Range Queries over a Compact Representation of Minimum Bounding Rectangles

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Outline

1. Motivation
2. SW-Tree
3. Experiments
4. Conclusions and Future Work

Motivation

- Spatial indexes are a key component in GIS
  - Large collections of geographic data
  - Geographic operations are very complex
    - Sequential search is not feasible
- Filter/Refine Strategy
  - Minimum Bounding Rectangle (MBR)

Motivation

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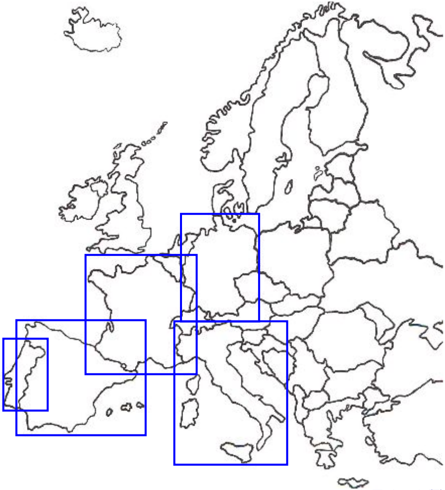

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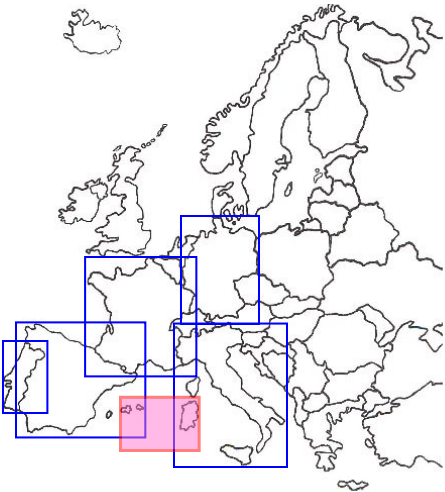

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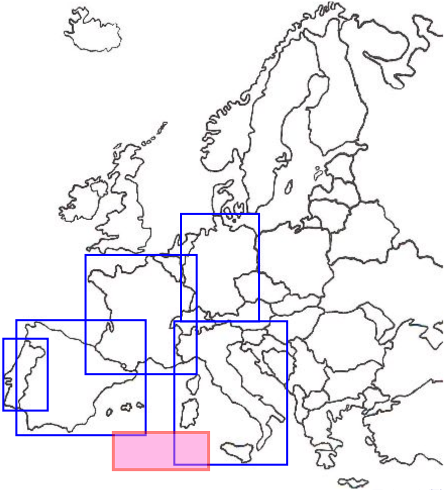

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- Typical requirements of spatial indexes:
  - Dynamic operations: inserts, deletes, updates, ...
  - Secondary storage management
    - Space consumption is a less important issue
  - ...
- Nowadays, some of these requirements have changed
  - Static data collections are useful in many domains
  - Memory hierarchy evolution
    - Reduction of the main memory cost
    - New levels (flash memory)
- Our goal is a new spatial access method: SW-Tree
  - Static geographic data collections
  - Main memory: compact
  - Efficiency similar to classical indexes

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Motivation

Quote

"The time difference between accessing a piece of information in RAM vs reading it from disk is similar to the time difference between picking up a pen from this desk and taking a plane to Spain and picking up a pen from my desk"

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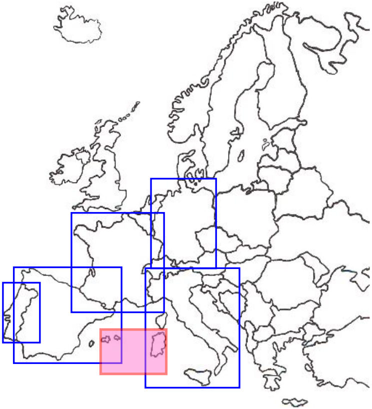
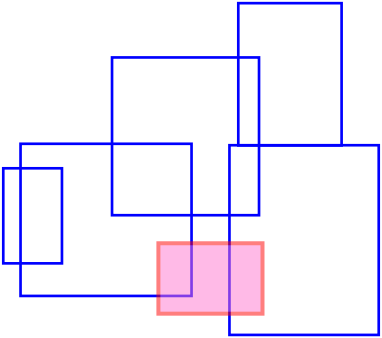
SW-Tree

- Remind the problem...



