Scalable Ranked Publish/Subscribe

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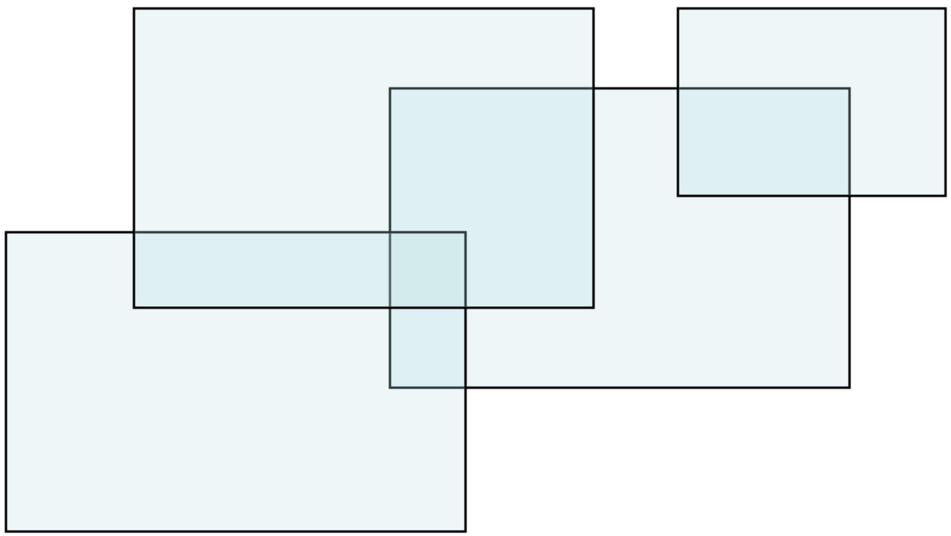
Traditional Pub/Sub

- Many subscribers, each specify some target of interest
  - E.g. Company looking for nursing employees,
    where job pays $40-$60/hr and work is 20-30 hrs/week
- Events arrive, each labeled with a number of attributes
  - E.g. Job seeker, looking for a nursing job paying $50/hr and 25 hours/week
- Subscribers notified about every event they target
  - E.g. All matching companies notified about job seeker

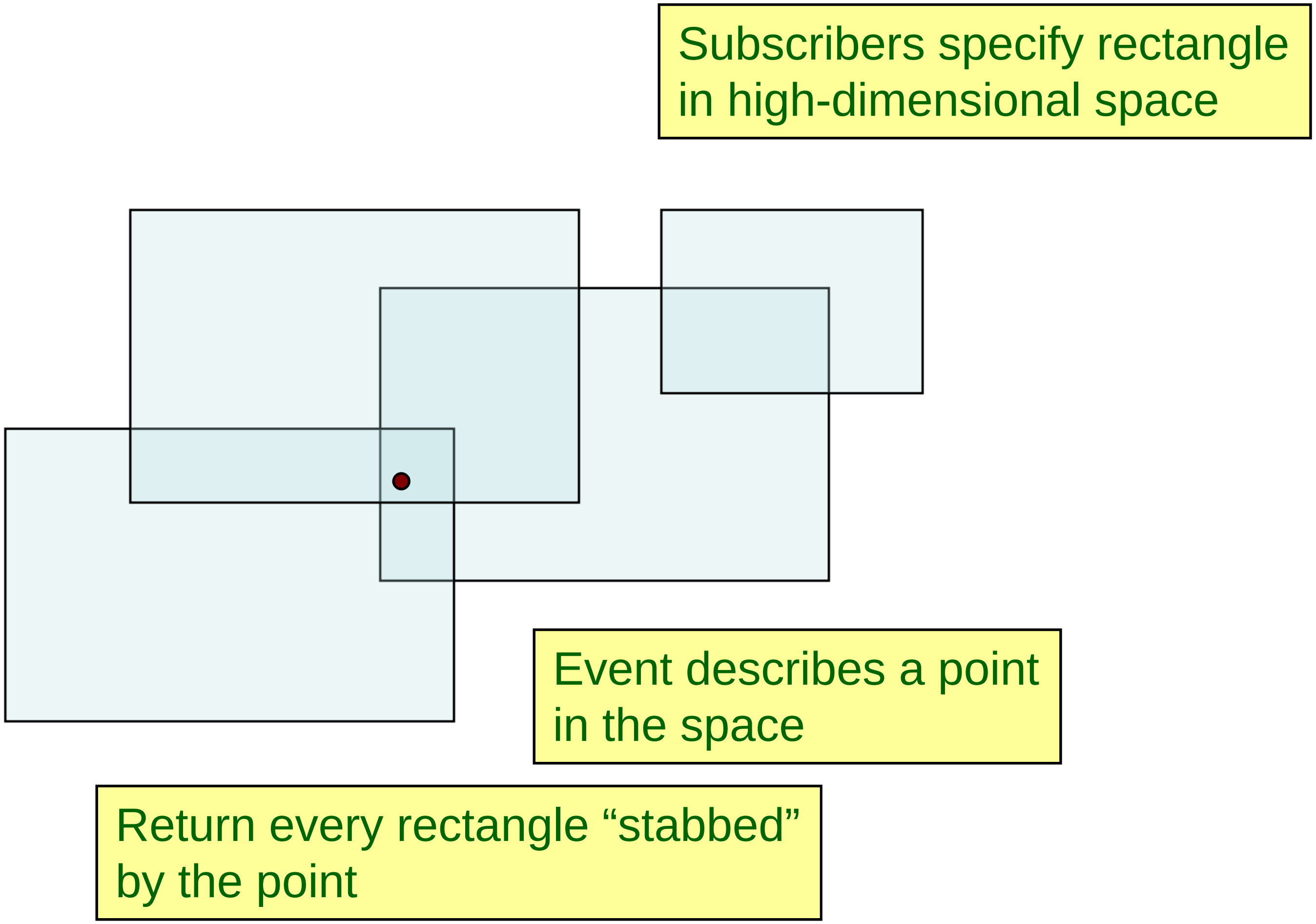
Traditional Pub/Sub (Geometric view)

Subscribers specify rectangle in high-dimensional space



May preprocess rectangles

Traditional Pub/Sub (Geometric view)



The same example on the web

- Companies are looking for potential employees
  - Specify some target attributes
- Users arrive, looking for jobs
  - Specify some attributes
- User is shown companies that match his search

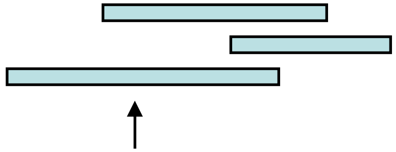
- BUT– ***only top 5*** are shown due to space limitations
- Same space limitations for applications like display advertising, load shedding

