Pagination done the Right Way

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iStockPhoto/Mitshu

Takeaways

- OFFSET kills performance
- Paging can be done without OFFSET
- It’s faster and has fewer side effects

Note

In this presentation

index means B-tree index.

A Trivial Example

A query to fetch the 10 most recent news:

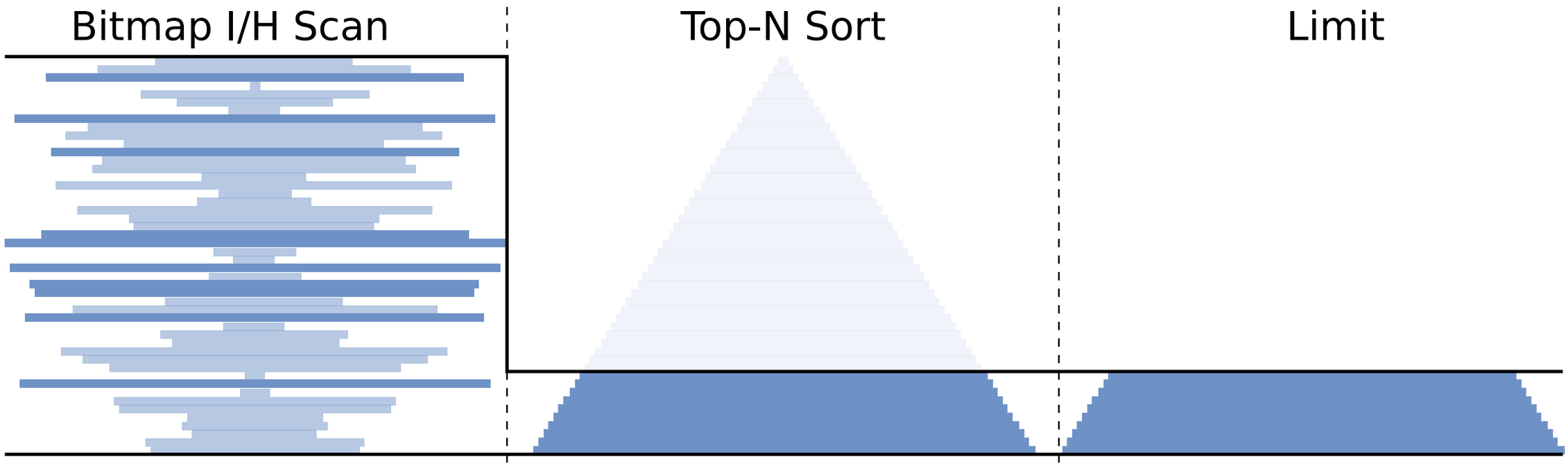
```
select *
  from news
 where topic = 1234
 order by date desc, id desc
 limit 10;

create index .. on news(topic);
```

Using `order by` to get the most recent first and `limit` to fetch only the first 10.

Alternative SQL-2008 syntax (since PostgreSQL 8.4)

```
fetch first 10 rows only
```

Worst Case: No Index for `order by`

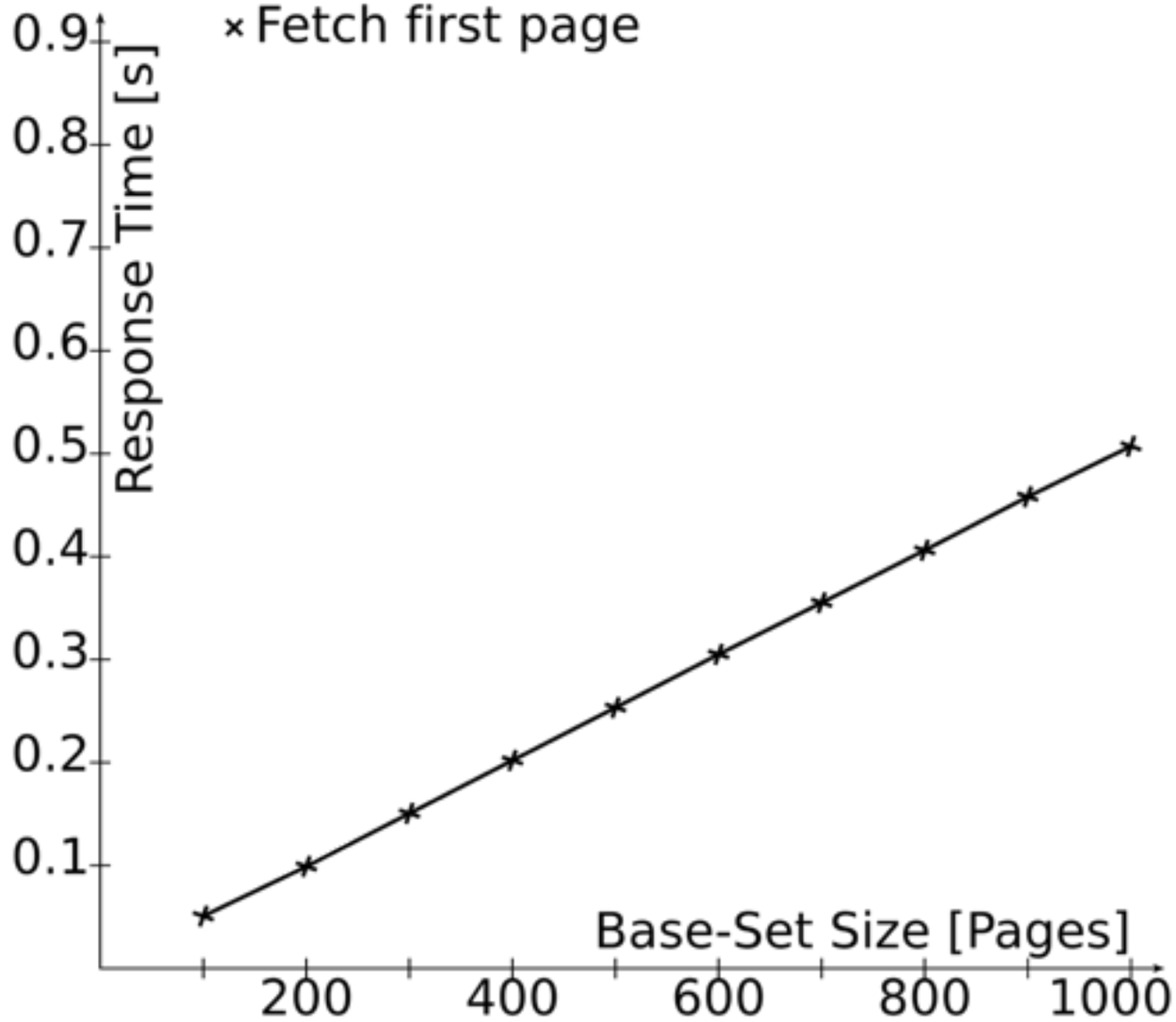



```
Limit (actual rows=10)
-> Sort (actual rows=10)
   Sort Method: top-N heapsort  Memory: 18kB
   -> Bitmap Heap Scan (rows=10000)
      Recheck Cond: (topic = 1234)
      -> Bitmap Index Scan (rows=10000)
         Index Cond: (topic = 1234)
```

Worst Case: No Index for order by

The limiting factor is the number of rows that match the `where` clause (“Base-Set Size”).

The database might use an index to satisfy the `where` clause, but must still fetch all matching rows to “sort” them.

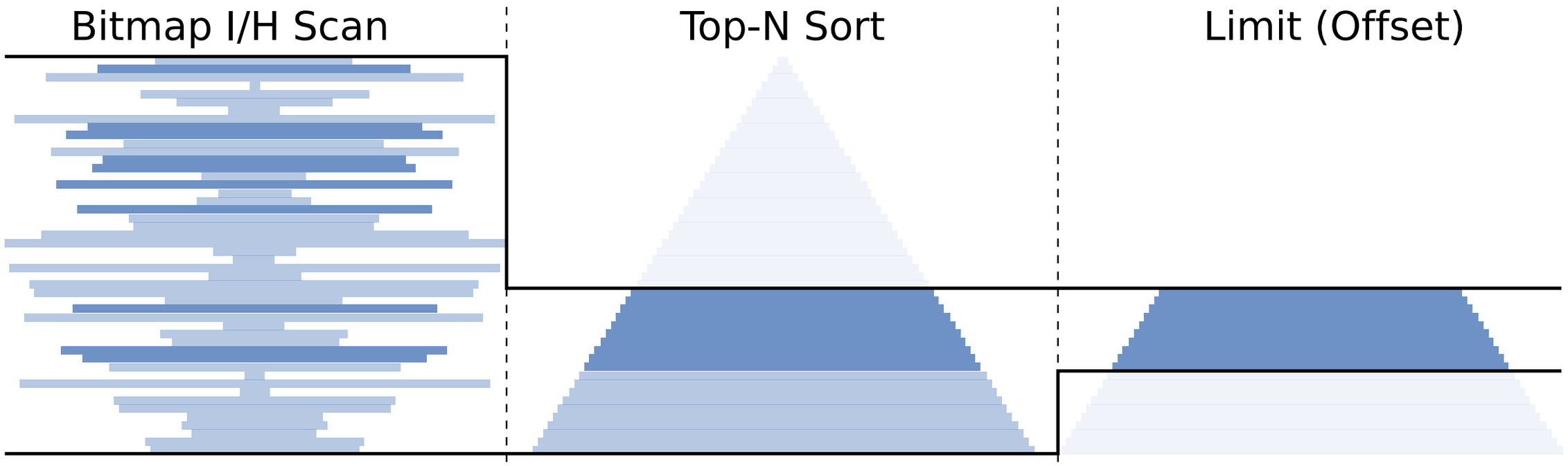


Another Benchmark: Fetch Next Page

Fetching the next page is easy using the `offset` keyword:

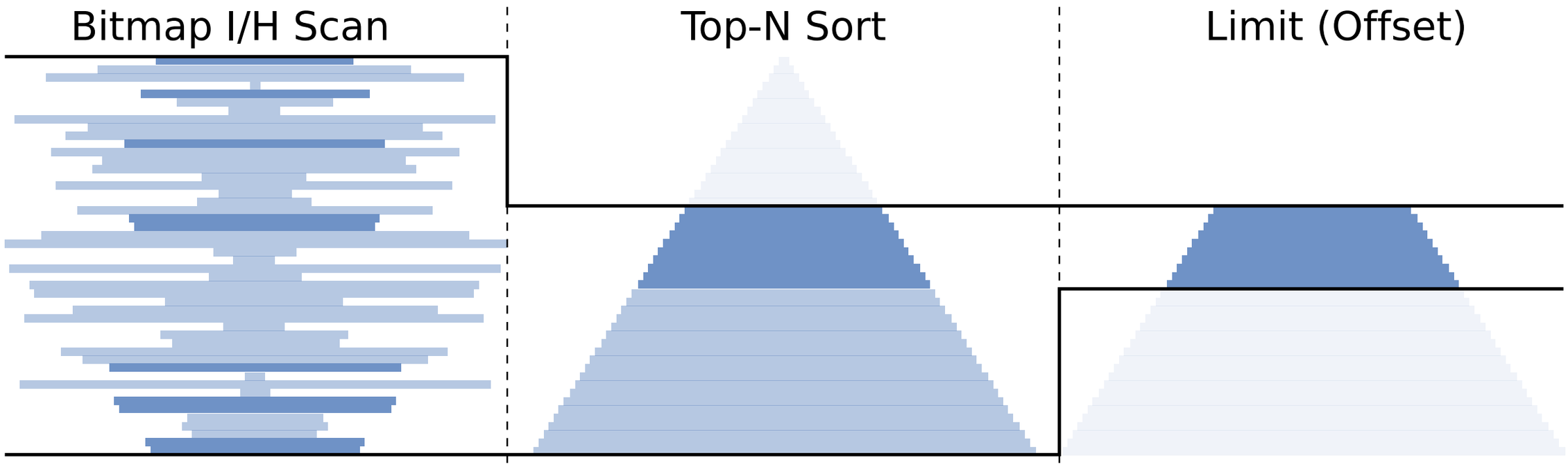
```
    select *
      from news
     where topic = 1234
     order by date desc, id desc
    offset 10
     limit 10;
```

