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

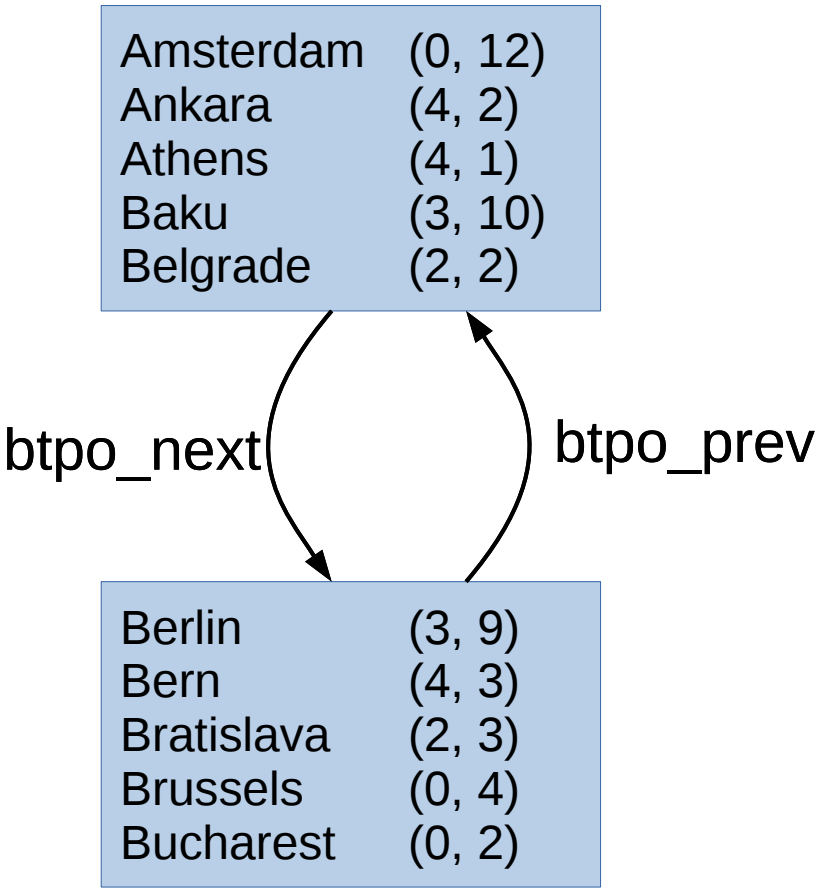
Good old B-tree

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

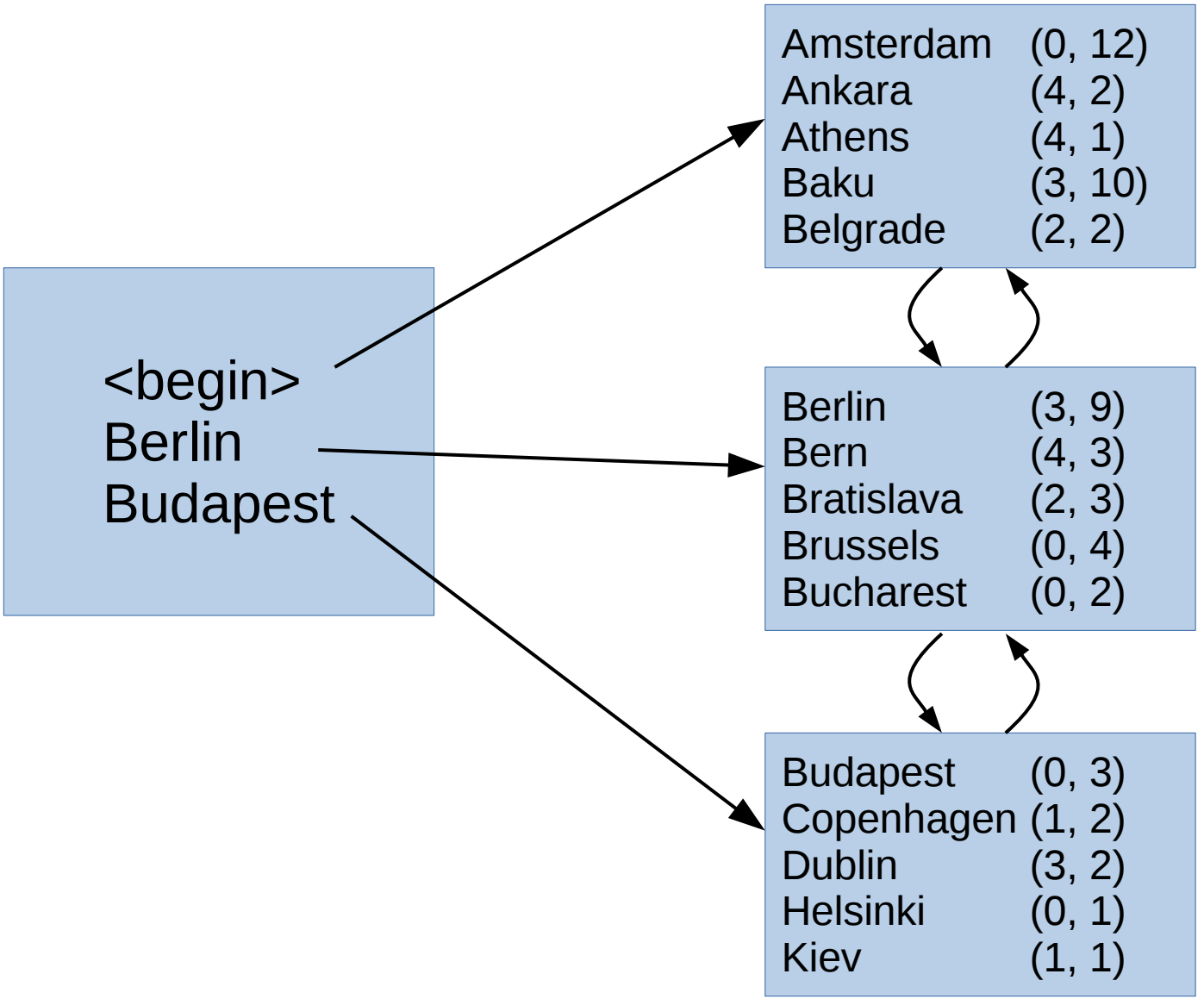
B-tree, single page

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

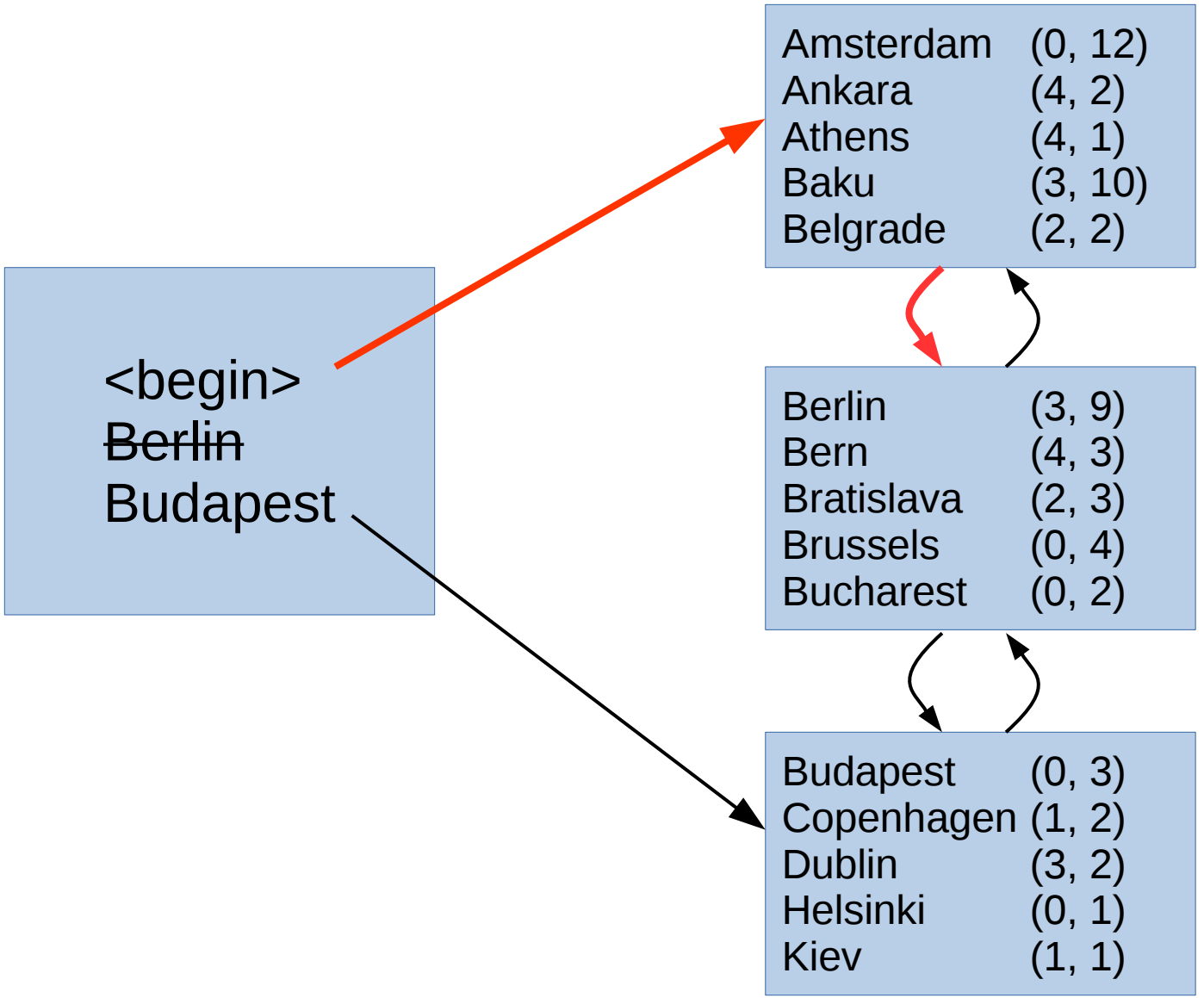