Ranked Pub/Sub Problem

- Given a set of subscriptions:
  - Each subscription describes a rectangle in high-dim space
    - Each attribute corresponds to a dimension
  - Each subscription gets a score
    - May be static, or function of attribute scores
  - Allowed to preprocess
- Events arrive online:
  - Each event describes a point in high-dim space
  - Each event also associated with a value k
- **Return the k highest-scoring subscribers**

Our focus

- Examine range queries in single dimensional case
  - Subscribers specify intervals (and score)
  - Events are 1-dim points



- Single dimension is building block for multi-dimensional case
  - If score is static across attributes, do standard list intersection
  - If score function of attribute-scores, apply threshold algorithm

Our focus

- Examine range queries in single dimensional case
  - Subscribers specify intervals (and score)
  - Events are 1-dim points
- Single dimension is building block for multi-dimensional case

- Restrict our attention to small memory structures
  - i.e. Intervals never broken into pieces (hence, linear space)
- Propose several novel data structures
- Compare these structures with variants of standards
  - Show marked improvement for low dimensional problems
  - Do well even compared to larger-memory structures

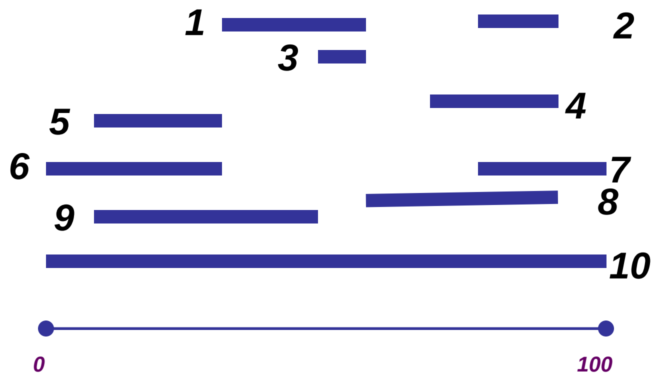
Standard structures for pub/sub

- Interval Tree
- R-Tree
- Segment Tree
  - Space blow-up is O(log n)
    - This is actually an issue– our experiments showed an order of magnitude larger memory footprint

Reminder…

Interval Trees

Intervals
higher = higher score



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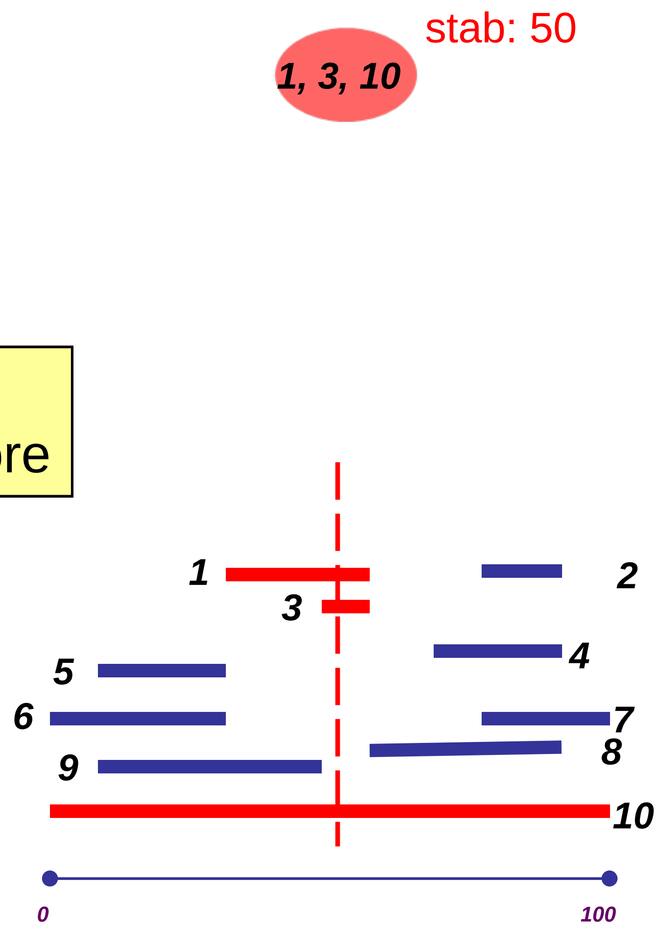
Interval Trees



Intervals
higher = higher score

Pick a stabbing line

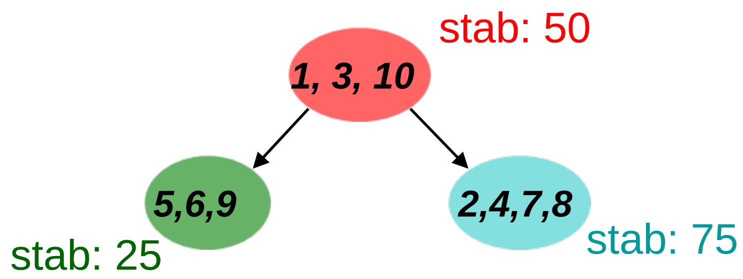
All stabbed intervals go into one node

Left intervals

Right intervals

Reminder…

Interval Trees



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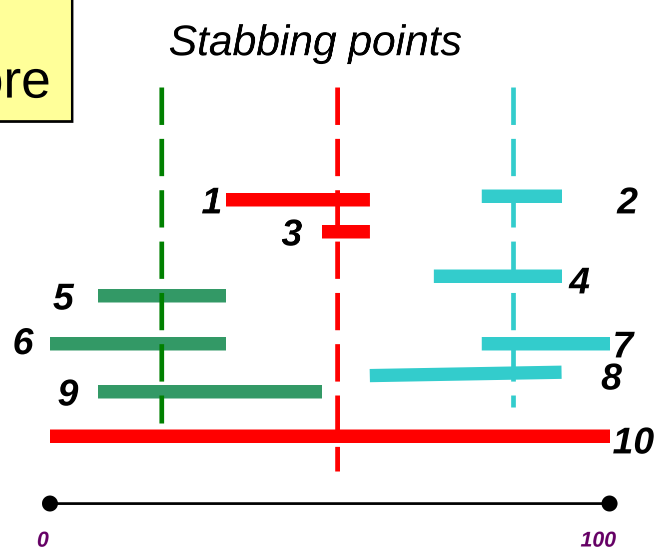


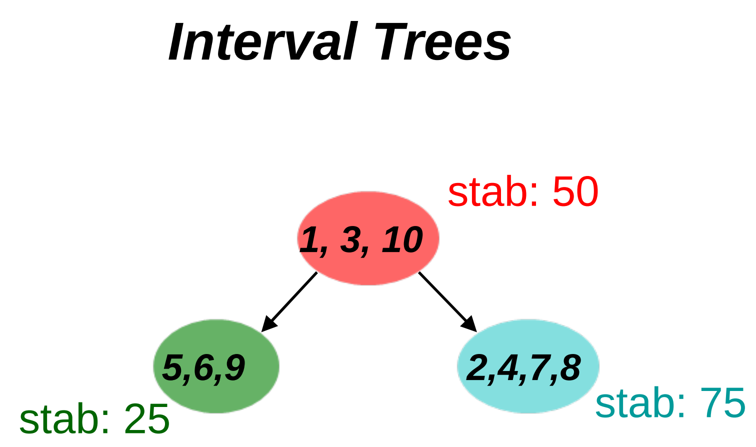
Pick a stabbing line

All stabbed intervals go into one node

Repeat on left and right intervals

YAHOO!