Worst Case: No Index for order by



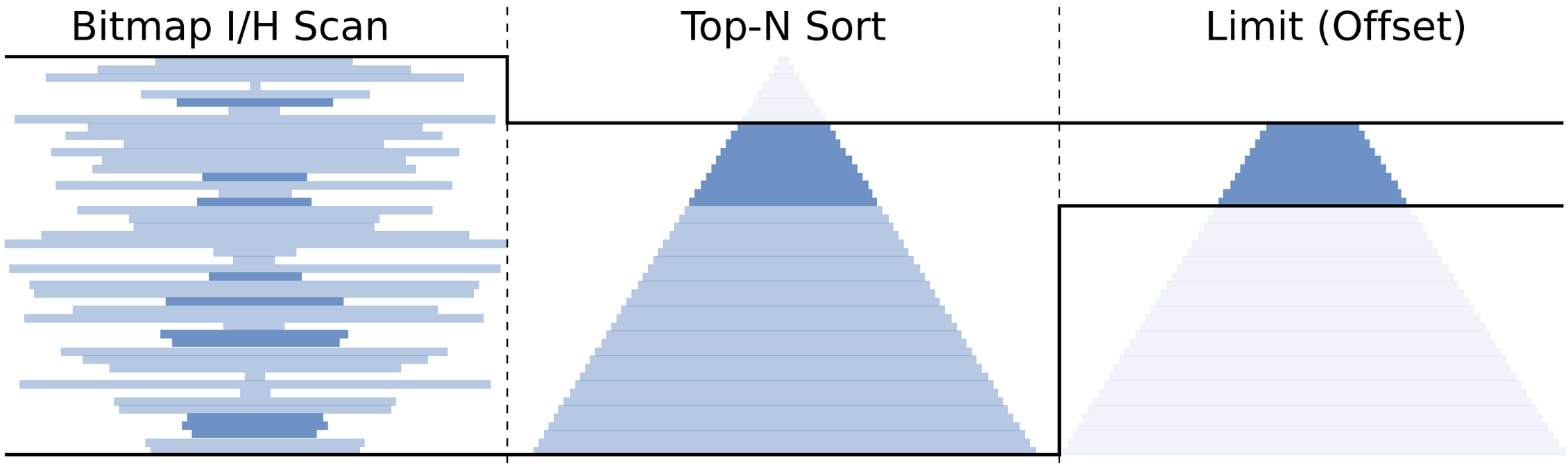

```
Limit (actual rows=10)
-> Sort (actual rows=20)
   Sort Method: top-N heapsort  Memory: 19kB
   ->  Bitmap Heap Scan (actual rows=10000)
       Recheck Cond: (topic = 1234)
       -> Bitmap Index Scan (actual rows=10000)
          Index Cond: (topic = 1234)
```

Worst Case: No Index for order by



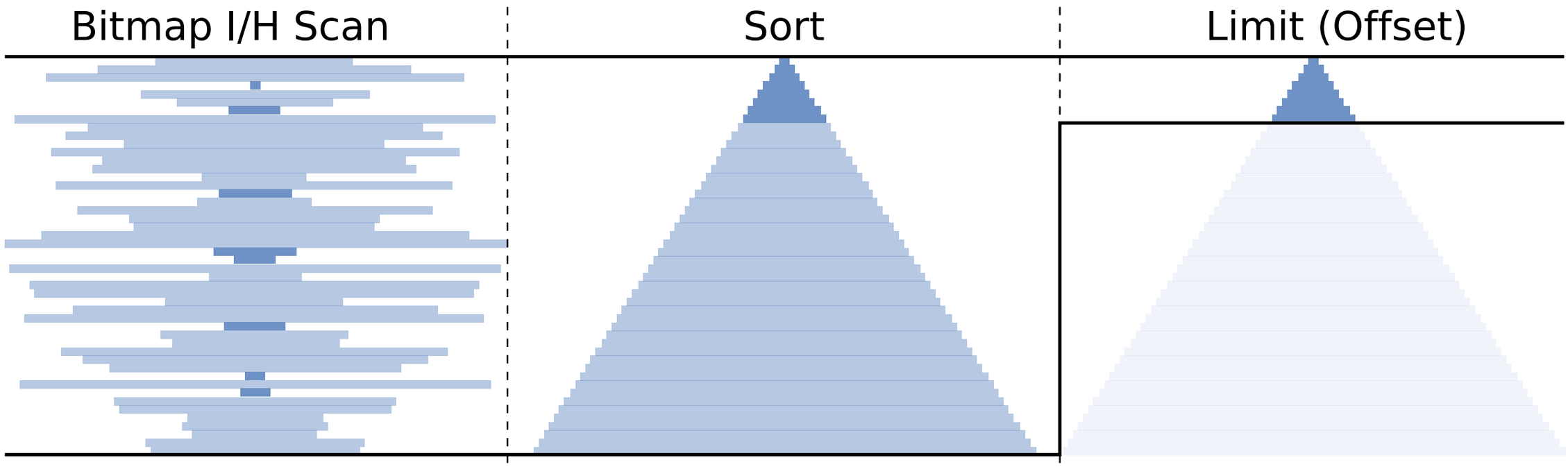

```
Limit (actual rows=10)
-> Sort (actual rows=30)
    Sort Method: top-N heapsort  Memory: 20kB
    ->  Bitmap Heap Scan (actual rows=10000)
        Recheck Cond: (topic = 1234)
        -> Bitmap Index Scan (actual rows=10000)
            Index Cond: (topic = 1234)
```

Worst Case: No Index for order by




```
Limit (actual rows=10)
-> Sort (actual rows=40)
   Sort Method: top-N heapsort  Memory: 22kB
   ->  Bitmap Heap Scan (actual rows=10000)
       Recheck Cond: (topic = 1234)
       -> Bitmap Index Scan (actual rows=10000)
          Index Cond: (topic = 1234)
```

Worst Case: No Index for order by

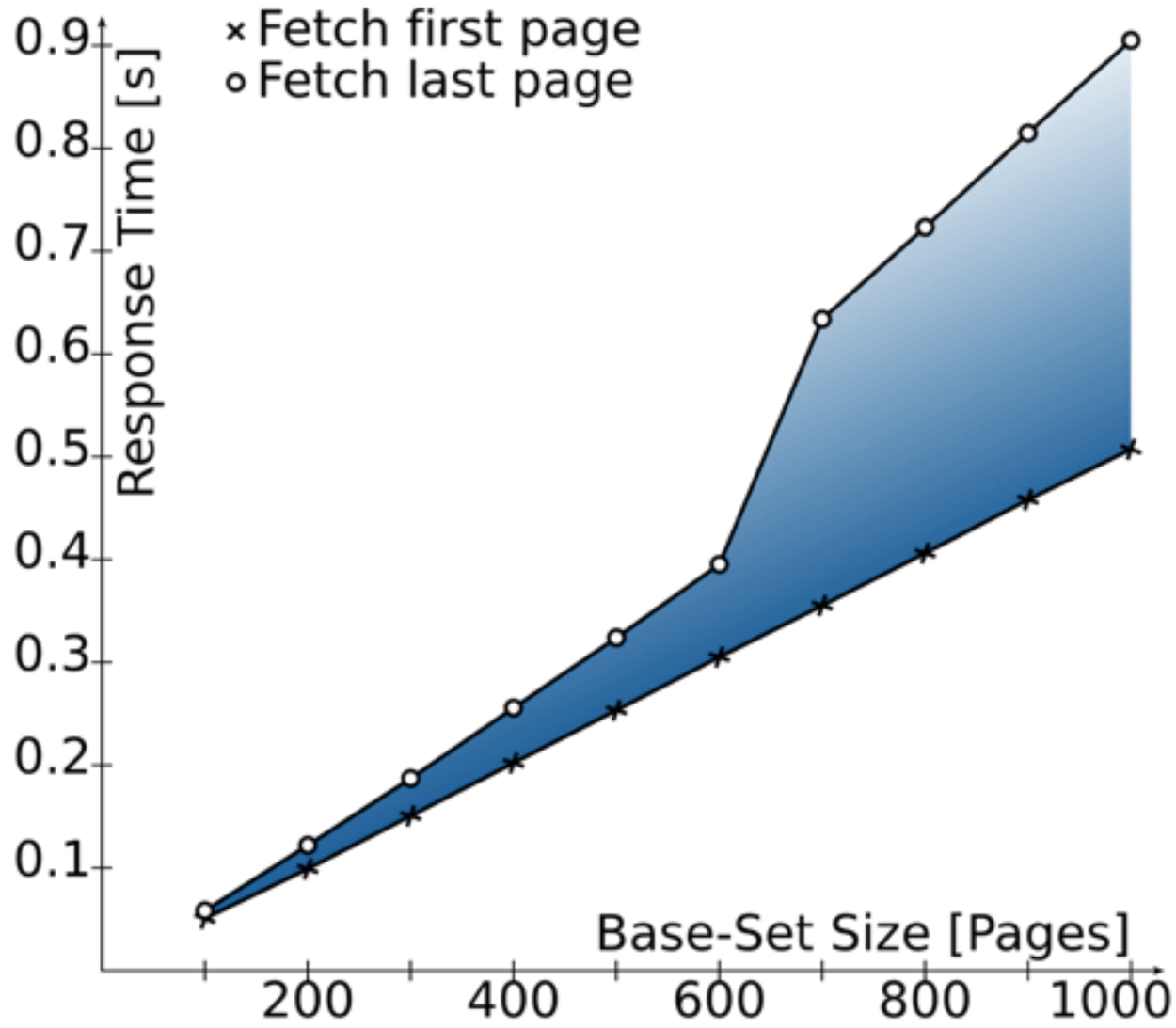



```
Limit (actual rows=10)
-> Sort (actual rows=10000)
   Sort Method: external merge  Disk: 1200kB
   ->  Bitmap Heap Scan (actual rows=10000)
       Recheck Cond: (topic = 1234)
       -> Bitmap Index Scan (actual rows=10000)
          Index Cond: (topic = 1234)
```

Worst Case: No Index for order by

Sorting might become the limiting factor when browsing farther back.

Fetching the last page can take considerably longer than fetching the first page.



Improvement 1 : Indexed order by

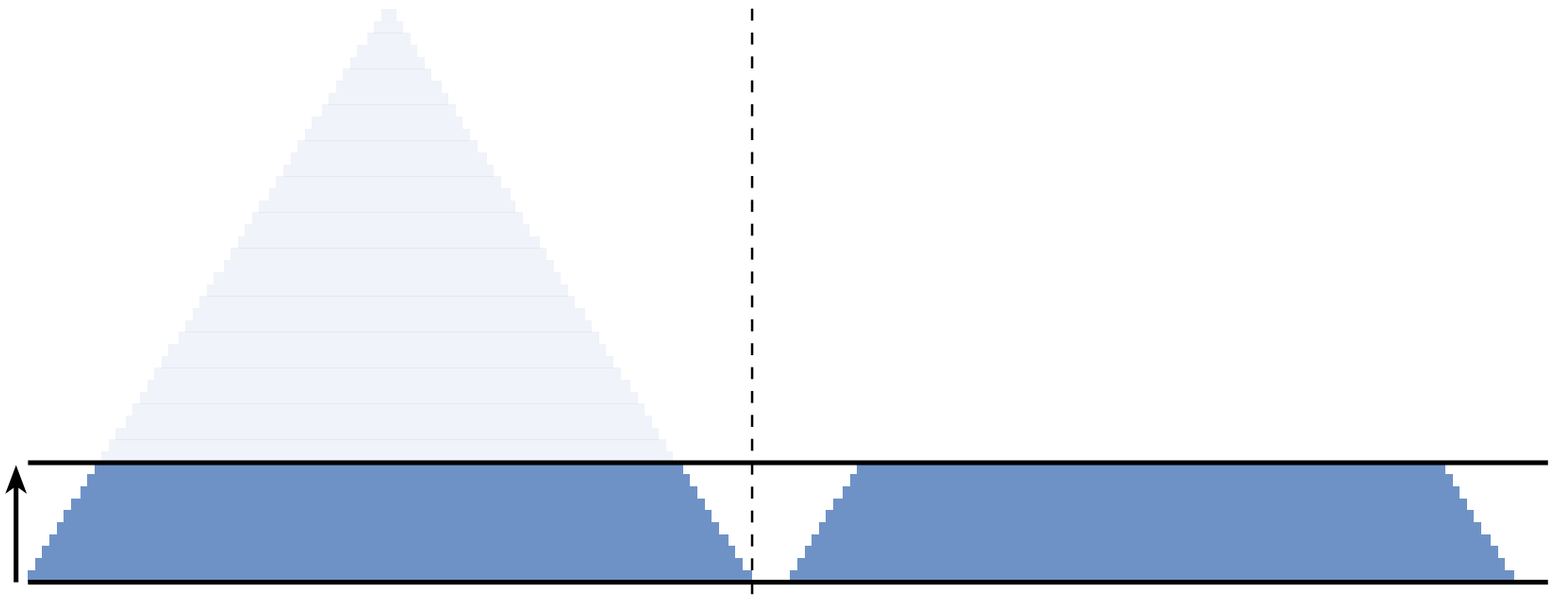
```
select *
  from news
 where topic = 1234
 order by date desc, id desc
offset 10
 limit 10;
```

```
create index .. on news (topic, date, id);
```

A single index to support the `where` and `order by` clauses.

