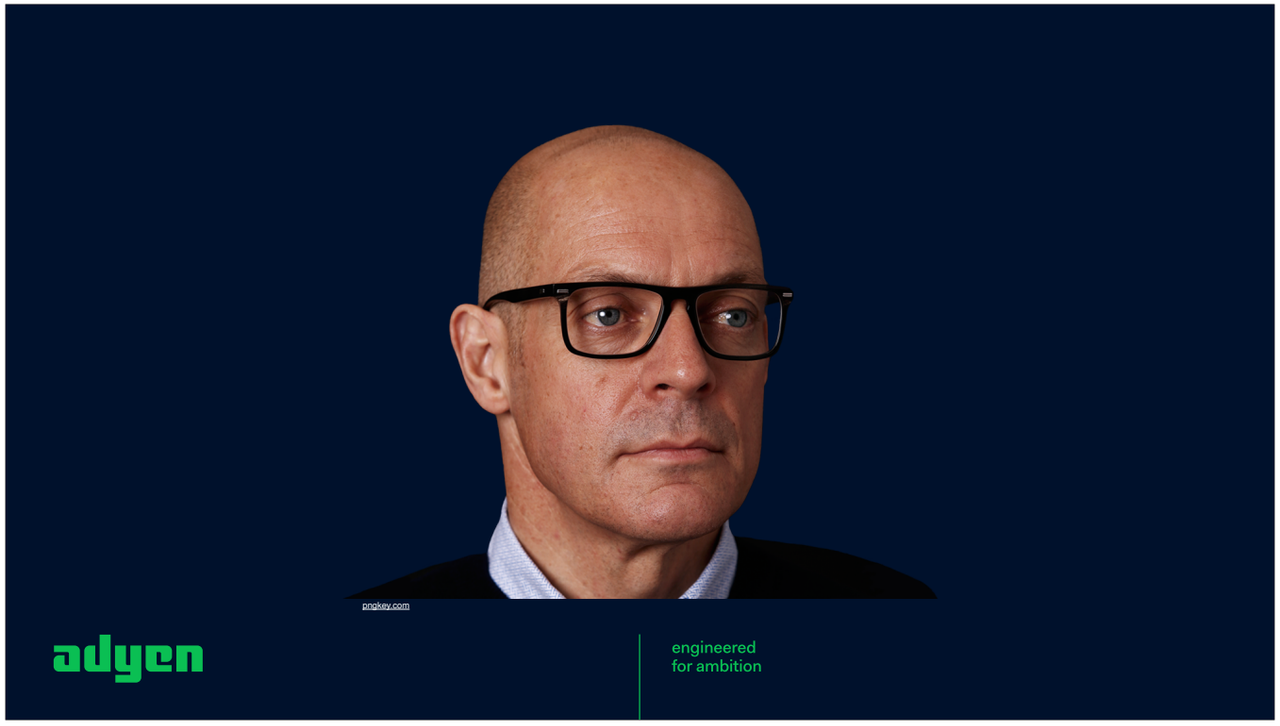
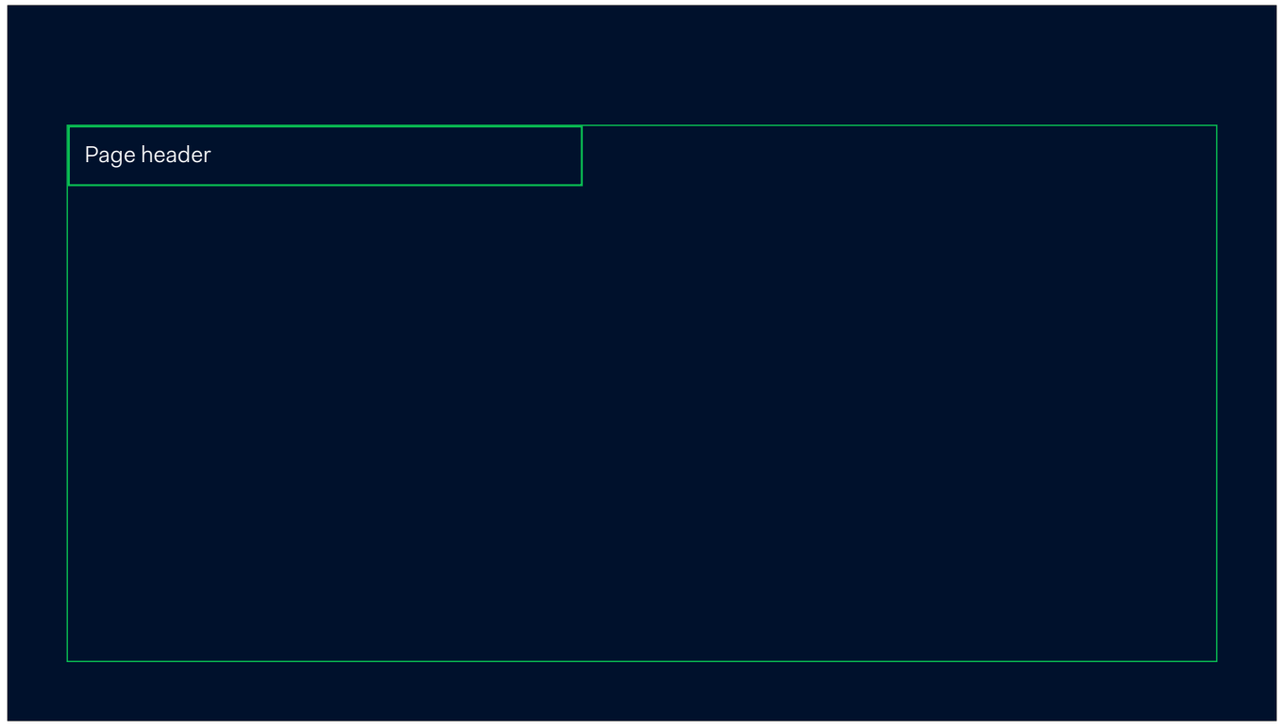
Adding small gains for maximum results

adyen

engineered
for ambition

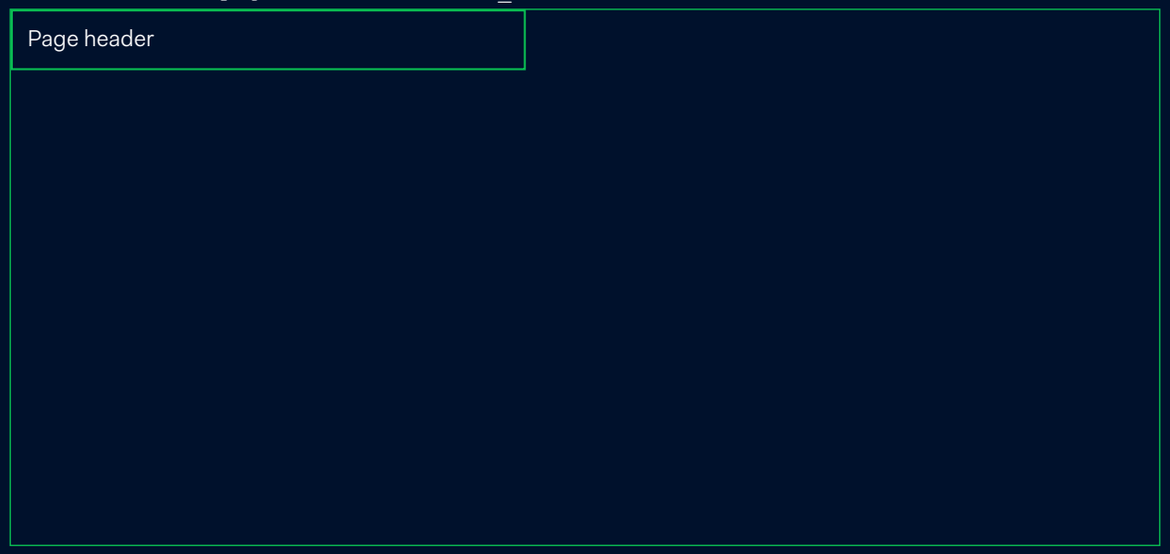


Sir David Brailsford, Team Principal, Team Sky




```
-- Establish row sizing: repeat('x', 700) produces a 704-byte varlena column.
-- Each full tuple is 744 bytes (24 header + 8 id + 704 text + 4 date + 4 alignment padding),
-- aligned to 8 bytes. With a 4-byte line pointer, each row consumes 748 bytes.
-- An 8192-byte page holds at most 10 such rows:
--   page header: 24 bytes
--   10 line pointers: 40 bytes  → pd_lower = 64
--   10 × 744 bytes of tuple data  → pd_upper = 8192 - 7440 = 752
--   free space: 752 - 64 = 688 bytes (not enough for an 11th row)
```

```
CREATE TABLE onepage (id bigint, t text, d date);
ALTER TABLE onepage SET (autovacuum_enabled = false);
```




```
-- Establish row sizing: repeat('x', 700) produces a 704-byte varlena column.
-- Each full tuple is 744 bytes (24 header + 8 id + 704 text + 4 date + 4 alignment padding),
-- aligned to 8 bytes. With a 4-byte line pointer, each row consumes 748 bytes.
-- An 8192-byte page holds at most 10 such rows:
--   page header: 24 bytes
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--   10 × 744 bytes of tuple data  → pd_upper = 8192 - 7440 = 752
--   free space: 752 - 64 = 688 bytes (not enough for an 11th row)
```
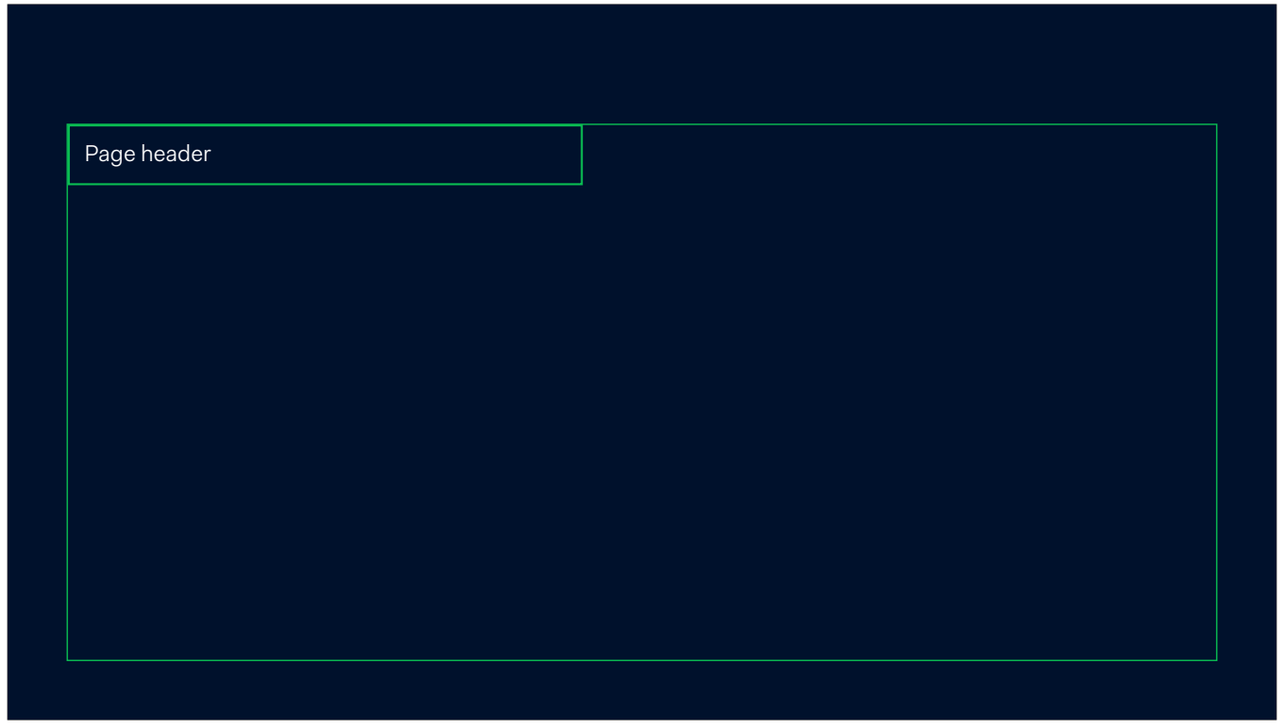
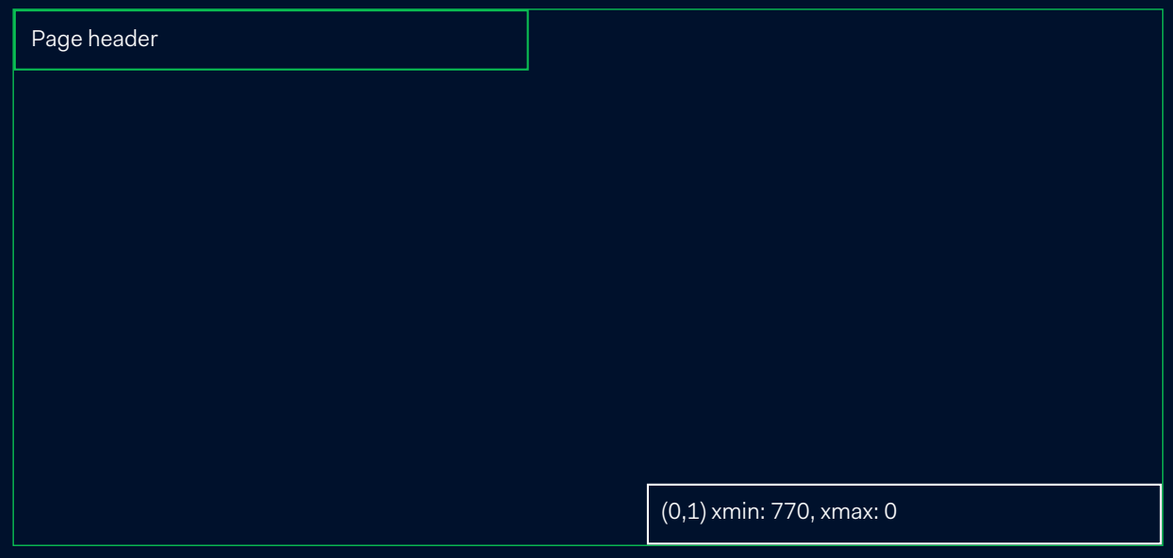