Reminder…



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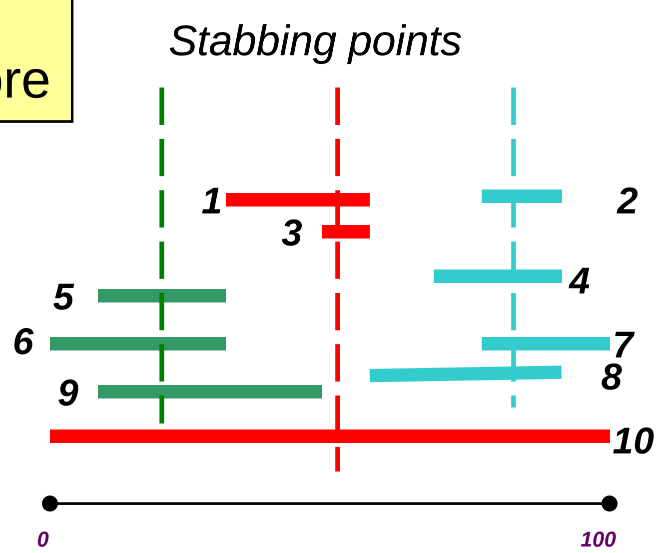


Pick a stabbing line

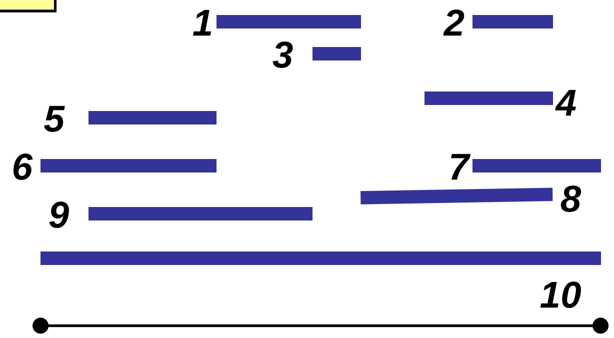
All stabbed intervals go into one node

Repeat on left and right intervals

For each node, store intervals sorted by left endpoint and sorted by right endpoint

R-Trees

Intervals
higher = higher score

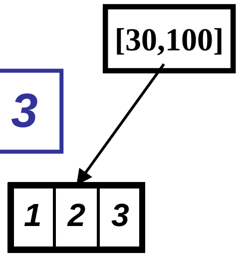


Score sorted R-Trees

Each node stores containing interval

Group intervals by score

branching factor = 3



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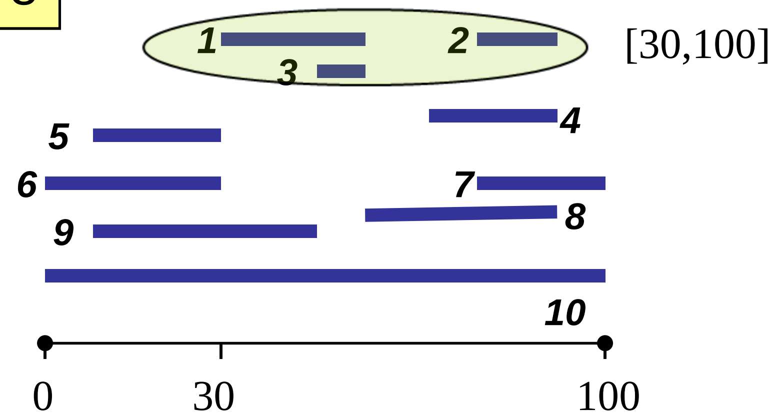

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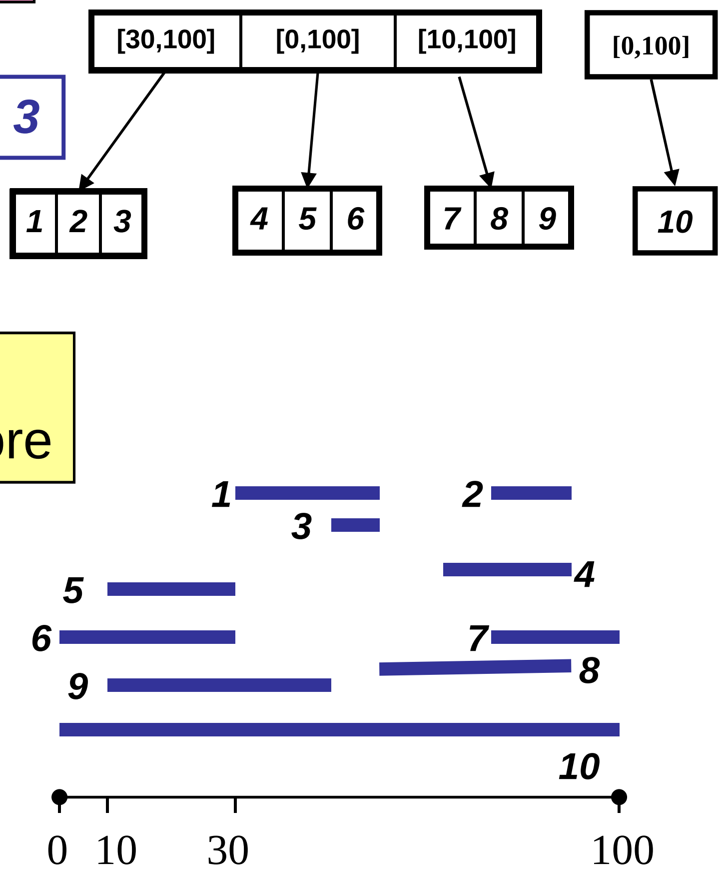

