Index Internals

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Index Access Methods in PostgreSQL 9.5

- B-tree
- GiST
- GIN
- SP-GiST
- BRIN

- (Hash)

… but first, the Heap

Heap

- Stores all tuples in table
- Unordered

Heap

- Divided into 8k blocks

TID: Physical location of heap tuple

Example: **Helsinki,** Block 1, item 2 within block

Item pointer

Example: **Helsinki,** Block 1, item 2 within block

(1, 2)

- Block number and position within page
- Uniquely identifies a tuple version

Indexes in PostgreSQL

- Indexes store TIDs of heap tuples
  - except BRIN
- There is no visibility information in indexes
  - except for a simple “dead” flag, as an optimization
  - UPDATE inserts a new index tuple
  - Dead tuples are removed by VACUUM

B-tree

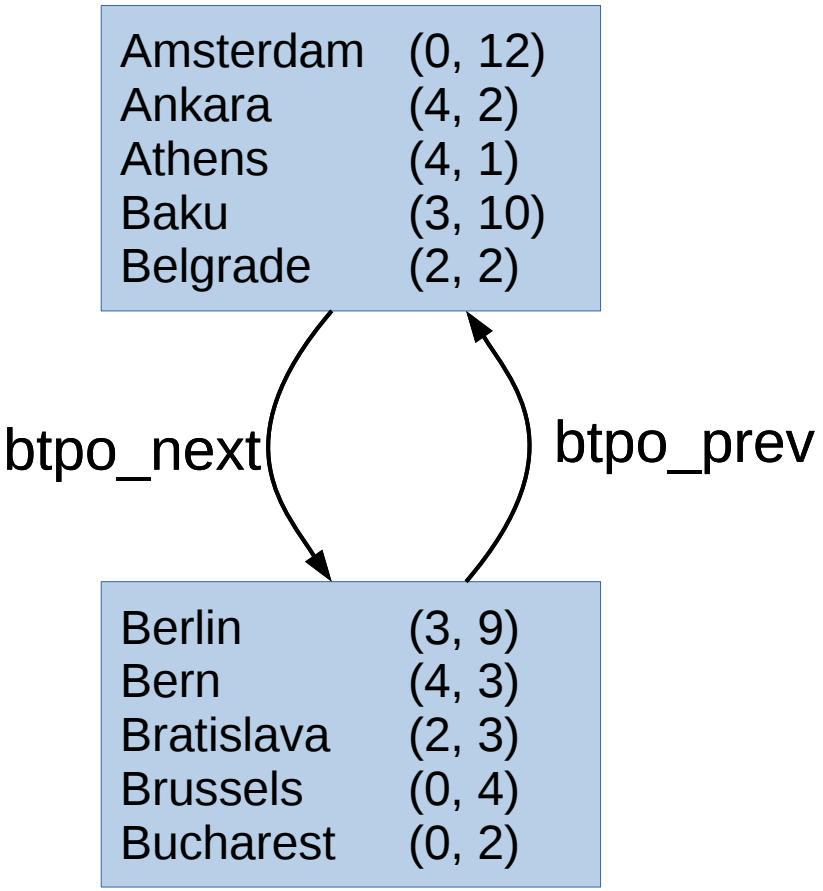
Good old B-tree

- Default index type
- Tuples are stored on pages, ordered by key
- Tree, every branch has same depth

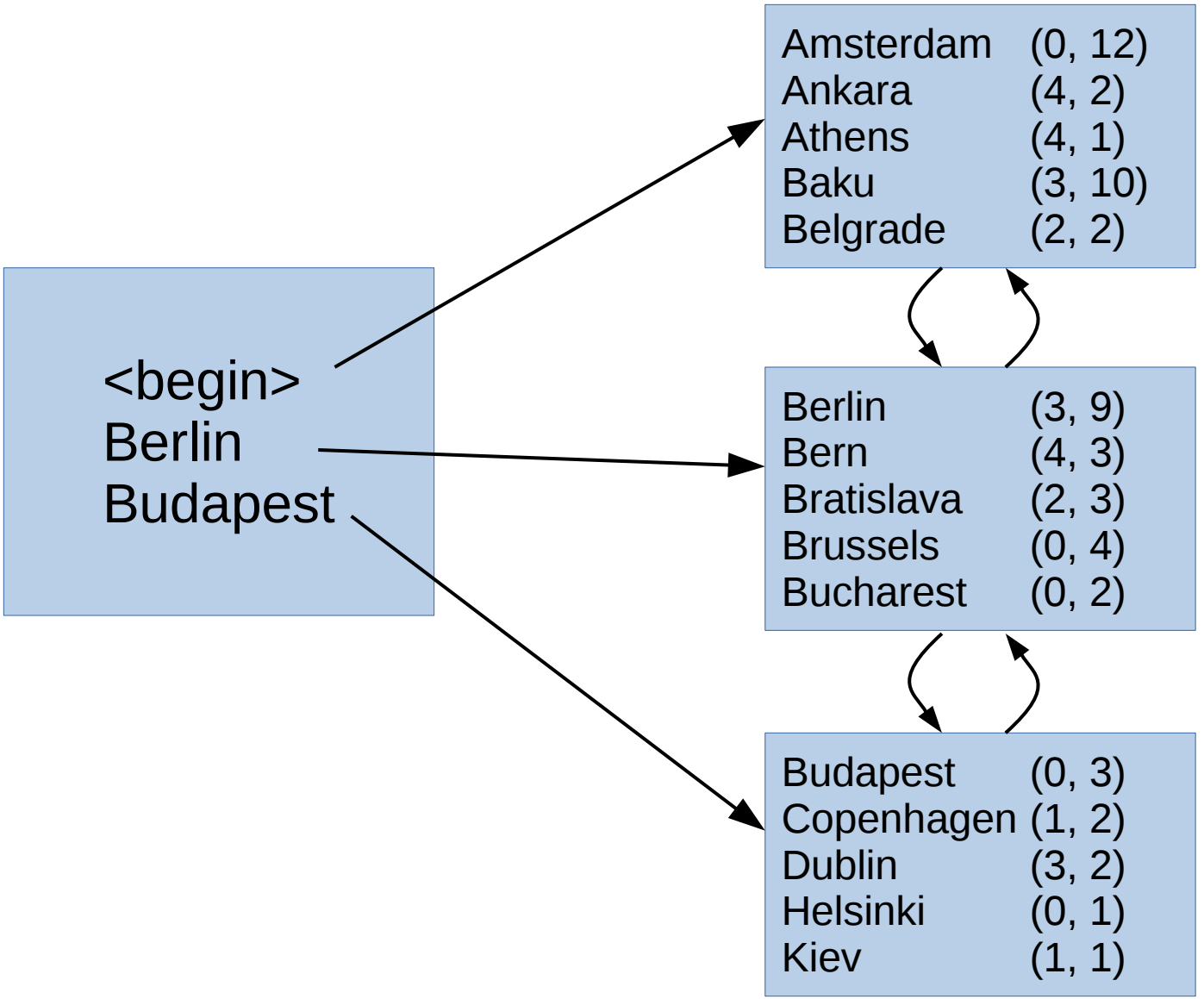
B-tree, single page

Amsterdam	(0, 12)
Ankara	(4, 2)
Astana	(1, 9)
Athens	(4, 1)
Baku	(3, 10)
Belgrade	(2, 2)