Improvement 1 : Indexed order by

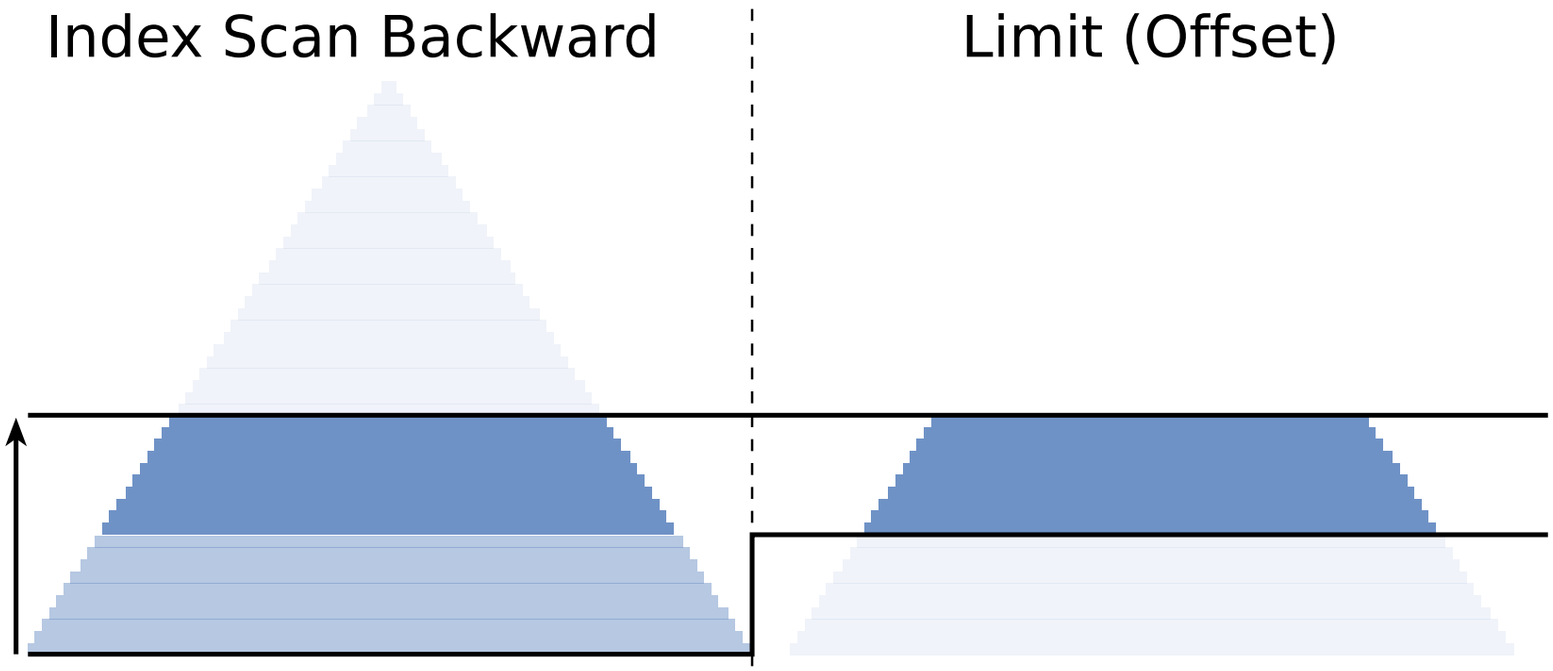
Index Scan Backward



Limit

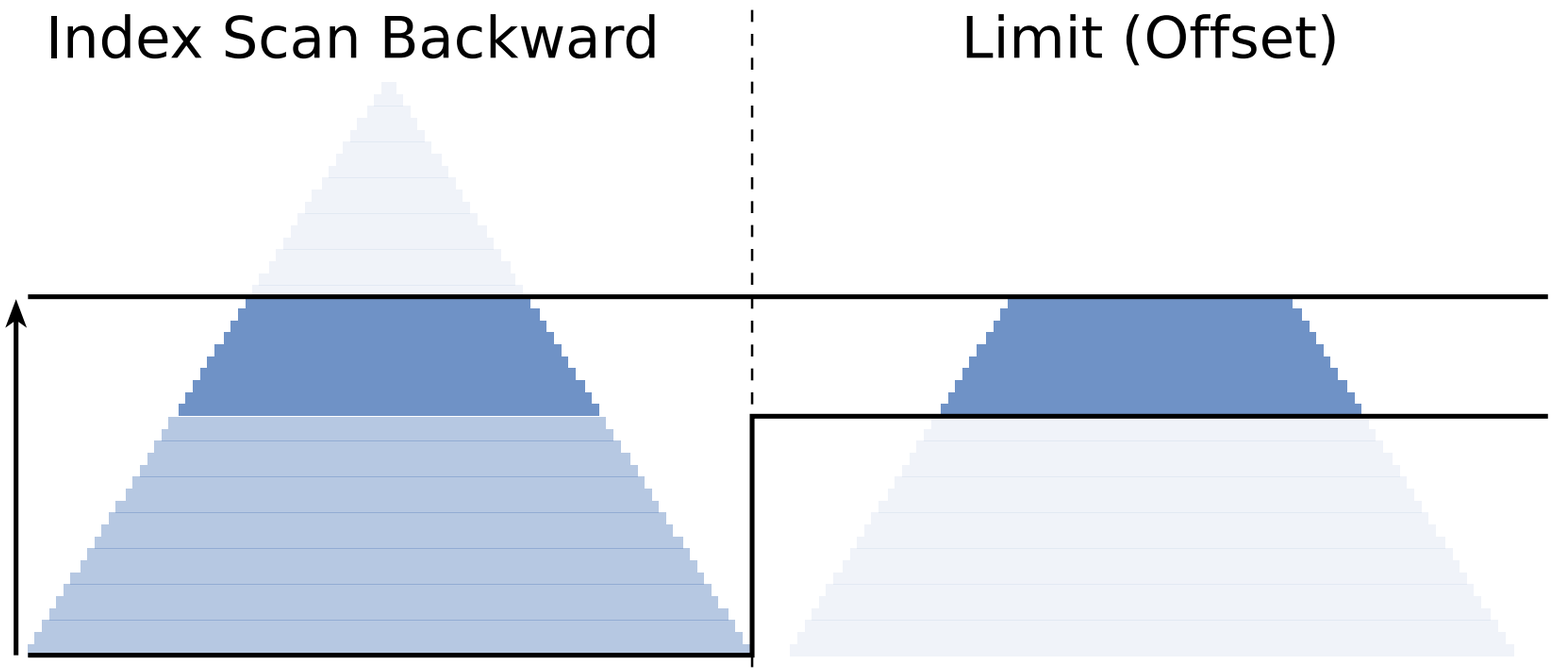
```
Limit (actual rows=10)
-> Index Scan Backward (actual rows=10)
   Index Cond: (topic = 0)
```

Improvement 1 : Indexed order by



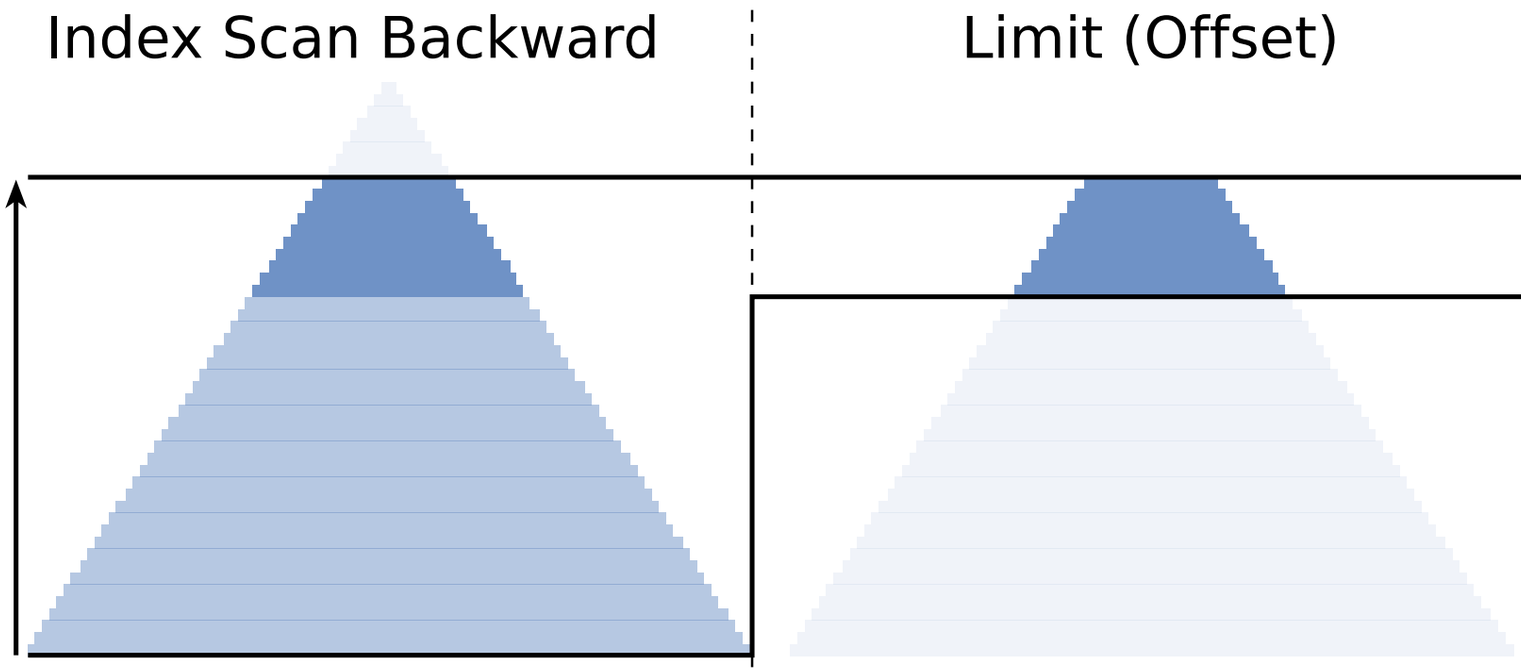

```
Limit (actual rows=10)
-> Index Scan Backward (actual rows=20)
   Index Cond: (topic = 0)
```

Improvement 1 : Indexed order by



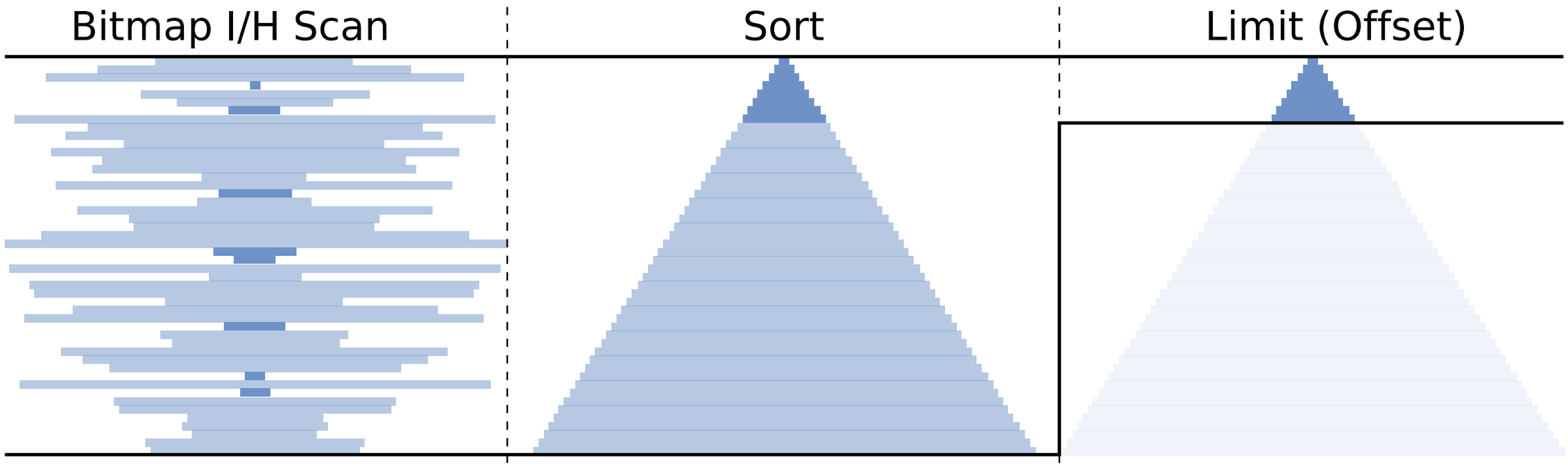

```
Limit (actual rows=10)
-> Index Scan Backward (actual rows=30)
   Index Cond: (topic = 0)
```

Improvement 1 : Indexed order by




```
Limit (actual rows=10)
-> Index Scan Backward (actual rows=40)
   Index Cond: (topic = 0)
```

