Plane Sweep Algorithm

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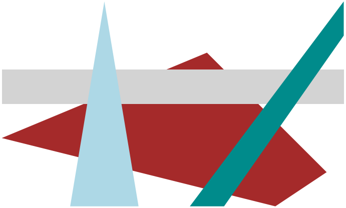
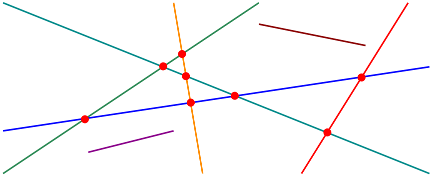
[1]Slide ideas borrowed from Marc van Kreveld and Subhash Suri

Intersection Detection



- Determine pairs of intersecting objects?
  - Collision detection in robotics and motion planning.
  - Visibility, occlusion, rendering in graphics.
  - Map overlay in GISs: e.g. road networks on county maps.

Line Segment Intersection



- Let's first look at the easiest version of the problem:
- Given a set of of n line segments in the plane, find all intersection points efficiently
- Naive algorithm?

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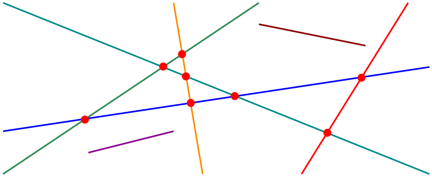

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- Naive algorithm?Check all pairs. $O(n^2)$.

Line Segment Intersection

Algorithm 1 FindIntersections(S)

Input: A set S of line segments in the plane.

Output: The set of intersection points among the segments in S.

for each pair of line segments $e_i, e_j \in S$ **do**
    if e_i and e_j intersect **then**
        report their intersection point
    end if
end for

Line Segment Intersection

Algorithm 2 FindIntersections(S)

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```
for each pair of line segments e_i, e_j ∈ S do
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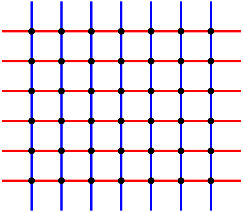
- Question: Why can we say that this algorithm is optimal?

Line Segment Intersection



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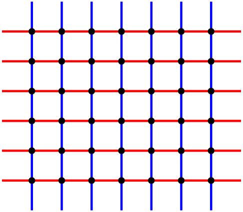

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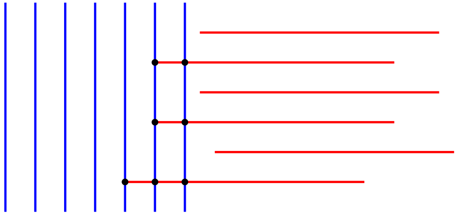

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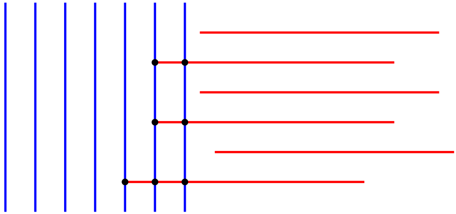

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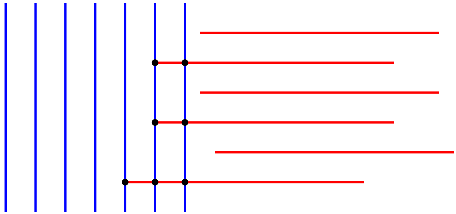

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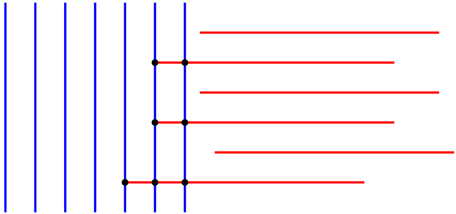

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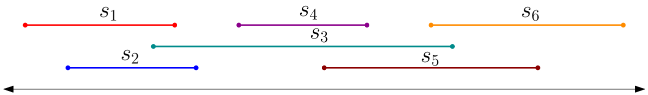
- If there are k intersections, then ideal will be $O(n \log n + k)$ time.
- We will describe a $O((n+k)logn)$ solution. Also introduce a new technique : PLANE SWEEP.

An Easier Problem:



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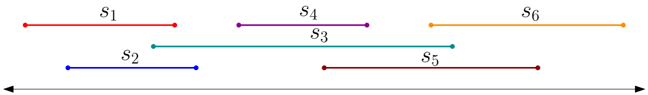

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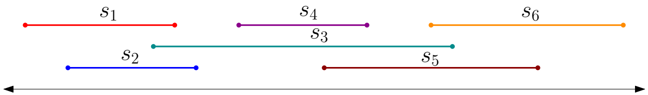

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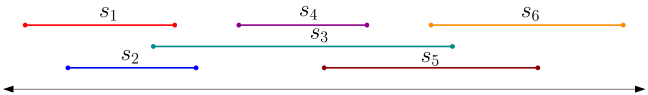

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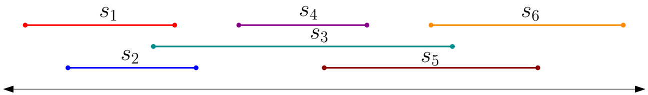

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- The algorithm knows everything it needs to know before the sweep line, and found all intersection pairs.

