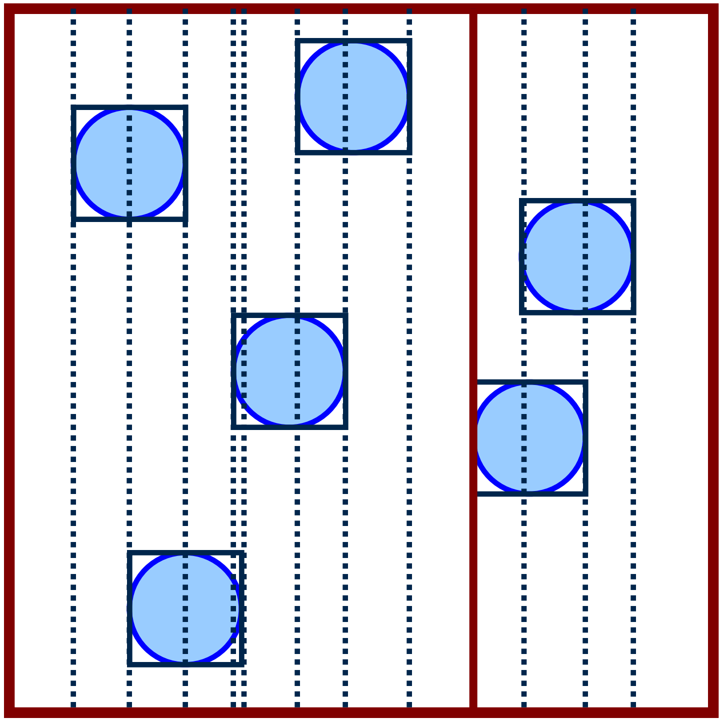
Where should split planes ideally be placed?

Axis-Aligned Bounding Boxes

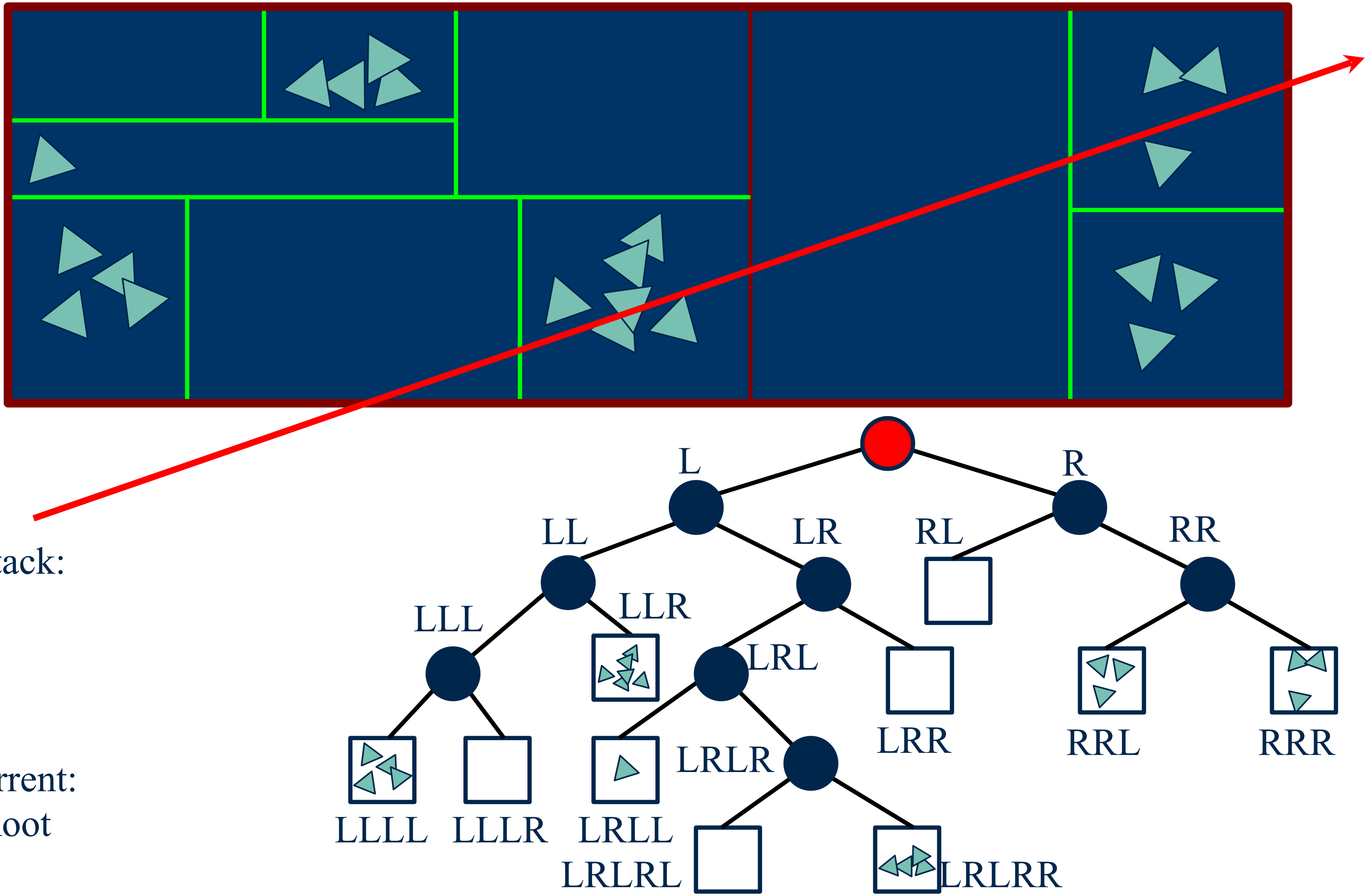
Choose candidate splits based on AABBs (use all three dimensions)

Reduces number of candidates in a sane way

Build time is important since k-d tree is **rebuilt after every time step!**



k-d Tree Traversal



Stack:

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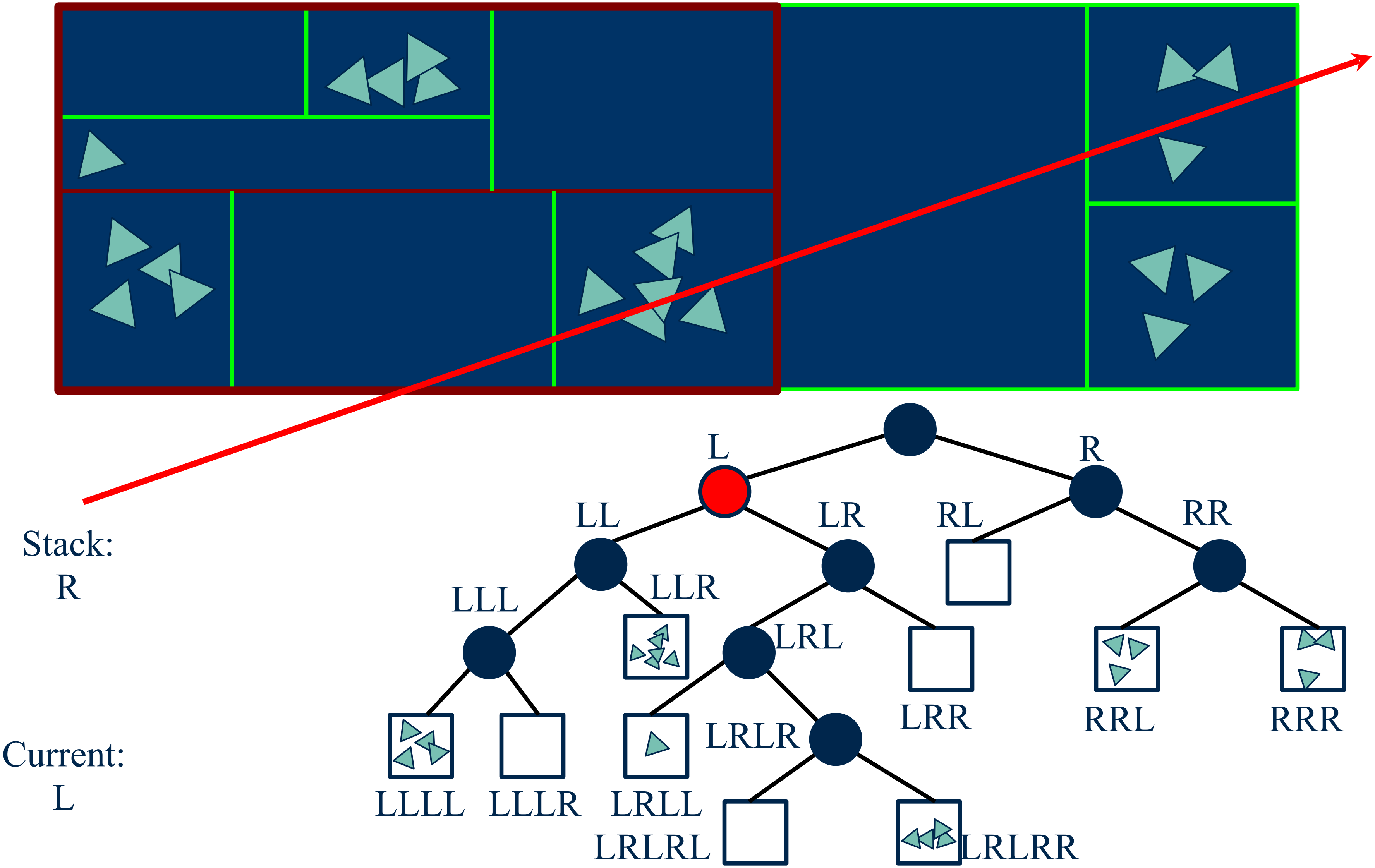
Root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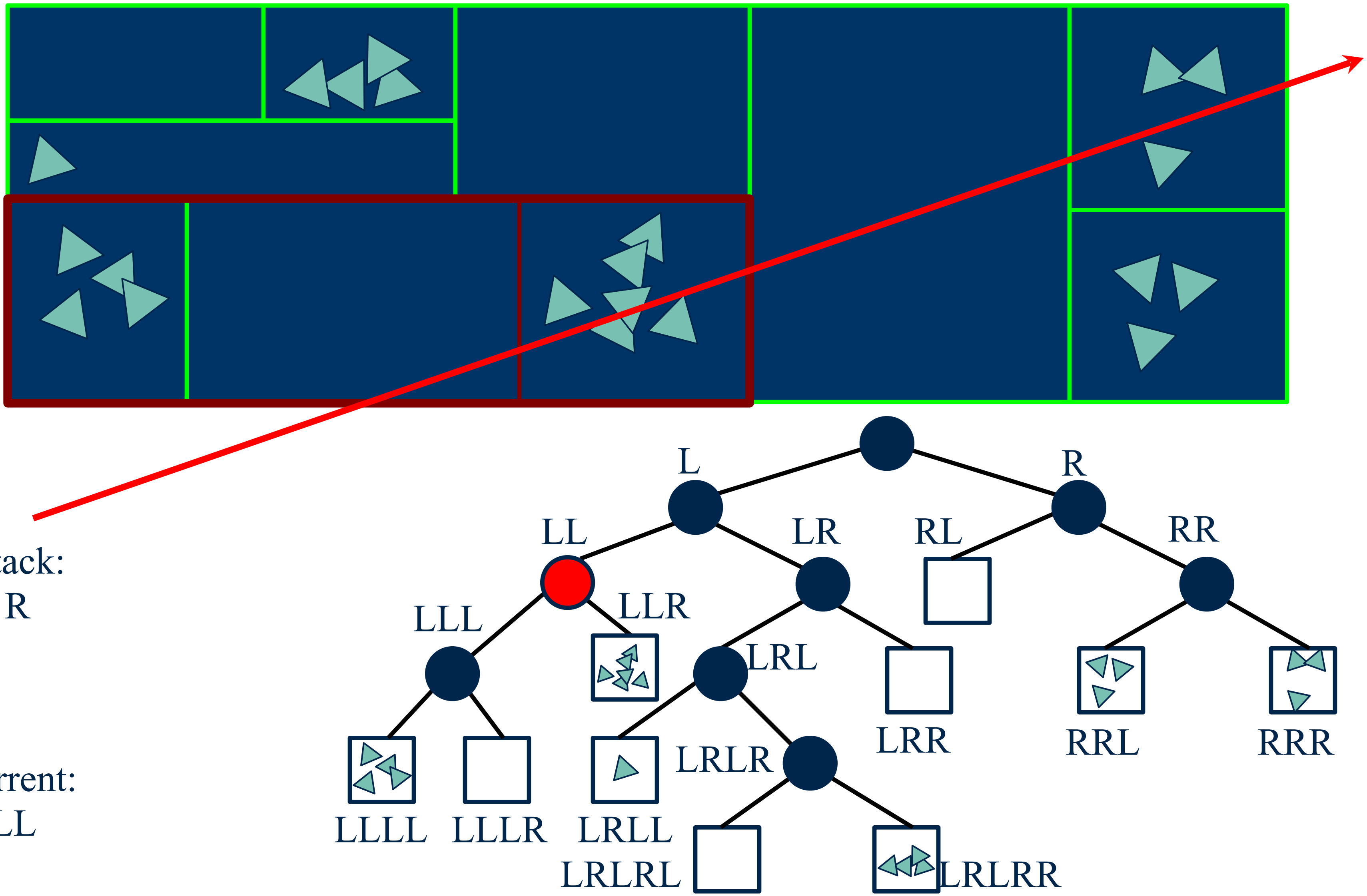