Improvement 1 : Indexed order by

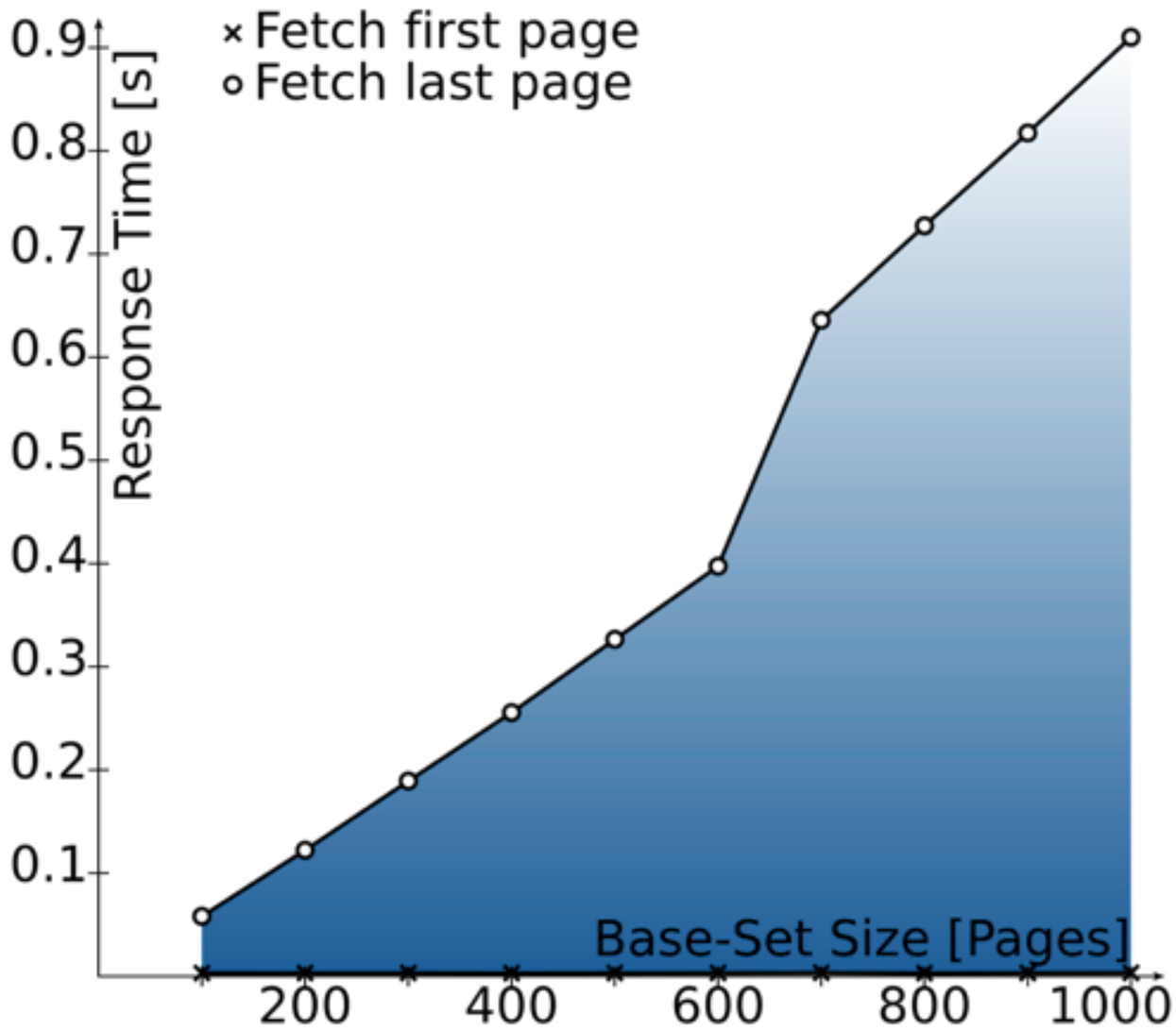



```
Limit (actual rows=10)
-> Sort (actual rows=10000)
    Sort Method: external merge  Disk: 1200kB
    ->  Bitmap Heap Scan (actual rows=10000)
        Recheck Cond: (topic = 1234)
        -> Bitmap Index Scan (actual rows=10000)
            Index Cond: (topic = 1234)
```

Improvement 1 : Indexed order by

Fetching the first page is not affected by the Base-Set size!

Fetching the next page is also faster.
However, PostgreSQL might take a Bitmap Index Scan when browsing to the end.



We can do better!

Don’t touch what you don’t need

Improvement 2: The Seek Method

Instead of `offset`, use a `where` filter to remove the rows from previous pages.

```
select *
  from news
 where topic = 1234
   and (date, id) < (prev_date, prev_id)
 order by date desc, id desc
 limit 10;
```

Only select the rows “before” (=earlier date) the last row from the previous page.

A definite sort order is really required!

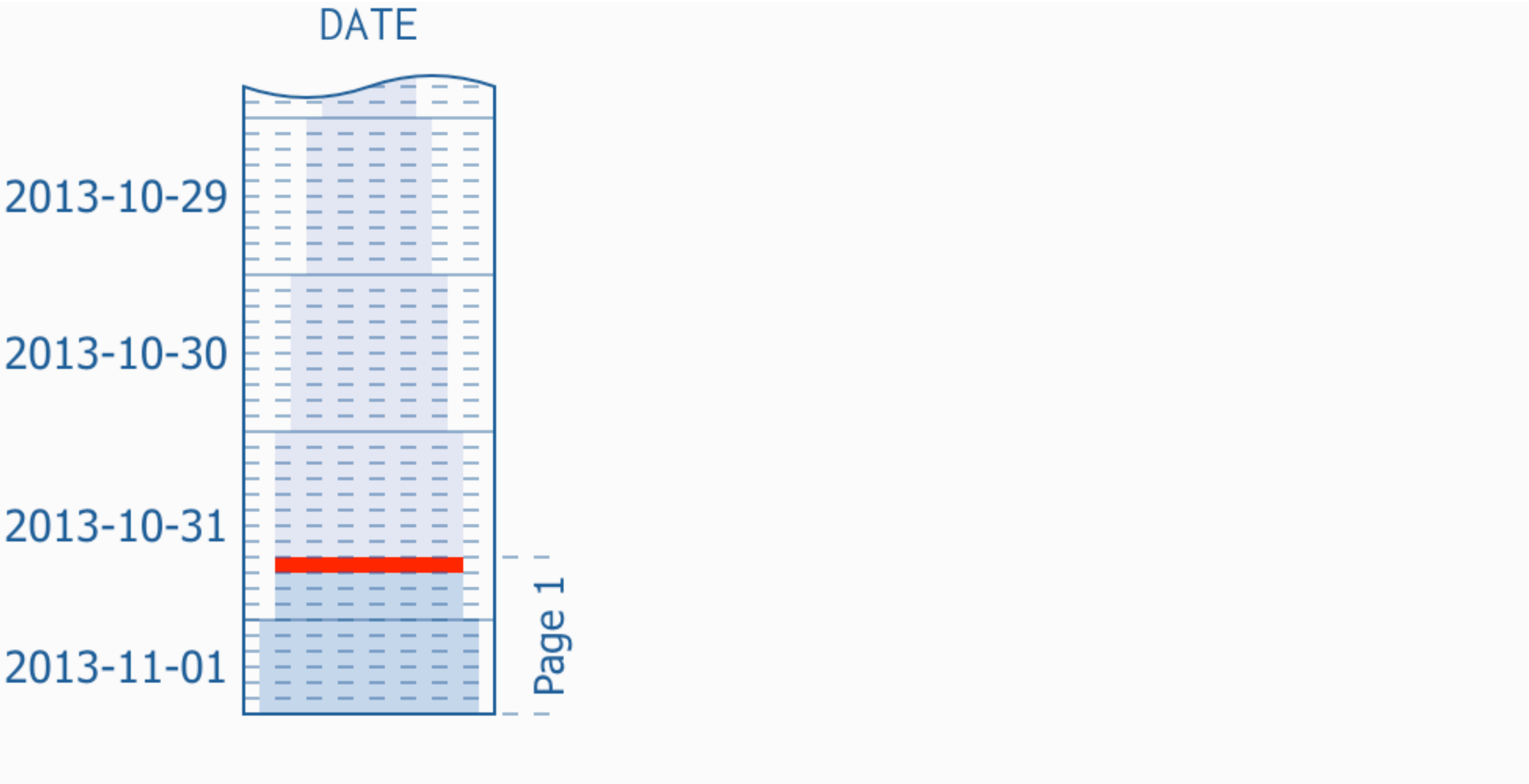
Side Note: Row Values

Besides scalar values, SQL also defines "row values" or "composite values."

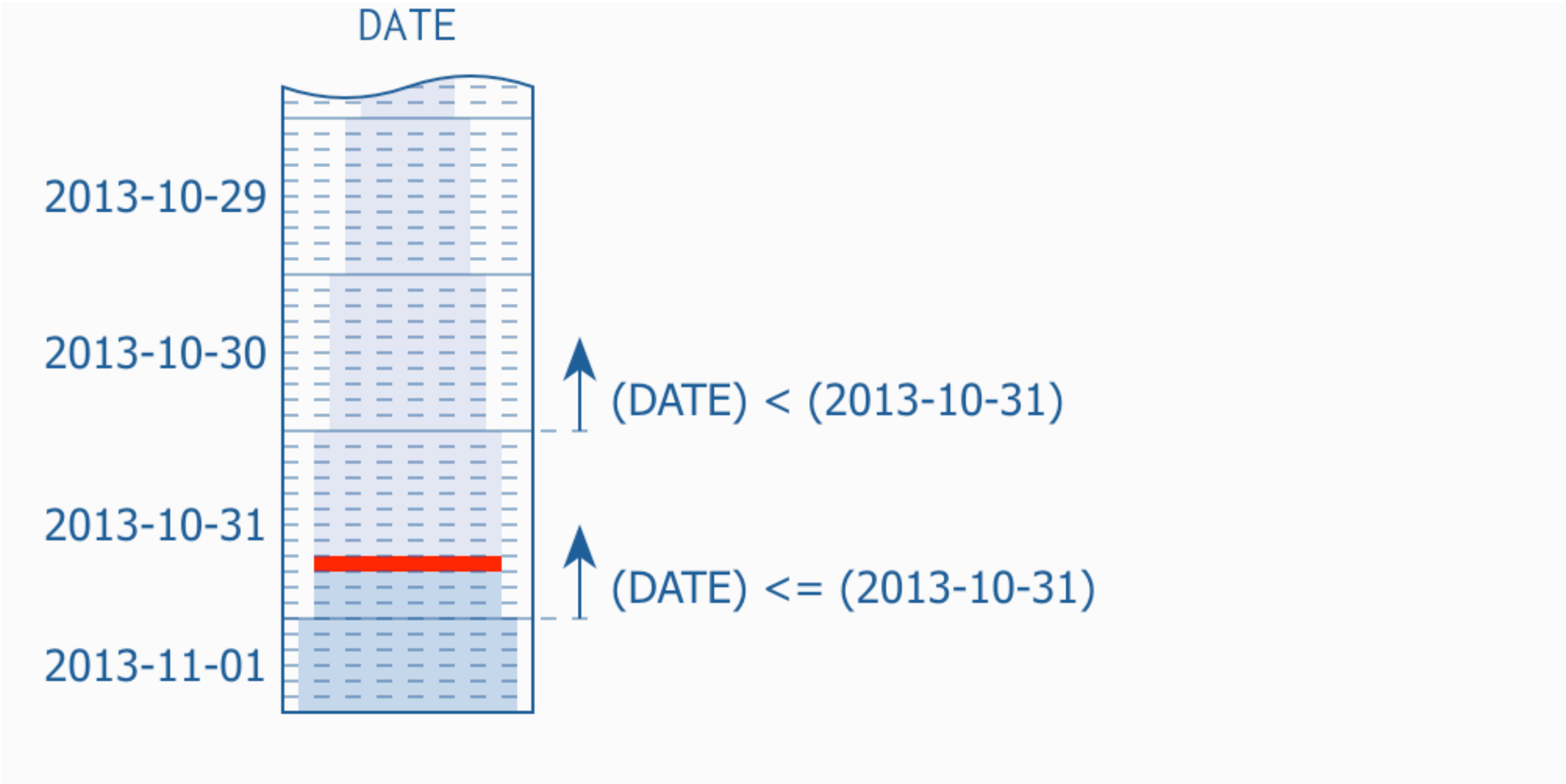
- In the SQL standard since ages (SQL-92)
- All comparison operators are well defined
  - E.g.: (x, y) > (a, b) is true iff

    (x > a or (x=a and y>b))
  - In other words, <u>when (x,y) sorts after (a,b)</u>
- Great PostgreSQL support since 8.0!