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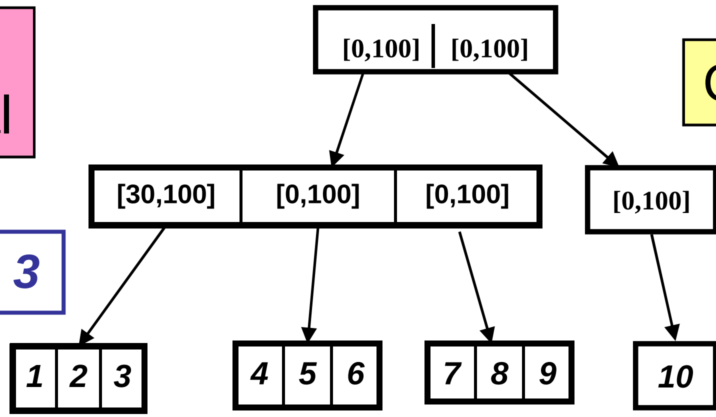

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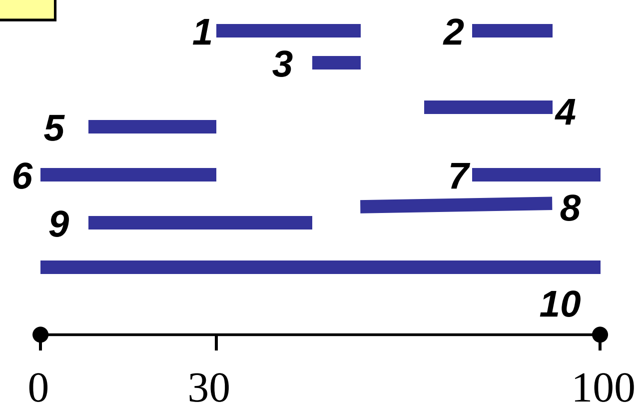

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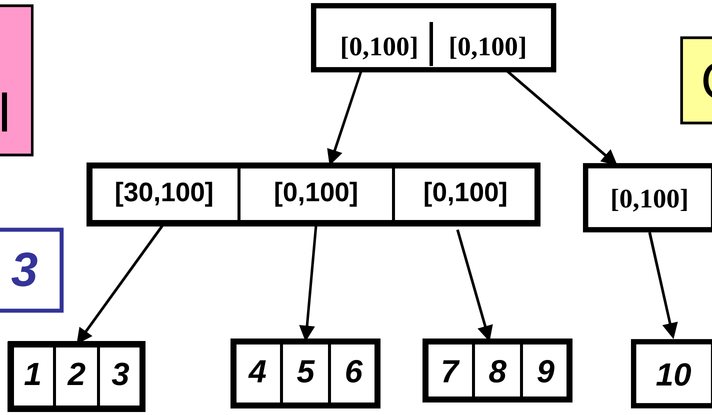
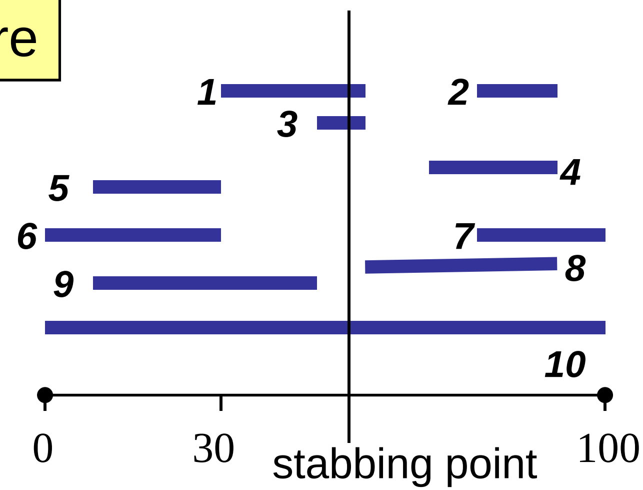


Group intervals by score

For a query, output first k hits

Intervals
higher = higher score

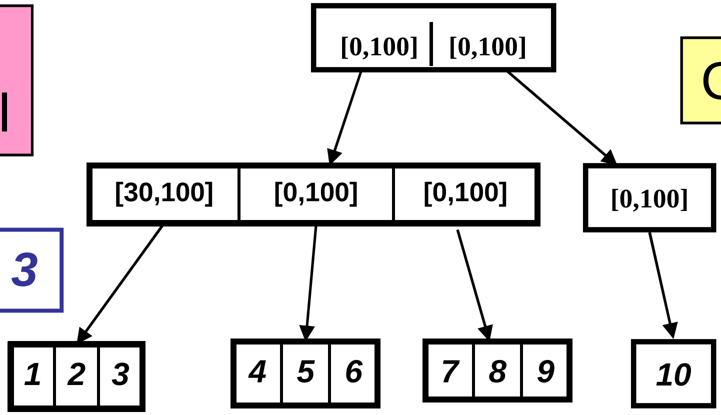


YAHOO!

Score sorted R-Trees

Each node stores containing interval

branching factor = 3



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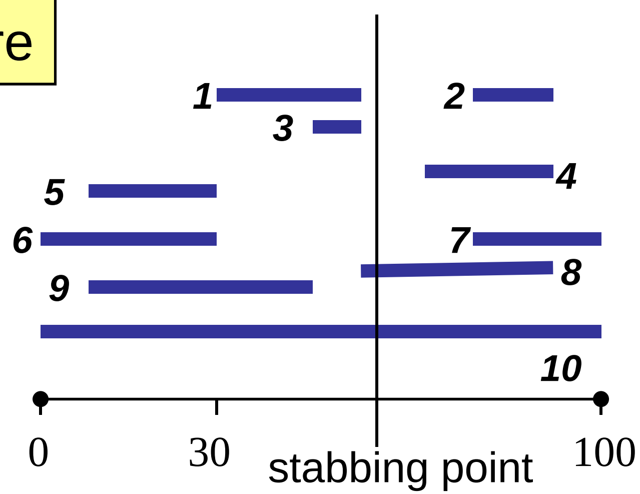
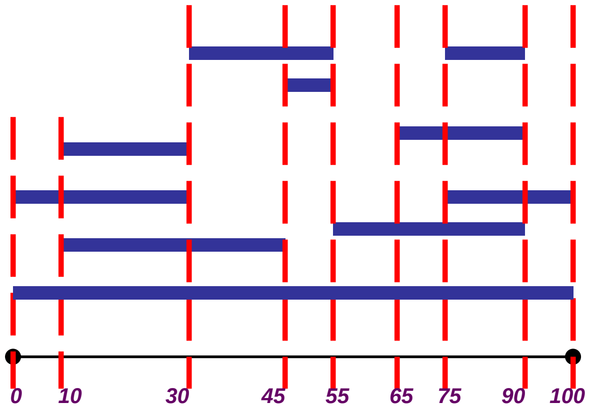