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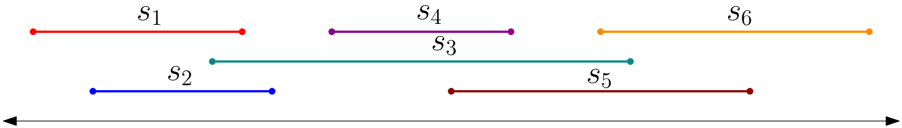

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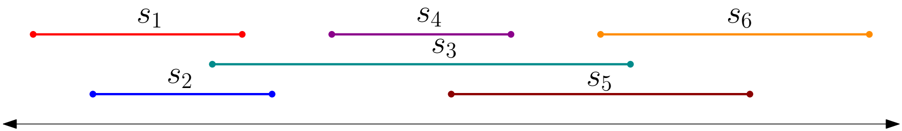

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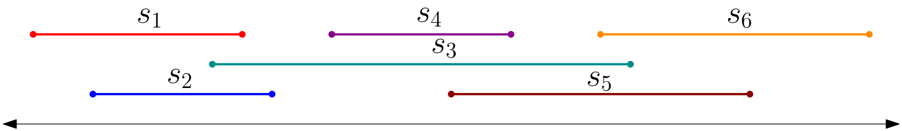

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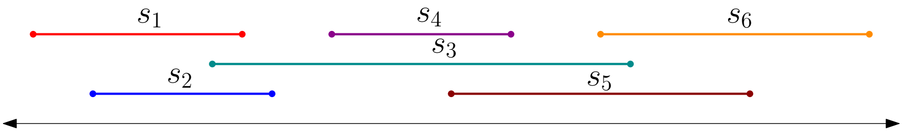

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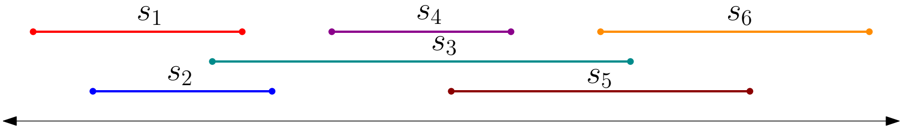

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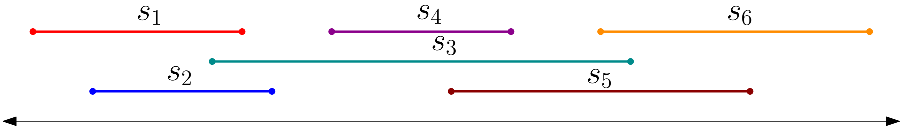

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- $2n * \log n + k$

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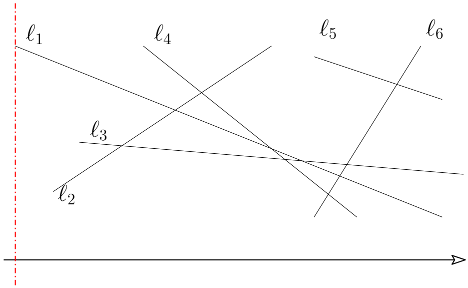

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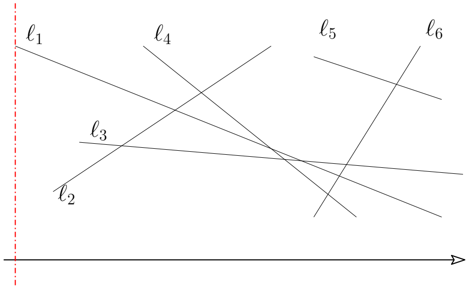

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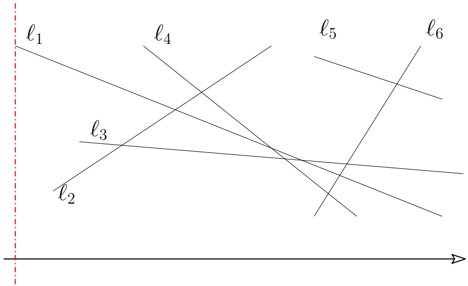

Imagine a horizontal line passing over the plane from top to bottom, solving the problem as it moves

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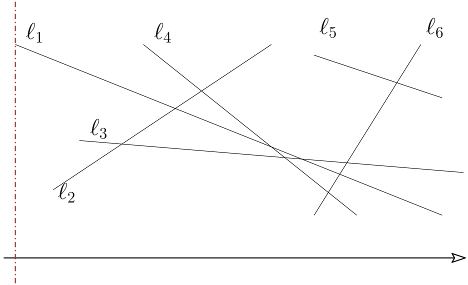
- Maintain vertical order of segments intersecting the sweep line;



- Insert ℓ_1, add the end point of ℓ_1 to the event queue

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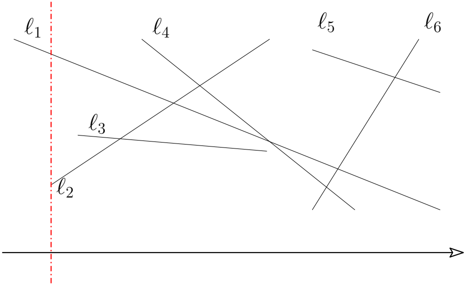

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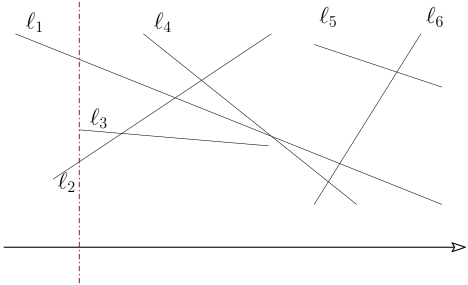