B-tree, leaf level



B-tree, two levels



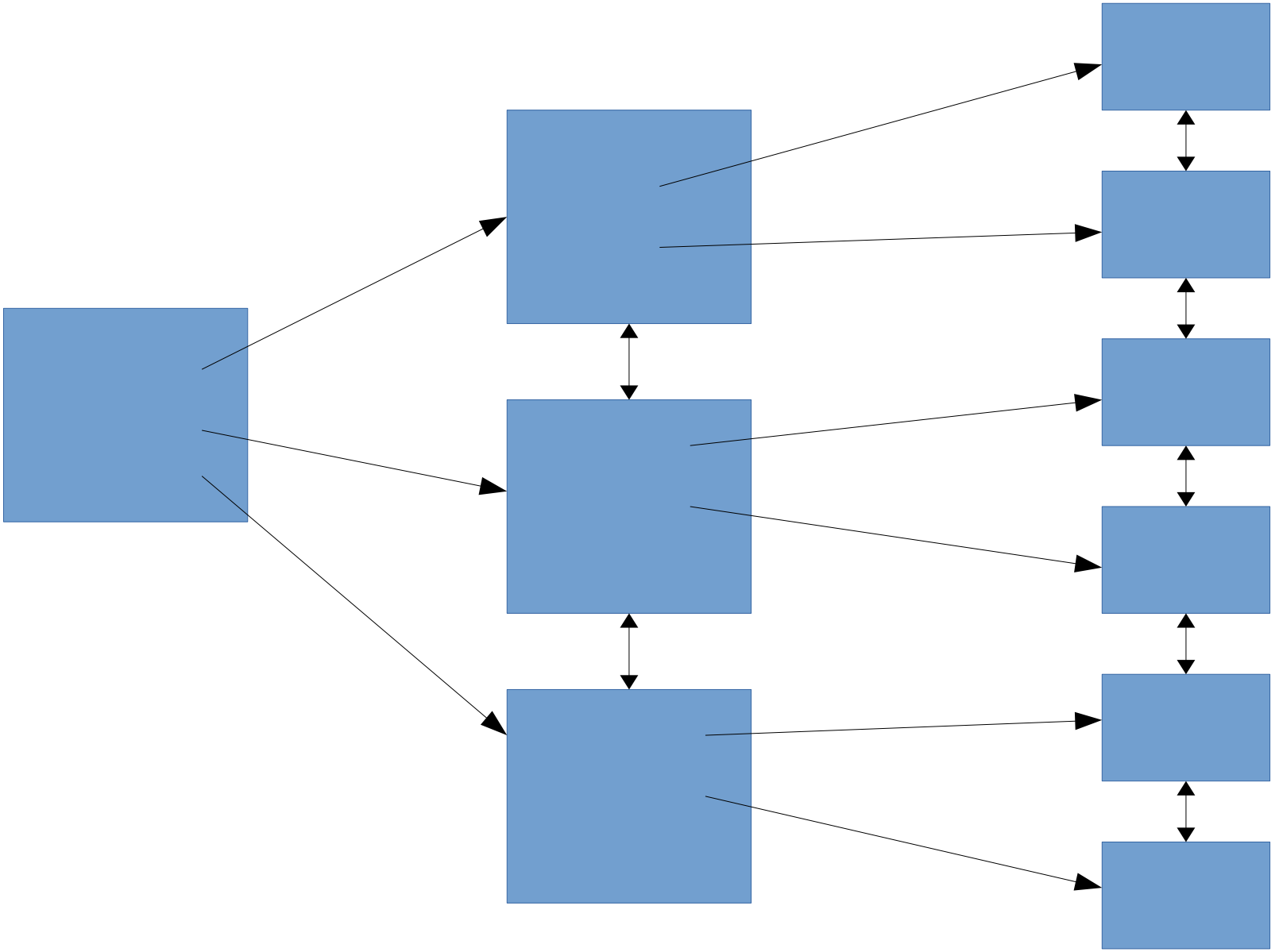
B-tree that's missing nodes still works!



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

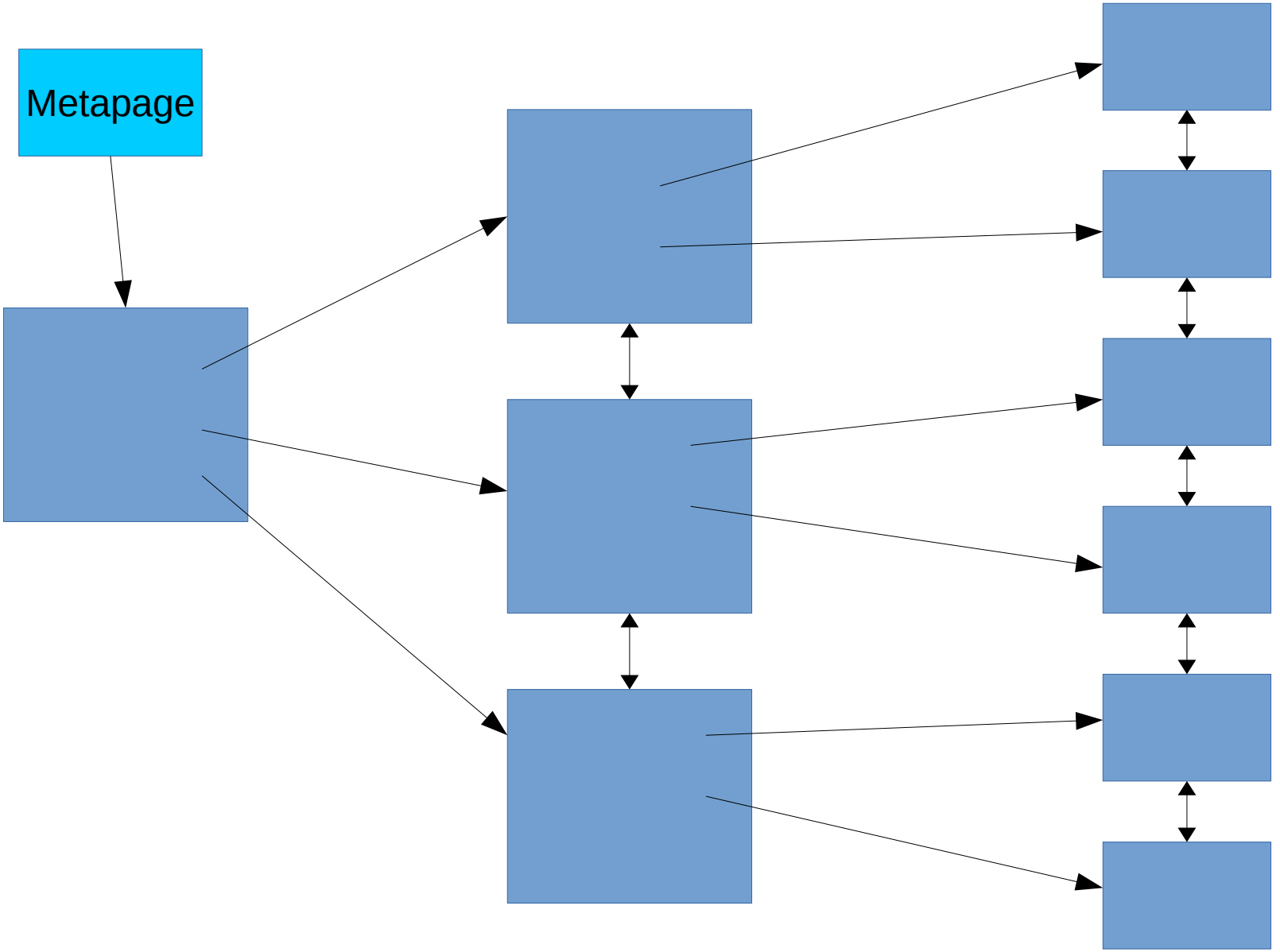
B-tree, three levels



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%'