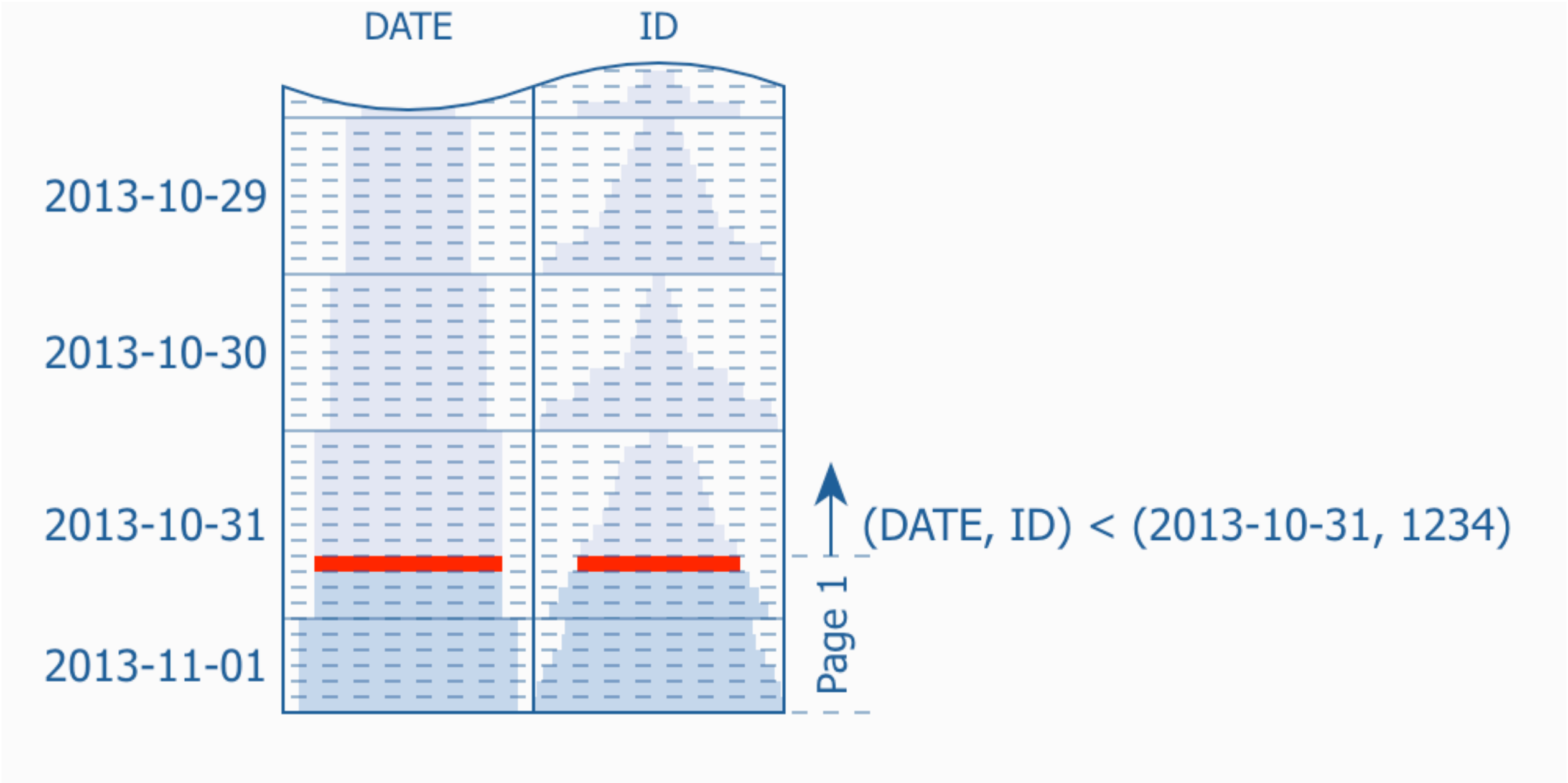
Row Values: How it works



Row Values: How it works



Row Values: How it works



Row Values: Emulating them

- There is only a single database that has sufficient Row-Values support for this trick (PostgreSQL).
- With all other database, you must emulate it according to this scheme:

```
WHERE sale_date <= ?
   AND (
          (sale_date < ?)
        OR
          (sale_date = ? AND sale_id < ?)
        )
```

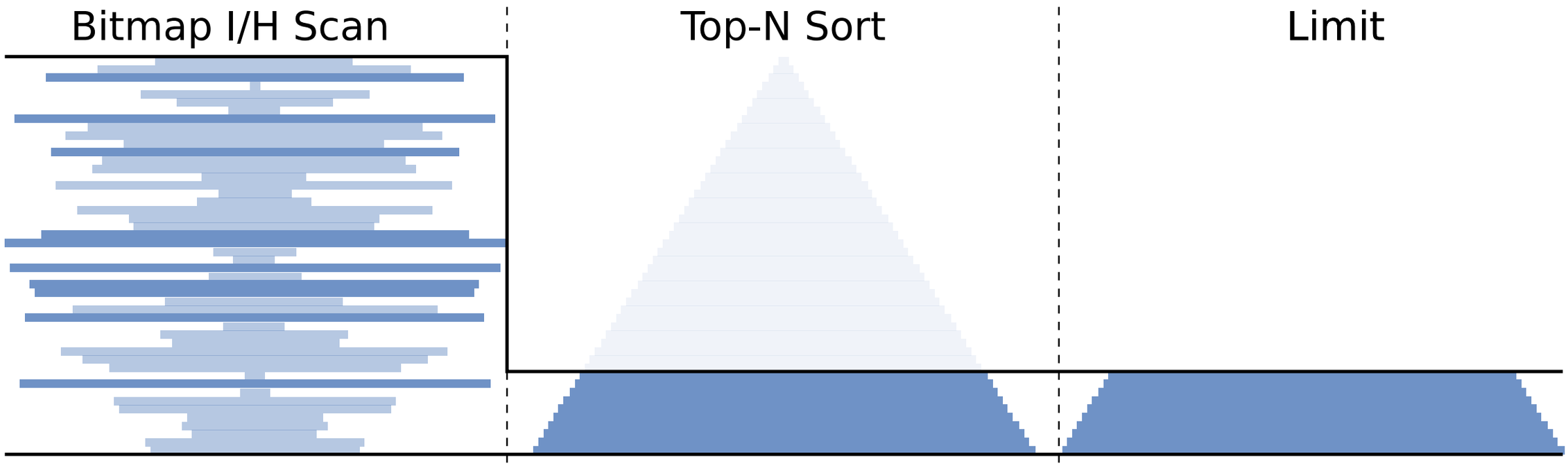
See: http://use-the-index-luke.com/sql/partial-results/fetch-next-page#sb-equivalent-logic

Seek-Method without Optimal Index

```
select *
  from news
 where topic = 1234
   and (date, id) < (prev_date, prev_id)
 order by date desc, id desc
 limit 10;
```

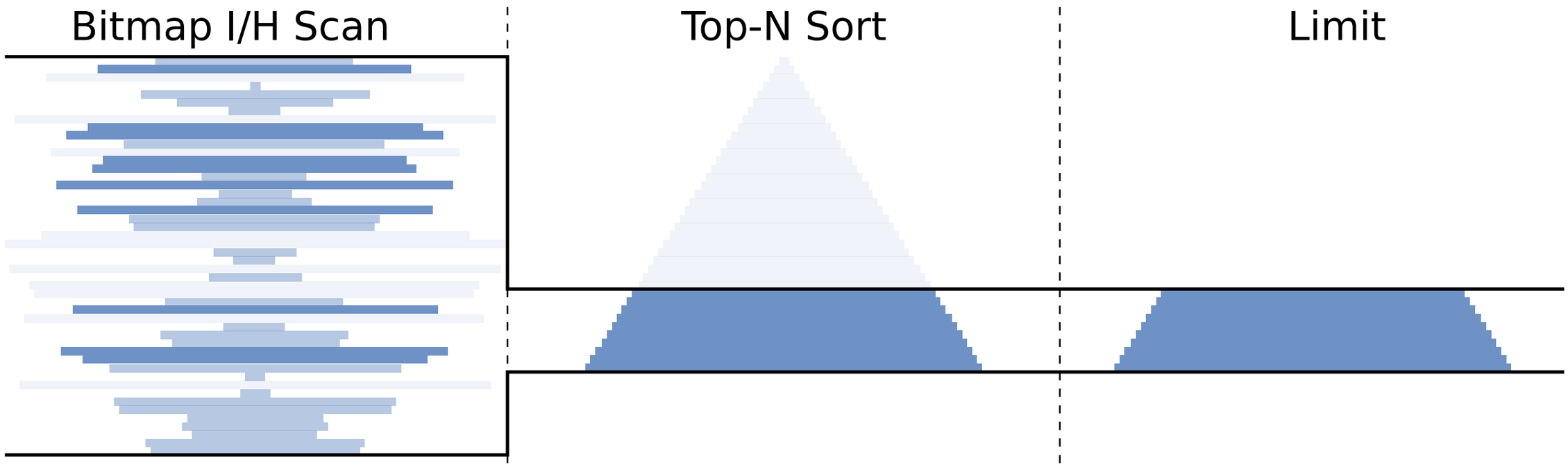
```
create index .. on news (topic);
```

Seek Method w/o Index for order by



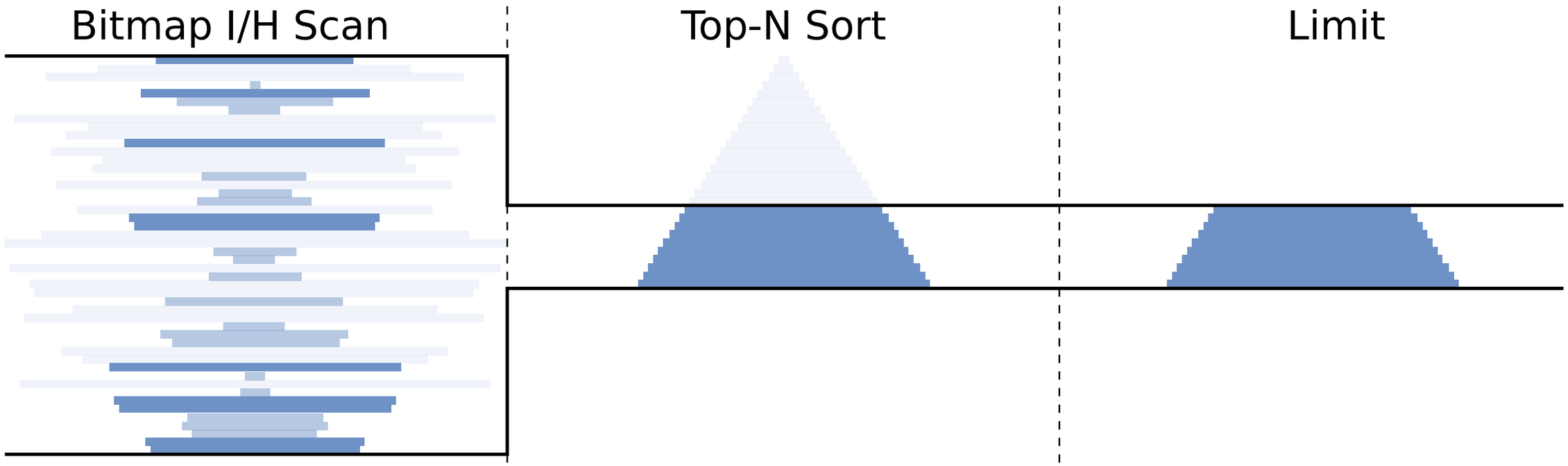

```
Limit (actual rows=10)
-> Sort (actual rows=10)
   Sort Method: top-N heapsort  Memory: 18kB
   -> Bitmap Heap Scan (rows=10000)
      Recheck Cond: (topic = 1234)
      -> Bitmap Index Scan (rows=10000)
         Index Cond: (topic = 1234)
```

Seek Method w/o Index for order by



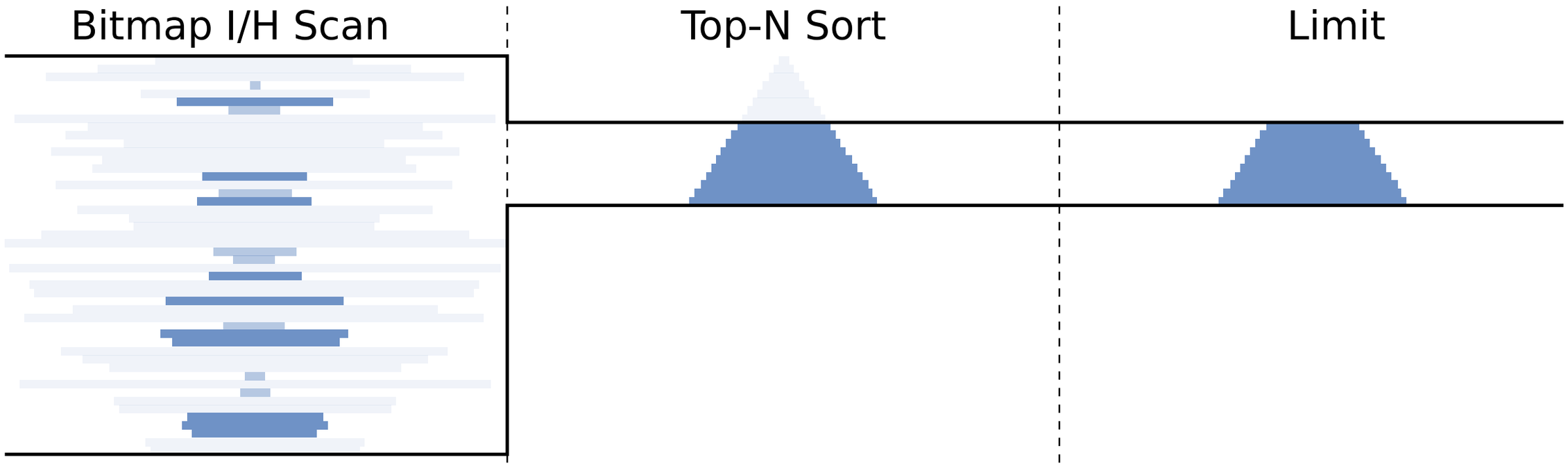

```
Limit (actual rows=10)
 -> Sort (actual rows=10)
    Sort Method: top-N heapsort  Memory: 18kB
    -> Bitmap Heap Scan (actual rows=9990)
       Rows Removed by Filter: 10 (new in 9.2)
       -> Bitmap Index Scan (actual rows=10000)
          Index Cond: (topic = 1234)
```