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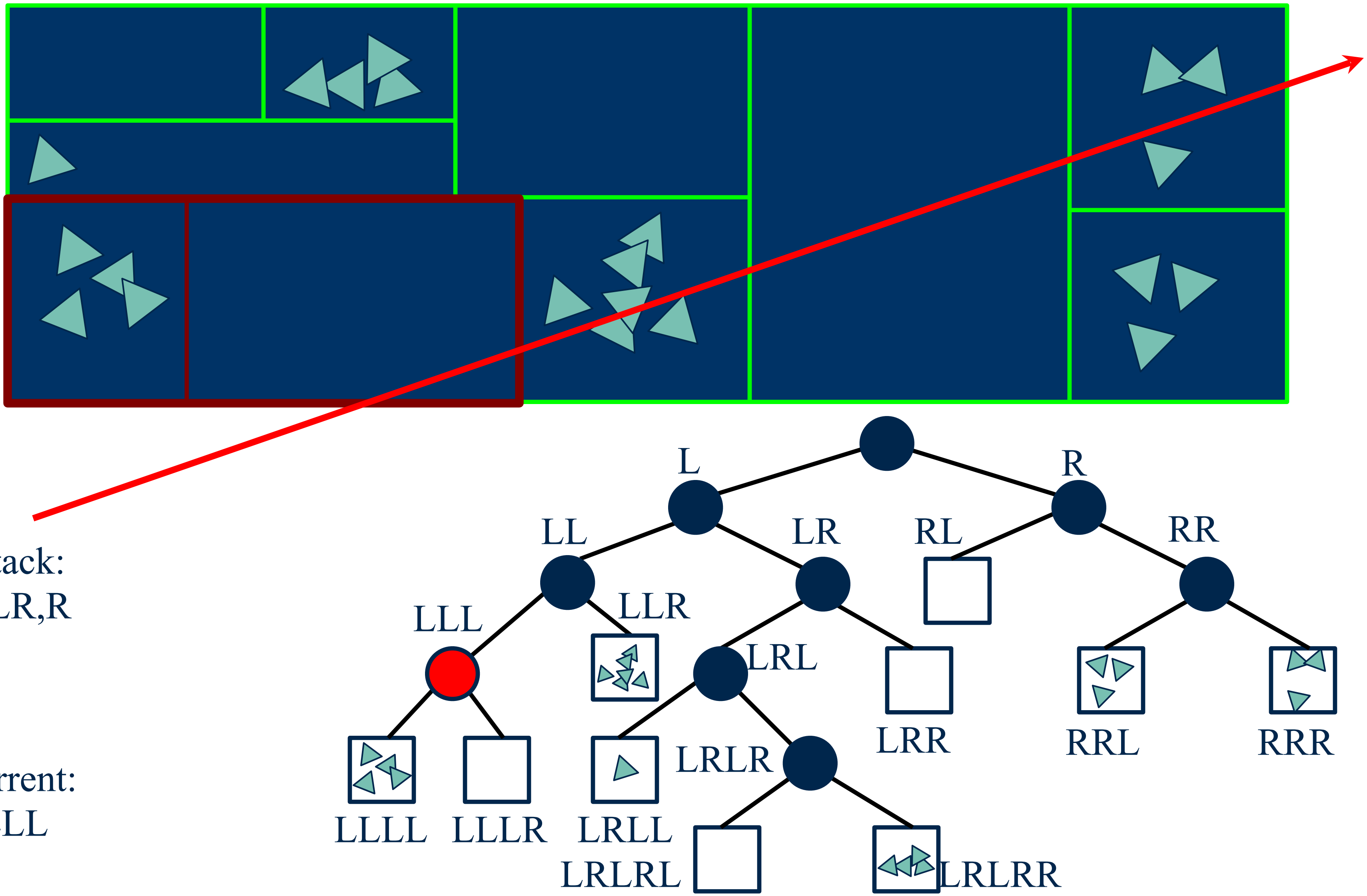

Stack:
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Current:
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Stack:
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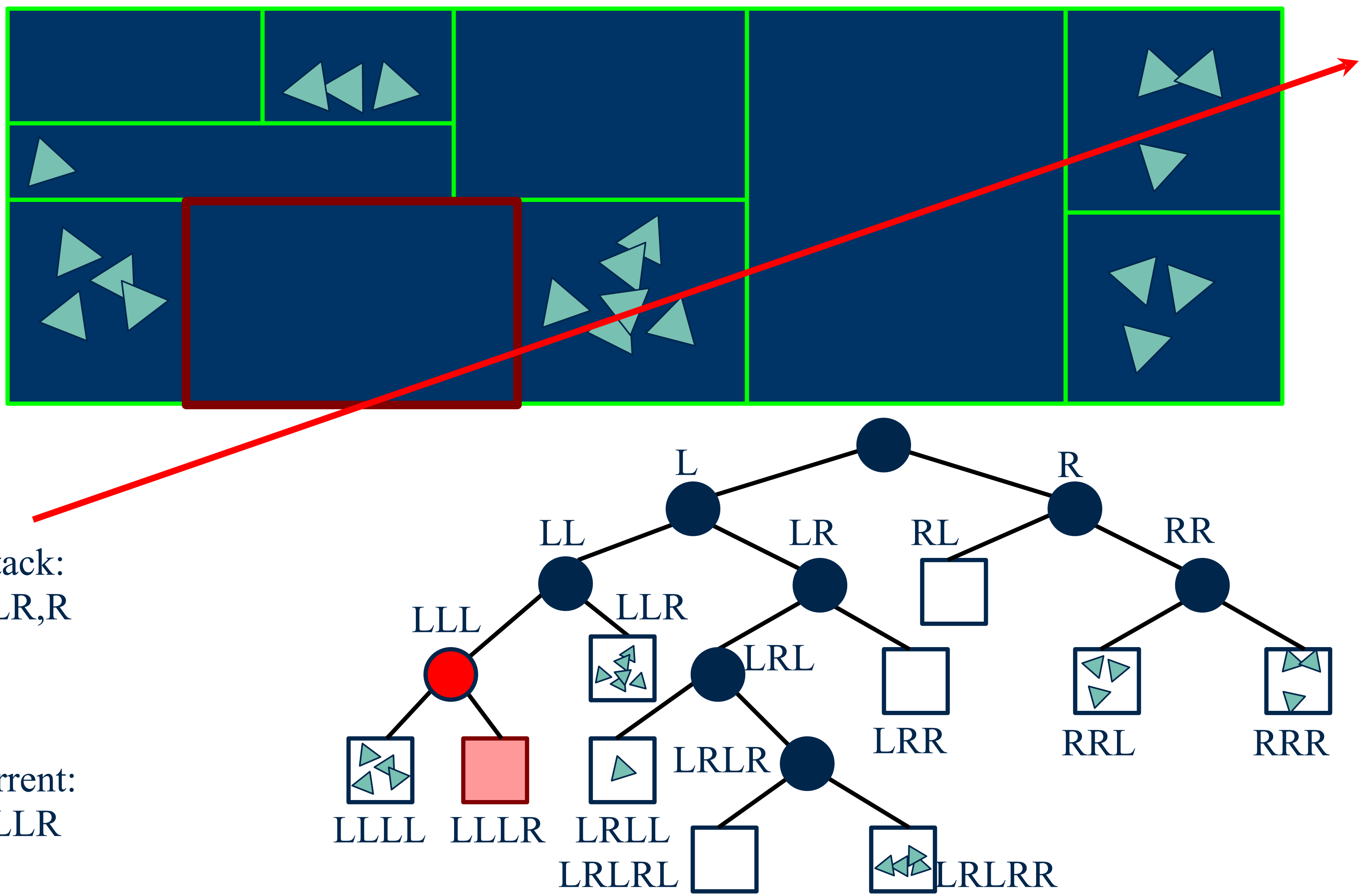