SW-Tree

- ... and forget the refinement step



Overview

- Orthogonal problem
  - Work with the rank of the coordinates
- Decomposition of a d-dimensional problem into its d dimensions ($d = 2$)
  - Solve d (one-dimensional) subproblems and intersect their results
- Transform the original space
  - A one-dimensional interval can be represented as a 2-dimensional point

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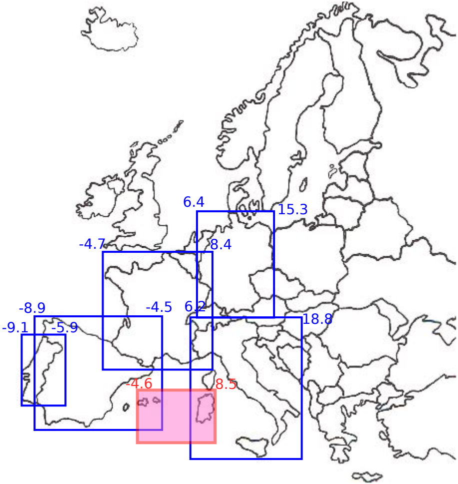
Orthogonal Problem

- Gabow et al. (1984)
- Work with the rank of the coordinates
- Practical solution:
  - Store the real coordinates into sorted arrays
  - Perform binary searches to translate real queries to the rank space

Orthogonal Problem



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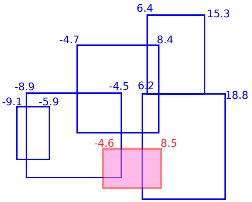

1	2	3	4	5	6	7	8	9	10
-9.1	-8.9	-5.9	-4.7	-4.5	6.2	6.4	8.4	15.3	18.8

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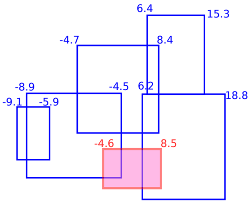

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				-4.6			8.5		

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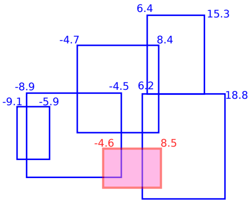

- Coordinates encoding:
  - Scaling
  - Differential compression

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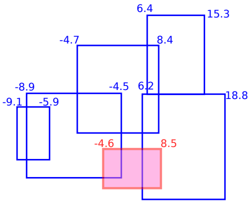

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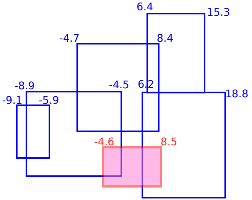

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-91	-89	-59	-47	-45	62	64	84	153	188

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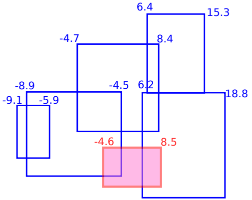

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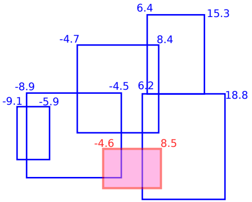

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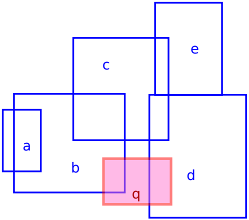
$\phi(0)$	$\phi(2)$	$\phi(30)$	$\phi(12)$	$\phi(2)$	$\phi(107)$	$\phi(2)$	$\phi(20)$	$\phi(69)$	$\phi(35)$

$\phi()$ coding integers function (e.g. γ-codes, δ-codes, Rice, Vbytes)

Decomposition



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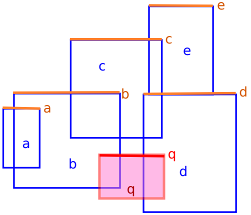

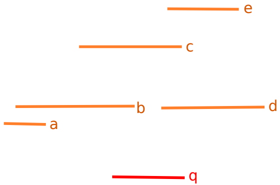

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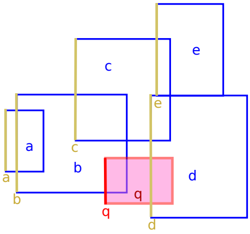

