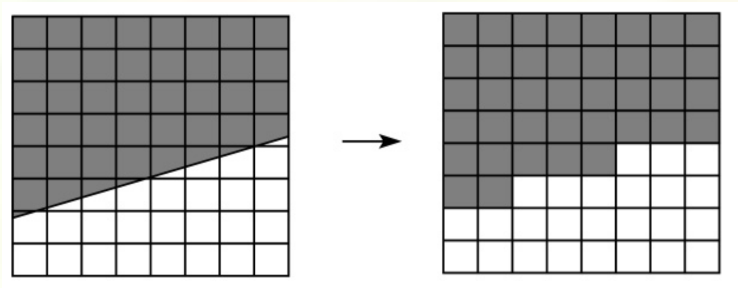
Anti-aliased and accelerated ray tracing

Reading

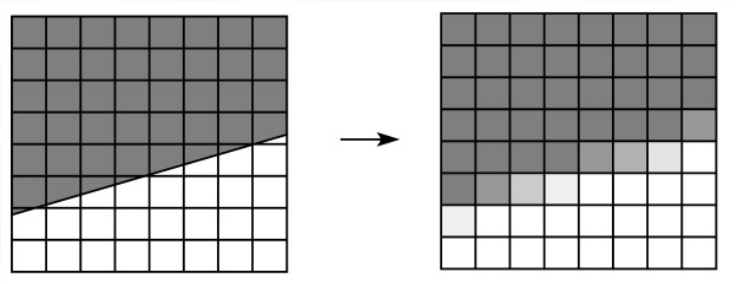
- Required:
  - Watt, sections 12.5.3 – 12.5.4, 14.7
- Further reading:
  - A. Glassner. An Introduction to Ray Tracing. Academic Press, 1989. [In the lab.]

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:

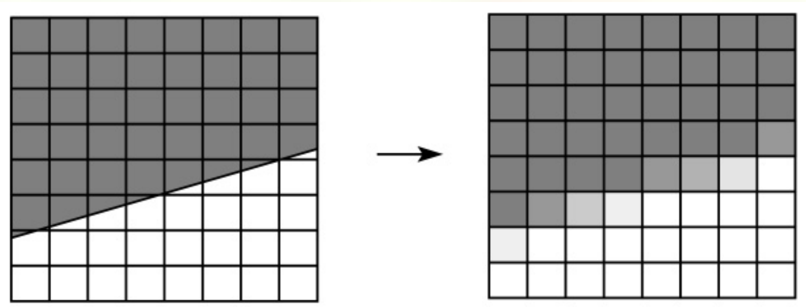


Anti-aliasing

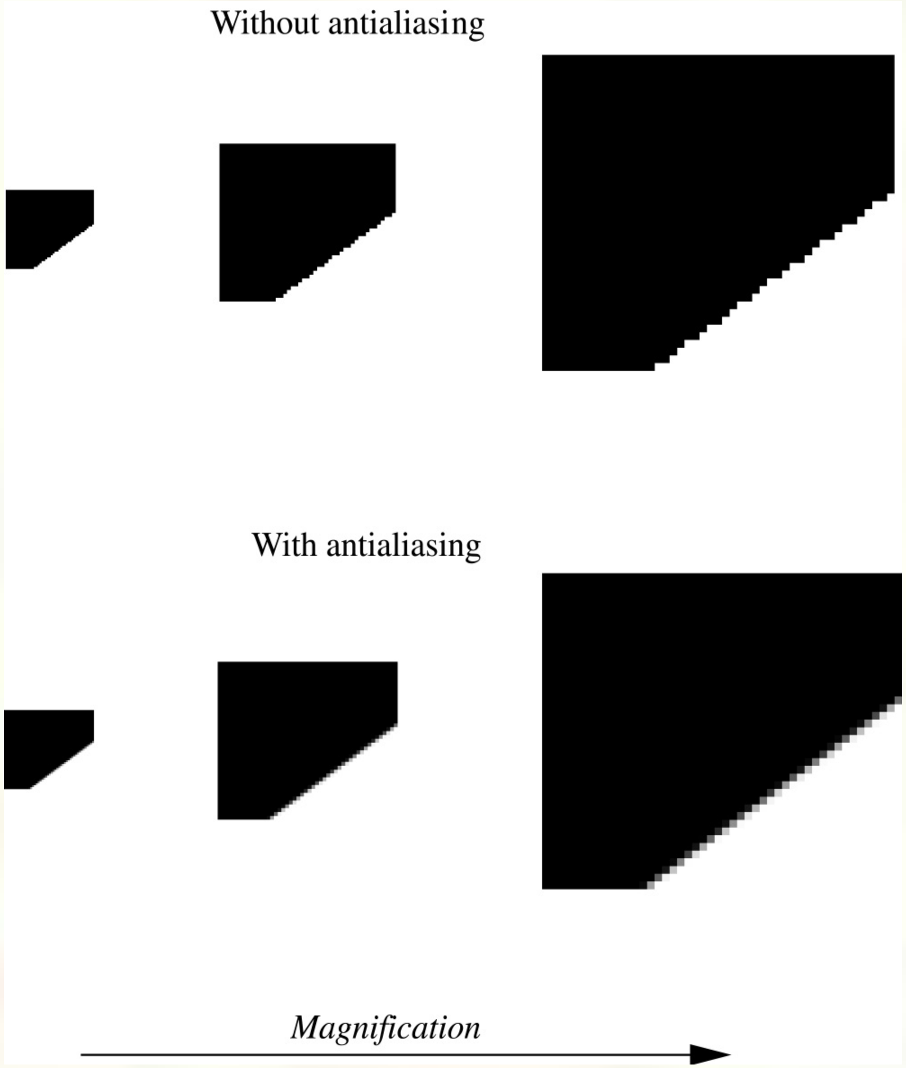
- **Q**: How do we avoid aliasing artifacts?

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

- Example - polygon:

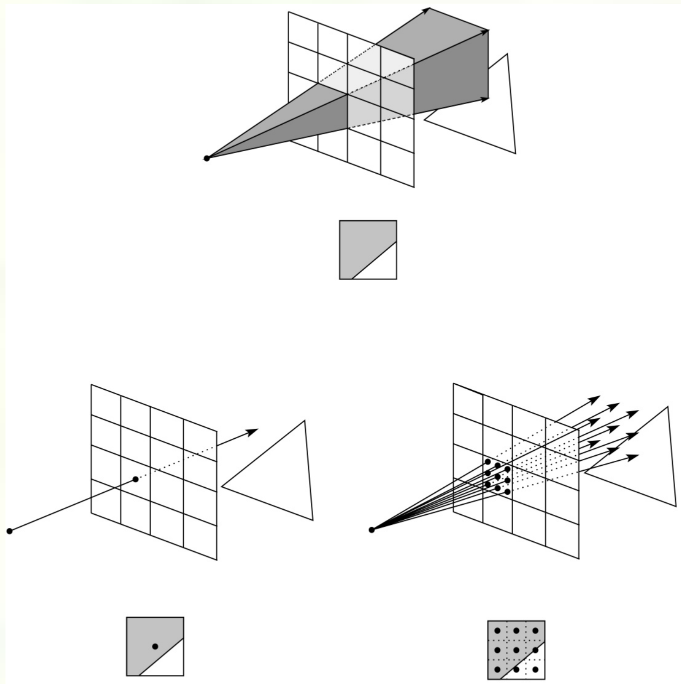


Polygon anti-aliasing



Antialiasing in a ray tracer

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



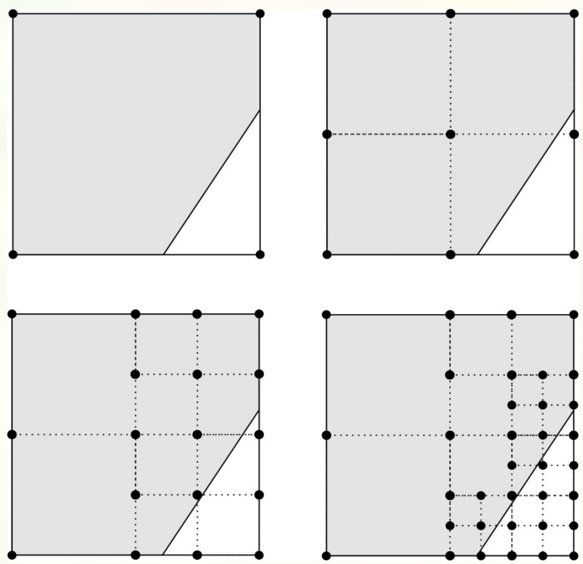
- When casting one ray per pixel, we are likely to have aliasing artifacts.
- To improve matters, we can cast more than one ray per pixel and average the result.
- A.k.a., **super-sampling and averaging down**.

Speeding it up

- Vanilla ray tracing is really slow!
- Consider: m x m pixels, k x 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

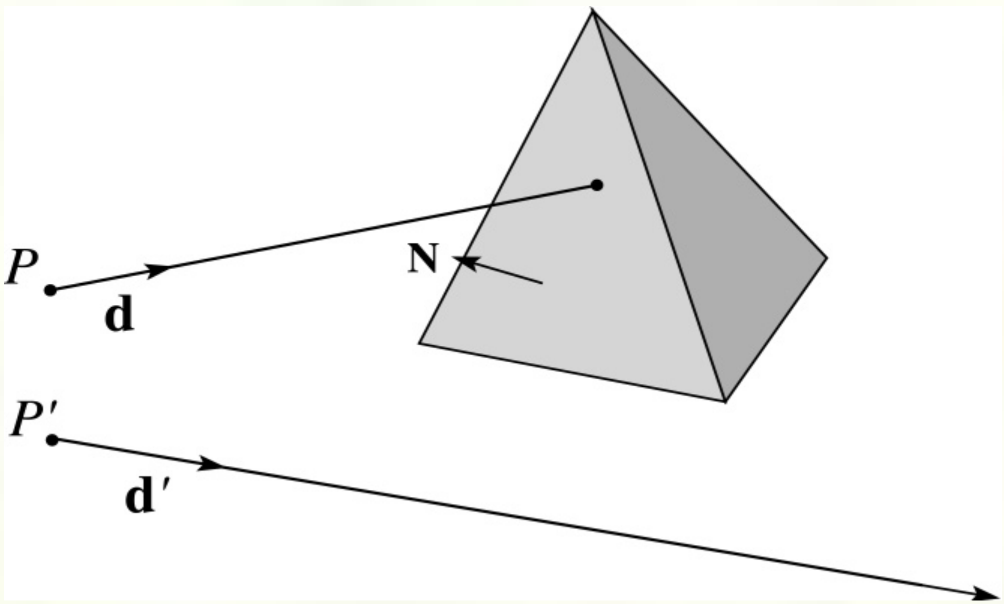
- Casting many rays per pixel can be unnecessarily costly.
- For example, if there are no rapid changes in intensity at the pixel, maybe only a few samples are needed.
- Solution: **adaptive sampling**.



- **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:



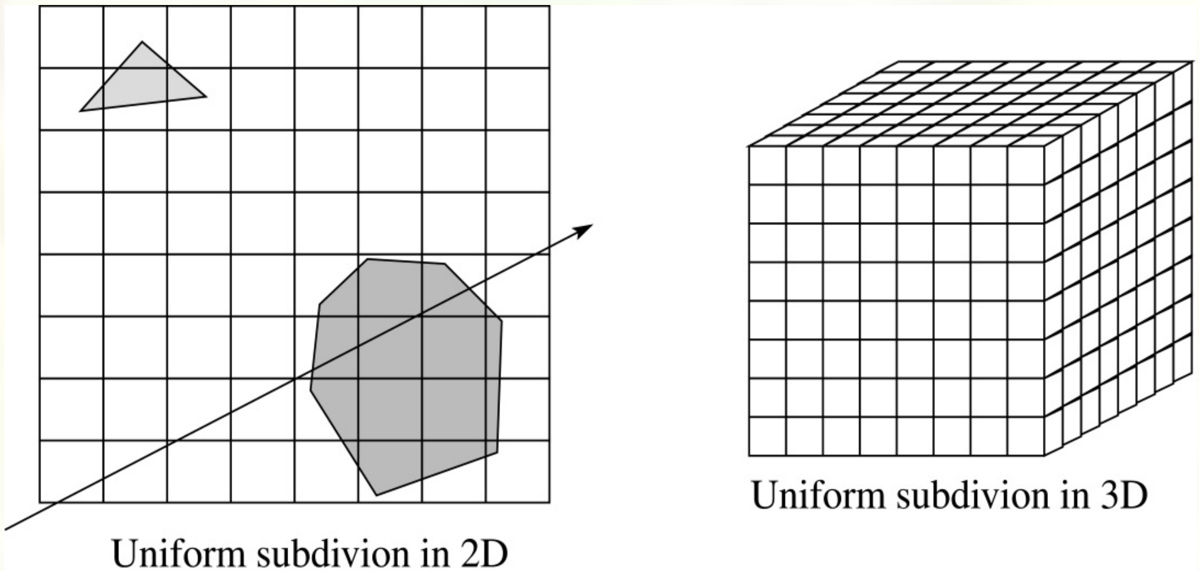
- Straightforward method
  - intersect the ray with each triangle
  - return the intersection with the smallest *t*-value.
- **Q**: How might you speed this up?