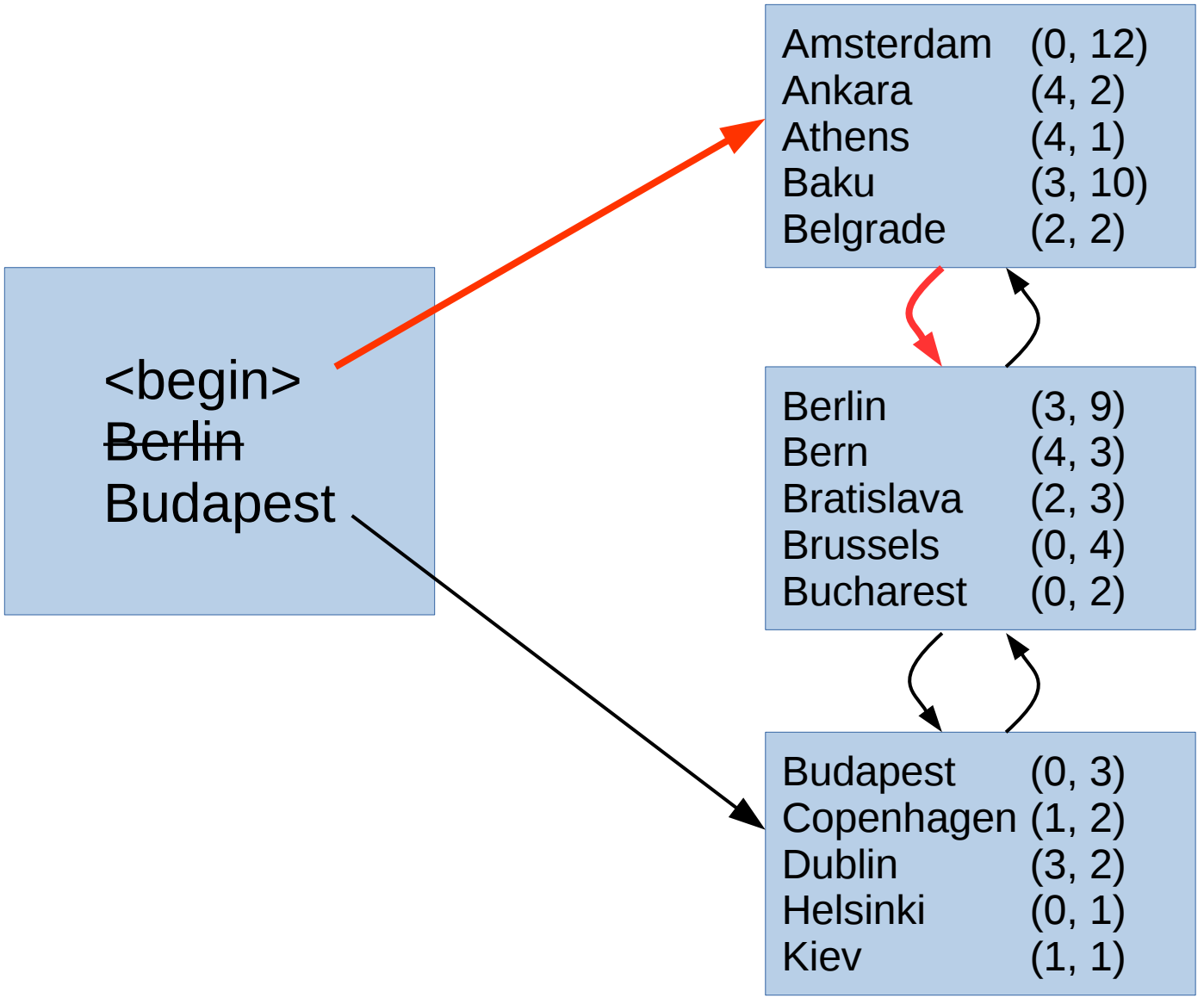
B-tree, leaf level



B-tree, two levels



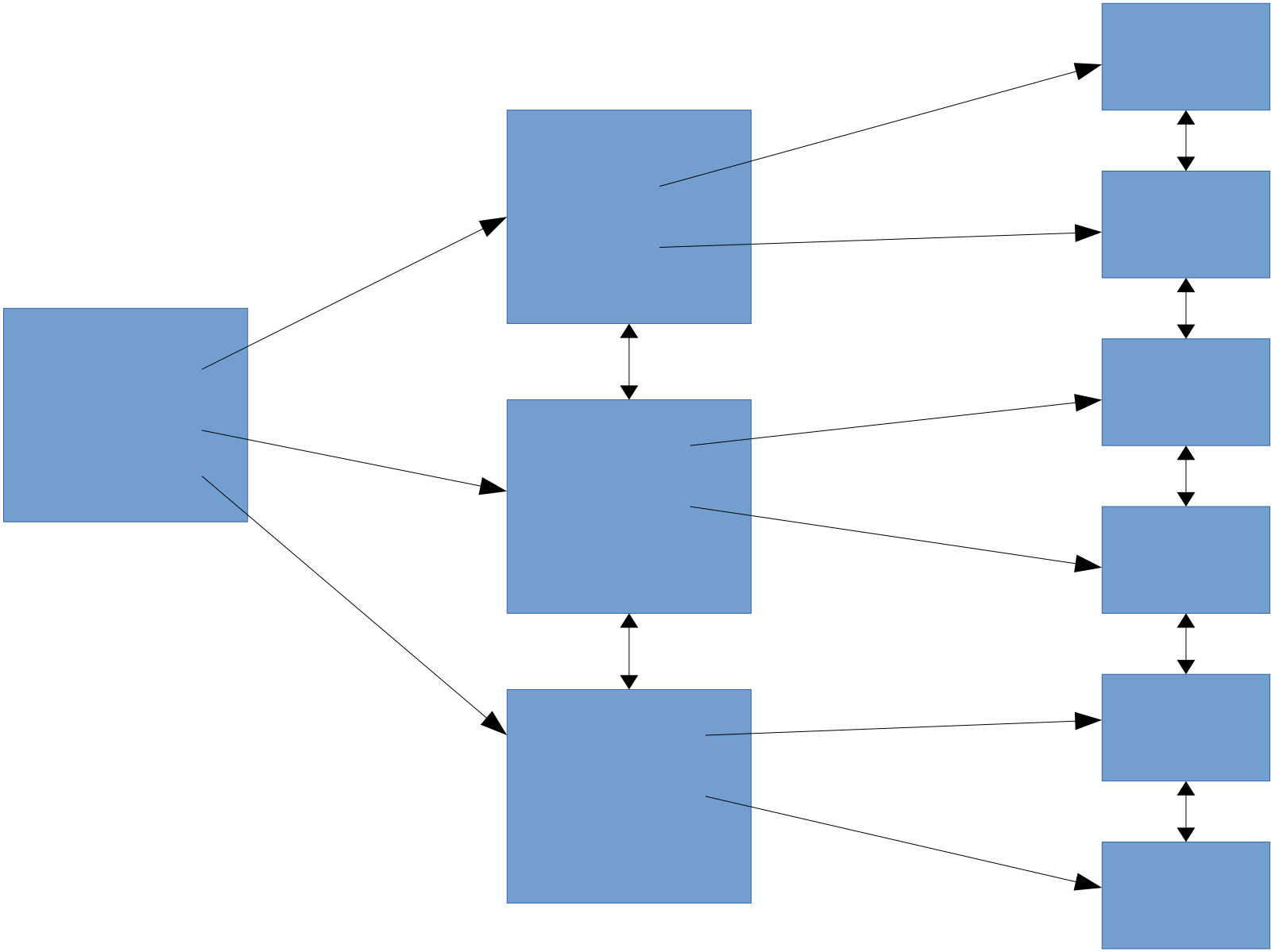
B-tree that's missing nodes still works!



B-tree details

- Lehman & Yao
- When a page becomes completely empty, it can be removed and recycled
- Half-empty pages are never merged
- Free Space Map to track unused pages

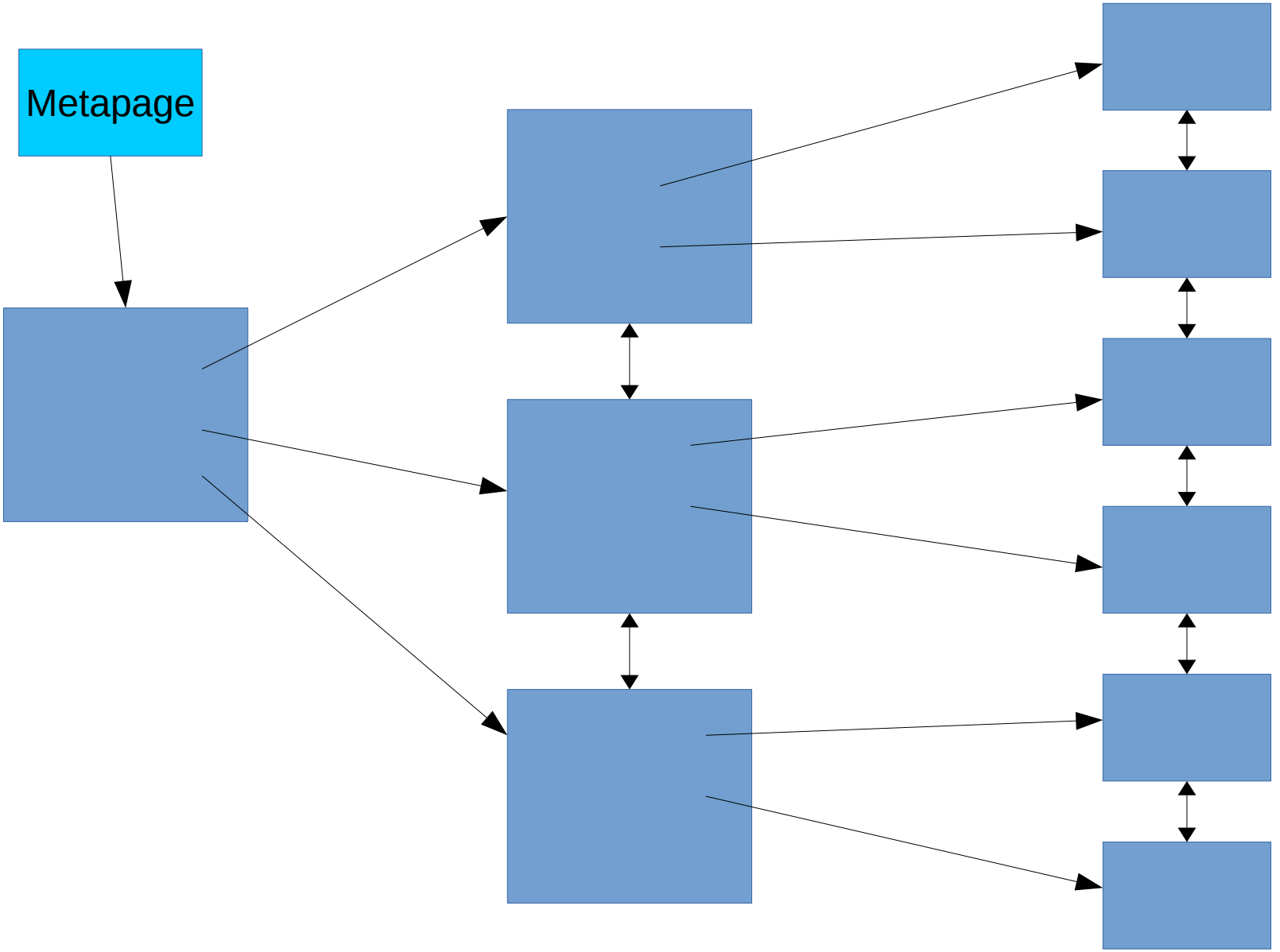
B-tree, three levels



Sidenote: Metapage

- Most index types in PostgreSQL has a metapage at block 0
  - All but GiST
- B-tree Metapage
  - Pointer to root page
  - Pointer to “fast root”

Complete B-tree



What can you do with a B-tree?

- Find key = X
- Find keys < X or > X
- ORDER BY
- LIKE 'foo%'