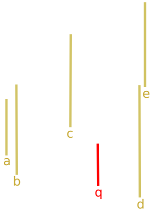

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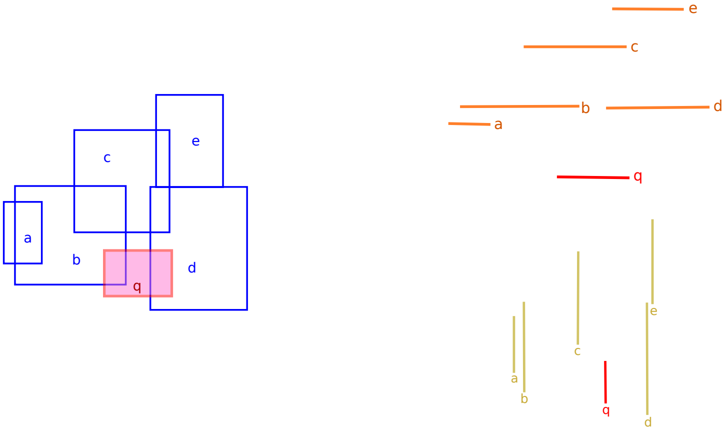

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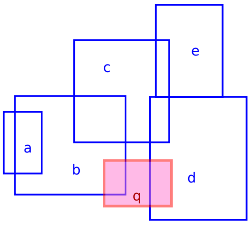

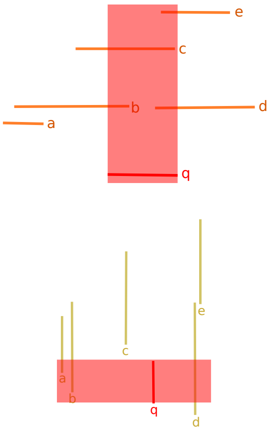

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- d-dimensional range query decomposition:
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- Interval Intersection:
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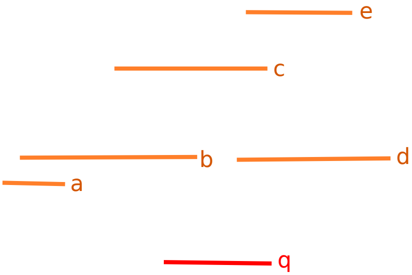

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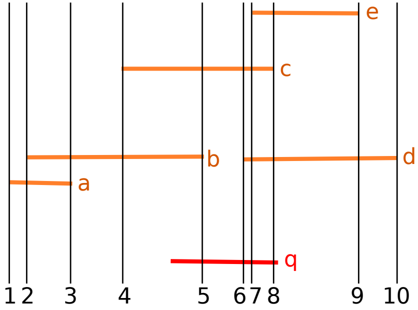

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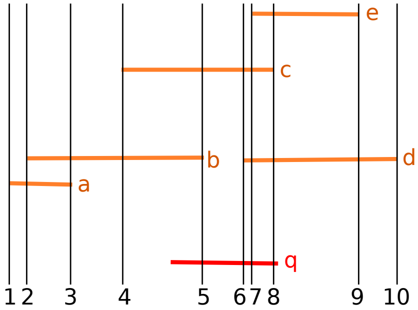

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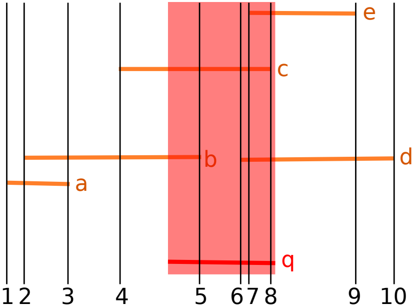

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Transformation

- A one-dimensional interval can be represented as a 2-dimensional point
- Solve an interval intersection query in the original space is equivalent to solve a two-sided range query in the transformed space:
  - $q = [l^q, u^q]$
  - $(l_i, u_i) / l_i \leq u^q \ \wedge \ u_i \geq l^q$
- Two-dimensional range reporting:
  - Wavelet tree $(O(m \log(n/m) + m))$
  - K-d-tree $(O(\sqrt{n} + m))$
  - Alstrup et al. $(O(\log\log(n) + m))$
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Wavelet Tree-based Solution

- Many alternatives:

Data Structure	Worst-case search time
Interval, Segment, and Priority trees	$\Omega(\log n + m)$
Schmidt'09	$O(1 + m)$
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- Which are the virtues of the wavelet tree?
  - Good space/time trade-off (space: $n \log n + o(n \log n)$ bits)
  - No significant implementation overhead
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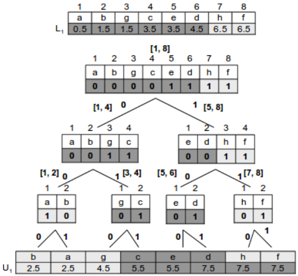
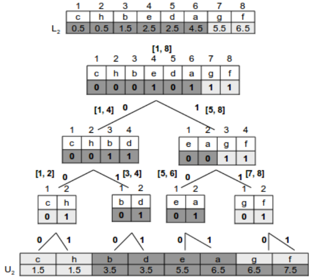
Wavelet Tree-based Solution

- SeCoGIS'09: *A New Point Access Method based on Wavelet Trees*
- Permutation in the order of the points in each dimension
- Balanced binary tree
- Constant time operation: $rank_1(B, i)$

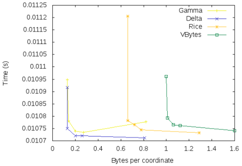




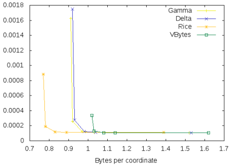
Experimental Environment

- Structures
  - R*-tree, STR R-tree (Spatial Index Library)
  - SW-tree
- Datasets
  - Synthetic (1,000,000 MBRs each)
    - Uniform
    - Gauss (world size $= 1,000 \times 1,000$, $\mu = 500$, $\sigma = 200$)
    - Zipf (world size $= 1,000 \times 1,000$, $\rho = 1$)
  - Real
    - EIEL (569,534 MBRs from buildings in A Coruña)
    - TIGER (2,249,727 MBRs from California roads)
- Experiments in:
  - Intel Pentium 4 3.00GHz with 4GB of RAM
  - GNU/Linux kernel 2.6.27
  - gcc 4.3.2 and -O9 optimizations
  - Time represents CPU user-time

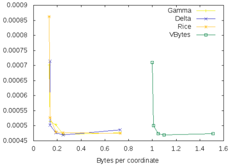
Coordinates Encoding



(a) Zipf

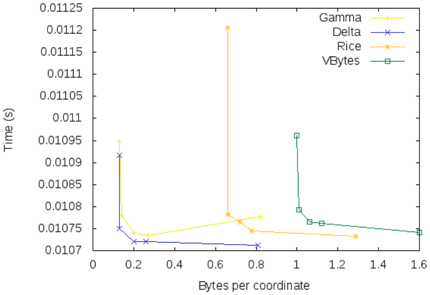


(b) EIEL



(c) Tiger

Coordinates Encoding



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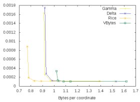

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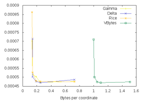

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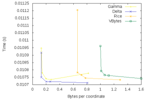

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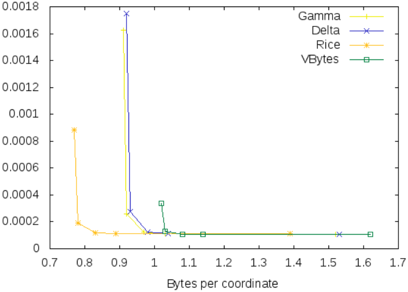

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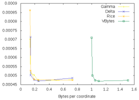

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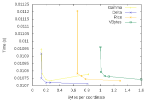

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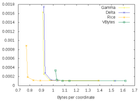

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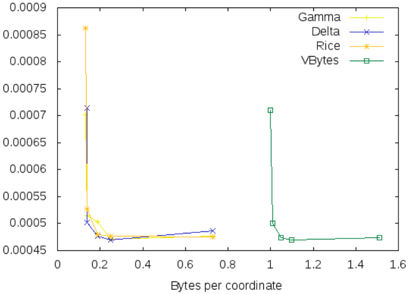