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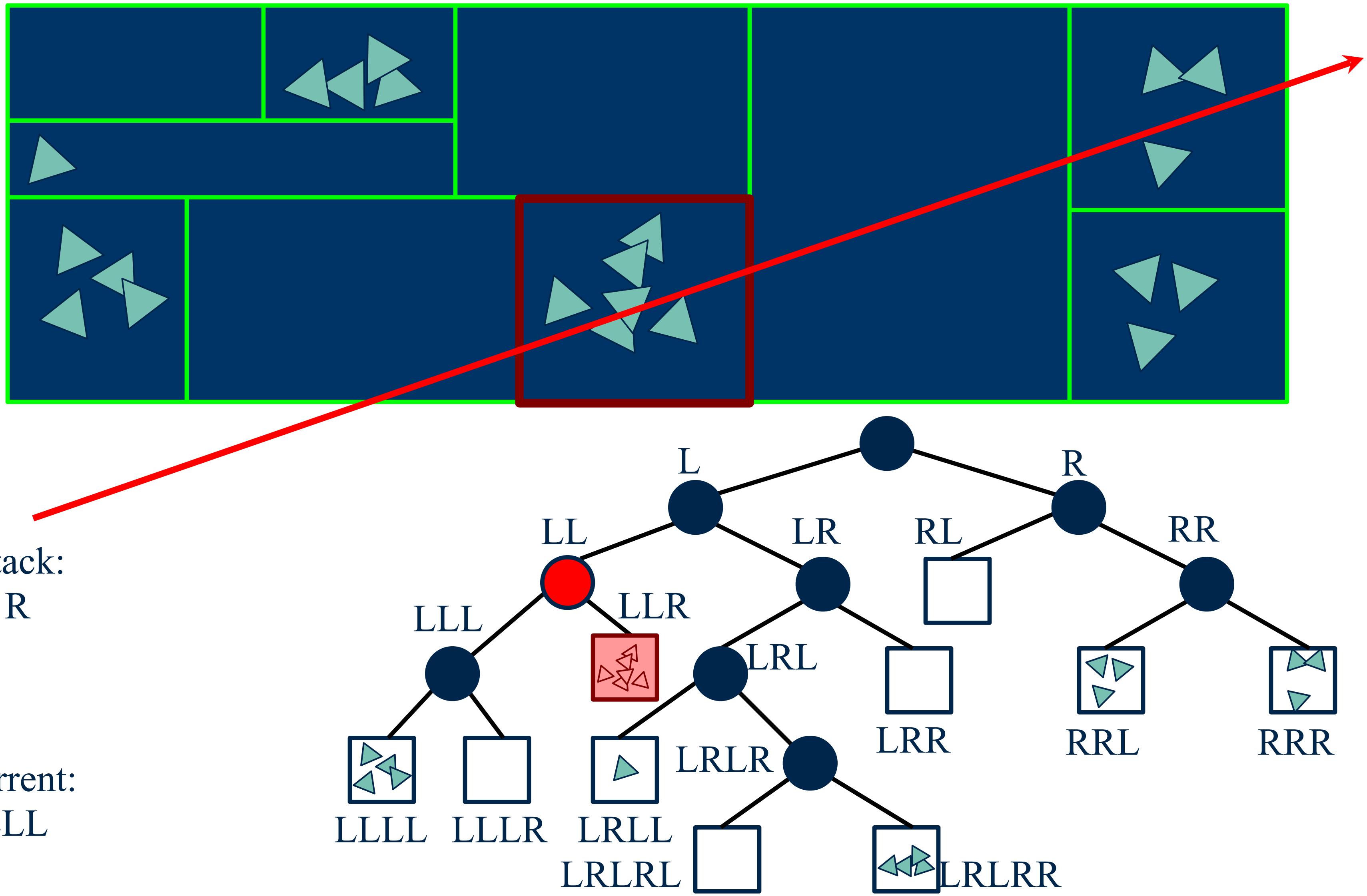

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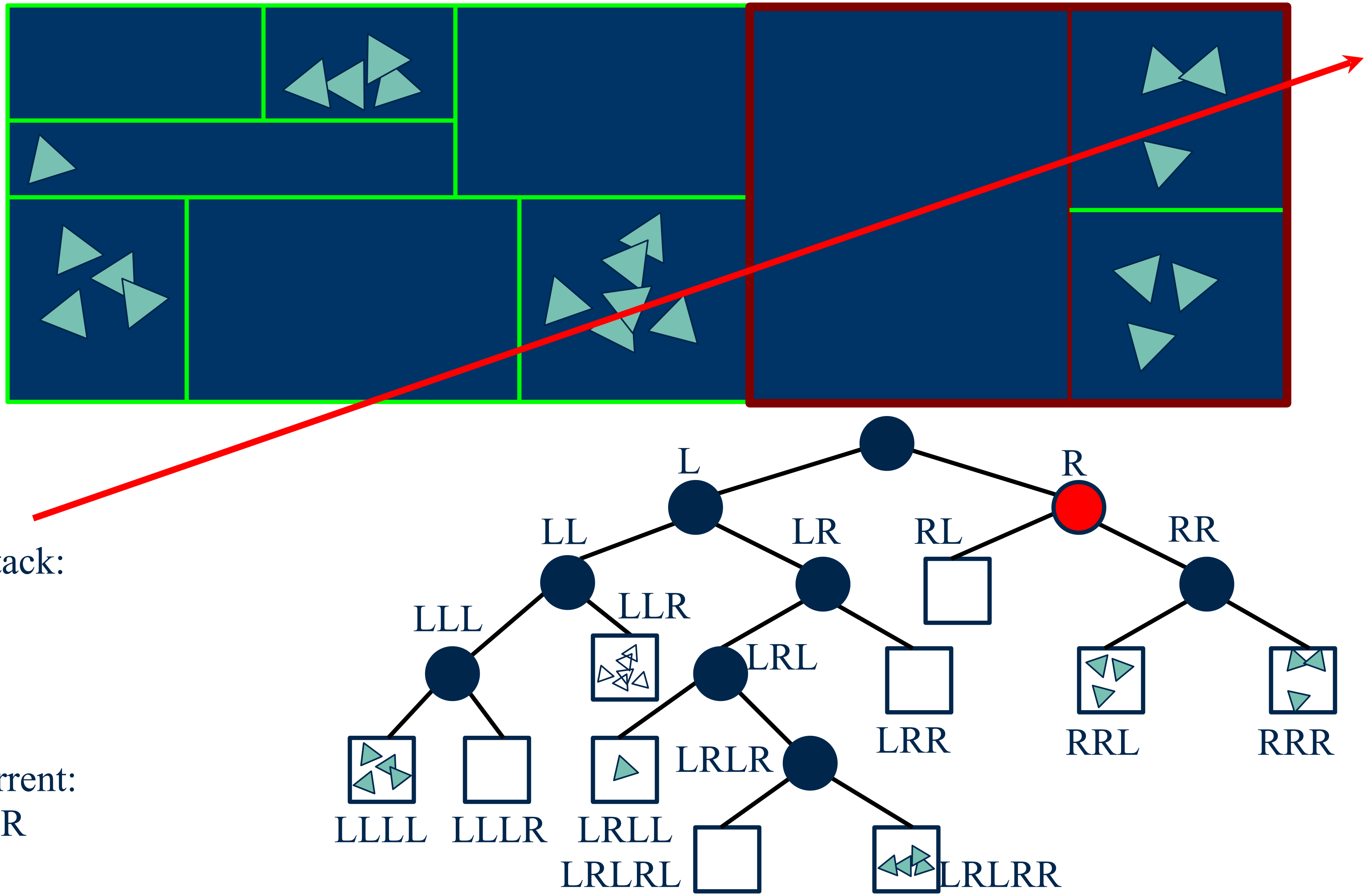