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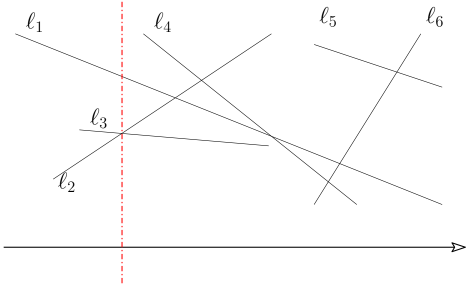

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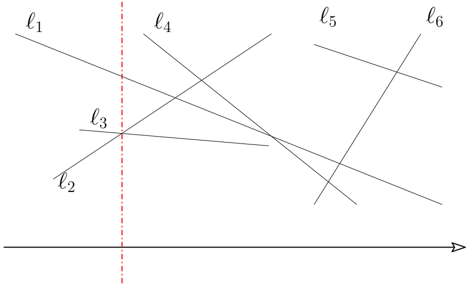

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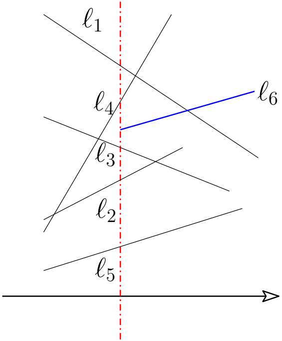
. . . and so on . . .

Events

When do the events happen? When the sweep line is at

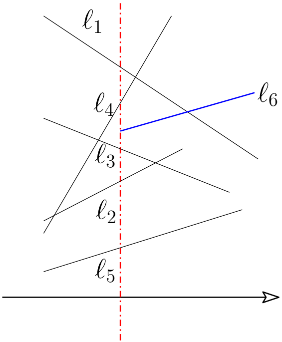
- a left endpoint of a line segment
- a right endpoint of a line segment
- an intersection point of a line segment

A left endpoint of a line segment



- We use a balanced binary search tree with the line segments in the leaves as the status structure.
- Search and insert.

A left endpoint of a line segment



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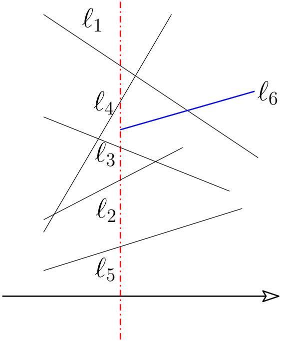

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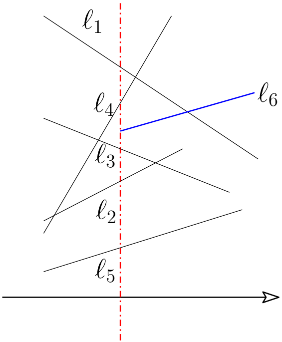

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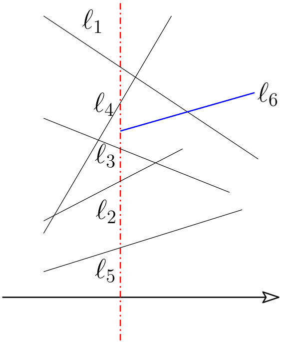

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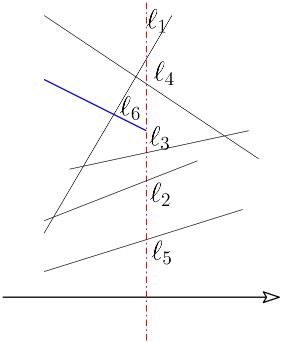
A right endpoint of a line segment



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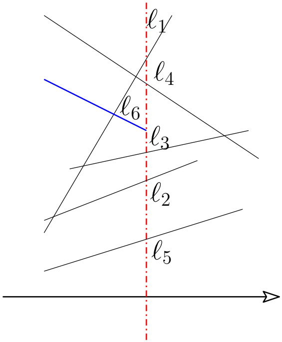
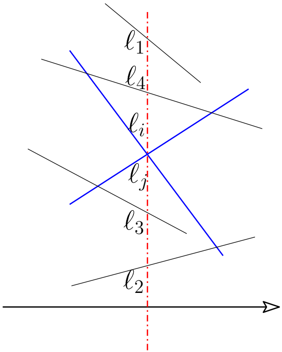


- Sweep line reaches right endpoint of a line segment: delete the line segment
- After deletion of ℓ_6, ℓ_3 and ℓ_4 becomes adjacent.
- If ℓ_3 and ℓ_4 intersects insert the intersection point into the event queue.



Sweep line reaches an intersection point of ℓ_i and ℓ_j

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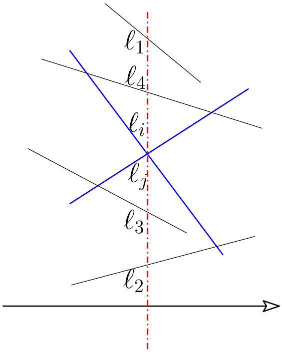

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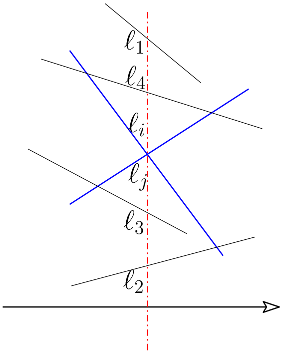

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- Report the intersection point.