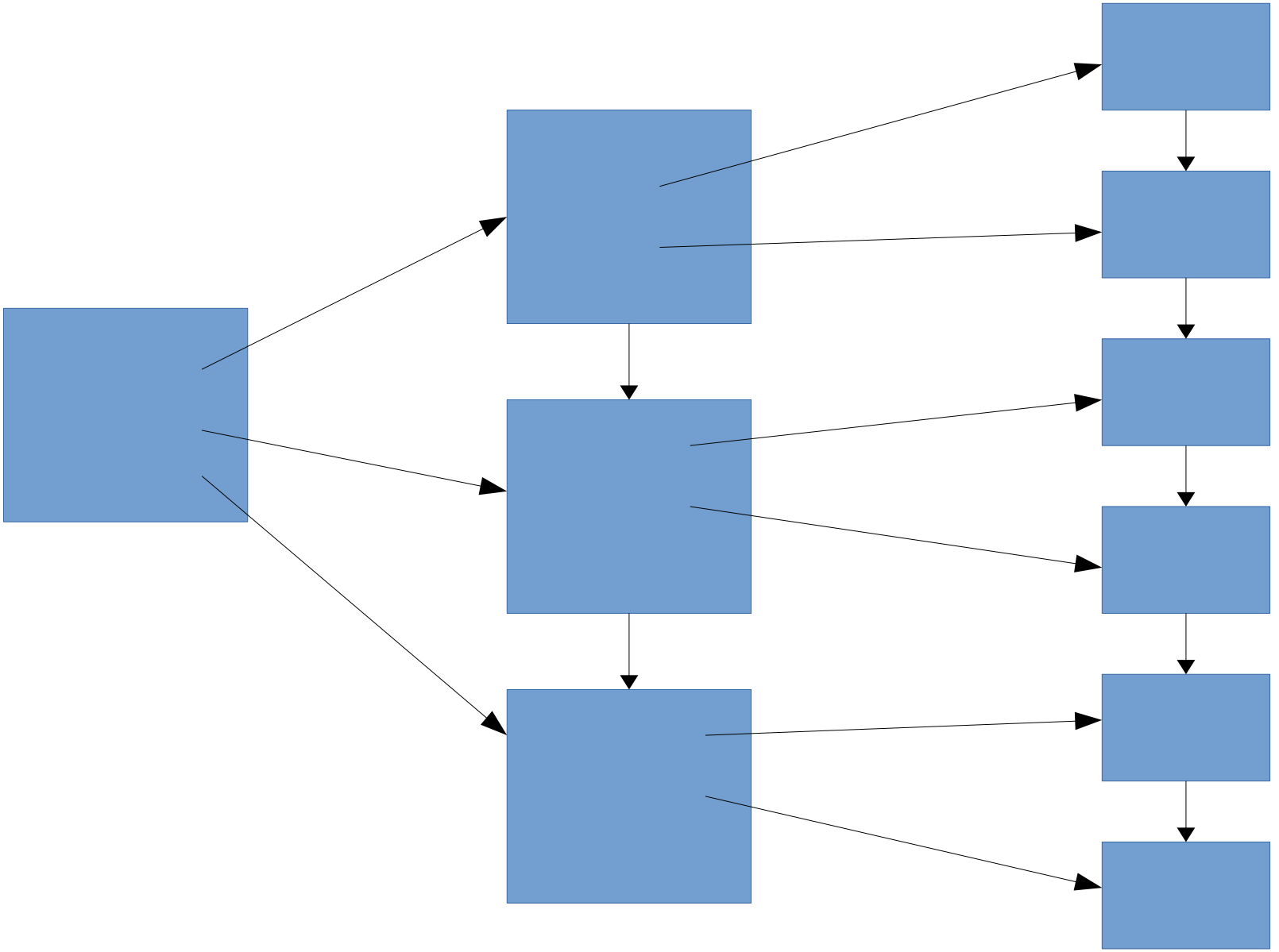
GIN

= Generalized Inverted Index

GIN

- Internal structure is basically just a B-tree
  - Optimized for storing a lot of duplicate keys
  - Duplicates are ordered by heap TID
- Interface supports indexing more than one key per indexed value
  - Full text search: “foo bar” → “foo”, “bar”
- Bitmap scans only

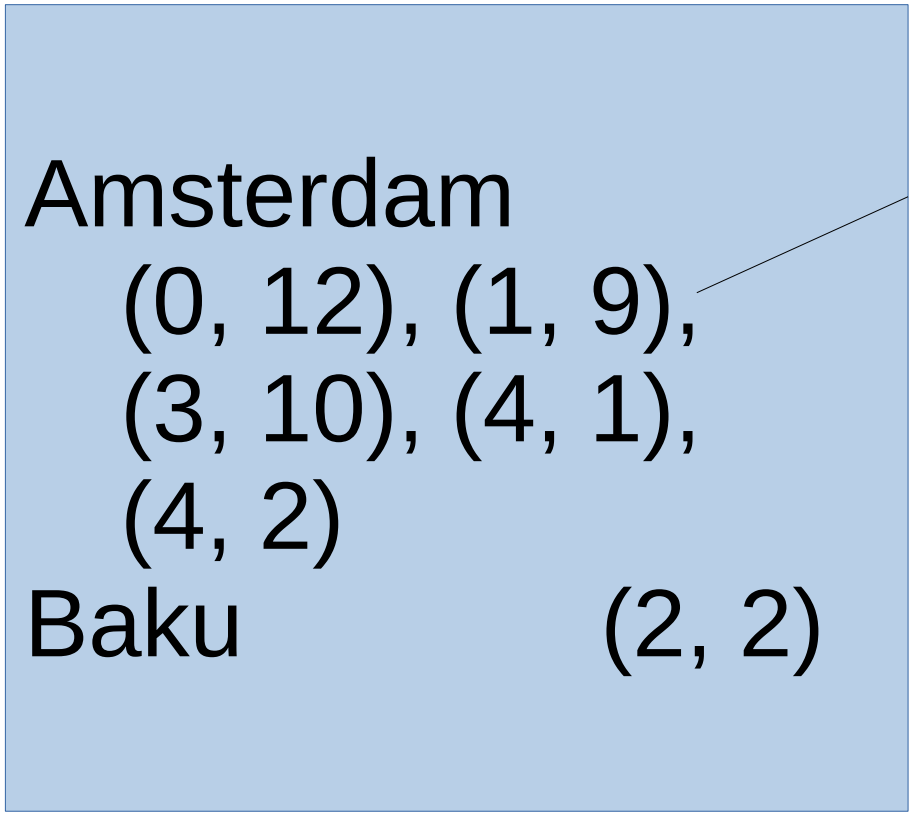
GIN entry tree



B-tree page

Amsterdam	(0, 12)
Amsterdam	(4, 2)
Amsterdam	(1, 9)
Amsterdam	(4, 1)
Amsterdam	(3, 10)
Baku	(2, 2)

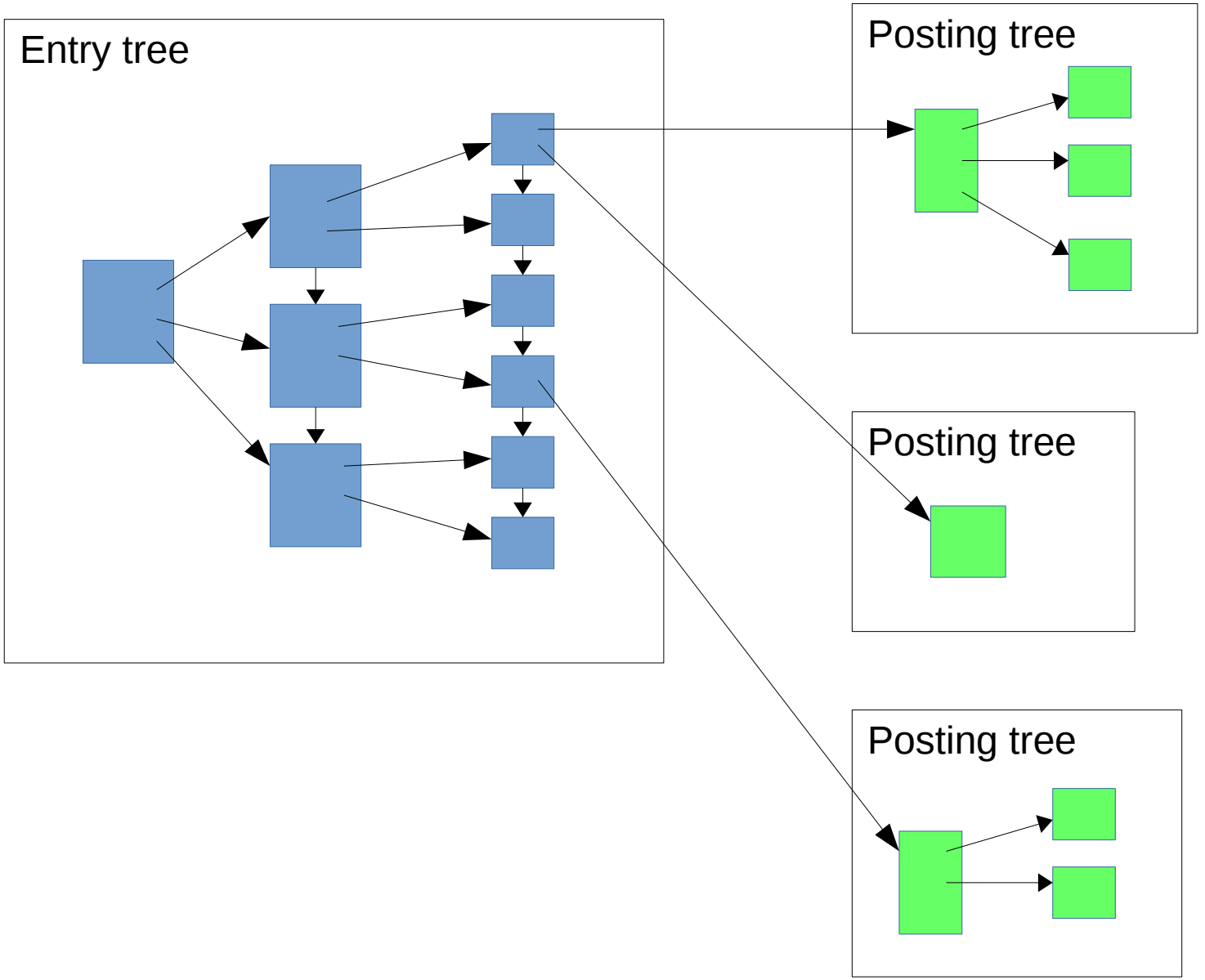
GIN entry tree page



Three ways to store heap TIDs in entry item

1. Single heap TID
   - trivial case, like normal B-tree
2. Compressed list of heap TIDs
   - also known as a “posting list”
3. Pointer (= blk #) to the root of posting tree
   - TIDs stored on a separate page or tree of pages, in TID order