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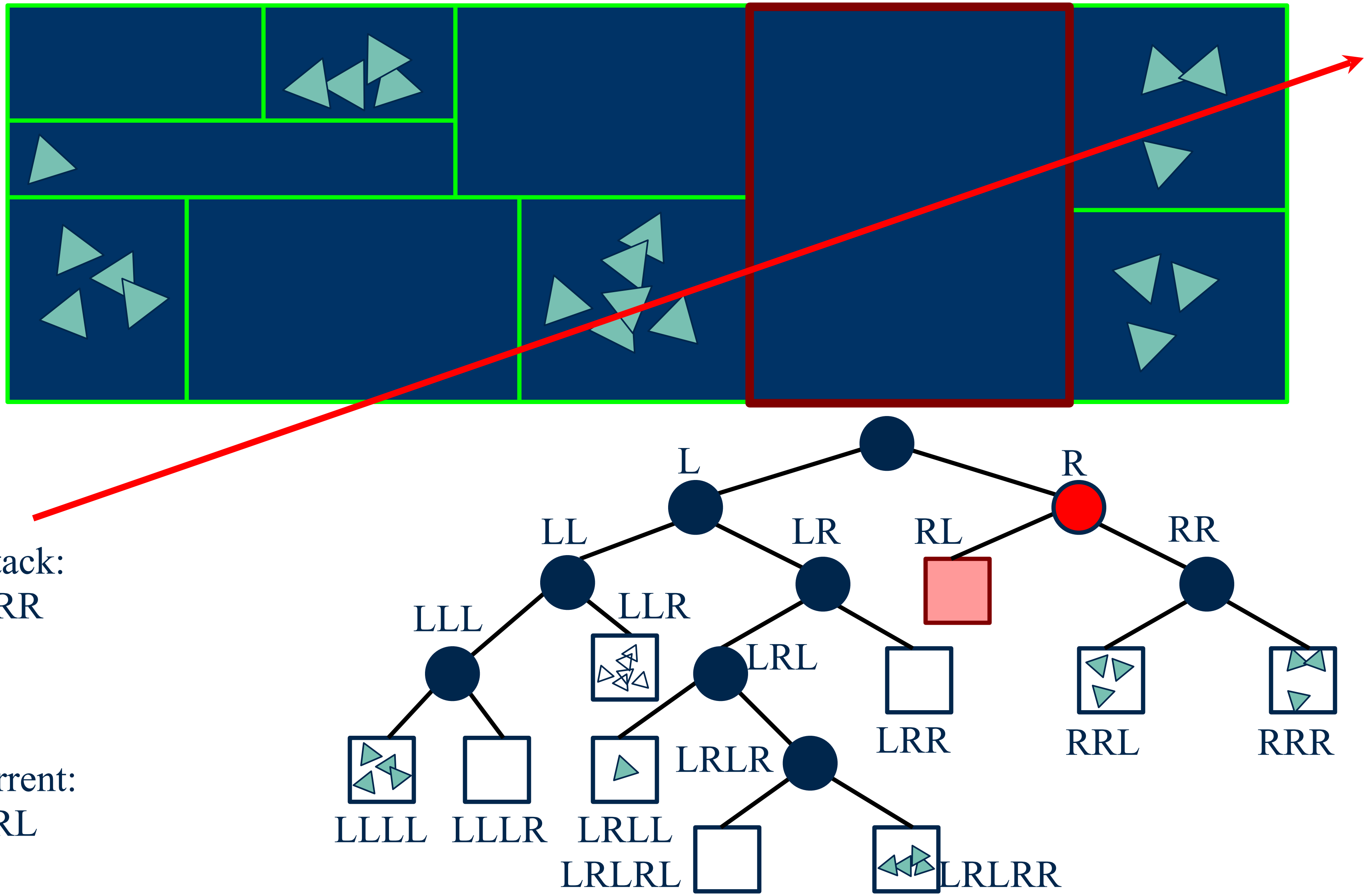

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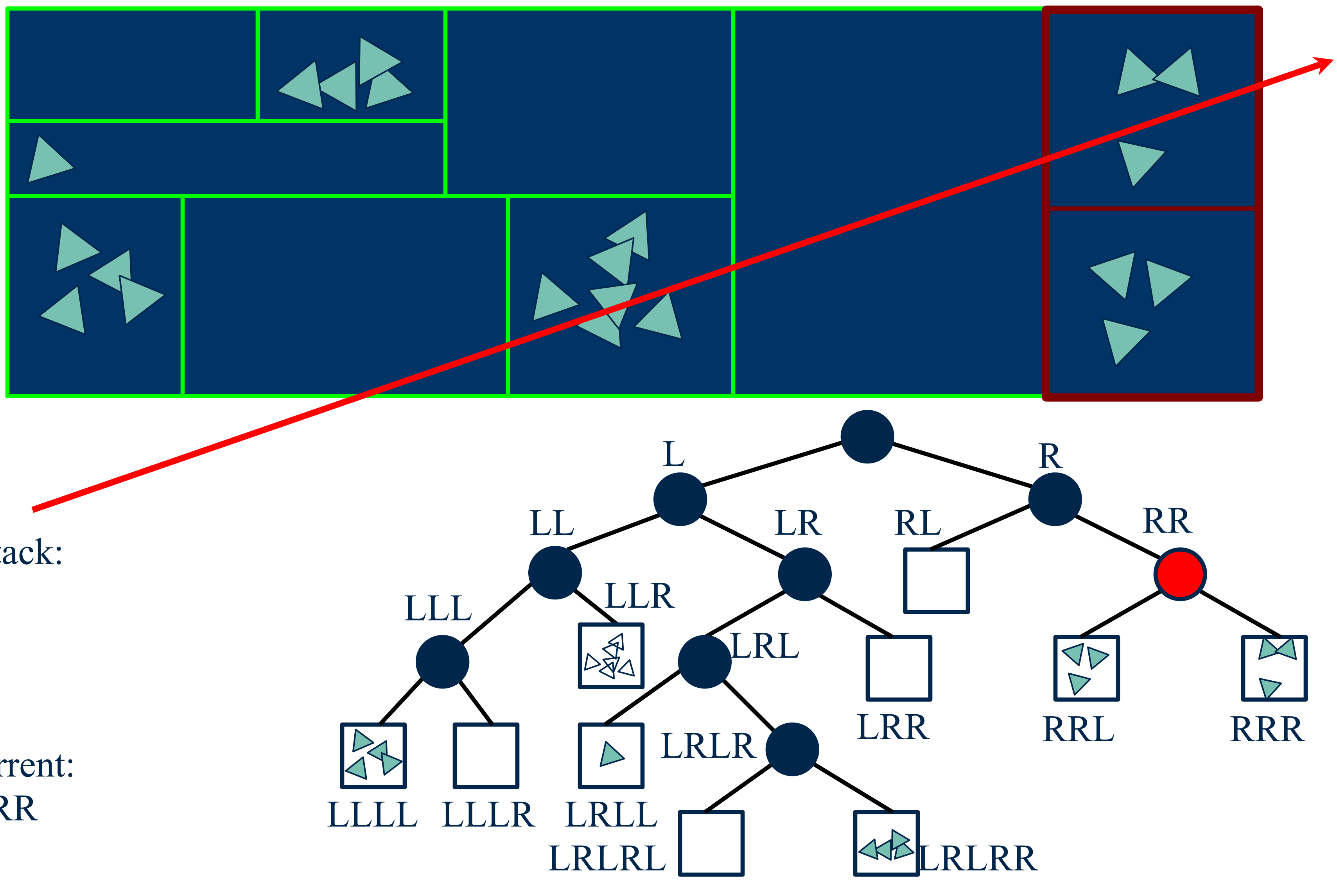

