MISTRAL

Processing Relational Queries Using a Multidimensional Access Method

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FORWISS

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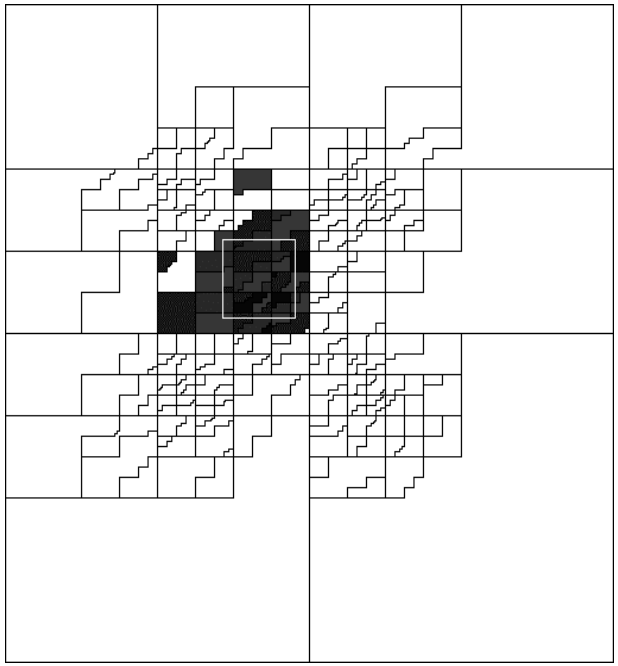
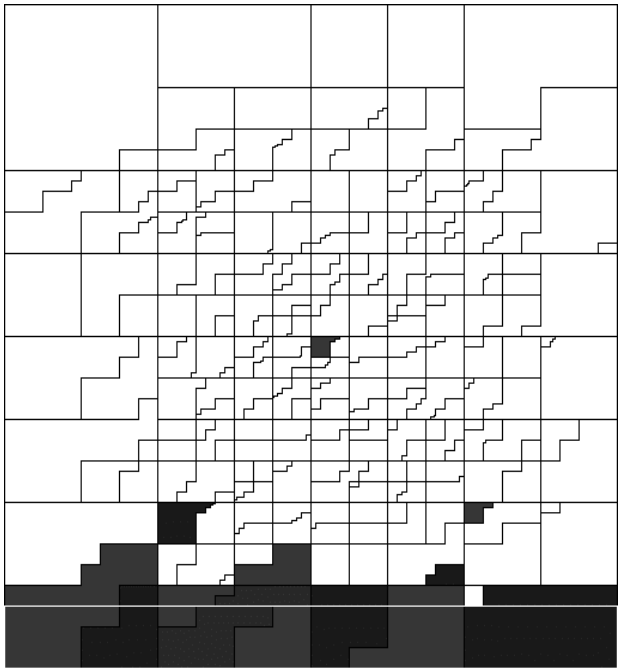
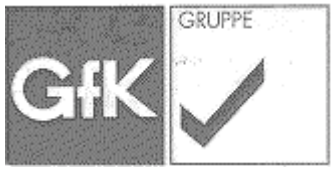
Range Queries



Tetris Algorithm



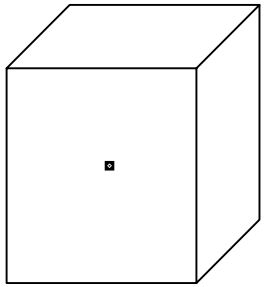


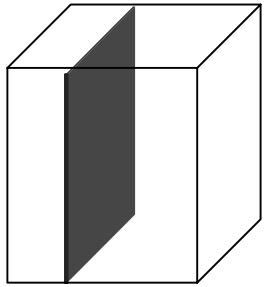
Overview

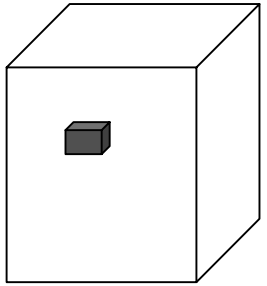
1. Concept of the UB-Tree: Z-Regions
2. Insertion
3. Range Query Algorithm
4. Tetris Algorithm
5. Kernel Integration
6. Performance Overview

Relations and MD Space

- Decision Support Relation (similar to TPC-D)
  - Fact(customer, product, time, Sales)
  - → defines a three dimensional cube
- Point Query
  - All sales for one customer for one specific product on a certain day
- Partial Match Query
  - All sales for product X
- Range Query
  - All sales for year 1999 for a specific product group for a specific customer group





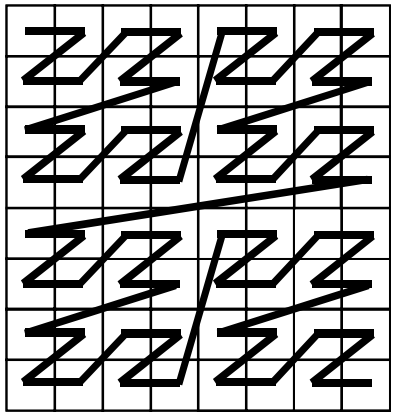


Design Goals

- clustering tuples on disk pages while preserving spatial proximity
- efficient incremental organization
- logarithmic worst-case guarantees for insertion, deletion and point queries
- efficient handling of range queries
- good average memory utilization

Z-Ordering

$$Z(x) = \sum_{i=0}^{s-1} \sum_{j=1}^{d} x_{j,i} \cdot 2^{i \cdot d + j - 1}$$



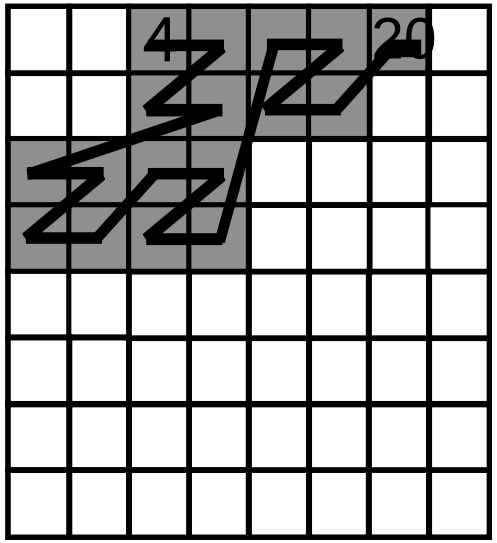
(a)

	0	1	2	3	4	5	6	7
0	0	1	4	5	16	17	20	21
1	2	3	6	7	18	19	22	23
2	8	9	12	13	24	25	28	29
3	10	11	14	15	26	27	30	31
4	32	33	36	37	48	49	52	53
5	34	35	38	39	50	51	54	55
6	40	41	44	45	56	57	60	61
7	42	43	46	47	58	59	62	63

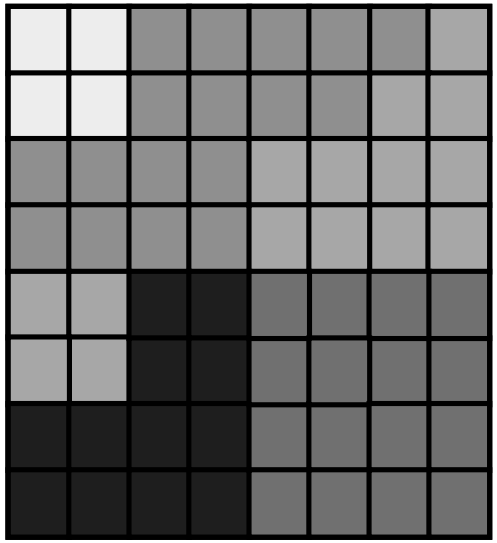
(b)

Z-regions/UB-Trees

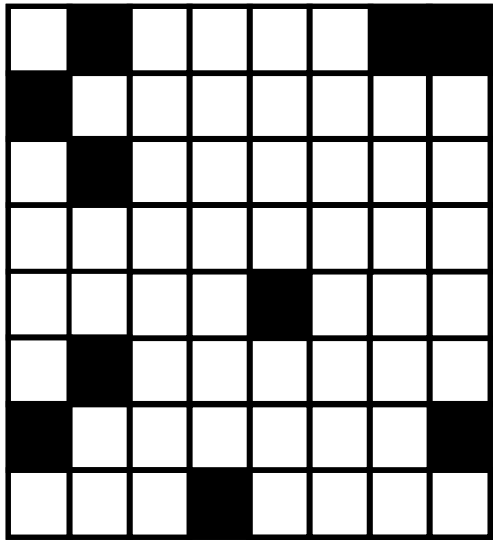
A *Z-region* [α : β] is the space covered by an interval on the Z-curve and is defined by two Z-addresses α and β.



