



Anti-aliased and accelerated ray tracing





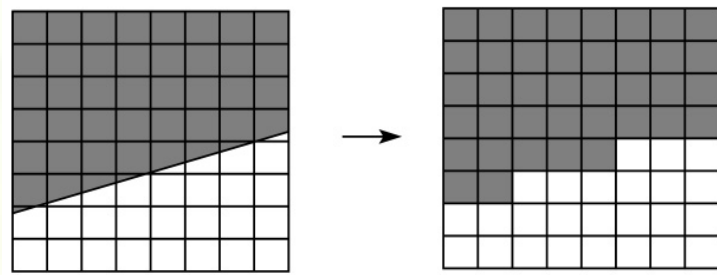
Reading

- Required:
 - Watt, sections 12.5.3 – 12.5.4, 14.7
- Further reading:
 - A. Glassner. *An Introduction to Ray Tracing*. Academic Press, 1989. [In the lab.]

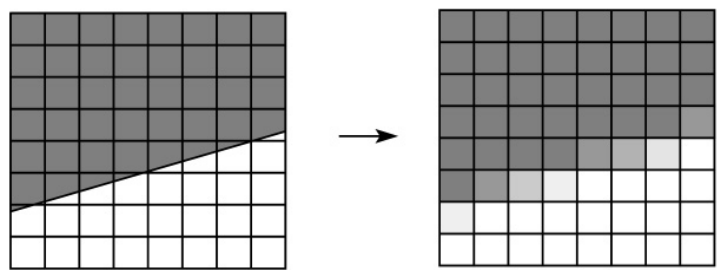


Aliasing in rendering

- One of the most common rendering artifacts is the “jaggies”. Consider rendering a white polygon against a black background:



- We would instead like to get a smoother transition:



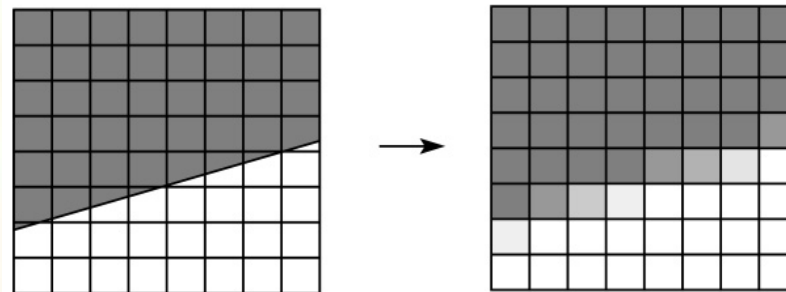


Anti-aliasing

- **Q: How do we avoid aliasing artifacts?**

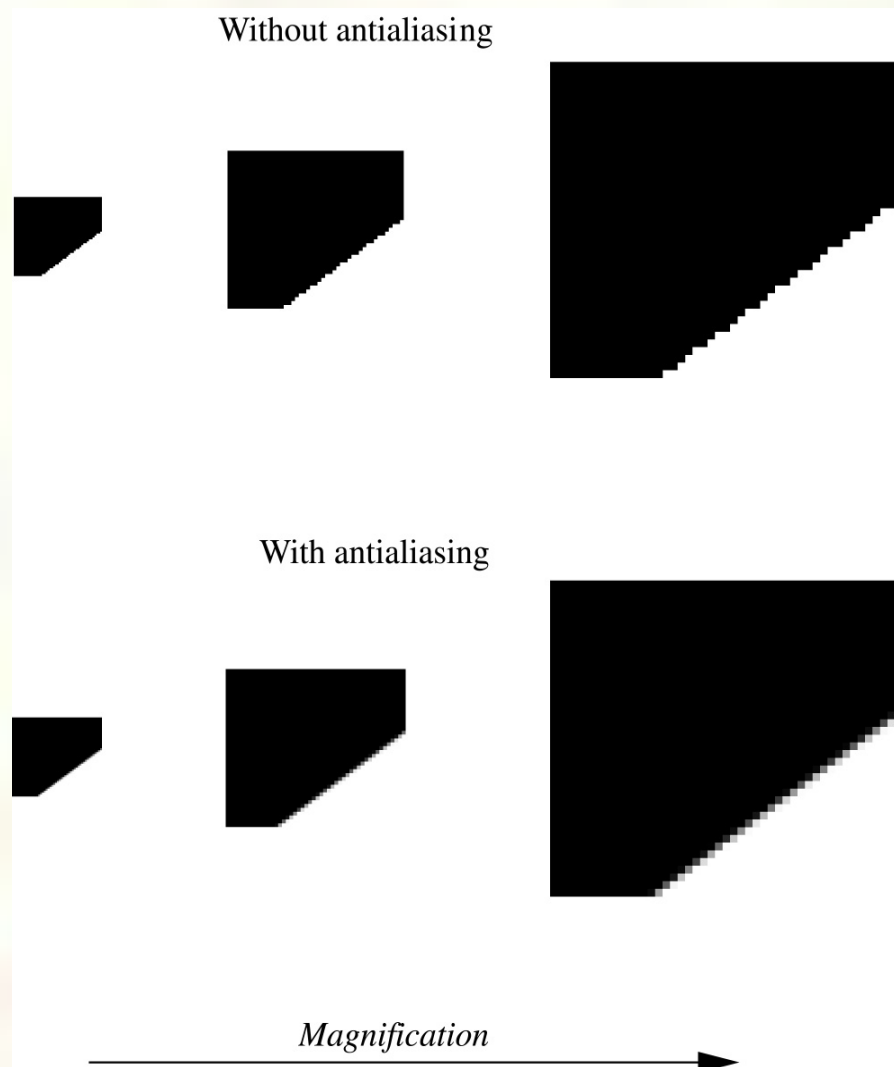
1. Sampling:
2. Pre-filtering:
3. Combination:

- **Example - polygon:**





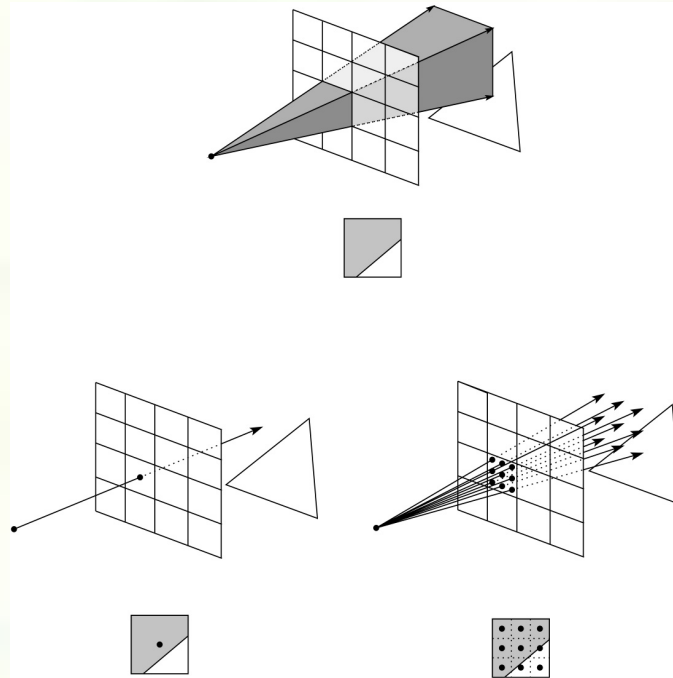
Polygon anti-aliasing





Antialiasing in a ray tracer

- We would like to compute the average intensity in the neighborhood of each pixel.



- When casting one ray per pixel, we are likely to have aliasing artifacts.
- To improve matters, we can cast more than one ray per pixel and average the result.
- A.k.a., **super-sampling and averaging down.**



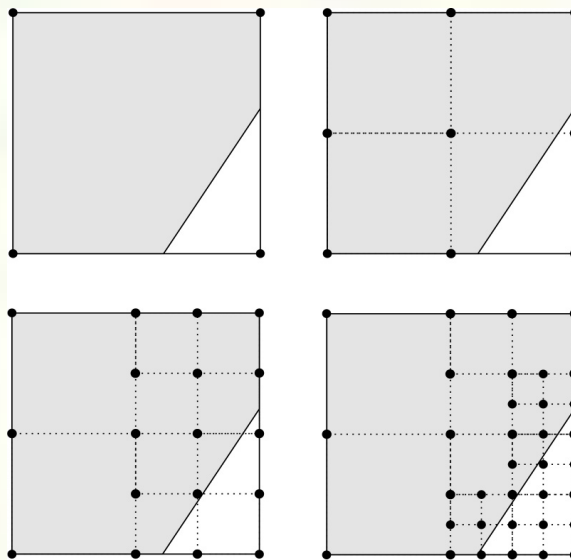
Speeding it up

- Vanilla ray tracing is really slow!
- Consider: $m \times m$ pixels, $k \times k$ supersampling, and n primitives, average ray path length of d , with 2 rays cast recursively per intersection.
- Complexity =
- For $m=1,000,000$, $k = 5$, $n = 100,000$, $d=8$...very expensive!!
- In practice, some acceleration technique is almost always used.
- We've already looked at reducing d with adaptive ray termination.
- Now we look at reducing the effect of the k and n terms.



Antialiasing by adaptive sampling

- Casting many rays per pixel can be unnecessarily costly.
- For example, if there are no rapid changes in intensity at the pixel, maybe only a few samples are needed.
- Solution: **adaptive sampling**.

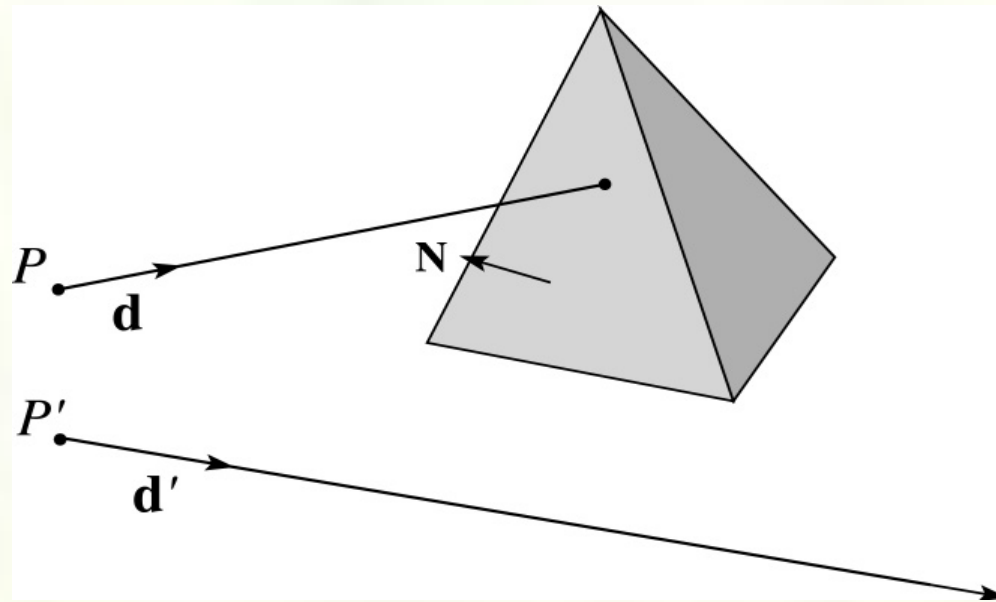


- **Q:** When do we decide to cast more rays in a particular area?



Faster ray-polyhedron intersection

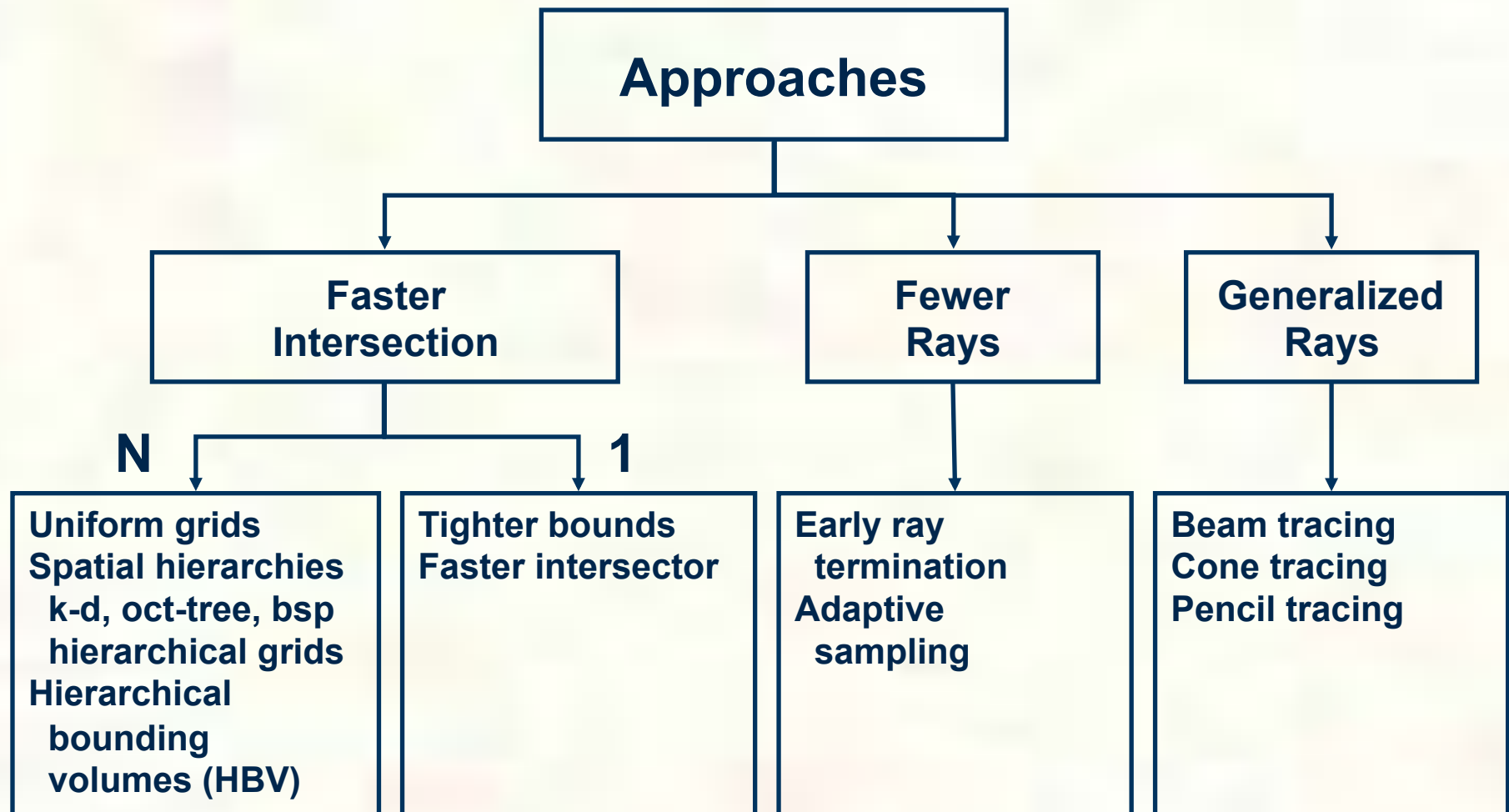
- Let's say you were intersecting a ray with a polyhedron:



- Straightforward method
 - intersect the ray with each triangle
 - return the intersection with the smallest t -value.
- **Q:** How might you speed this up?



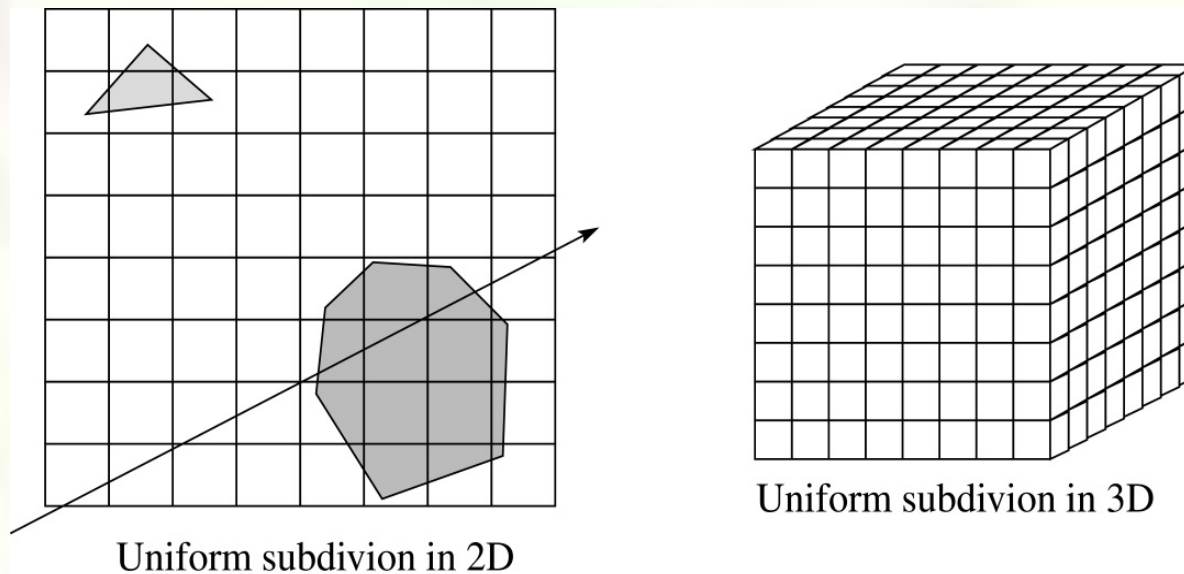
Ray Tracing Acceleration Techniques





Uniform spatial subdivision

- Another approach is **uniform spatial subdivision**.