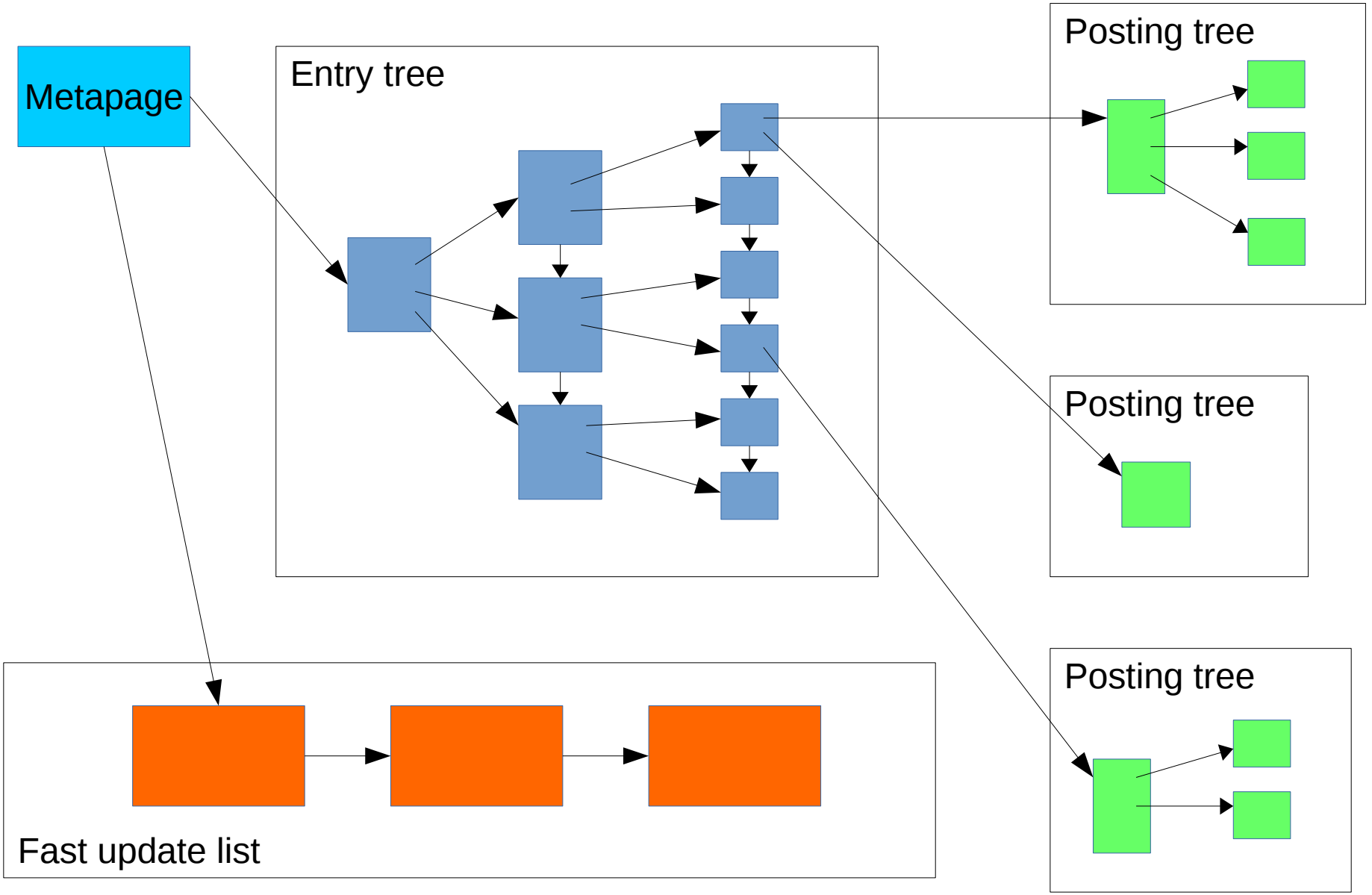
GIN



GIN “fast updates”

- Insertions to GIN index go to a list of “fast updated” tuple.
  - Every search scans the list in addition to index
- Moved to index proper by VACUUM
  - Or by inserts, if grows too big
- Can be disabled with FASTUPDATE = off option

Complete GIN



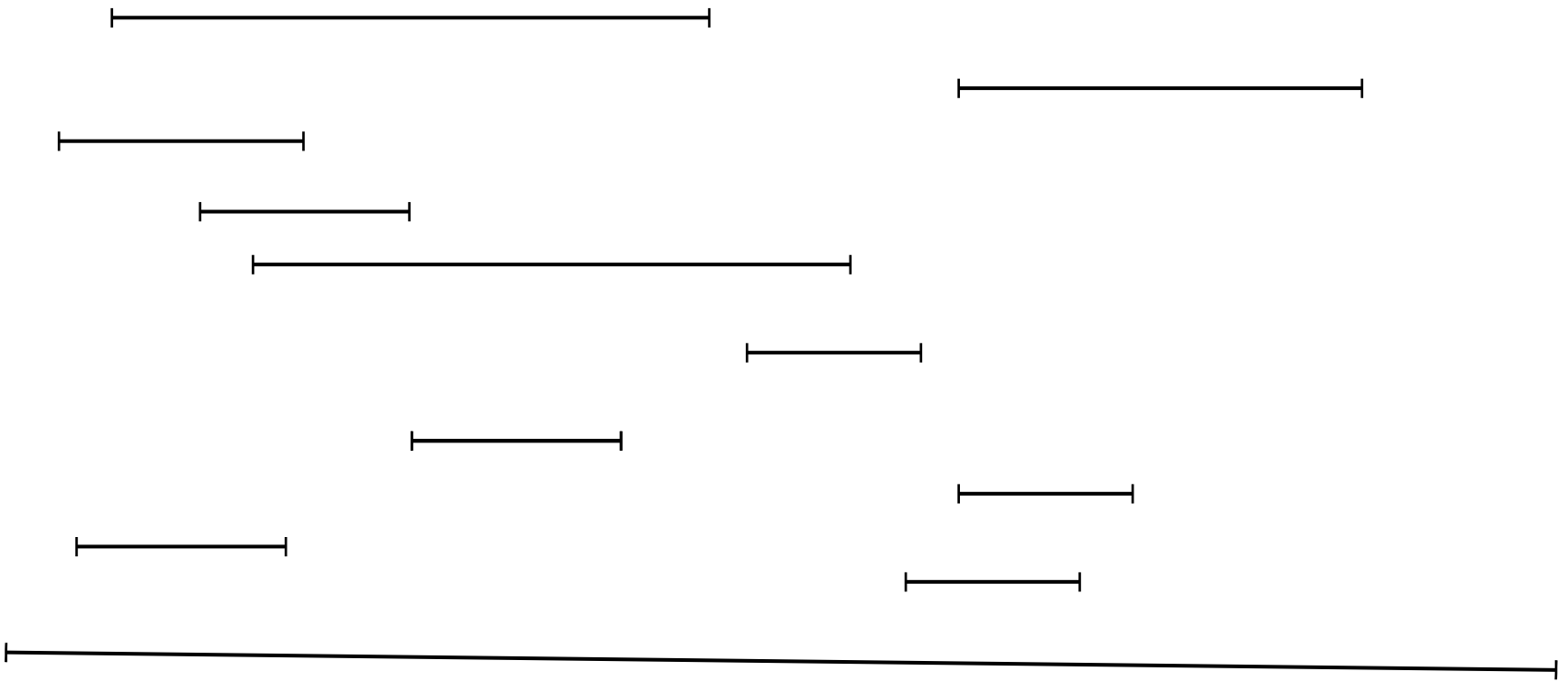
GiST

= Generalized Search Tree

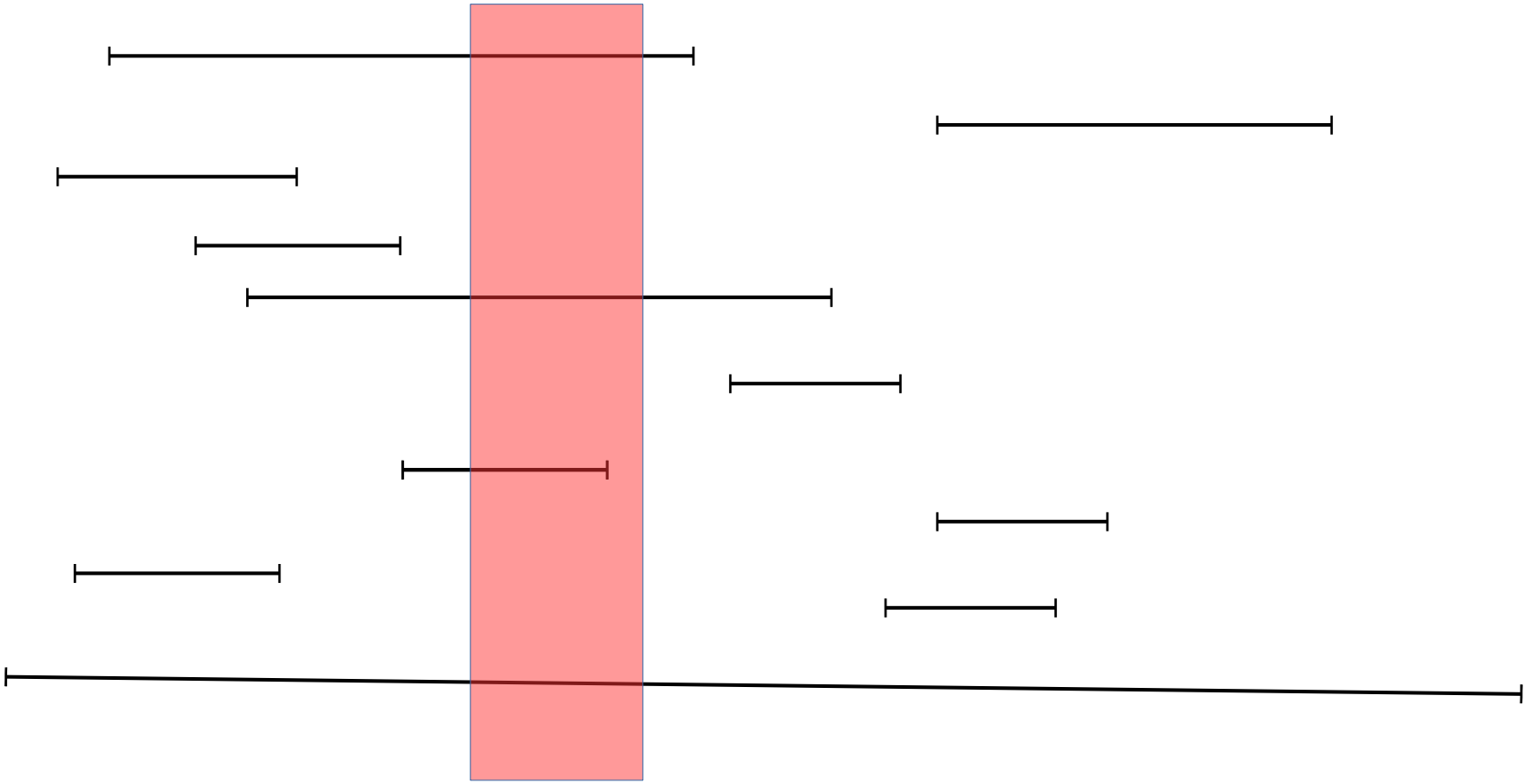
GiST

- Tree-structure
- No order within pages
- Key ranges of pages can overlap
  - No single “correct” location for a particular tuple