MVCC

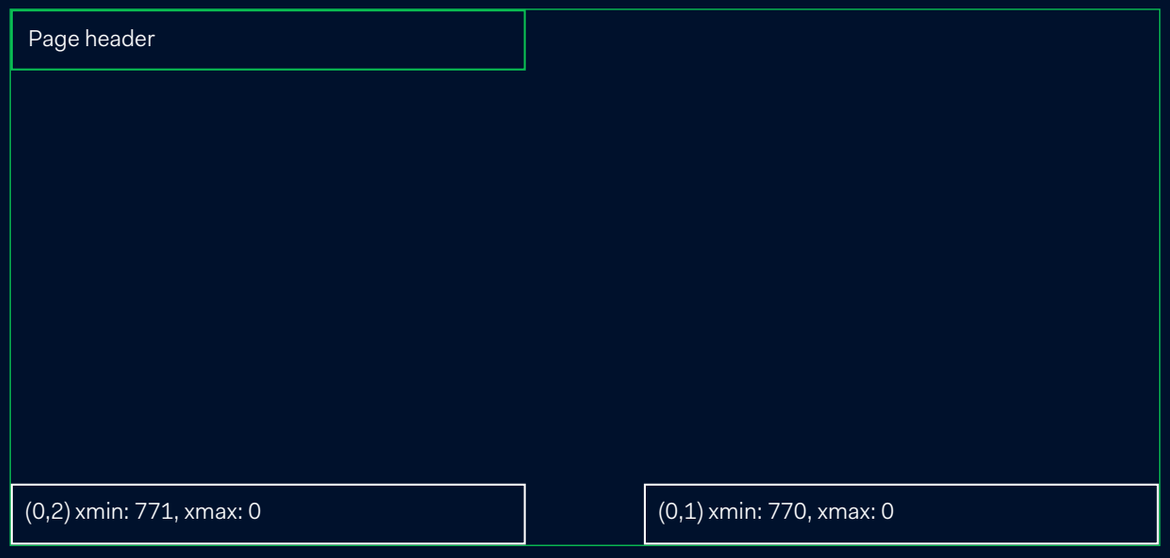

Page header

```
INSERT INTO onepage VALUES (1, repeat('x', 700), '2024-01-01');
```

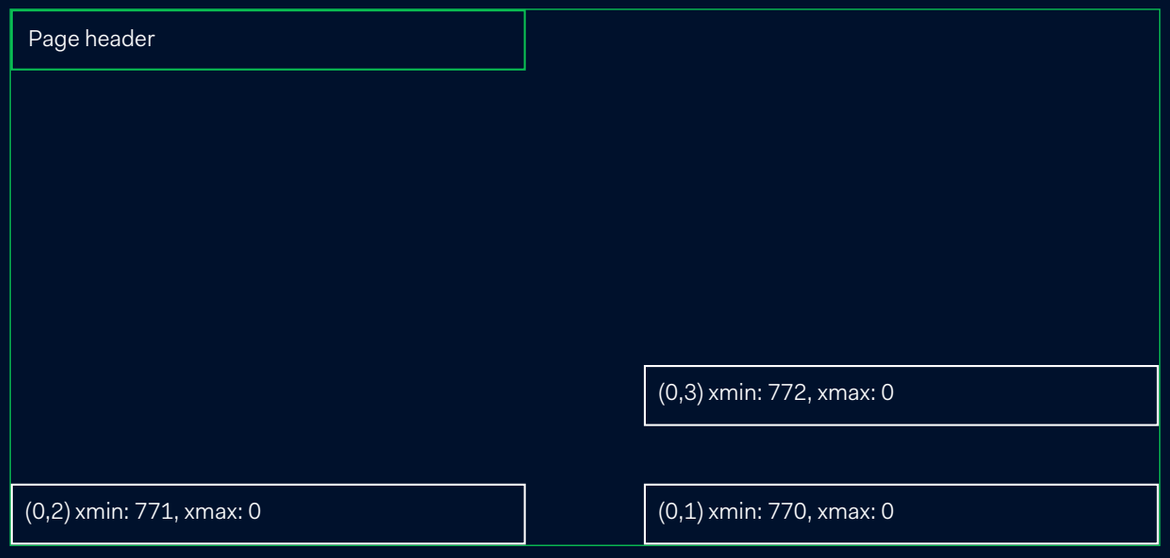



```
-- Establish row sizing: repeat('x', 700) produces a 704-byte varlena column.
-- Each full tuple is 744 bytes (24 header + 8 id + 704 text + 4 date + 4 alignment padding),
```

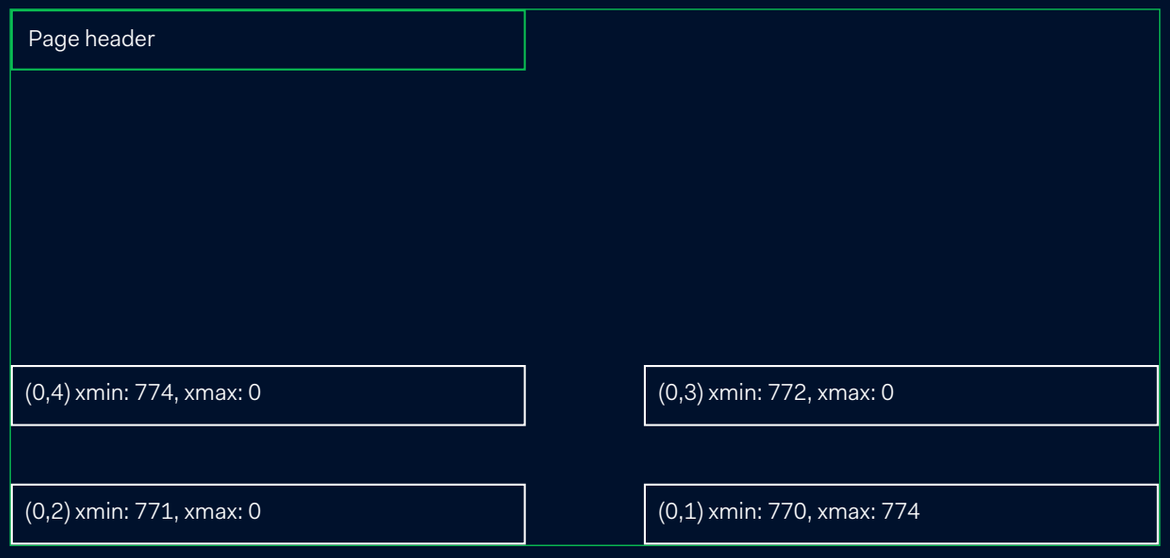
```
INSERT INTO onepage VALUES (2, repeat('x', 700), '2024-01-01');
```

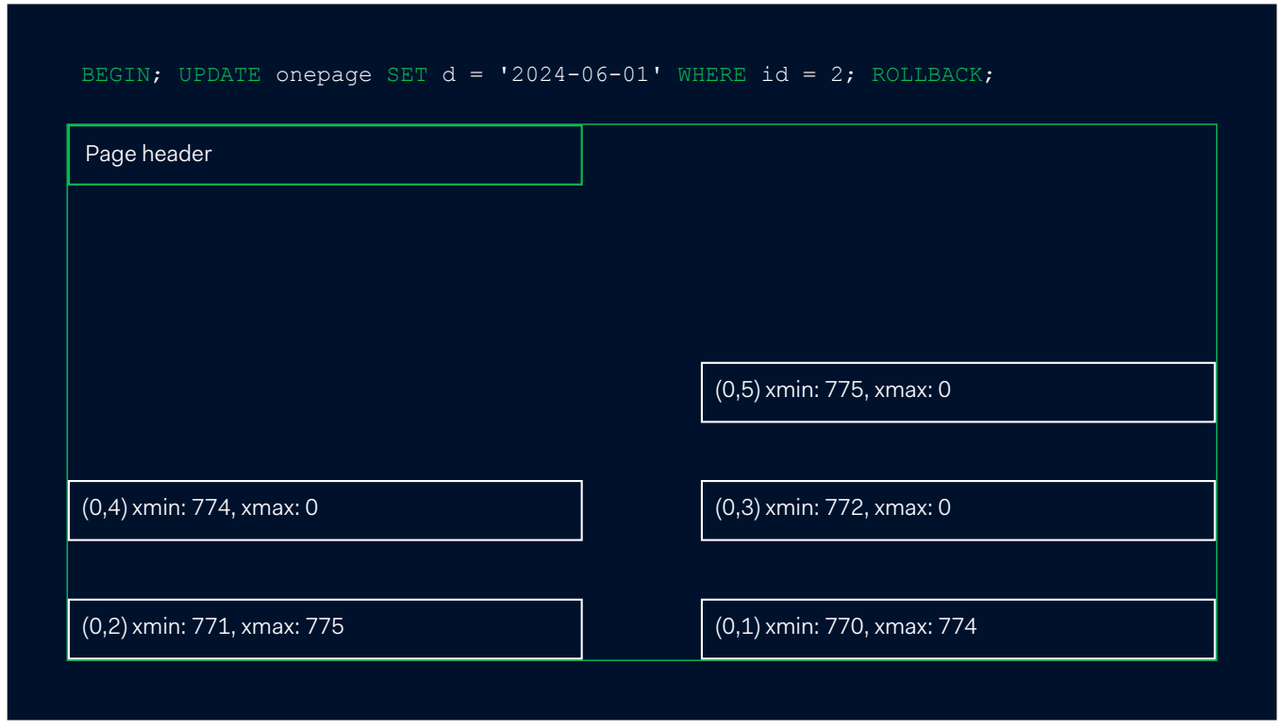


```
INSERT INTO onepage VALUES (3, repeat('x', 700), '2024-01-01');
```



```
UPDATE onepage SET d = '2024-06-01' WHERE id = 1;
```



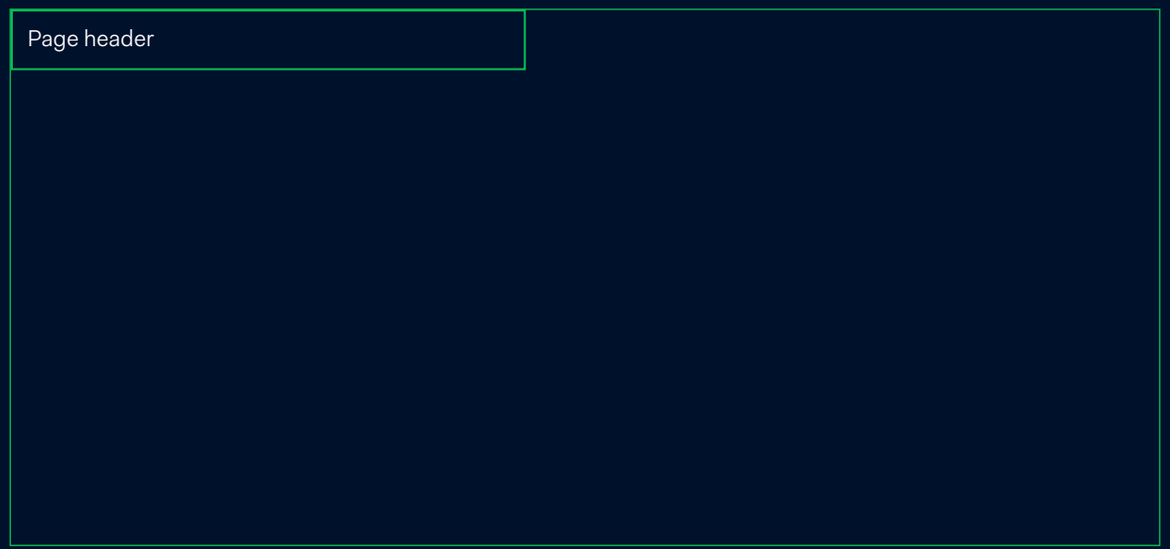


Update and abort leaves a ghost tuple. xmax of the original row is also marked as being aborted.