Z-region [4 : 20]

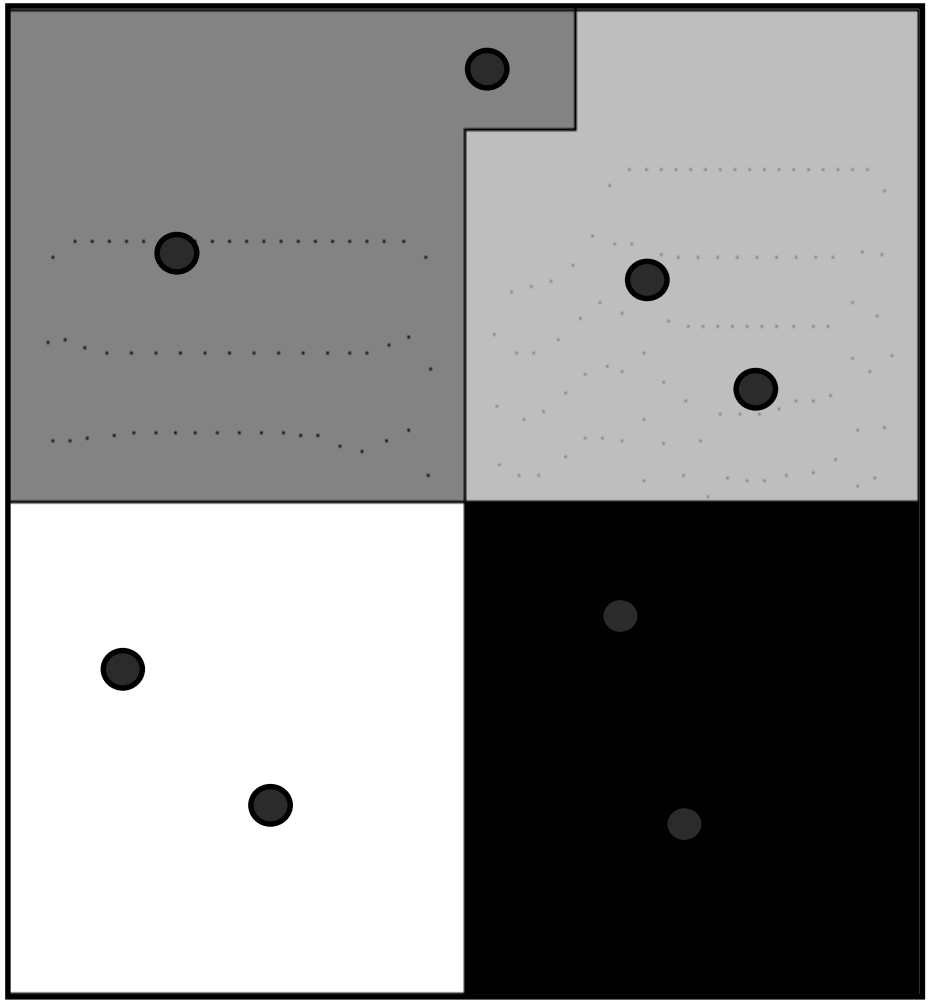


UB-Tree partitioning: [0 : 3],[4 : 20], [21 : 35], [36 : 47], [48 : 63]

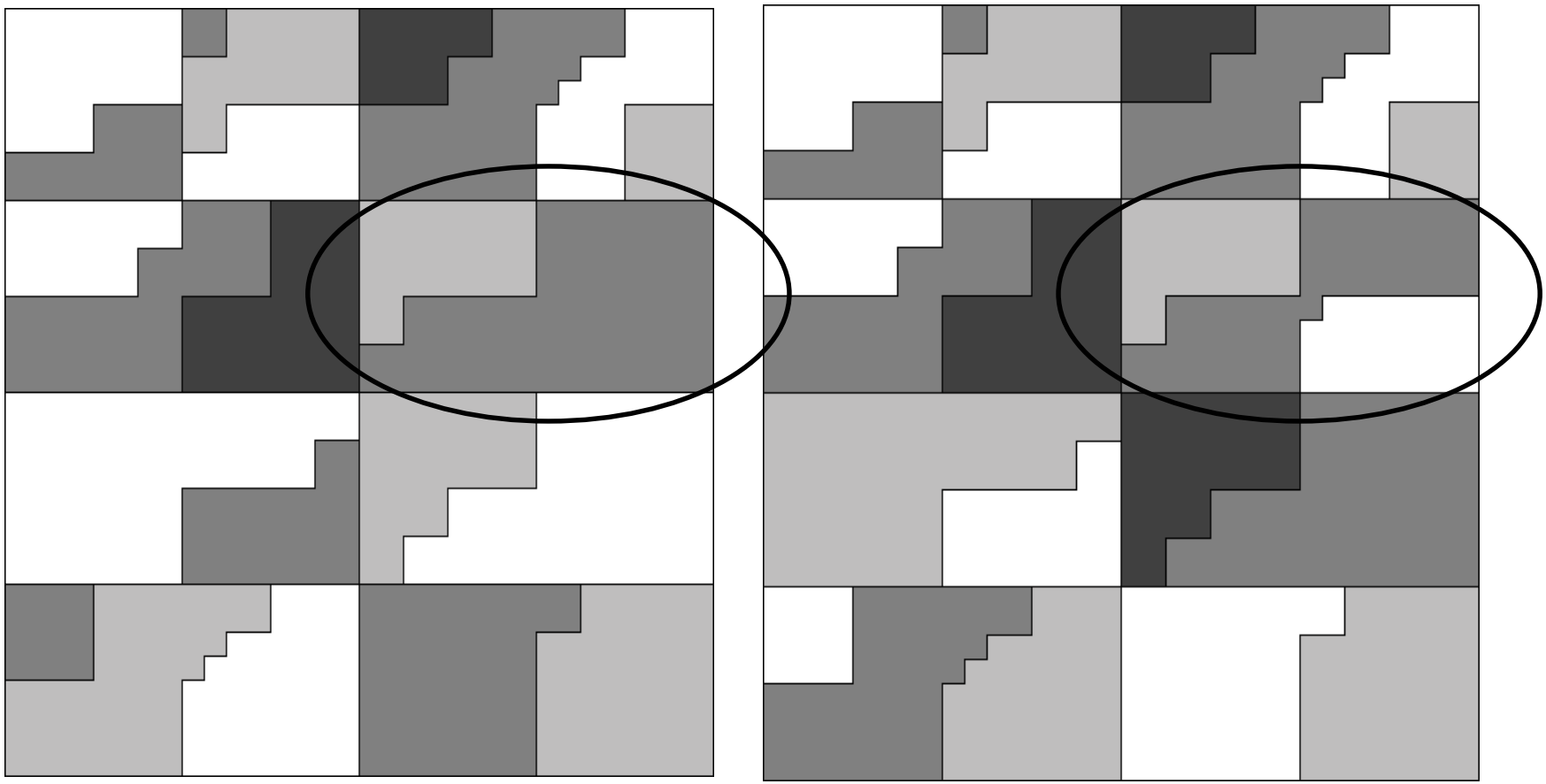


point data creating the UB-Tree on the left for a page capacity of 2 points

UB-Tree Insertion 1/2/3/4



UB-Tree Insertion 18/19

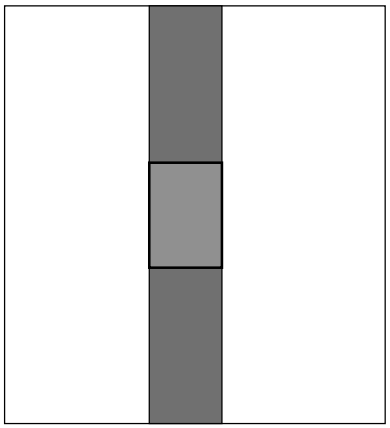


Multidimensional Range Query

SELECT * FROM table

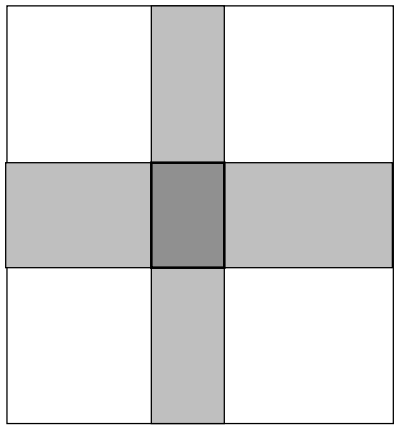
WHERE (A_1 BETWEEN a_1 AND b_1) AND
(A_2 BETWEEN a_2 AND b_2) AND
.....
(A_n BETWEEN a_n AND b_n)