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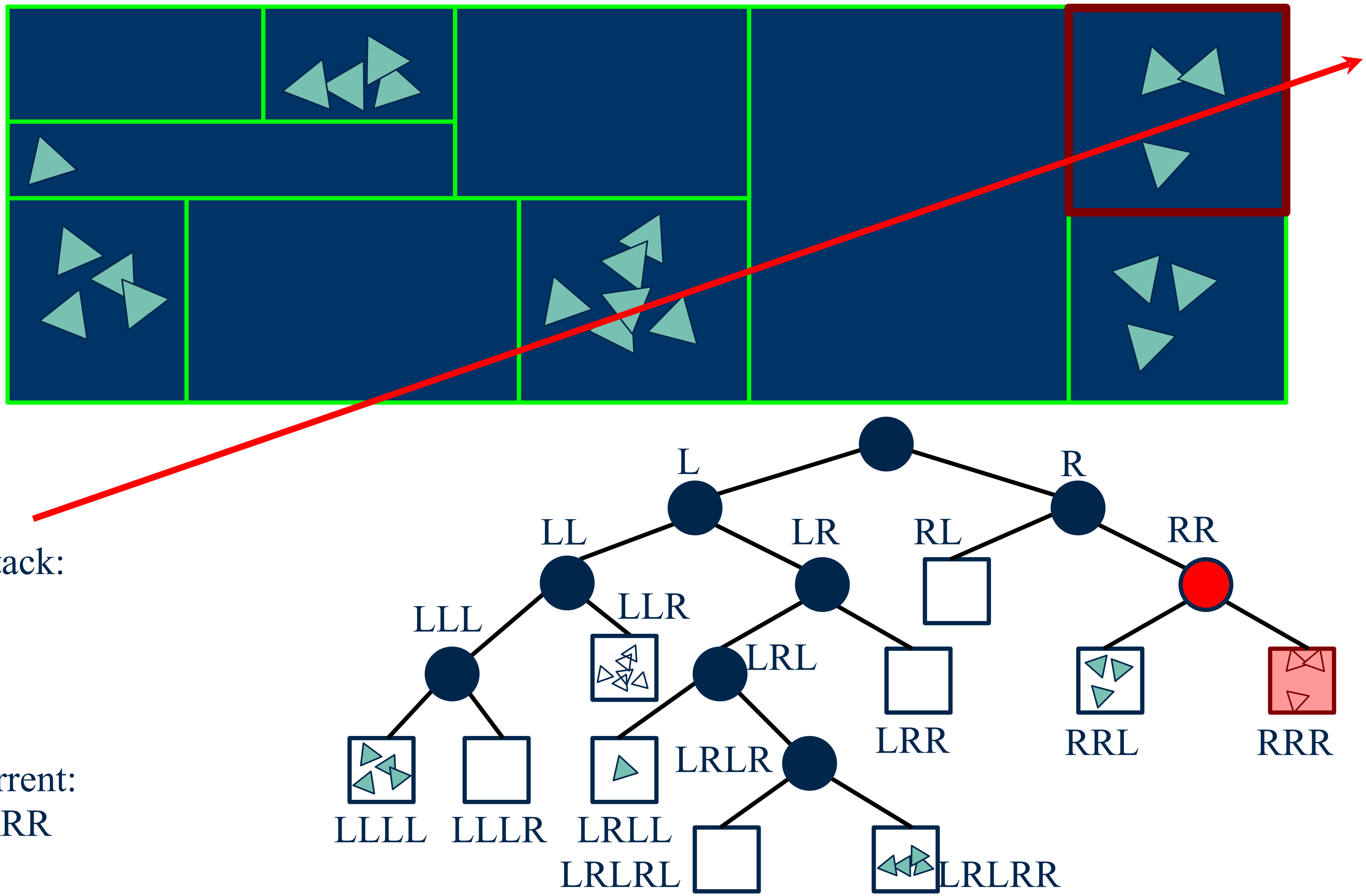

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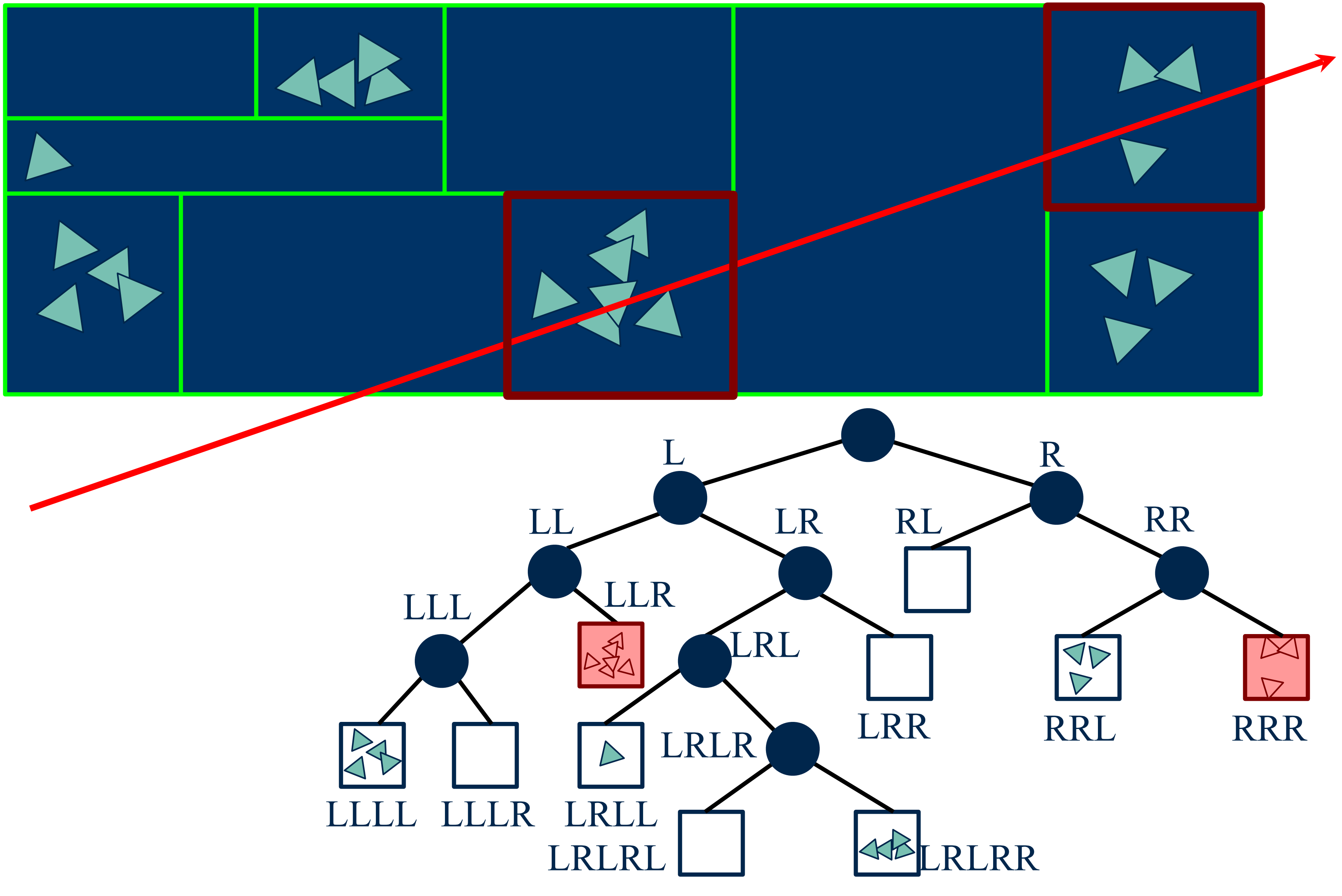