May have many "holes" = wasted probes

Segment trees

All intervals broken into segments, based on set of endpoints



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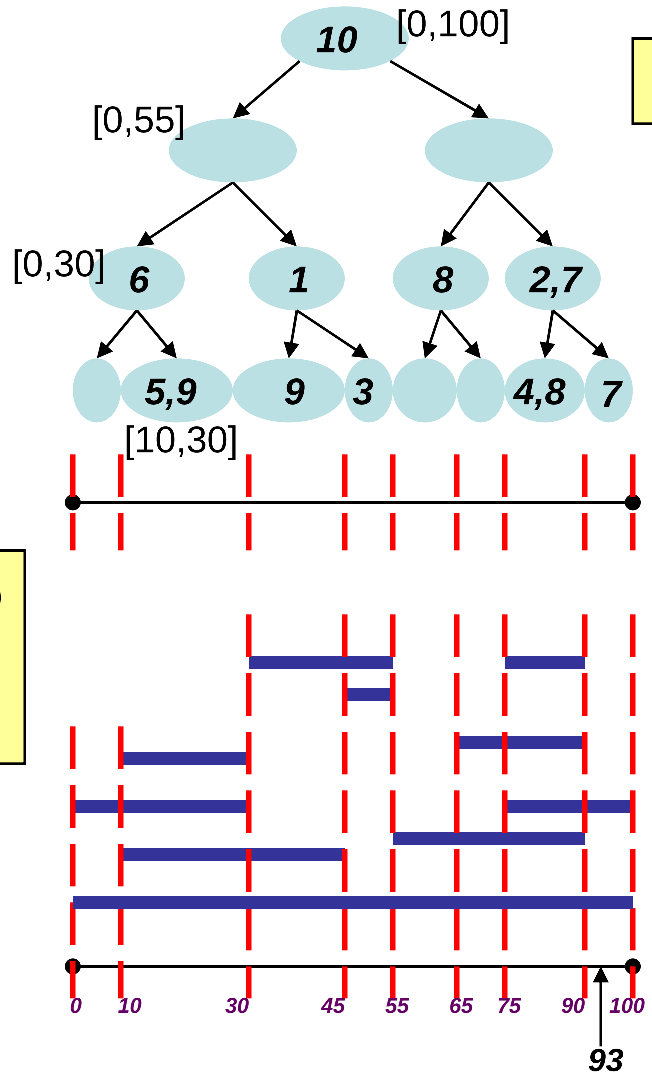
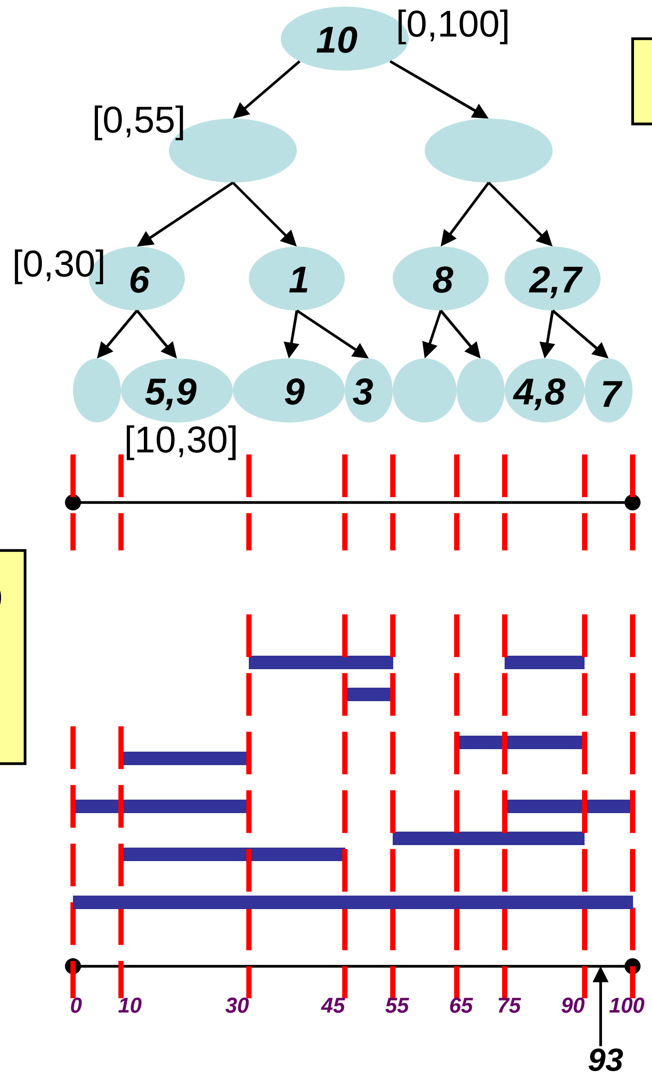


Form tree on segments

Each node records segment: [a, b]

All intervals broken into segments, based on set of endpoints

Segment trees



Form tree on segments

Each node records segment: [a, b]

Advantage: if interval stored at node, then interval contains all of [a,b]

So each node stores intervals in ***score-sorted*** order!

All intervals broken into segments, based on set of endpoints

Standard structures for *ranked* pub/sub

- Interval Tree
  - Sort intervals by score, or by interval– not both
- R-Tree
  - Scored R-tree
  - “Holes” can get you
- Segment Tree
  - Space blow-up is O(log n)
    - This is actually an issue– our experiments showed an order of magnitude larger memory footprint
  - “Gold standard”: Scoring is no problem!