Theoretical Comparison of the Rangequery Performance



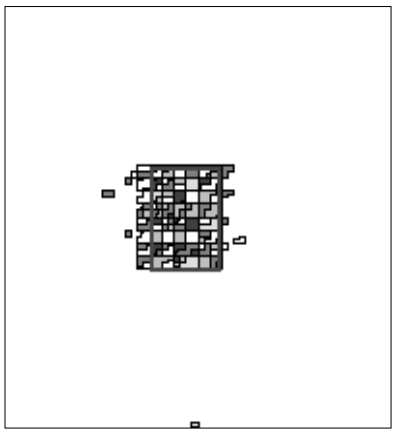
composite key clustering B-Tree

$s_1 * P$



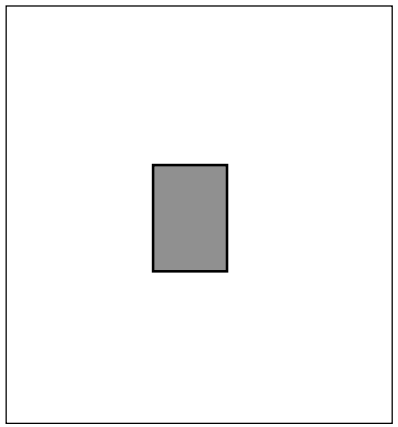
multiple B-Trees, bitmap indexes

$s_1 * l_1 + s_2 * l_2 + s_1 * s_2 * T$



multidimensional index

$s_1^{\uparrow} * s_2^{\uparrow} * P$



ideal case

$s_1 * s_2 * P$

```
rangeQuery(Tuple ql, Tuple qh)
{
  Zaddress start  = Z(ql);
  Zaddress cur    = start;
  Zaddress end    = Z(qh);
  Page page = {};

  while (1)
  {
    cur = getRegionSeparator(cur);
    page = getPage(cur);
    outputMatchingTuples(page, ql, qh);
    if ( cur >= end ) break;
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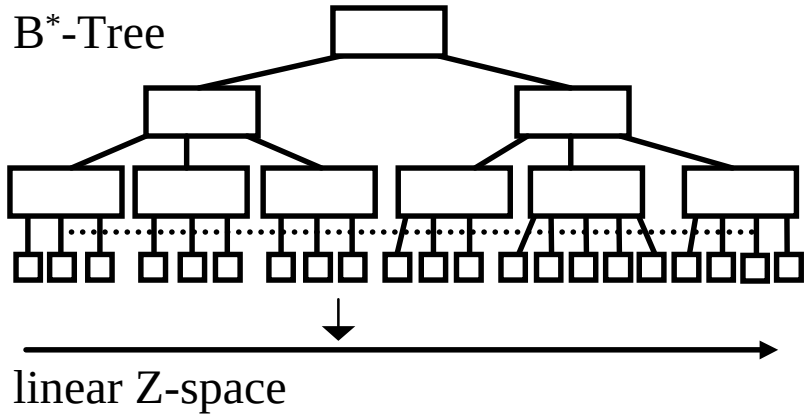
UB-Tree

B*-Tree



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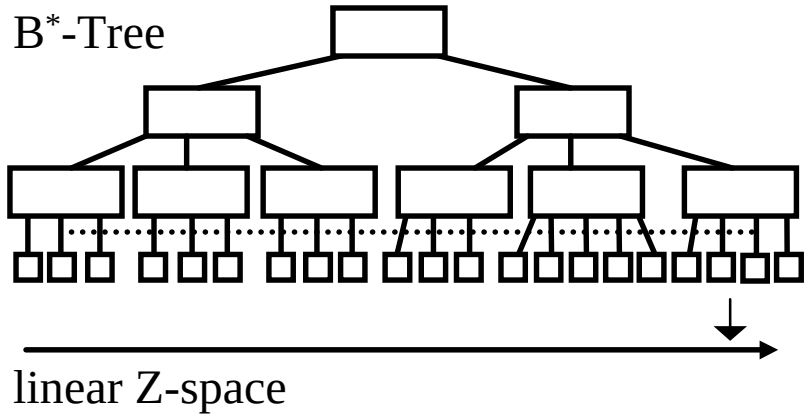