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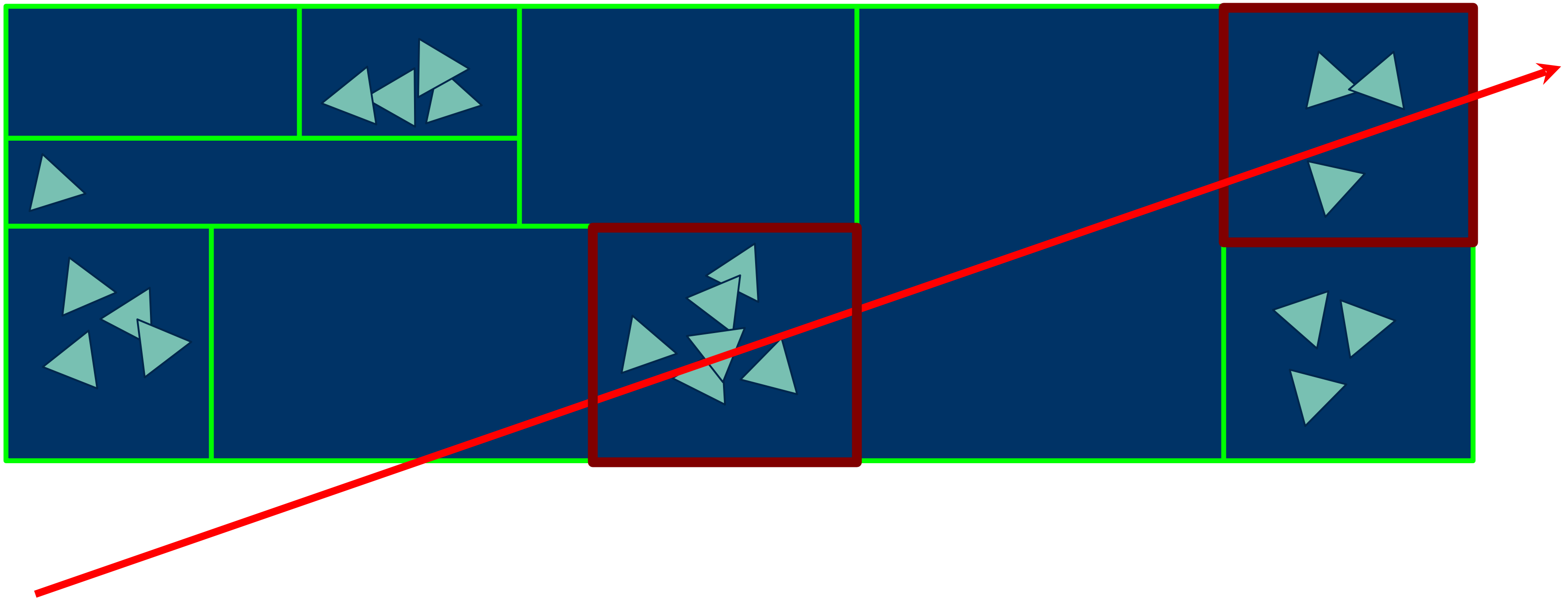
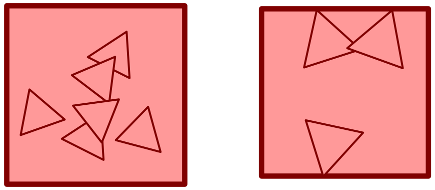
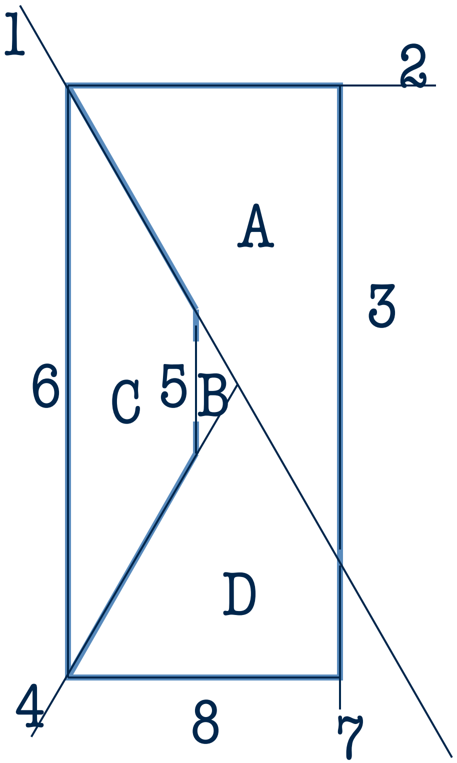