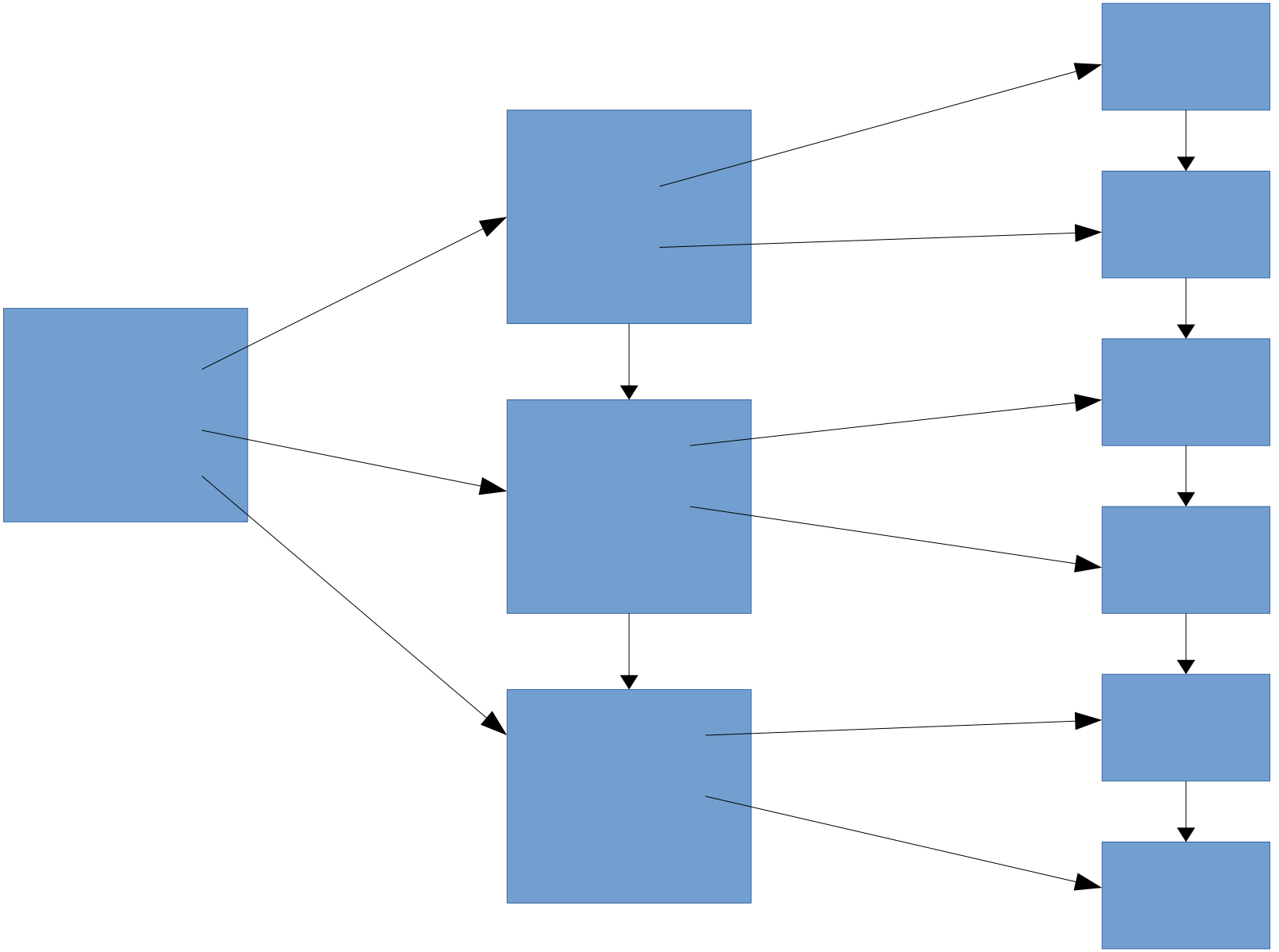
GIN

= 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

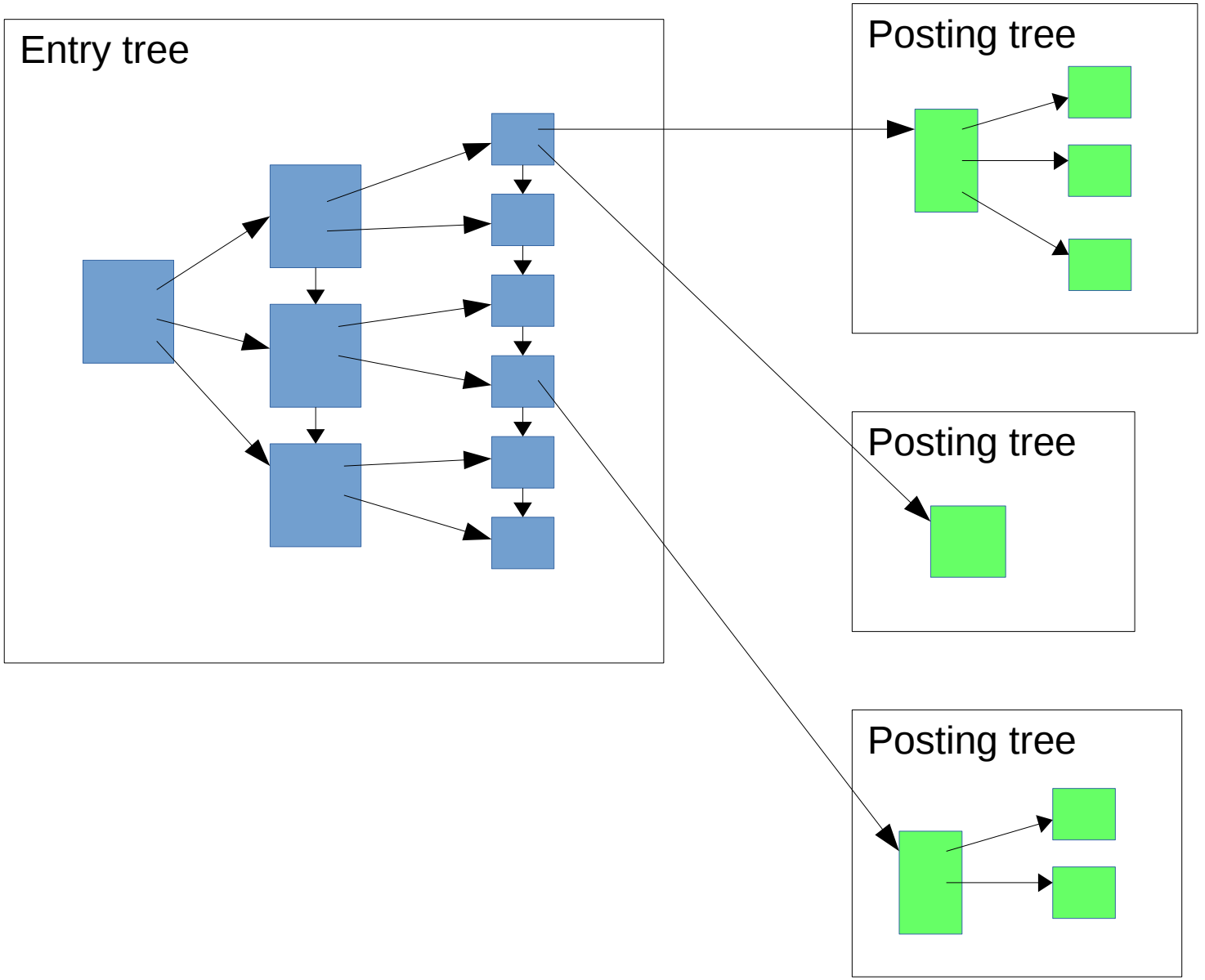
GIN entry tree



Three ways to store heap TIDs in entry item

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

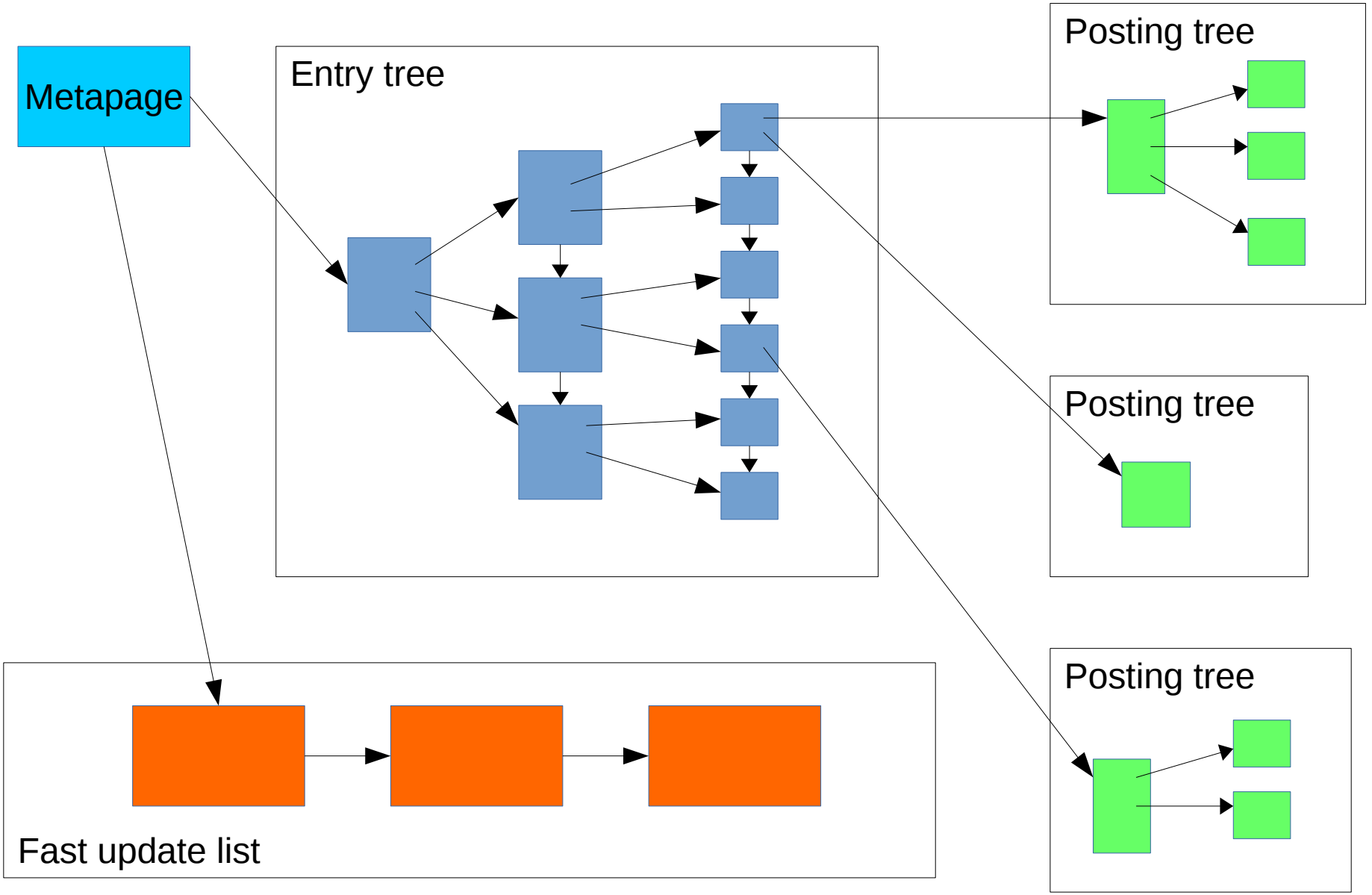
