Binary Space Partitions (BSP)
BSP and the painter algorithm
Quad trees and R-trees

BSP tree

Given a set of triangles $S = \{t_1 \ldots t_n\}$ in 3D, a BSP T, for S is an tree where

1. Each leaf stores a triangle t_i

1. Each internal (non-leaf) node v stores a plane h_v and pointers to two children $v.right$, $v.left$

3. All triangles in the subtree $v.left$ are fully **below** h_v, and all triangles in $v.right$ are fully on or above h_v

See further example on the board.

Sometimes we need to split triangles to construct the BSP

If a (perfect) BSP exist, then for any location of a viewer, we can use the painter algorithm.

Numerous other applications in graphics. (e.g. combine with imposers/billboards)

If the number of triangles above and below h_v are roughly the same, then the height is $O(\log n)$

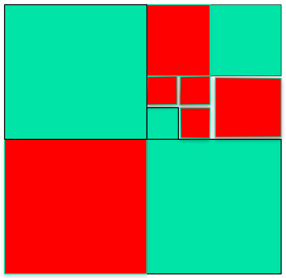
Quad Trees

A data simple data structure for geometric objects(e.g. points, houses, an image, 3D scene)

Support efficiently a very wide variety of queries.

Hierarchical Partition of the scene

QuadTrees

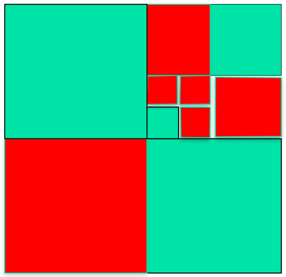


Assume we are given a red/green picture defined a $2^h \times 2^h$ grid. E.g. pixels.
Each pixel is either **green** or **red**.

(more general and interesting examples – soon)

Need to represent the shape "compactly"

QuadTrees



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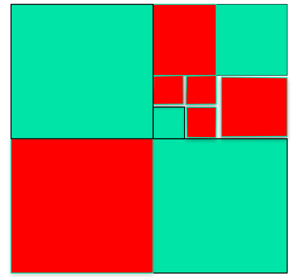

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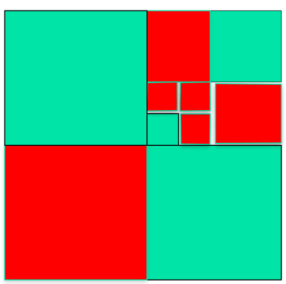

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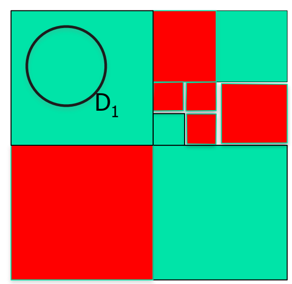
2.For a given query disk D, are there any green points in D ?

QuadTrees



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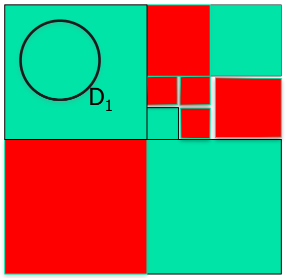

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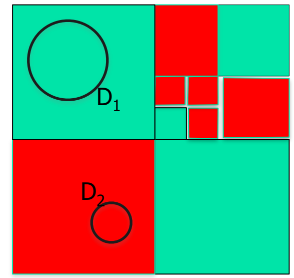
2. For a given query disk D, are there any green points in D ?
3. How many green points are there in D ?
4. Etc etc

QuadTrees



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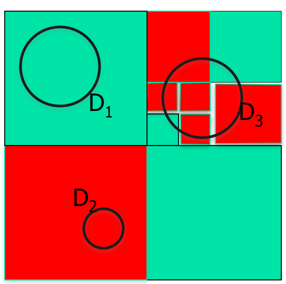

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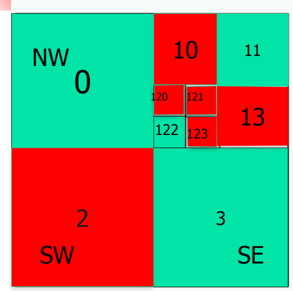
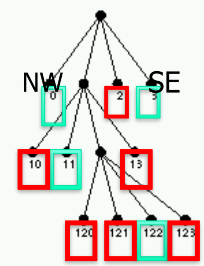




- Assume we are given a red/green picture defined on a $2^h \times 2^h$ grid of **pixels**.
- Each pixel has as a unique color (Green or Red)
- Every node $v \in \boldsymbol{T}$ is associated with a geometric region $\boldsymbol{R(v)}$.
- This is the region that v *is* "in charge of".