Ray Tracing Acceleration Techniques

- **Approaches**
  - **Faster Intersection**
    - N
      - Uniform grids
      - Spatial hierarchies
        - k-d, oct-tree, bsp
        - hierarchical grids
      - Hierarchical bounding volumes (HBV)
    - 1
      - Tighter bounds
      - Faster intersector
  - **Fewer Rays**
    - Early ray termination
    - Adaptive sampling
  - **Generalized Rays**
    - Beam tracing
    - Cone tracing
    - Pencil tracing

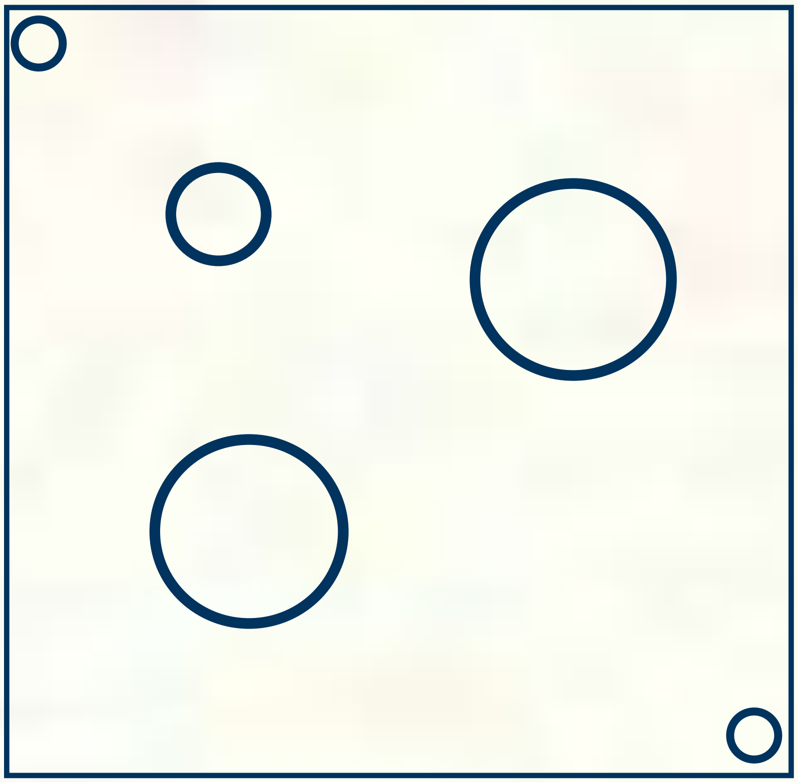
Uniform spatial subdivision

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



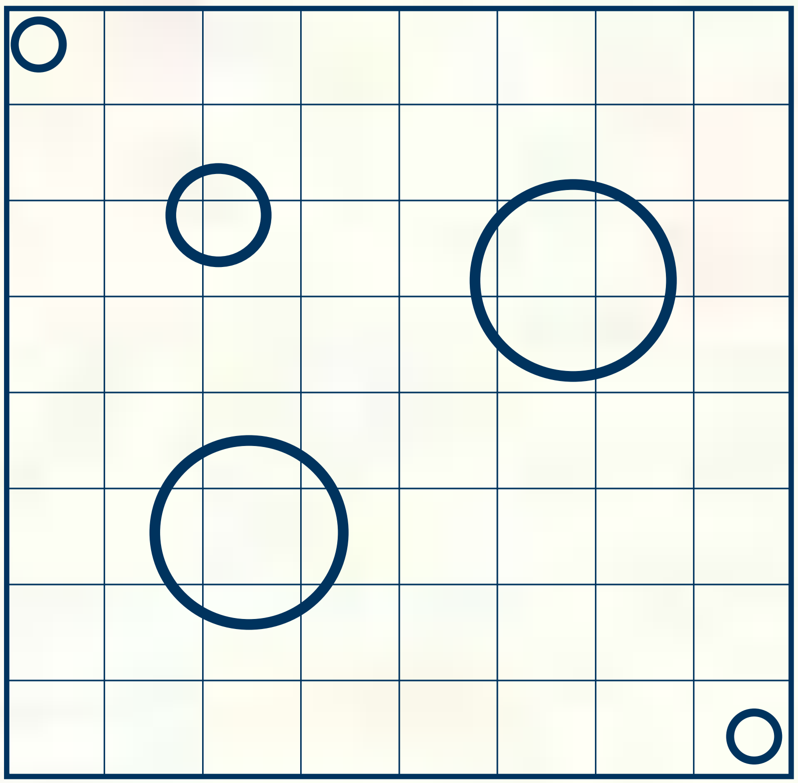
- Idea:
  - Partition space into cells (voxels)
  - Associate each primitive with the cells it overlaps
  - Trace ray through voxel array *using fast incremental arithmetic* to step from cell to cell

Uniform Grids



- Preprocess scene
  - Find bounding box

Uniform Grids

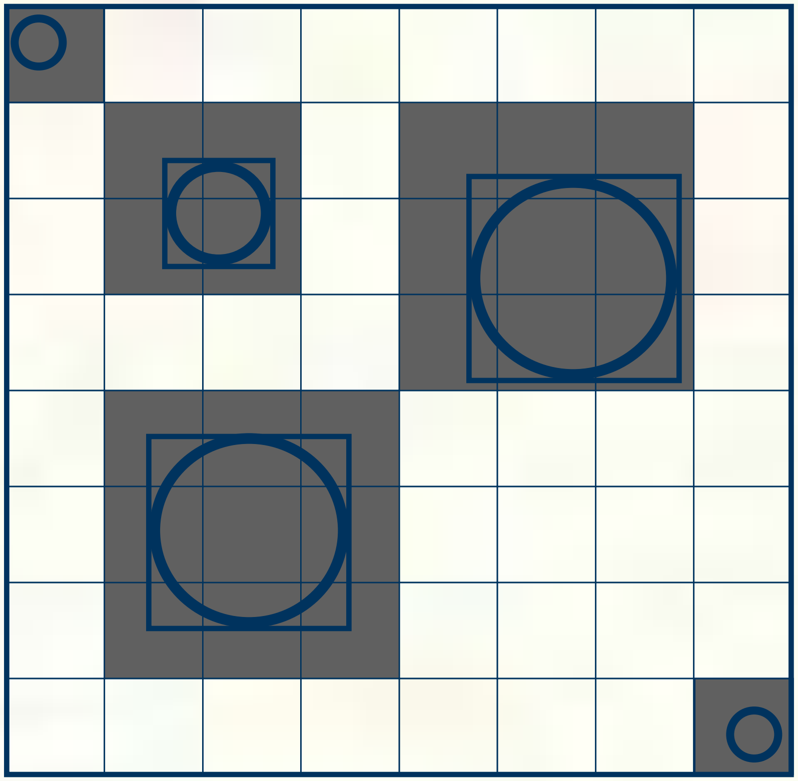


- Preprocess scene
  - Find bounding box
  - Determine resolution

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

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

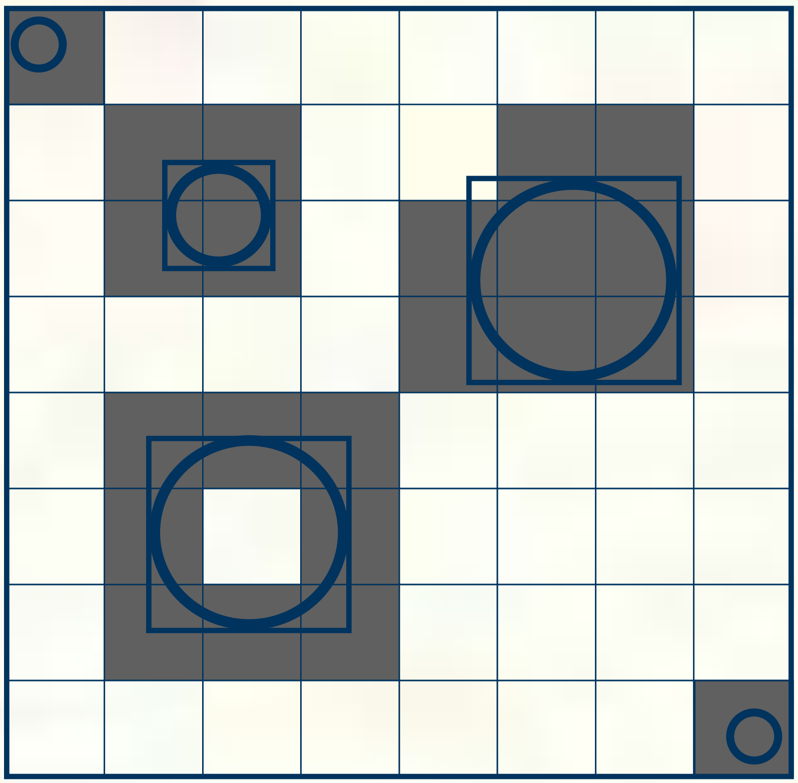
Uniform Grids



- 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

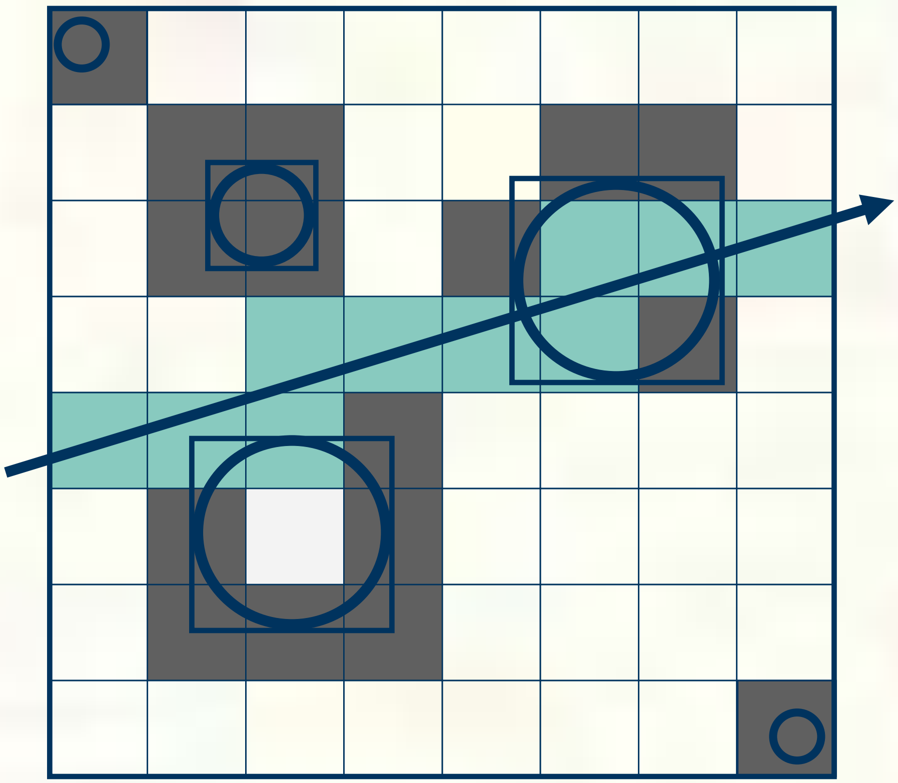


- Preprocess scene
  - Find bounding box
  - Determine resolution

  - Place object in cell, if object overlaps cell
  - Check that object intersects cell

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

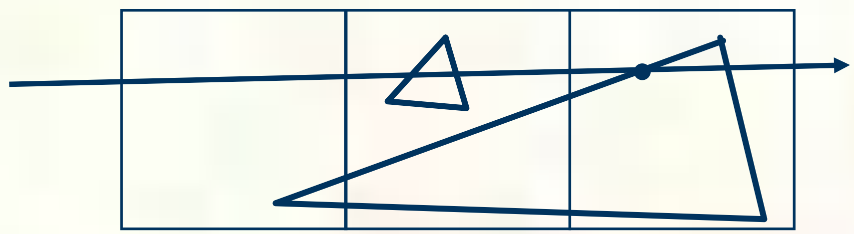
Uniform Grids



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

Caveat: Overlap

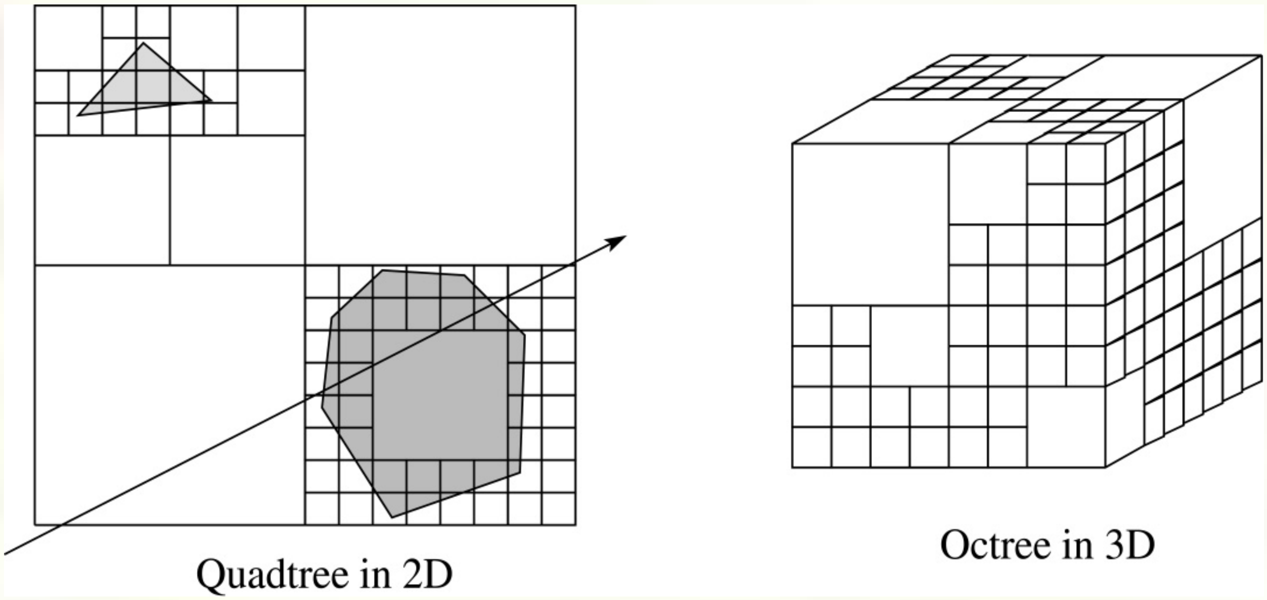
- *Optimize for objects that overlap multiple cells*



- Traverse until tmin(cell) > tmax(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.

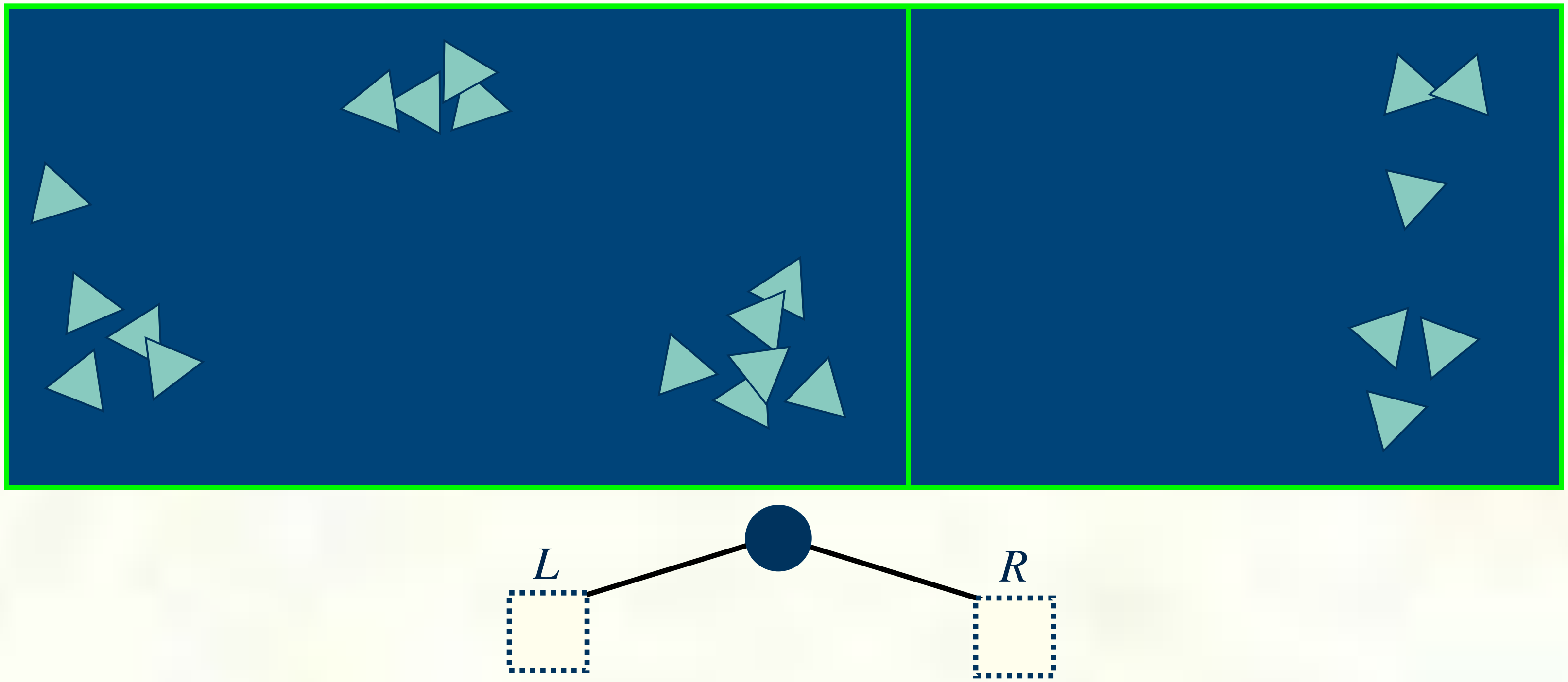
- Various combinations of these ray intersections techniques are also possible. See Glassner and pointers at bottom of project web page for more.