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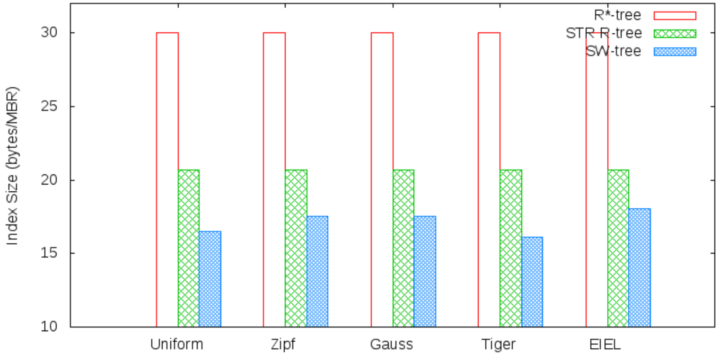
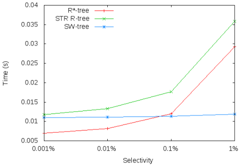
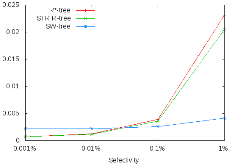
Space Comparison



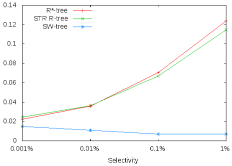
Time Comparison (Synthetic Datasets)



(a) Uniform

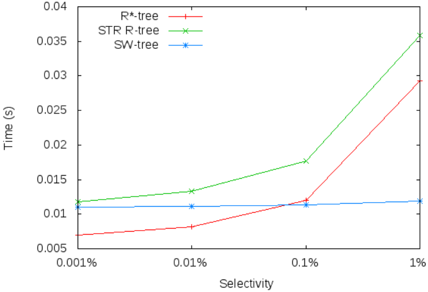


(b) Gauss

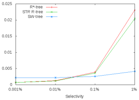


(c) Zipf

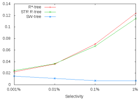
Time Comparison (Synthetic Datasets)



(a) Uniform

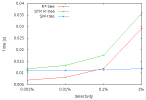


(b) Gauss

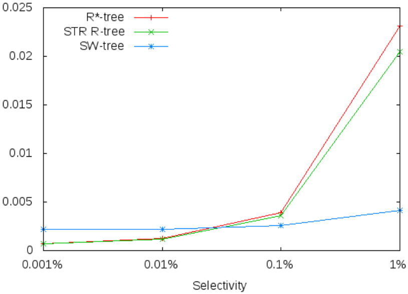


(c) Zipf

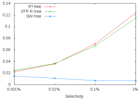
Time Comparison (Synthetic Datasets)



(a) Uniform

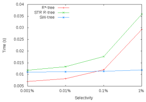


(b) Gauss

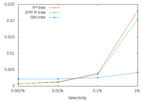


(c) Zipf

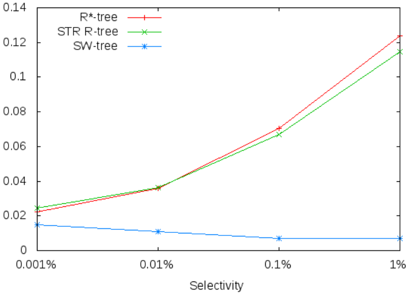
Time Comparison (Synthetic Datasets)



(a) Uniform

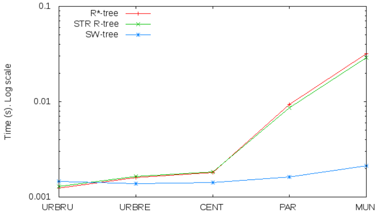


(b) Gauss

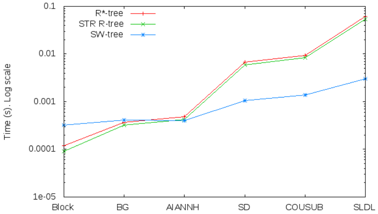


(c) Zipf

Time Comparison (Real Datasets)



(a) EIEL



(b) Tiger

Conclusions and Future Work

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- Compact structure to index semi-static collections of MBRs
- Good space/time trade-off

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Conclusions

- ~~Compact structure to index semi-static collections of MBRs~~
- General technique to index semi-static collections of MBRs
- ~~Good space/time trade-off~~
- Different space/time trade-offs
- Closing the gap with other very active research fields (information retrieval and text compression)

Conclusions and Future Work

Future Work

- Lossy compressed spatial indexes (CR-tree)
- Dynamic bitmaps supporting *rank*
- Other operations: k-nearest neighbors, spatial join

The End

Questions?