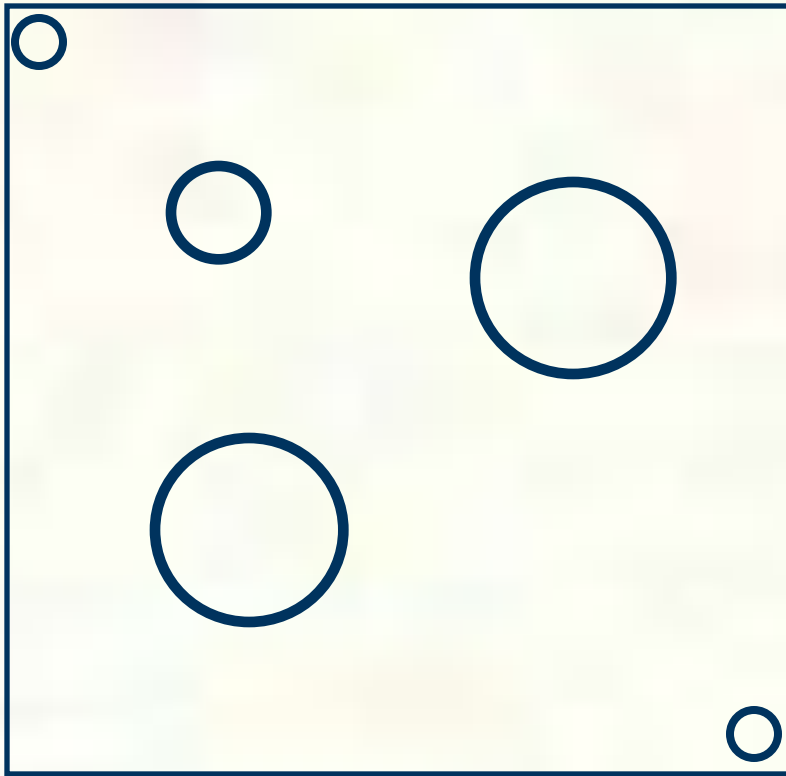


- Idea:

- Partition space into cells (voxels)
- Associate each primitive with the cells it overlaps
- Trace ray through voxel array *using fast incremental arithmetic* to step from cell to cell



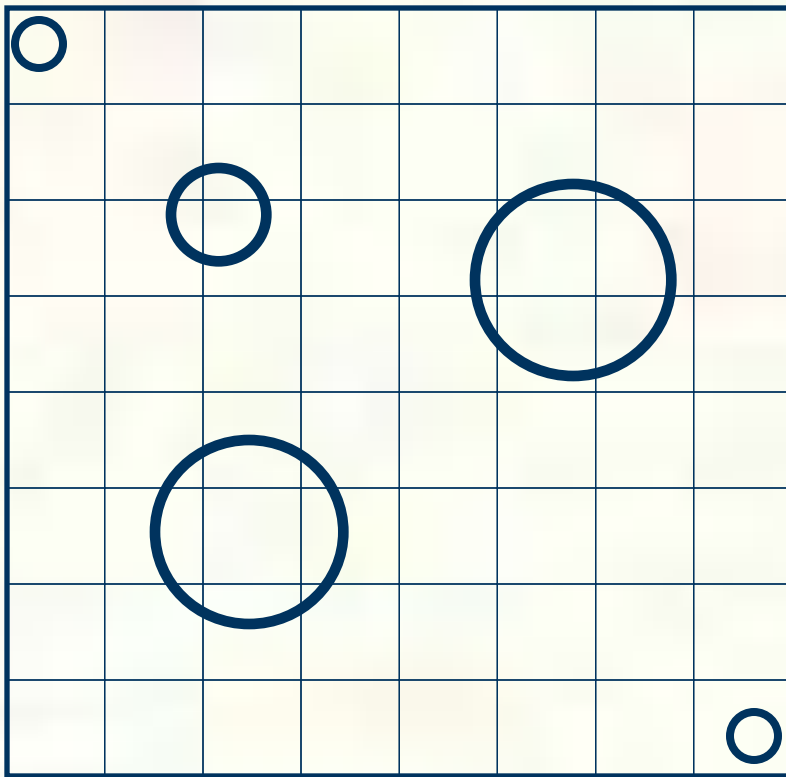
Uniform Grids



- Preprocess scene
 - Find bounding box



Uniform Grids



- Preprocess scene

- Find bounding box

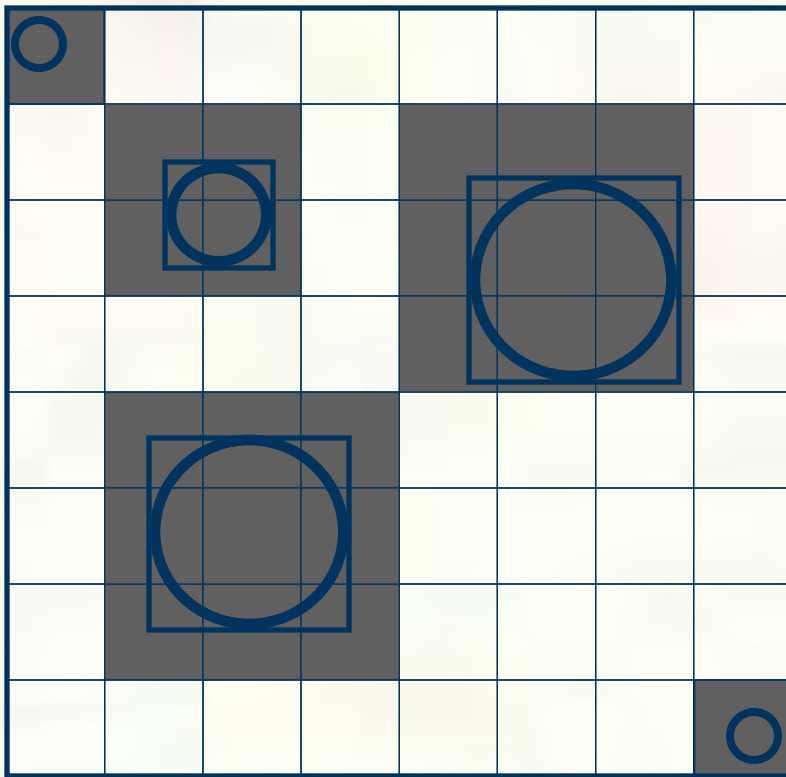
- Determine resolution

$$n_v = n_x n_y n_z \propto n_o$$

$$\max(n_x, n_y, n_z) = d \sqrt[3]{n_o}$$



Uniform Grids

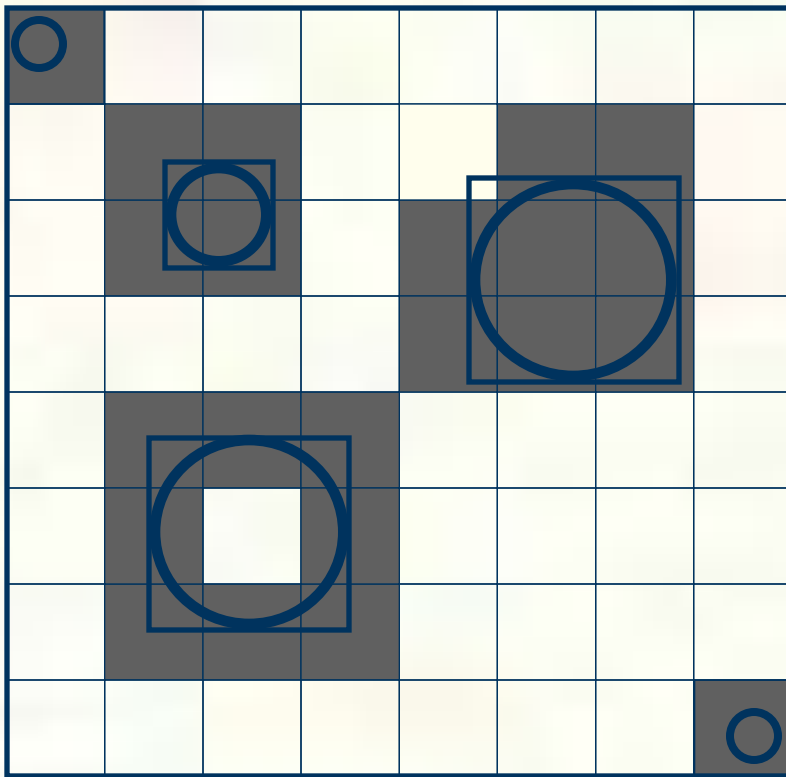


- Preprocess scene
 - Find bounding box
 - Determine resolution
 - Place object in cell, if object overlaps cell

$$\max(n_x, n_y, n_z) = d \sqrt[3]{n_o}$$



Uniform Grids

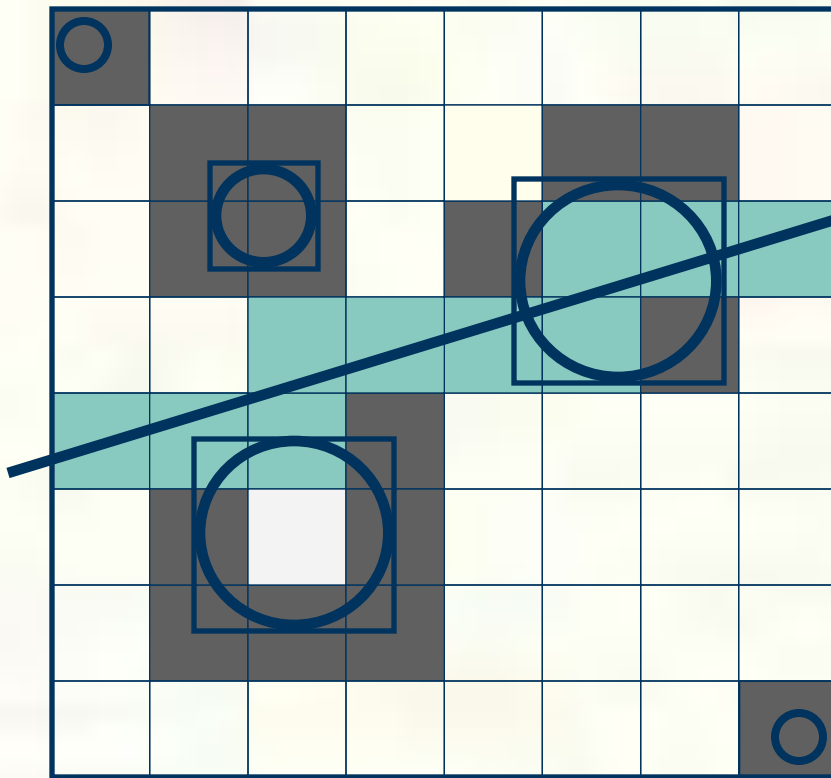


- Preprocess scene
 - Find bounding box
 - Determine resolution
 - Place object in cell, if object overlaps cell
 - Check that object intersects cell

$$\max(n_x, n_y, n_z) = d \sqrt[3]{n_o}$$



Uniform Grids

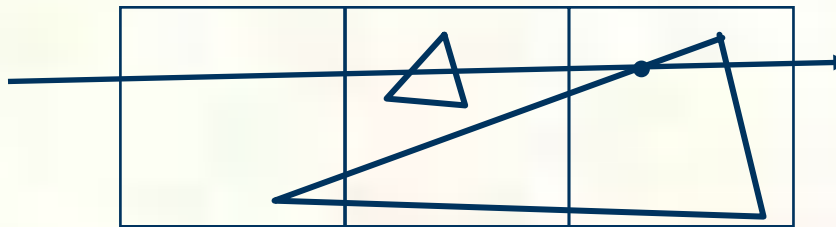


- Preprocess scene
- Traverse grid
 - 3D line – 3D-DDA
 - 6-connected line



Caveat: Overlap

- *Optimize for objects that overlap multiple cells*

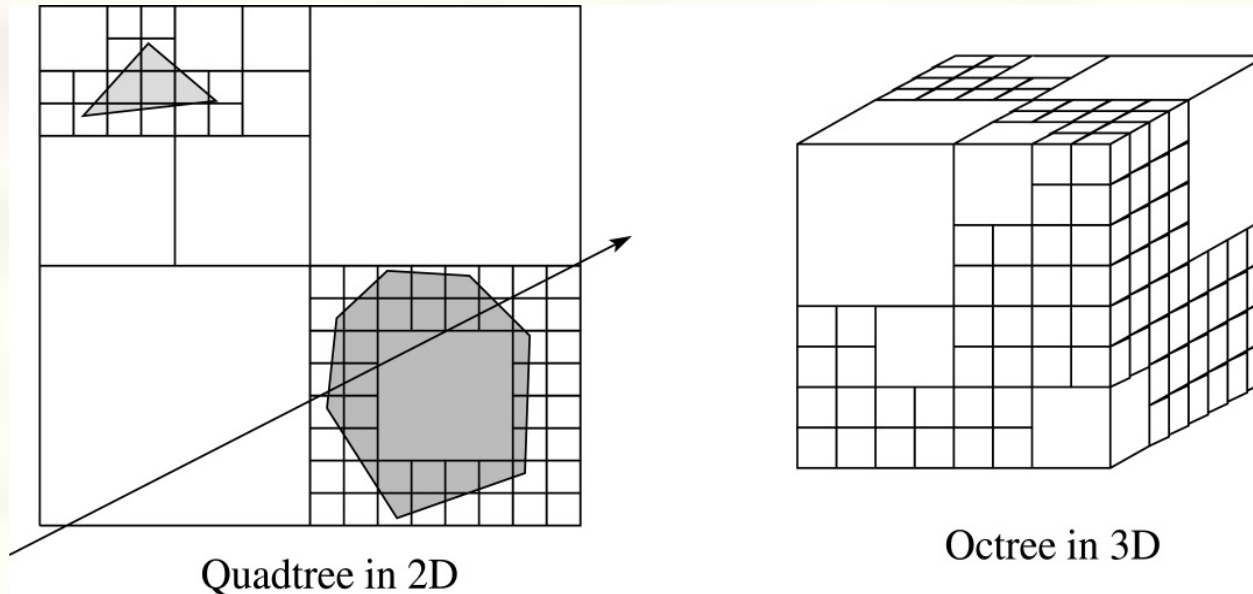


- Traverse until $t_{\min}(\text{cell}) > t_{\max}(\text{ray})$
- Problem: Redundant intersection tests:
- Solution: Mailboxes
 - Assign each ray an increasing number
 - Primitive intersection cache (mailbox)
 - Store last ray number tested in mailbox
 - Only intersect if ray number is greater



Non-uniform spatial subdivision

- Still another approach is **non-uniform spatial subdivision**.



- Other variants include k-d trees and BSP trees.
- Various combinations of these ray intersections techniques are also possible. See Glassner and pointers at bottom of project web page for more.

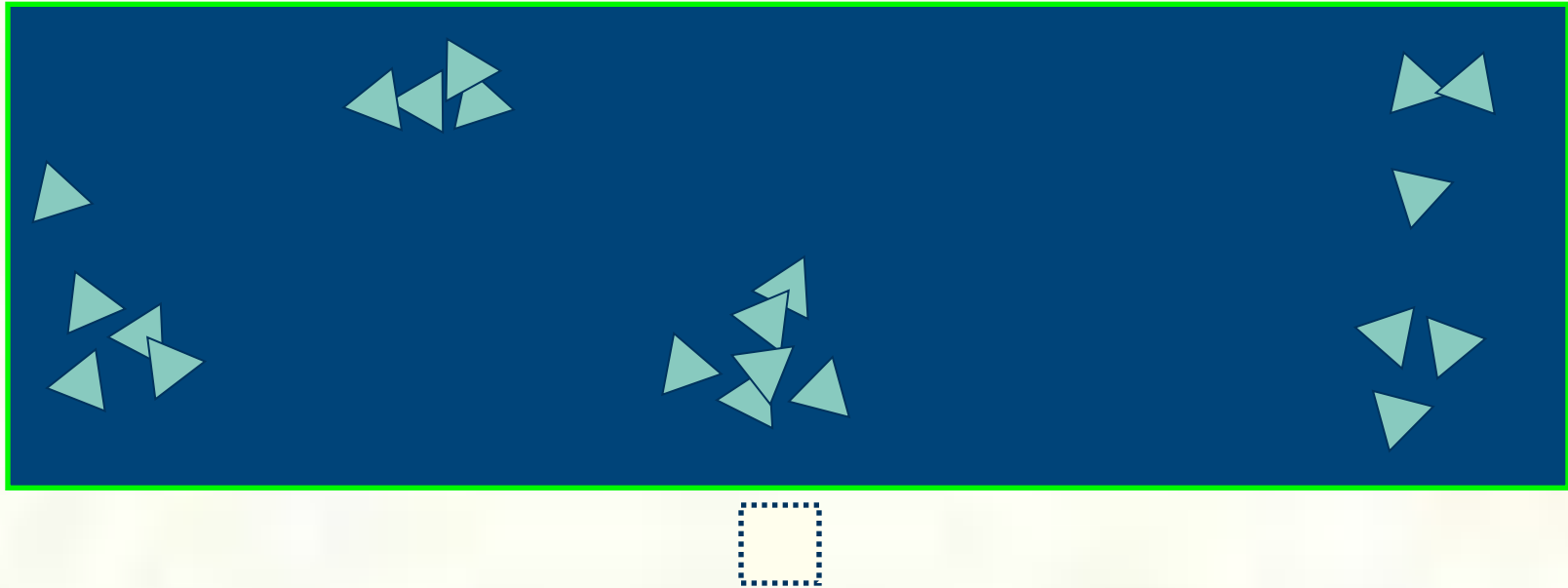


Non-uniform spatial subdivision

- Best partitioning approach - k-d trees or perhaps BSP trees
 - More adaptive to actual scene structure
 - BSP vs. k-d tradeoff between speed from simplicity and better adaptability
- Non-partitioning approach
 - Hierarchical bounding volumes
 - Build similar to k-d tree build