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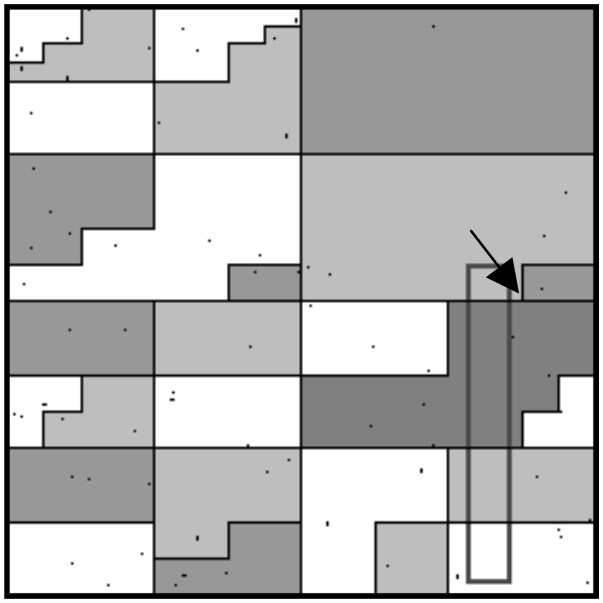
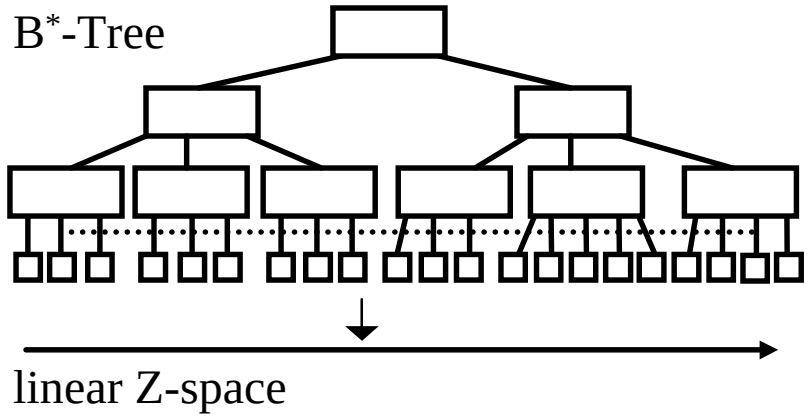


B*-Tree



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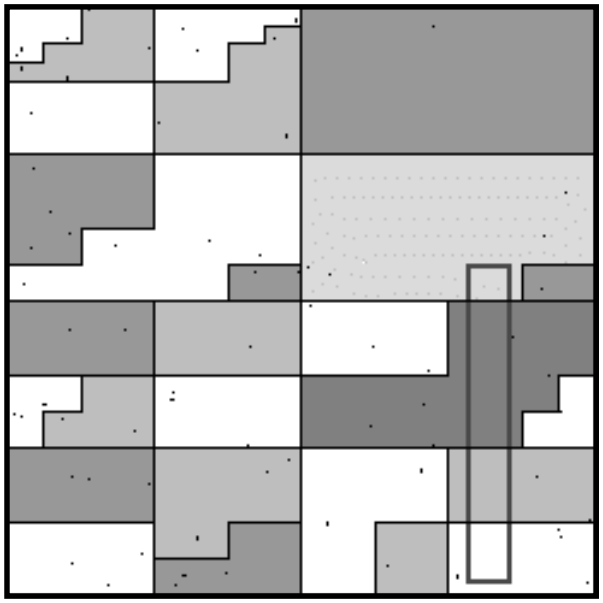

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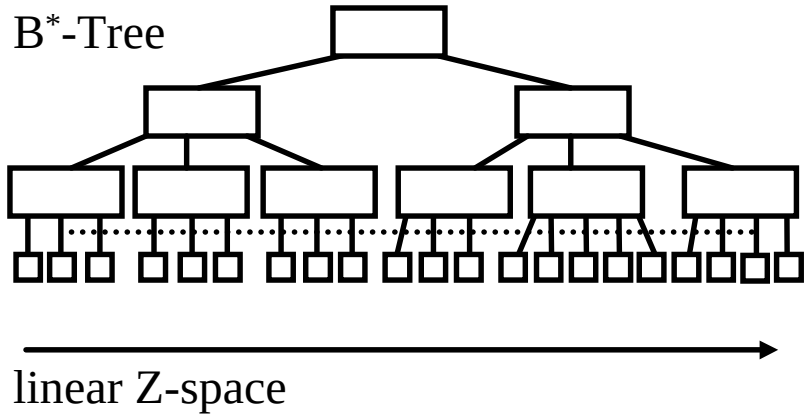

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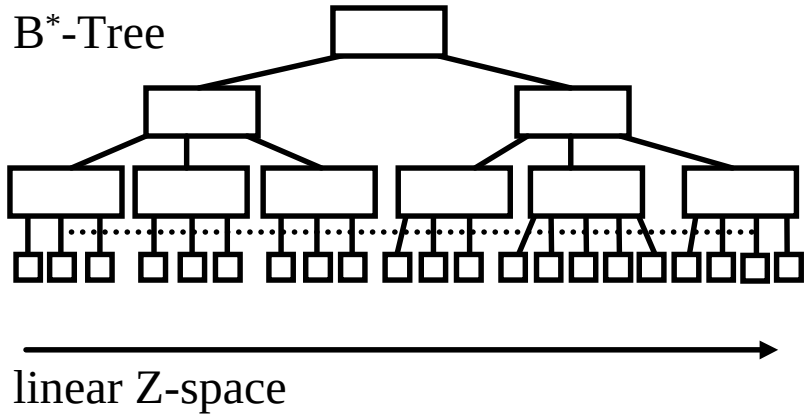

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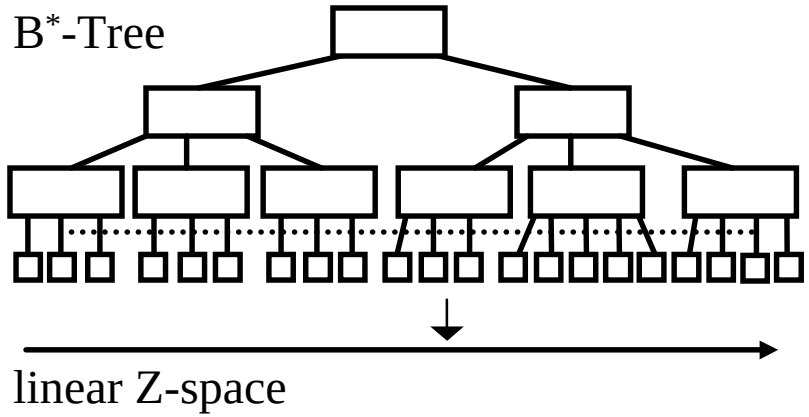

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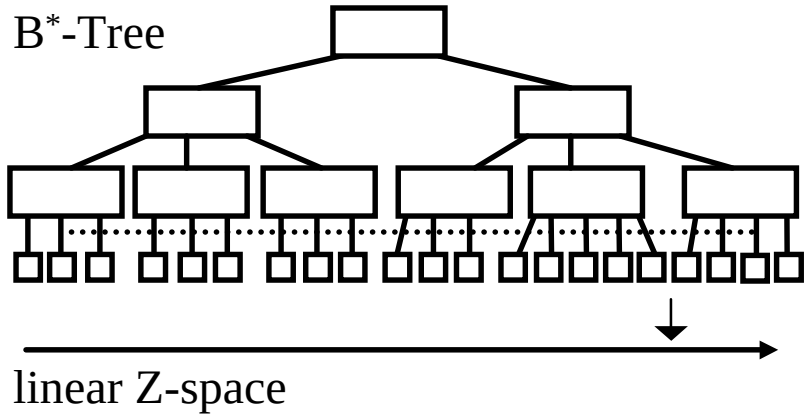

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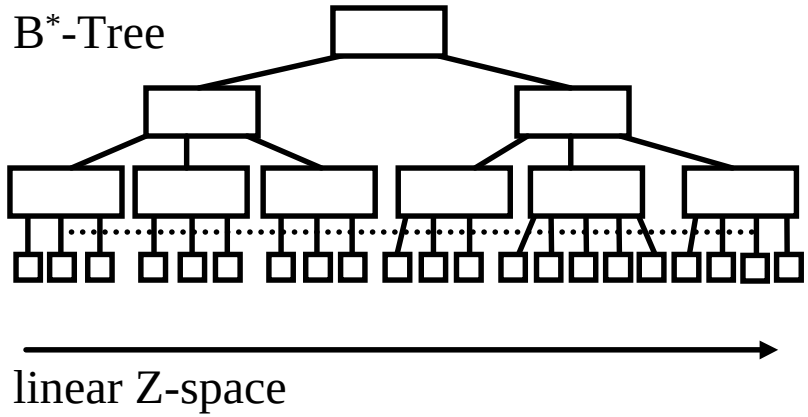

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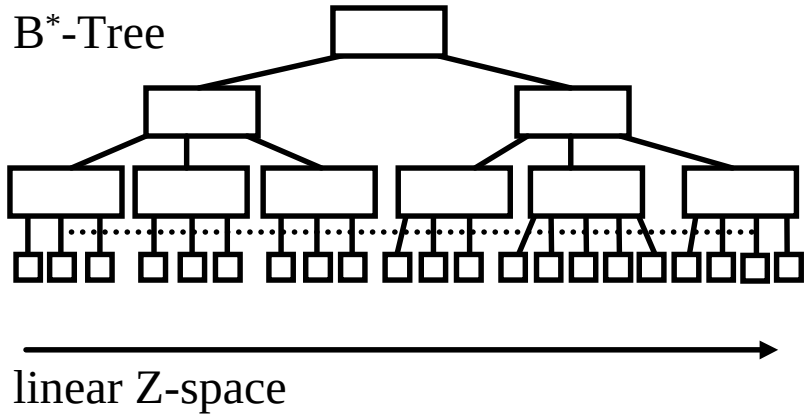