Our data structures

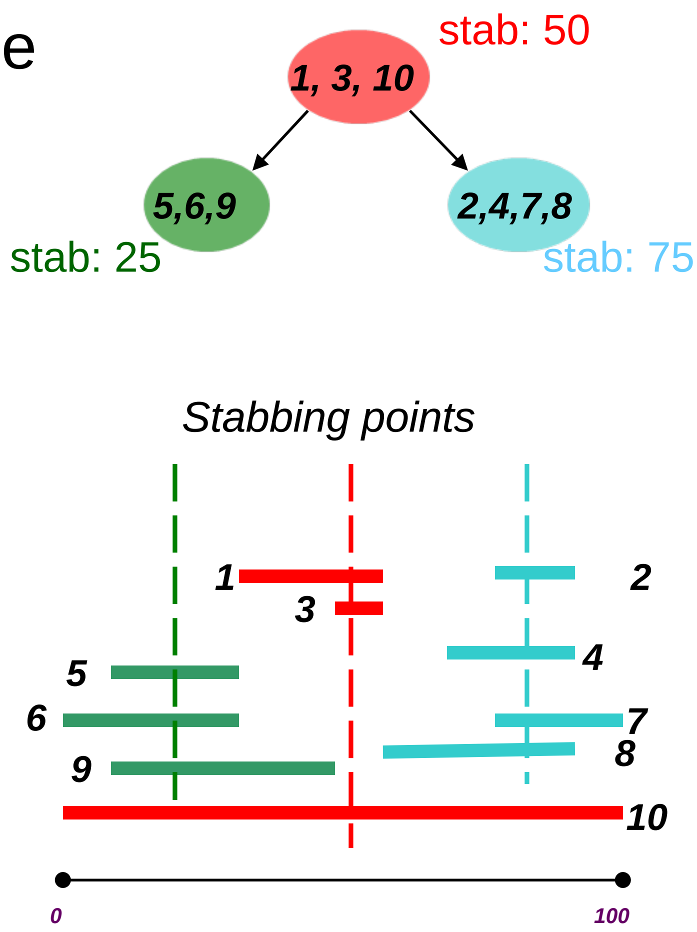
- IR-tree
  - Interval tree with R-tree sitting in each node
- OptR-tree
  - R-tree, but with intervals sorted to support scoring in an optimized way

- Main insight– R-trees in 1 dimension very fast, except for the wasted probes (i.e. “holes”)
  - Both data structures use R-trees, with guarantees on number of wasted probes

IR-tree

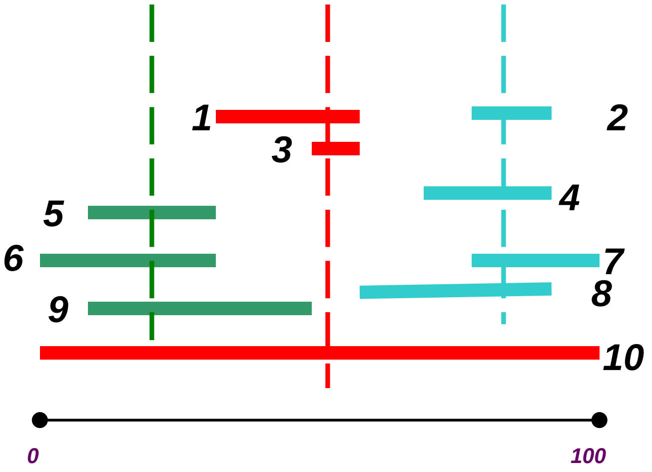
- Form basic tree as an interval tree

- For each node, index the intervals with an R-tree



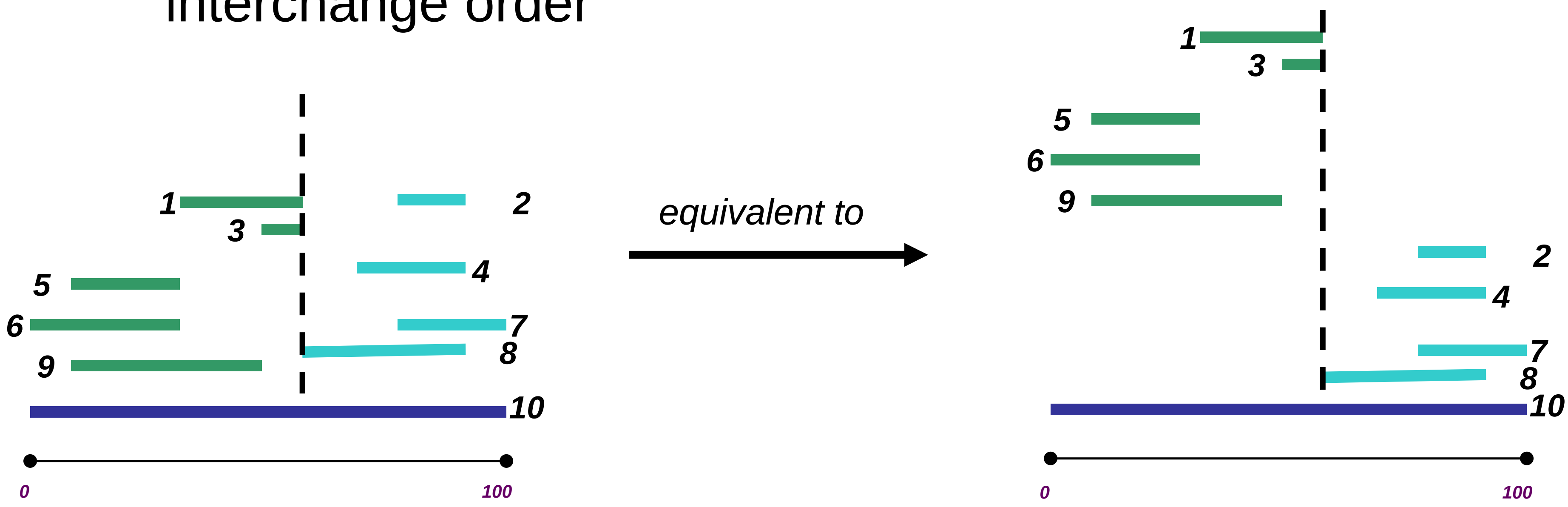
IR-tree

- Why index by R-trees?
- Key lemma: All intervals at a node overlap, so the R-tree has no holes! (i.e. Every probe in the R-tree leads to a valid interval)
- R-trees also lightweight, simple, good in practice
- Each getNext() call takes at most **O(log log n + height(R-tree))**



Opt-R-Trees

- Data structure is a R-tree
- However, we can sort the intervals more intelligently
- Key insight: If two intervals do not overlap, then can interchange order