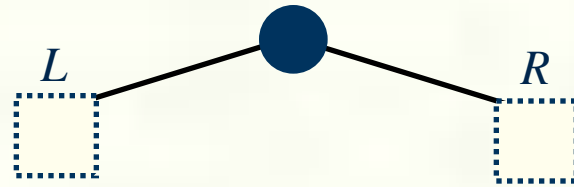
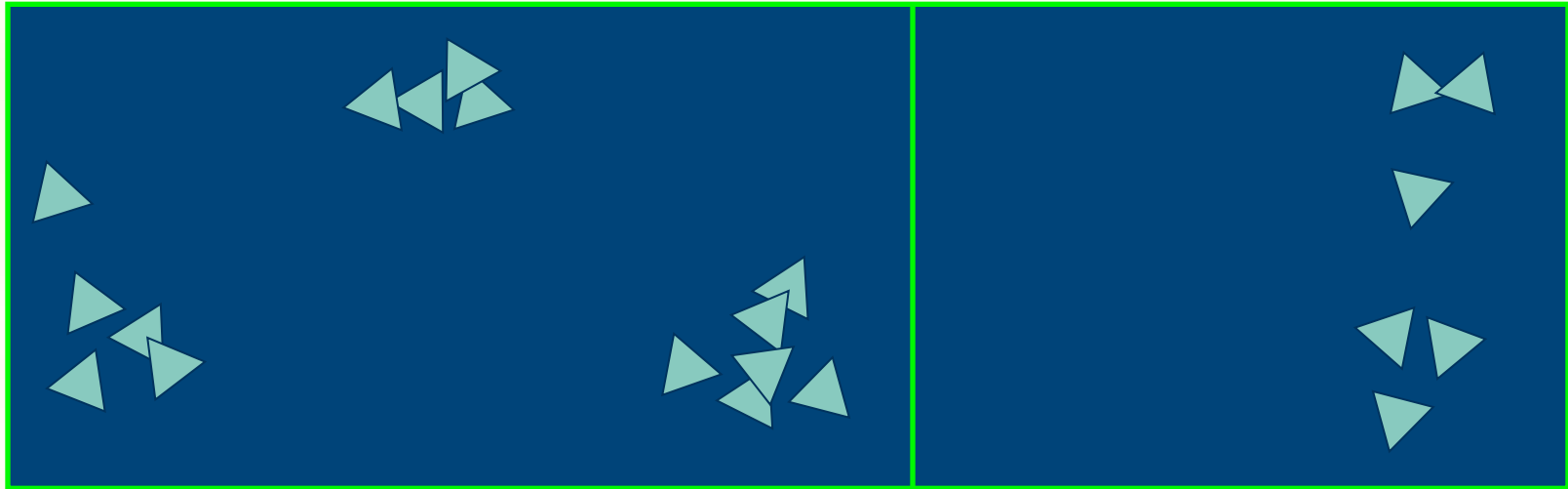


Kd-tree - Build



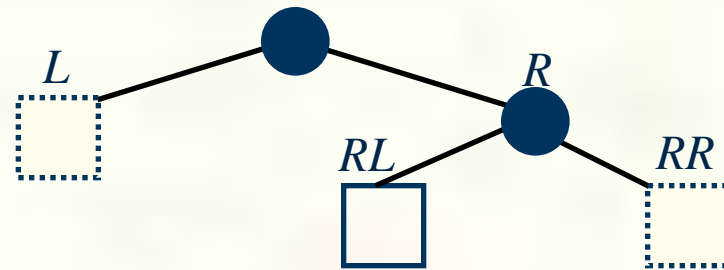
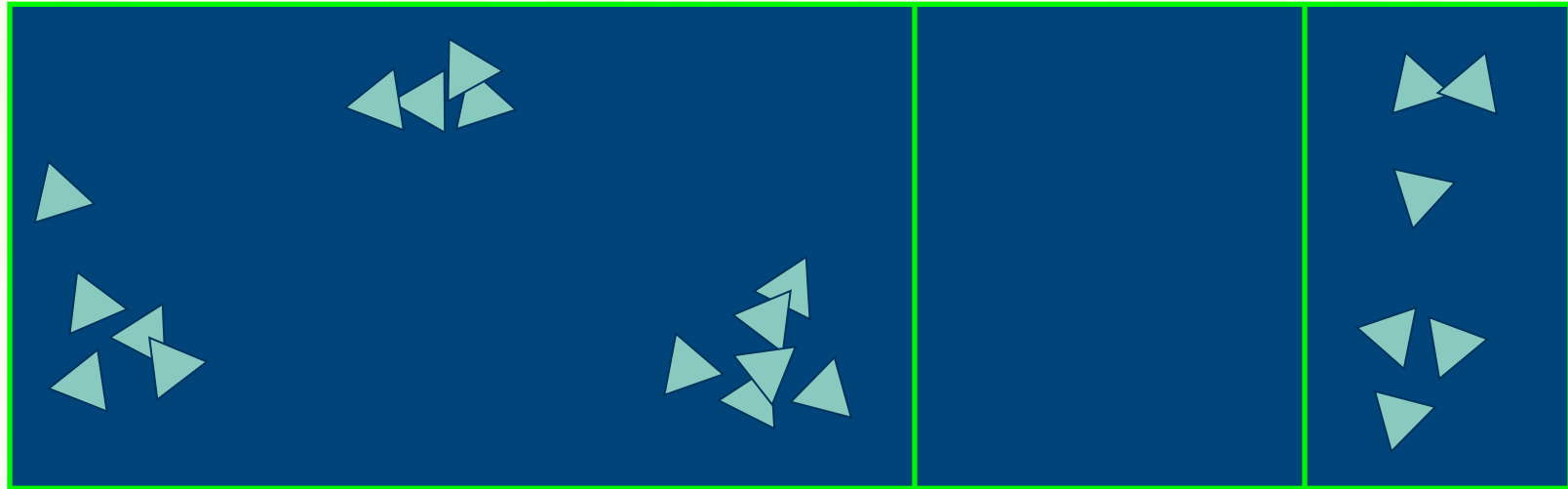


Kd-tree



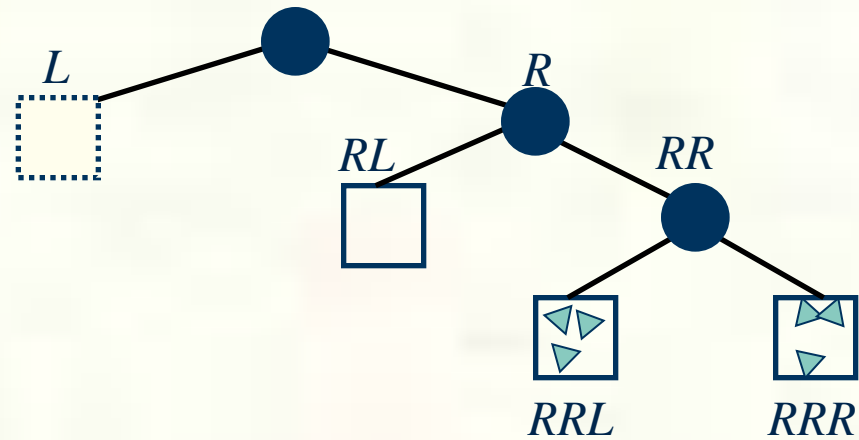
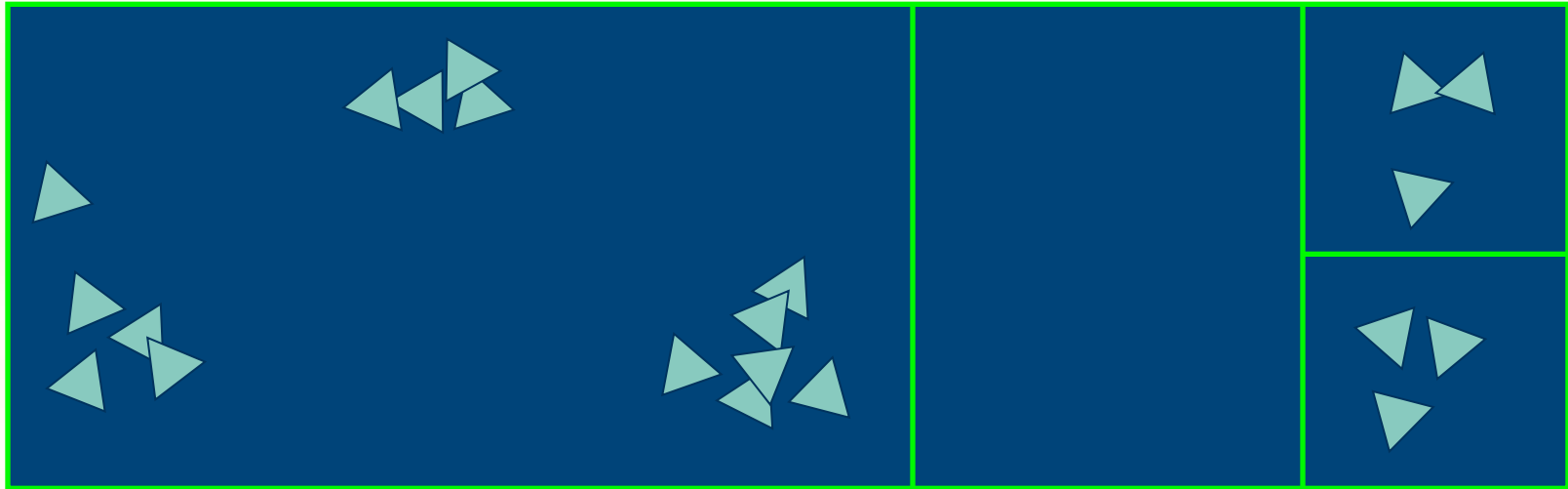


Kd-tree



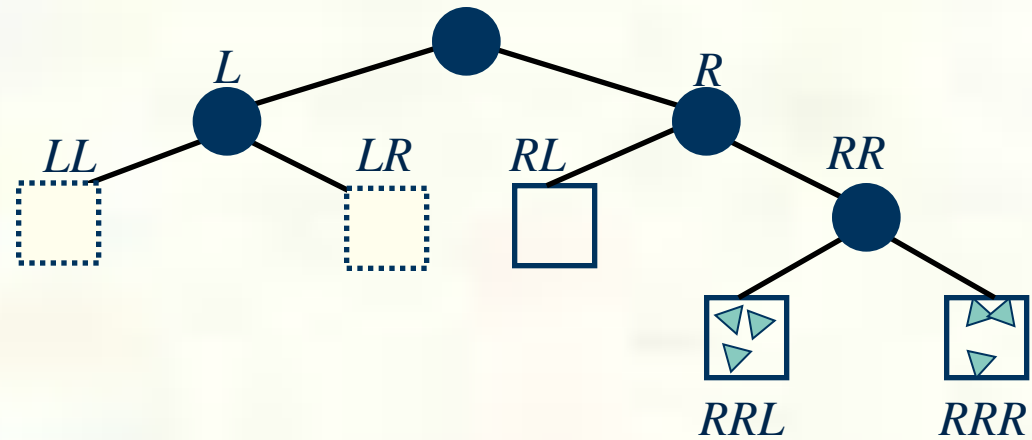
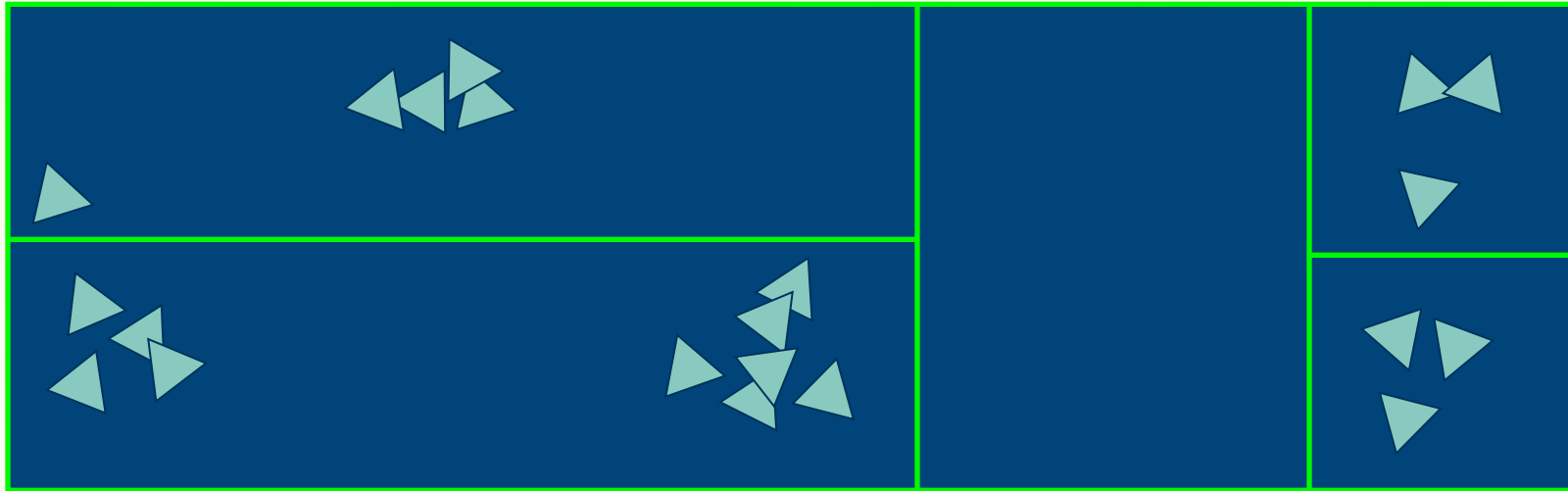


Kd-tree



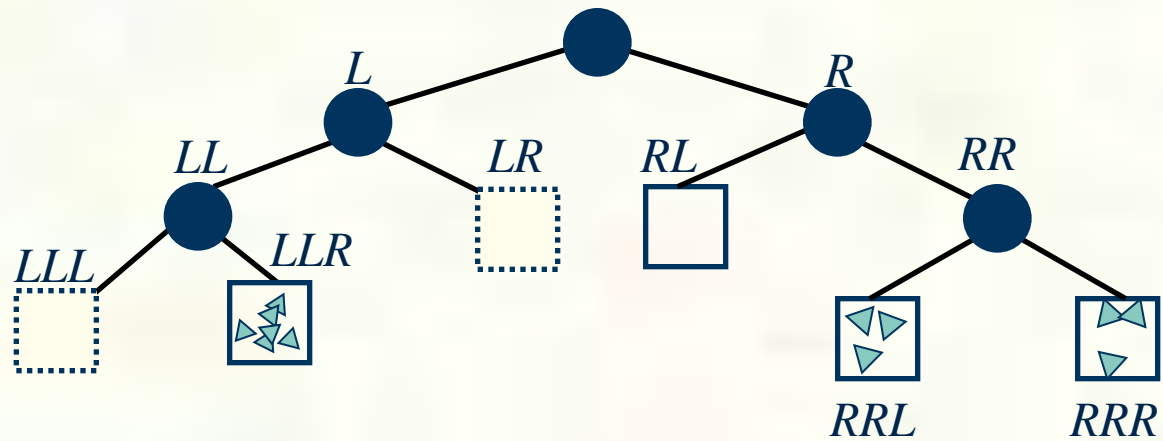
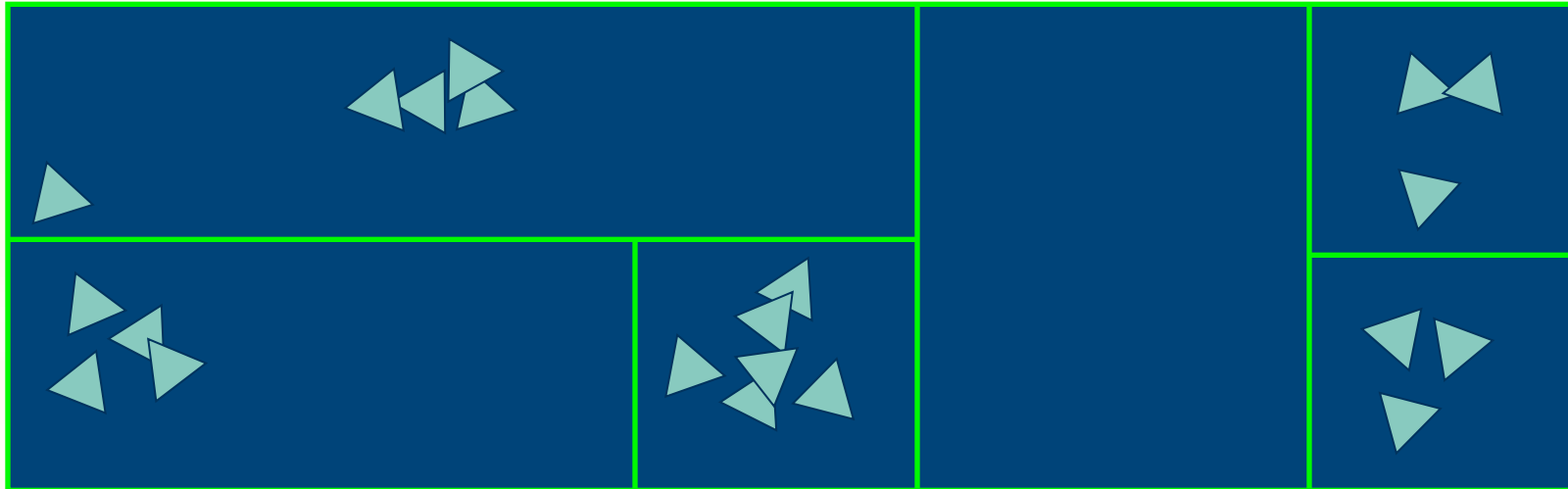