Why does this matter?

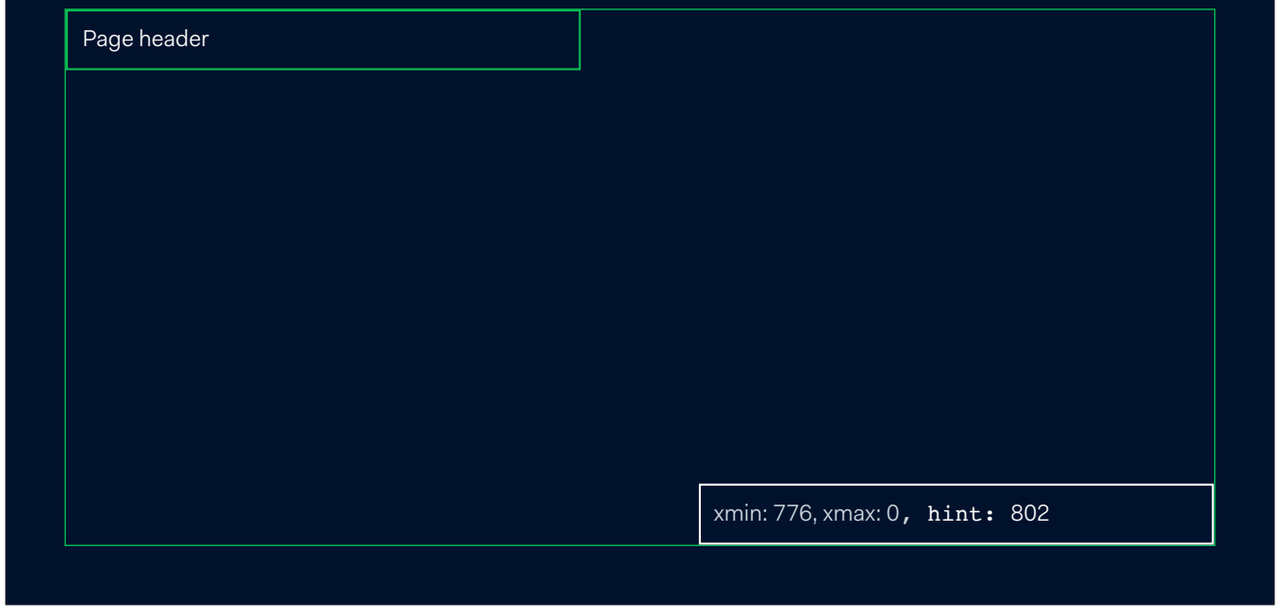
Hint bits

```
TRUNCATE onepage;
```



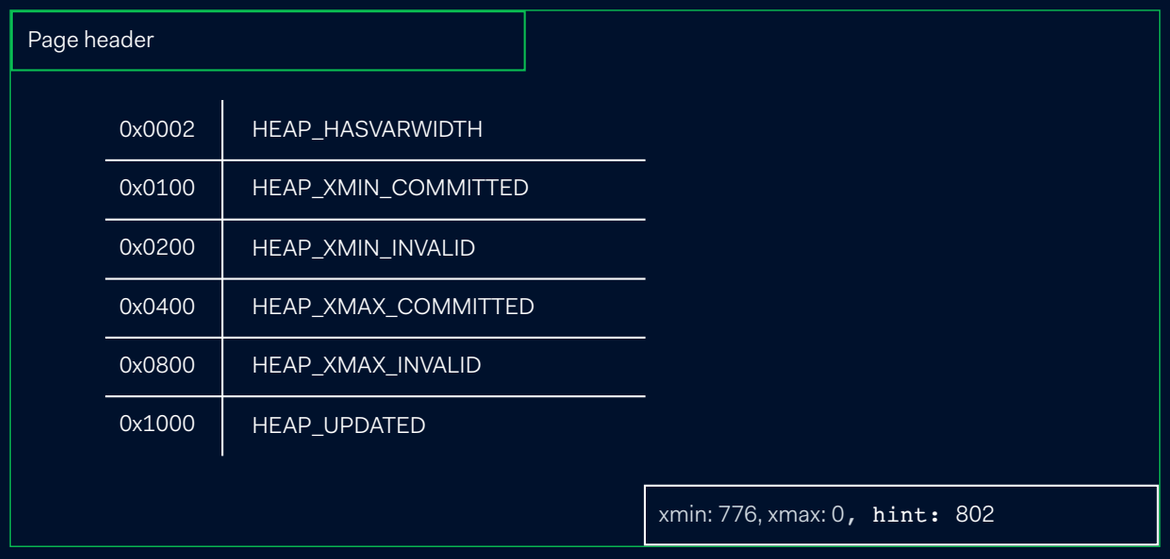
Checking whether `xmin` or `xmax` is committed requires reading the transaction status from the commit log (CLOG/pg_xact). This is a disk I/O per tuple on every visibility check — very expensive. PostgreSQL caches the result directly in the tuple's `t_infomask` field as **hint bits**, set lazily on the first read after commit.

```
INSERT INTO onepage VALUES (1, repeat('x', 700), '2024-01-01');
```

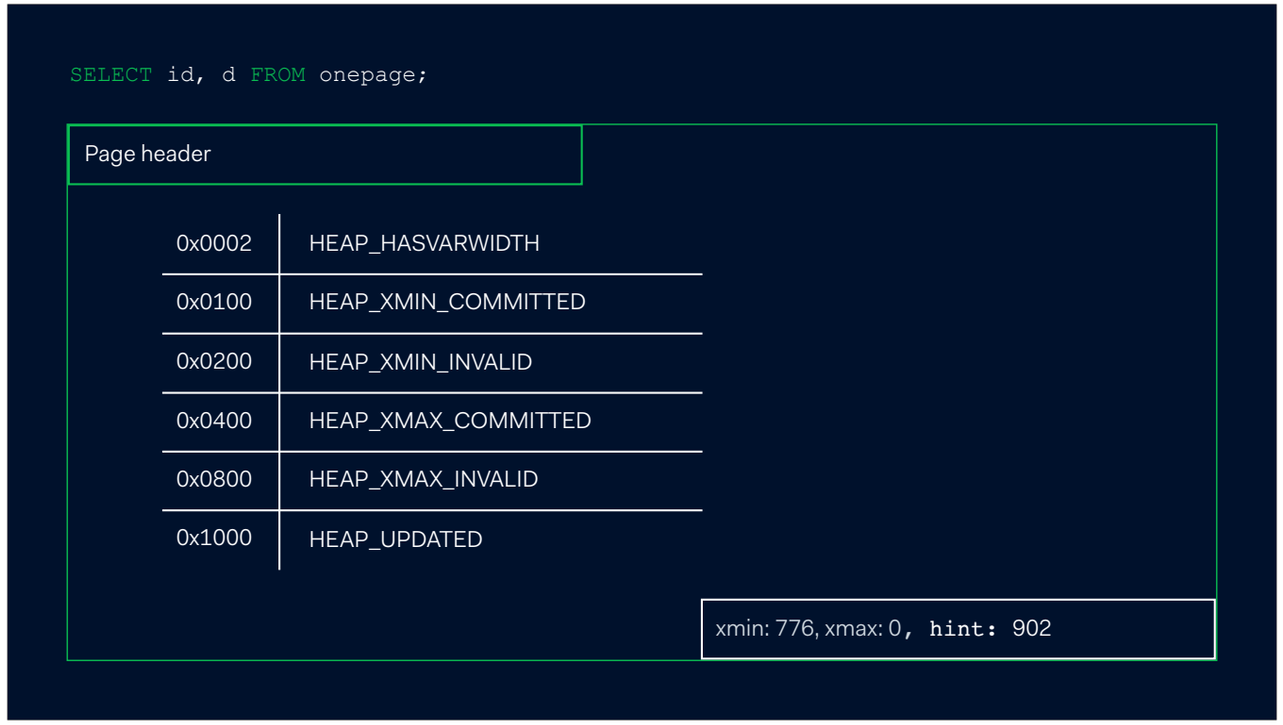


0x0002	HEAP_HASVARWIDTH
0x0100	HEAP_XMIN_COMMITTED
0x0200	HEAP_XMIN_INVALID
0x0400	HEAP_XMAX_COMMITTED
0x0800	HEAP_XMAX_INVALID
0x1000	HEAP_UPDATED

```
INSERT INTO onepage VALUES (1, repeat('x', 700), '2024-01-01');
```

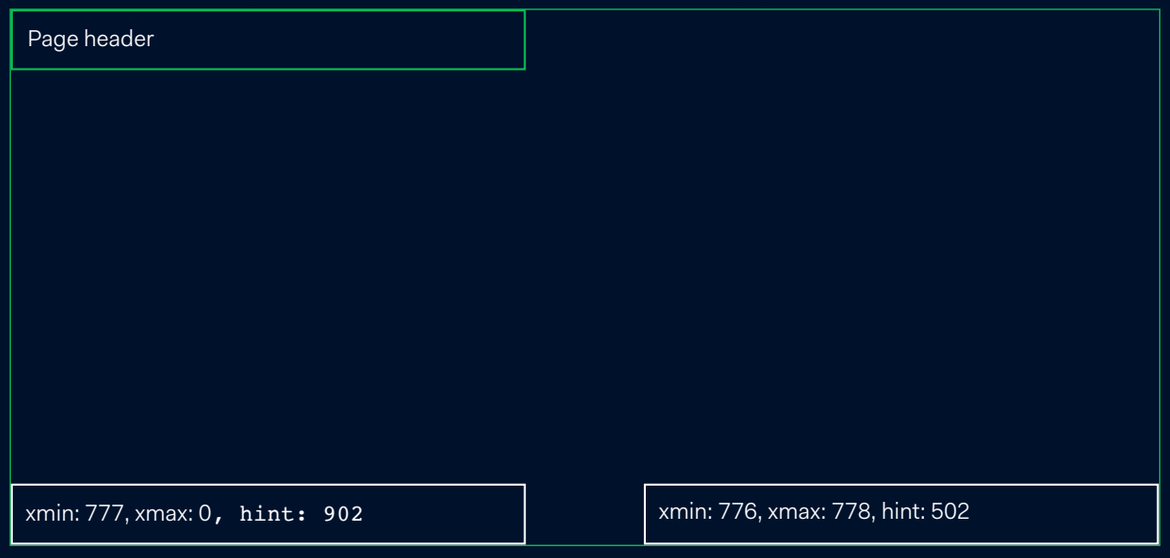


802 translates to varwidth + xmax invalid
The transaction is not listed as being committed