Alg **ConstructQT** for a shape S.

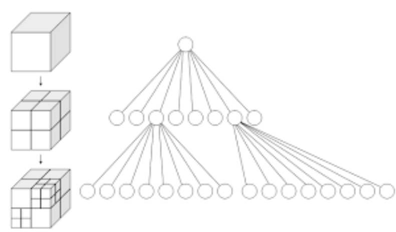
- **input** – a node $v \in T$, and a shape *S.*
- **Output** – a Quadtree T_v representing the shape of *S within R(v)*).

- If *S* is fully green in *R(v)*, or S is fully red in *R(v)* – then
- *v* is a leaf, labeled Green or Red. Return ;
- Otherwise, divide *R(v)* into 4 equal-sized quadrants, corresponding to nodes v.*NW,* v.*NE,* v.*SW,* v.*SE*.
- Call **ConstructQT** recursively for each quadrant.

3D-Quadtess

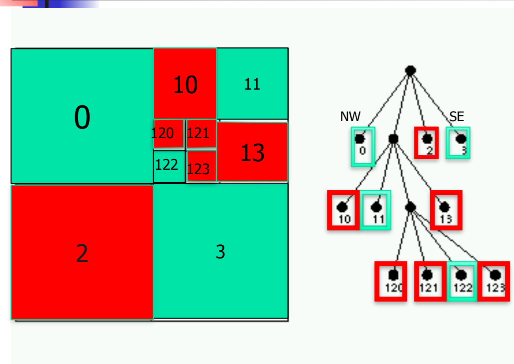
There are no 3D Quadtrees. We call them Oct-trees

Each node is either a leaf, or is split into 8 equal-volume octants.



credit for image: wikipedia.

QuadTrees



Consider a picture stored on an $2^h \times 2^h$ grid. Each pixel is either red or green.

We can represent the shape "compactly" using a QT.

Height – at most h.

Point location operation – given a point q, is it black or white

– takes time O(h)

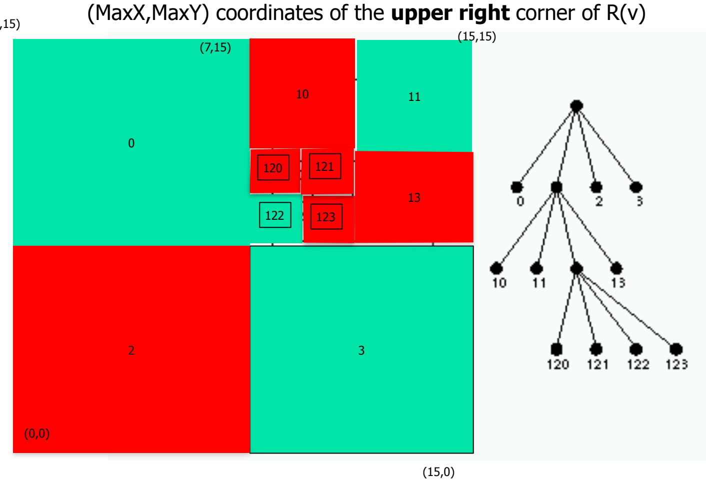
- could it be much smaller ?

Many other operations are very simple to implement.

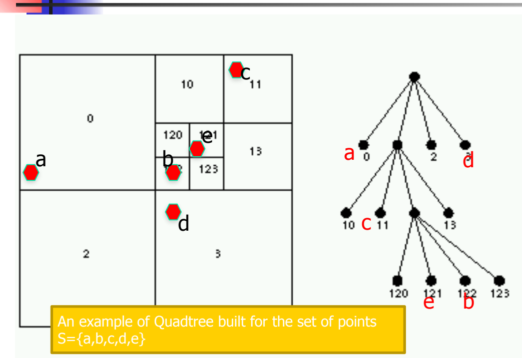
Storing the **range** R(v) of a node

Each node v is associated with a range R(v) – a square. The node v stores (in addition to other info) 4 values

(MinX,MinY) – coordinates of the **lower left** corner of R(v)
(MaxX,MaxY) coordinates of the **upper right** corner of R(v)



QuadTree for a set of points

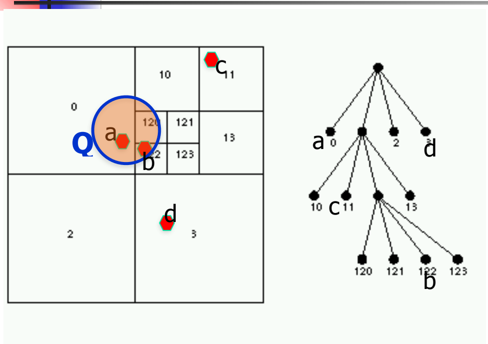


Now consider a set of points (red) but on a $2^h \times 2^h$ grid.