Candidate geometry for narrow phase intersection test

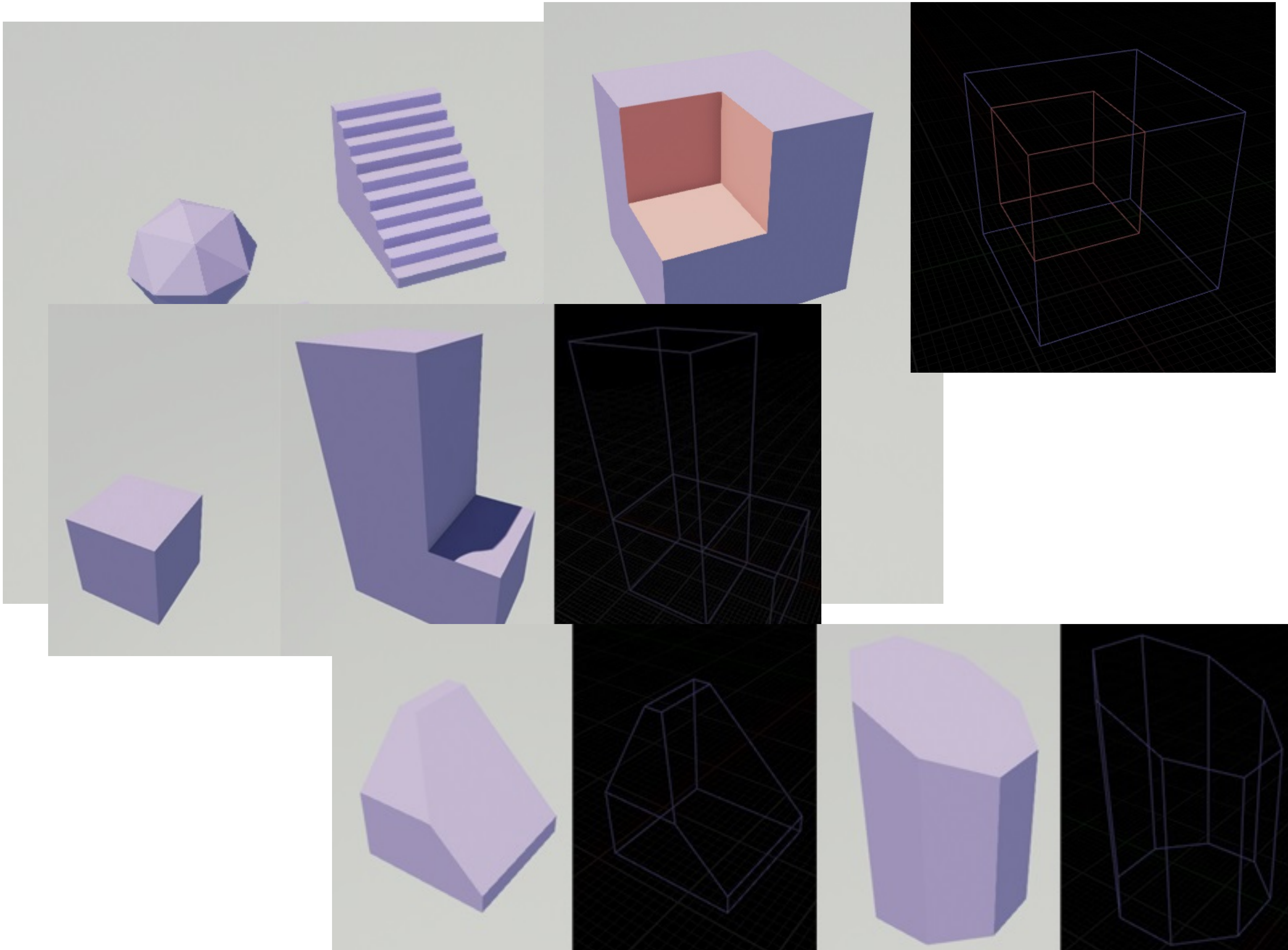


BSP Trees



Binary Space Partition Trees

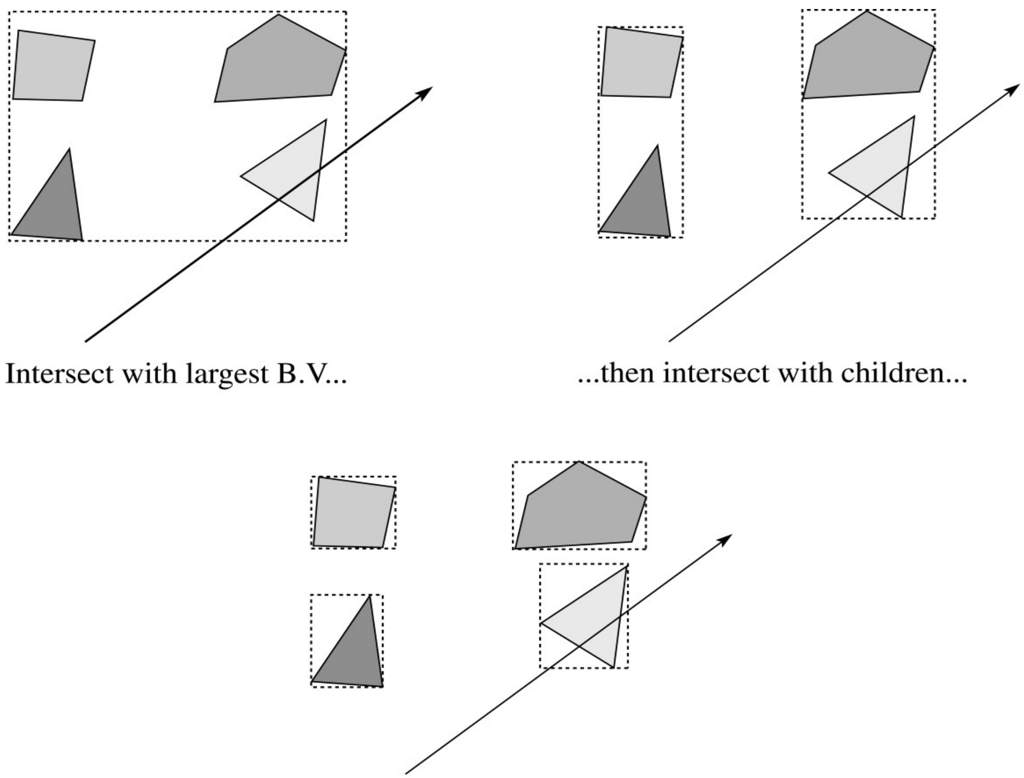
- Cutting planes can be any orientation
- Industry standard for spatial subdivision in many game environments



Bounding Volume Hierarchies

- Bounding volume for each object
  - Sphere, AABBs, etc
- Parents bounds bound child’s bounds
- No notion of cells
- Bounding volumes can overlap

BVH Example



Intersect with largest B.V...

...then intersect with children...

...until you reach the leaf nodes - the primitives.

Ideally have:

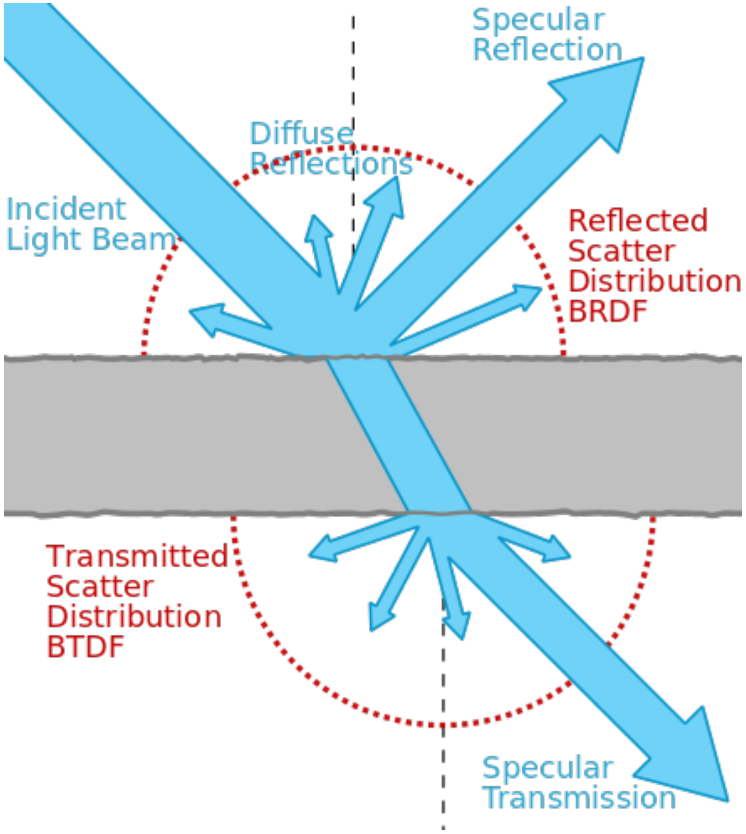
- Tight bounding volumes
- Balanced trees

Current Global Illumination

Bidirectional Pathtracing

Shoot rays from light source in addition to scene

Gather rays from pixel based on light sources on surfaces



Naturally Captures:

- Soft shadows
- Caustics
- Depth of field
- Motion blur
- Indirect light
- Glossy and blurred reflections

Brigade

https://www.youtube.com/watch?v=aKqxonOrl4Q

Cascading Light Propagation Volumes

https://www.youtube.com/watch?v=vPQ3BbuYVh8

VXGI

https://www.youtube.com/watch?v=cH2_RkfStSk

HDRP

https://www.youtube.com/watch?v=QNXbAUKkbEc

Additional Examples

http://realtimeradiosity.com/demos/