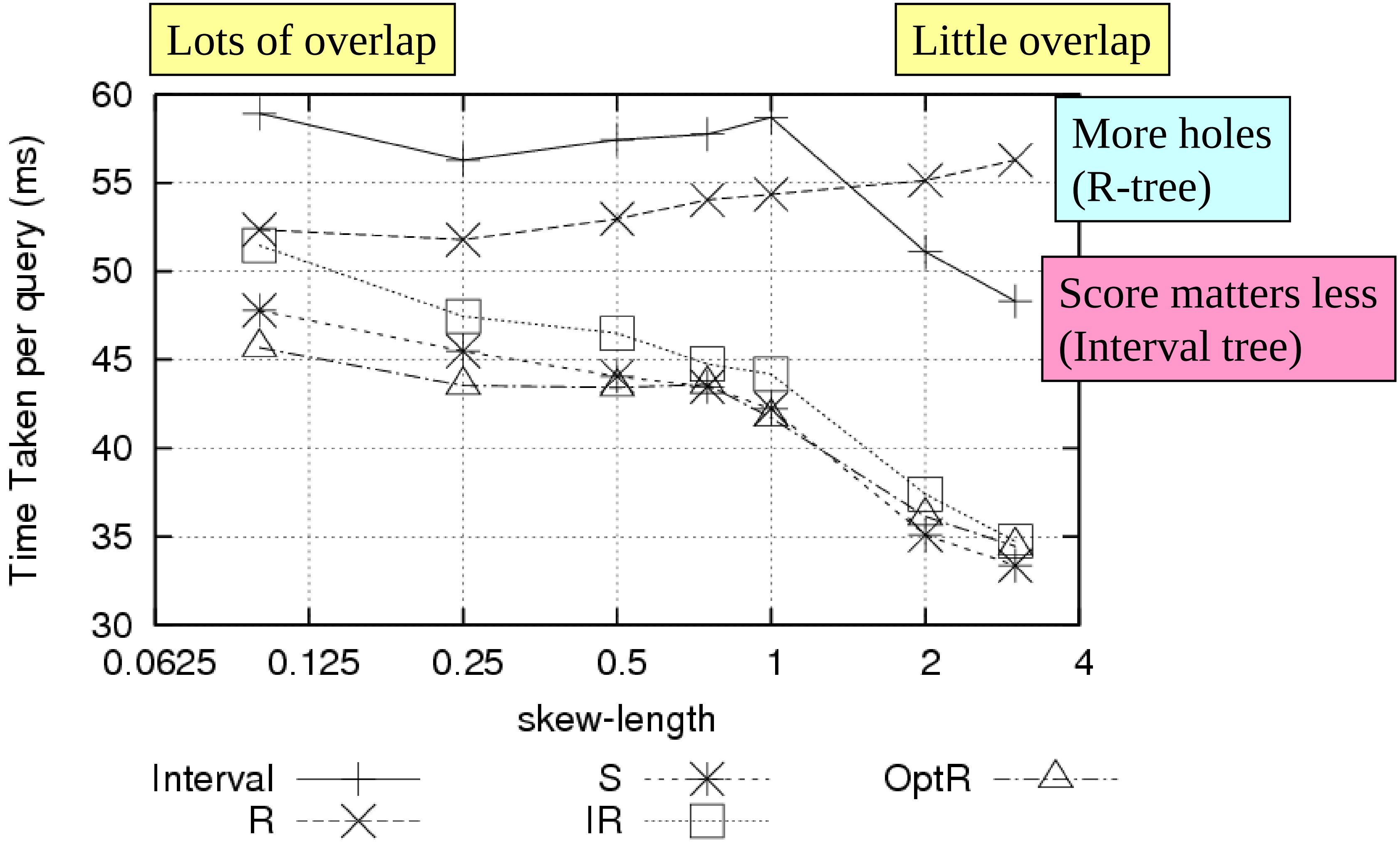
Opt-R-Trees

- Intervals induce a topological graph
  - (Edge from i1 to i2 if **score(i1) > score(i2)** AND **i1, i2 overlap**)
  - We give a way of constructing taking time O(n log n) by ignoring some transitive edges
- Any grouping that respects this graph is okay
  - We take left-most interval with indegree 0 at each step
- Key lemma: To get top k intervals, need at most 2k probes
  - Roughly, there is a hole only when there must be one

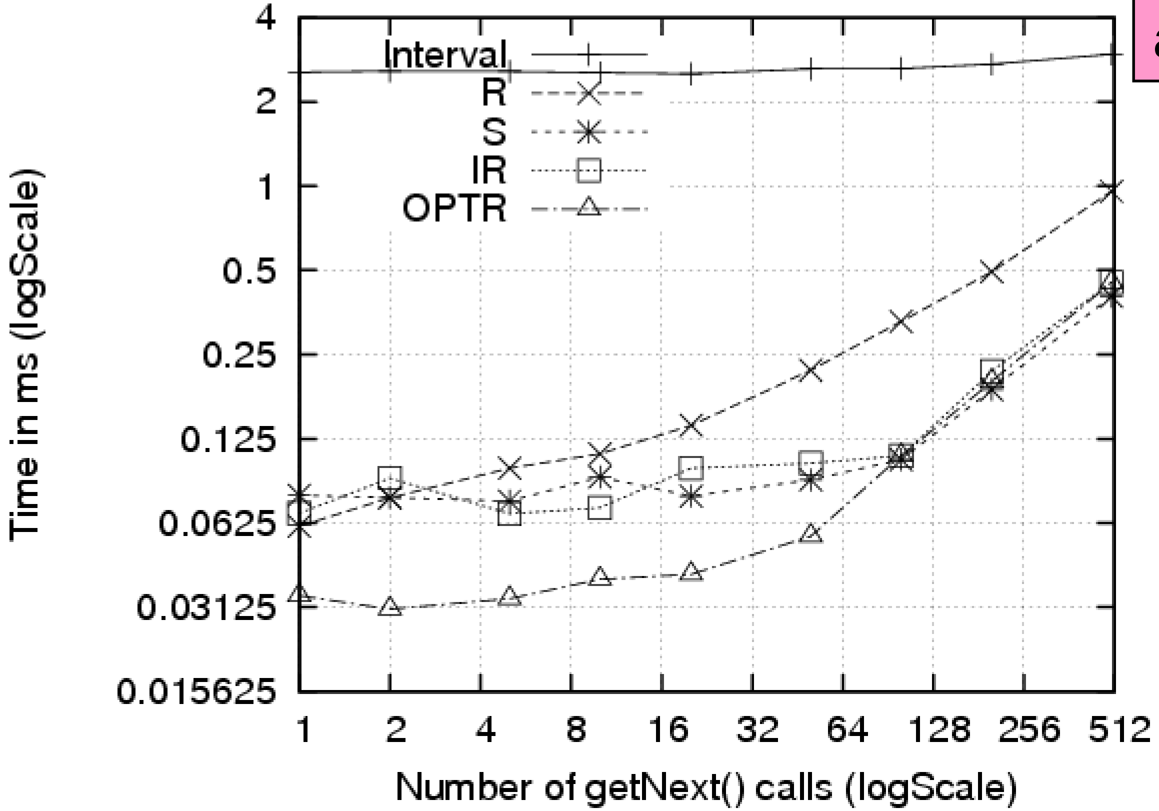
Experiments

- Used synthetic data
- 1M intervals
- Left endpoint and length of interval zipfian distributed
  - Vary the skew, zipfian power
- Looked at varying number of dimensions