Splitting policy: Split until each quadrant contains ≤ 1 point.

- Build a similar QT, but we stop splitting a quadrant when it contain ≤ 1 point (or some other small constant).
- Could be easily built by inserting the points one after the other. A leaf is split if contains 2 points.
- Point location operation – given a point q, is it black or white
- – takes time O(h) (and less in practice)
- Many other splitting polices are very simple to implement. (eg. a leaf could contain contains ≤ 17 points)

QuadTrees for a set of points

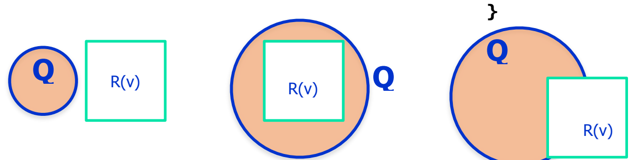


Report(Q,v) {

// Q – a query disk. v- node of a quad tree that stores a set S of points (e.g. S={a,b,c,s}).
Prints all data point the points in stored at the subtree rooted at v, which are also inside Q. */

1. If R(v) is disjoint from Q –**return** **//**no point to report at v's subtree
2. If R(v) is fully contained in Q – print all of S stores at the subtree rooted at v.
3. Else // $R(v)$ partially overlaps Q. {
   - If v is a leaf – check each point in R(v) if inside Q and print if yes.
   - Else // v internal node
     - Report(Q, NW(v)) and ..
     - Report(Q, NE(v)) and ..
     - Report(Q, SW(v)) and ..
     - Report(Q, SE(v)) }

}

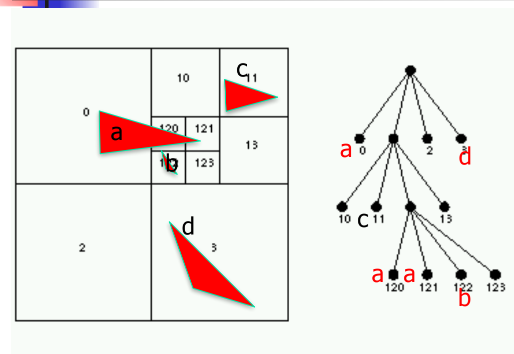


$R(v)$ is disjoint from Q

$R(v)$ is contained in Q

$R(v)$ partially overlapQ

QuadTrees for shape



- Input: A set S of triangles $S=\{t_1 \dots t_n\}$.
- Each leaf v stores a list *v.TriangleList* of all triangles intersecting *R(v)*.
- Splitting policy: Split a quadrant if it intersects more than 5 (say) triangle of *S*.

Note – a triangle might be stored in multiple leaves.
Some leaves might store no triangles.

Finding all triangles inside a query region Q. We essentially use the function *Report(Q,v)* from the previous slide (with minor modifications)

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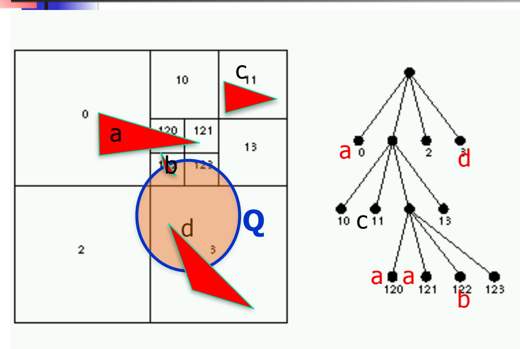

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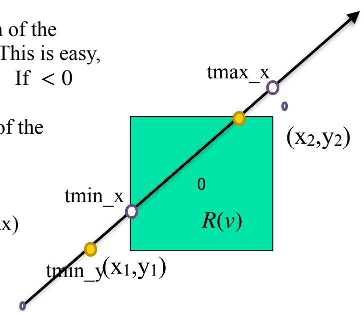
Ray tracing and QuadTrees

- Consider a quadrant $R(v)$ with corners LL=(x_1,y_1) and UR=(x_2,y_2).
- To find if a ray $r = p_0 + t \cdot \vec{v}$ intersects this quadrant
  - Find tmin_x, tmax_x, where the ray is in the x-span of the quadrant (the vertical slab containing the quadrant). This is easy, since we only need to check the x-component of $\vec{v}$. If < 0 then this ray does not intersect $R(v)$
  - Find tmin_y, tmax_y, where the ray is in the y-span of the quadrant
  - Set tmin=max(tmin_x, tmin_y)
  - Set tmax=min(tmax_x, tmax_y)
  - The ray is inside the quadrant only for $t \in$ (tmin,tmax)