GIN



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



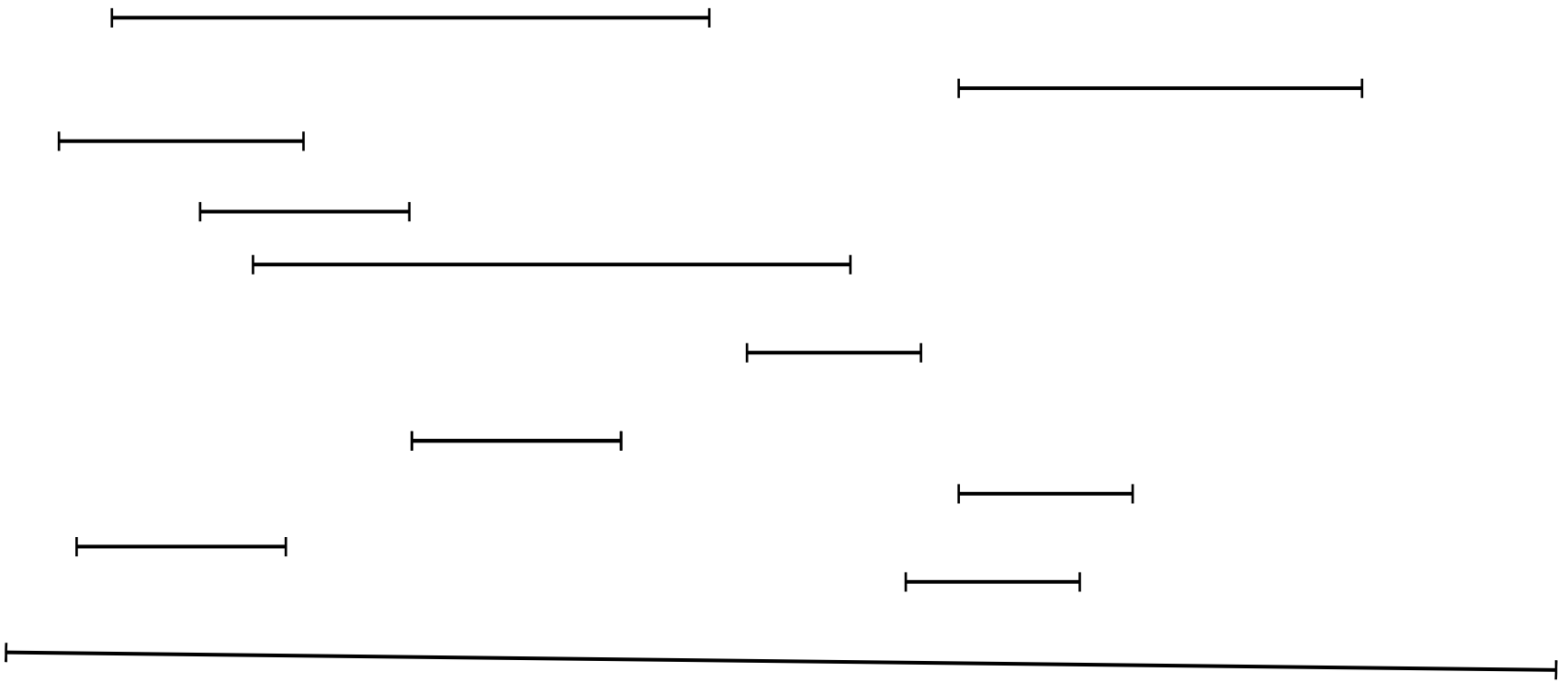
GiST

= Generalized Search Tree

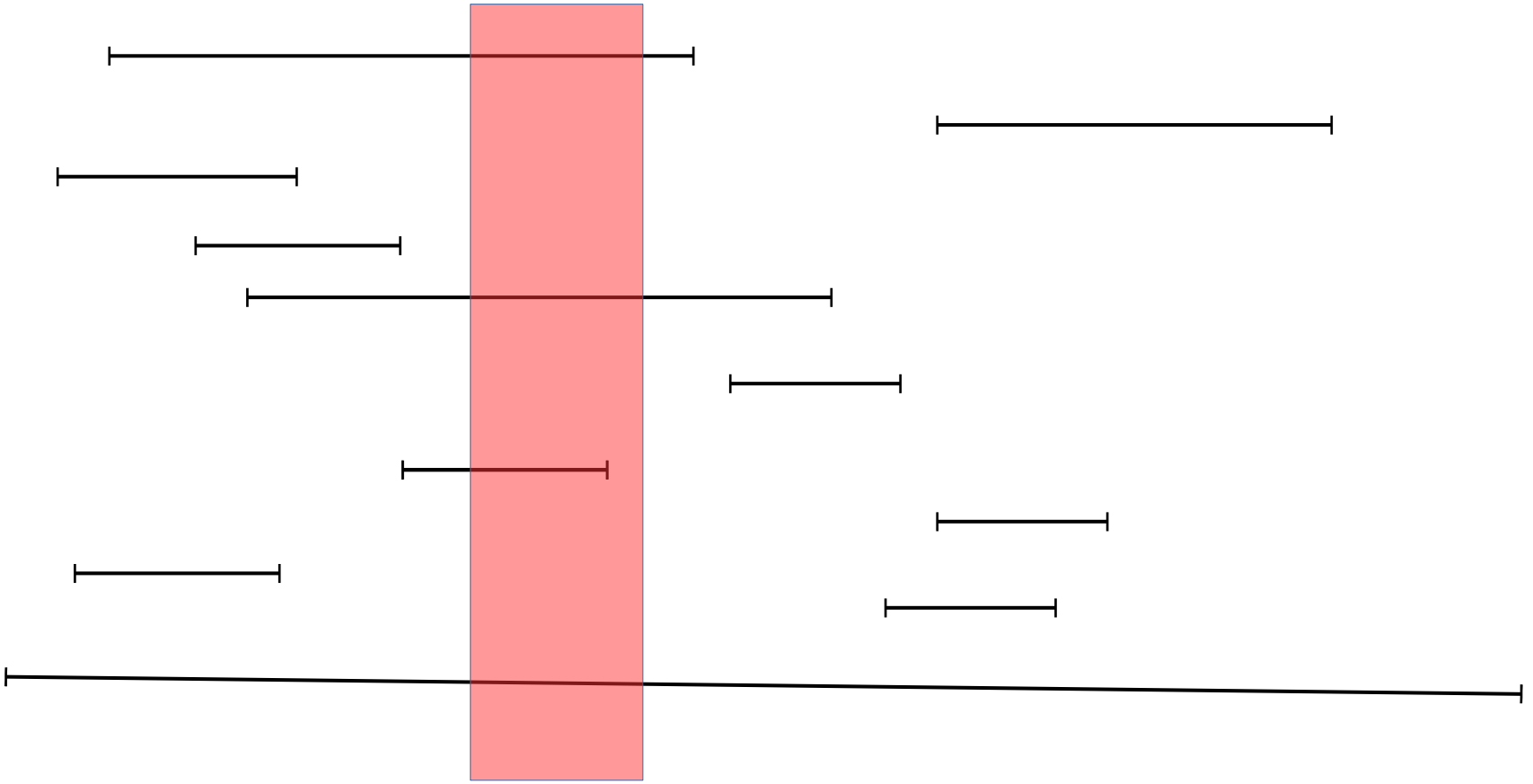
GiST

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

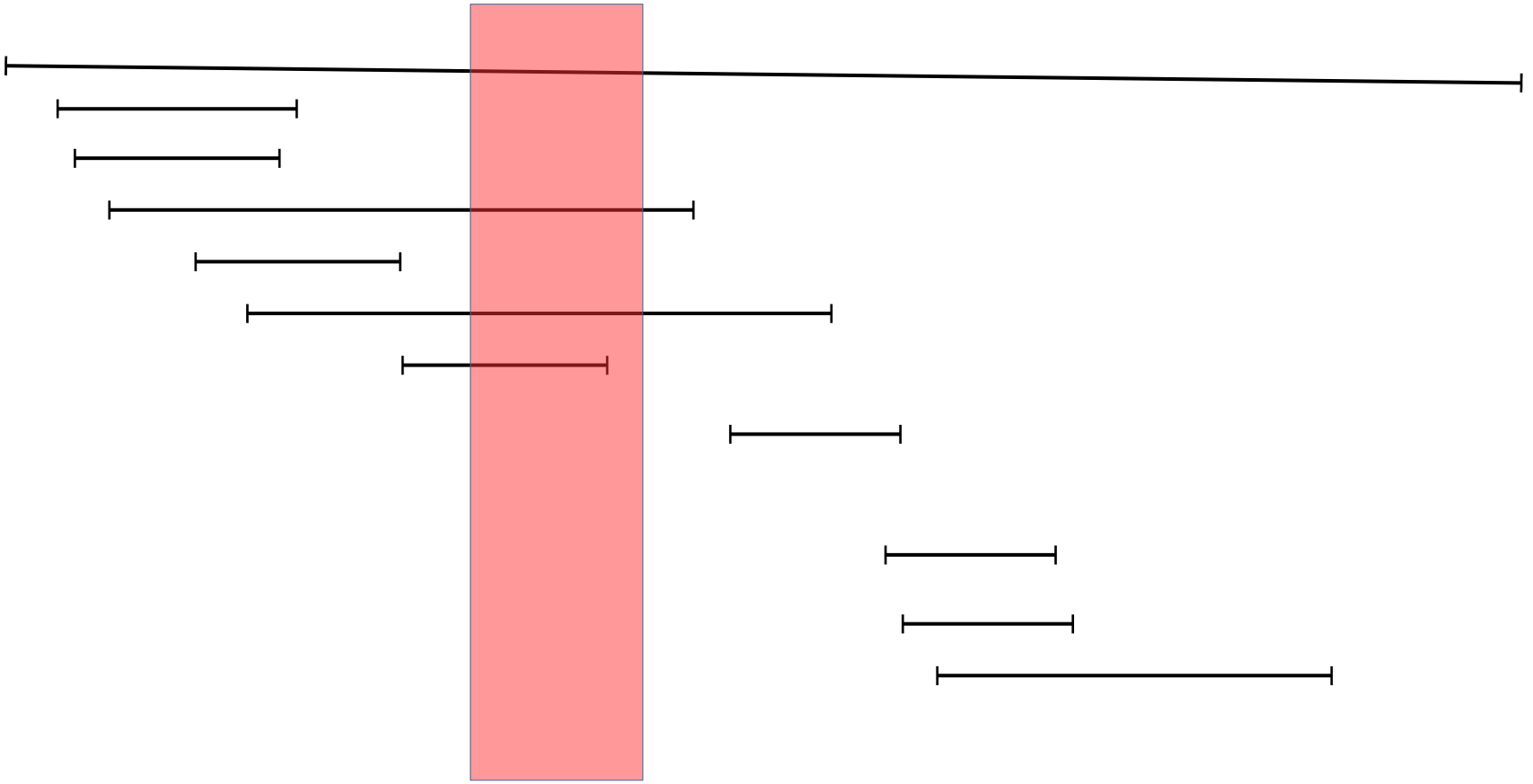