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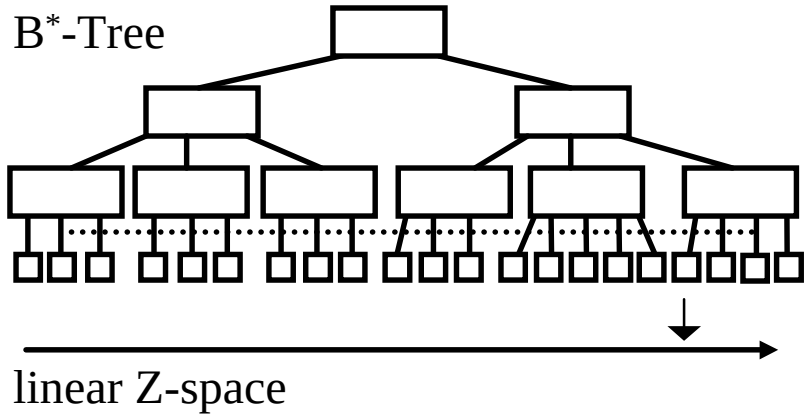

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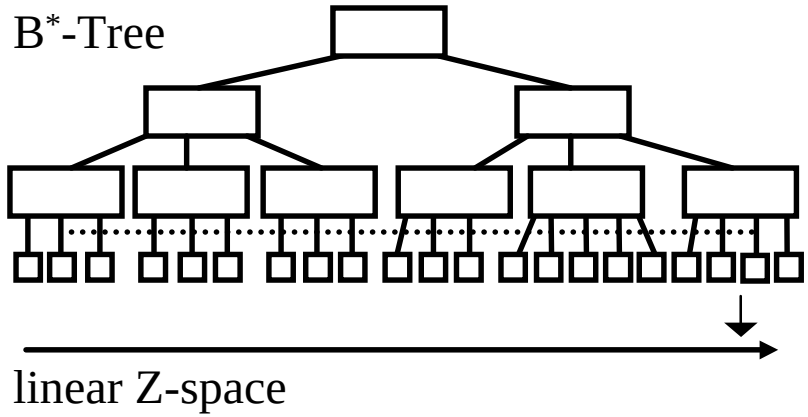

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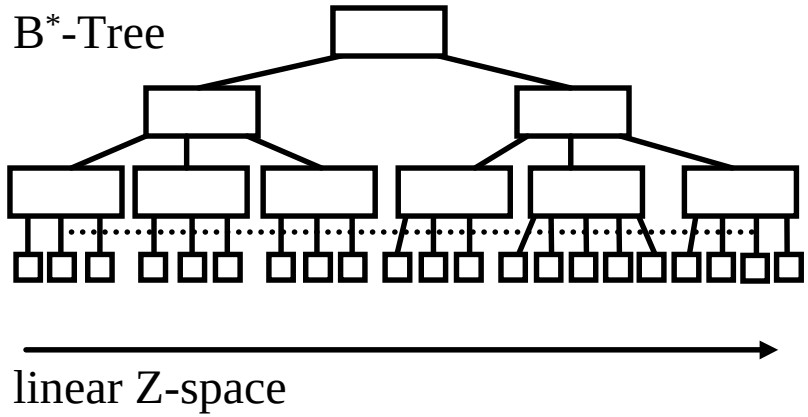

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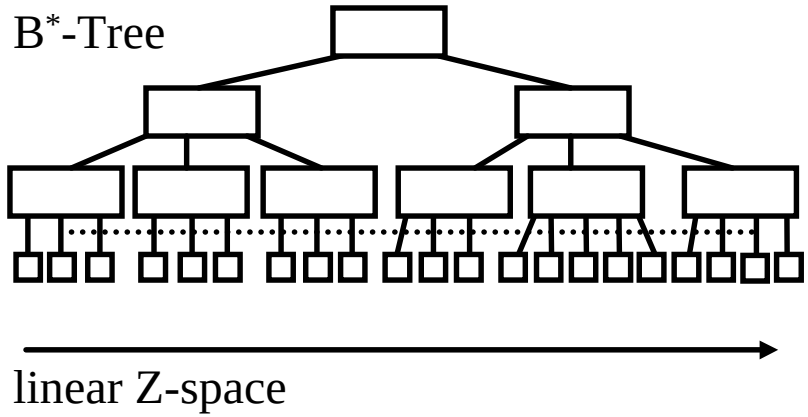

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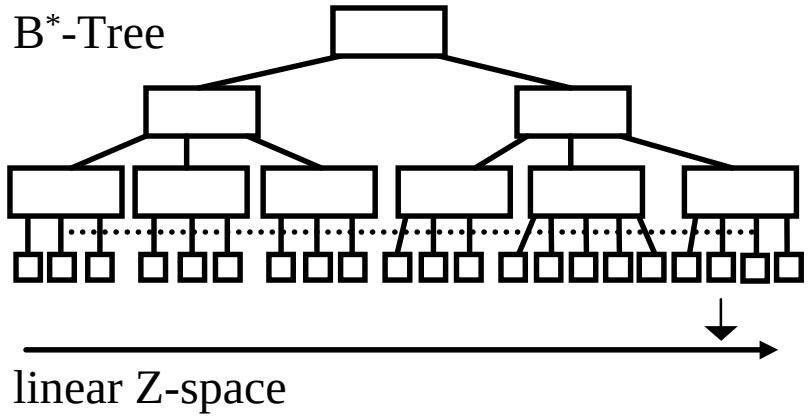

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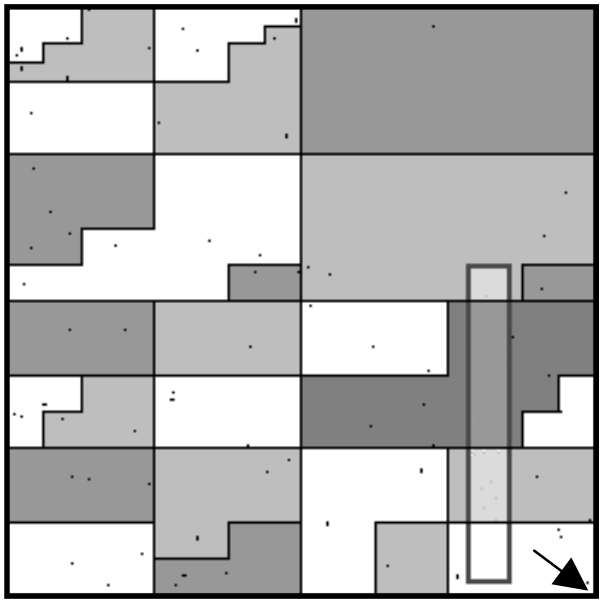
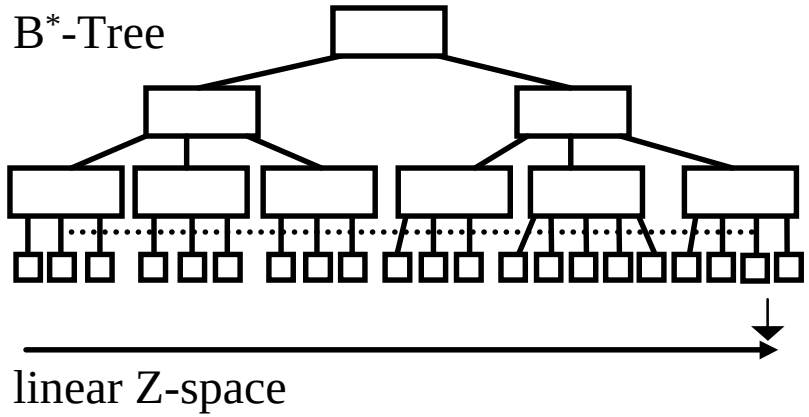


B*-Tree



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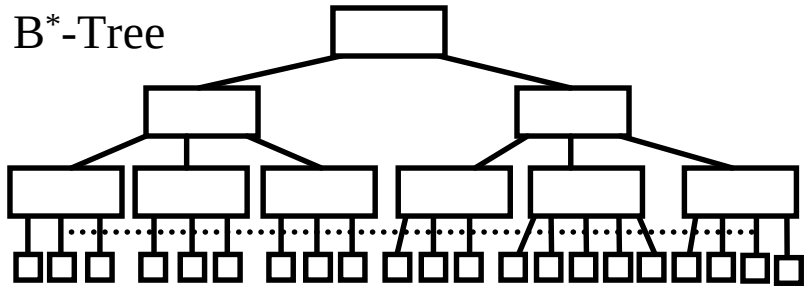


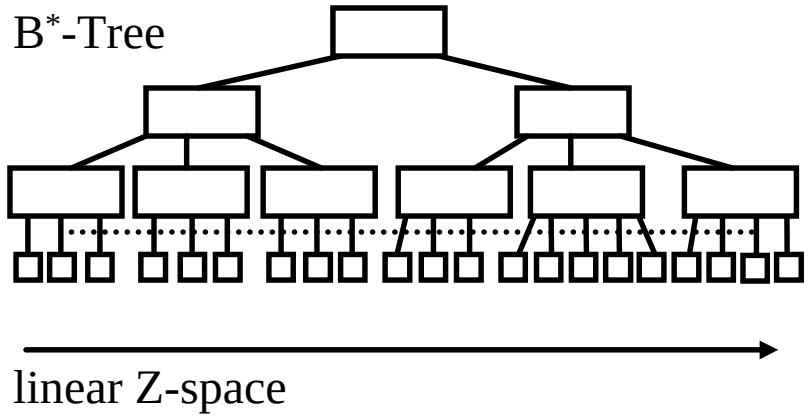
linear Z-space