In 3D, we also check tmin_z, tmax_z



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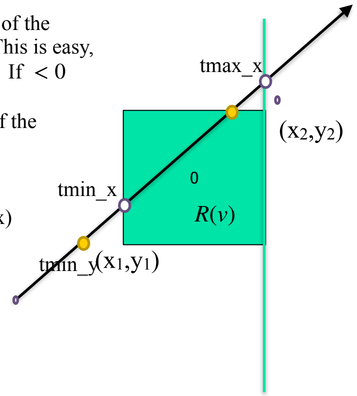

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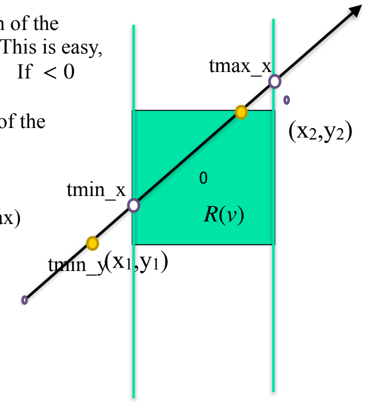

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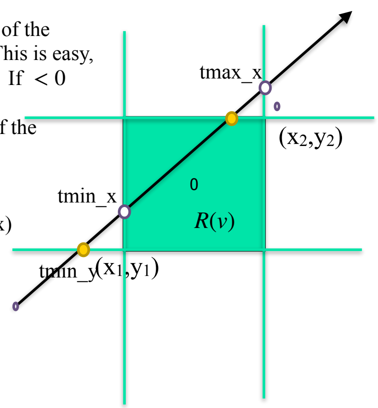

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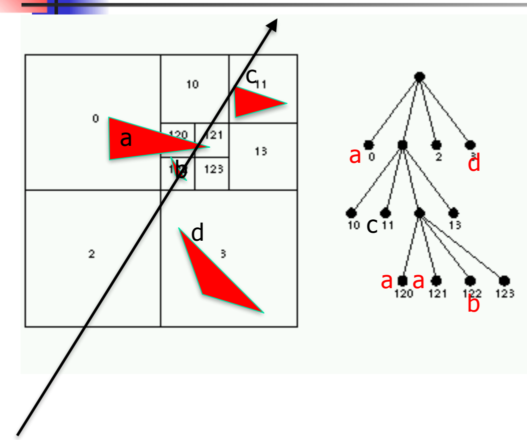
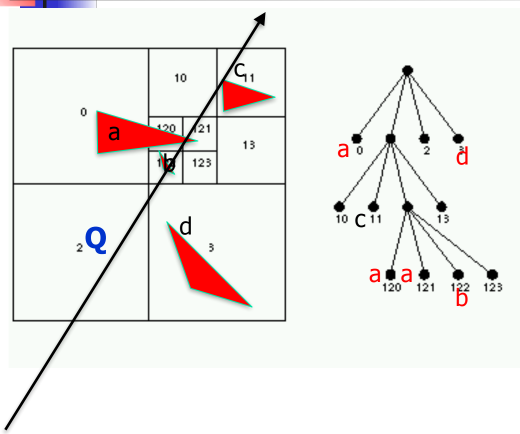


- Now, it is easy to find the first triangle hit by a ray r:
- Start from v=root. If empty, then continue tracing the ray from the point it leaves the quadrant.
- If v is internal node, check which of its quadrants is first hit by r, and continue recursively.
- If v=leaf, check each triangle in v

Ray tracing and QuadTrees



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Inserting a new triangle

insert(triangle t_i ,node v) {

// Inserting a new triangle t_i into an existing node v of the Quadtree.

// v is not necessarily a leaf.

If v is NULL - Error

If $R(v)$ is disjoint from t_i (share no points)– Return. Nothing to do.

If v is not a leaf, then for each child u of v, call **insert(t_i,u)**;

Else // v is a leaf

Add t_i to **v.TrianglesList**

If number of triangles in **v.SegmentsList** is too long (e.g. >5) Call **Split(v)**

}

Split(v){

// Assumption – v is a leaf, but has too many triangles in its list.

// Create 4 children for v (make sure they know which regions they cover.)