Range types



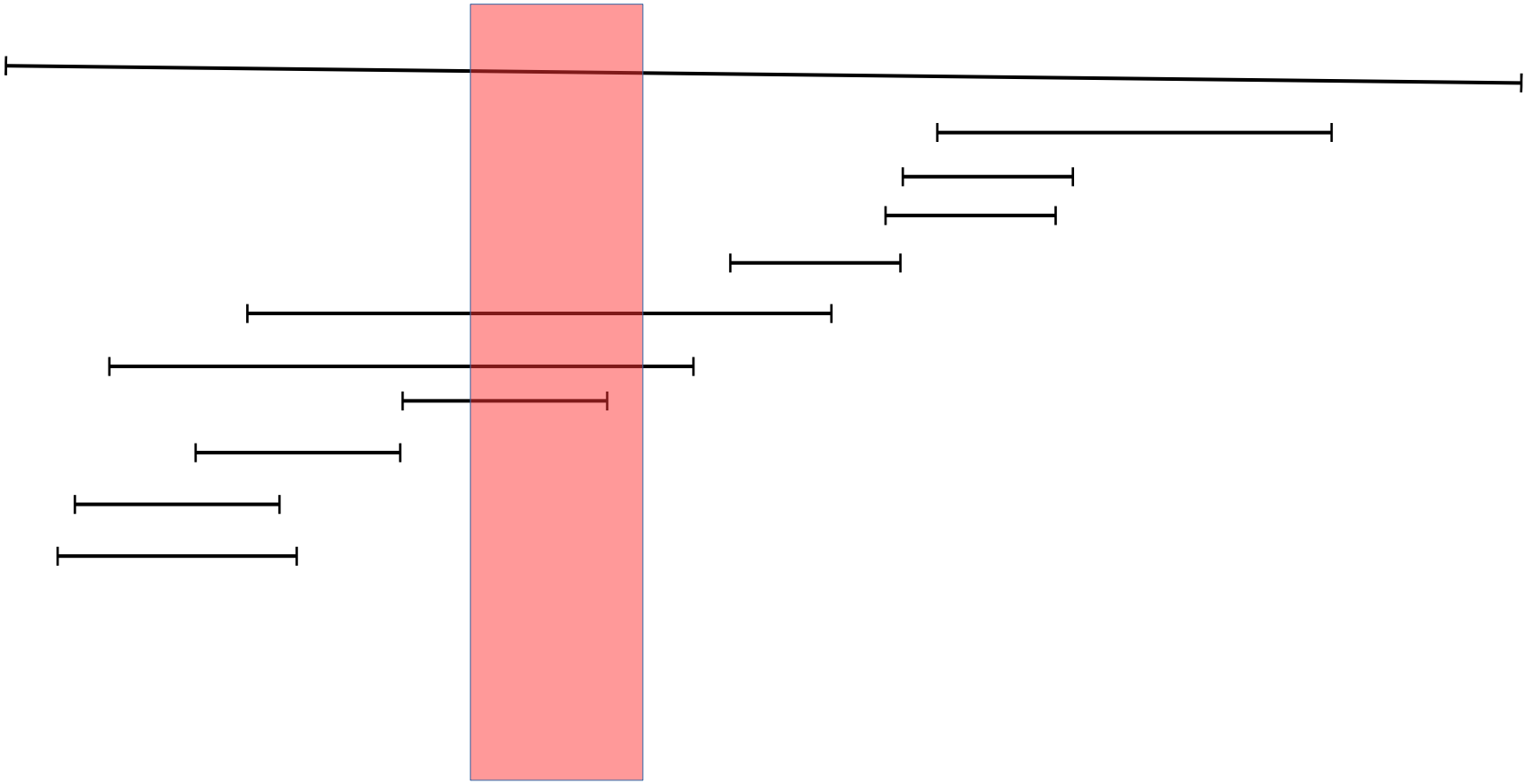
Find ranges that overlap



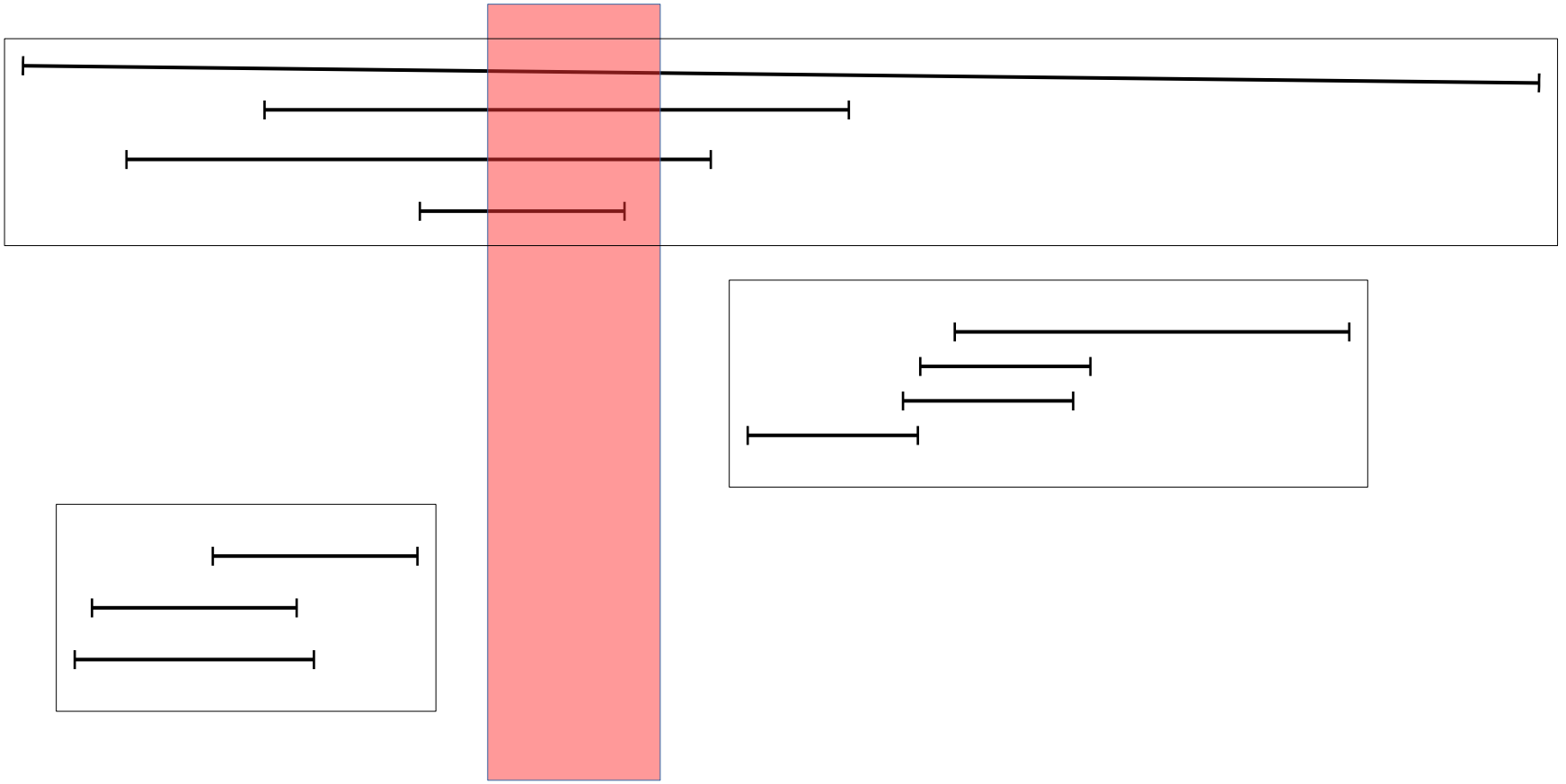
Sort by min



Sort by max

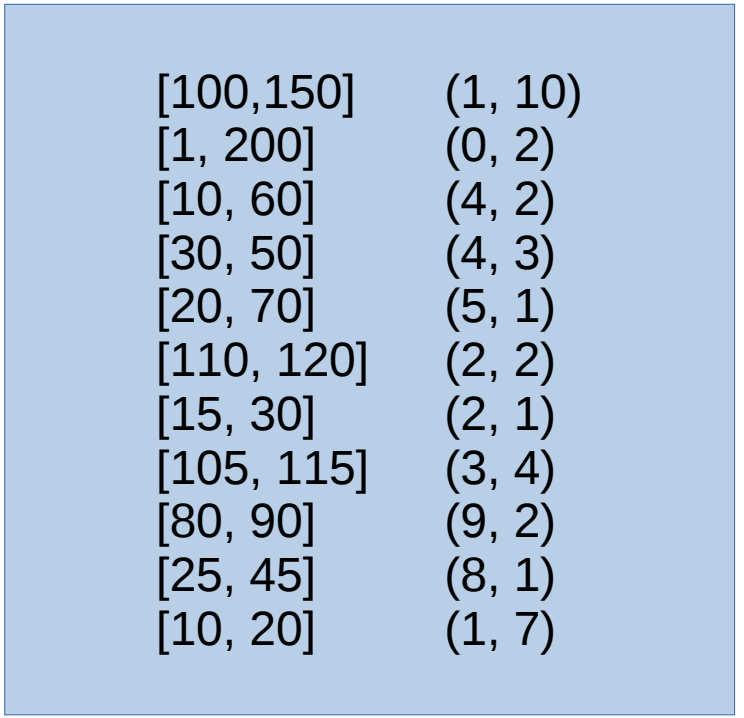


Group into clusters

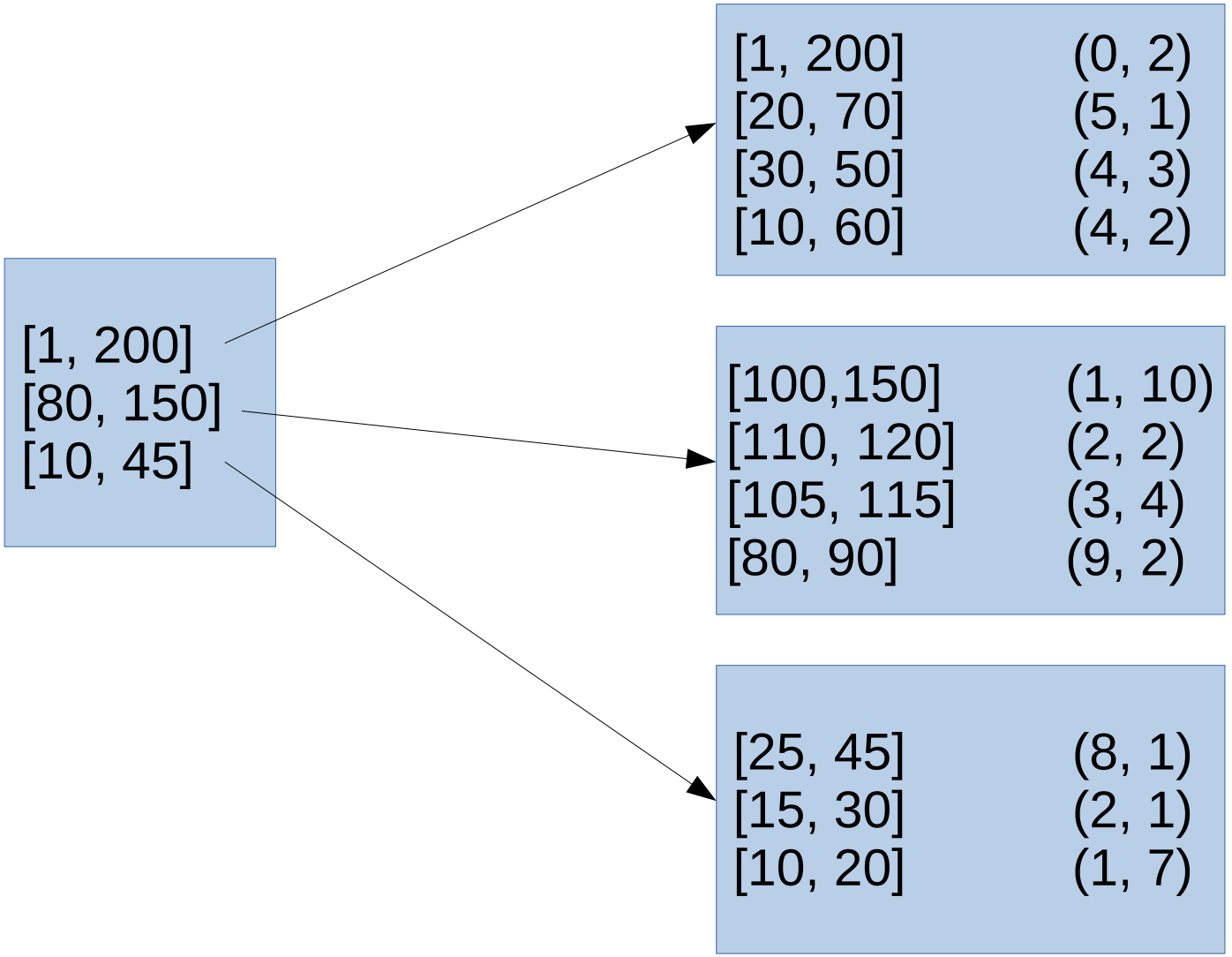


GIST, single page