Seek Method w/o Index for order by



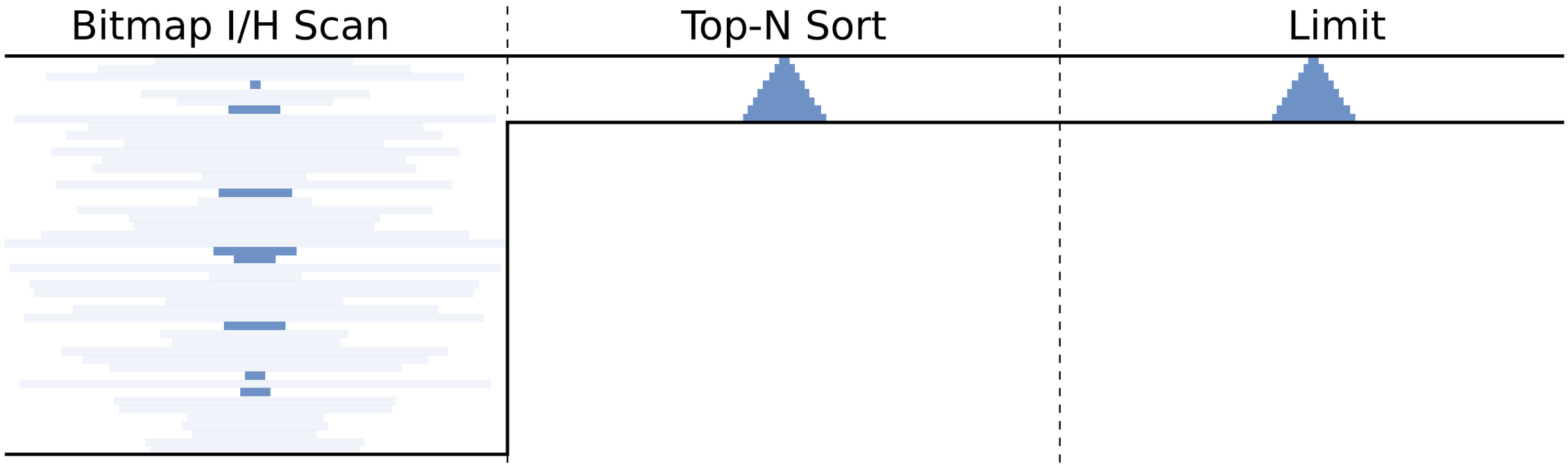

```
Limit (actual rows=10)
 -> Sort (actual rows=10)
    Sort Method: top-N heapsort  Memory: 18kB
    -> Bitmap Heap Scan (actual rows=9980)
       Rows Removed by Filter: 20 (new in 9.2)
       -> Bitmap Index Scan (actual rows=10000)
          Index Cond: (topic = 1234)
```

Seek Method w/o Index for order by




```
Limit (actual rows=10)
 -> Sort (actual rows=10)
    Sort Method: top-N heapsort  Memory: 18kB
    -> Bitmap Heap Scan (actual rows=9970)
       Rows Removed by Filter: 30 (new in 9.2)
       -> Bitmap Index Scan (actual rows=10000)
          Index Cond: (topic = 1234)
```

Seek Method w/o Index for order by

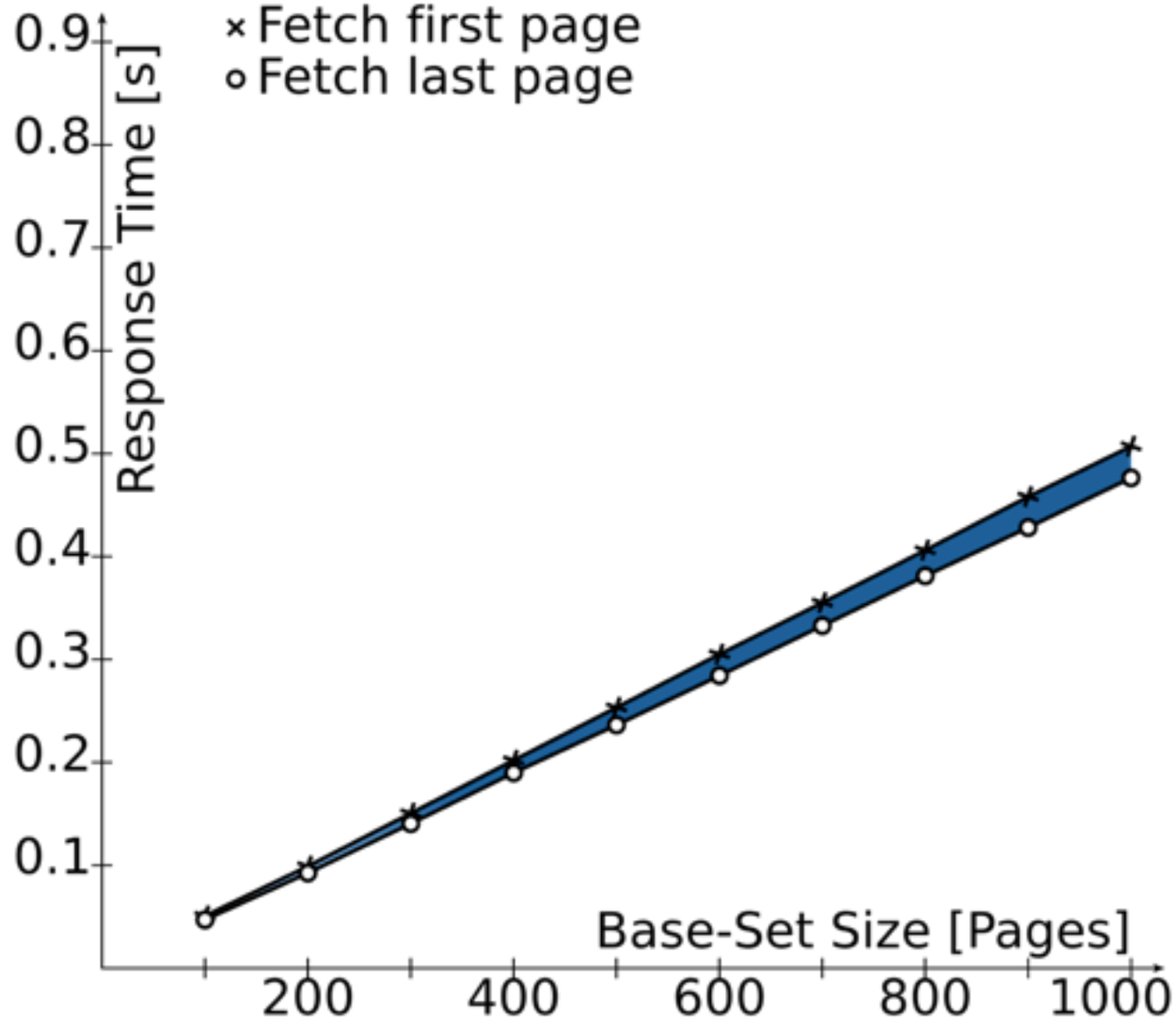



```
Limit (actual rows=10)
 -> Sort (actual rows=10)
    Sort Method: top-N heapsort  Memory: 18kB
    -> Bitmap Heap Scan (actual rows=10)
       Rows Removed by Filter: 9990 (new in 9.2)
       -> Bitmap Index Scan (actual rows=10000)
          Index Cond: (topic = 1234)
```

Seek Method w/o Index for order by

Always needs to retrieve the full base set, but the top-n sort buffer needs to hold only 10 rows.

The response time remains the same even when browsing to the last page. And the memory footprint is very low!



Seek-Method with Optimal Index

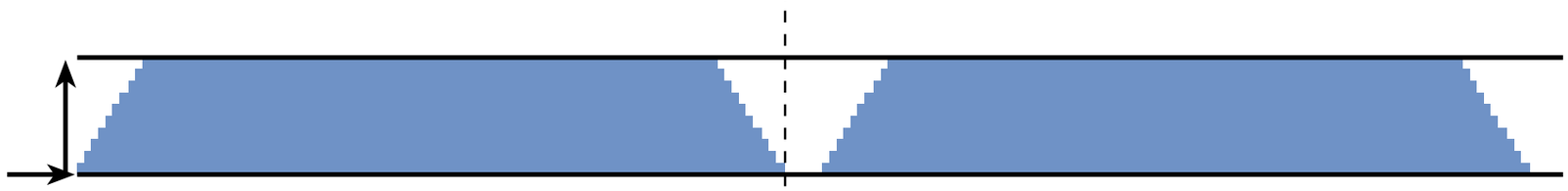
```
select *
  from news
 where topic = 1234
   and (date, id) < (prev_date, prev_id)
 order by date desc, id desc
 limit 10;
```

```
create index .. on news (topic, date, id);
```