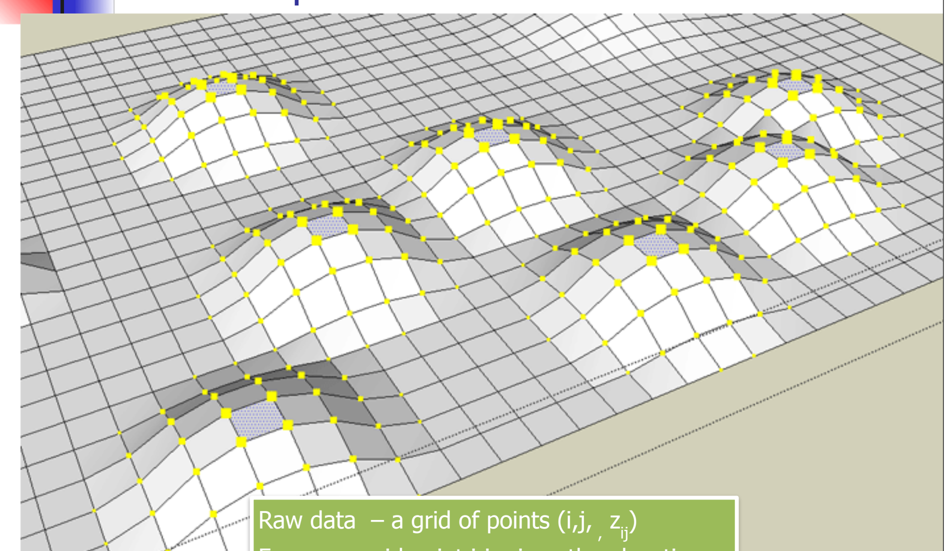
For each child u of v

For each segment **s** in **v.TrianglesList** Call **insert(s, u)**

Empty **v.TrianglesList**

}

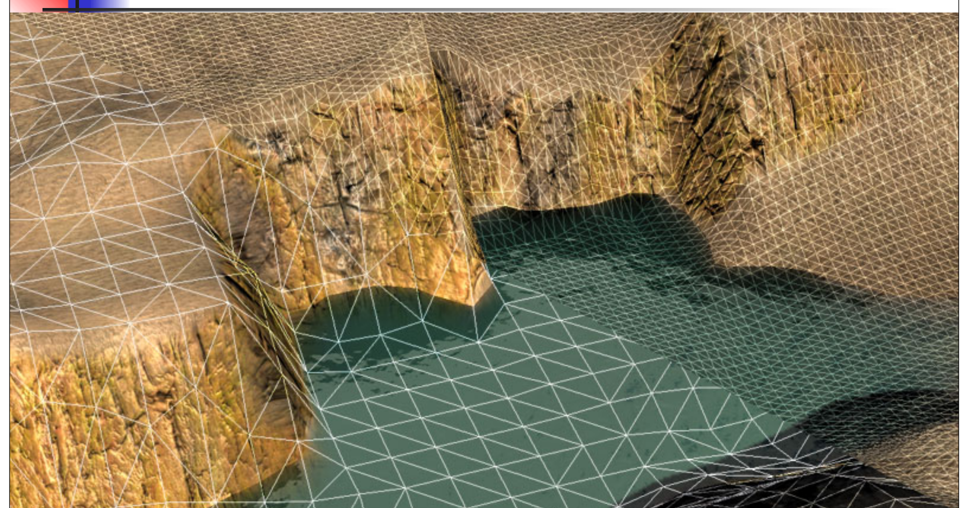
Terrain representations and levels-of-details



Raw data – a grid of points (i,j, z_{ij})

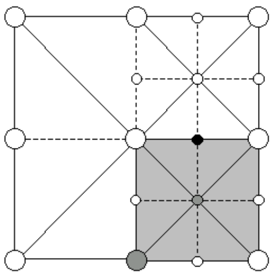
For every grid point i,j, given the elevation z_{ij}

(TIN – Triangulated Irregular Network)



Each triangle approximately fits the surface below it

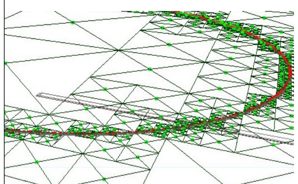
How to find good triangulation ?



- Input – a very large set of points $S=\{ (i,j, z_{ij}) \}$.
- z_{ij} is the elevation at point ***(i,j) (latitude and longitude)***
- Want to create a surface, consists of triangles, where each triangle interpolates the data points underneath it.
- Idea: Build a QT T for the 2D points.
- (If want triangles: Each quadrant is split into 2 right-hand triangles)
- Assign to each vertex the height of the terrain above it.
- The approximated elevation of the terrain at any point (x,y) is the linear interpolation of its elevated vertices.