Non-uniform spatial subdivision

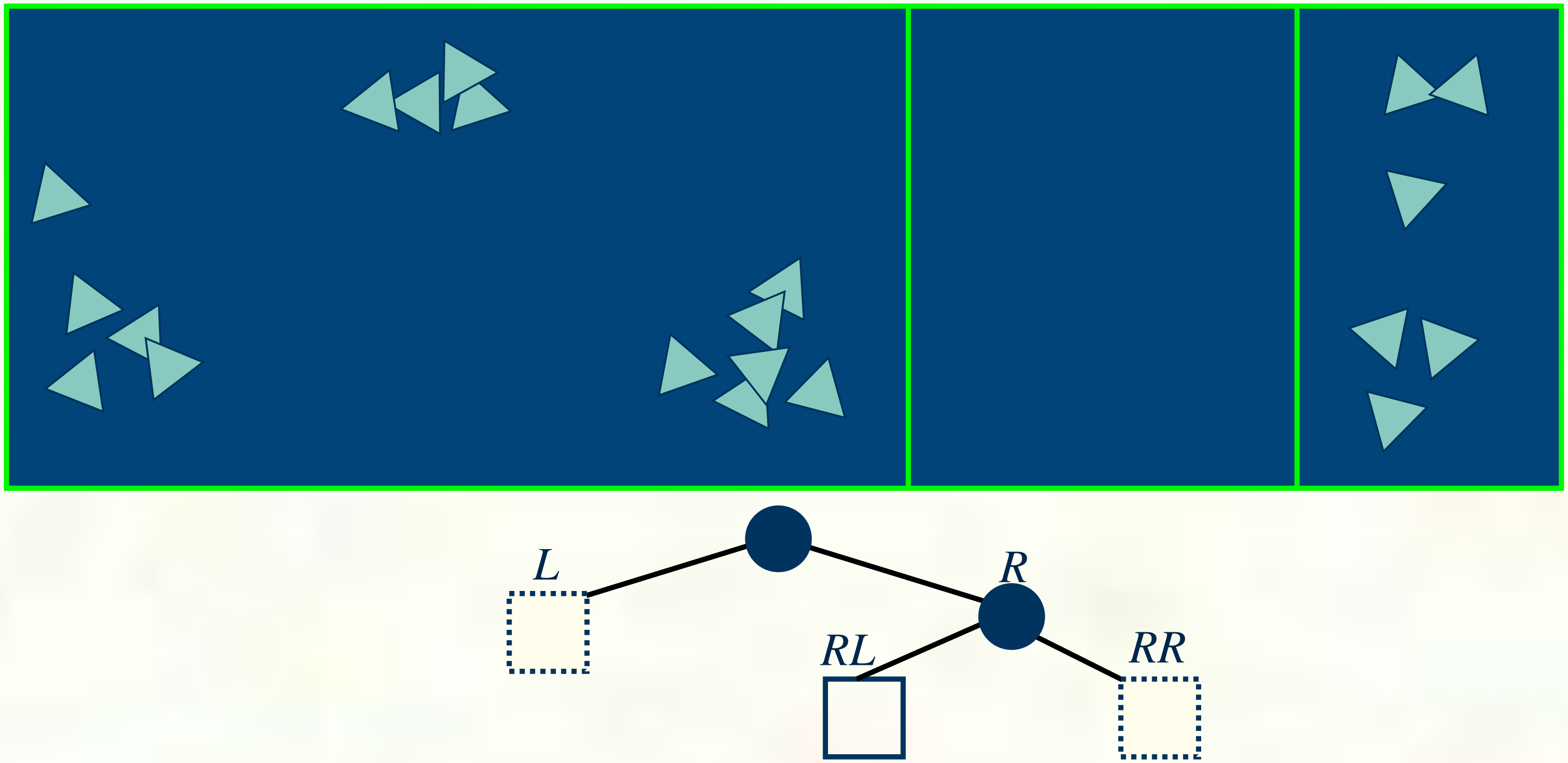
- Best partitioning approach - k-d trees or perhaps BSP trees
  - More adaptive to actual scene structure
  - BSP vs. k-d tradeoff between speed from simplicity and better adaptability
- Non-partitioning approach
  - Hierarchical bounding volumes
  - Build similar to k-d tree build