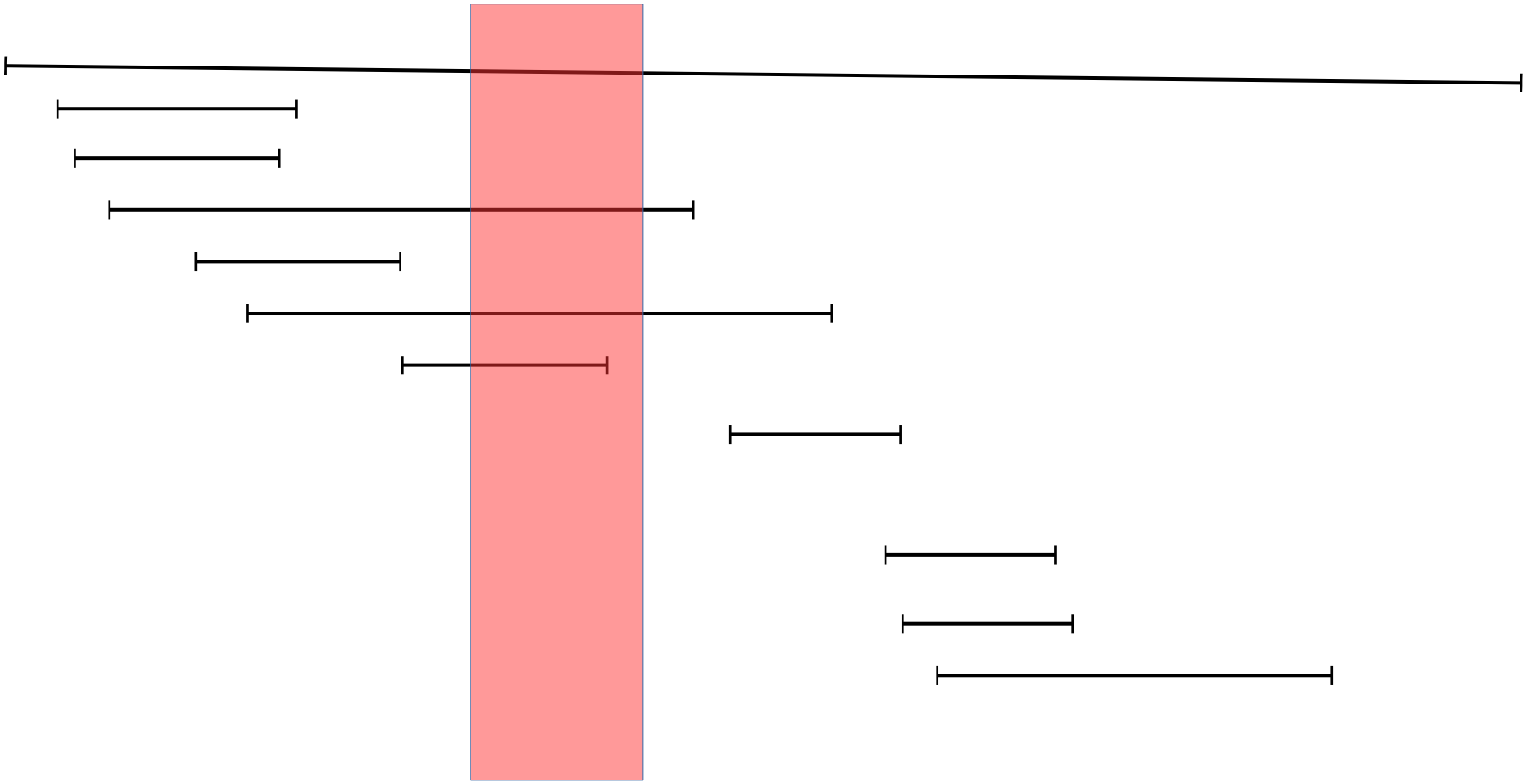
Range types



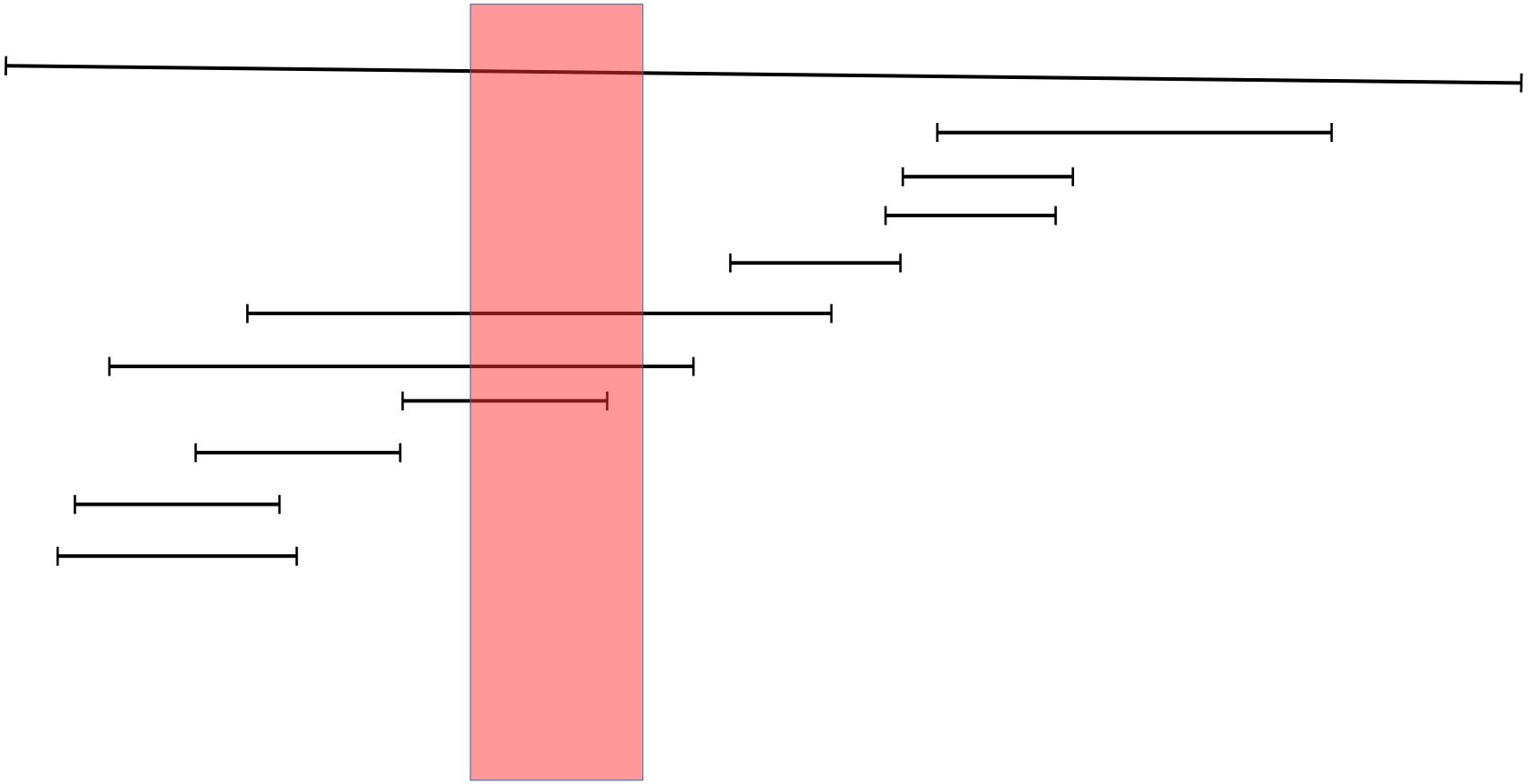
Find ranges that overlap



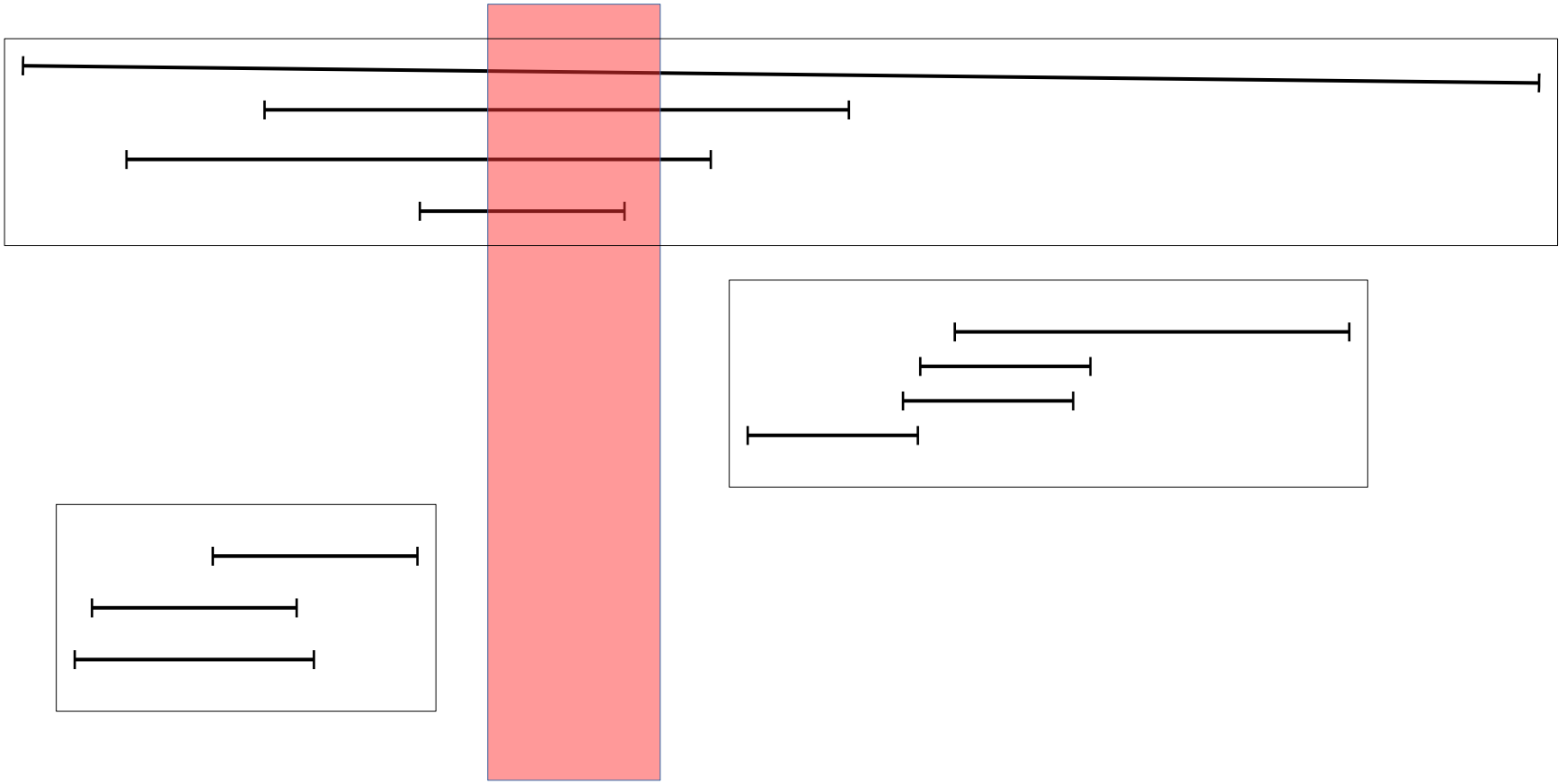
Sort by min



Sort by max

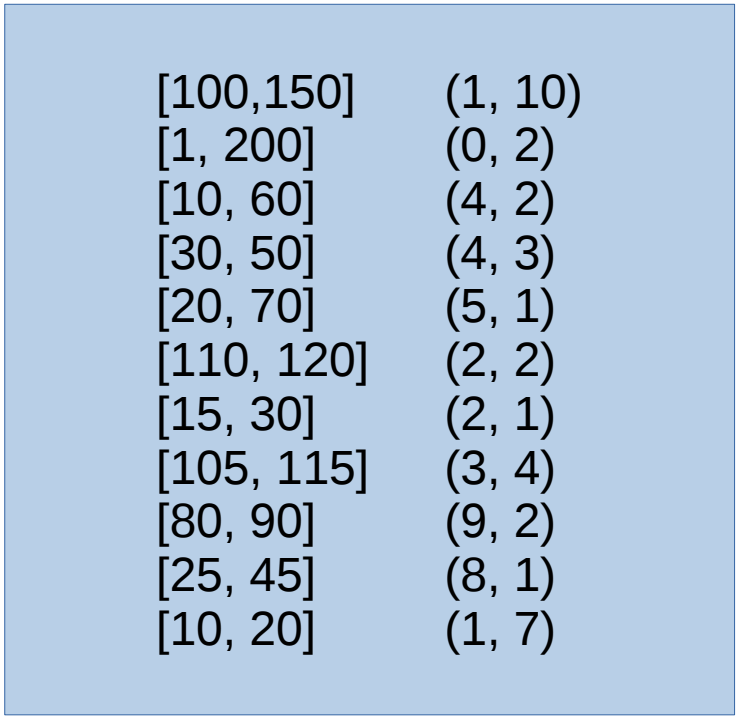


Group into clusters

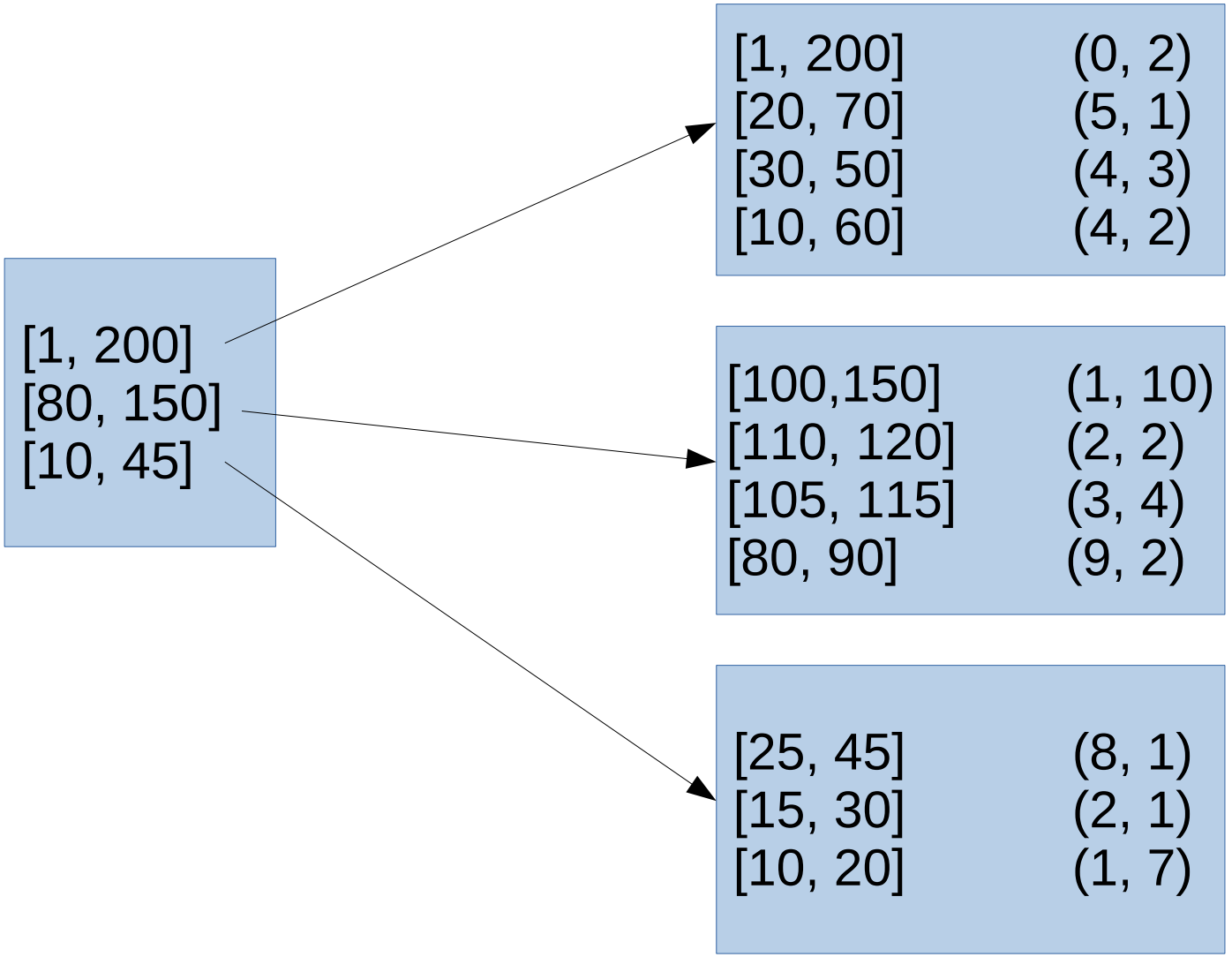


GIST, single page

- Stores key + TID
- One index tuple per heap tuple
- Unordered

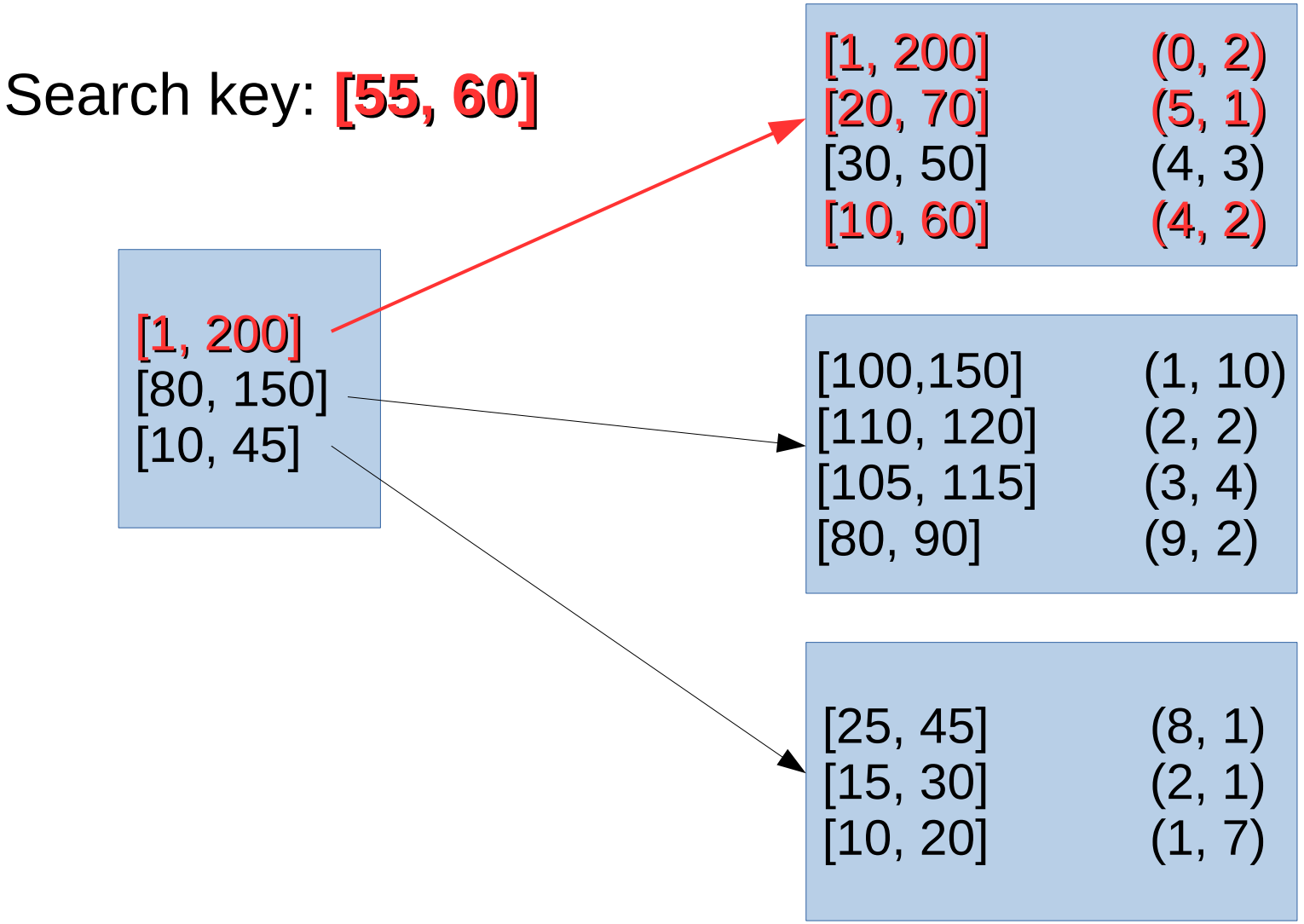


GIST, two levels



GIST search

Search key: **[55, 60]**



GiST

- Loose ordering
- Any key can legitimately be stored anywhere in the tree
  - As long as the keys in the upper levels are updated accordingly.
  - Performance goes out the window if you do that.
- Performance depends on how well the user-defined Picksplit and Choose functions can group keys

What can you do with GiST?