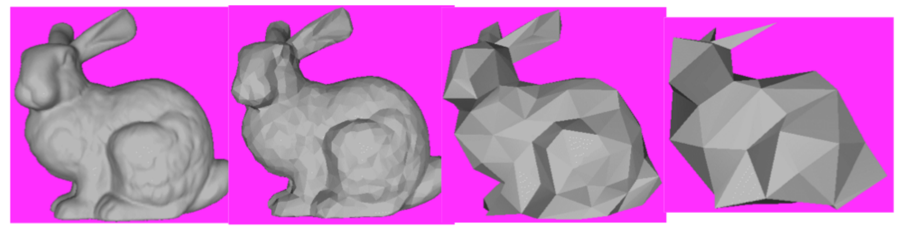
QT Split Policy: Splitting a quadrant into 4 sub-quadrants:

- split a node $\boldsymbol{v}$ if for some date point $(x_i, y_i) \in R(v)$, the elevation of z_{ij} is too far from the the corresponding triangle. If not, leave $\boldsymbol{v}$ as a leaf.
- That is, for any point (i,j) on the plane, the elevation (i,j, z_{ij}) it is too far from the interpolated elevation.
- Note: A quadrant might contain a huge number of points, but they behave smoothly. E.g. all a the sloop of a mountain, but this slope is more or less linear.



Level Of Details

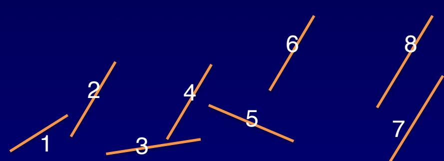
- Idea – the same object is stored several times, but with a different level of details
- Coarser representations for distant objects
- Decision which level to use is accepted `on the fly'
  (eg in graphics applications, if we are far away from a terrain, we could tolerate usually large error. E.g., sub pixels error are not noticeable.)



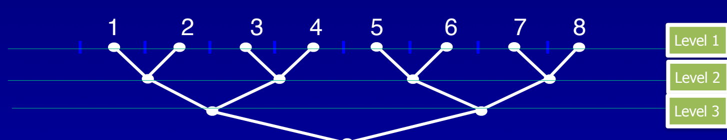
69,451 polys | 2,502 polys | 251 polys | 76 polys

R-trees

- Input: A set S of shapes (segments in this example. Triangles in graphics apps)
- Build a tree that could expedite
  - (i) finding the segments intersecting a query region,
  - (ii) answering ray tracing
  - (iii) Emptiness queries. etc



- We compute for each segment its bounding box (rectangle).
- These are the leaves of T. Call them ``Level 1''.
- Find the nearest pair of segments (say 7,8). Remove them from level 1, and replace them by a single BB encapsulate both. It corresponds to a node of level 2.
- Repeat until no vertex is left in level 1.
- Next, pick the nearest two BBs from level 2, and replace them by a vertex at level 3.
- In general, each internal node v in level **j** is created by merging two children nodes of level **j-1**.
  - $BB(v) = BB\left(BB(v.right) \bigcup BB(v.left)\right)$
- Repeat until we are left with one bounding box.



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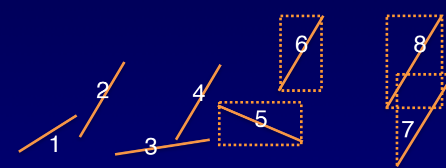

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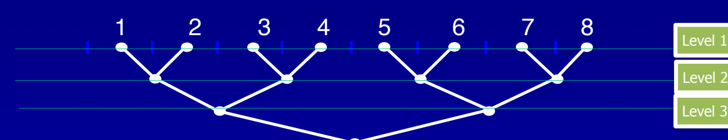

R-trees

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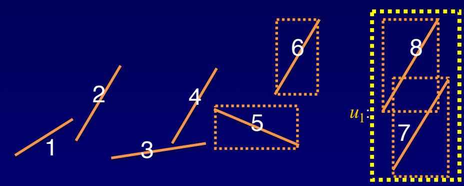

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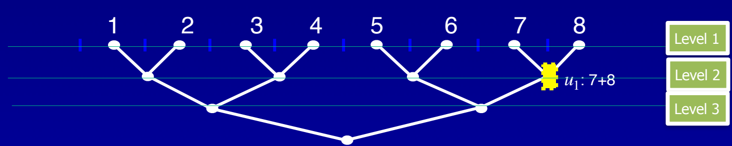

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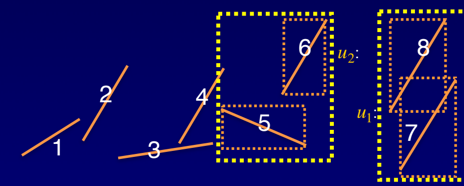