Kd-tree - Build

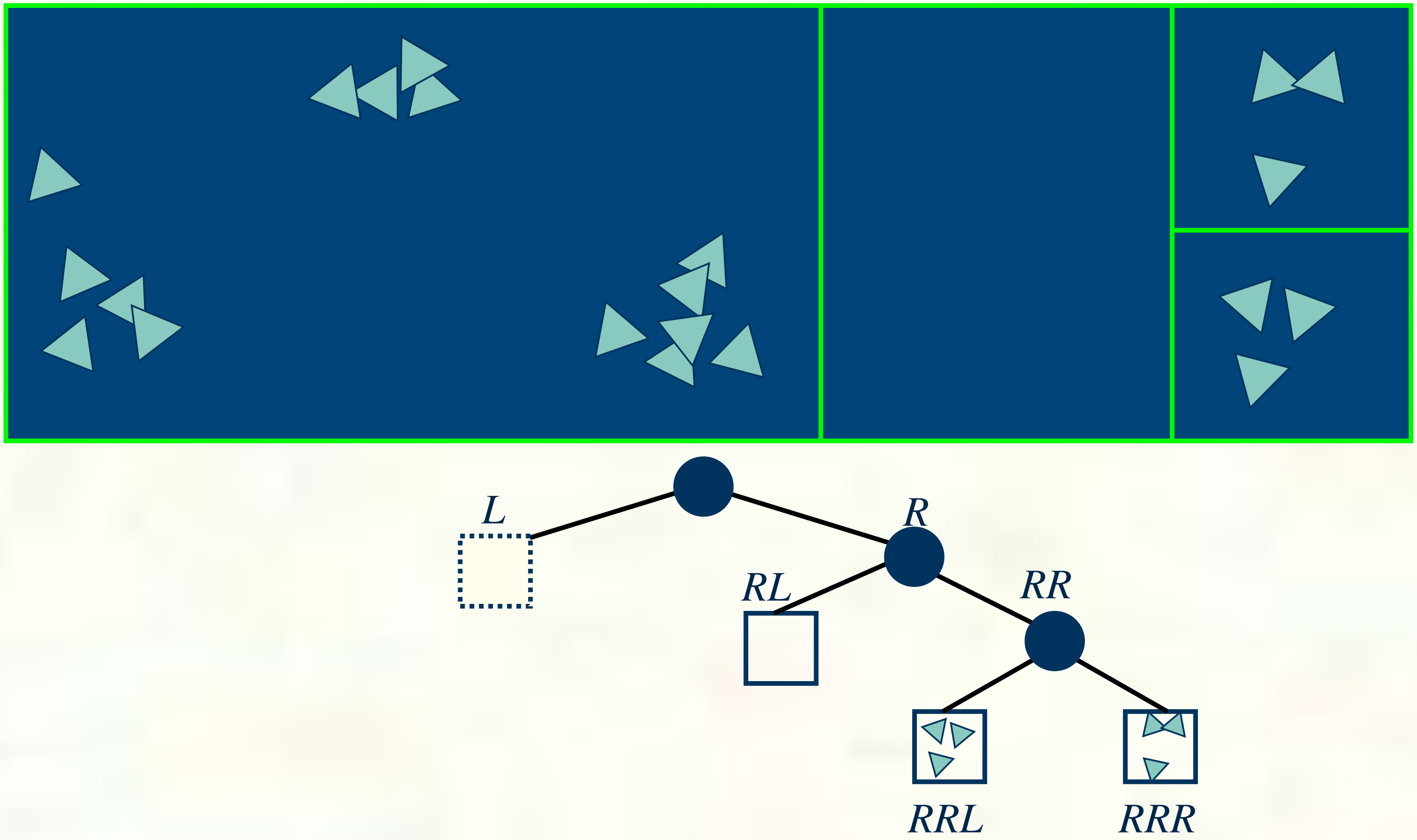
Kd-tree



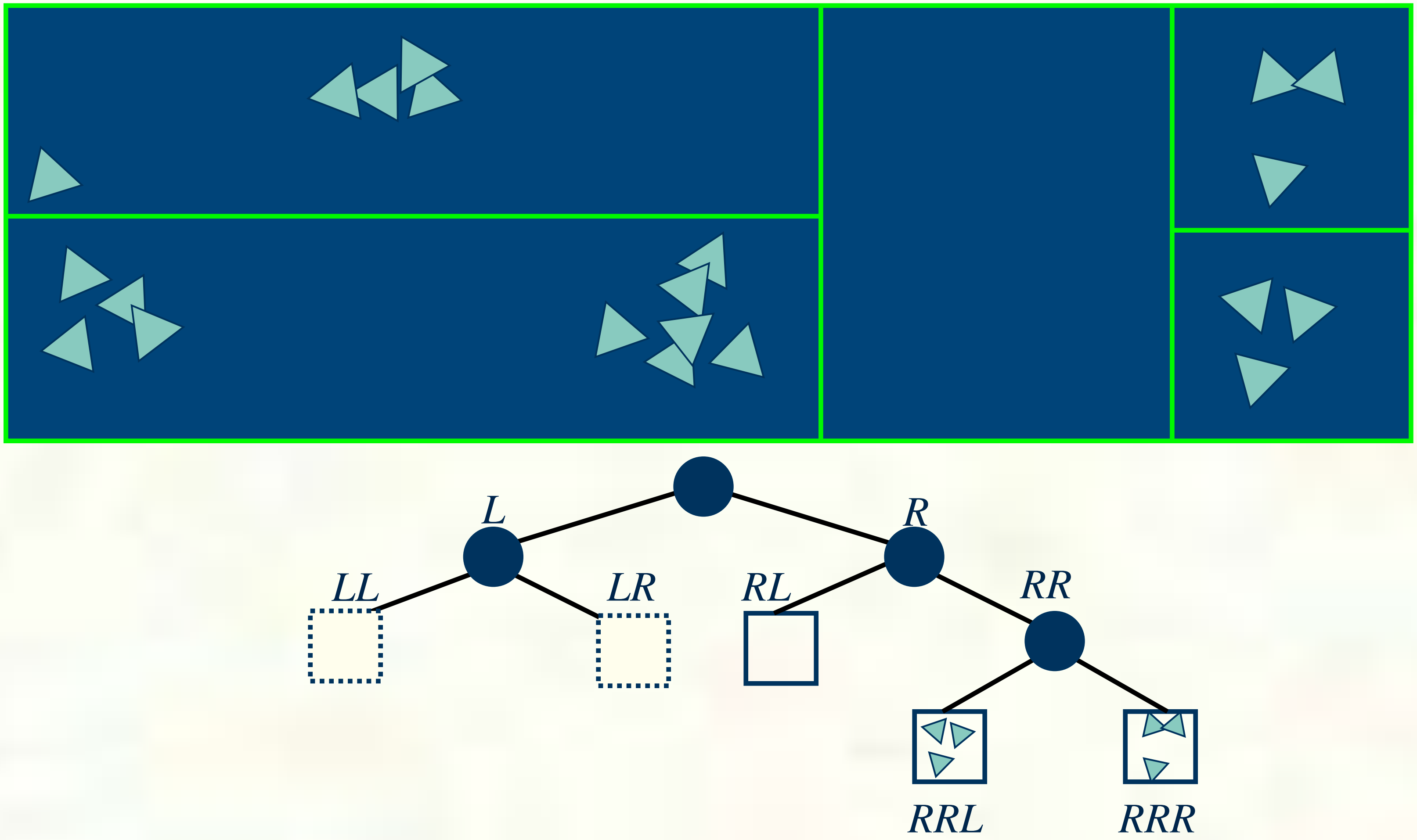
Kd-tree



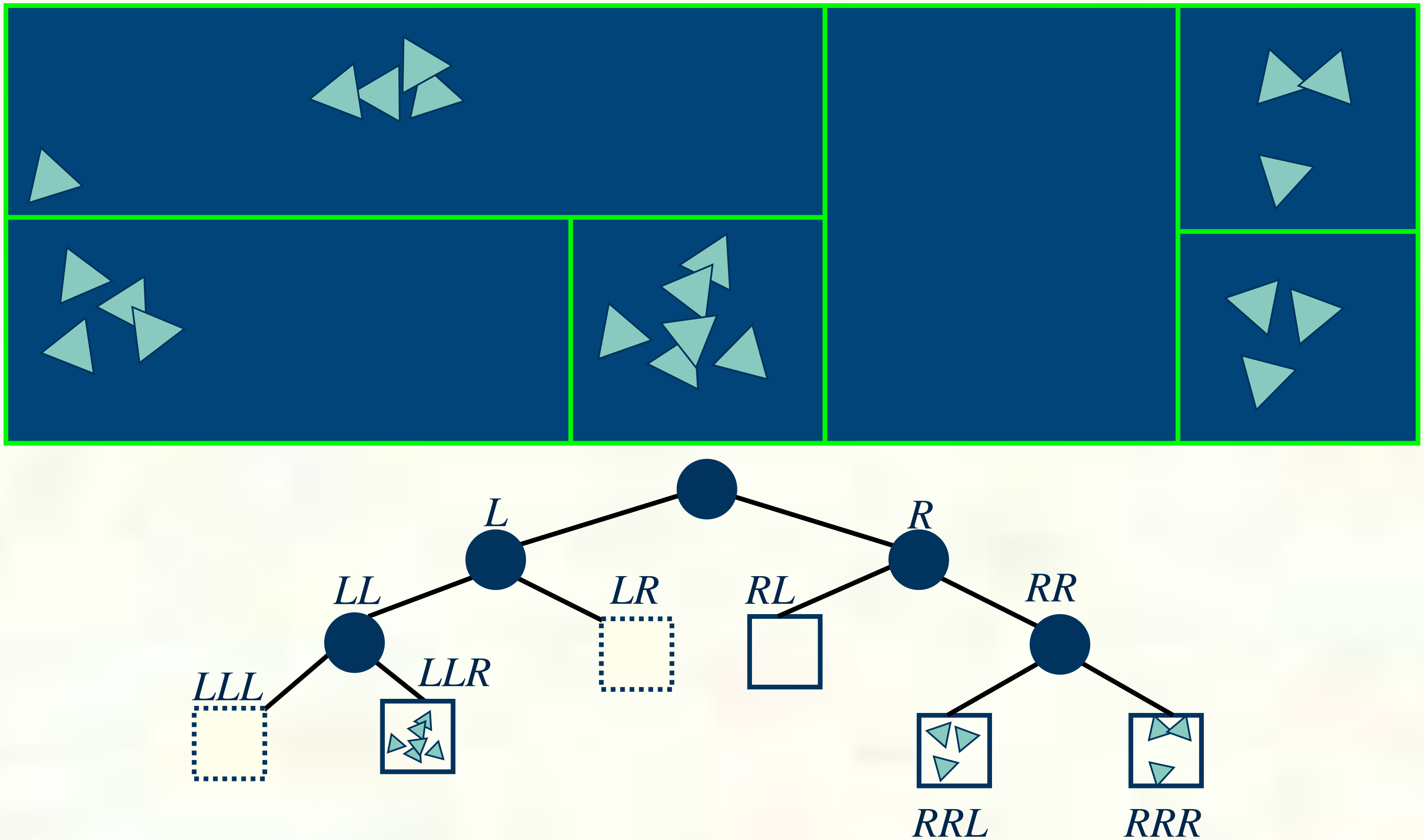
Kd-tree



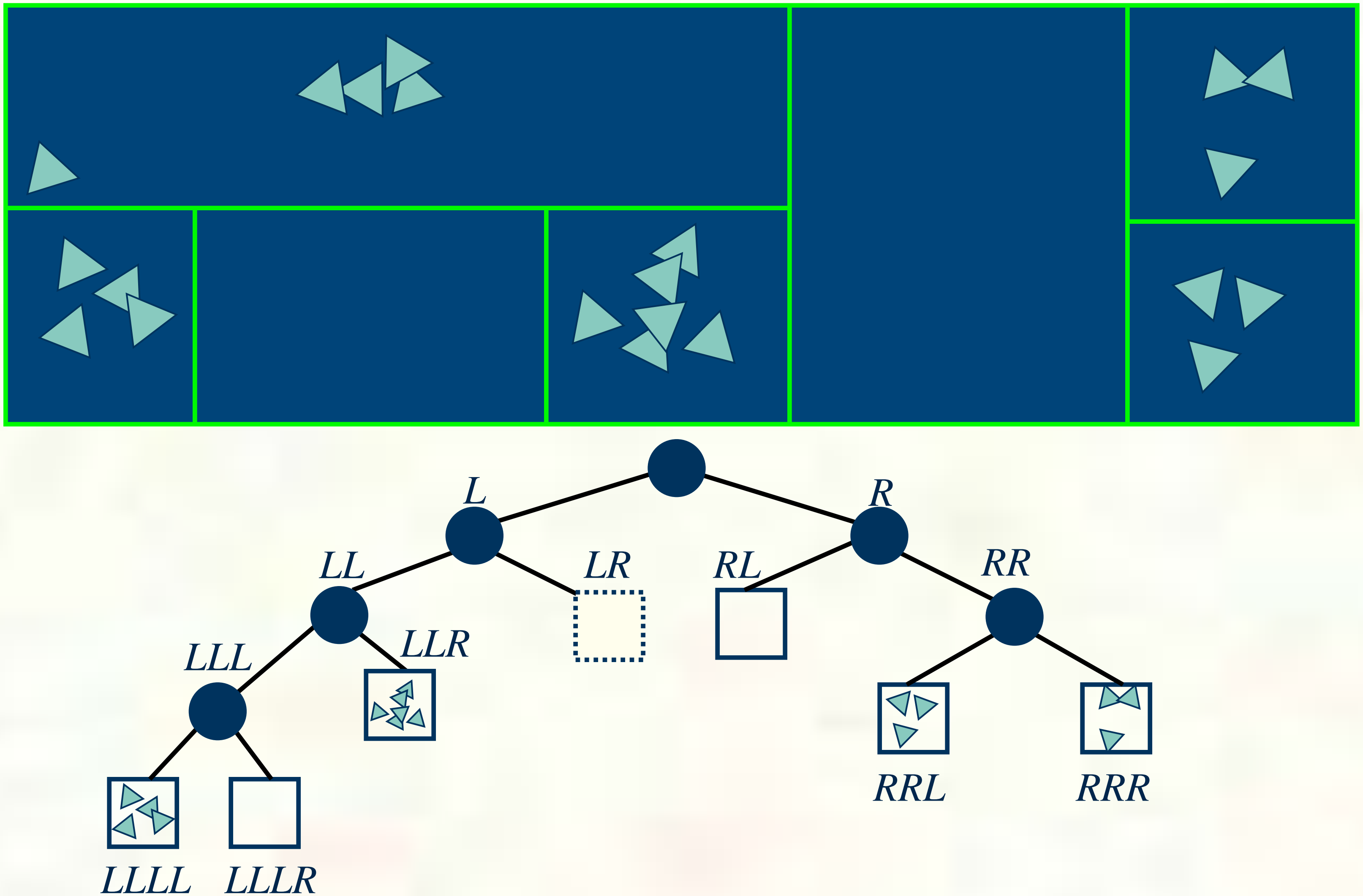
Kd-tree



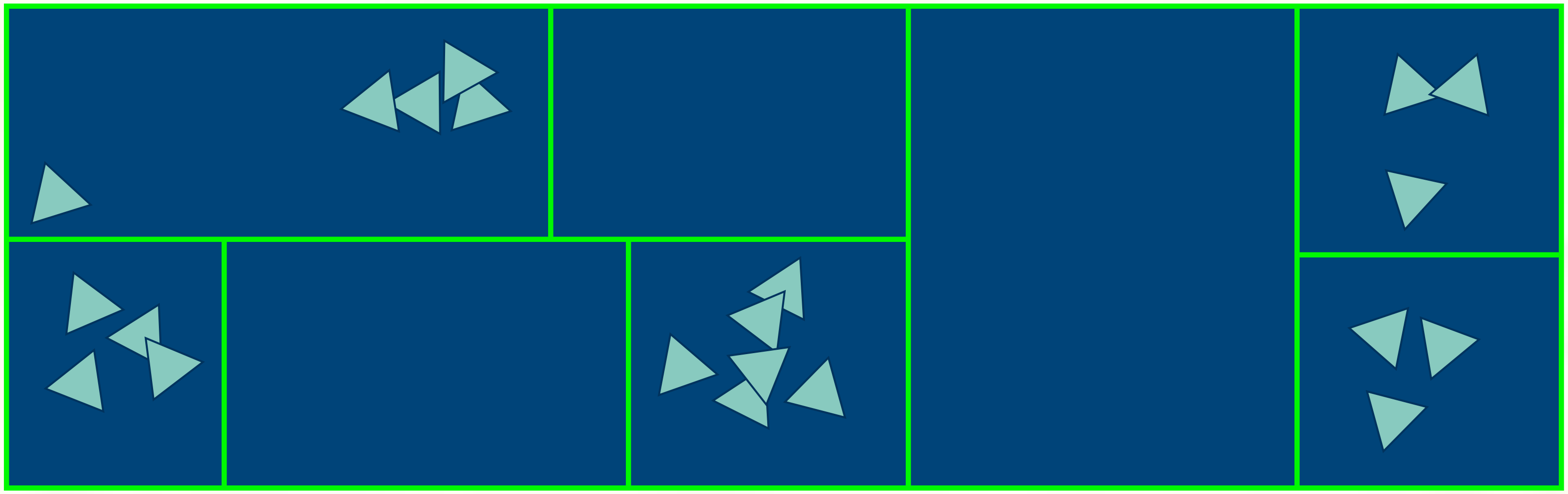
Kd-tree

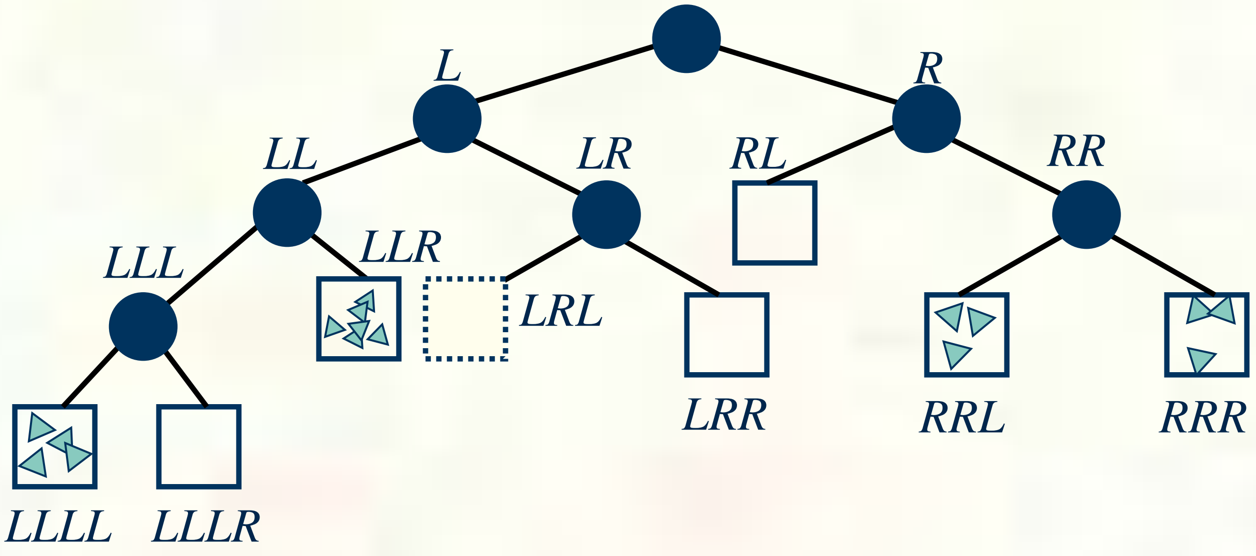


Kd-tree

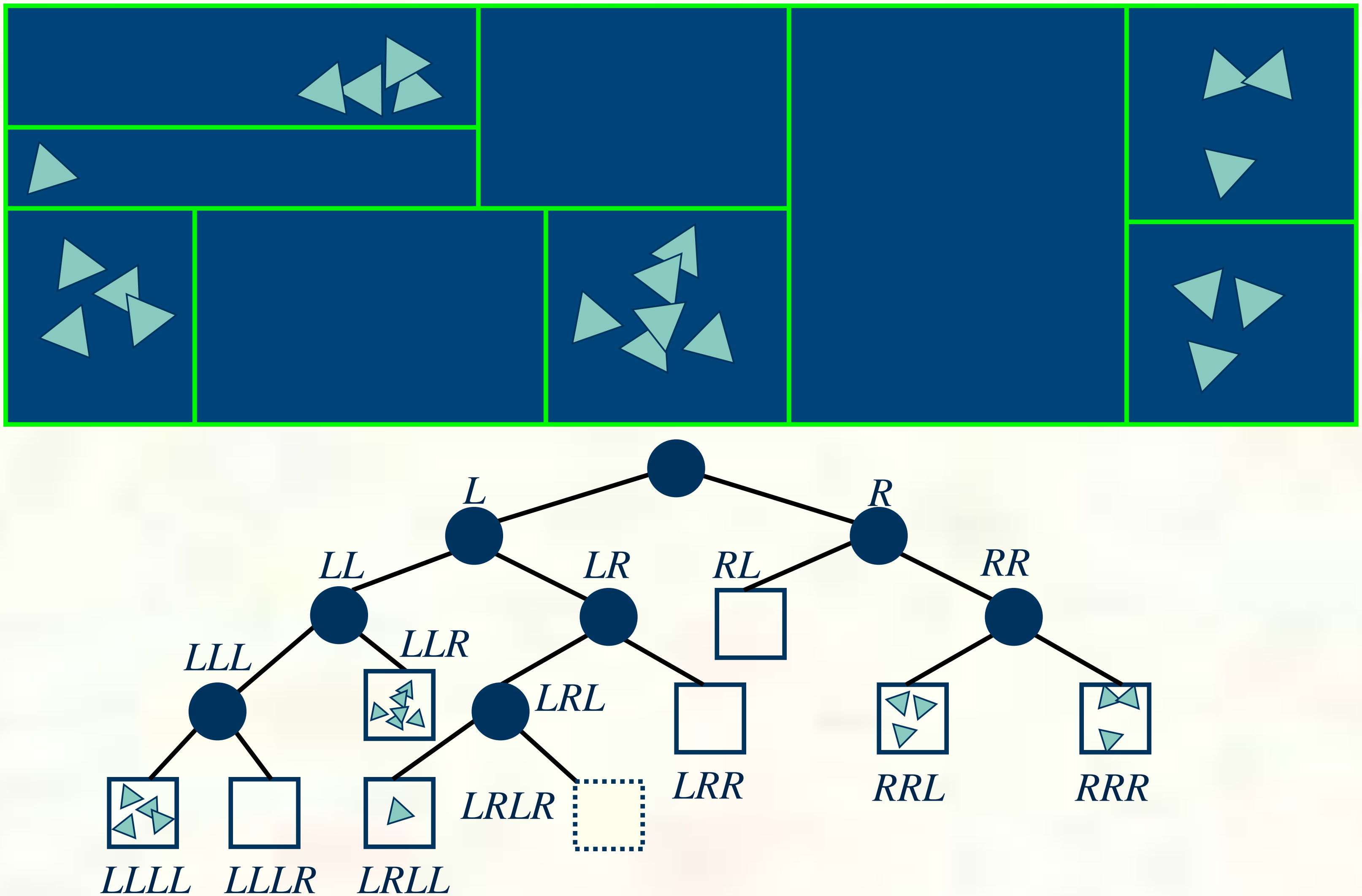


Kd-tree

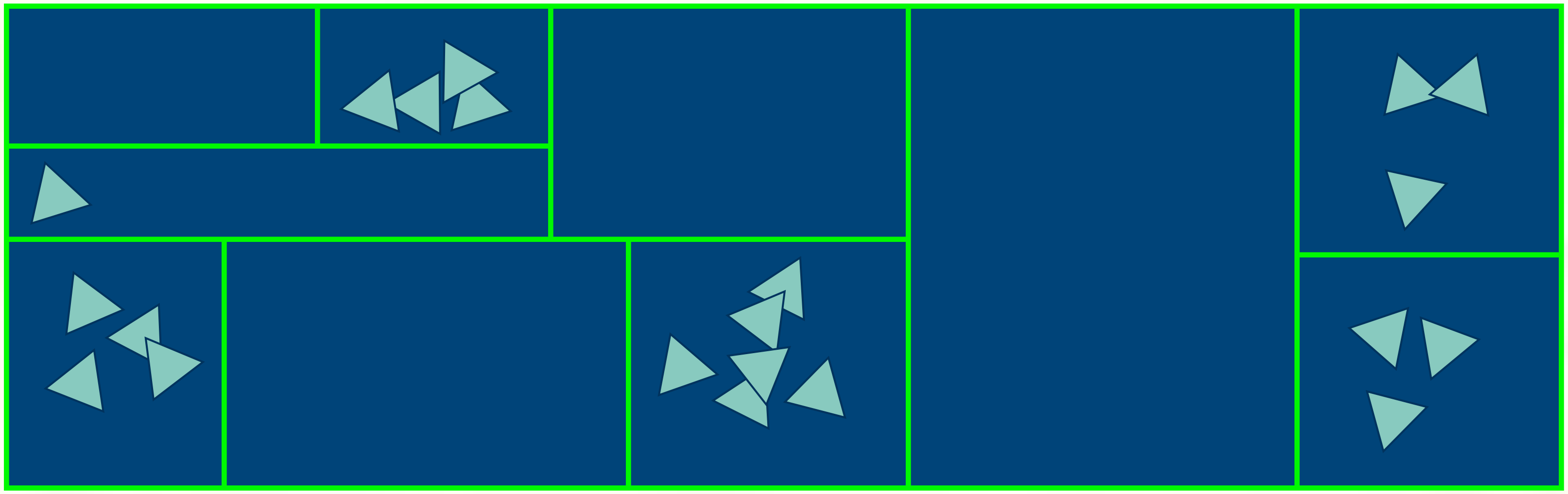


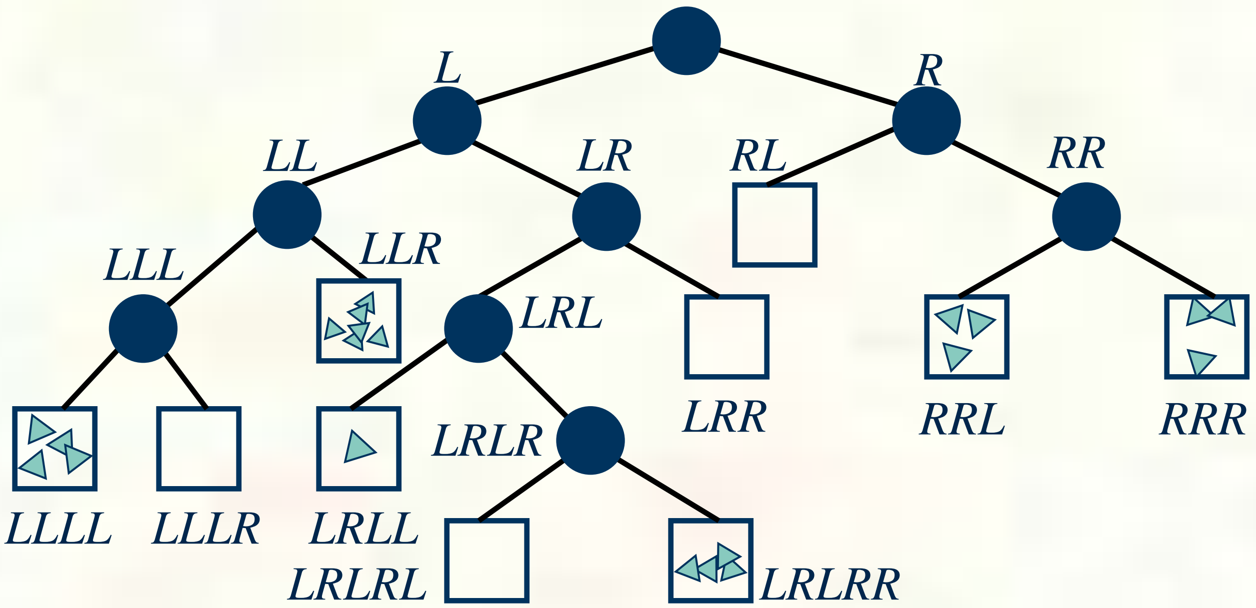


Kd-tree



Kd-tree




L
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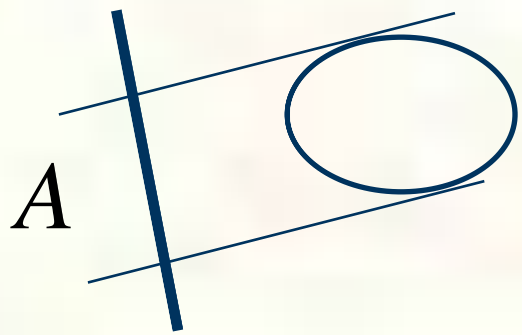
LRLRR

Surface Area and Rays

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

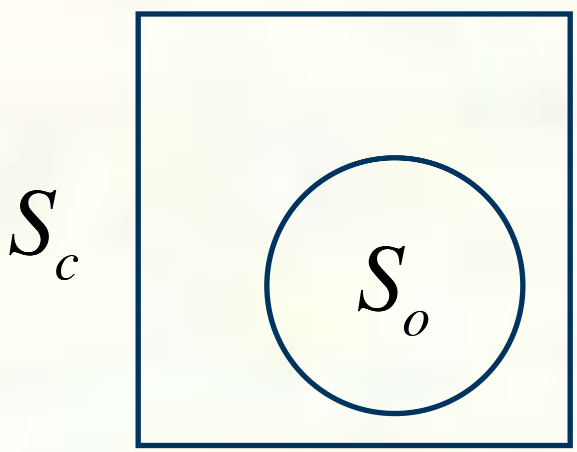


- The total number of rays hitting an object is $4\pi \bar{A}$
- Crofton's Theorem:
  - For a convex body $\bar{A} = \dfrac{S}{4}$
- For example: sphere

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

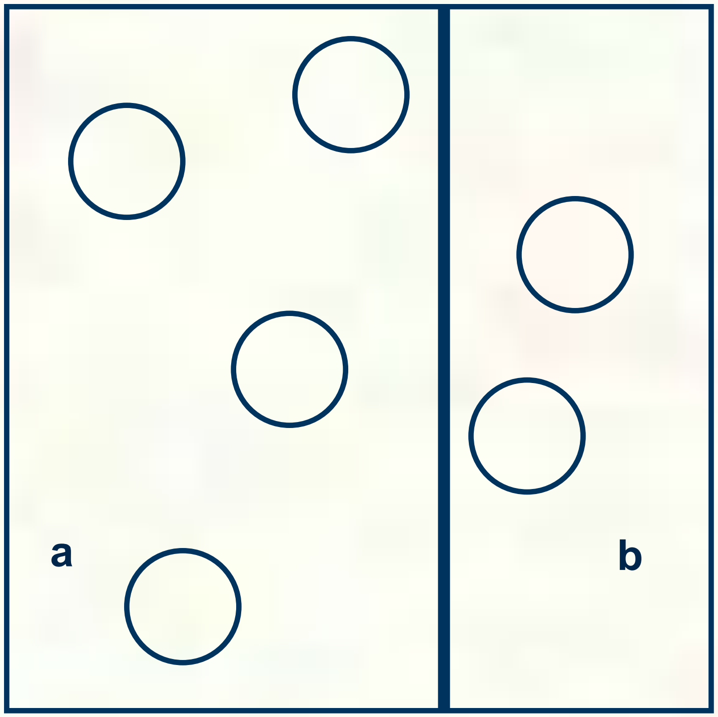
Surface Area and Rays

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



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

Surface Area Heuristic



Intersection time

$$t_i$$

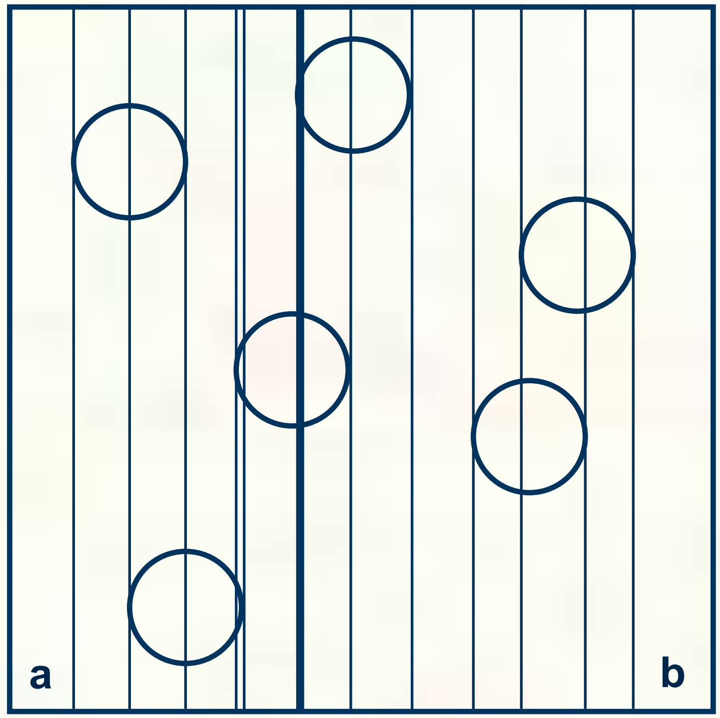
Traversal time

$$t_t$$

$$t_i = 80t_t$$

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

Surface Area Heuristic

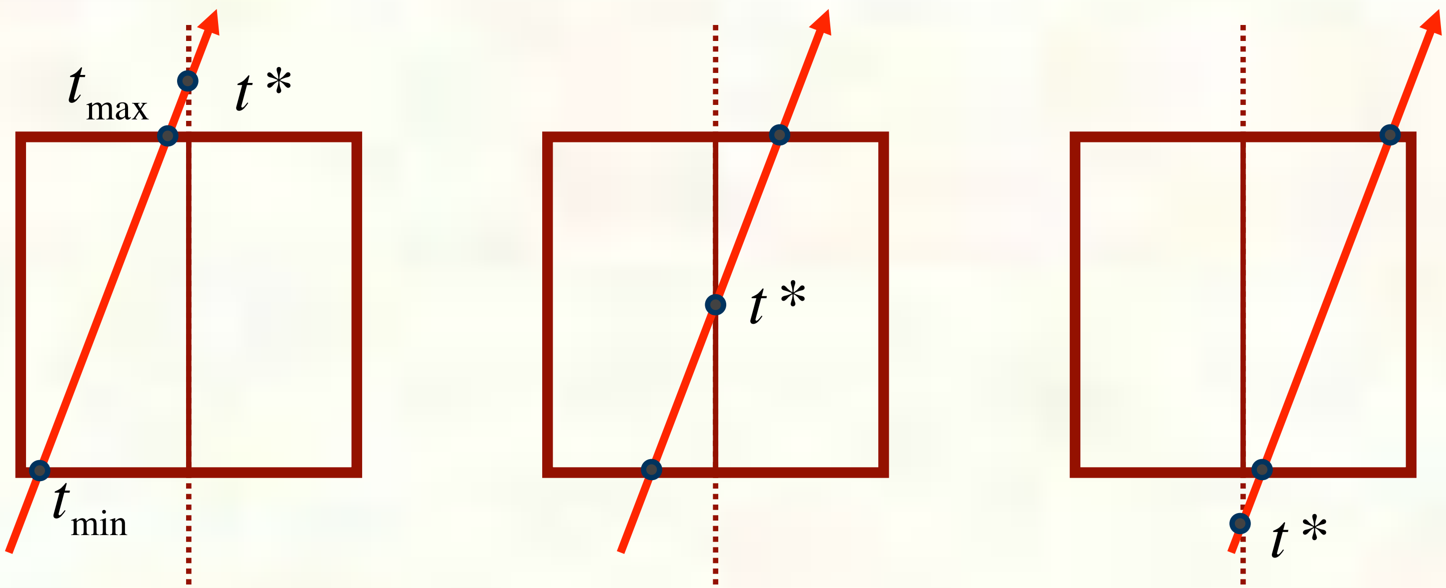


2n splits

$$p_a = \frac{S_a}{S} \qquad p_b = \frac{S_b}{S}$$

Ray Traversal Kernel

Depth first traversal



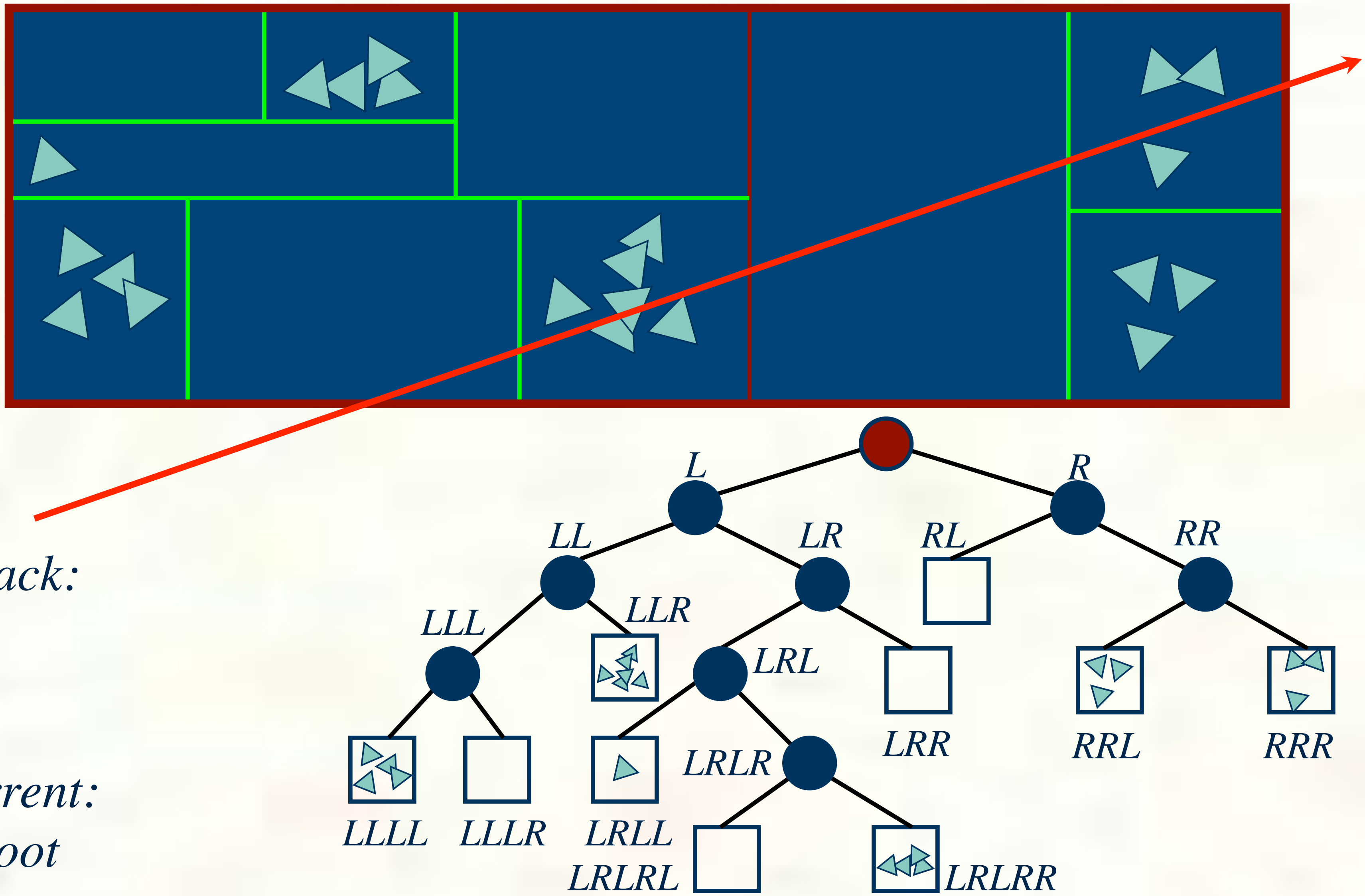
$t_{max} < t^*$ $\quad$ $t_{min} < t^* < t_{max}$ $\quad$ $t^* < t_{min}$