Finding events

- Before the sweep algorithm starts, we know all upper endpoint events and all lower endpoint events
- But: How do we know intersection point events??? (those we were trying to find . . .)
- Observe: Two line segments can only intersect if they are horizontal neighbors

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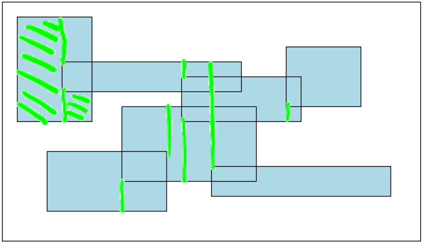
- Note that if k is really large, the brute force $O(n^2)$ time algorithm is more efficient

Area of Union of rectangles



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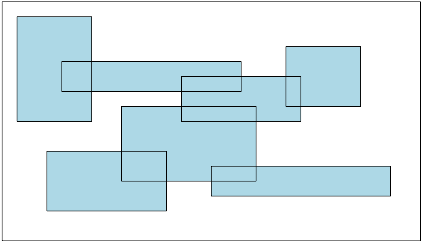

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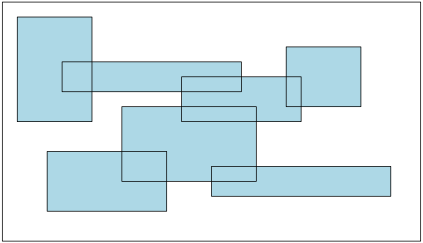

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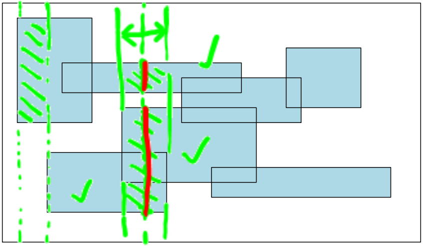
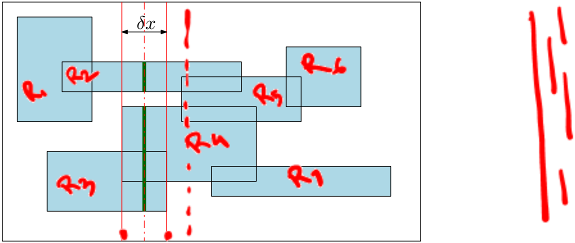
- PLANE SWEEP: Keep track of the area that being sweeped.
- EVENT POINTS: When is the intersection of the the rectangels with the sweep line changes?



- Given a layout in which objects are orthogonal polygons with sides parallel to the axises. The task is to find the area covered by all the objects.
- PLANE SWEEP: Keep track of the area that being sweeped.
- EVENT POINTS: When is the intersection of the the rectangels with the sweep line changes?Left and right end point of the rectangeles.
- What is the area between any two event points?



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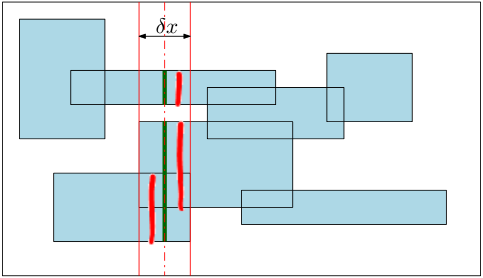
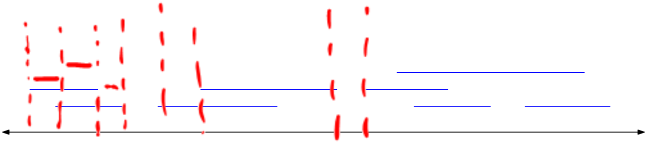
- $\delta x \times y$ where y is the length of the intersection of the the rectangels with the sweep line.

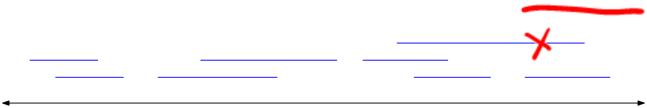


- Intersection of the the rectangels with the sweep line is a set of intervals.
- Thus the problem at hand becomes to maintain the intercepts. The y can change only at
    - The beginning of a rectangle.
    - The end of the rectangle.

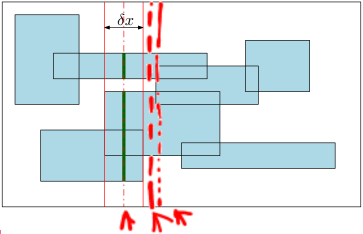


- Naïve Method:

Sum of the union of the intervals



- Naïve Method:
- At each event point find out y by a sweepline method.
  - EVENT POINTS: Left and right end point of an interval.
  - STATUS: Balanced binary search tree to store intervals.
  - At each event point if tree is not empty sum+= distance between current and last event point.