Kd-tree



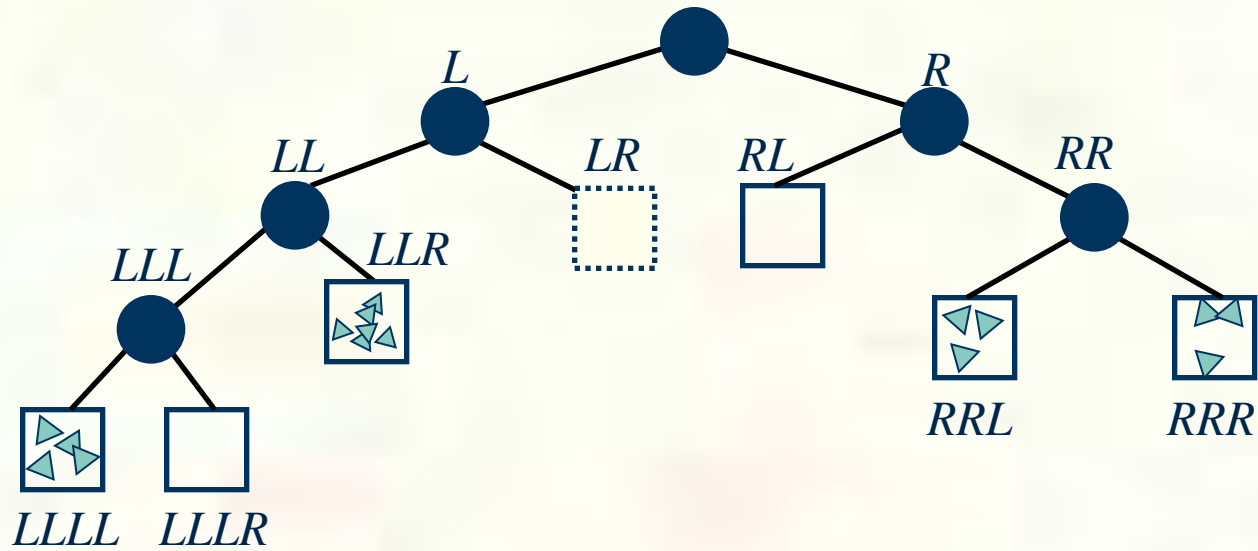
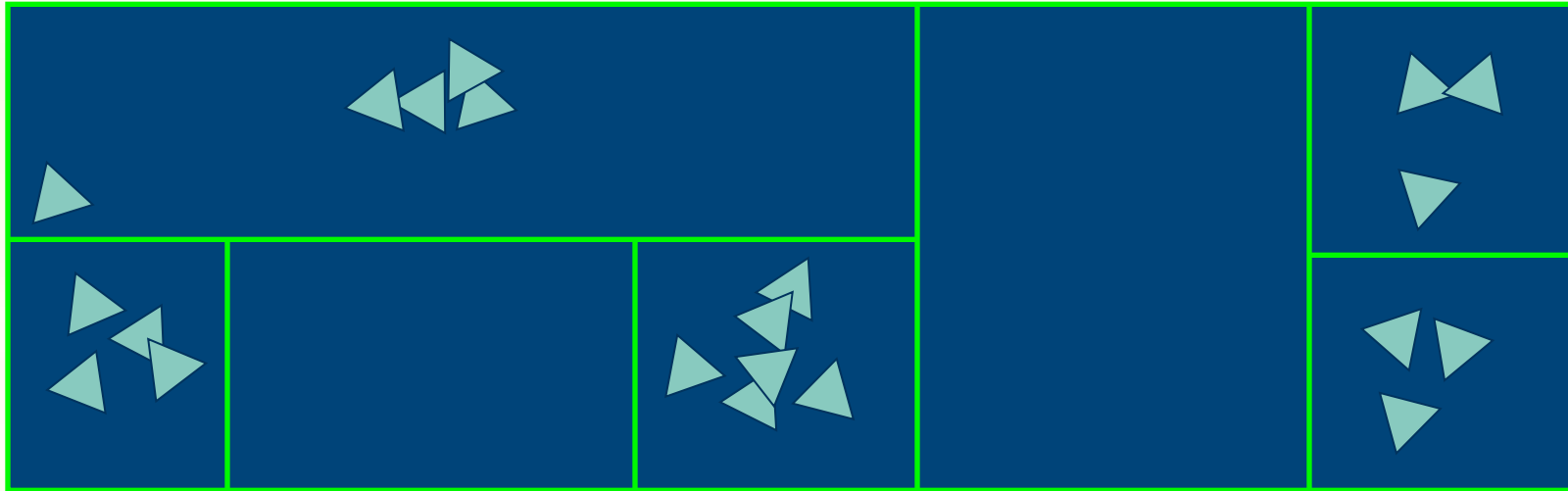


Kd-tree



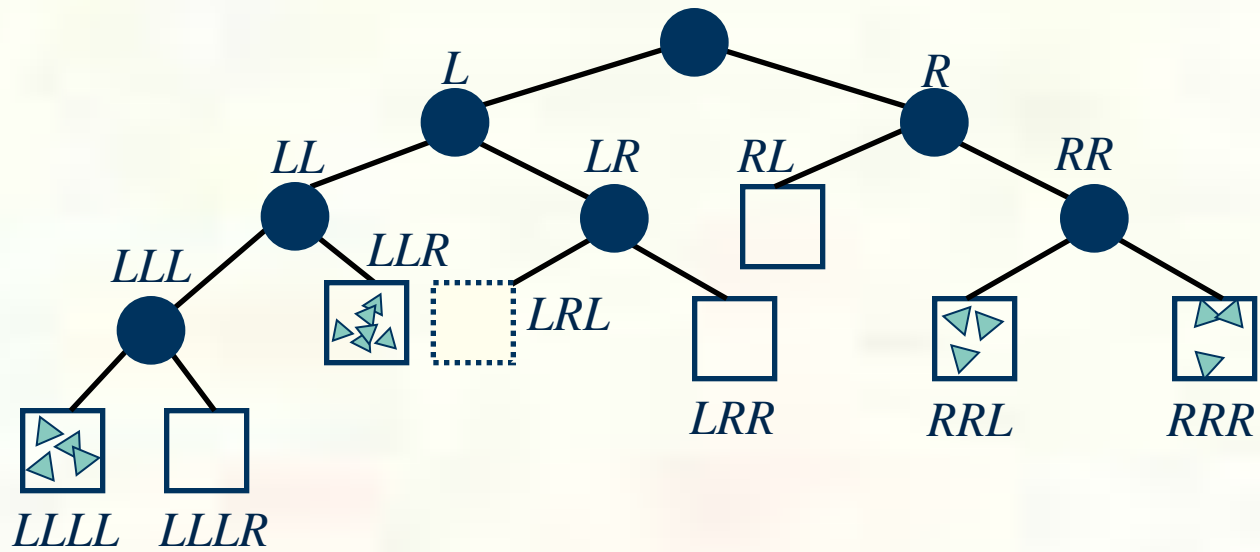
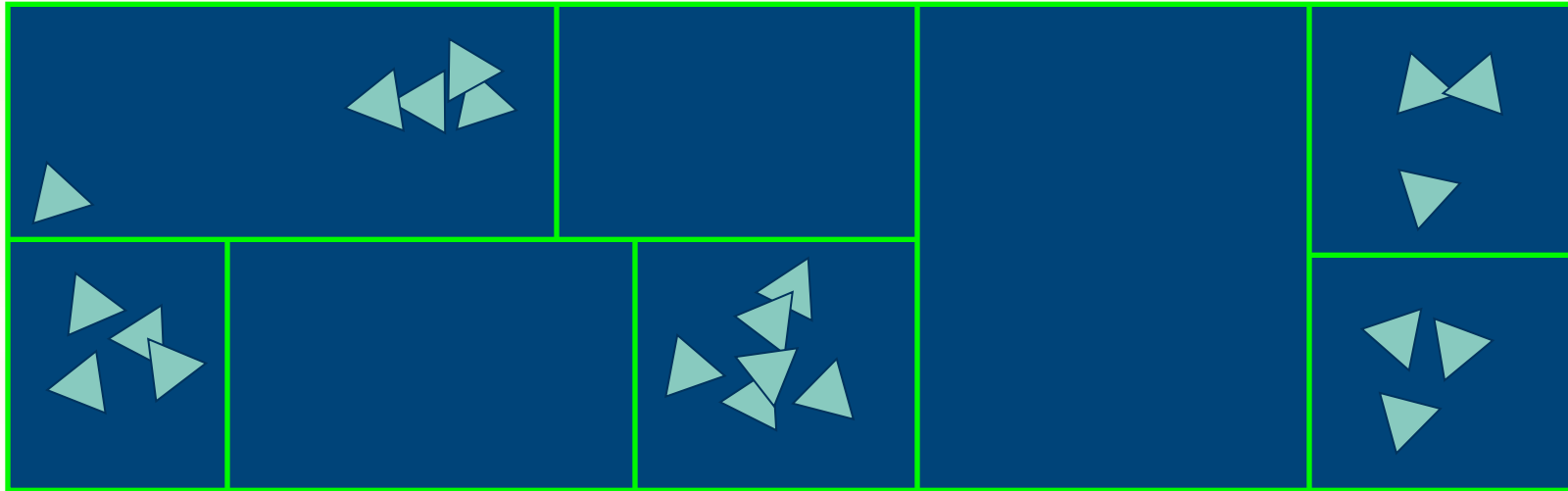


Kd-tree



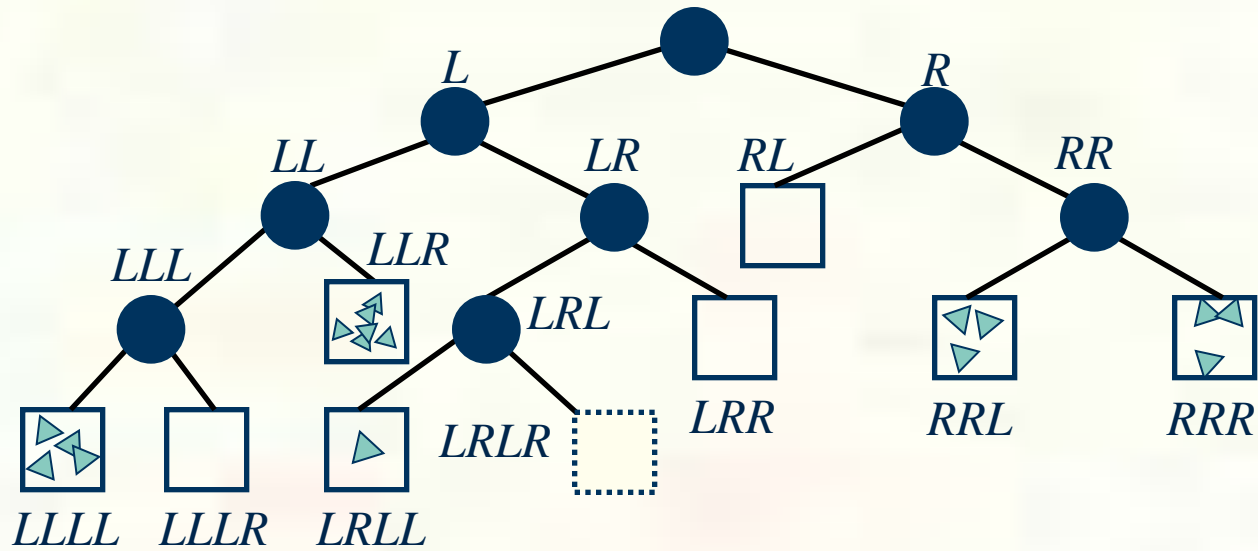
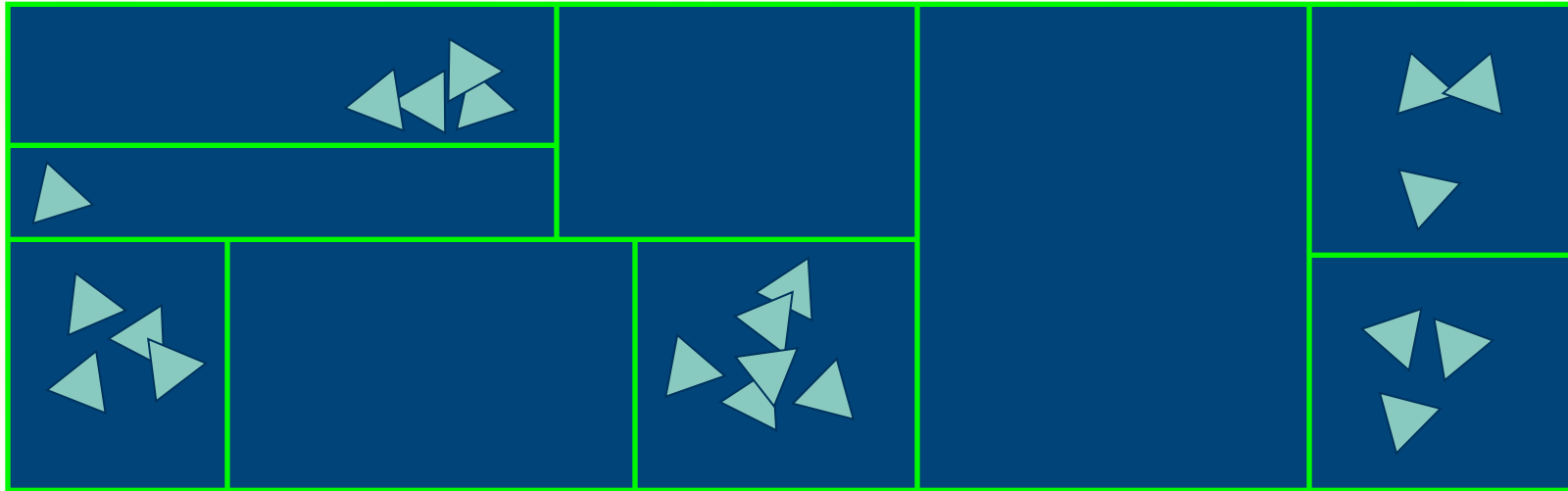


Kd-tree



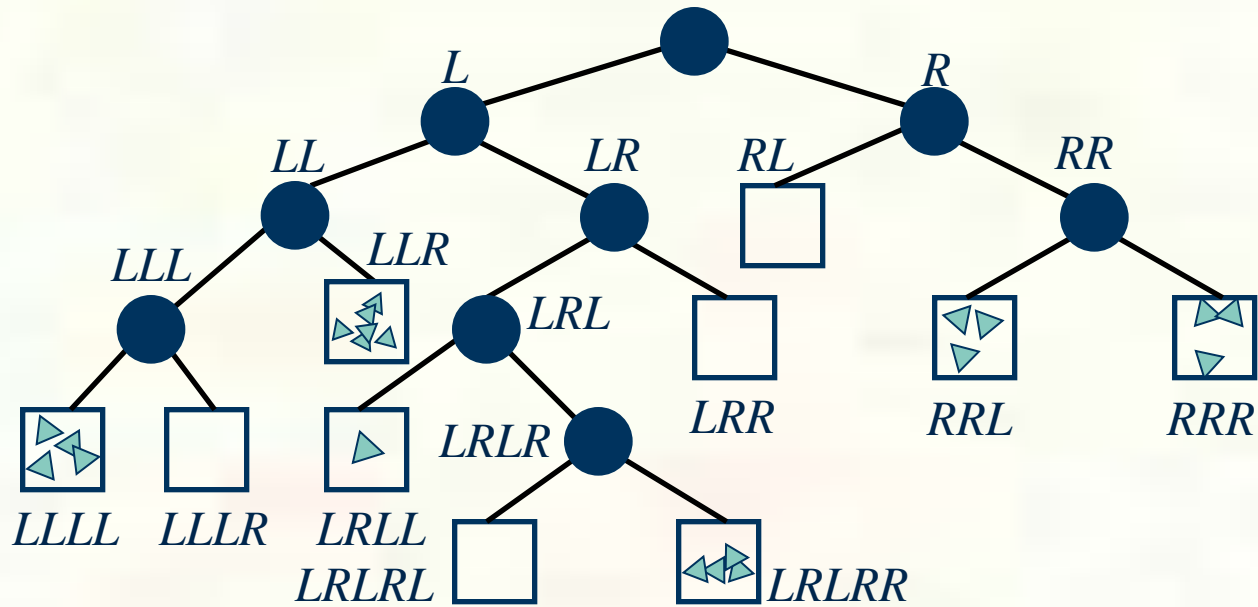
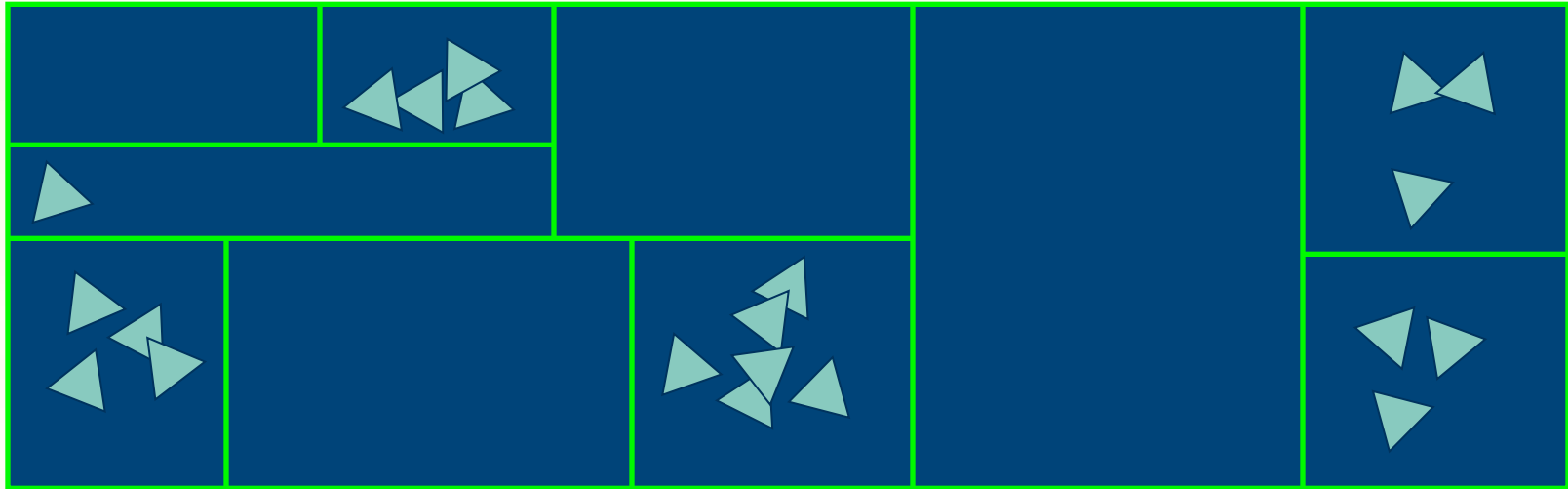