Intersect(L,tmin,tmax)

Intersect(L,tmin,t)*
Intersect(R,t,tmax)*

Intersect(R,tmin,tmax)

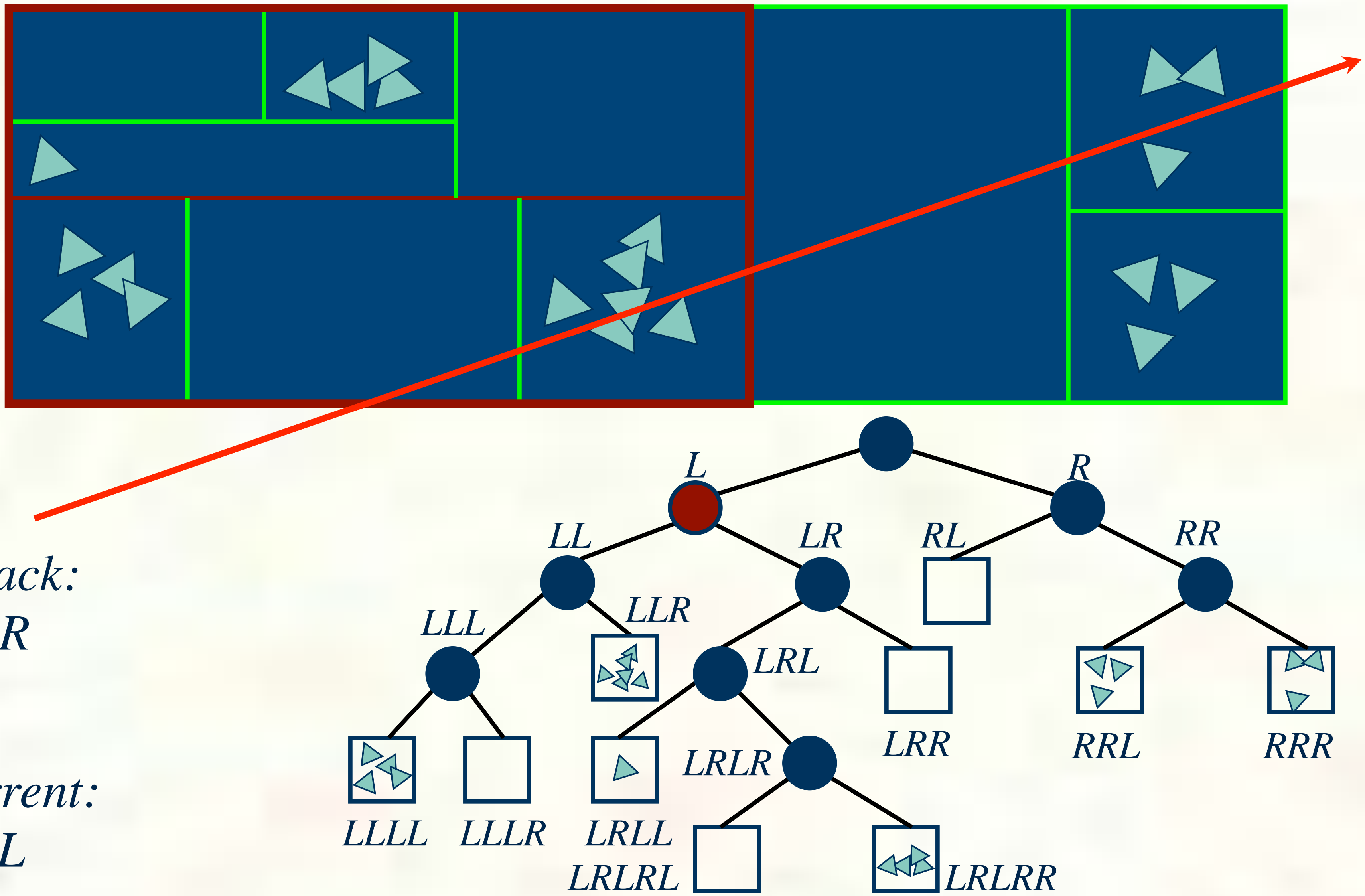
Kd-tree - Traversal



Stack:

Current:
Root

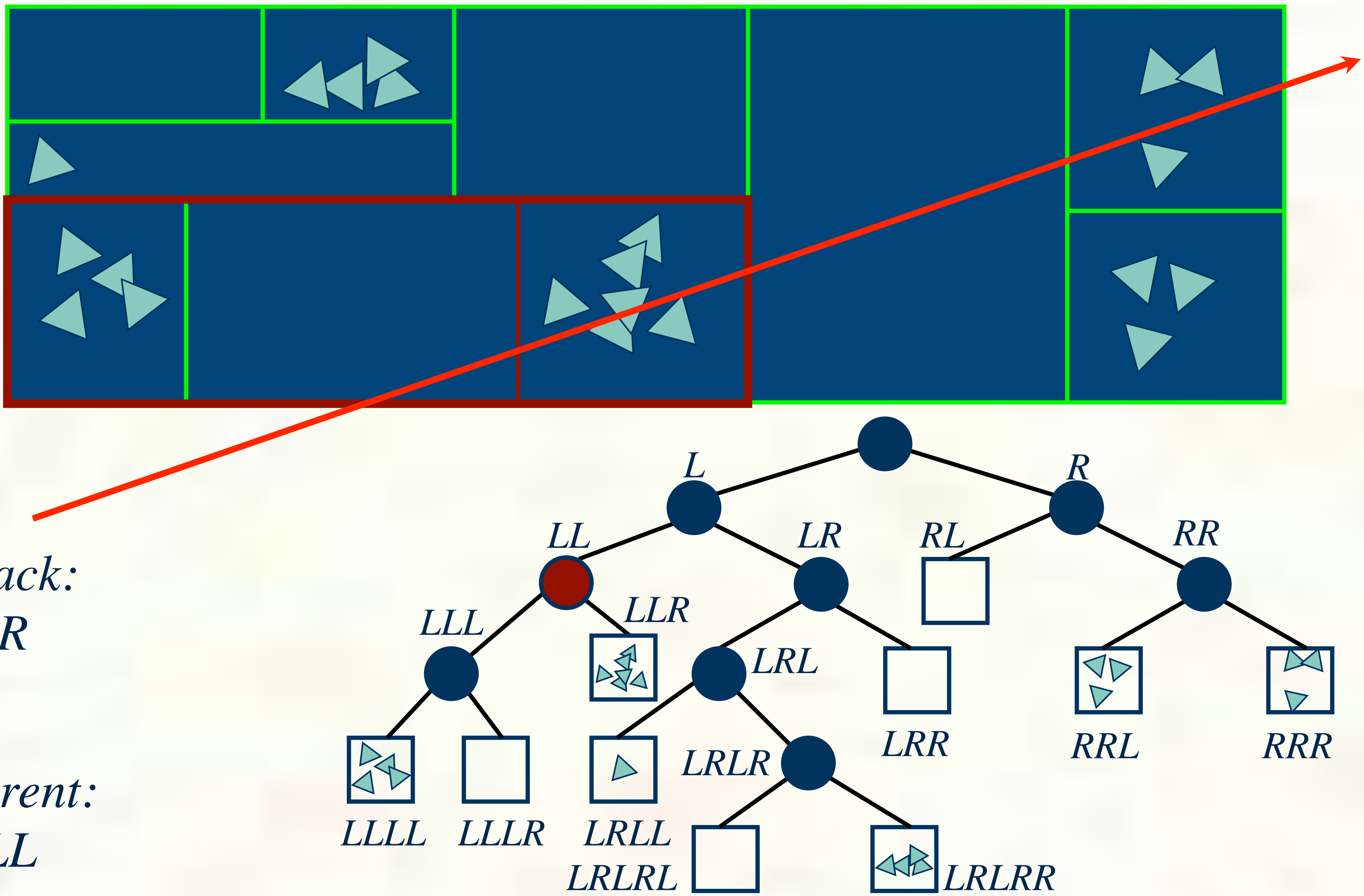
Kd-tree - Traversal



Stack:
R

Current:
L

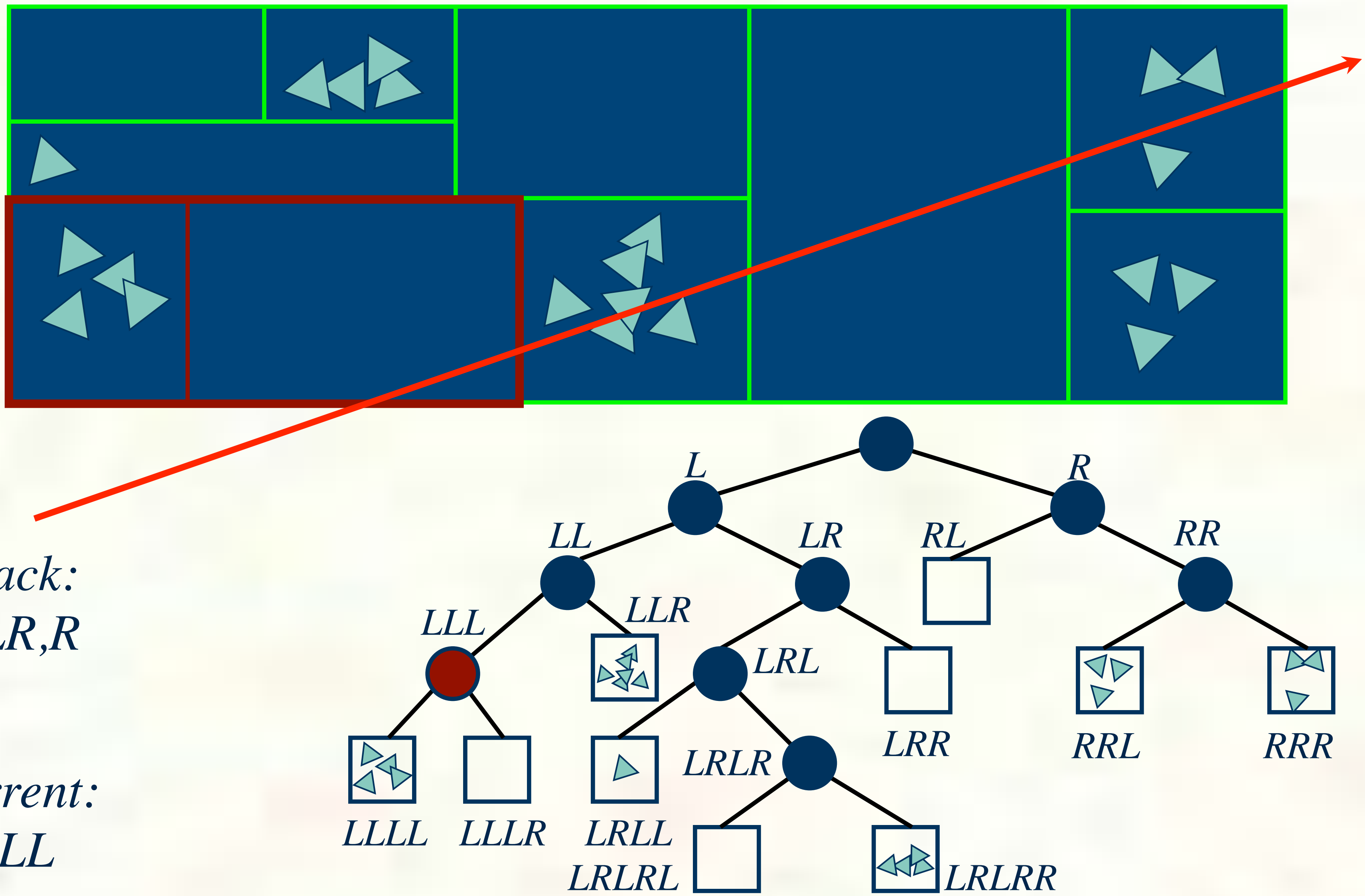
Kd-tree - Traversal



Stack:
R

Current:
LL

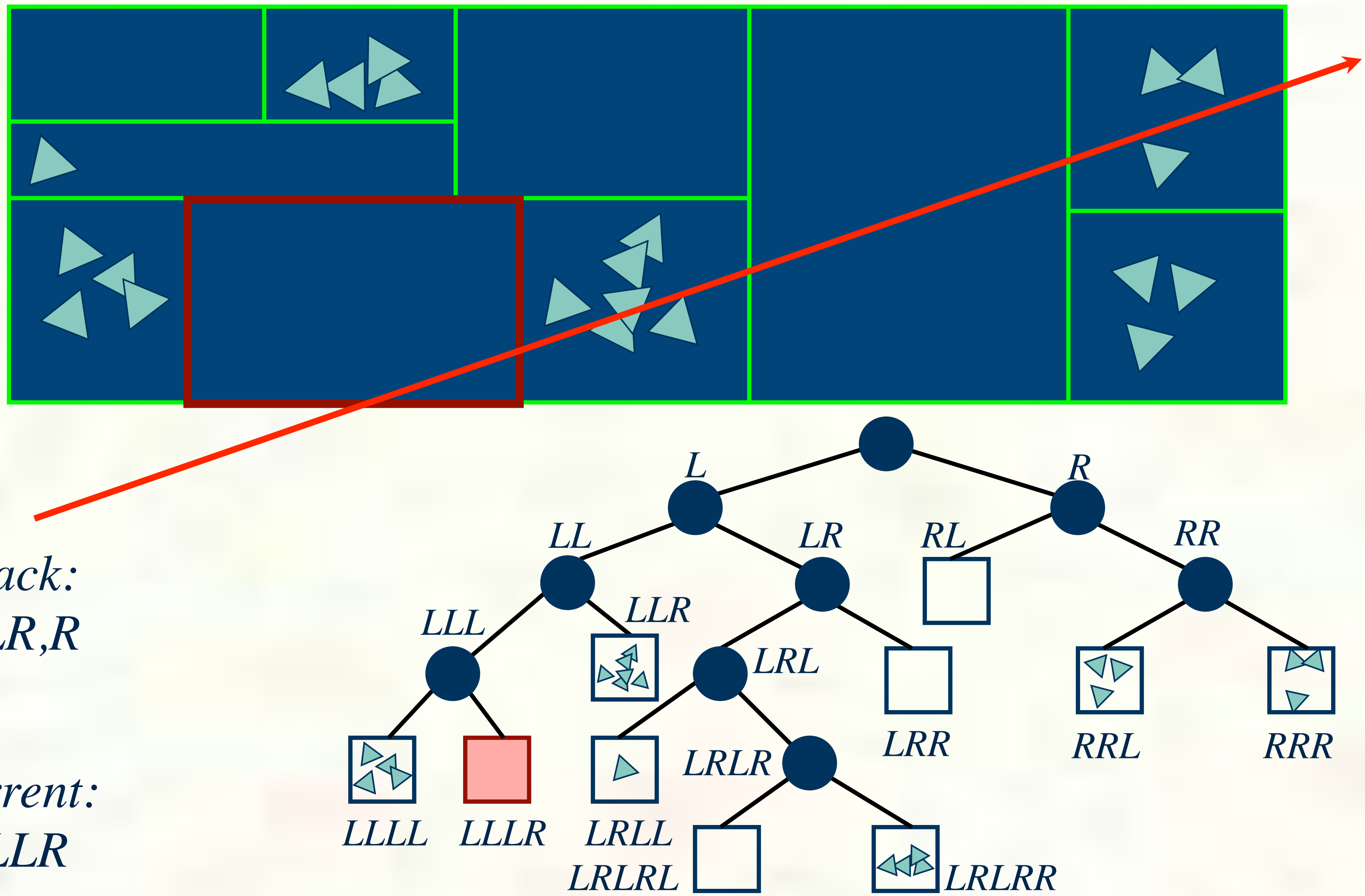
Kd-tree - Traversal



Stack:
LLR,R

Current:
LLL

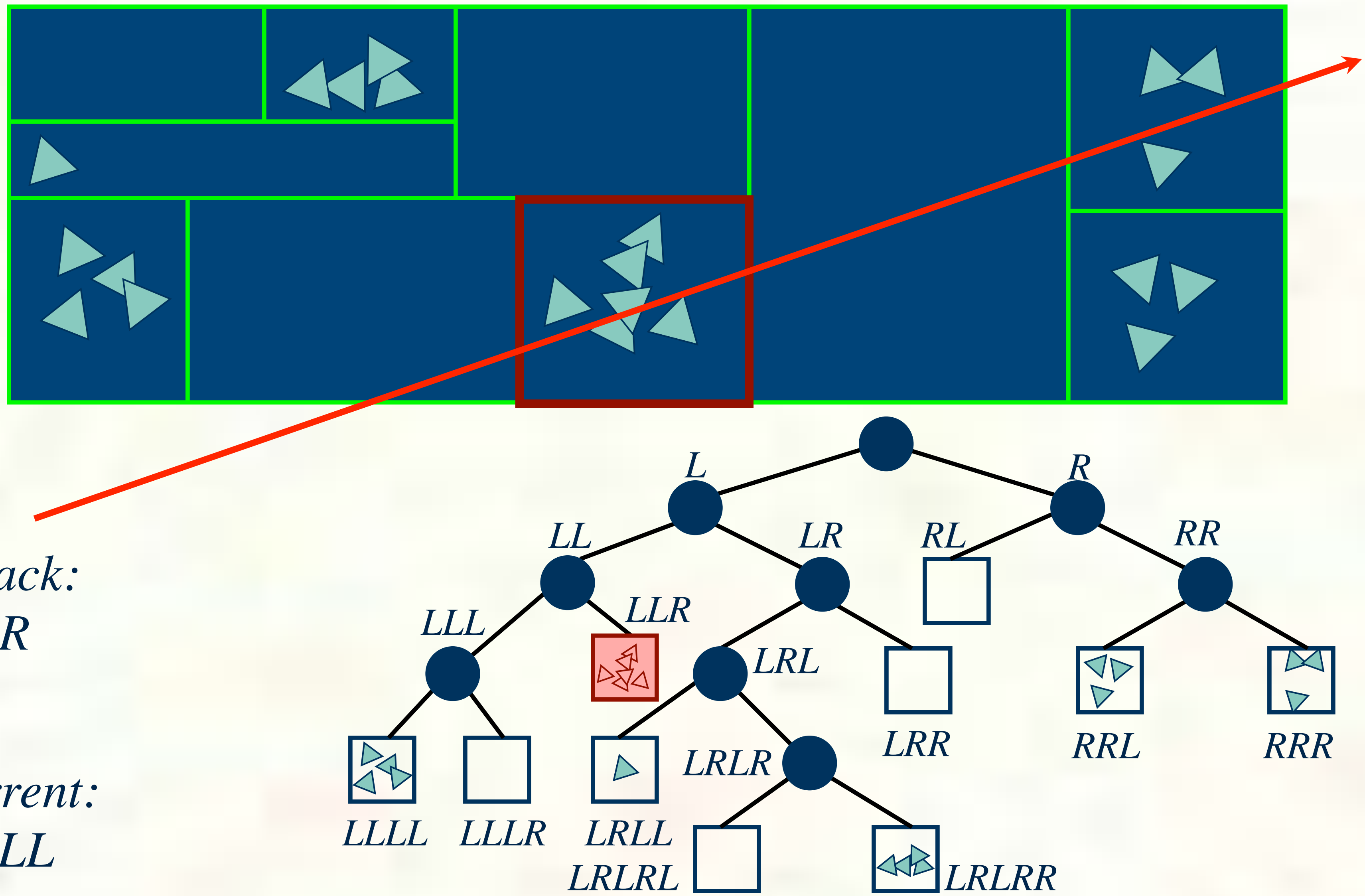
Kd-tree - Traversal



Stack:
LLR,R

Current:
LLLR

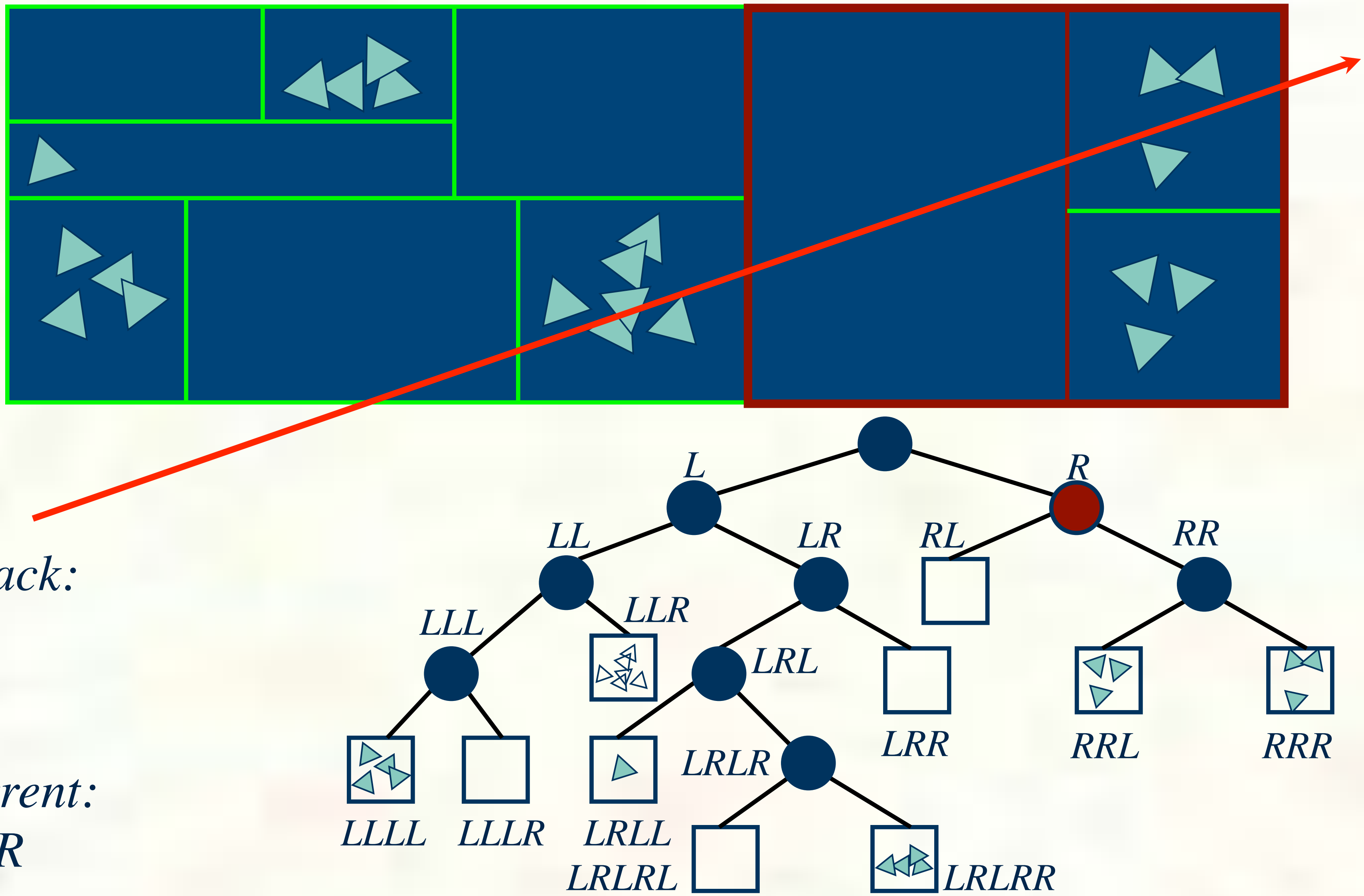
Kd-tree - Traversal



Stack:
R

Current:
LLL

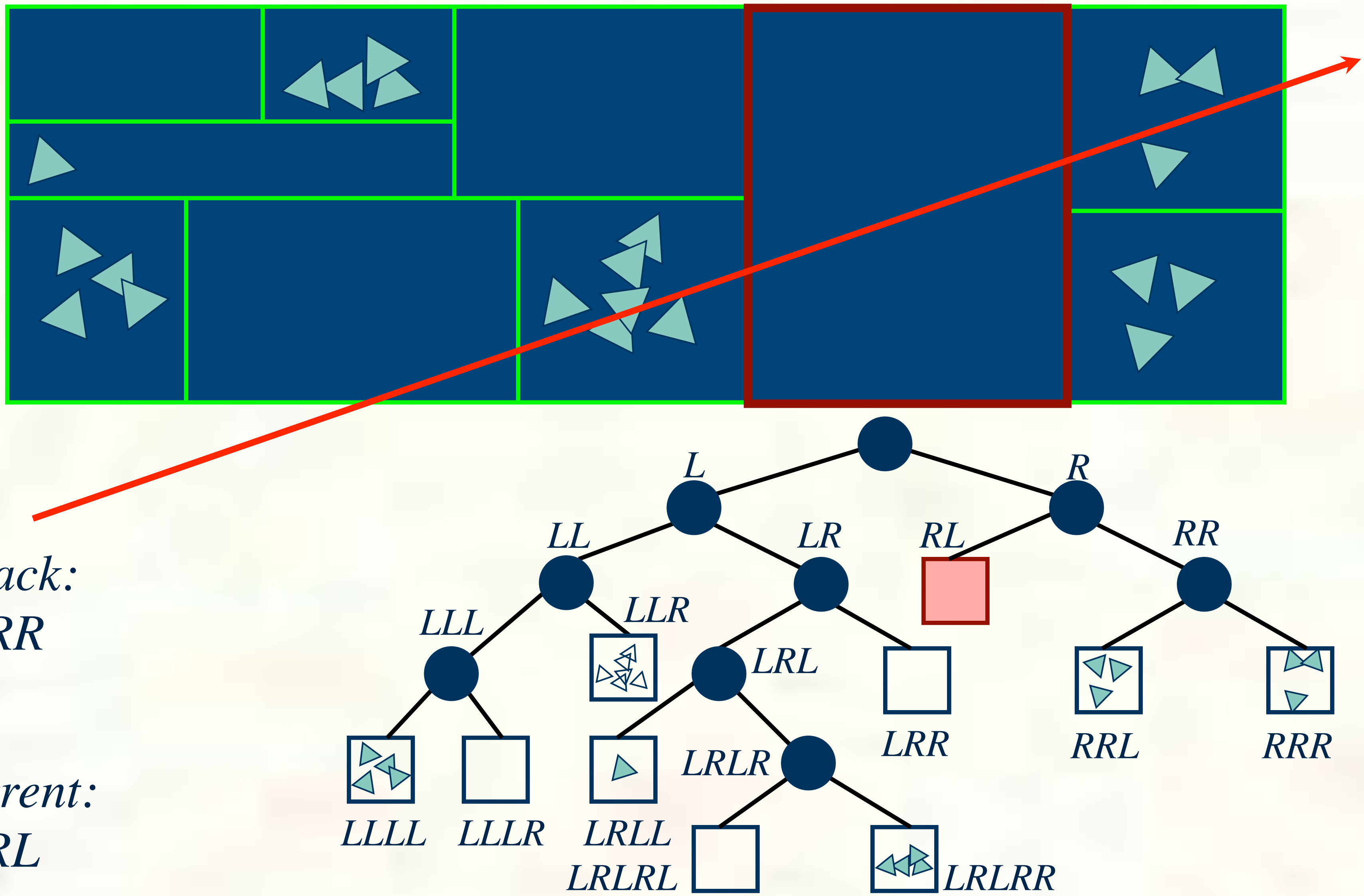
Kd-tree - Traversal



Stack:

Current:
R

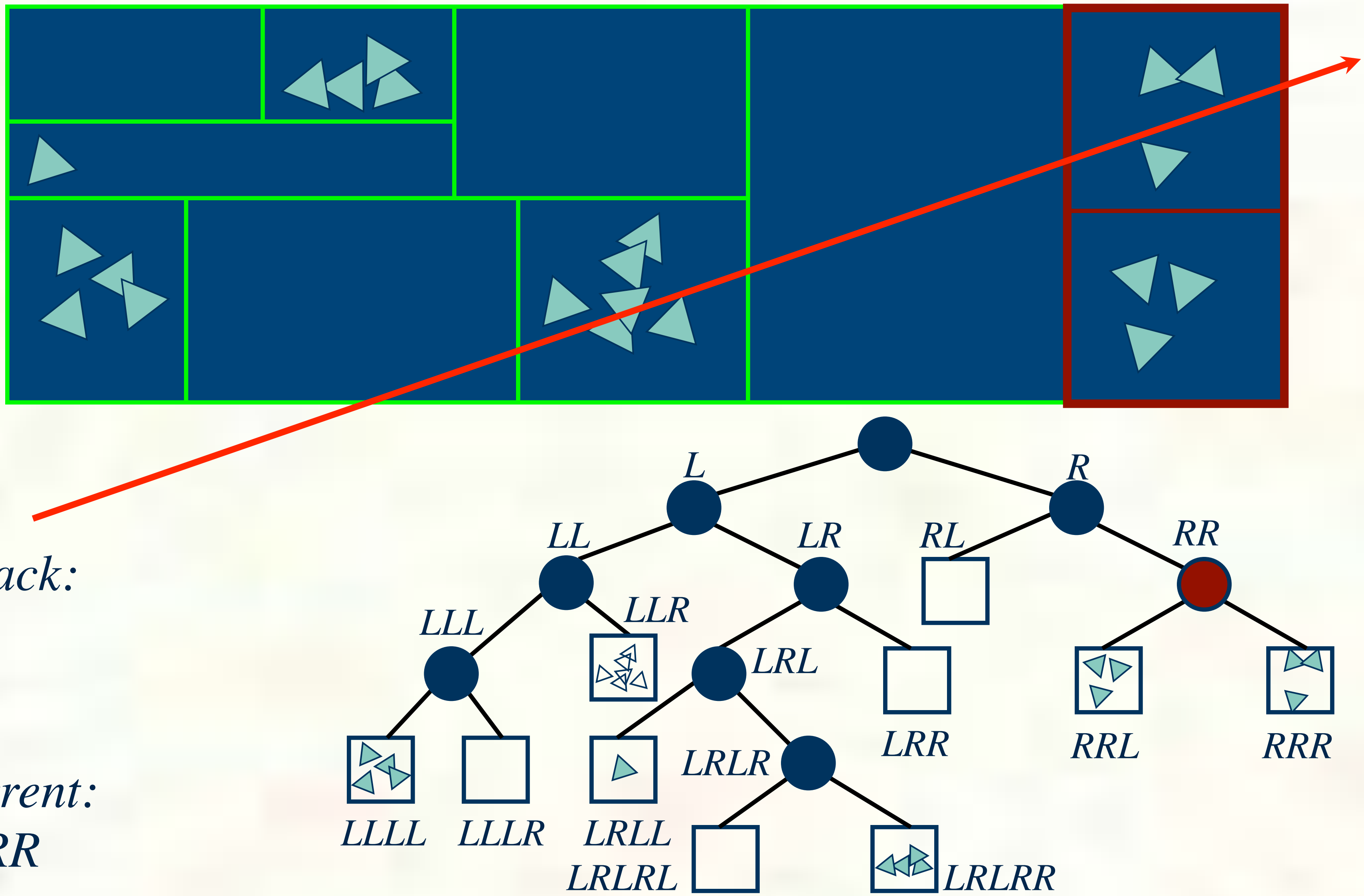
Kd-tree - Traversal



Stack:
RR

Current:
RL

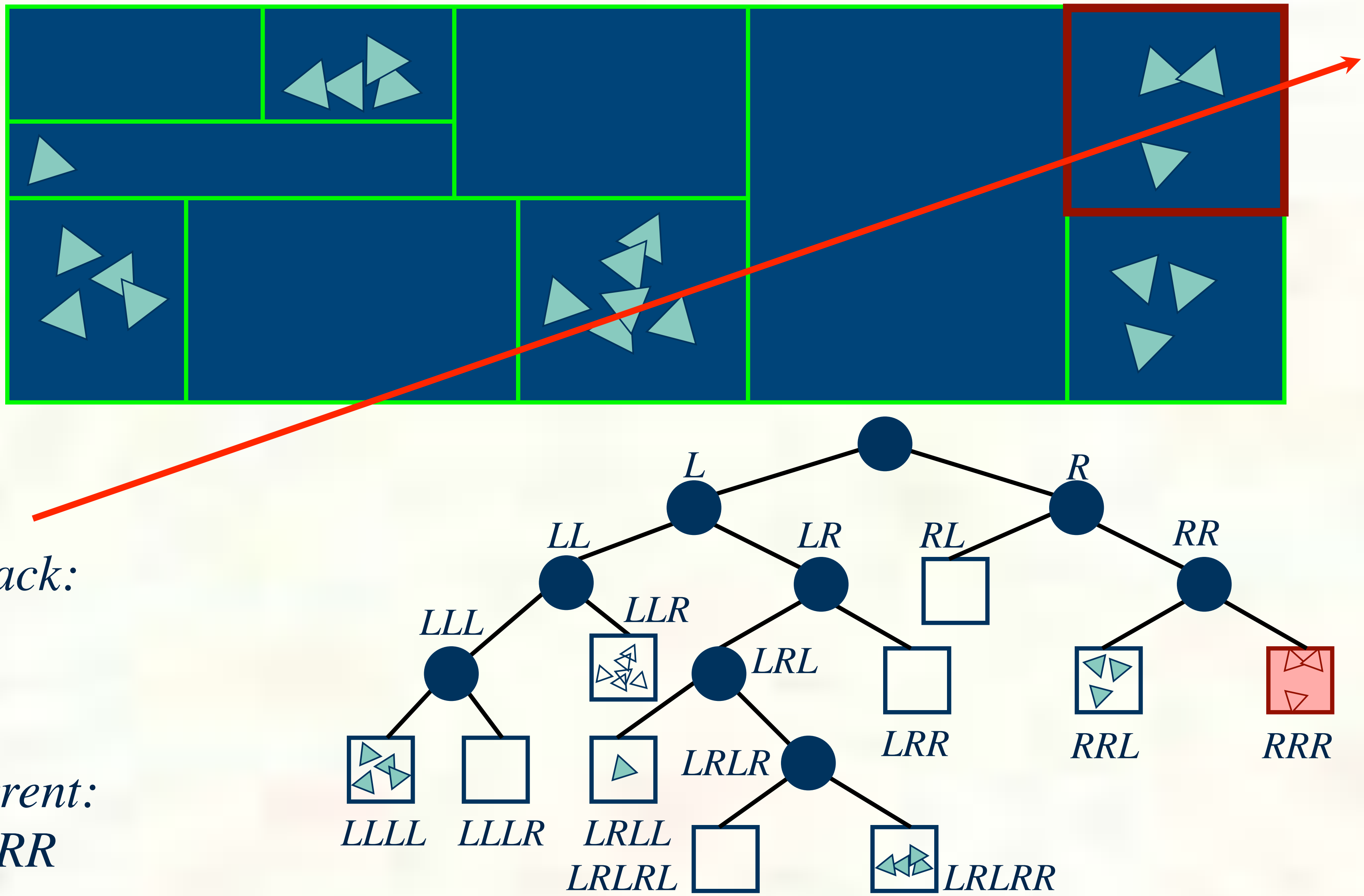
Kd-tree - Traversal



Stack:

Current:
RR

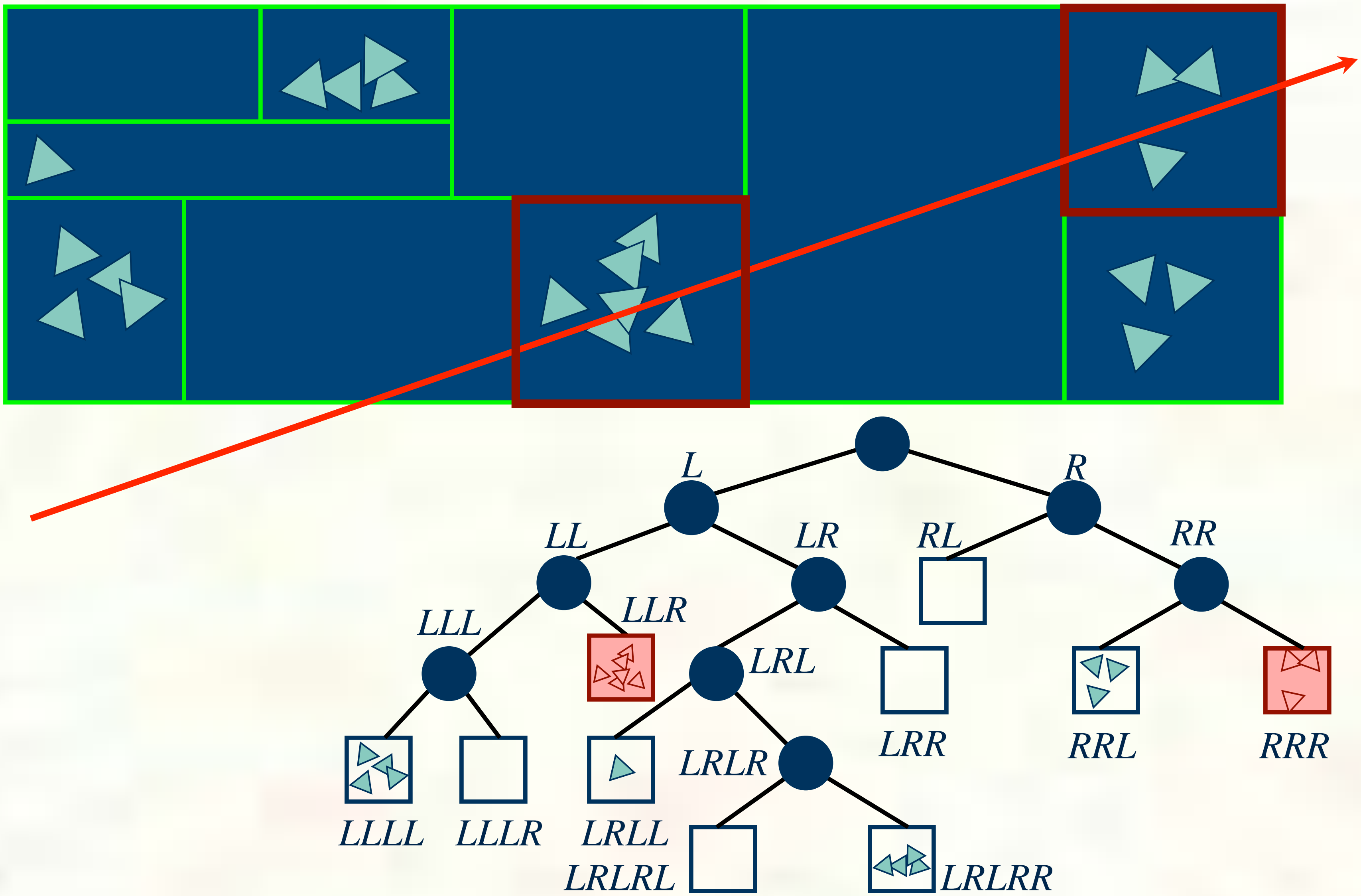
Kd-tree - Traversal



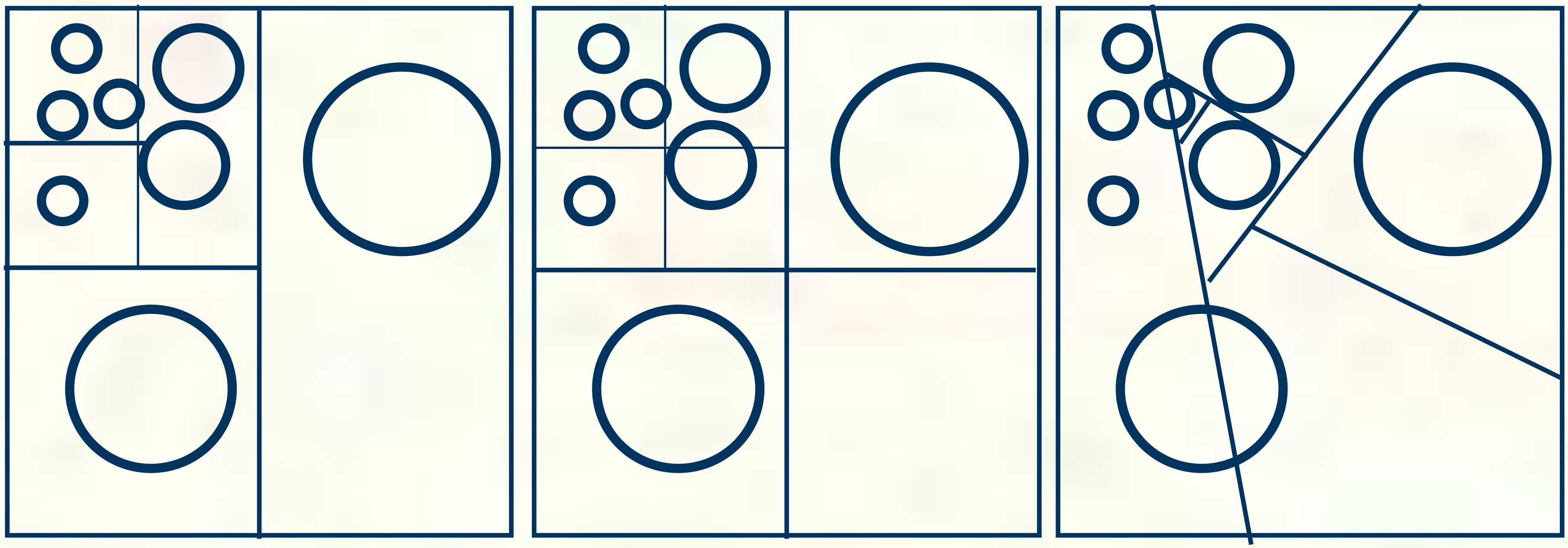
Stack:

Current:
RRR

Kd-tree - Traversal



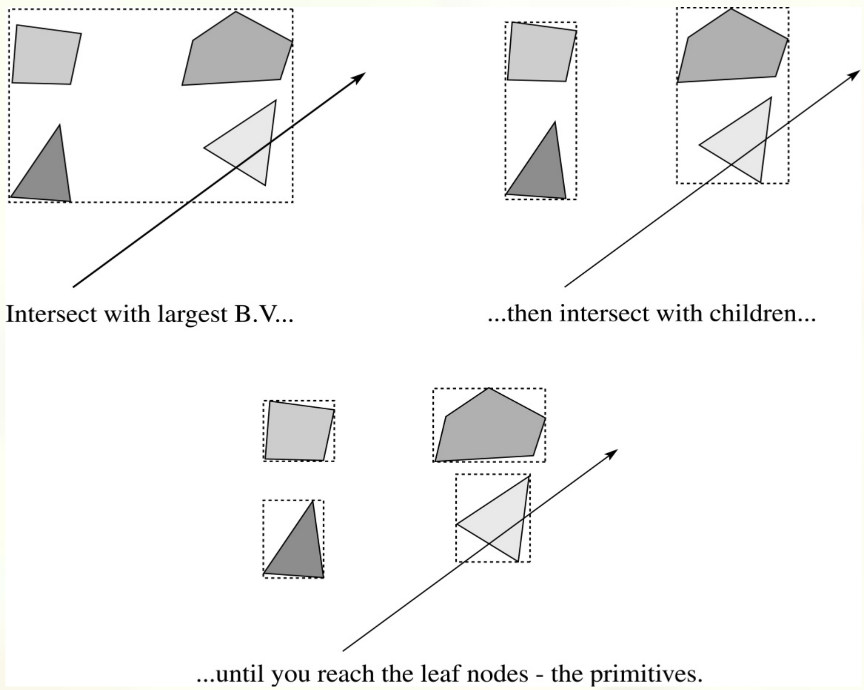
Variations



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.