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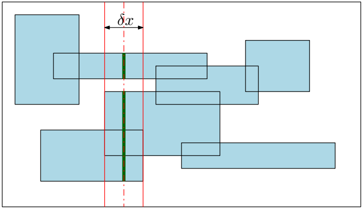

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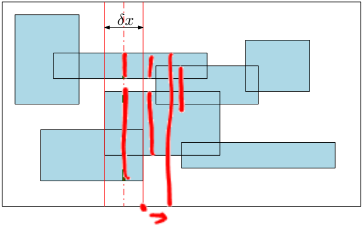
- Can we do better??



l_1

l_2

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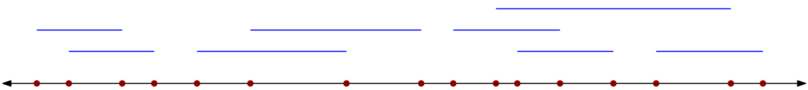
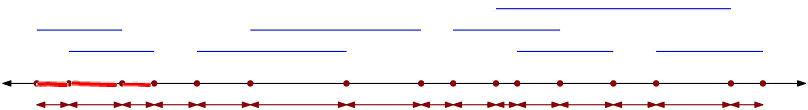
- Complexity of sum of intervals $O(n \log n)$
- Complexity of area of union of rectangles $O(n^2 \log n)$
- Can we do better??How to maintain sum of the union of the intervals with respect to insertion and deletion

Sum of the union of the intervals



- Sort the end points of the intervals.
- This will create a set of elementary intervals.



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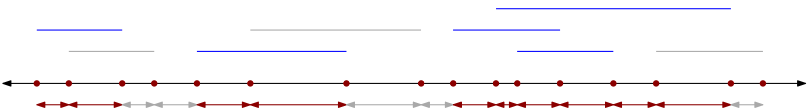
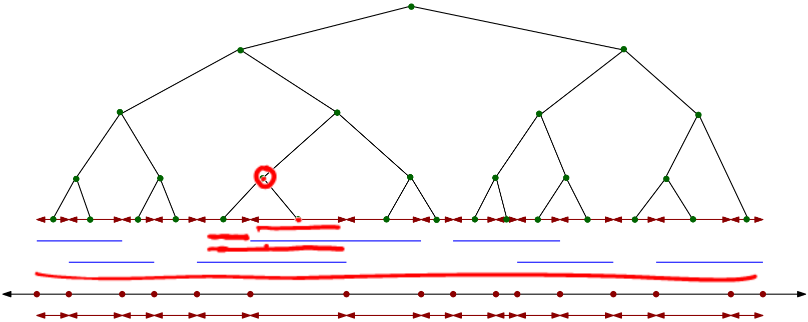
Sum of the union of the intervals

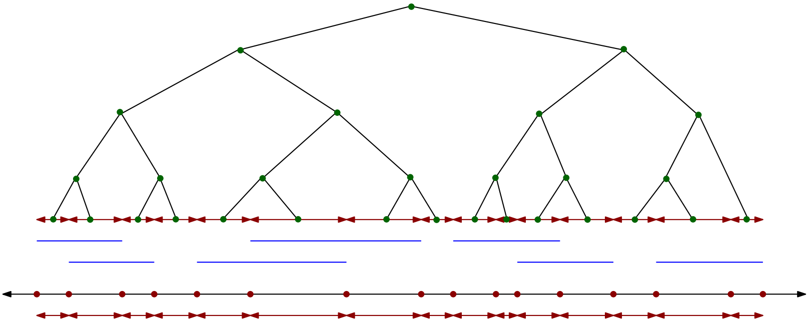


- Sort the end points of the intervals.
- This will create a set of elementary intervals.
- Depending on which intervals are ACTIVE , a set of elementary intervals will be ACTIVE .



- We maintain a special data structure called the INTERVAL-TREE

Interval-Tree



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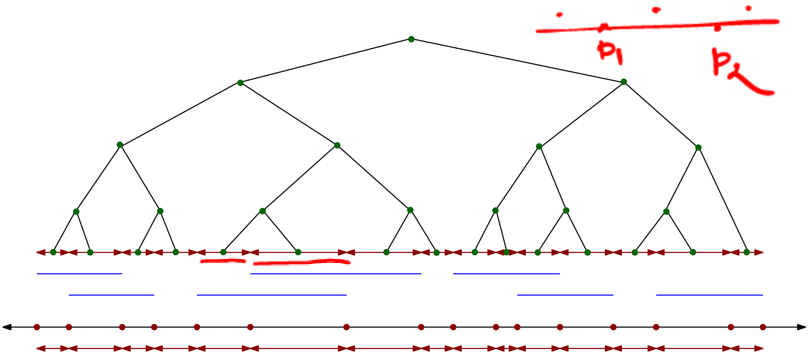
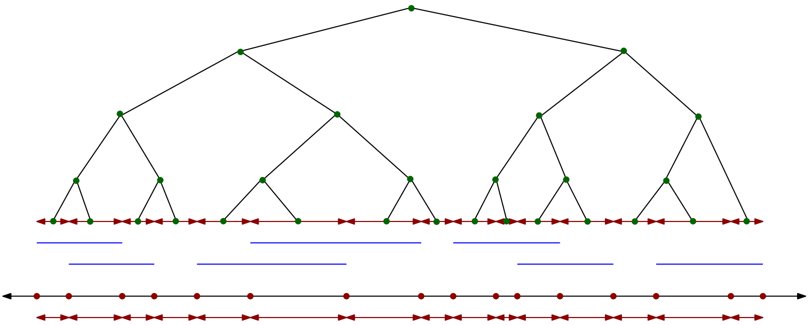
- It is a balanced binary tree $\mathcal{T}$ of the ELEMENTORY INTERVALS.