Seek Method with index for order by

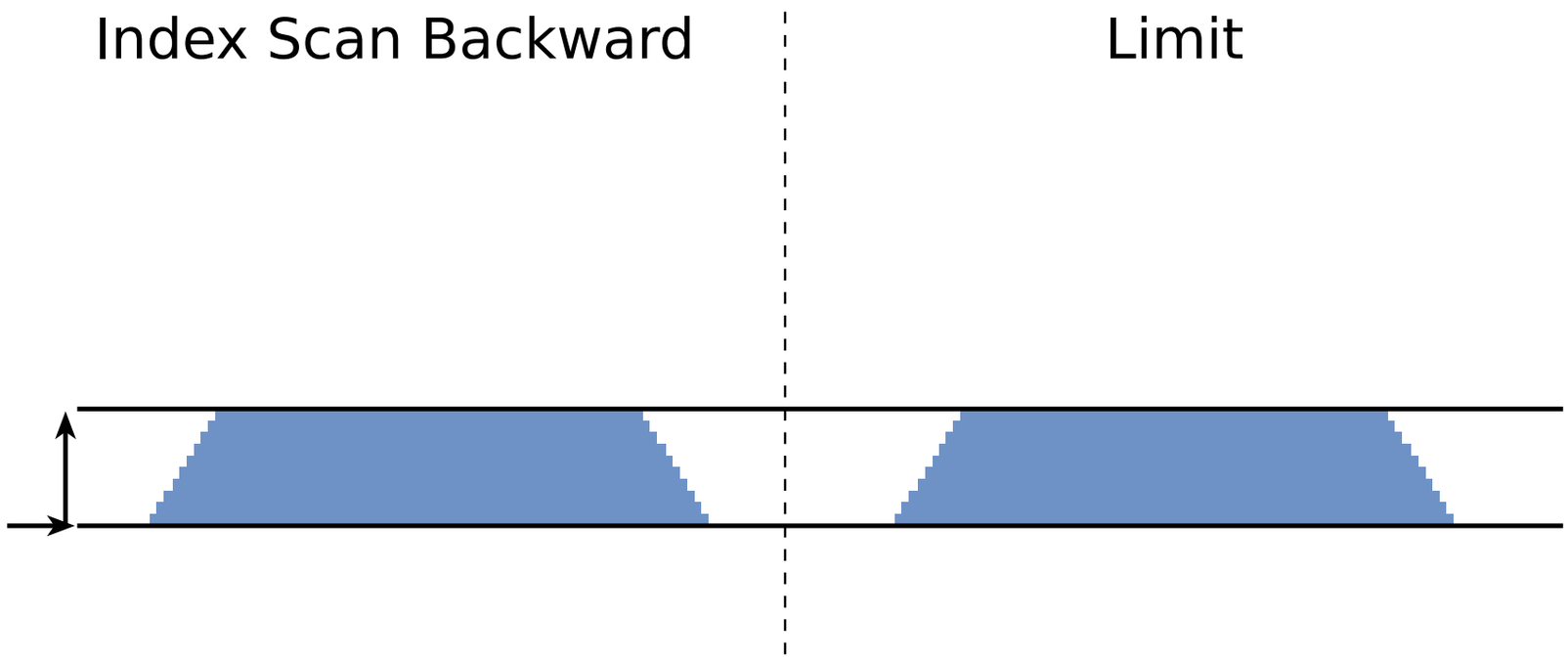
Index Scan Backward

Limit



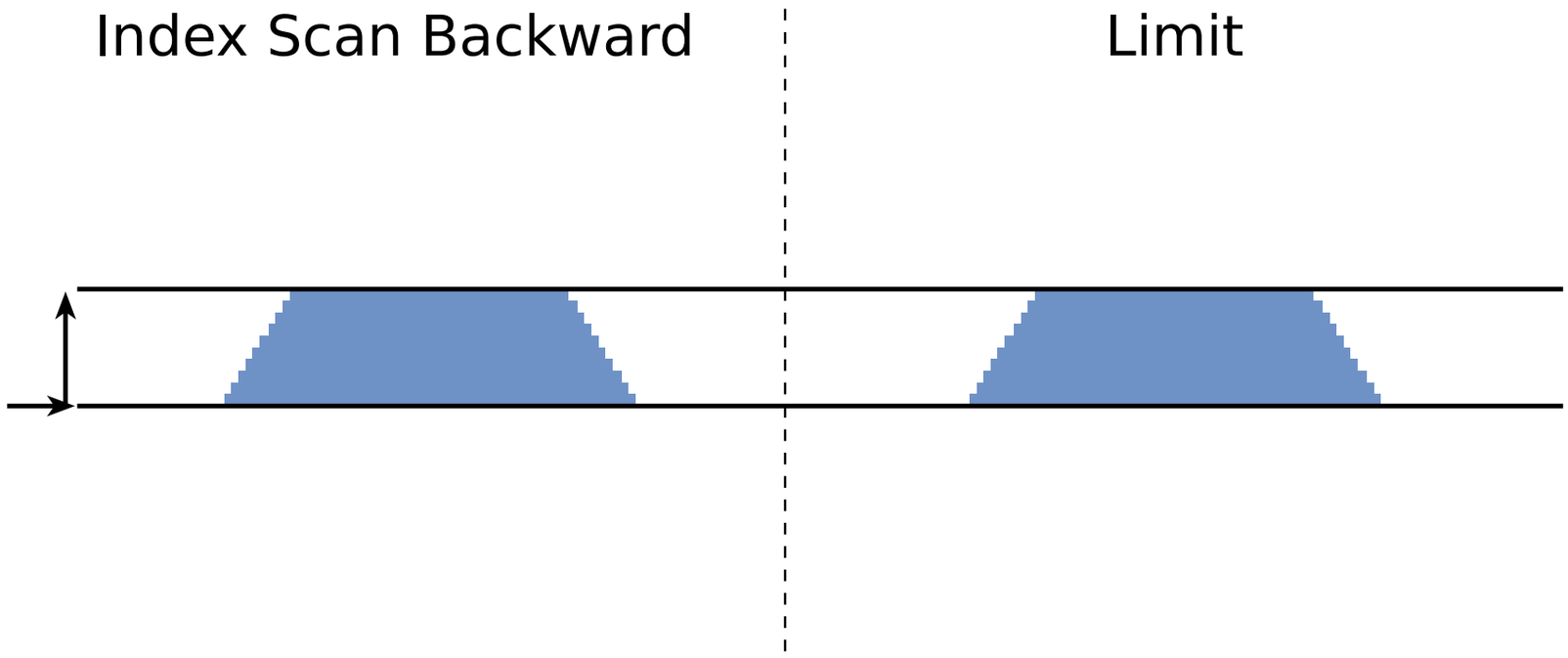
```
Limit (actual rows=10)
-> Index Scan Backward (actual rows=10)
   Index Cond: (topic = 1234)
```

Seek Method with index for order by



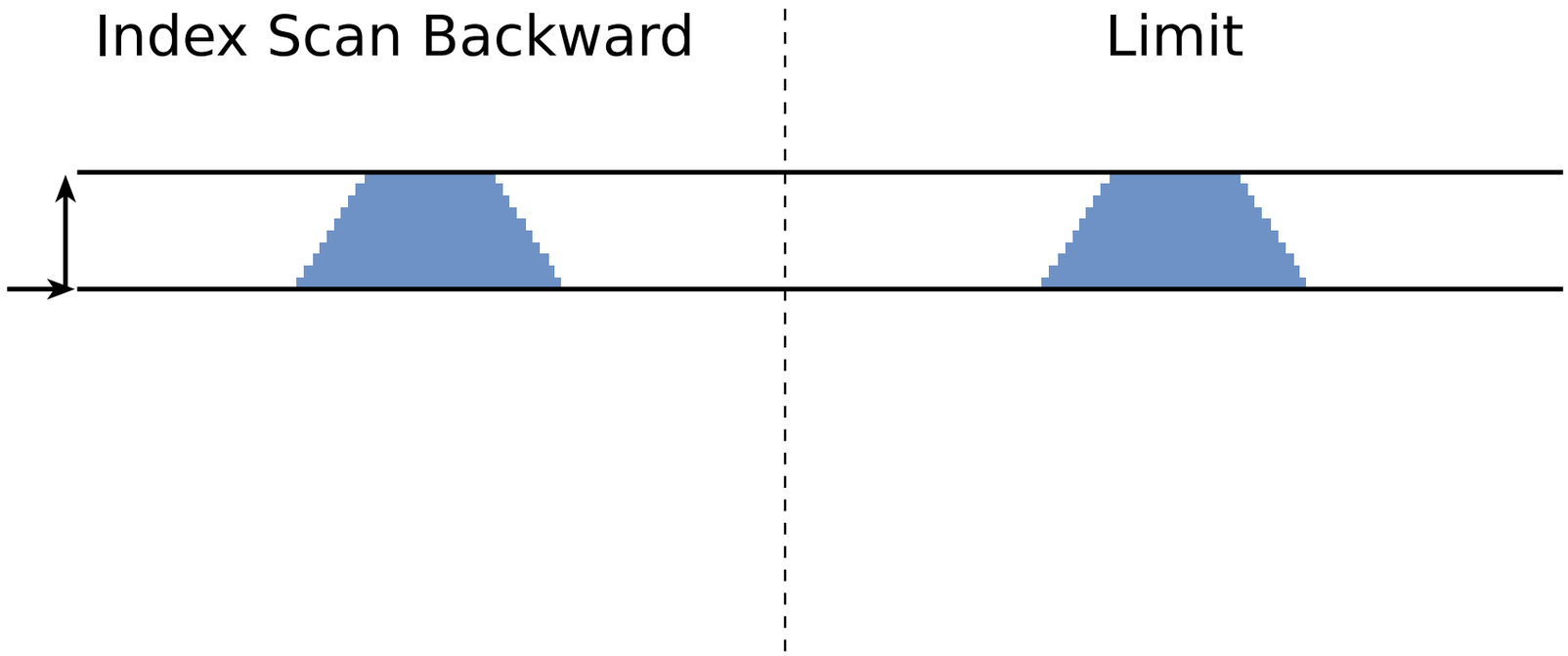

```
Limit (actual rows=10)
-> Index Scan Backward (actual rows=10)
   Index Cond: ((topic = 1234)
                AND (ROW(dt, id) < ROW('...', 23456)))
```

Seek Method with index for order by



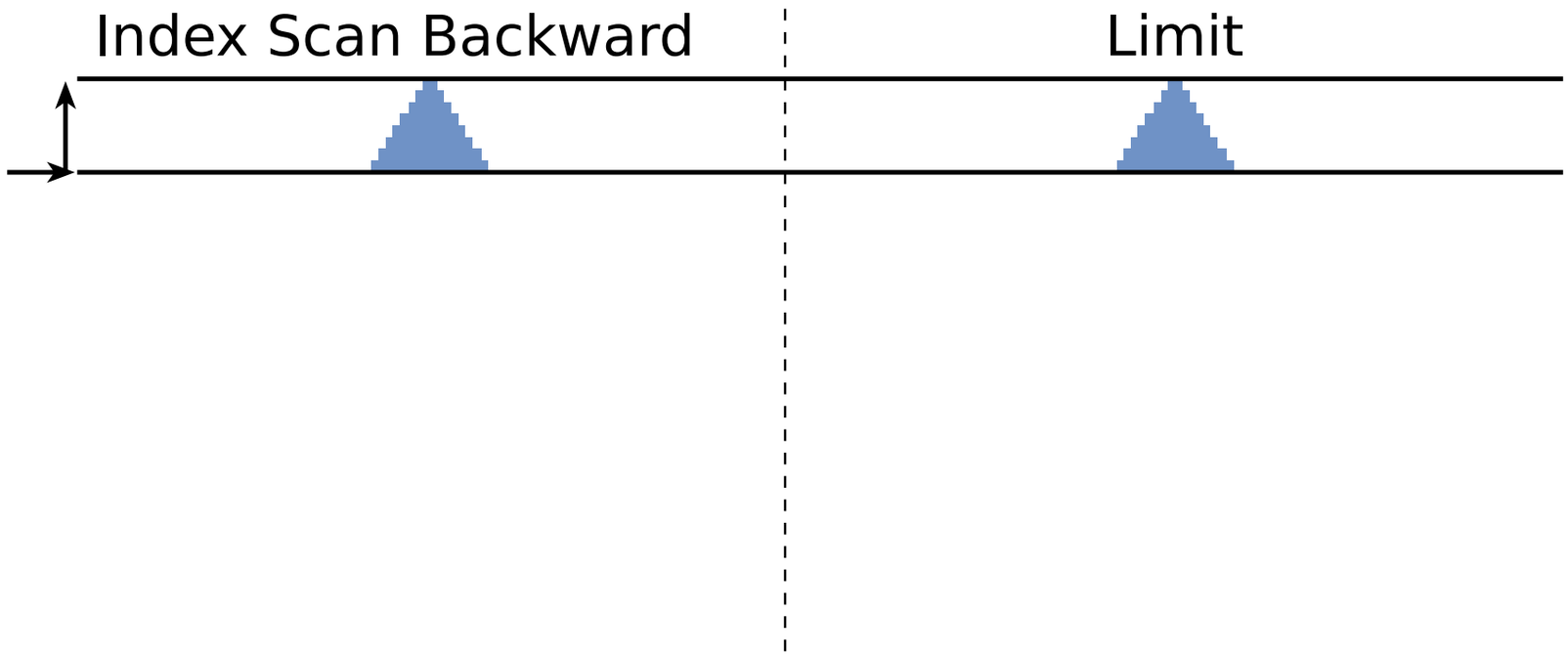

```
Limit (actual rows=10)
-> Index Scan Backward (actual rows=10)
   Index Cond: ((topic = 1234)
            AND (ROW(dt, id) < ROW('...', 34567)))
```

Seek Method with index for order by




```
Limit (actual rows=10)
-> Index Scan Backward (actual rows=10)
   Index Cond: ((topic = 1234)
            AND (ROW(dt, id) < ROW('...', 45678)))
```

Seek Method with index for order by



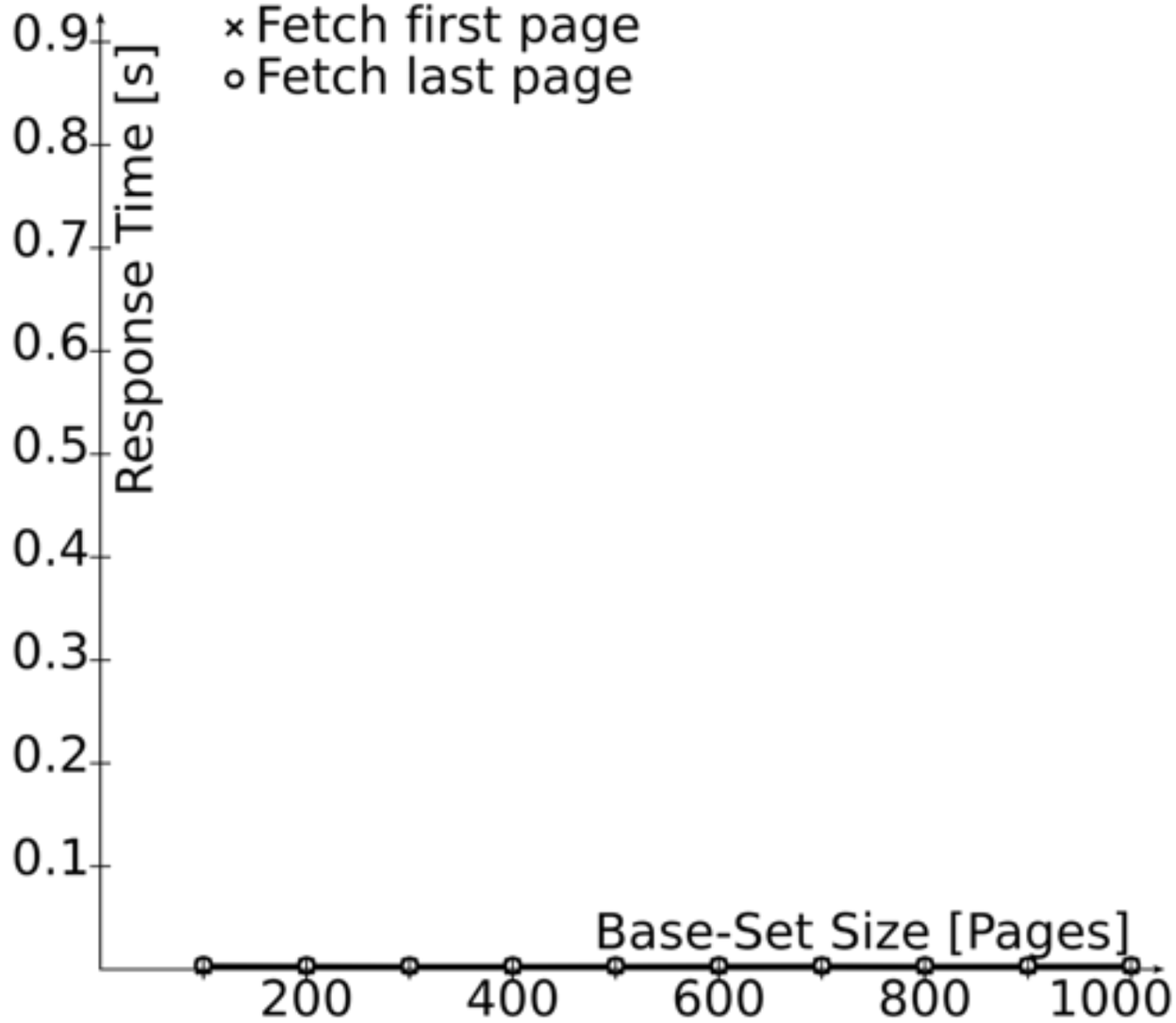

```
Limit (actual rows=10)
-> Index Scan Backward (actual rows=10)
   Index Cond: ((topic = 1234)
            AND (ROW(dt, id) < ROW('...', 56789)))
```

Seek Method with index for order by

Successively browsing back doesn't slow down.