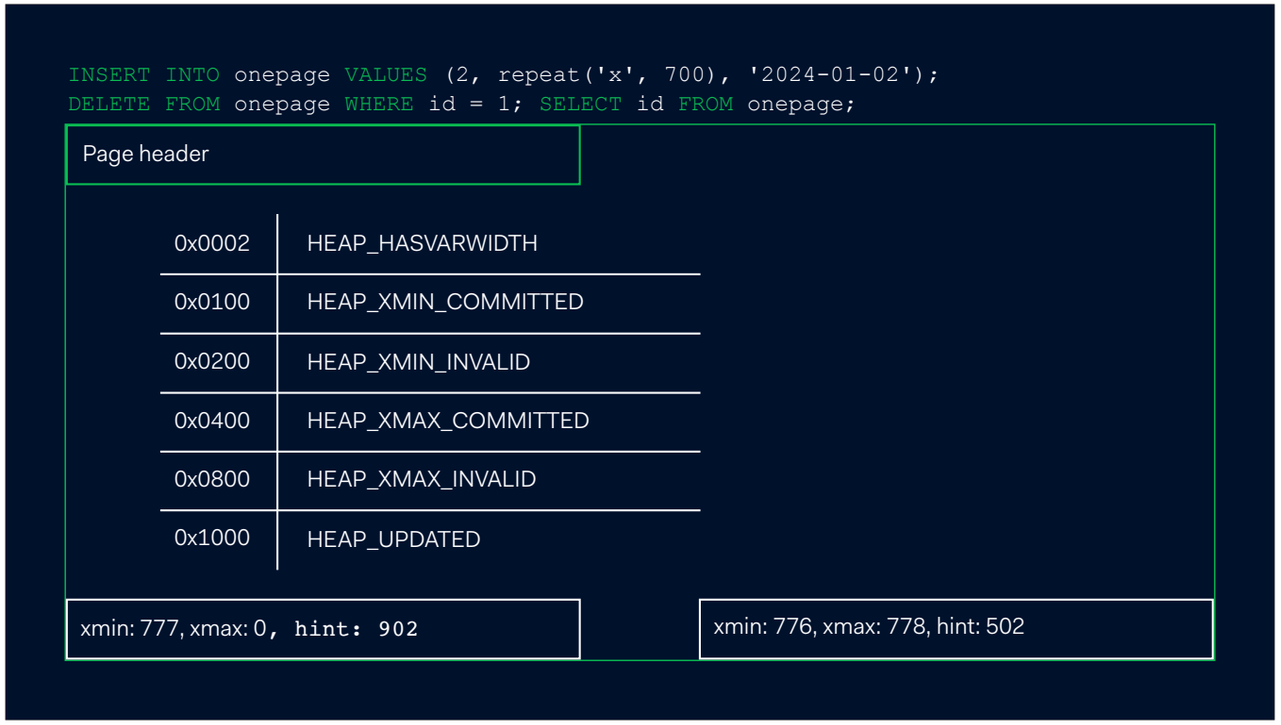


Now the hint bit is set as being committed and other transactions will rely on this information from now on.

```
INSERT INTO onepage VALUES (2, repeat('x', 700), '2024-01-02');
DELETE FROM onepage WHERE id = 1; SELECT id FROM onepage;
```



```
INSERT INTO onepage VALUES (2, repeat('x', 700), '2024-01-02');
DELETE FROM onepage WHERE id = 1; SELECT id FROM onepage;
```

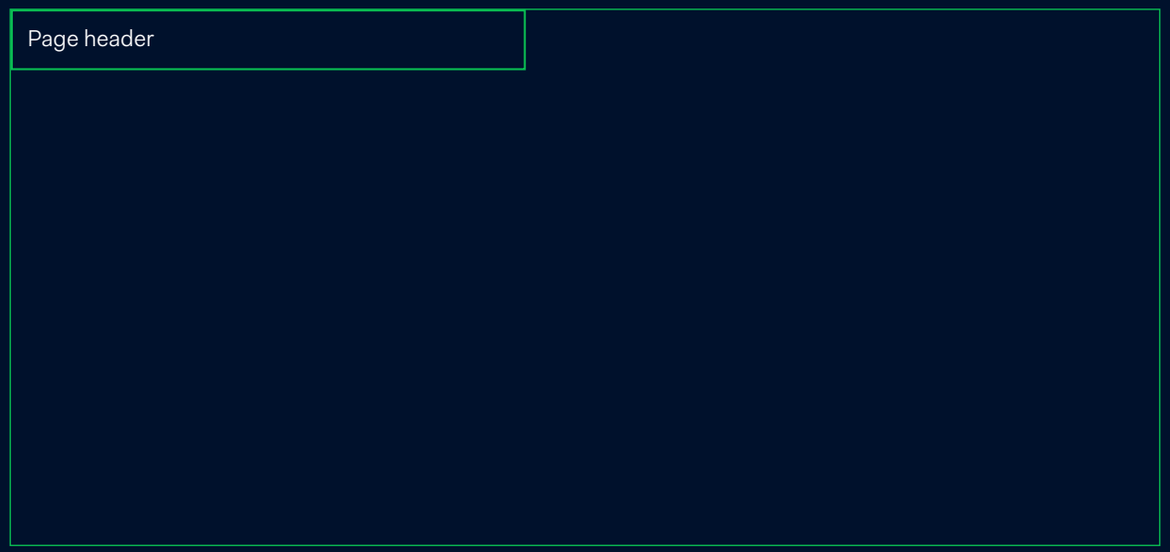


Row1 has xmin committed, xmax committed, var width
Row2 has xmin committed, xmax invalid

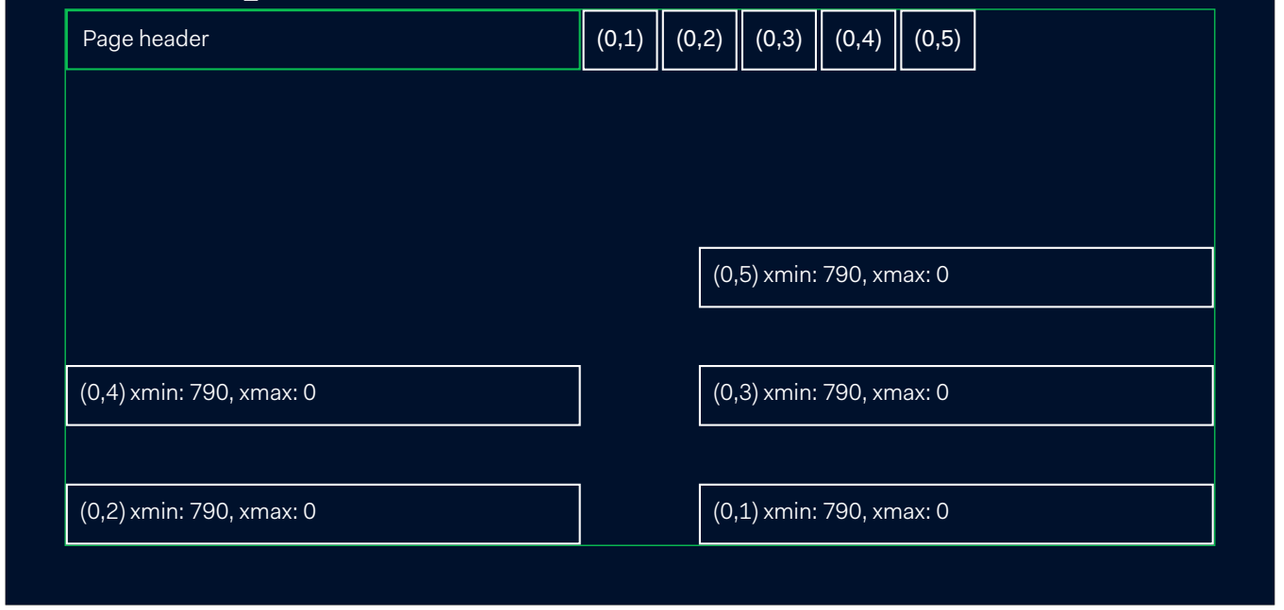
Why does this matter?

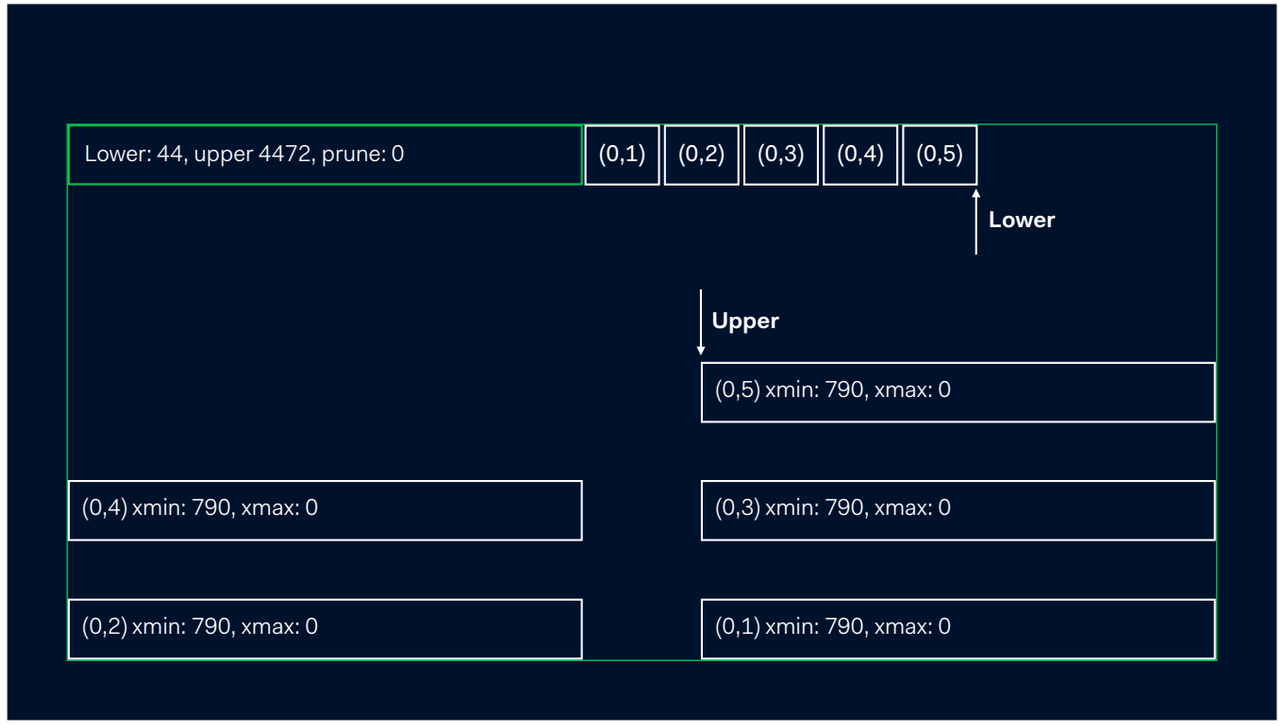
Single Page Cleanup

```
TRUNCATE onepage;
CREATE INDEX ON onepage(id);
```