Kd-tree





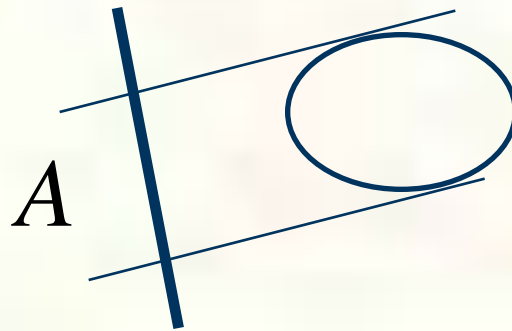
Kd-tree





Surface Area and Rays

- Number of rays in a given direction that hit an
- object is proportional to its projected area



- The total number of rays hitting an object is

$$4\pi \bar{A}$$

- Crofton's Theorem:
 - For a convex body

$$\bar{A} = \frac{S}{4}$$

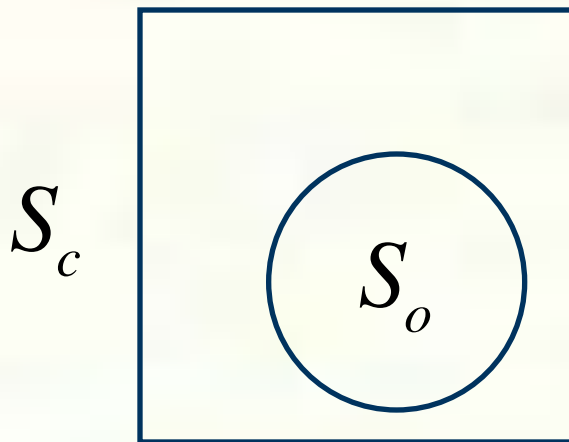
- For example: sphere

$$S = 4\pi r^2 \quad \bar{A} = A = \pi r^2$$



Surface Area and Rays

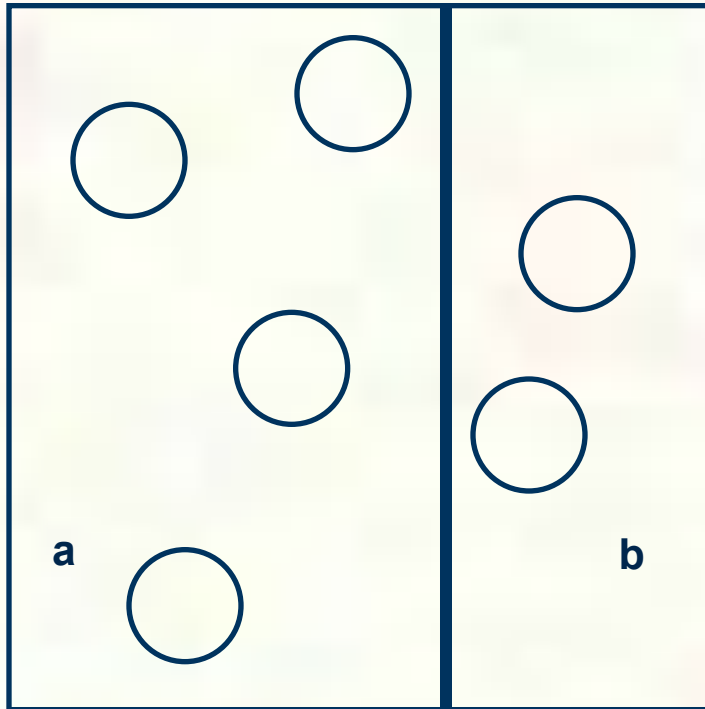
- The probability of a ray hitting a convex shape
- that is completely inside a convex cell equals



$$\Pr[r \cap S_o | r \cap S_c] = \frac{S_o}{S_c}$$



Surface Area Heuristic



Intersection time

$$t_i$$

Traversal time

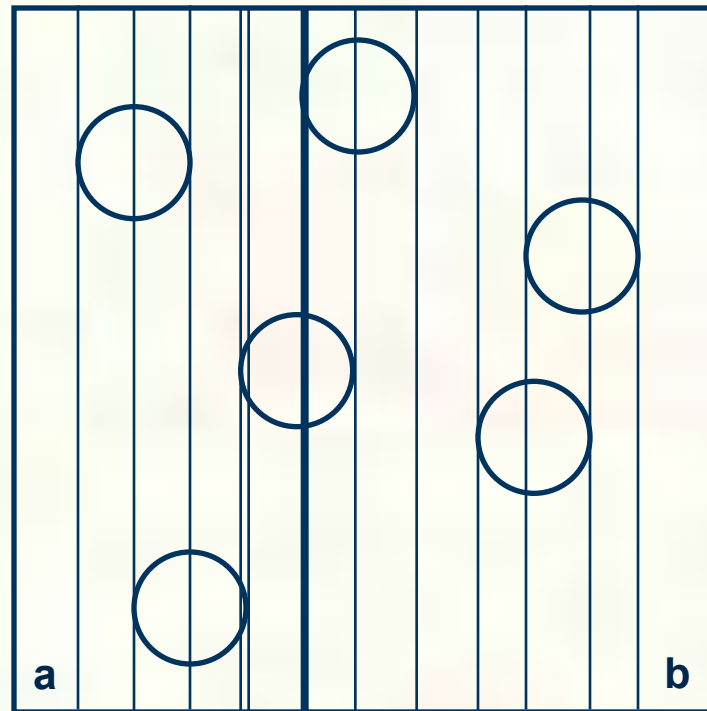
$$t_t$$

$$t_i = 80t_t$$

$$C = t_t + p_a N_a t_i + p_b N_b t_i$$



Surface Area Heuristic



2n splits

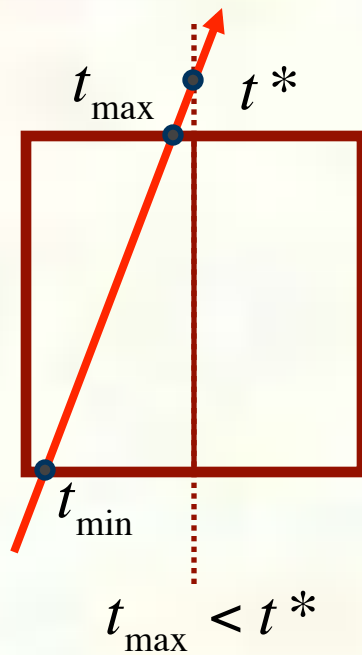
$$p_a = \frac{S_a}{S}$$

$$p_b = \frac{S_b}{S}$$

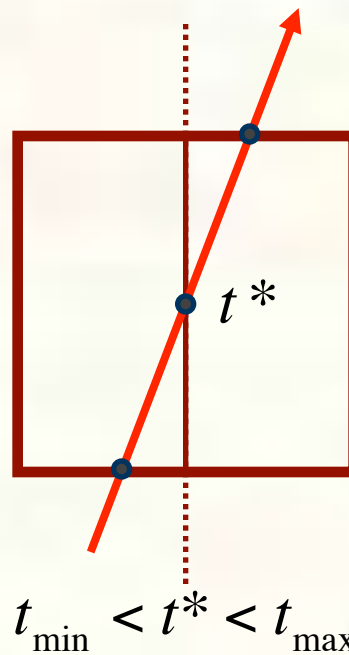


Ray Traversal Kernel

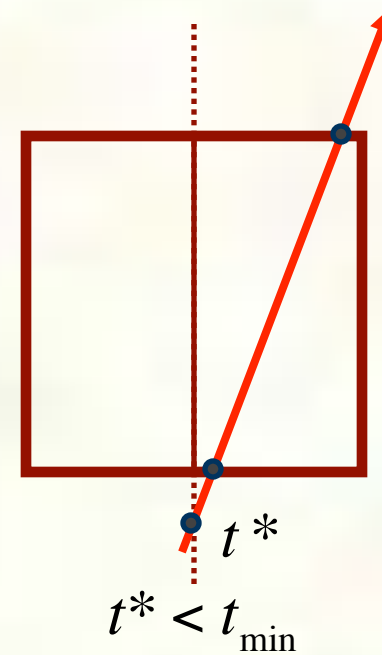
Depth first traversal



Intersect(L, t_{min}, t_{max})



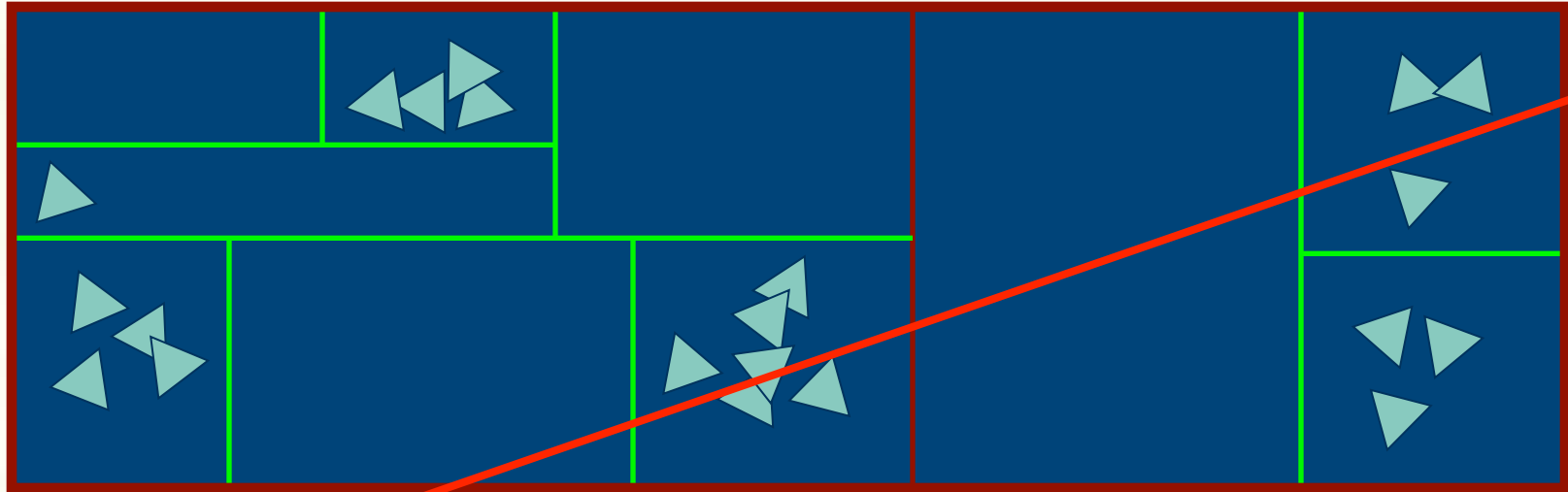
Intersect(L, t_{min}, t^{})*
Intersect(R, t^{}, t_{max})*



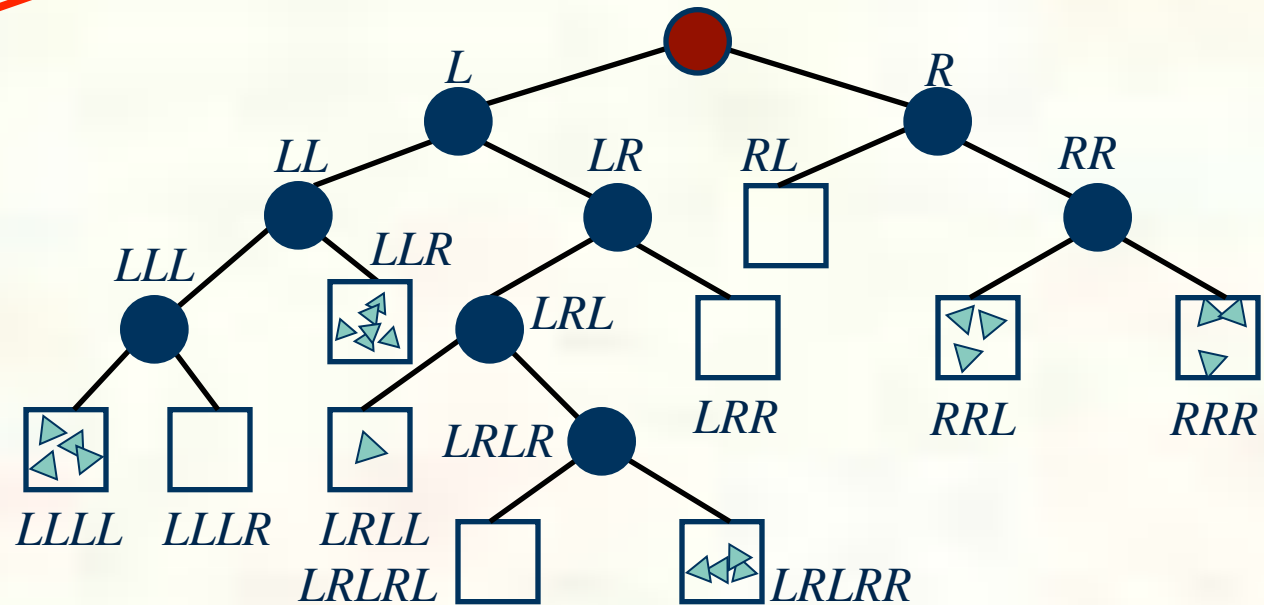
Intersect(R, t_{min}, t_{max})



Kd-tree - Traversal



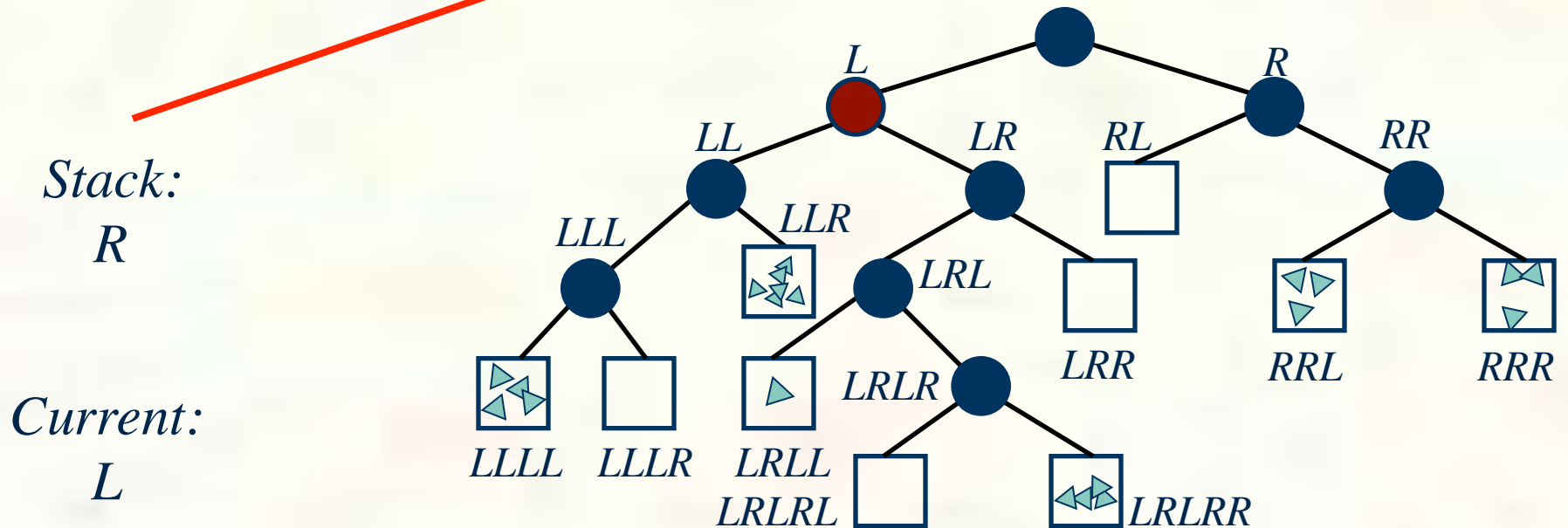
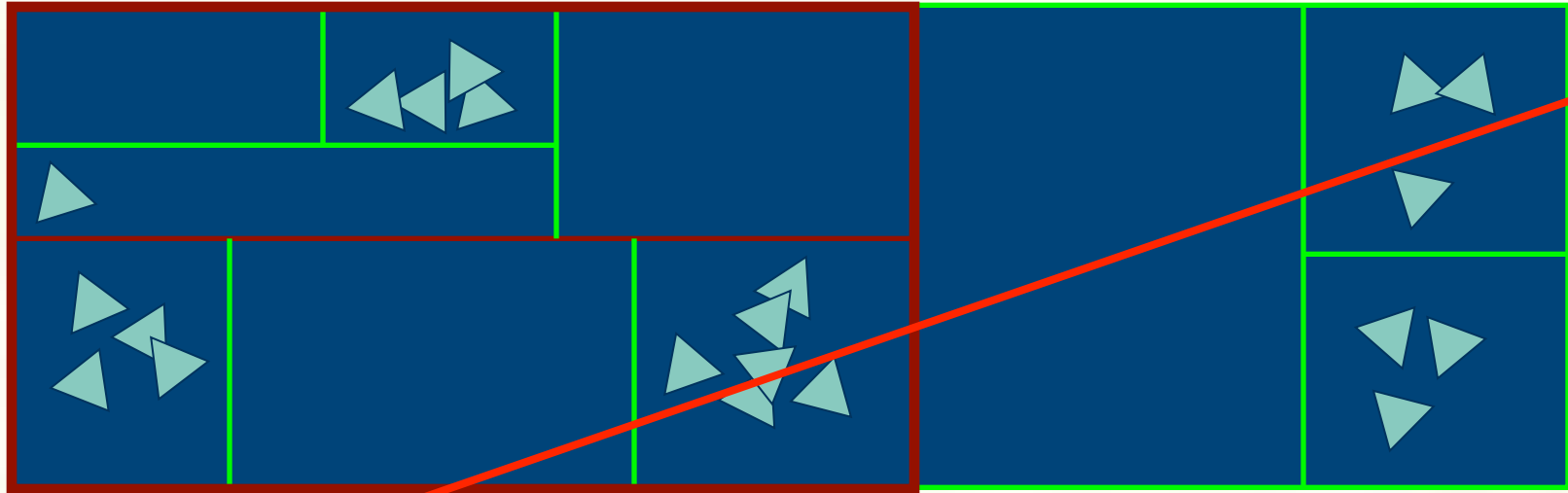
Stack:



Current:
Root

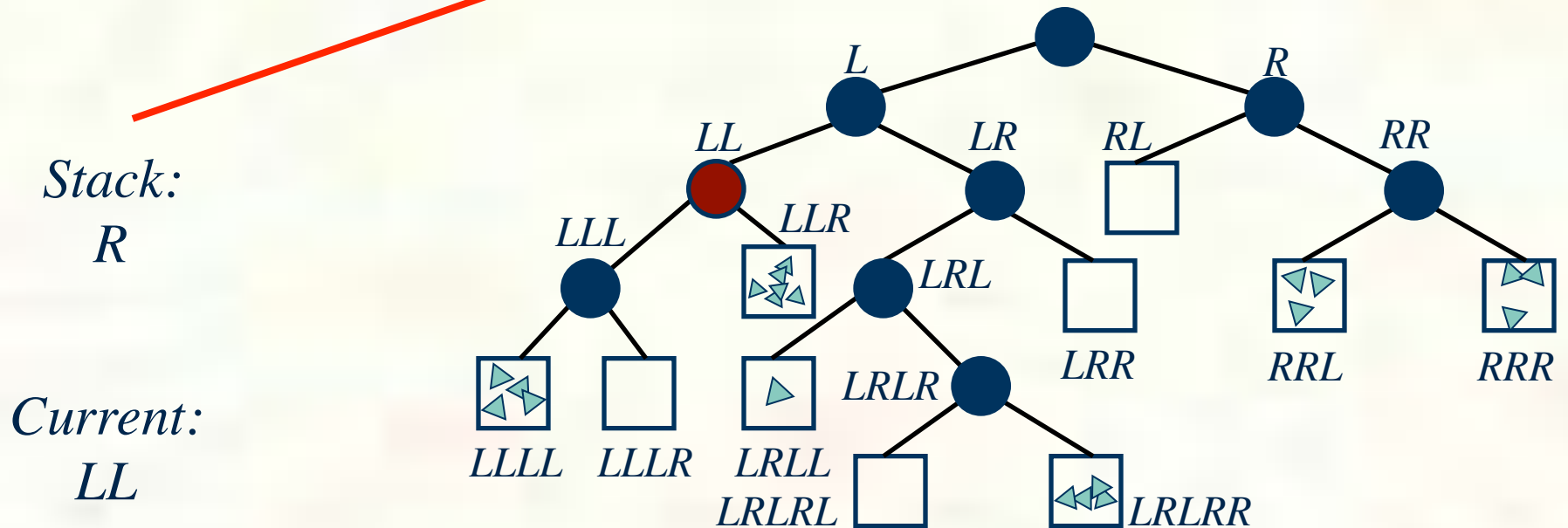
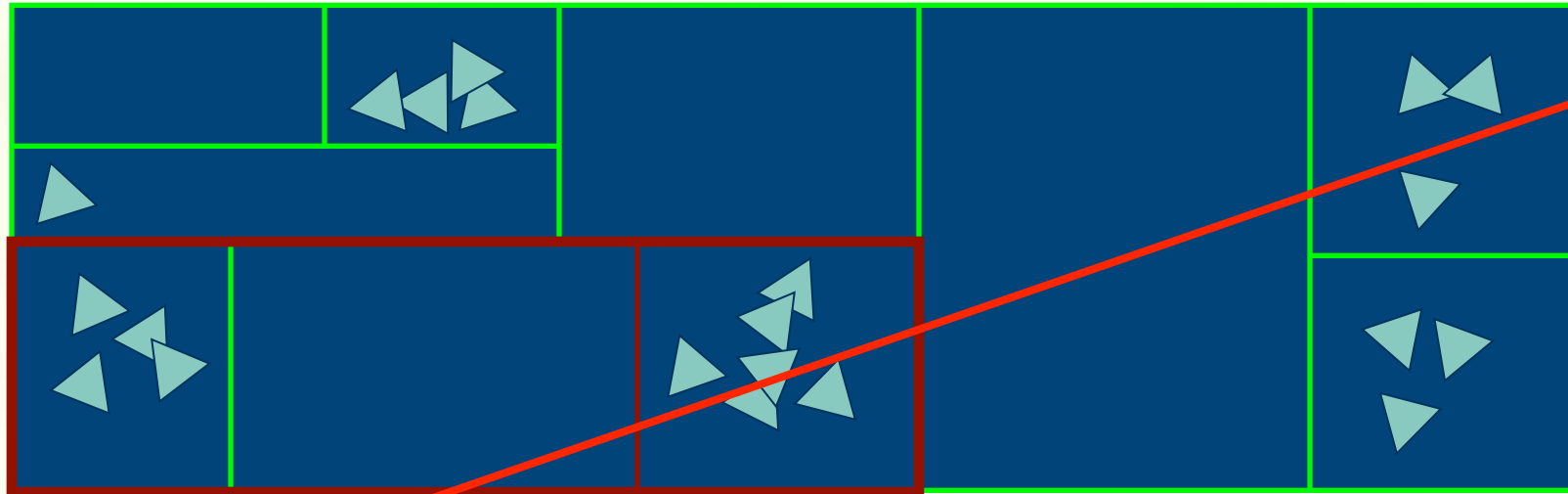


Kd-tree - Traversal



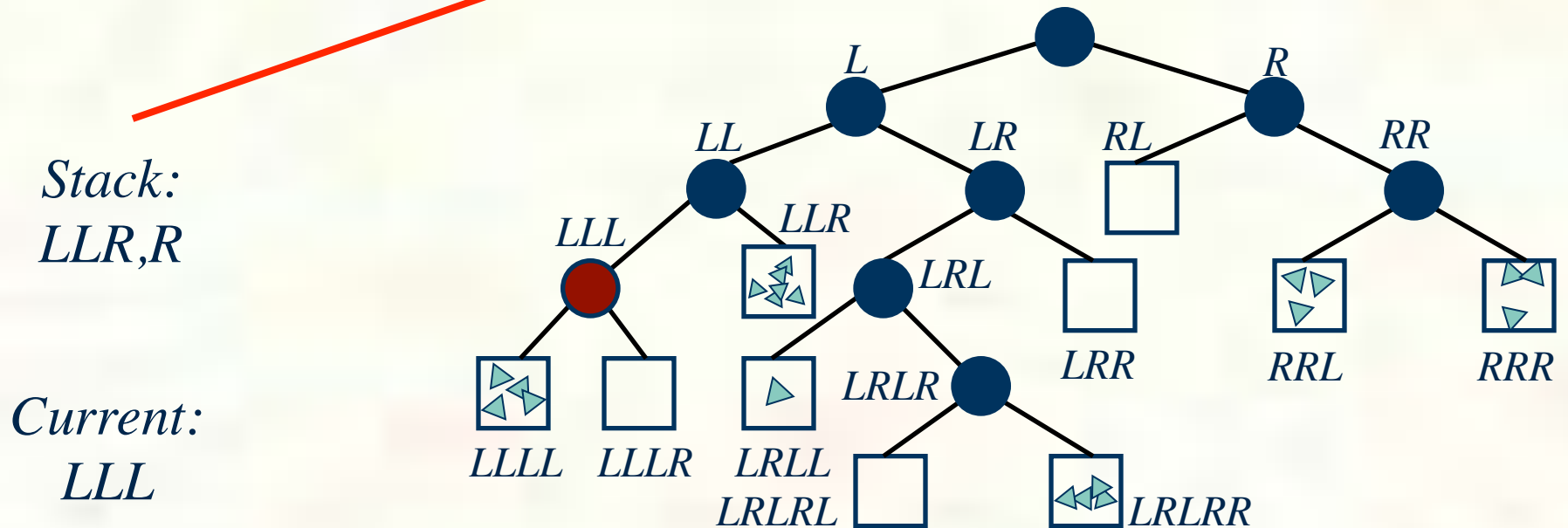
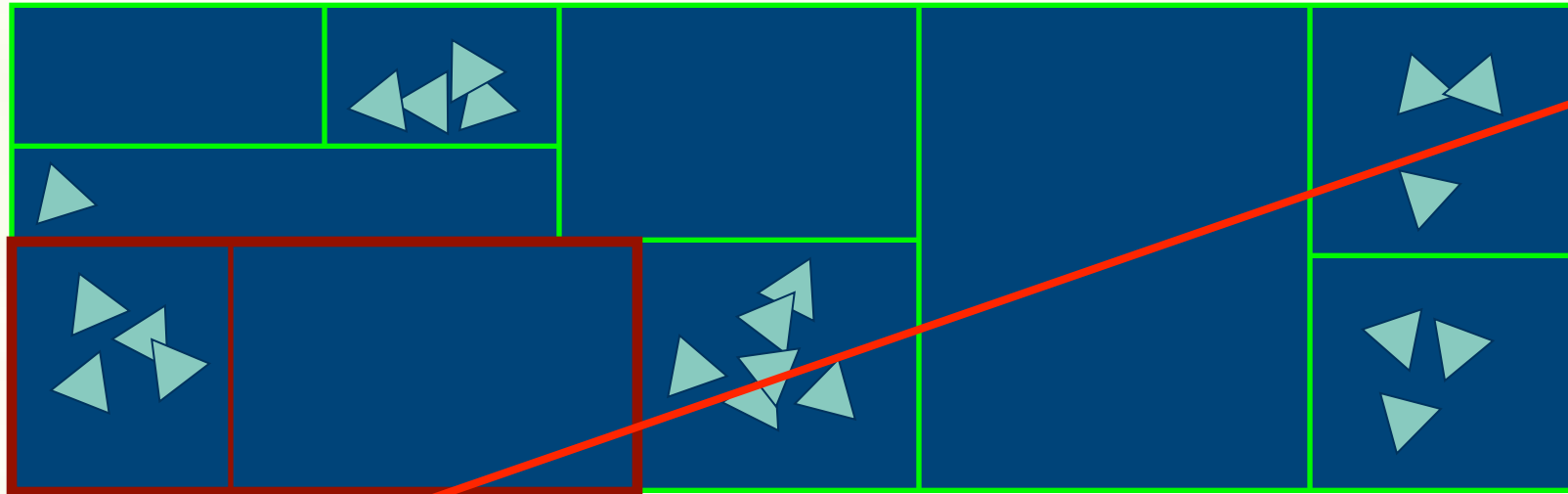


Kd-tree - Traversal



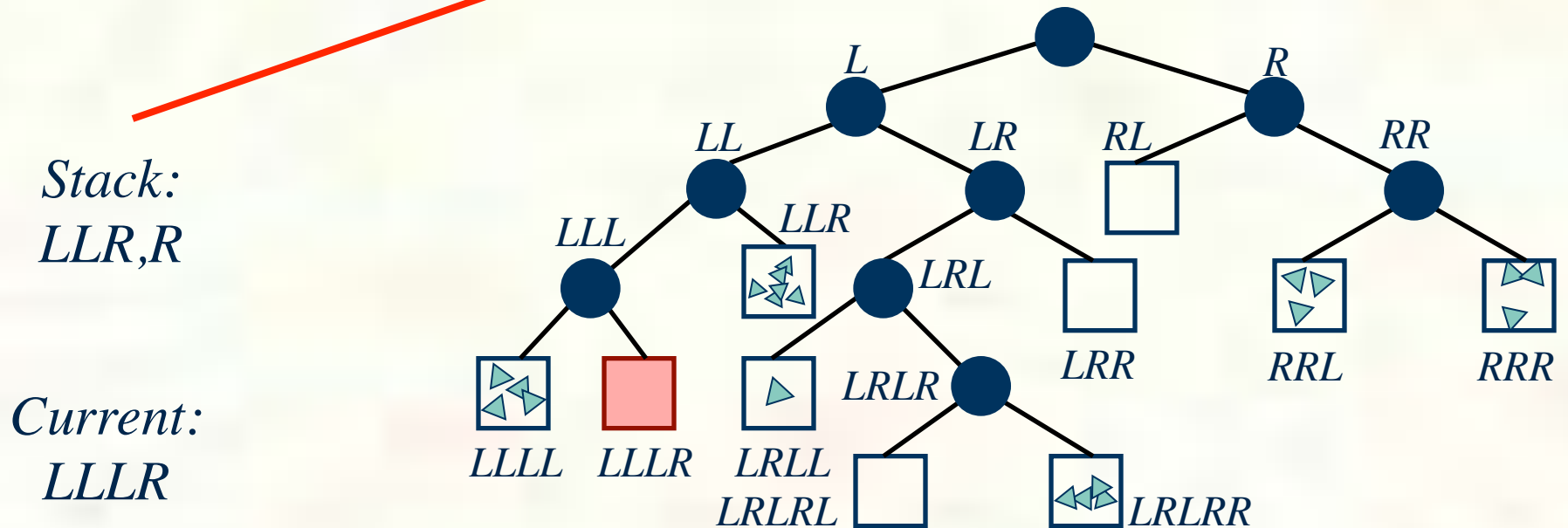
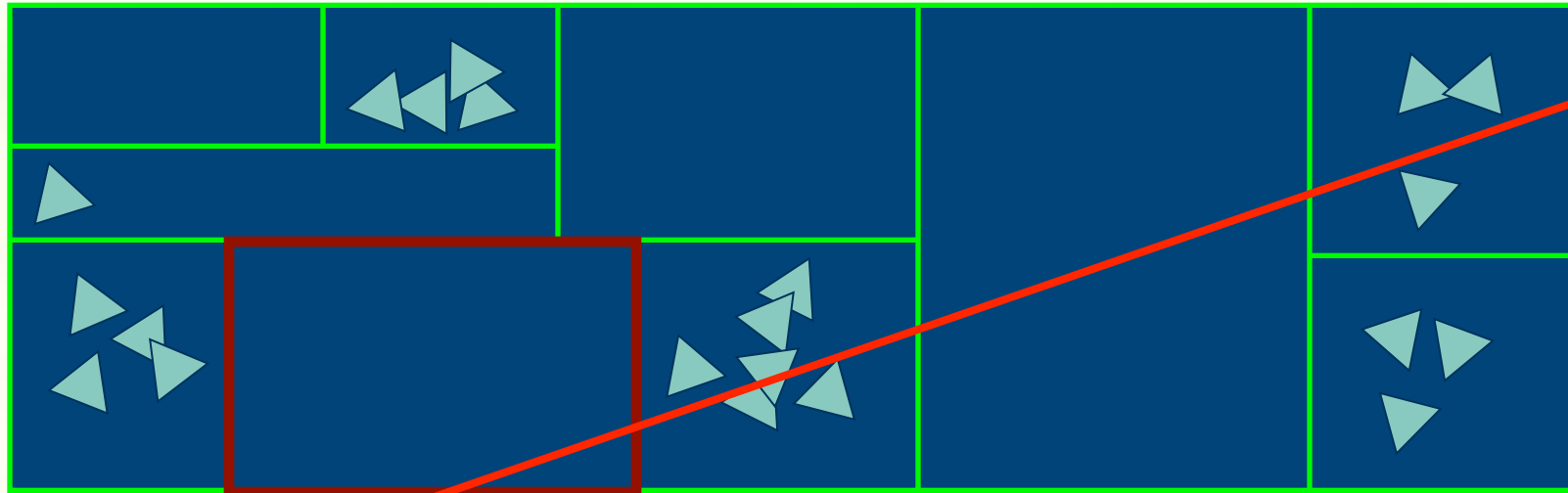