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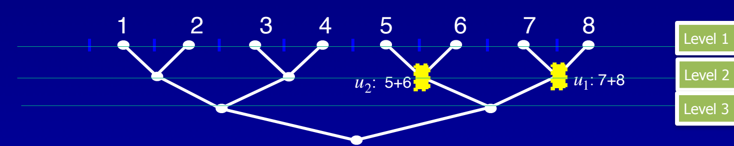

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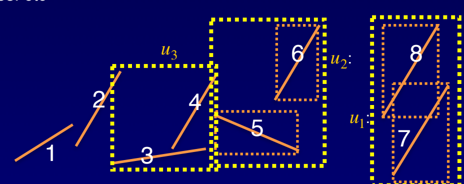

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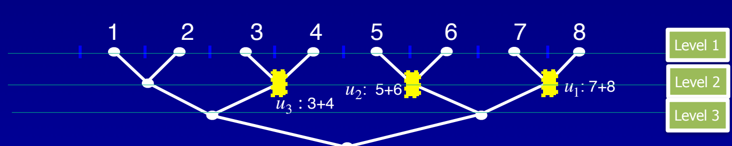

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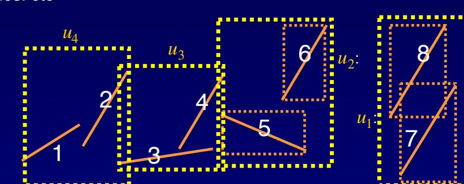

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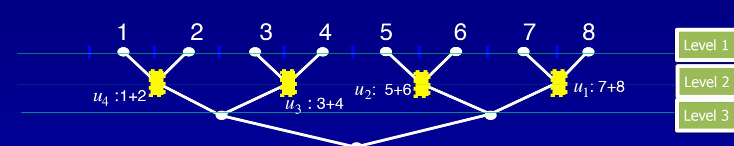

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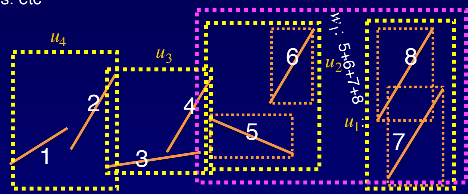

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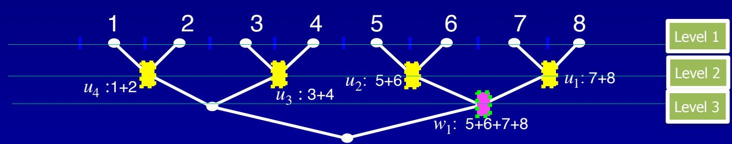

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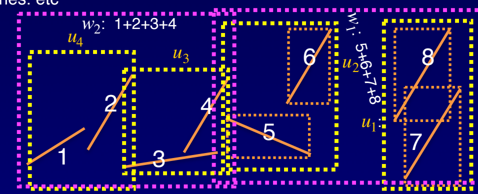

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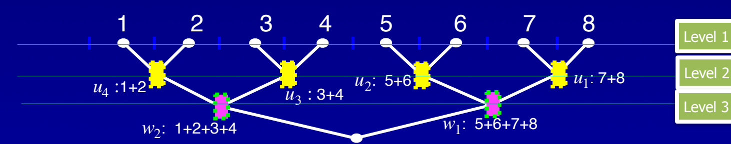

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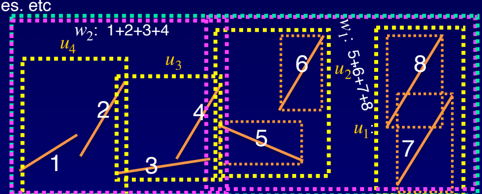

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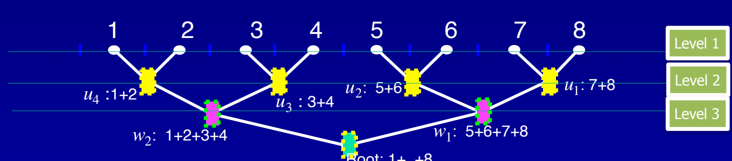

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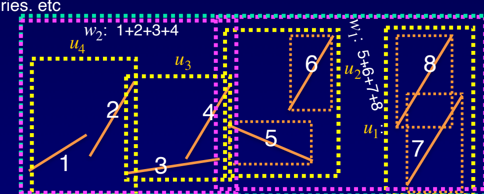

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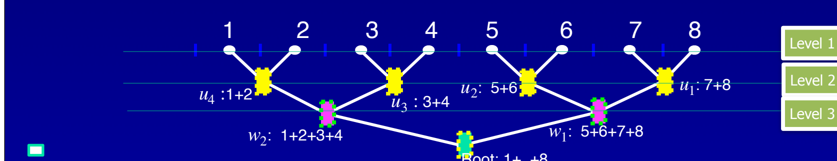