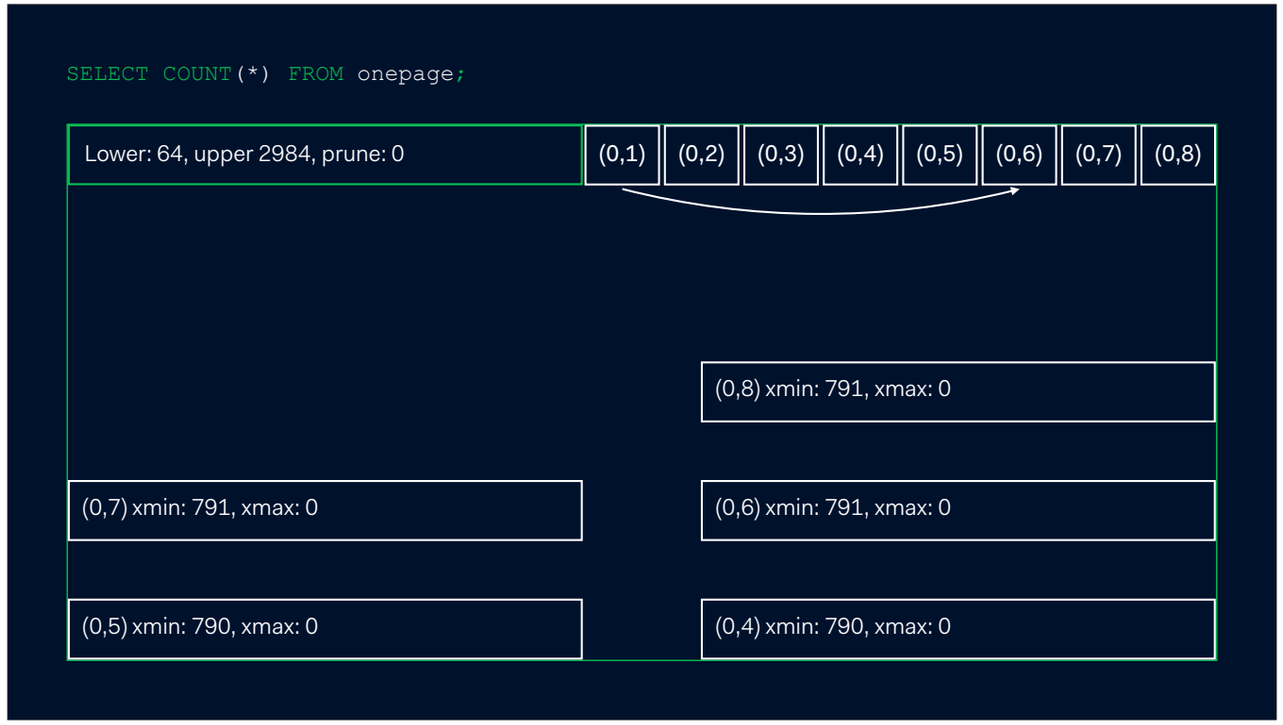
```
INSERT INTO onepage SELECT g, repeat('x', 700), '2024-01-01'::date
FROM generate_series(1, 5) g;
```



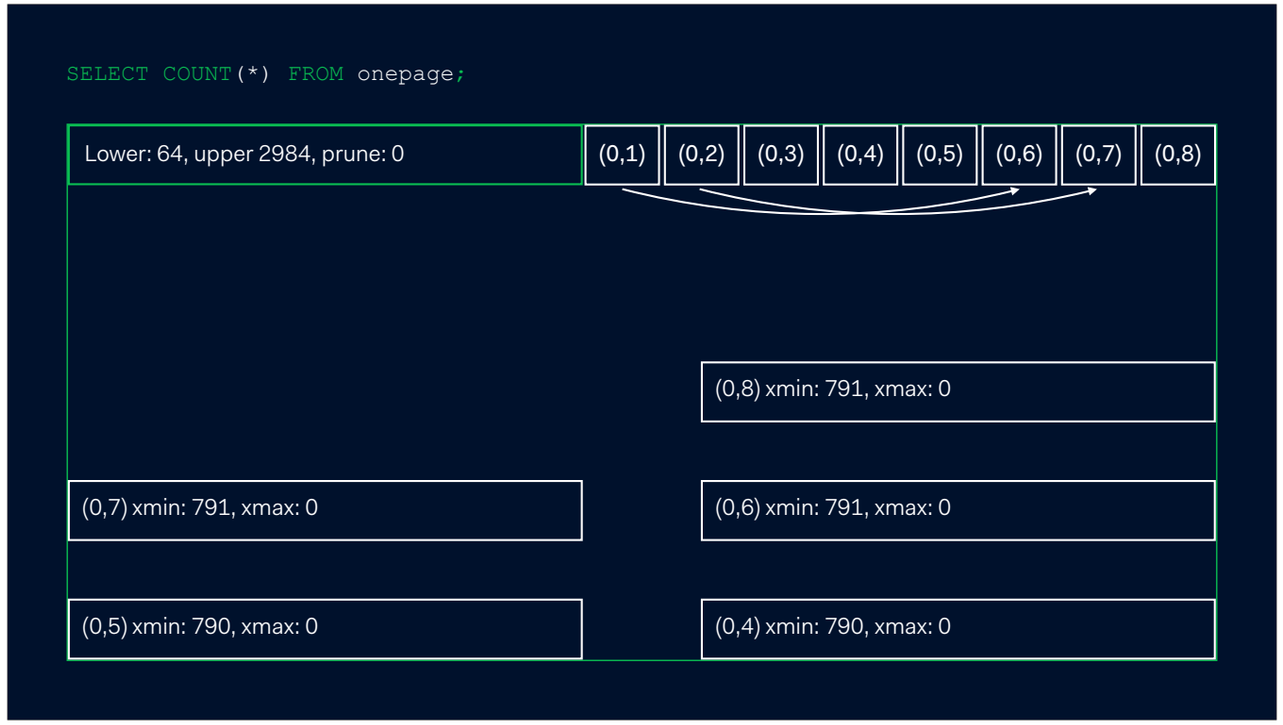


Lets take a look at the page header. It lists where the data in the page can go. We have 4472 - 44 =4.428 bytes left on this page

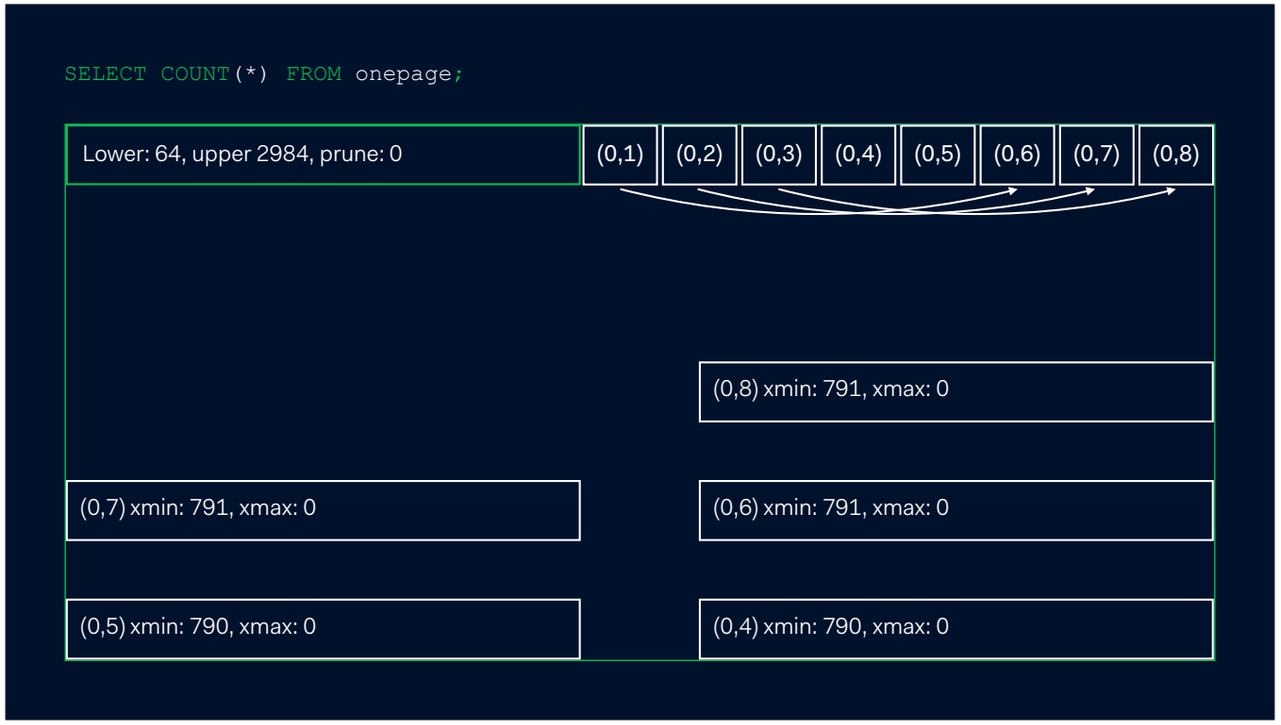
prune_txid is now set to 791, the oldest transaction id that needs information from this page.
The old versions of the updated rows still live within this page



prune_txid is now back to 0, no pruning possible



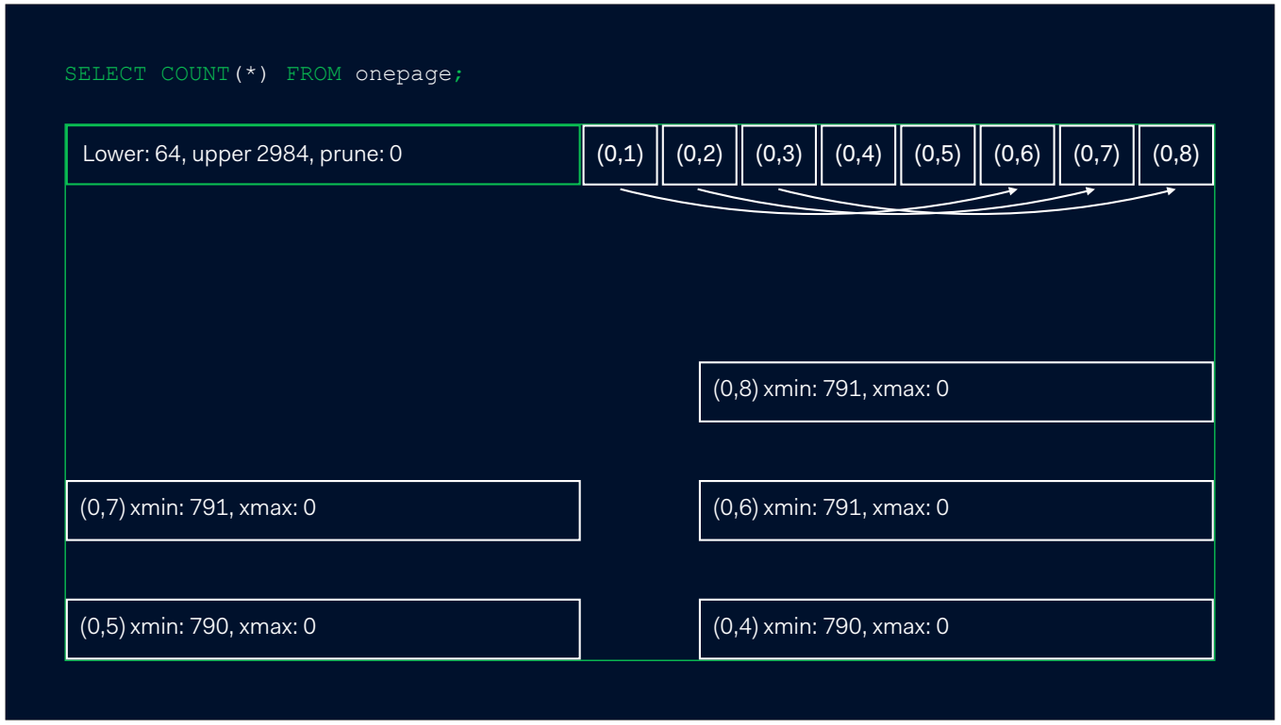
Tuple data has been removed, but line pointers remain and are not redirects to the live tuples.