- GIS stuff
- Find points within a bounding box
- Nearest Neighbor

GiST, not only for geometries

- Contrib/intarray
- Full-text search

- Upper node “contains” everything below it
  - For points, a bounding box of all points below it
  - For intarray, the OR of all the nodes below it

SP-GiST

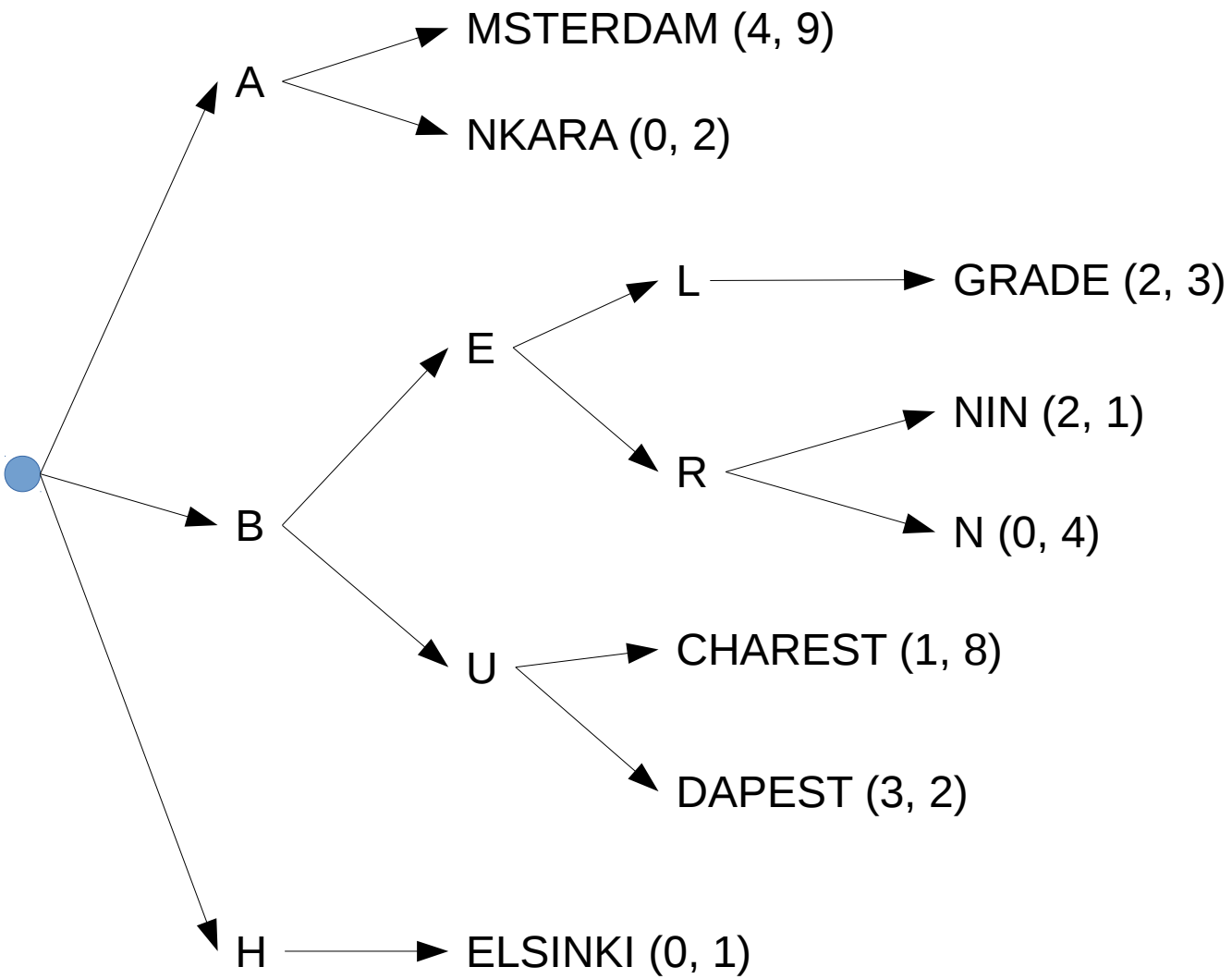
= Space-Partitioned GiST

SP-GiST

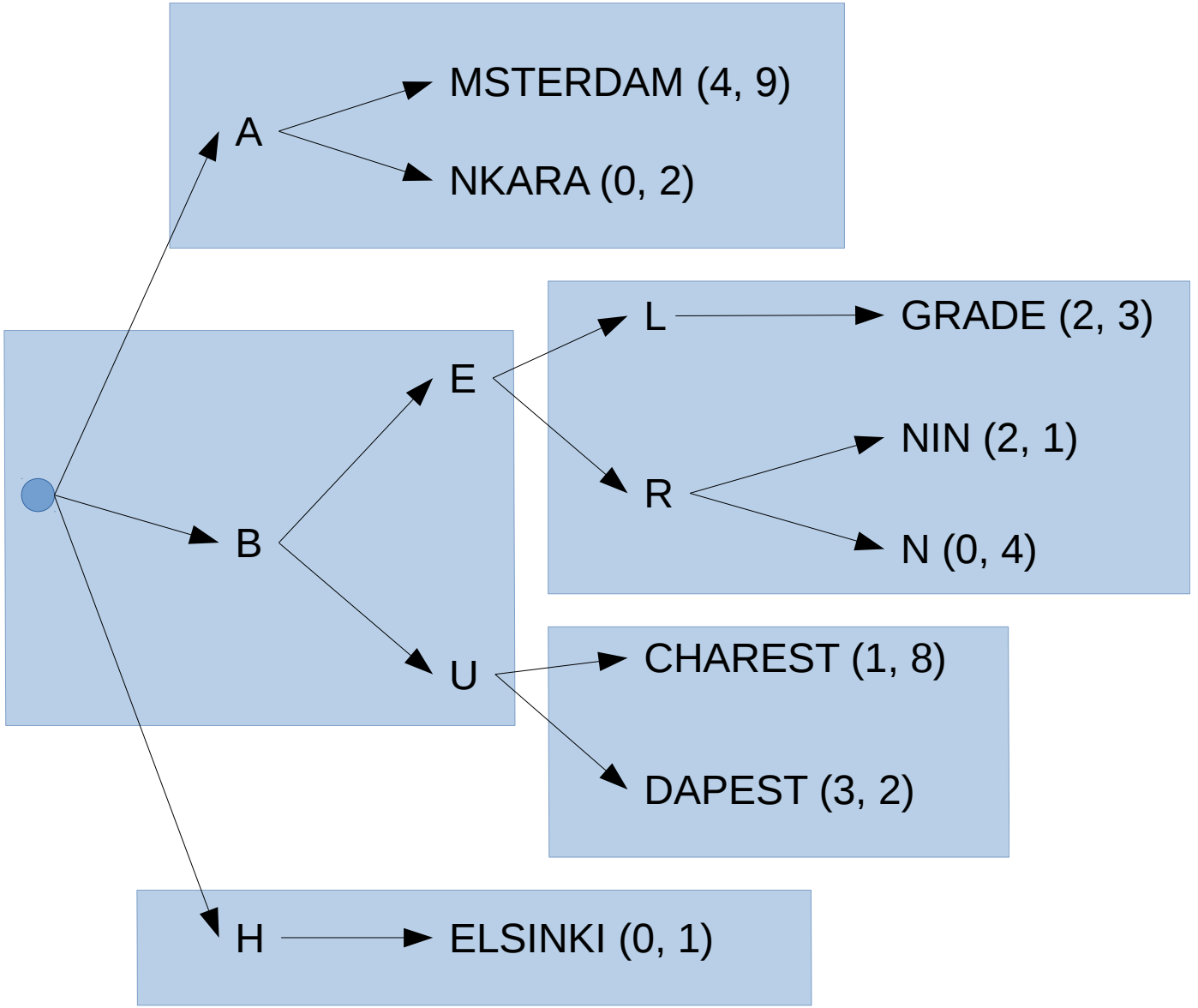
Space-Partitioned GIST

- No overlap between nodes
- Quite different from GiST
- Variable depth
- Multiple nodes per physical page

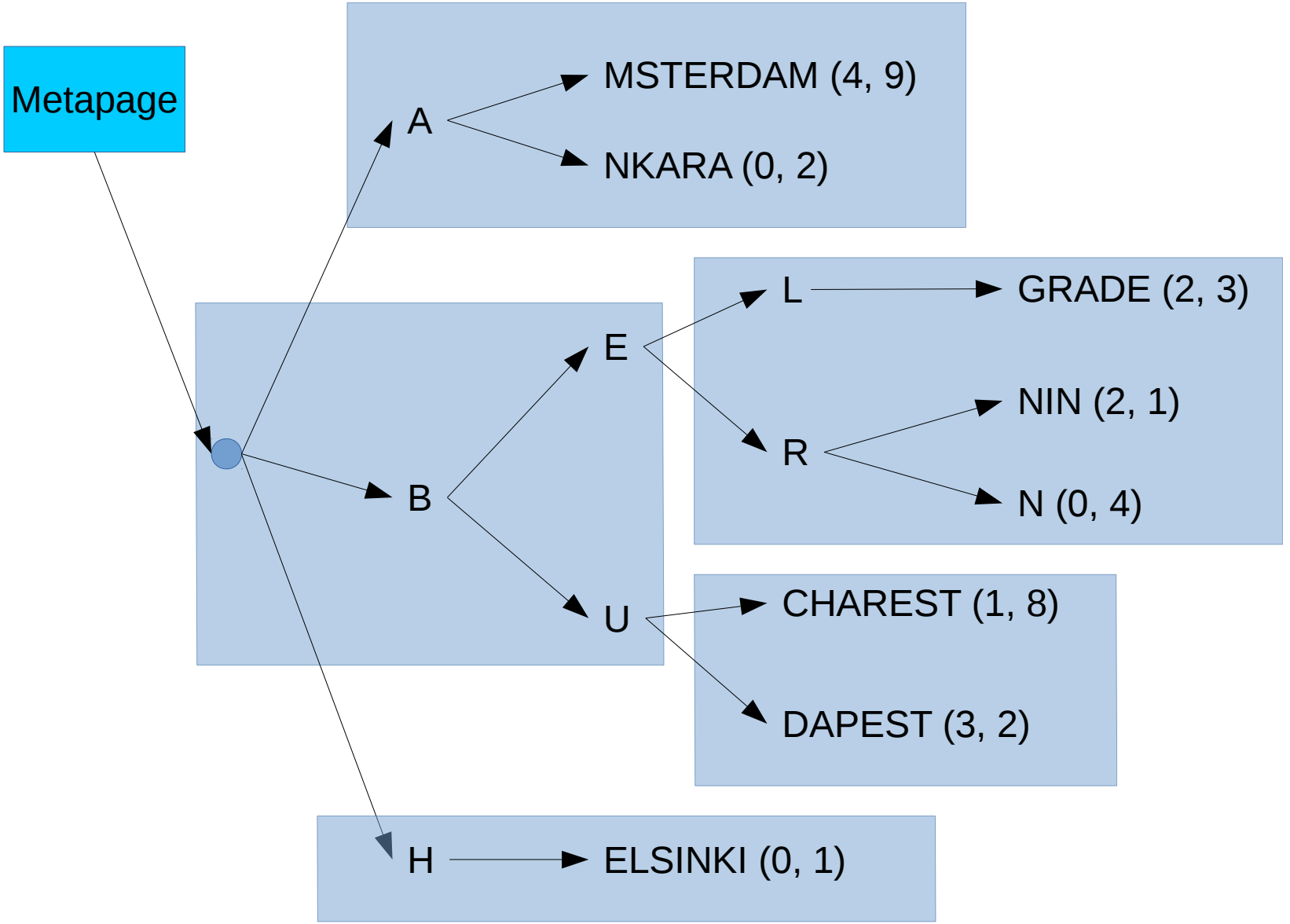
SP-GiST example: Trie



SP-GiST page layout



SP-GiST page layout



What can you do with it

- Kd-tree
  - Points only; shapes might overlap
- Prefix trie for text

BRIN

= Block Range Index

BRIN

- Not a tree
- Contains one entry per heap block (or range of heap blocks)
- **Very** compact
- Summary information for each block range

Approximation #1

BRIN Index

0: Amsterdam – Astana
1: Athens – Berlin
2: Bern – Bucharest
3: Budapest – Dublin
4: Helsinki – Ljubljana

Heap

Amsterdam
Andorra la Vella
Ankara
Astana

Athens
Baku
Belgrade
Berlin

Bern
Bratislava
Brussels
Bucharest

Budapest
Chișinău
Copenhagen
Dublin

Helsinki
Kiev
Lisbon
Ljubljana

...