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

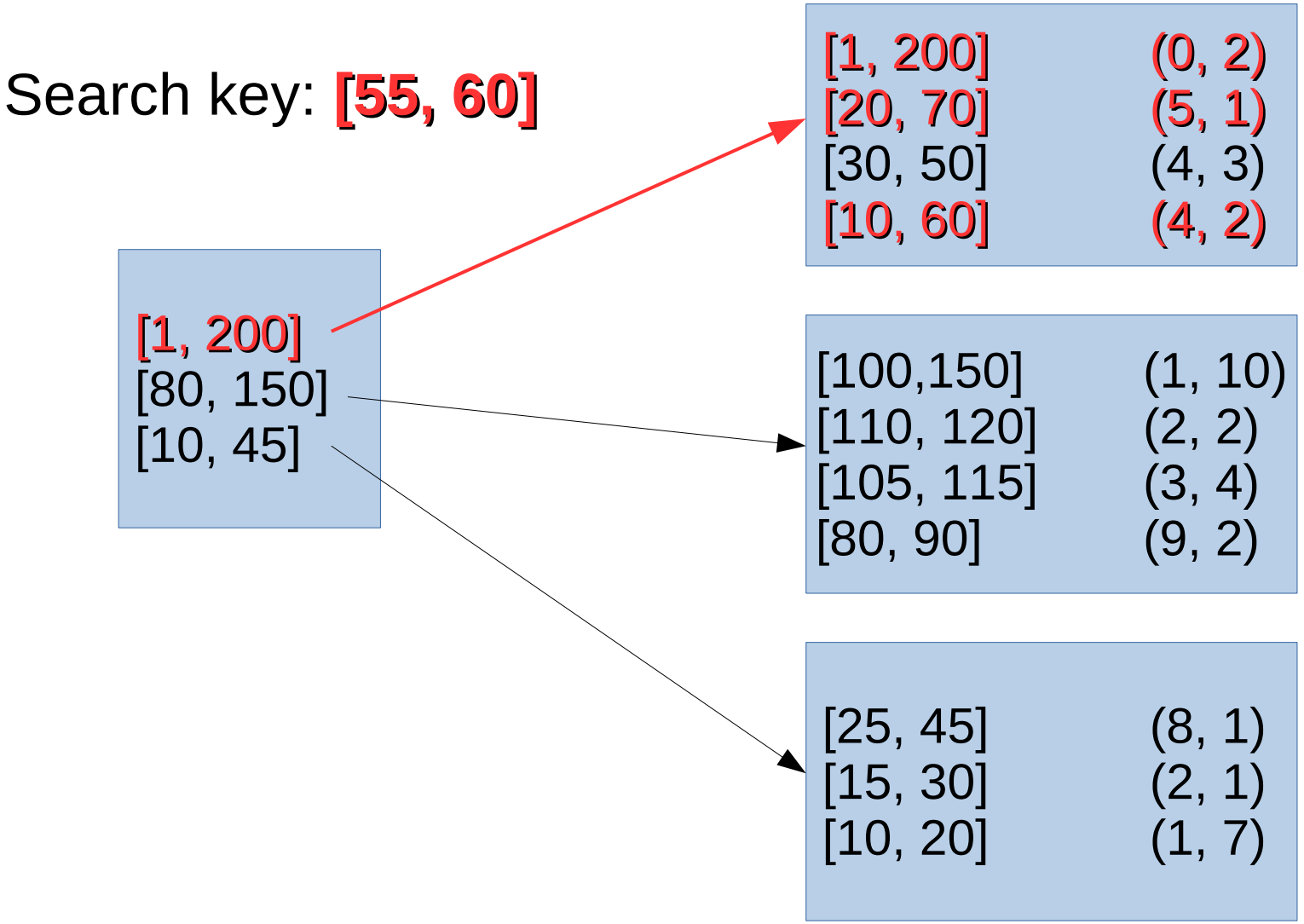


GIST, two levels



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

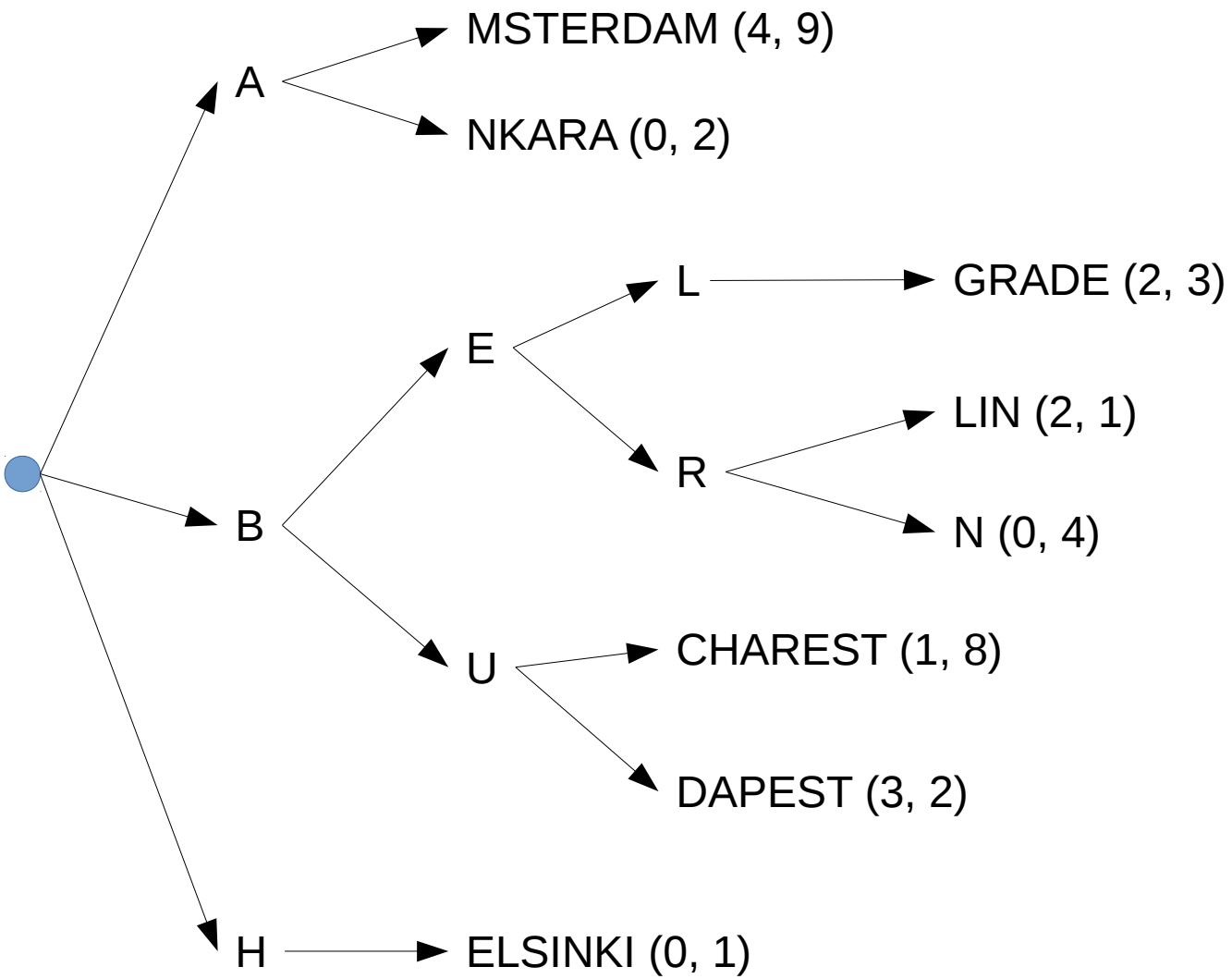
= Space-Partitioned GiST

SP-GiST

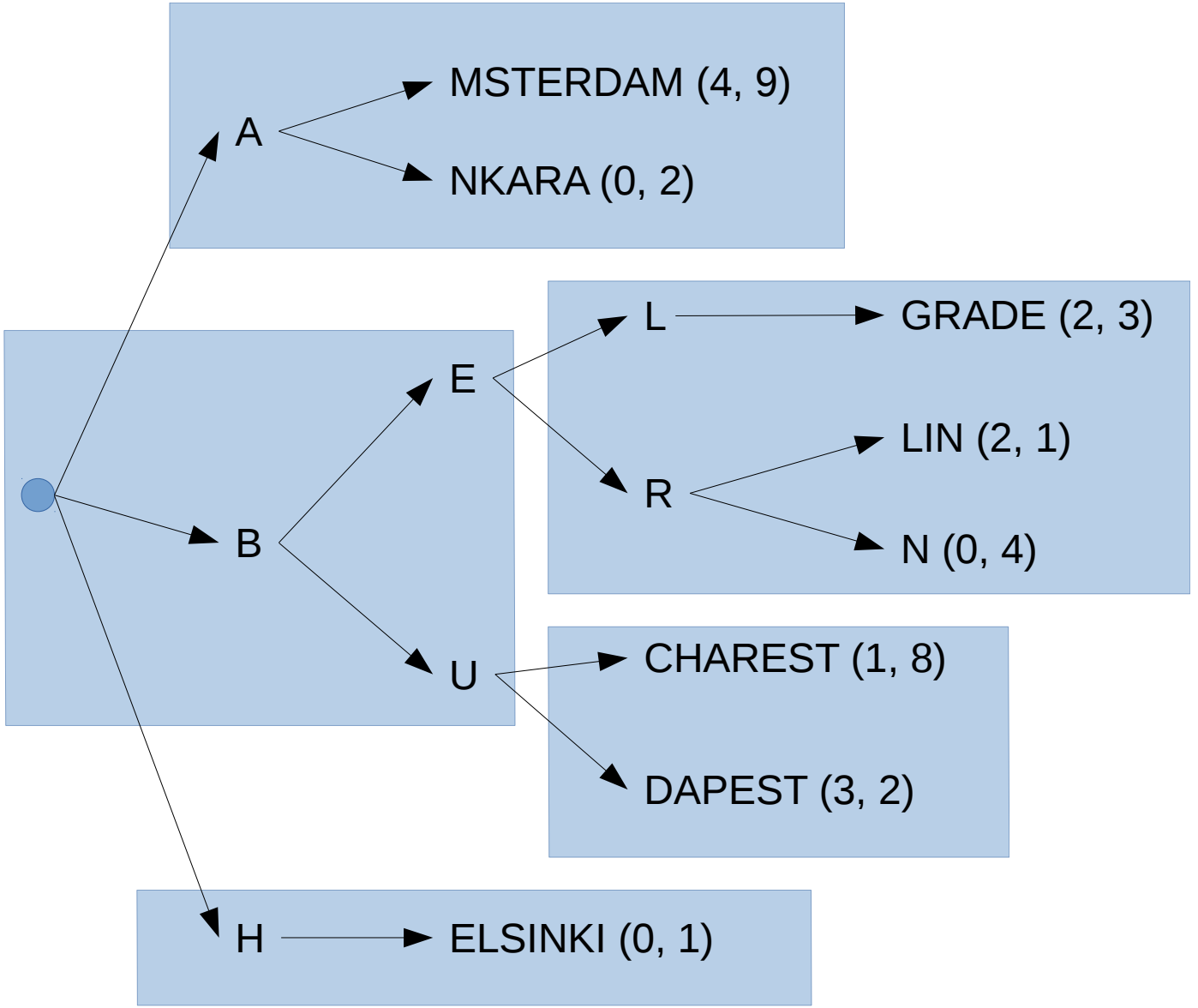