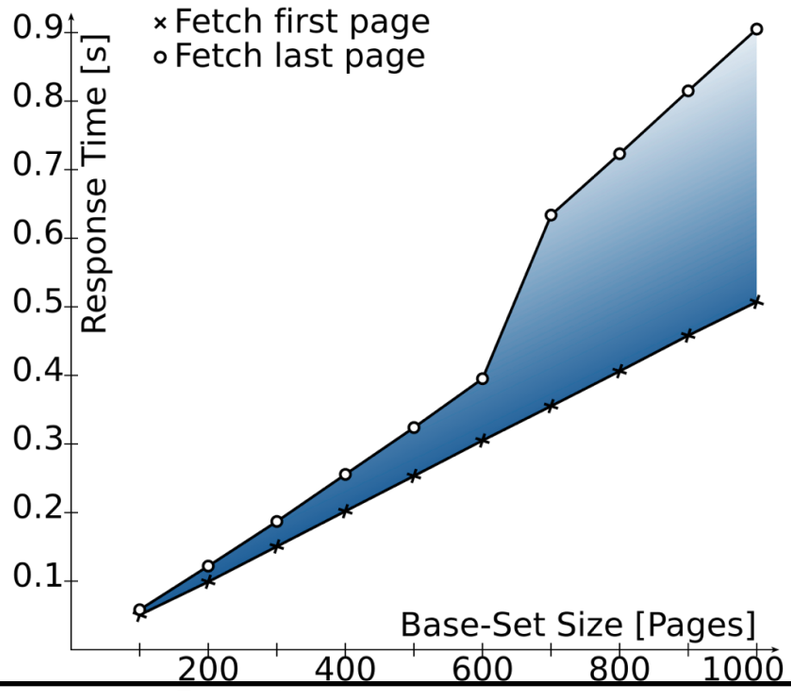
Neither the size of the base set(*) nor the fetched page number affects the response time.

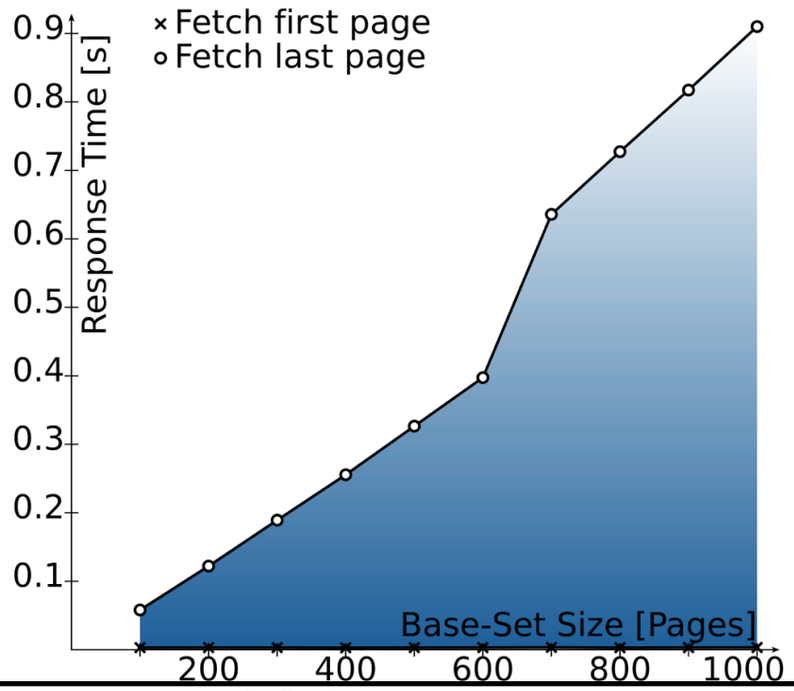
(*) the index tree depth still affects the response time.



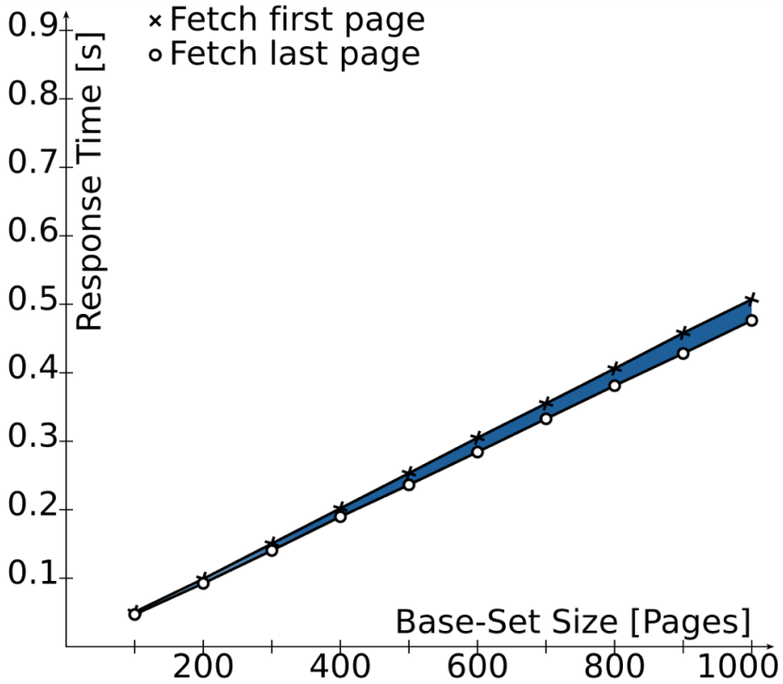
Comparison

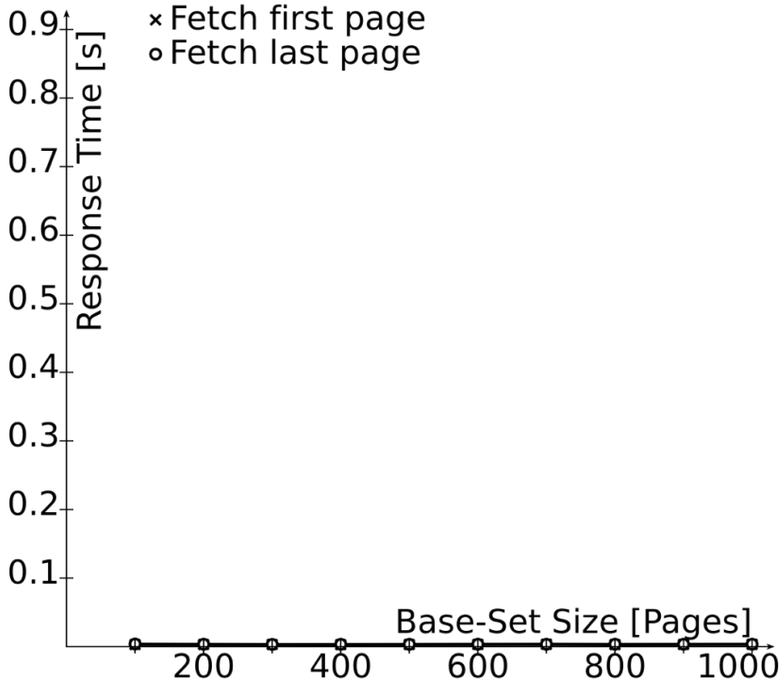
Offset





Seek





W/O index for `order by`

With index for `order by`

Too good to be true?

The Seek Method has serious limitations

- You cannot directly navigate to arbitrary pages
  - because you need the values from the previous page

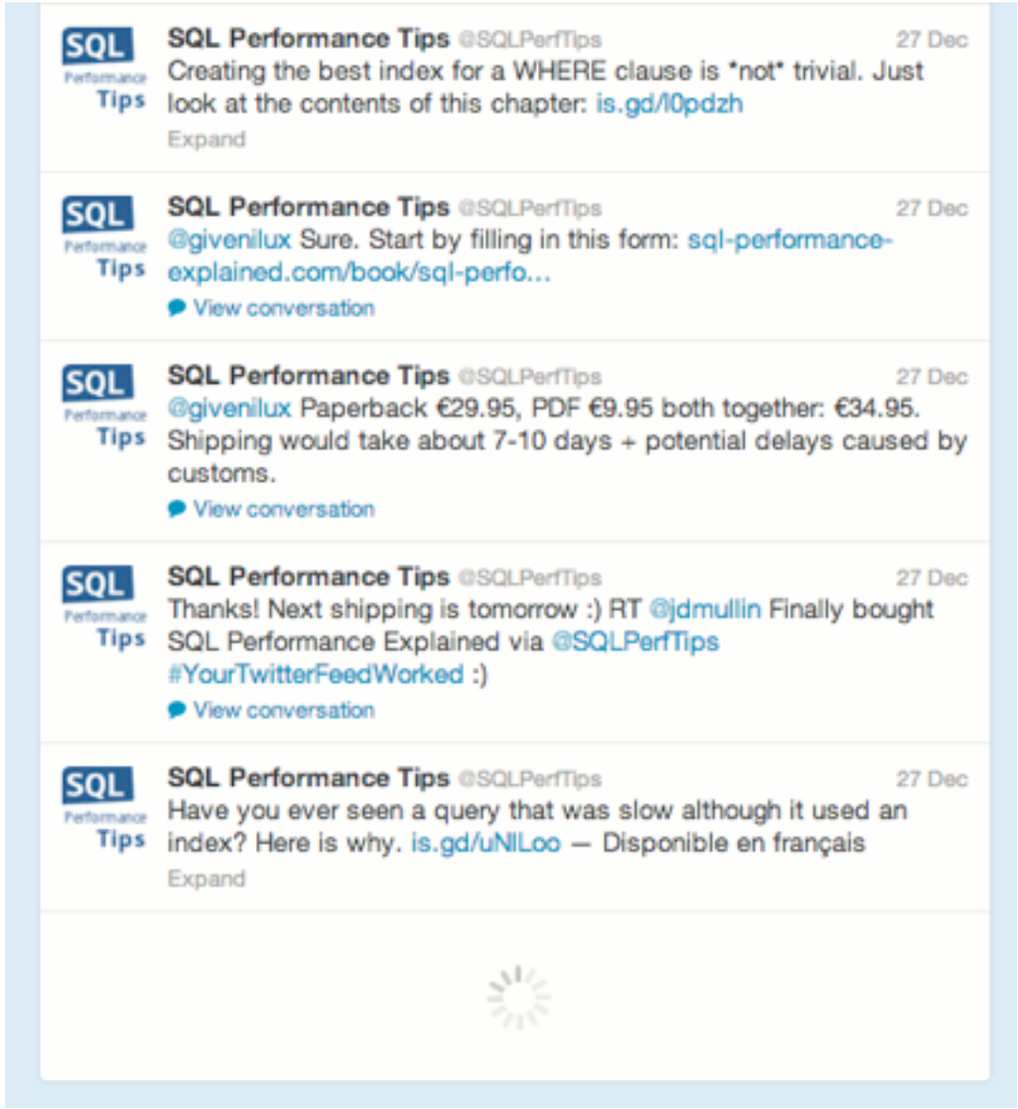
- Bi-directional navigation is possible but tedious
  - you need to revers the `order by` direction and RV comparison

- Works best with full row values support
  - Workaround is possible, but ugly and less performant
  - Framework support?
    - jOOQ 3.3 introduced native support for the Seek-Method
    - order_query for Ruby by @glebm: http://github.com/glebm/order_query

A Perfect Match for Infinite Scrolling

The “Infinite Scrolling” UI doesn’t need to ...

- navigate to arbitrary pages
  - there are no buttons
- Browse backwards
  - previous pages are still in the browser
- Stable results
  - New rows don’t affect the result
    No need for de-duplication in JS



Also a Perfect Match for PostgreSQL

row values support matrix

	MySQL	Oracle	PostgreSQL	SQLite	SQL Server
Supported in `where` clause	✓	✓	✓	✗	✗
Ranges supported (`<`,`>`)	✓	✗	✓	✗	✗
Optimal index usage	✗	✓	✓	✗	✗

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`order by` support matrix

	MySQL	Oracle	PostgreSQL	SQL Server
Read index backwards	✓	✓	✓	✓
Order by `ASC/DESC`	✓	✓	✓	✓
Index `ASC/DESC`	✗	✓	✓	✓
Order by `NULLS FIRST/LAST`	✗	✓	✓	✗
Default `NULLS` order	First	Last	Last	First
Index `NULLS FIRST/LAST`	✗	✗	✓	✗

Popular

Advanced

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