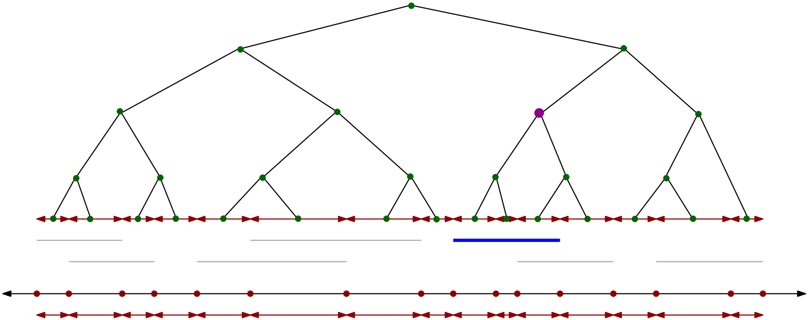
- We maintain a special data structure called the INTERVAL-TREE
- It is a balanced binary tree $\mathcal{T}$ of the ELEMENTORY INTERVALS.
- Each node represents an interval.

Interval-Tree



- How an interval I is stored in the tree?

Interval-Tree



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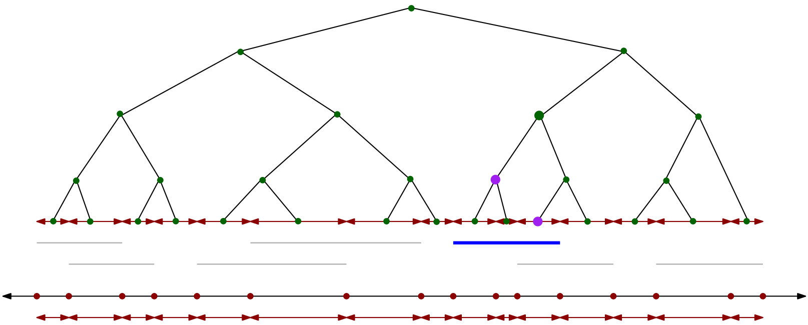

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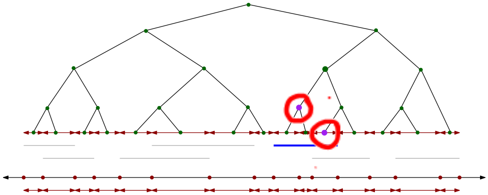
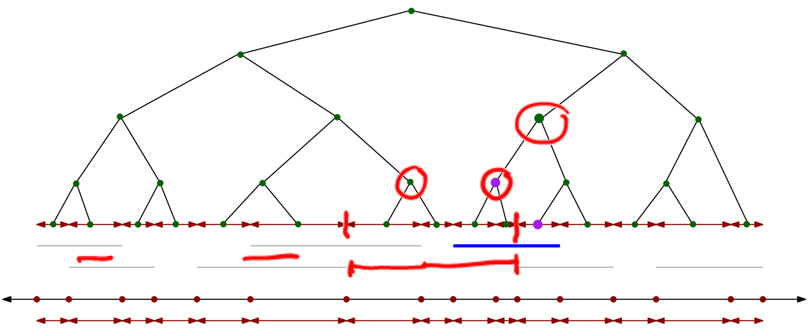


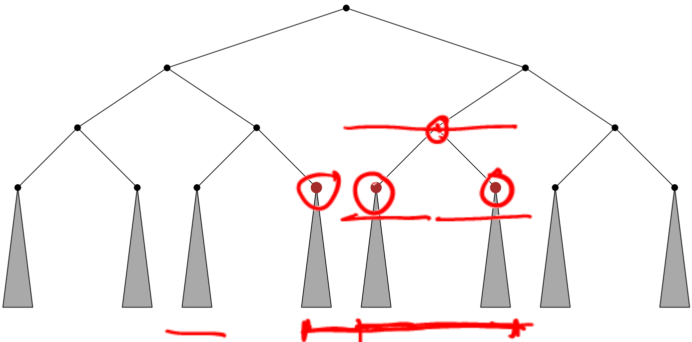
Algorithm 3 ReportInterval($\mathcal{T}, v, I$)

if $v \subseteq I$ **then**
  Report v
  return
end if
if $I \cap lc(v) \neq emptyset$ **then**
  ReportInterval($\mathcal{T}, lc(v), I \cap lc(v)$)
end if
if $I \cap rc(v) \neq emptyset$ **then**
  ReportInterval($\mathcal{T}, rc(v), I \cap rc(v)$)
end if

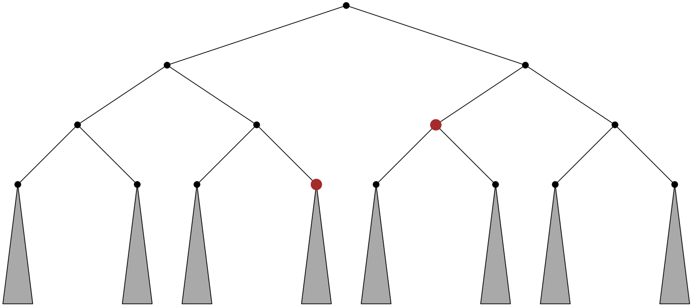
Interval-Tree



- Claim: Each interval is stored in $O(\log n)$ nodes.



- Claim: Each interval is stored in $O(\log n)$ nodes.
- At each level there can be at most two nodes representing the interval.
- All of them have to be consecutive.