Space-Partitioned GIST

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

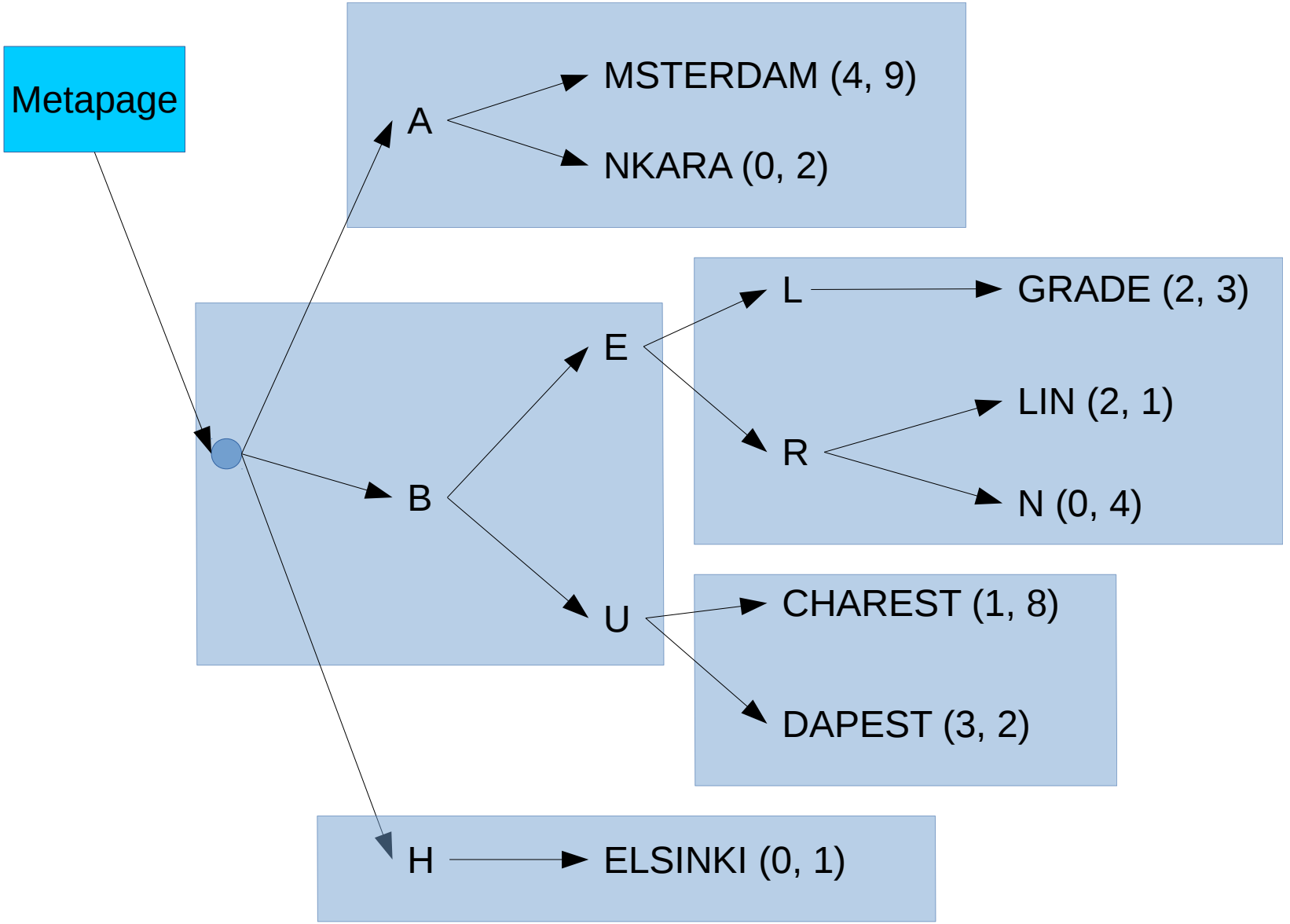
SP-GiST example: Trie



SP-GiST page layout



SP-GiST page layout



What can you do with it

- Kd-tree
  - Points only; shapes might overlap