Approximation #2

BRIN Index

3: Budapest – Dublin
0: Amsterdam – Astana
2: Bern – Bucharest

4: Helsinki – Ljubljana
1: Athens – Berlin

Heap

Amsterdam
Andorra la Vella
Ankara
Astana

Athens
Baku
Belgrade
Berlin

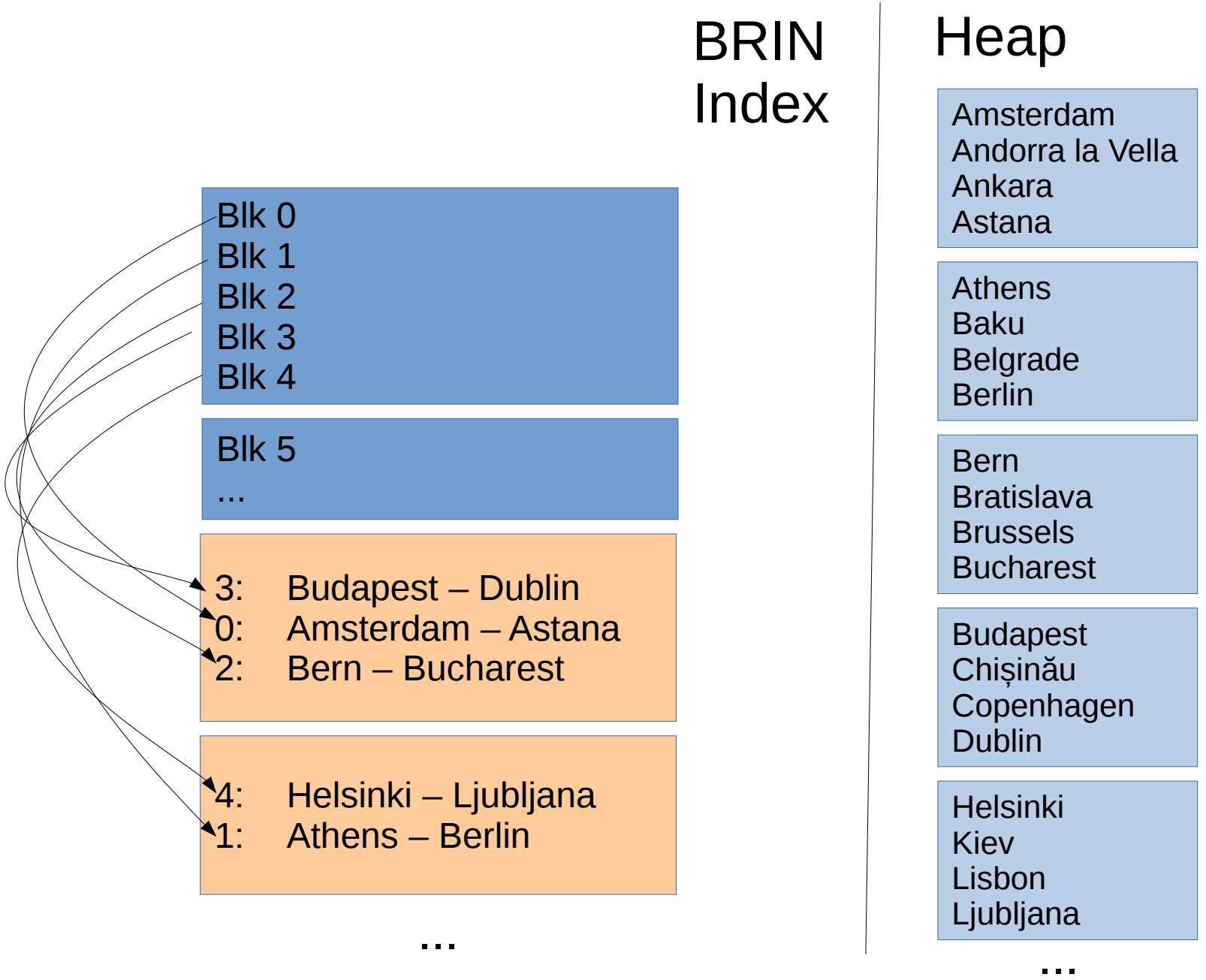
Bern
Bratislava
Brussels
Bucharest

Budapest
Chișinău
Copenhagen
Dublin

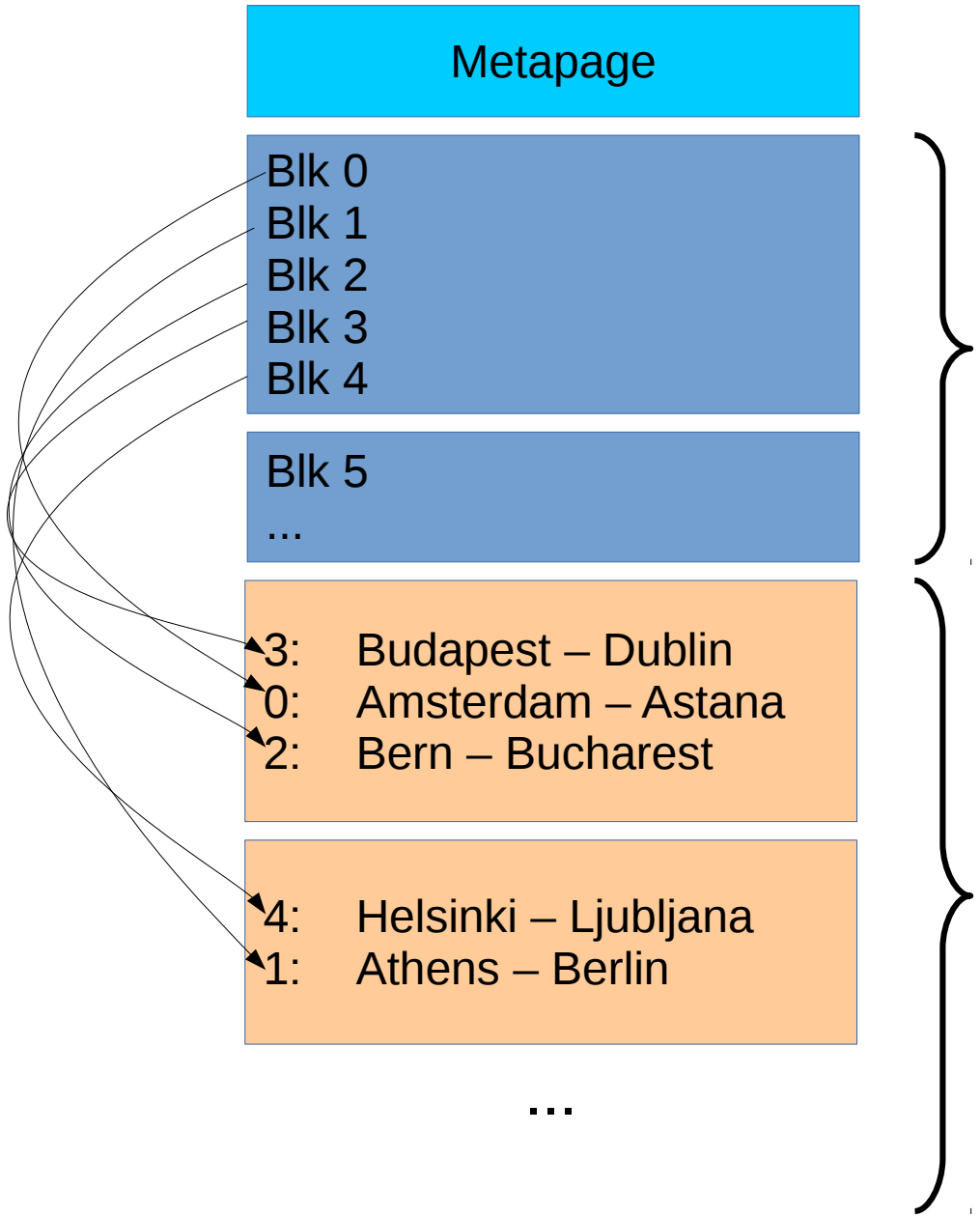
Helsinki
Kiev
Lisbon
Ljubljana

...

Approximation #3



Complete BRIN



Metapage

Revision map

Contains fixed-width slot for each heap block range, pointing to the BRIN tuple for that range.

“Regular” BRIN pages

Contain BRIN tuples, in no particular order

BRIN: clustering is important!

0: Amsterdam – Astana
1: Athens – Berlin
2: Bern – Bucharest
3: Budapest – Dublin
4: Helsinki – Ljubljana

Amsterdam
Andorra la Vella
Ankara
Astana

Athens
Baku
Belgrade
Berlin

Bern
Bratislava
Brussels
Bucharest

Budapest
Chișinău
Copenhagen
Dublin

Helsinki
Kiev
Lisbon
Ljubljana

BRIN: clustering is important!

UPDATE cities SET name='Zagreb' WHERE ...

0: Amsterdam – Zagreb
1: Athens – Zagreb
2: Bern – Zagreb
3: Budapest – Zagreb
4: Helsinki – Zagreb

What can you do with BRIN?

- Min-max for each block range
- Allows <, =, > searches
  - Much slower than B-tree lookups
  - Always scans the whole index (which is tiny though)
  - Always scans the whole heap page (range)
- Store bounding box for points, shapes
- Bloom filters

What can you do with BRIN?

- Good for large tables with natural or accidental ordering
  - Tables loaded in primary key order
  - Timestamp columns
- A single out-of-order tuple in a page will “pollute” the index, and searches degenerate to full sequential scans.

Summary

- B-tree

  = < >
- GIN
  - B-tree on steroids
  - Stores duplicates efficiently
  - Multiple keys per heap tuple
- GiST
  - “containment” hierarchy
- Sp-GIST
  - Non-overlapping
- BRIN
  - Containment
  - For clustered data
  - Tiny index, slow searches