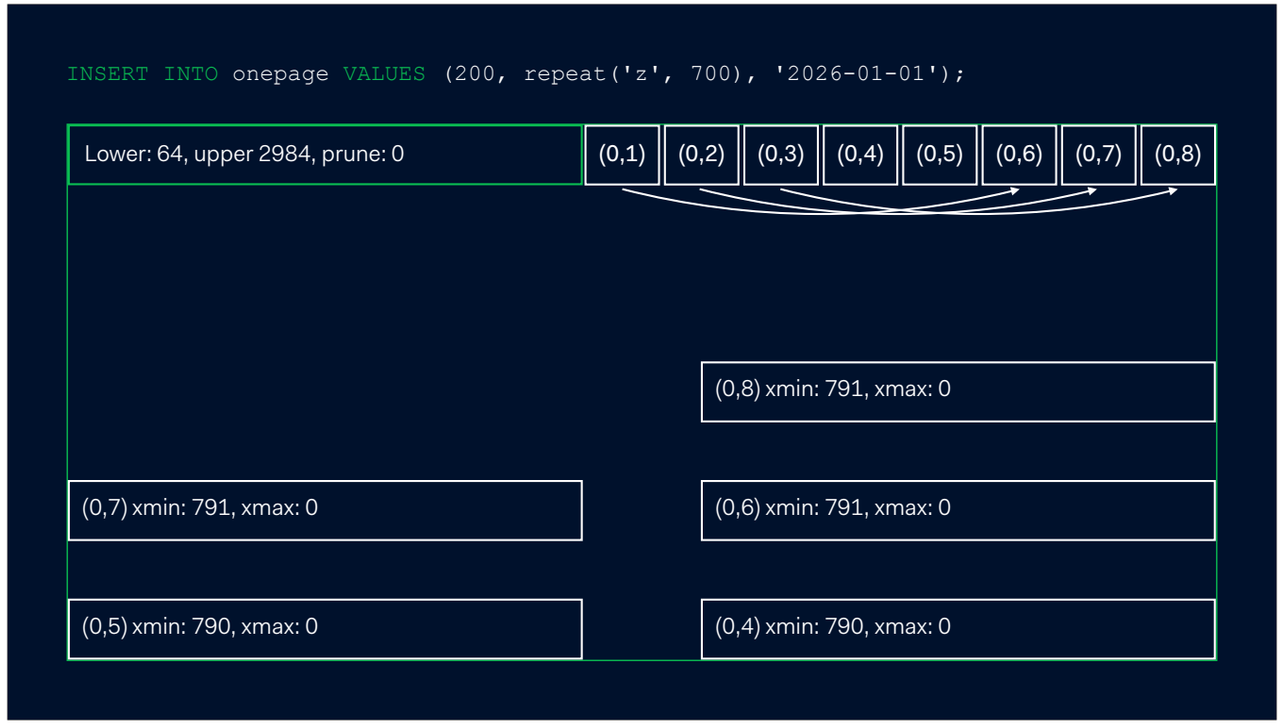
Tuple data has been removed, but line pointers remain and are not redirects to the live tuples.

Why does this matter?

Where to insert a row?



Tuple data has been removed, but line pointers remain and are now redirects to the live tuples.



Where to insert the next incoming row —> didn't arrive at this page.
Logic for where to insert is based on the free space map. The free space map is usually not updated on Single Page Cleanup.

```
VACUUM onepage;
INSERT INTO onepage VALUES (300, repeat('z', 700), '2026-06-01');
```

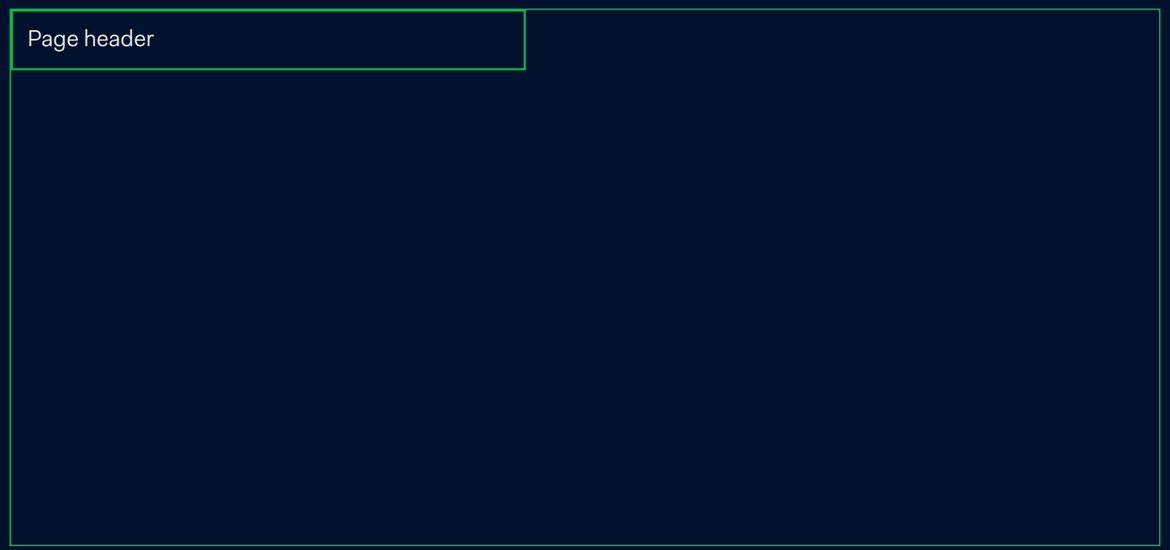
Where to insert the next incoming row —> didn't arrive at this page.
Logic for where to insert is based on the free space map. The free space map is usually not updated on Single Page Cleanup.

TODO: when does pruning update FSM
get confirmation on lp cleanup
Update lower and upper and prune values.

Why does this matter?

Fillfactor

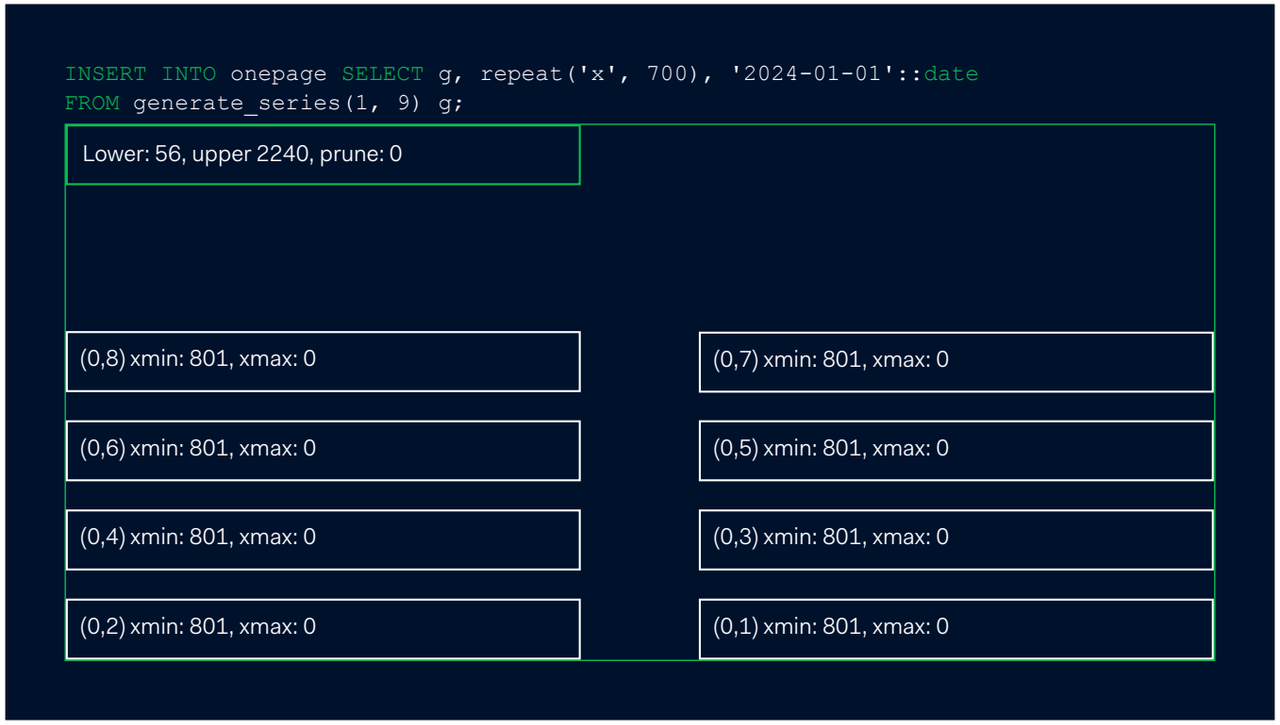
```
TRUNCATE onepage; DROP INDEX onepage_id_idx;
ALTER TABLE onepage SET (fillfactor = 75);
```



With fillfactor=75, PostgreSQL reserves 25% of each page for updates. Threshold calculation:

Available space: 8192 bytes
Reserved: 8192 × 25% = 2048 bytes minimum free space required after each INSERT
A new row needs: 748 bytes (4 LP + 744 tuple)
After 7 rows: free = 8168 – (7 × 748) = 2932 bytes → check: 2932 – 748 = 2184 ≥ 2048 → row 8 fits
After 8 rows: free = 8168 – (8 × 748) = 2184 bytes → check: 2184 – 748 = 1436 < 2048 → row 9 does NOT fit on page 0

```
INSERT INTO onepage SELECT g, repeat('x', 700), '2024-01-01'::date
FROM generate_series(1, 9) g;
```



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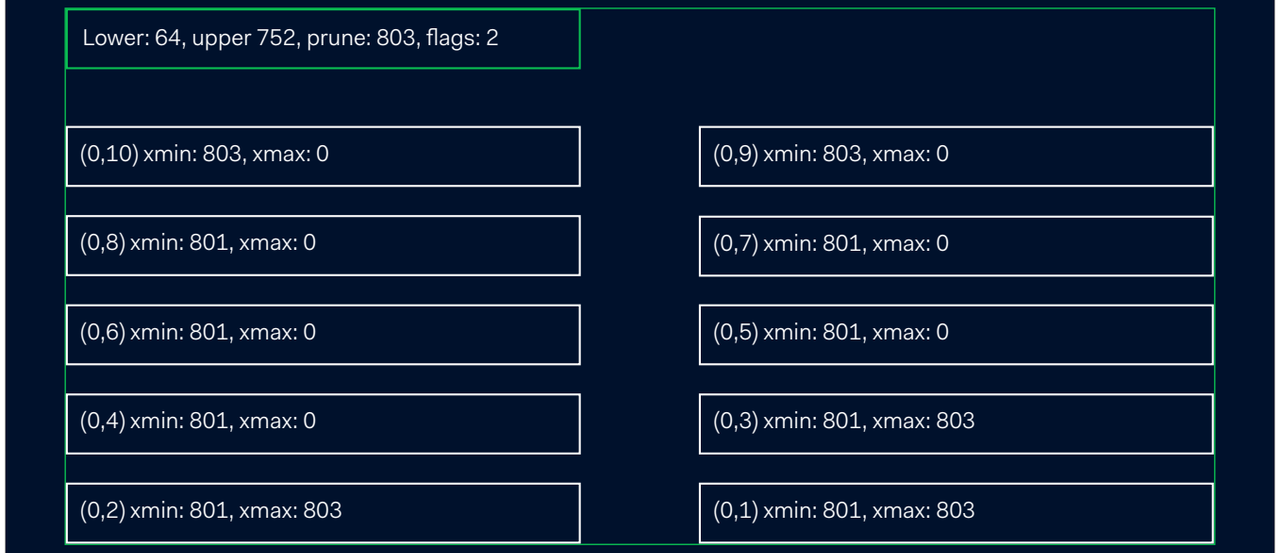
```
CREATE INDEX onepage_id_idx ON onepage(id);
UPDATE onepage SET d = '2025-06-01' WHERE id IN (1, 2,3);
```



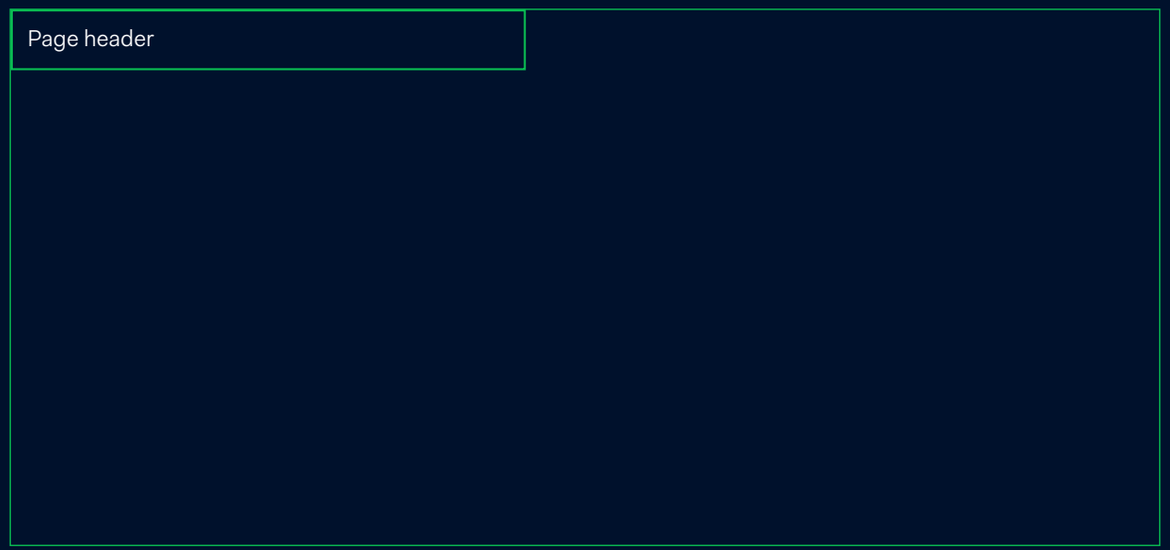
Flags 2: page full
The third update went to page 1, didn't fit this page anymore
Free space = 752 - 64 = 688; doesn't fit a 744 wide row.