```
rangeQuery(Tuple ql, Tuple qh)
{
   Zaddress start  = Z(ql);
   Zaddress cur    = start;
   Zaddress end    = Z(qh);
   Page page = {};

   while (1)
   {
     cur = getRegionSeparator(cur);
     page = getPage(cur);
     outputMatchingTuples(page, ql, qh);
     if ( cur >= end ) break;
        cur = getNextZAddress(cur, start, end);
   }
}
```

UB-Tree

B*-Tree



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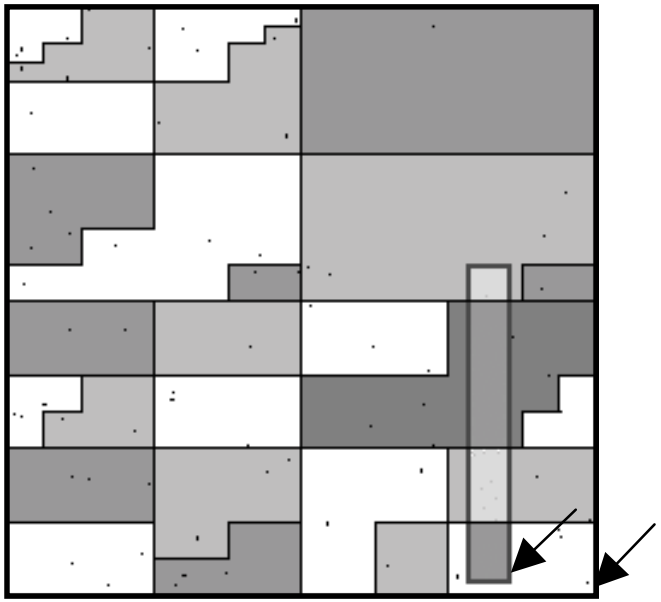
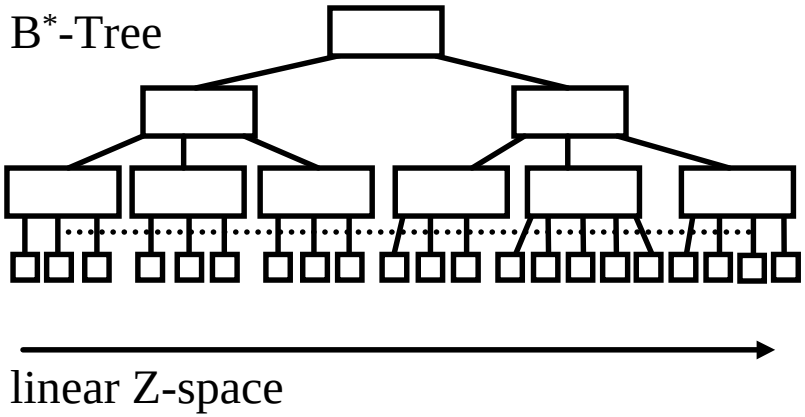
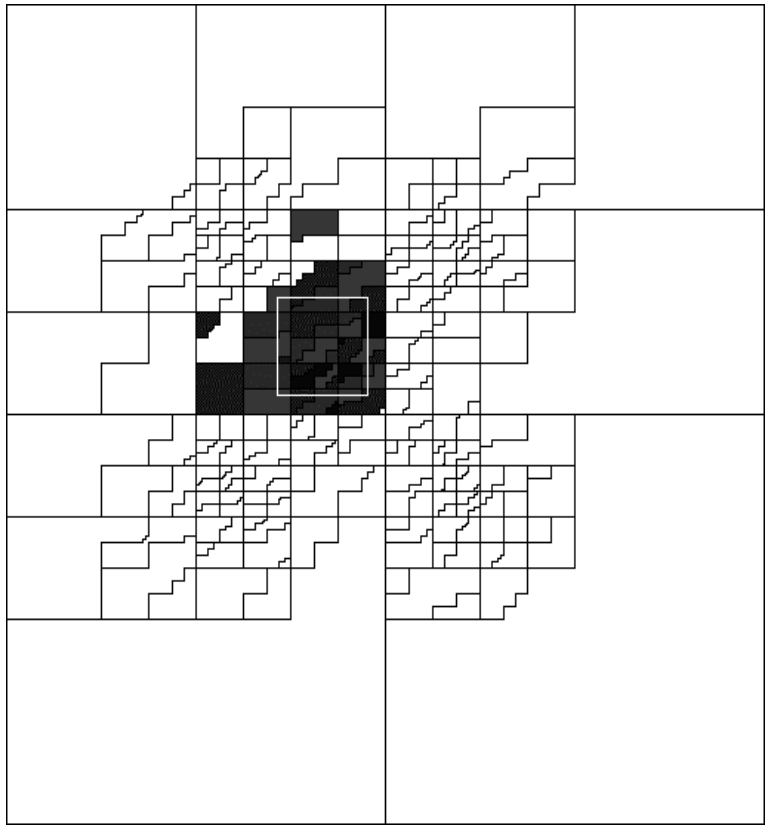
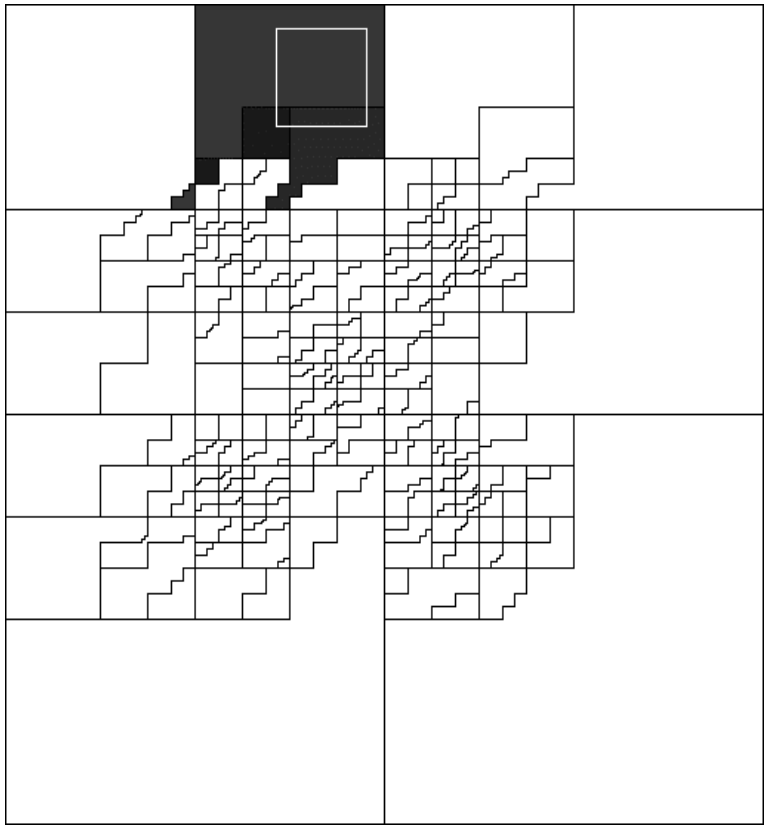


B*-Tree

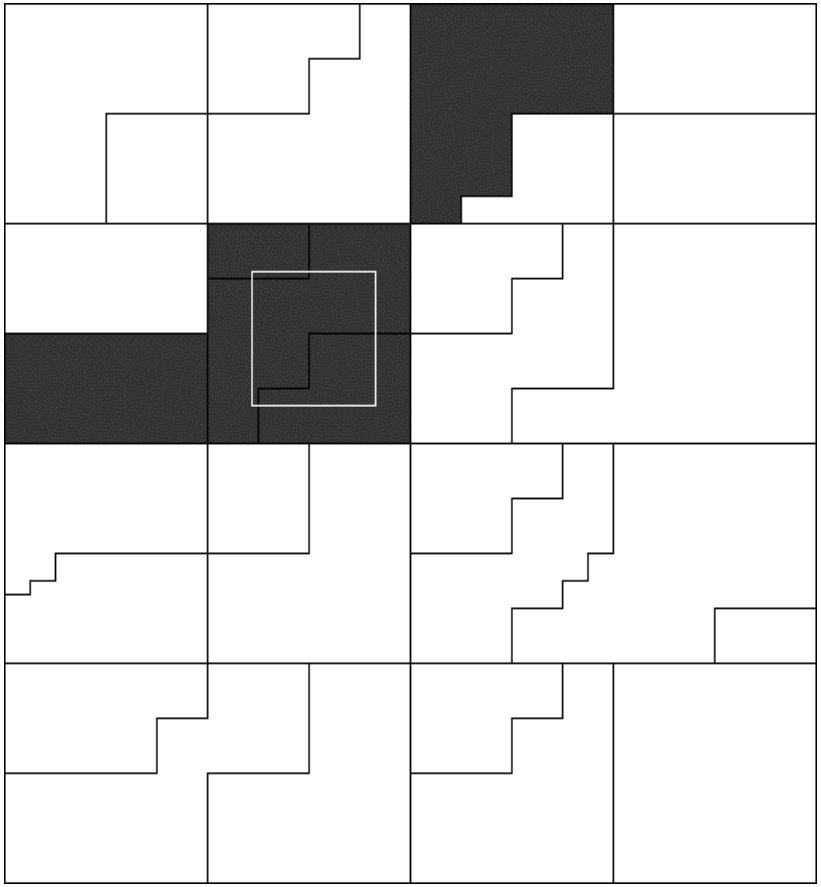


Range Queries and Data Distributions

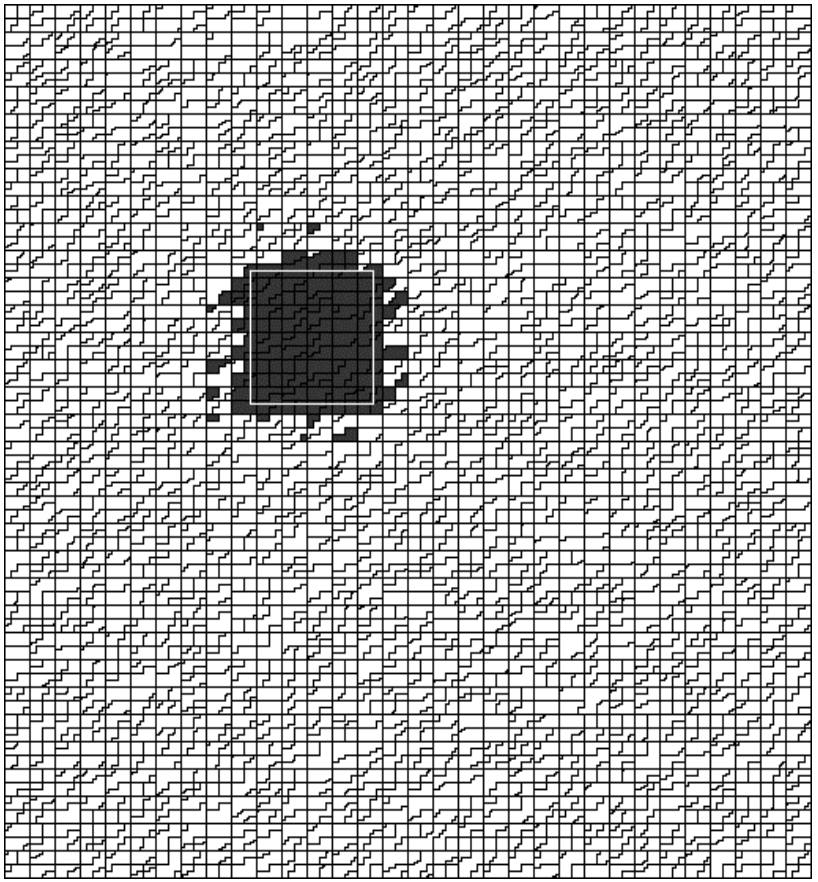




Growing Databases



1000 tuples



50 000 tuples

Summary UB-Trees

- 50% storage utilization, dynamic updates
- Efficient Z-address calculation (bit-interleaving)
- Logarithmic performance for the basic operations
- Efficient range query algorithm (bit-operations)
- Prototype UB/API above RDBMS (Oracle 8, Informix, DB2 UDB, TransBase, MS SQL 7.0) using ESQL/C
- **Patent application**

Standard Query Pattern

SELECT * FROM table

WHERE (A_1 BETWEEN a_1 AND b_1) AND