- Prefix tree 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

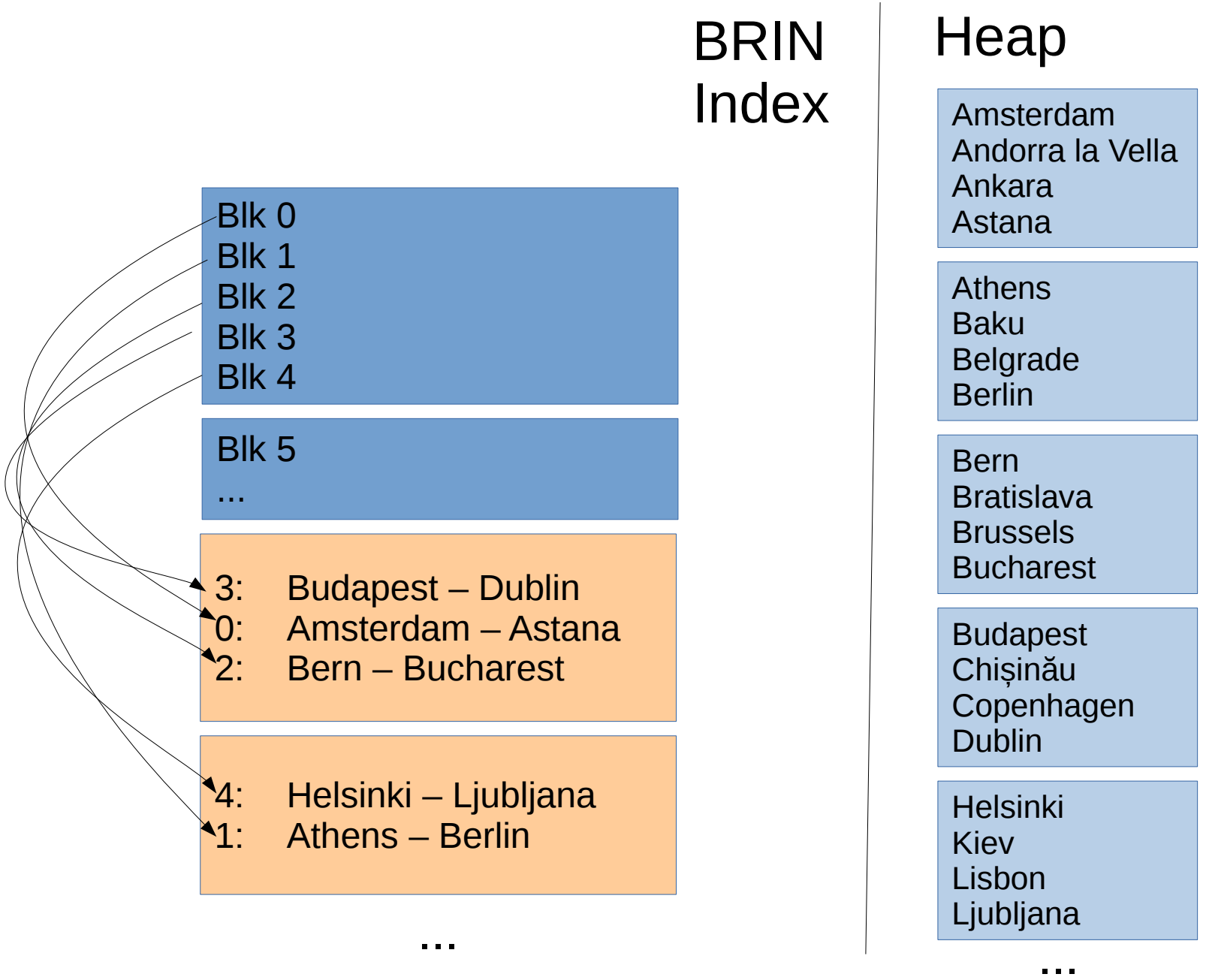
Bern
Bratislava
Brussels
Bucharest

Budapest
Chișinău
Copenhagen
Dublin

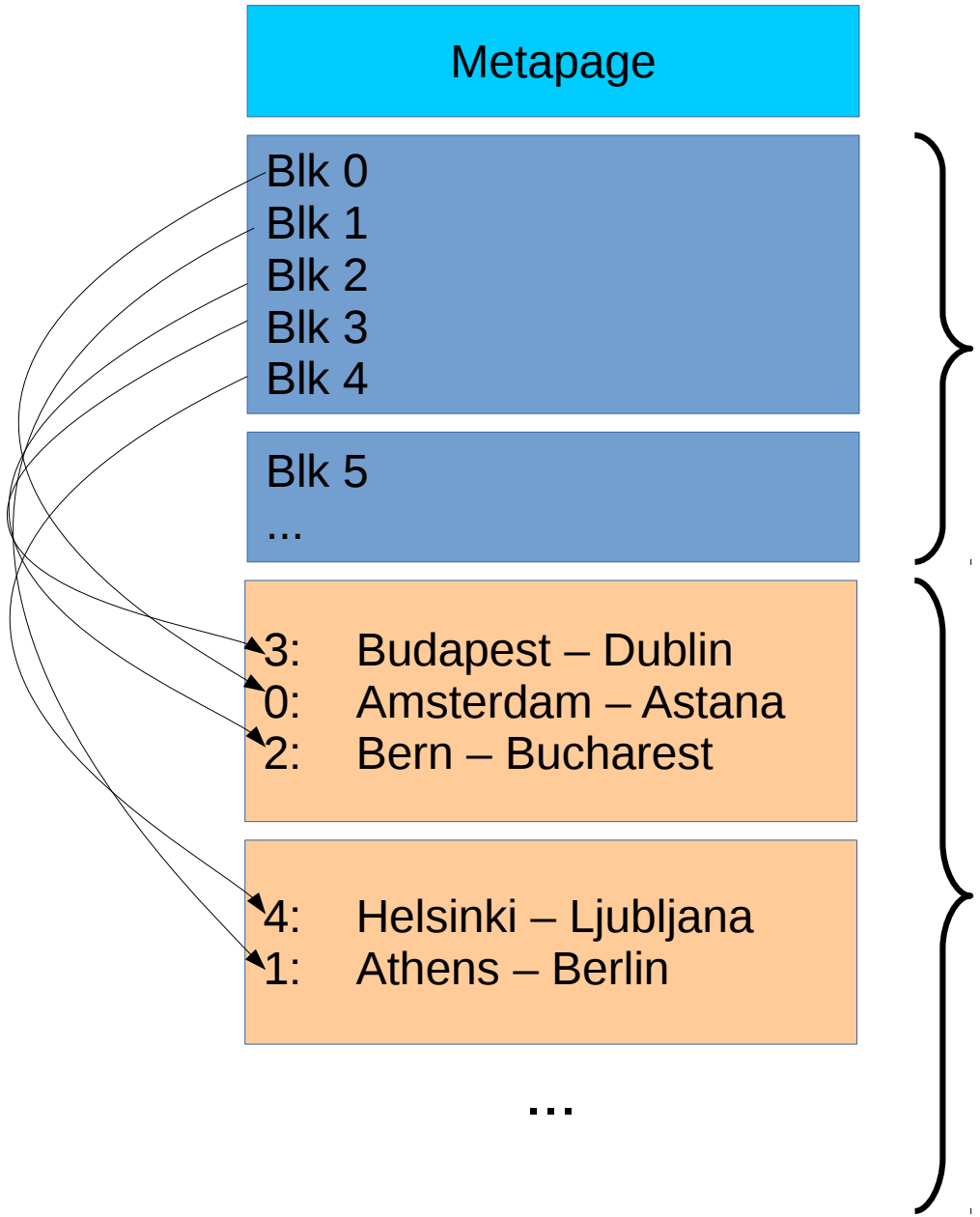
Helsinki
Kiev
Lisbon
Ljubljana

...

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