Kd-tree - Traversal





Kd-tree - Traversal

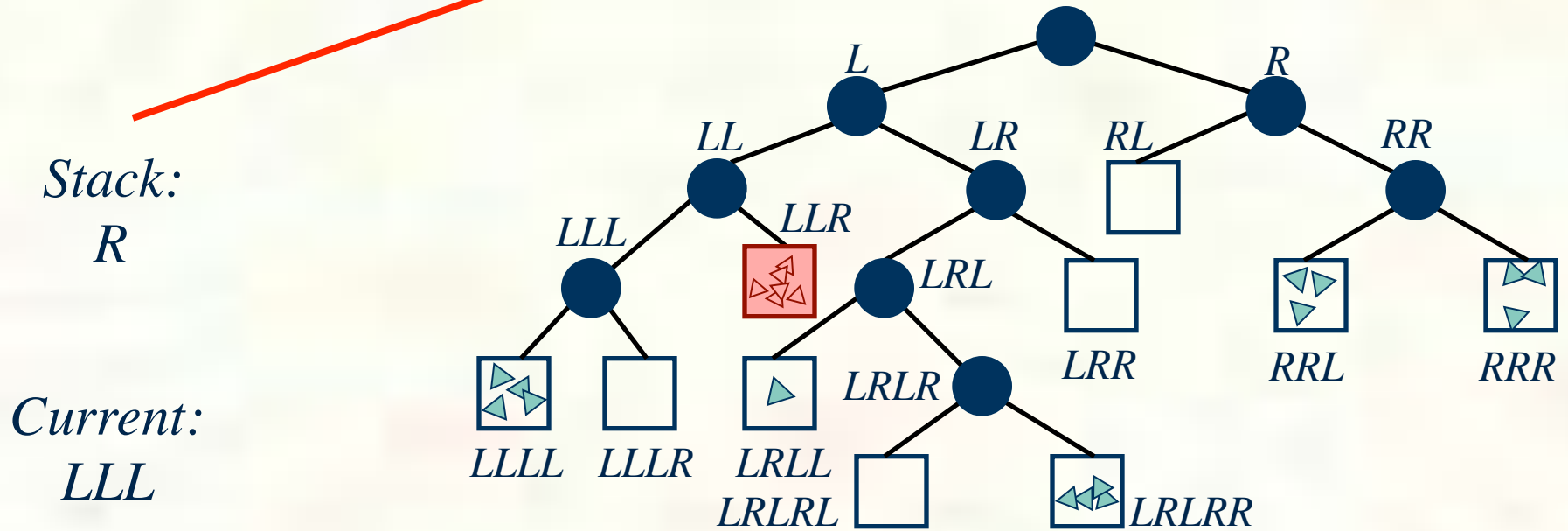
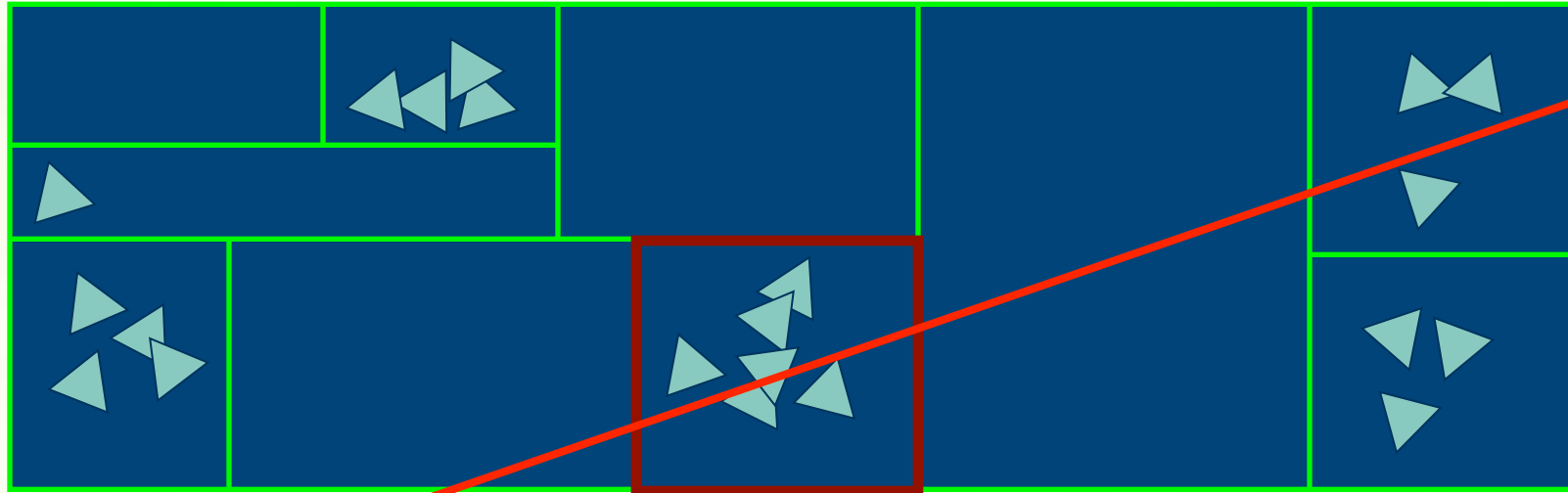


Stack:
LLR,R

Current:
LLL

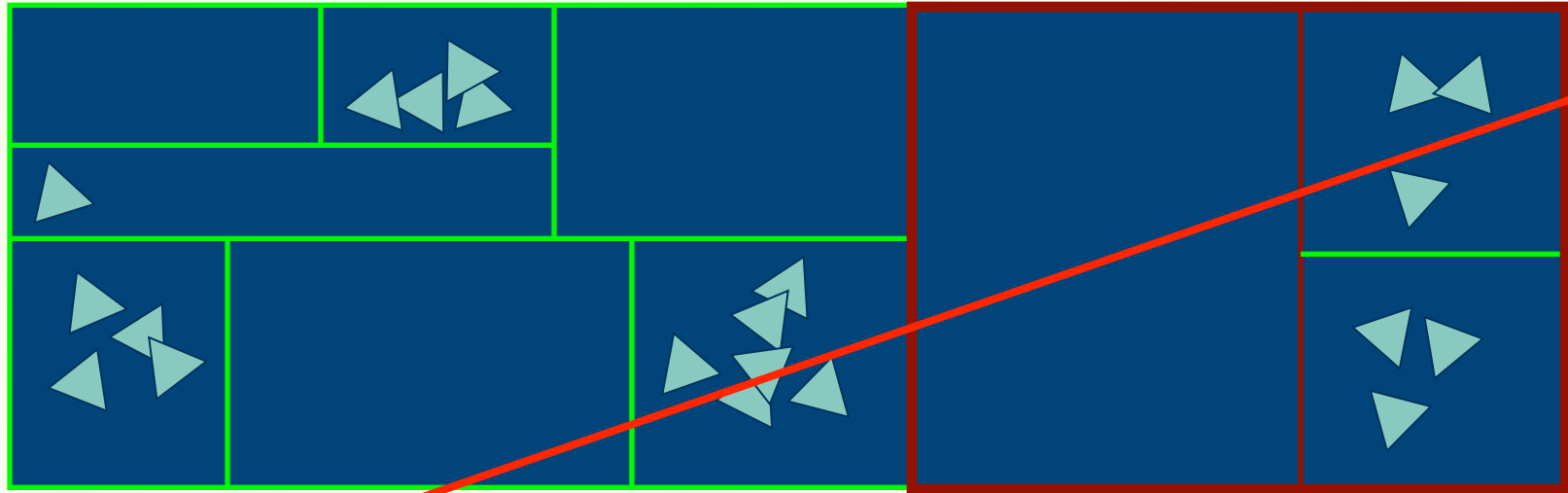


Kd-tree - Traversal

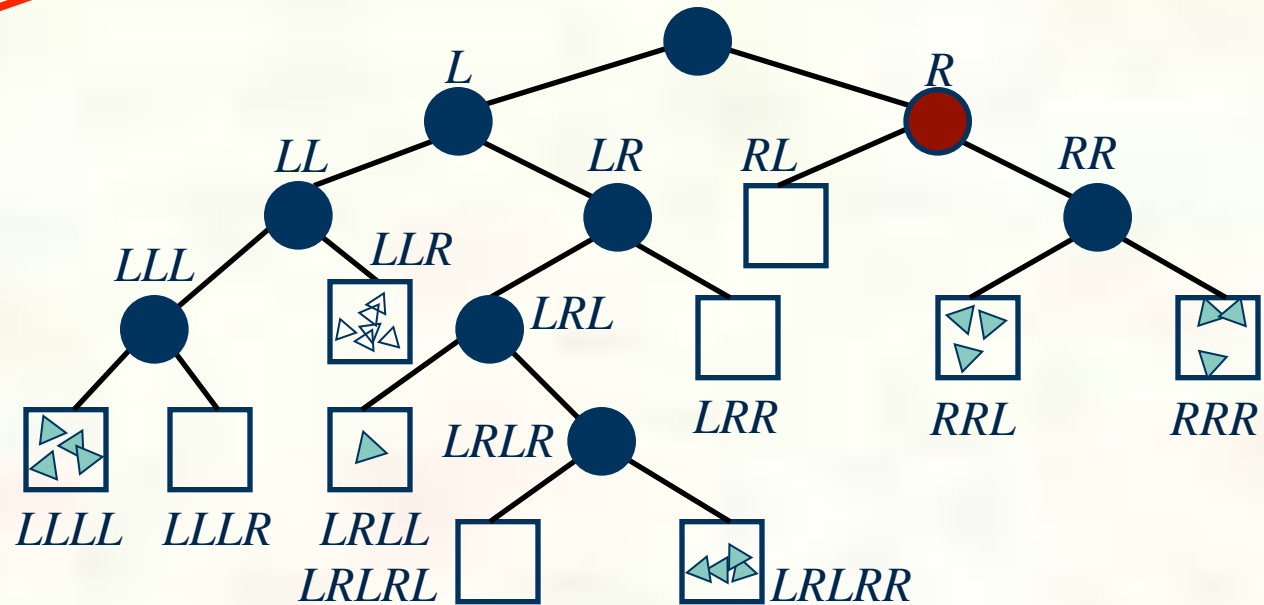




Kd-tree - Traversal



Stack:

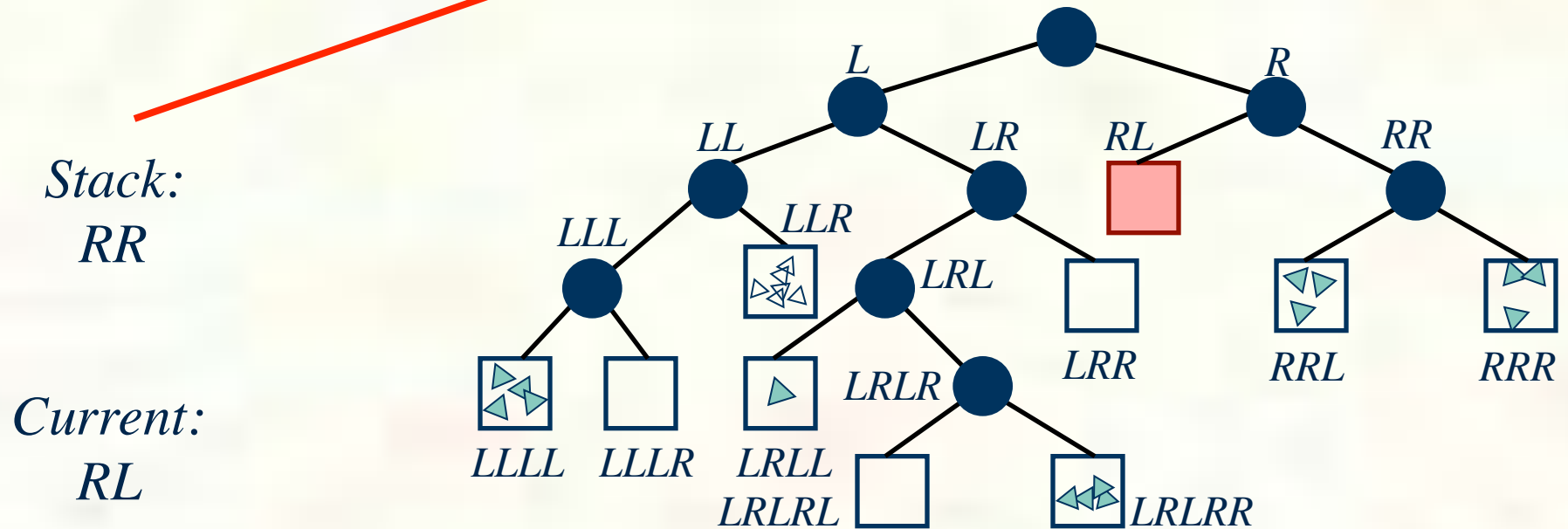
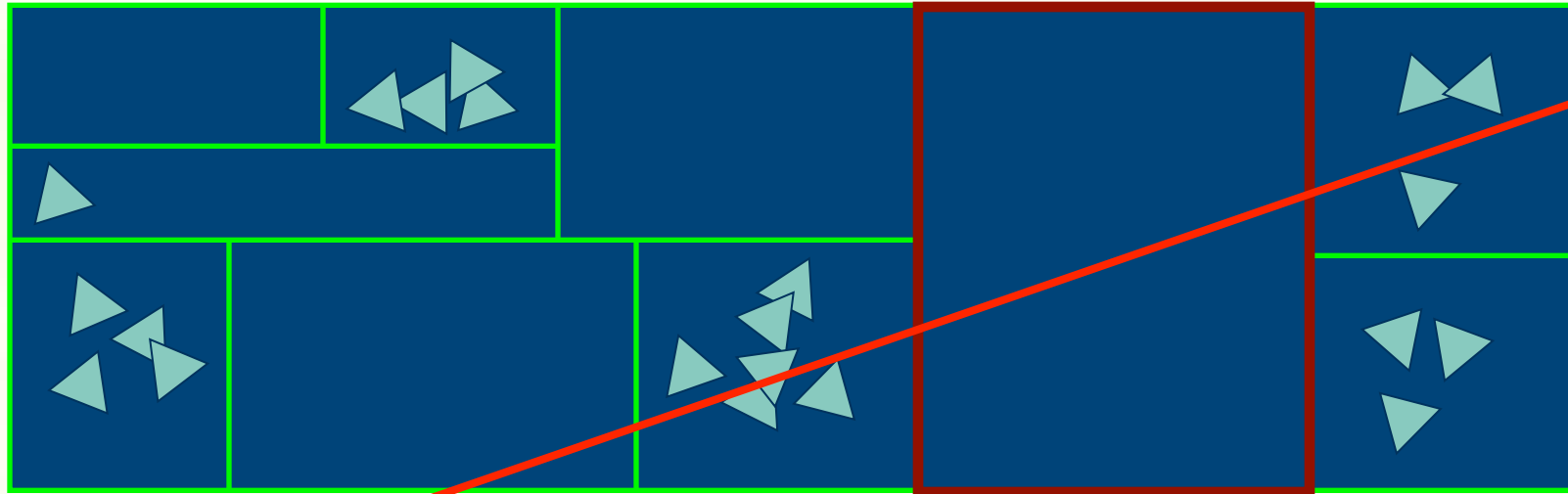


Current:

R

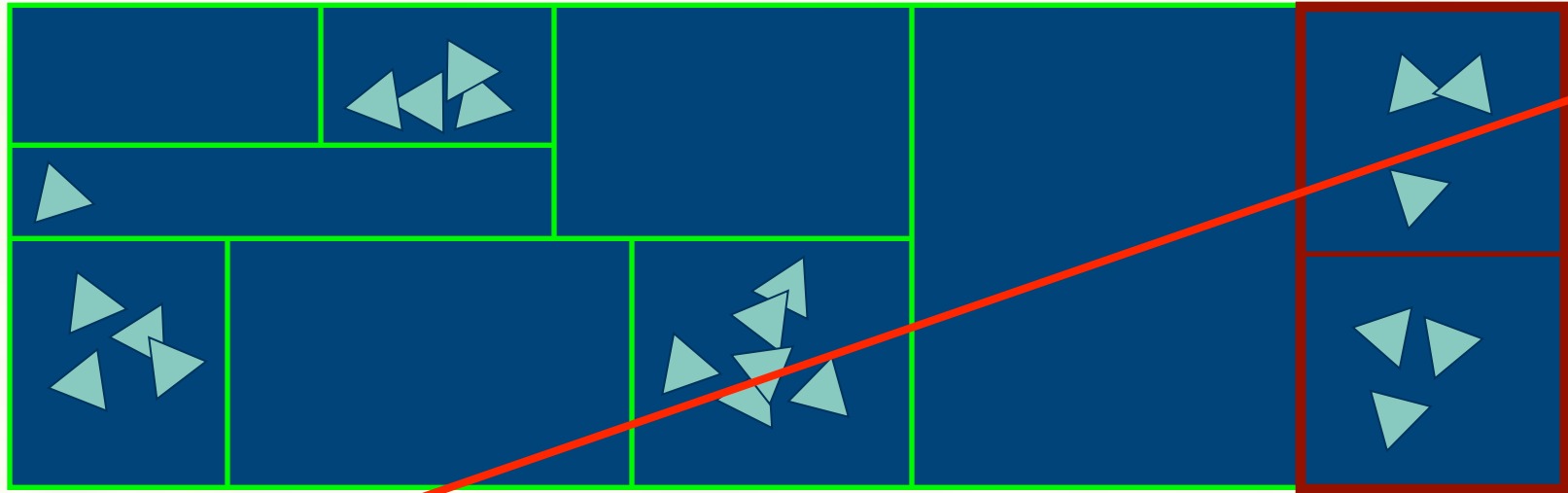


Kd-tree - Traversal

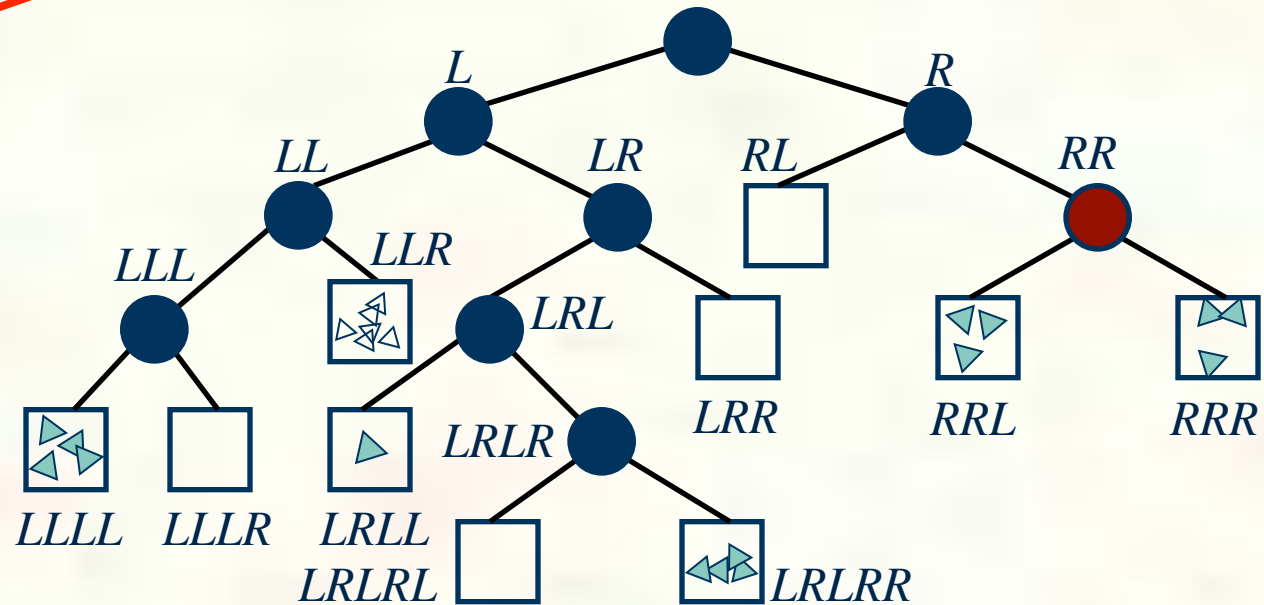




Kd-tree - Traversal



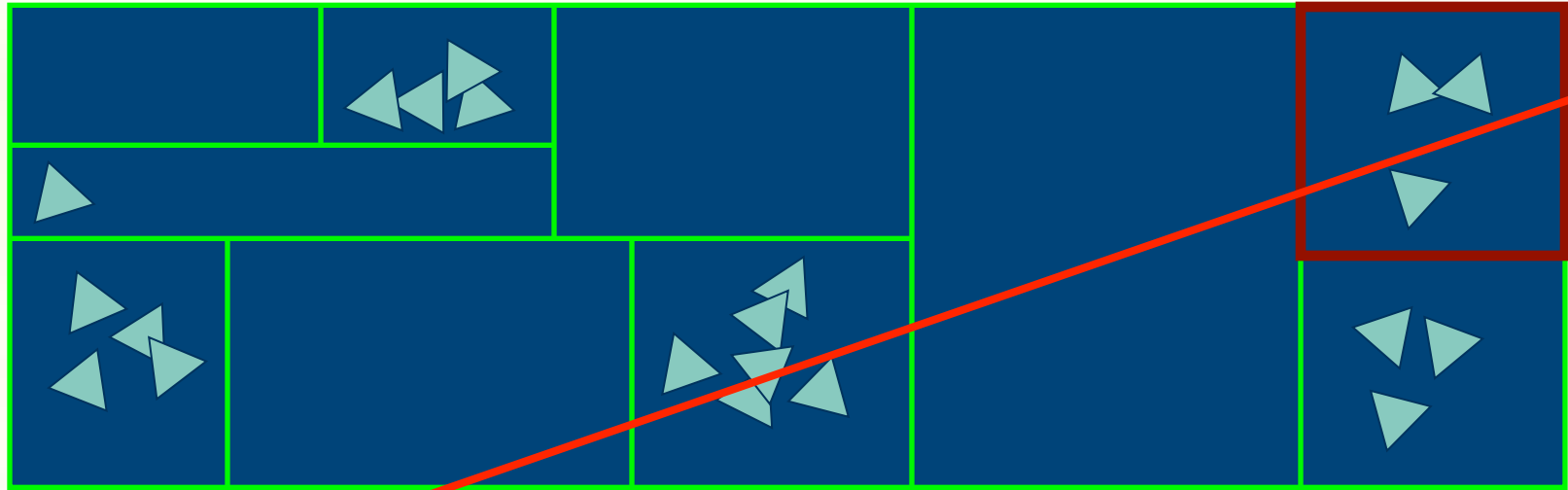
Stack:



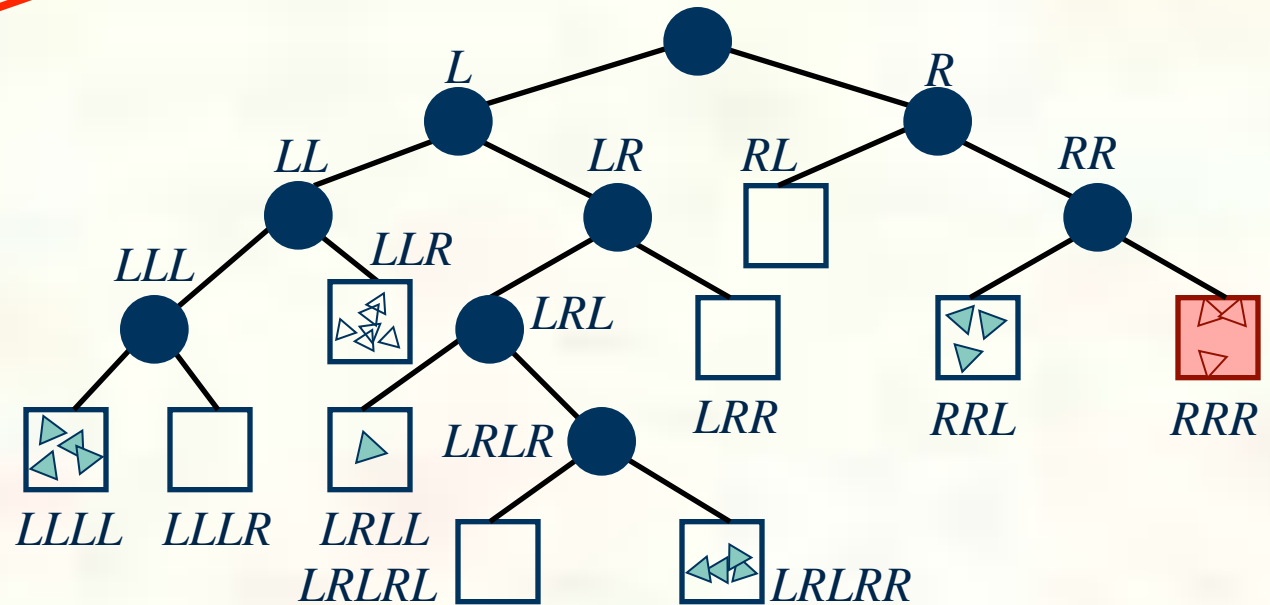
Current:
RR



Kd-tree - Traversal



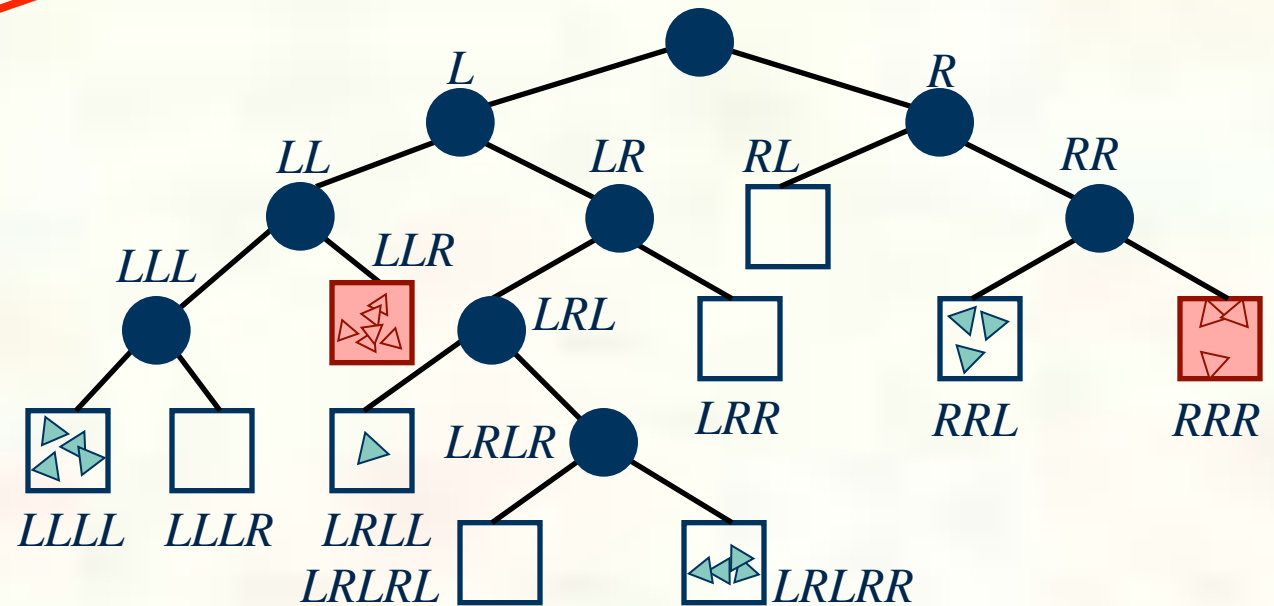
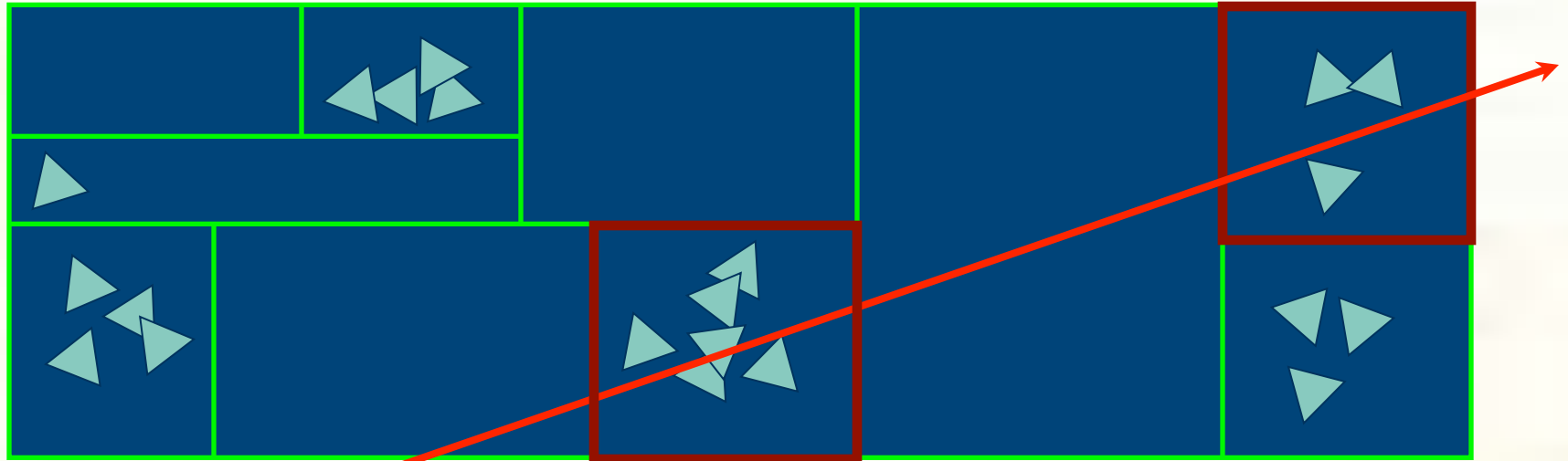
Stack:



Current:
RRR

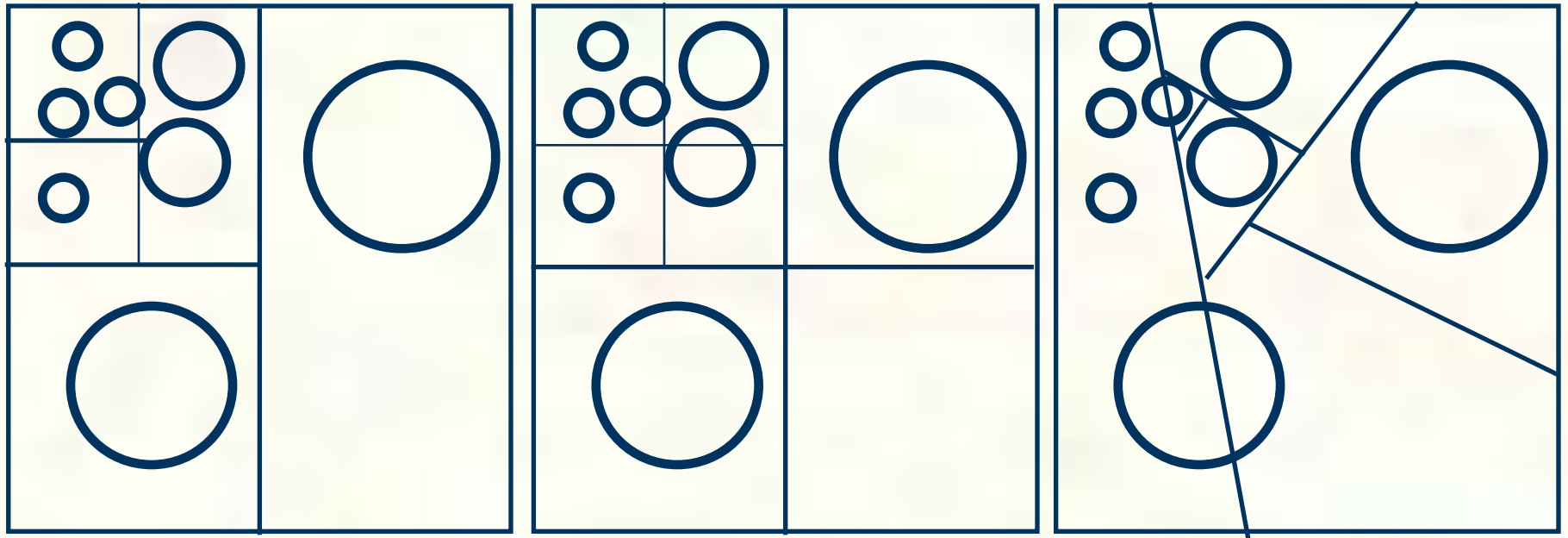


Kd-tree - Traversal





Variations



kd-tree

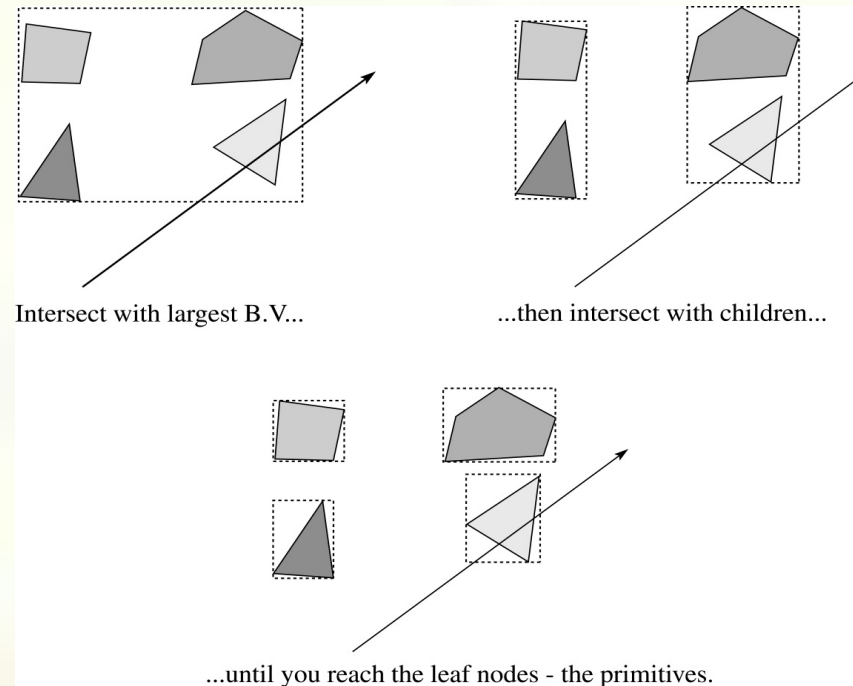
oct-tree

bsp-tree



Hierarchical bounding volumes

- We can generalize the idea of bounding volume acceleration with **hierarchical bounding volumes (or bounding volume hierarchies (BVH))**.



- Key: build balanced trees with *tight bounding volumes*.

Many different kinds of bounding volumes.

Note that bounding volumes can overlap.