(A_2 BETWEEN a_2 AND b_2) AND

.....

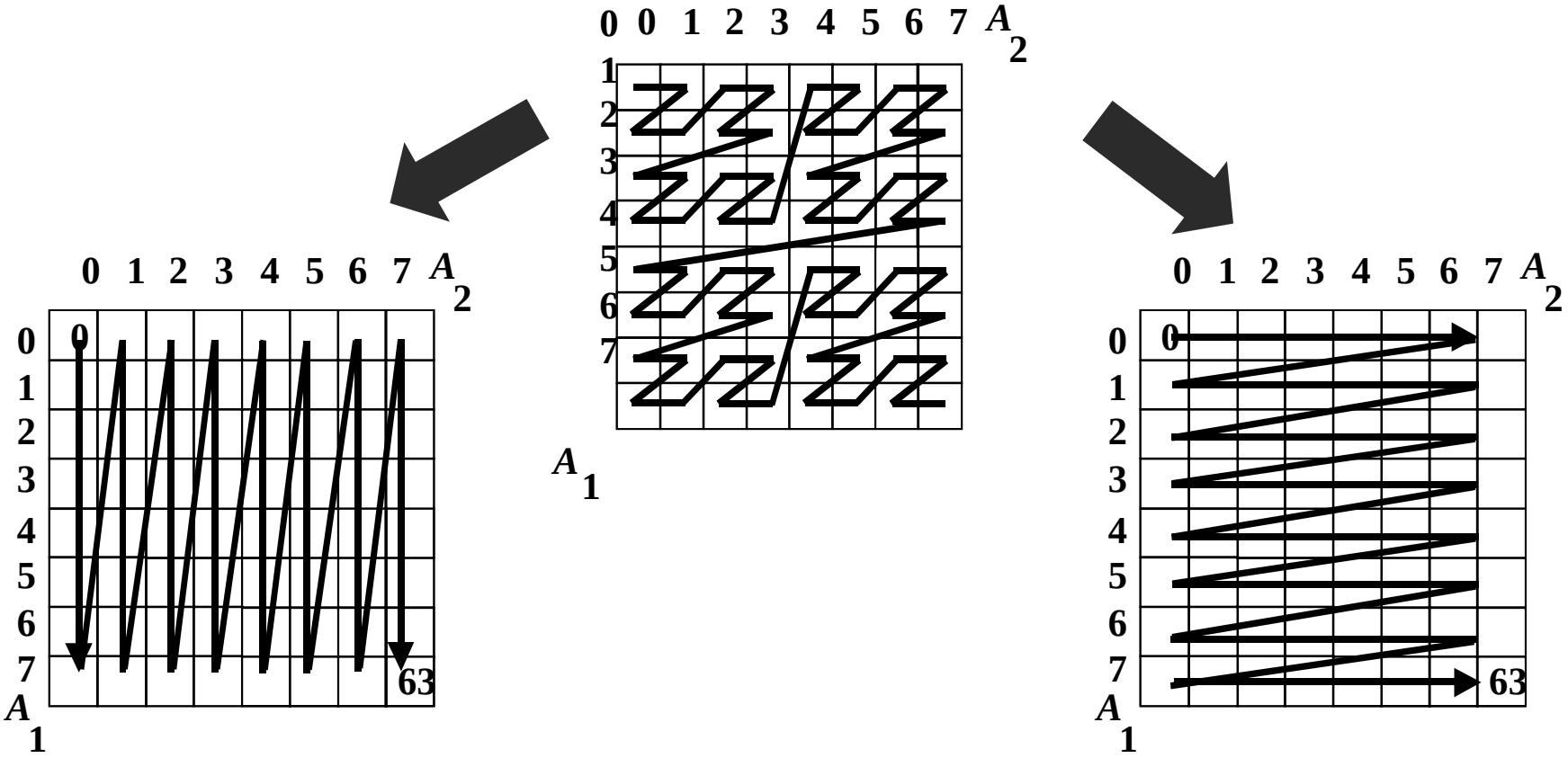
(A_n BETWEEN a_n AND b_n)

ORDER BY A_i, A_j, A_k, ...

(GROUP BY A_i, A_j, A_k, ...)

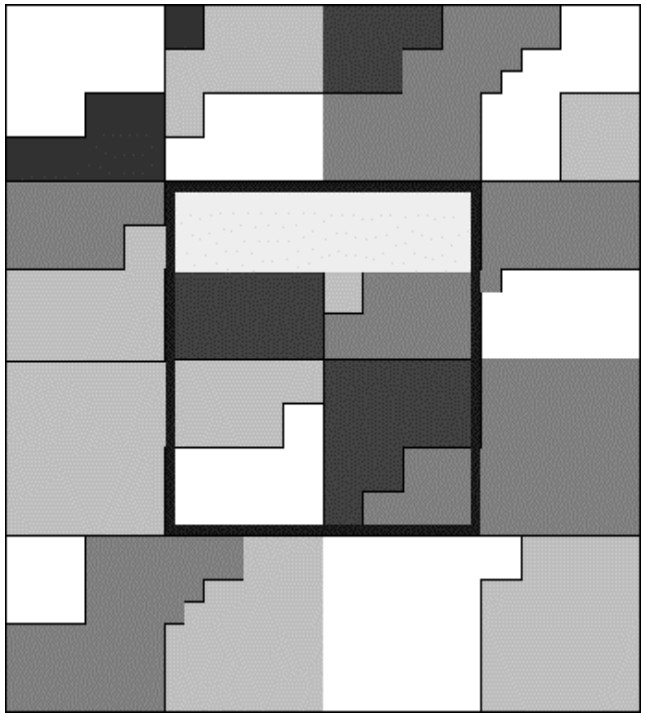
Z-Order/Tetris Order

$$T_j(x) = x_j \circ Z(x_1,\ldots,x_{j-1},x_{j+1},\ldots,x_d)$$



The Tetris Algorithm

sort direction



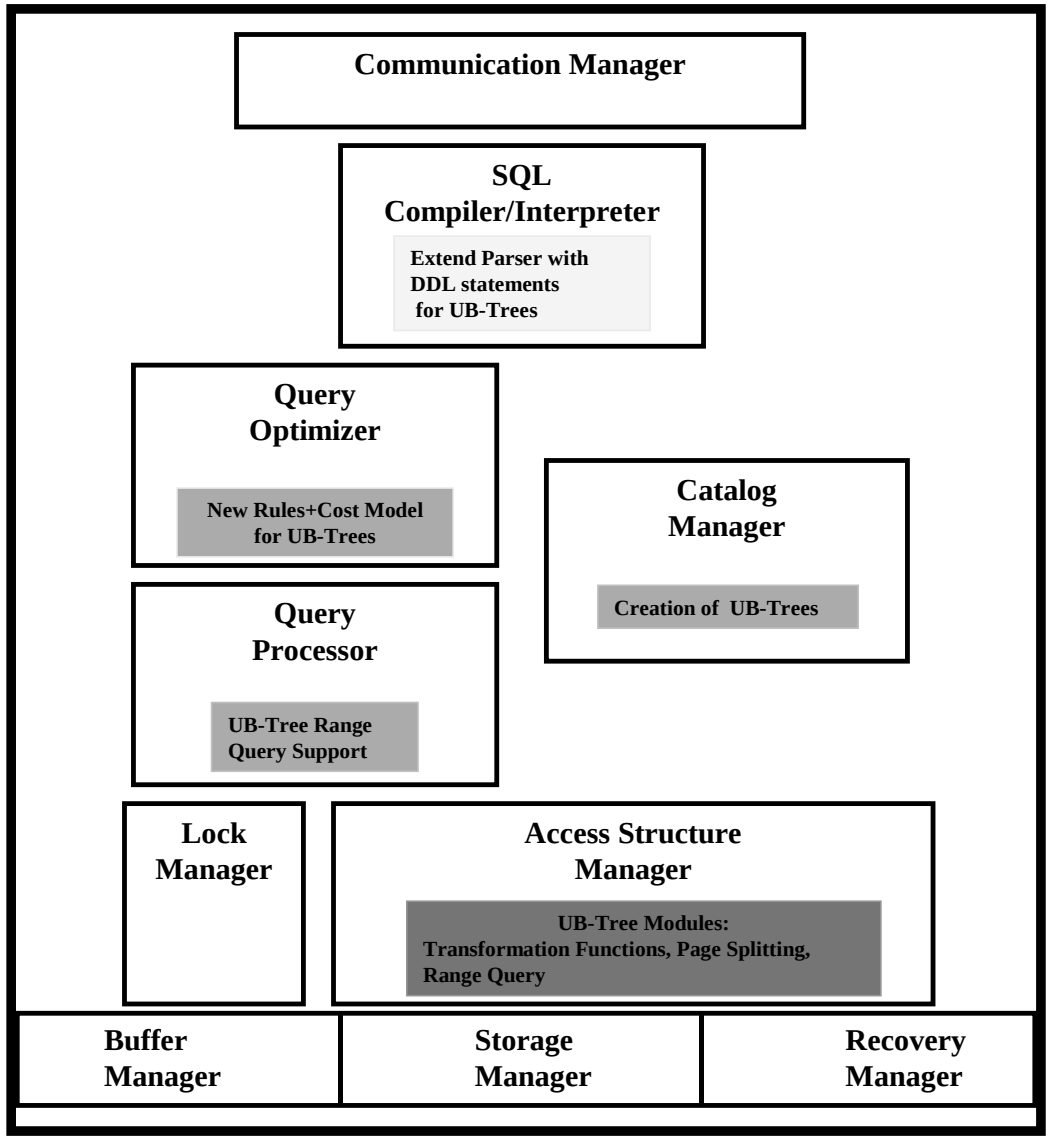
Summary Tetris

- Combines sort process and evaluation of multi-attribute restrictions in one processing step
- I/O-time linear w.r. to result set size
- temporary storage sublinear w.r. to result set size
- Sorting no longer a “blocking operation”

✍ **Patent application**

Integration Issues

- Starting point with TransBase:
  - clustering B*-Tree
  - appropriate data type for Z-values: variable bit strings
- Modifications to B*-Tree in TransBase:
  - support for computed keys:
    - » Z-values are only stored in the index, not together with the tuples
    - » tuples are stored in Z-order
  - generalization of splitting algorithm:
    - » computed page separators for improved space partitioning



- Minor extensions:
- Major extensions:
- New modules:
- **NO changes for:**