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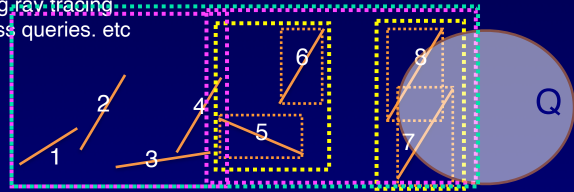
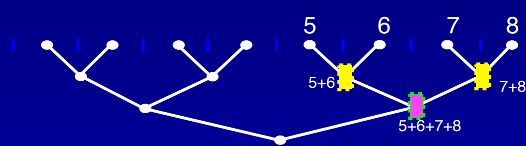


Once a query region Q is given, we need to report the segments intersecting Q.
Check if Q intersects BB(root)
If not, we are done. If yes, check recursively if Q intersects BB(v.left) and BB(v.right)



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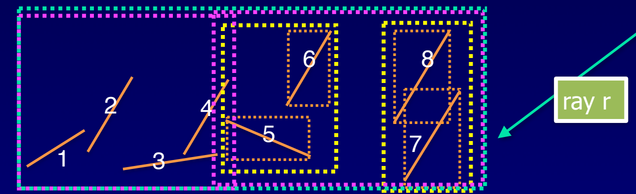
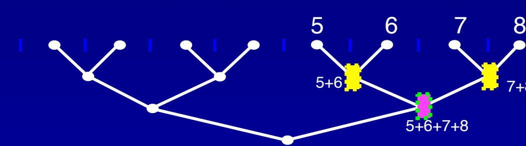
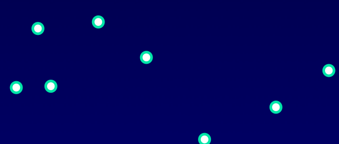


Analogously for a query ray *r*



kD-tree



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- Input - set of points in d-dimension
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- Always split along a horizontal or a vertical lines.
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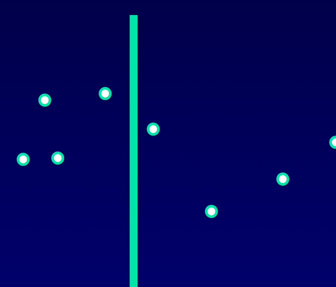

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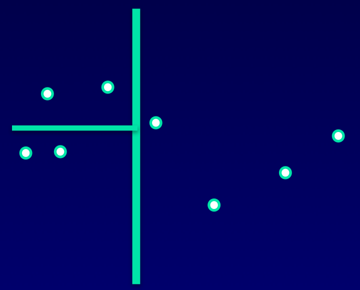

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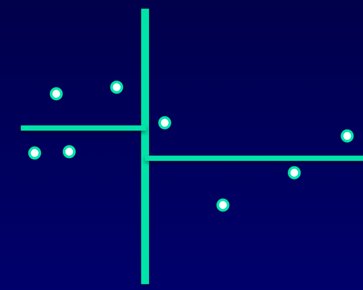

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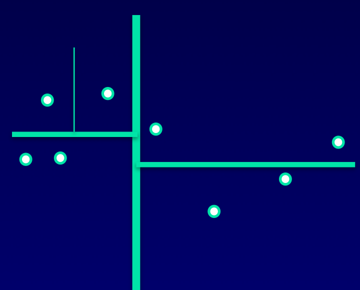

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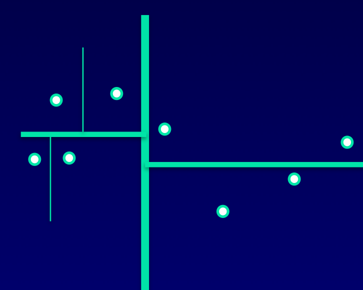

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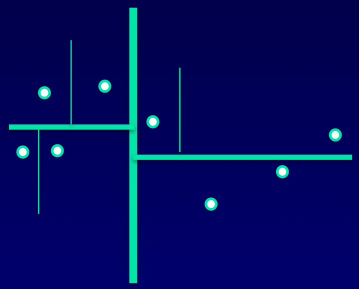

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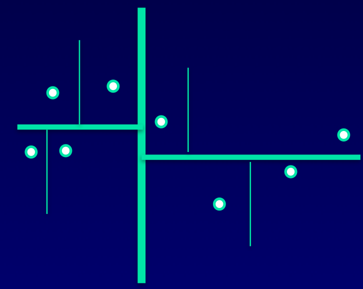

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