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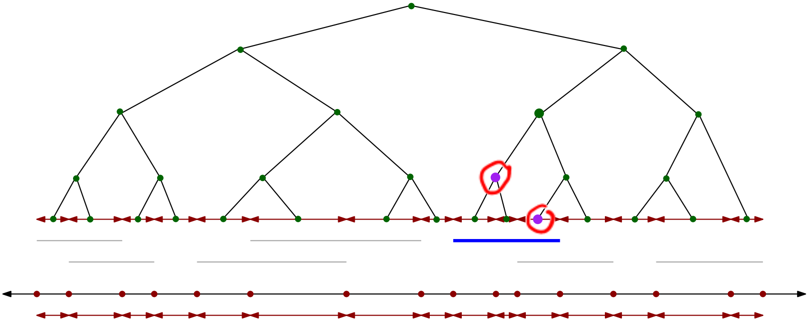
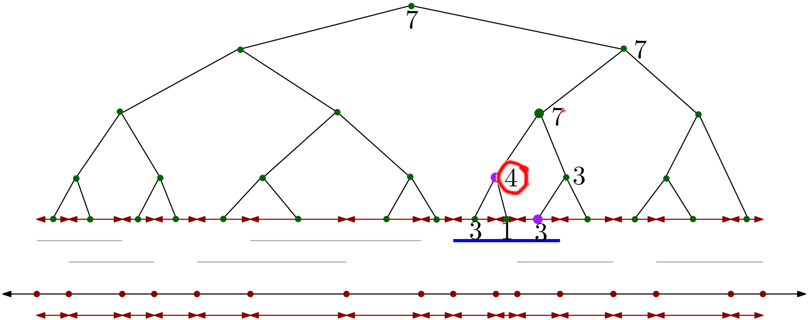


- Each interval can be inserted and deleted in $O(\log n)$ time.
- At each node we maintain the length of the active elementary intervals.



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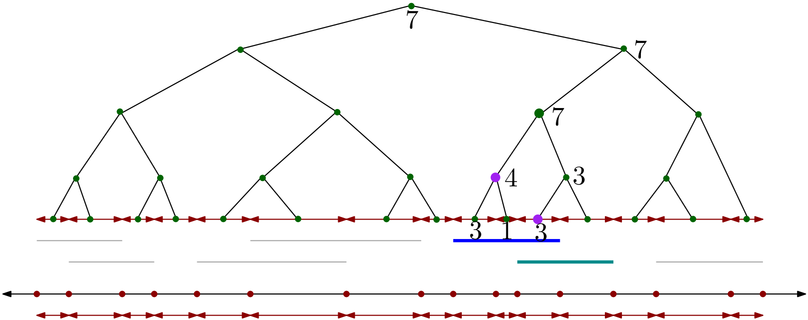

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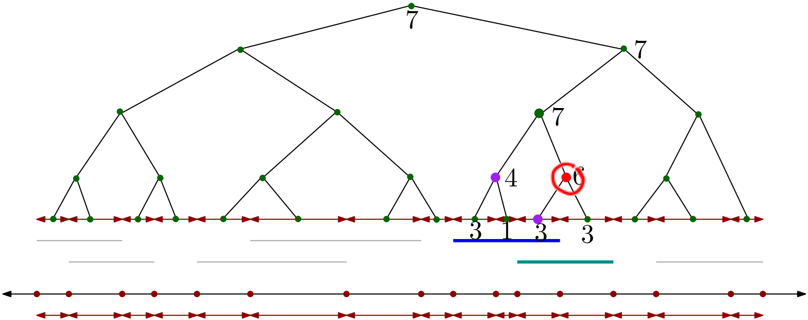

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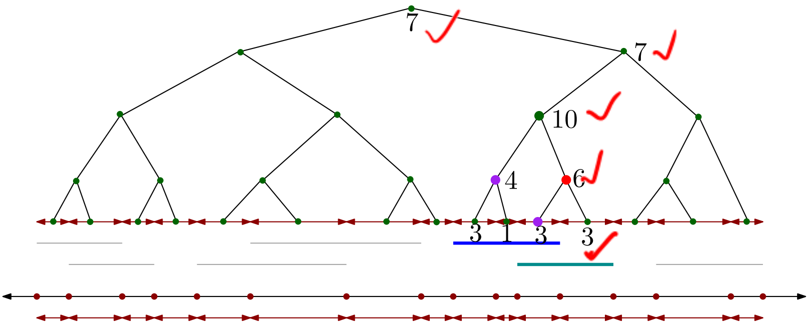

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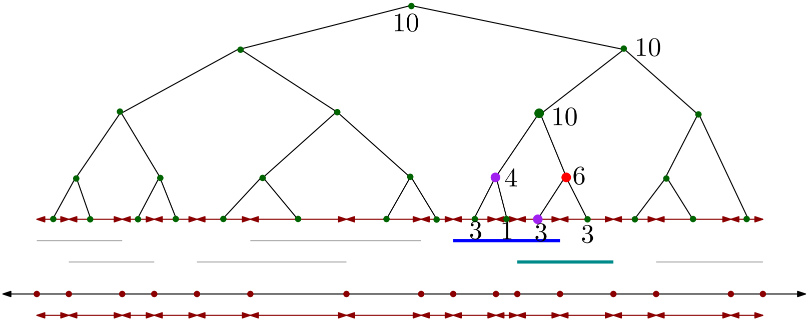