  - DML
  - Multi-user support, i.e., locking, logging facilities
    → handled by underlying B*-Tree

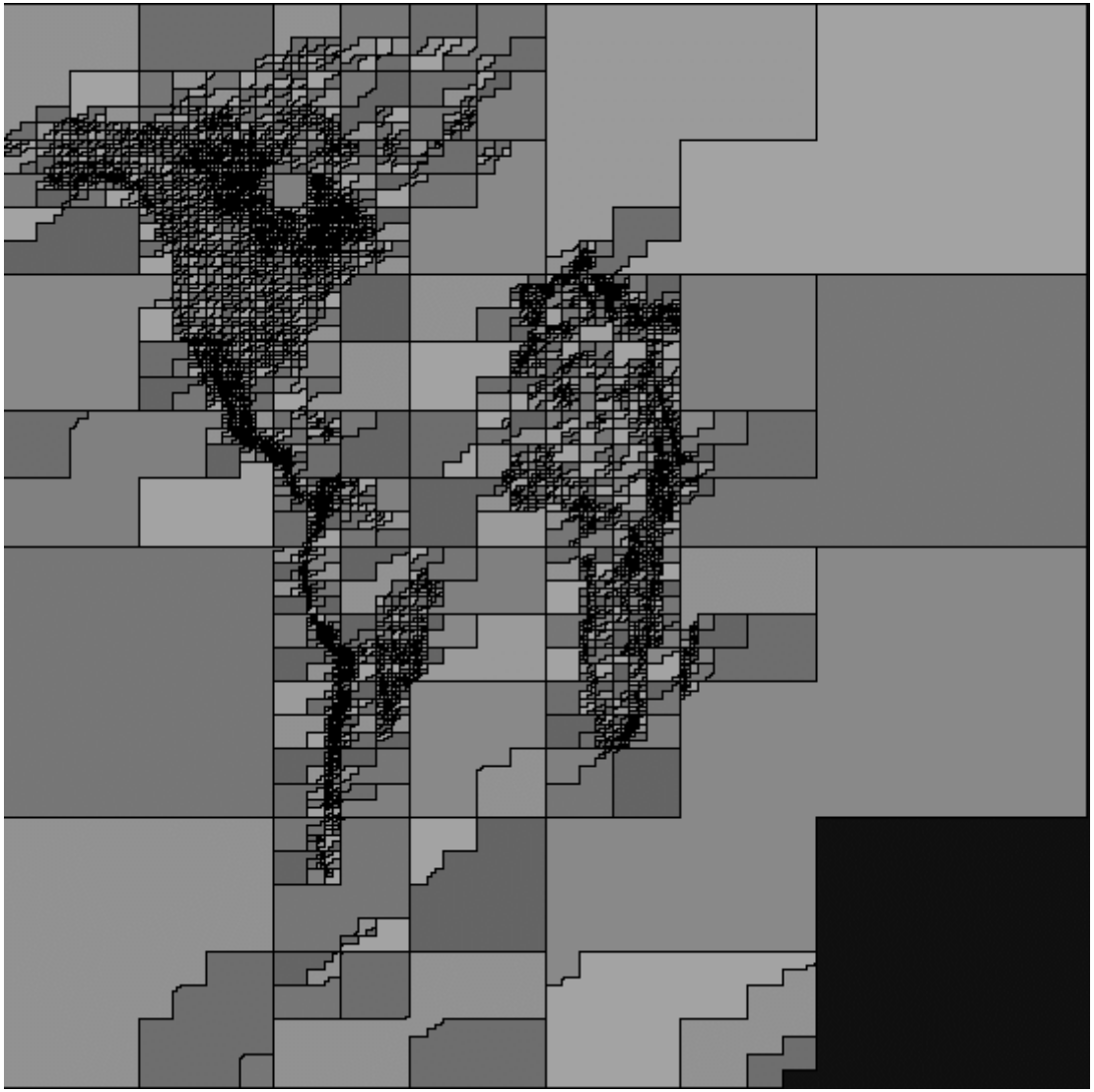
Summary Integration

- Integration of the UB-Tree has been achieved within one year
- TransBase HyperCube is shipping since Systems 1999 and was awarded the 2001 IT-Prize by EUROCASE and the European Commission
- UB-Trees speed up relational DBMS for multidimensional applications like Geo-DB and data warehouse up to two orders of magnitude
- Speedup is even more dramatic for CD-ROM databases (archives)

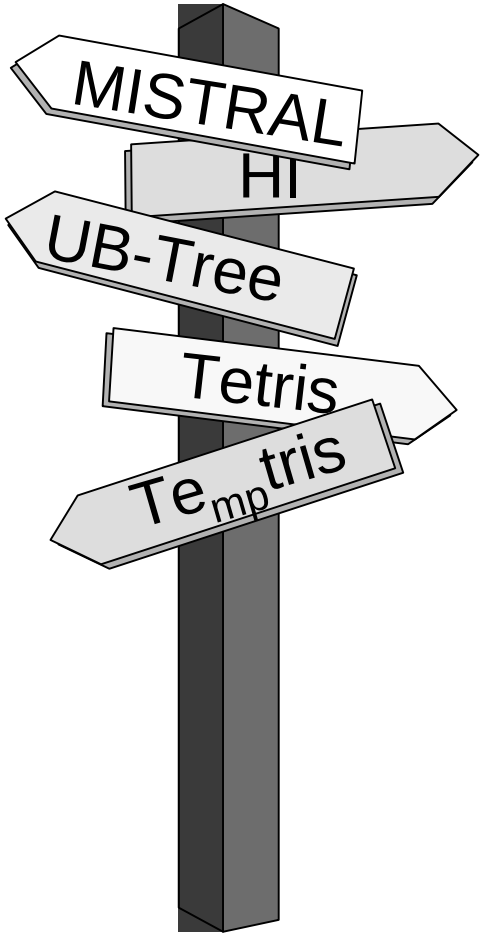
Application Fields of the UB-Tree

- Data Warehouses
  - Measurements with SAP BW Data
    - » UB-Tree/API for Oracle
    - » UB-Tree ***on top of*** Oracle outperforms conventional B-Tree and Bitmap indexes ***in*** Oracle!
  - Measurements with the GfK Data Warehouse
    - » UB-Tree in TransBase HyperCube
    - » significant performance increases (Factor of 10)
- Geographic Databases
- „Multidimensional Problems“
  - Archiving Systems, Lifecycle-Management, Data Mining, OLAP, OLTP, etc.

The UB-Tree



Further Information



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