This page only contains two new rows, the third row went to page 1.

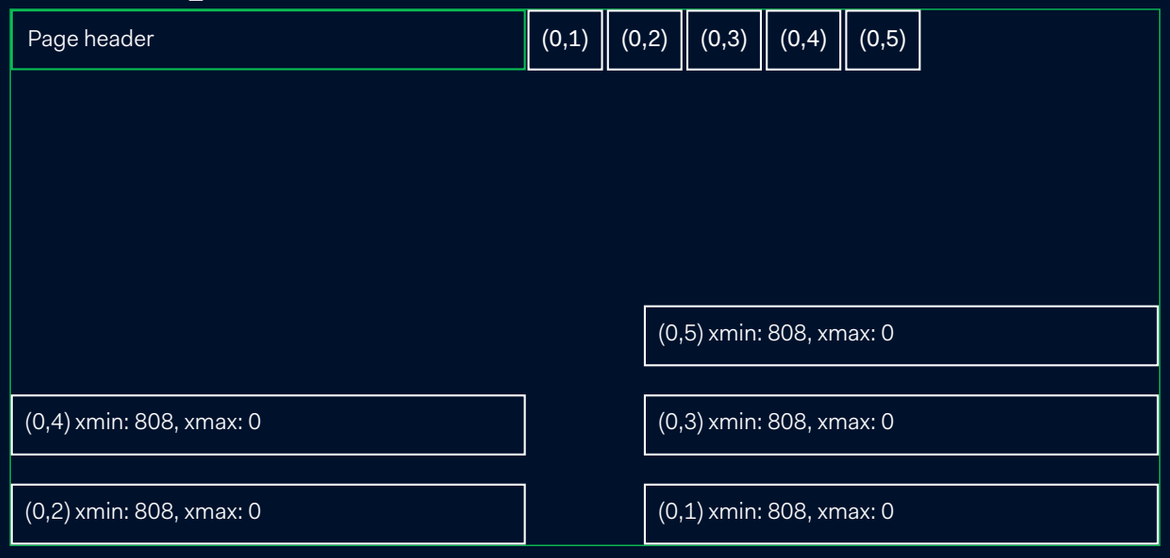
Why does this matter?

HOT Updates

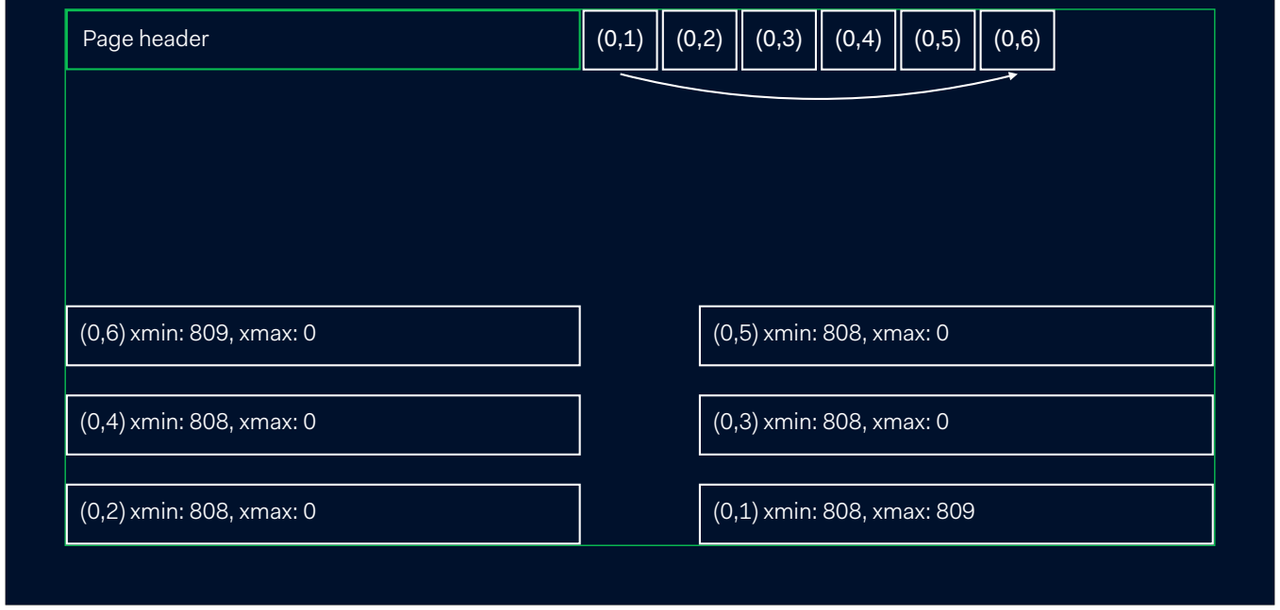
```
TRUNCATE onepage;
-- Fillfactor and index remain
```



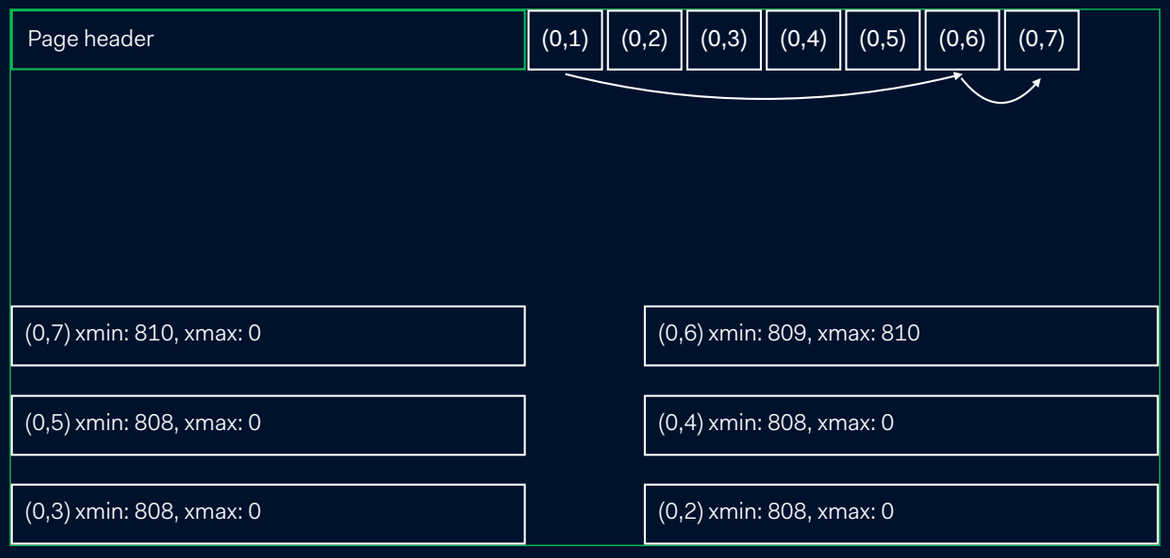
```
INSERT INTO onepage SELECT g, repeat('x', 700), '2024-01-01'::date
FROM generate_series(1, 5) g;
```



```
UPDATE onepage SET d = '2024-06-01' WHERE id = 1;
```



```
UPDATE onepage SET d = '2024-12-01' WHERE id = 1;
```

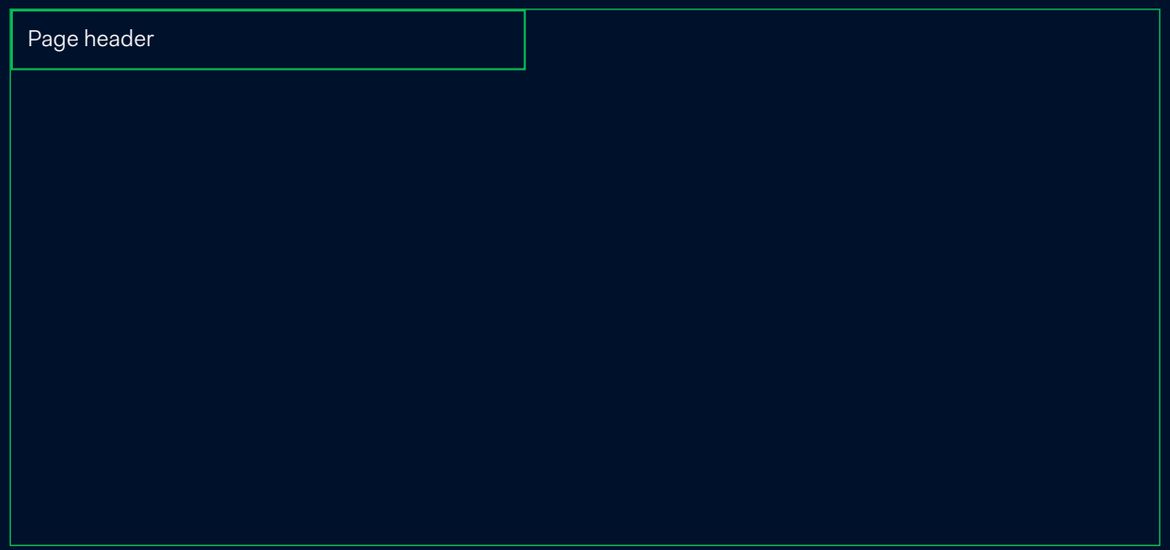


No index changes on the updates, no requirement to vacuum the index!
Number of pages changed for a single row with 10 indexes with and without HOT update
Impact of the fillfactor

Why does this matter?

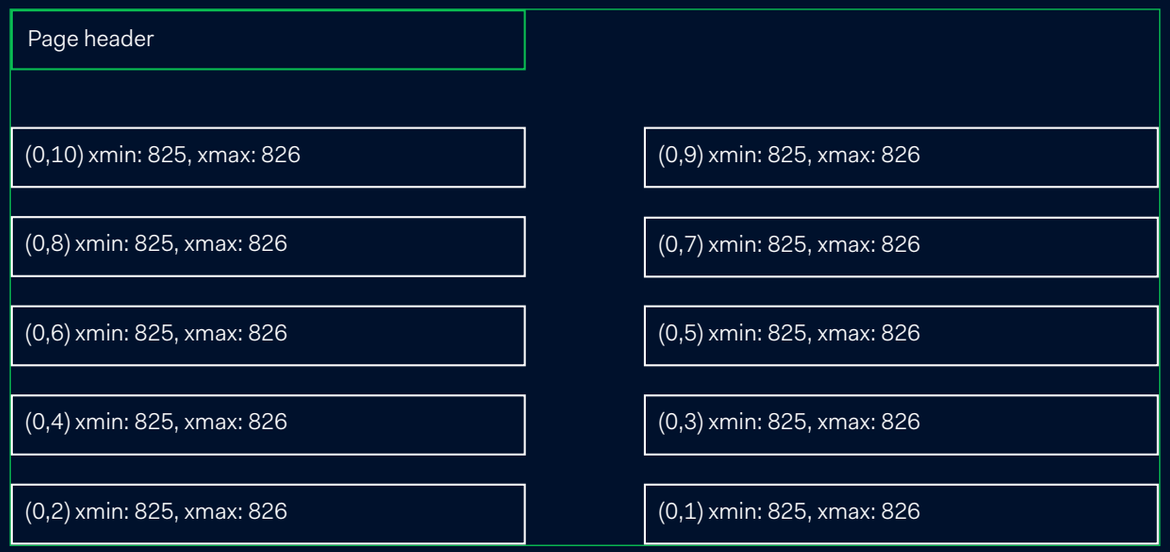
Dead rows vs bloat

```
TRUNCATE onepage; DROP INDEX onepage_id_idx;
ALTER TABLE onepage SET (fillfactor = 100);
```