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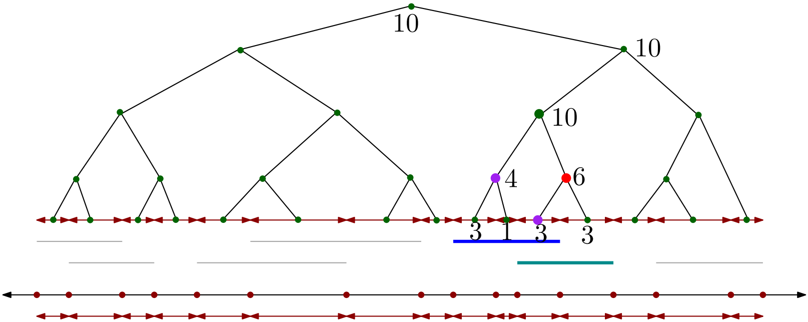
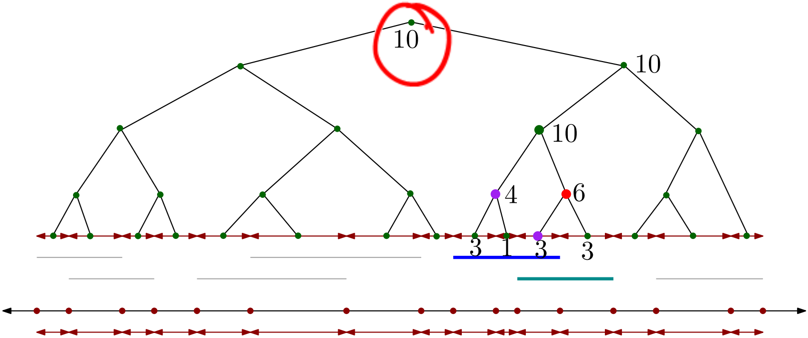


- $O(\log n)$ insert each takes $O(\log n)$ time.
- In time $O(\log^2 n)$ we can perform the updates.



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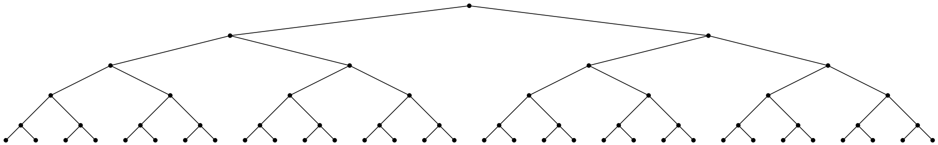
- In time $O(\log^2 n)$ we can perform the updates.
- Can be done in time $O(\log n)$



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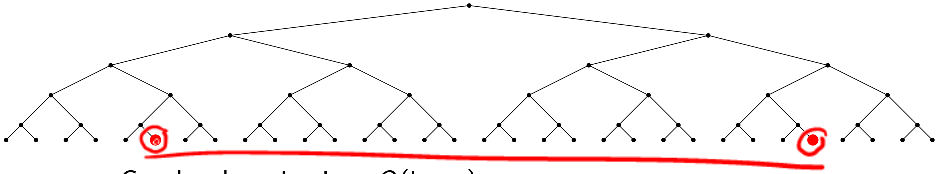
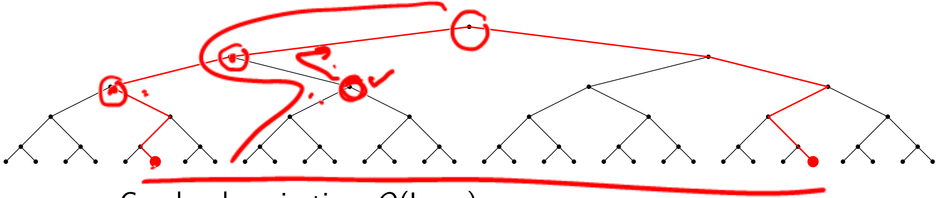


- Can be done in time $O(\log n)$.
- Consider the left most and right most elementary intervals.



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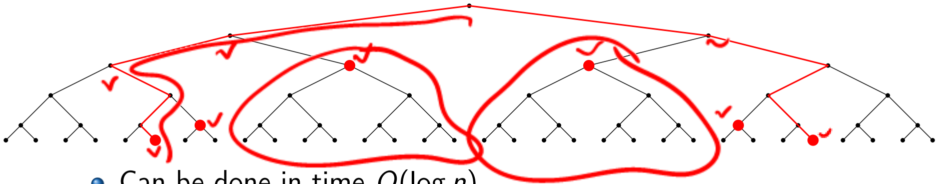

- Can be done in time $O(\log n)$.
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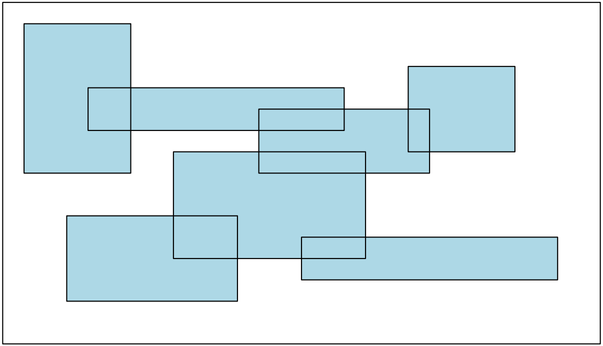
Sum of the union of the intervals



- In time $O(n \log n)$ we can find out the area of the union of n rectangles.