Speed vs. overlap (Threshold algorithm in 4 dimensions)



Time for getNext()

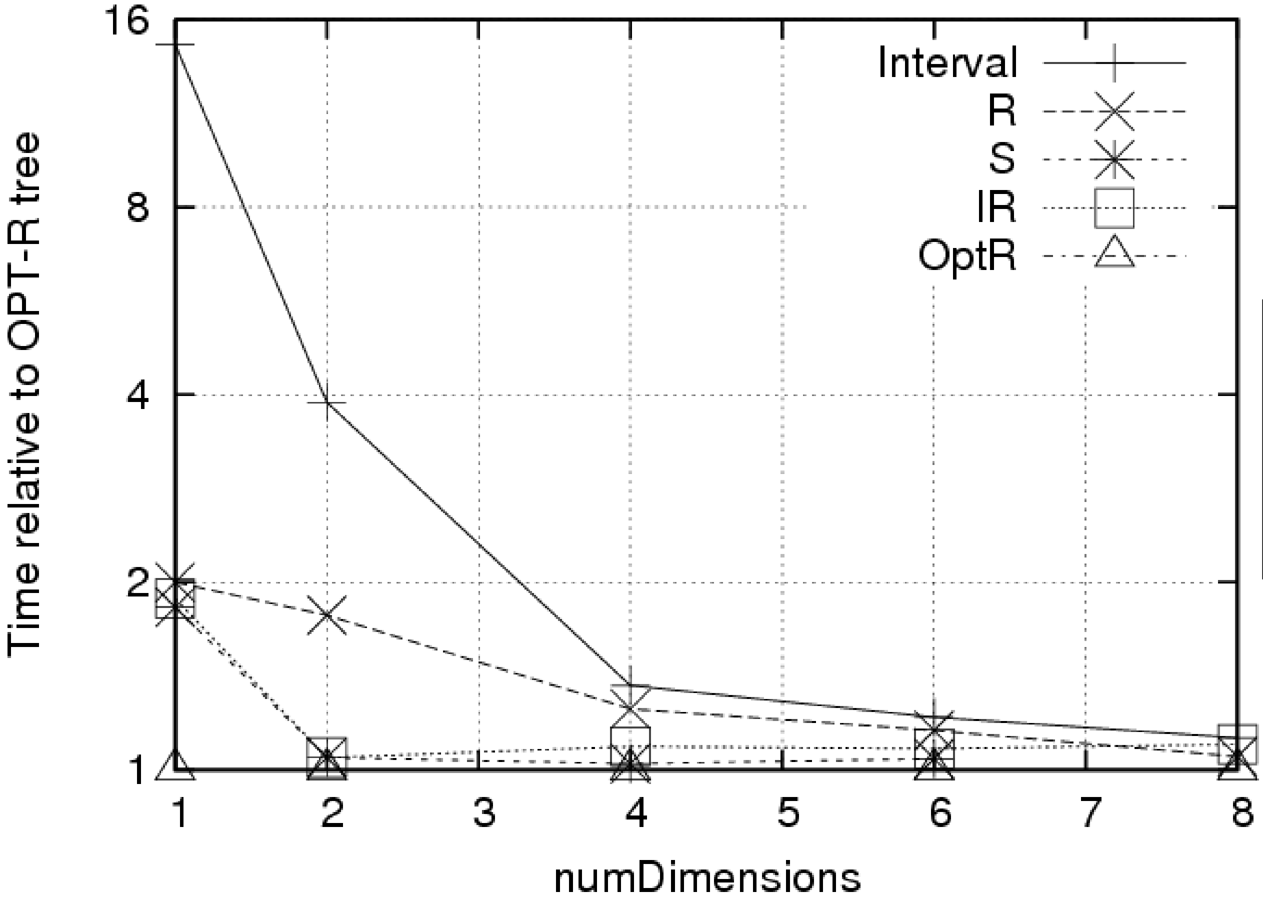


Interval trees process all matches

Opt-R tree great for small k

Segment trees, IR-trees must initialize their heap

Dimensionality (Threshold algorithm)

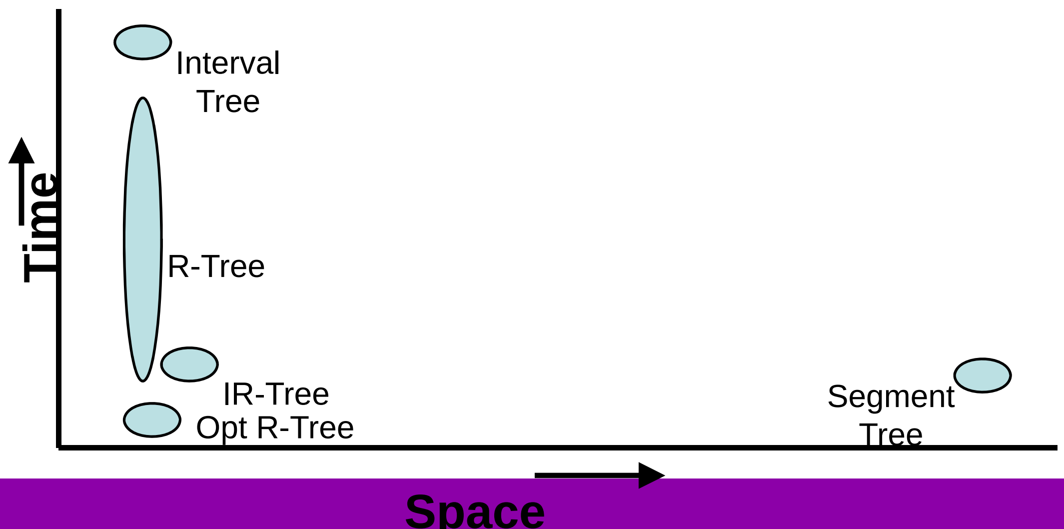


At larger number of dimensions, all methods have similar time

More overhead, more getNext() calls

Experimental summary

- IR-trees, OptR-trees, and segment trees are all comparable in speed
  - Segment trees require too much memory
  - Only IR-trees are easy to update intervals online
- Standard structures much slower in general



Conclusions

- Propose a new problem: Ranked Pub/Sub
- Give a novel solution for one dimension
  - Yields solutions for small dimensionality
- Data structure are lightweight, easy to implement, give good results
  - IR-trees: easy to maintain

- Open problems:
  - How do we extend this to larger dimensionality?
  - More expressive subscriptions, events
  - Score updates