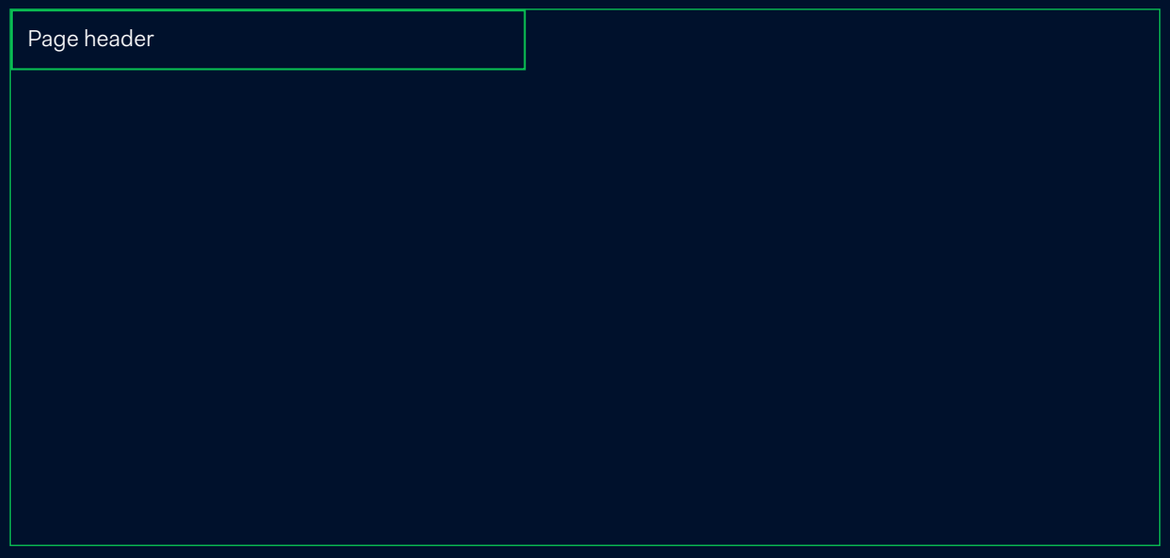
```
INSERT INTO onepage SELECT g, repeat('x', 700), '2024-01-01'::date FROM
generate_series(1,10) g;
```

```
UPDATE onepage SET d = '2025-01-01';
UPDATE onepage SET d = '2026-01-01';
```



Now the page has 10 dead rows, a row where xmax has been set;

```
SELECT * FROM onepage;
```



Now the page has 10 dead rows, a row where xmax has been set;

Page header

```
SELECT n_live_tup, n_dead_tup FROM pg_stat_user_tables
WHERE relname = 'onepage';
 n_live_tup | n_dead_tup
------------+------------
         10 |          20

SELECT pg_size_pretty(pg_relation_size('onepage'));
 pg_size_pretty
----------------
 24 kB
```

Now the page has 10 dead rows, a row where xmax has been set;

```
VACUUM onepage;
```

Page header

```
SELECT n_live_tup, n_dead_tup FROM pg_stat_user_tables
WHERE relname = 'onepage';
 n_live_tup | n_dead_tup
------------+------------
         10 |          0

SELECT pg_size_pretty(pg_relation_size('onepage'));
 pg_size_pretty
----------------
 24 kB
```

Now vacuum brings the table size back to 1 page! No need to run vacuum full.

```
UPDATE onepage SET d = '2026-04-21';
```

The next update moves all rows back to my first page

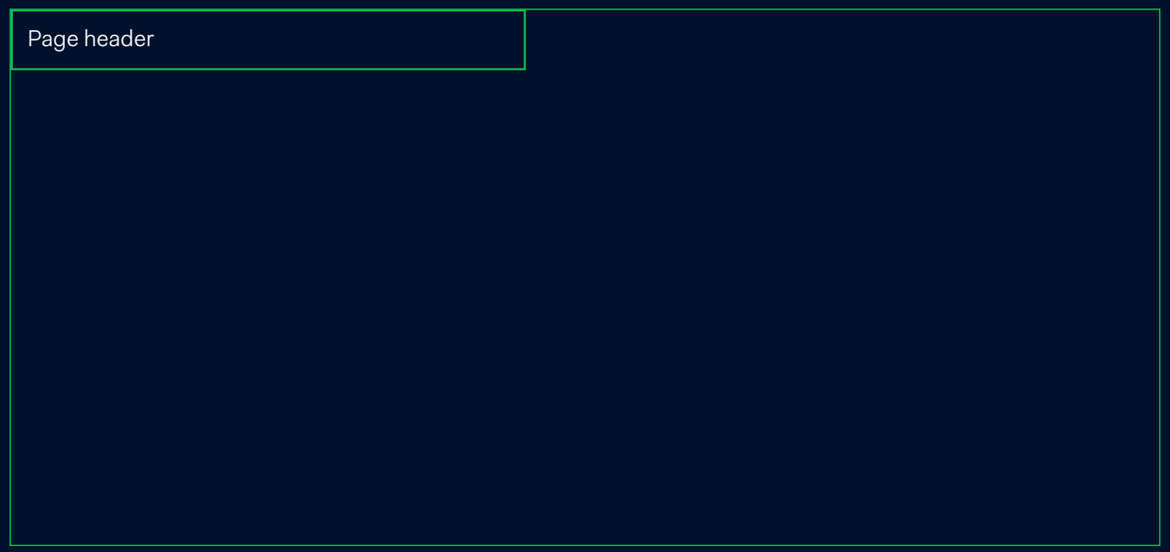
```
VACUUM onepage;
```

Page header

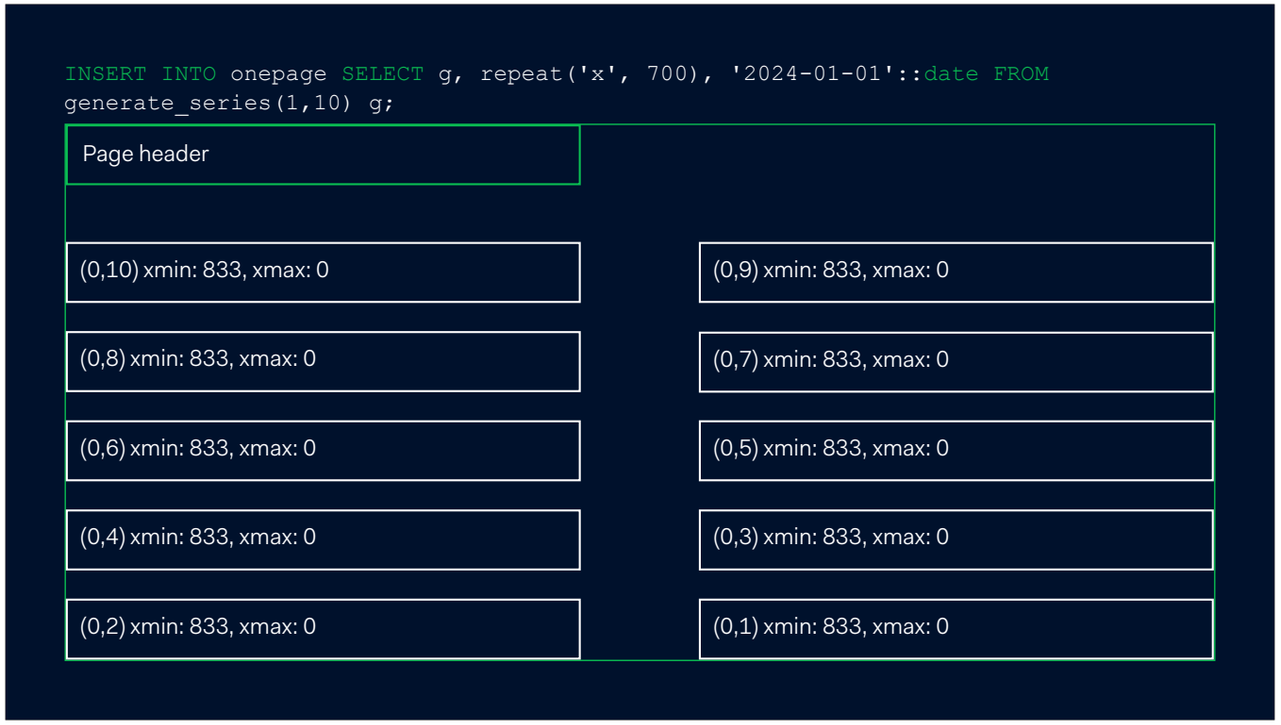
```
SELECT n_live_tup, n_dead_tup FROM pg_stat_user_tables
WHERE relname = 'onepage';
 n_live_tup | n_dead_tup
------------+------------
         10 |          0

SELECT pg_size_pretty(pg_relation_size('onepage'));
 pg_size_pretty
----------------
 8192 bytes
```

Now vacuum brings the table size back to 1 page! No need to run vacuum full.

```
TRUNCATE onepage;
```



```
INSERT INTO onepage SELECT g, repeat('x', 700), '2024-01-01'::date FROM
generate_series(1,10) g;
```



```
UPDATE onepage SET d = '2025-01-01';
UPDATE onepage SET d = '2026-01-01';
```

Now the page has 10 dead rows, a row where xmax has been set;

```
DELETE FROM onepage;
```

Page header

```
SELECT n_live_tup, n_dead_tup FROM pg_stat_user_tables
WHERE relname = 'onepage';
 n_live_tup | n_dead_tup
------------+------------
          0 |          30

SELECT pg_size_pretty(pg_relation_size('onepage'));
 pg_size_pretty
----------------
 24 kB
```

Now the page has 10 dead rows, a row where xmax has been set;

Why does this matter?

Adding small gains for maximum results

adyen

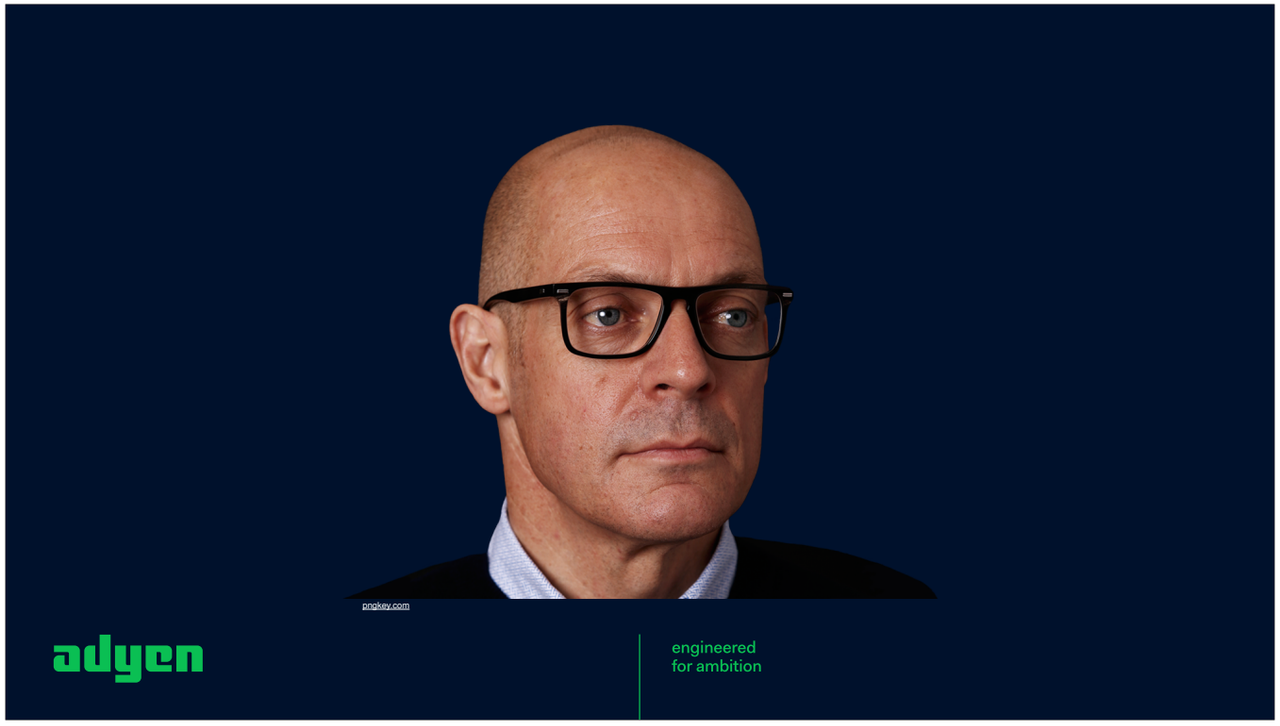
engineered
for ambition


Operational hazards of
managing PostgreSQL
DBs over 100TB

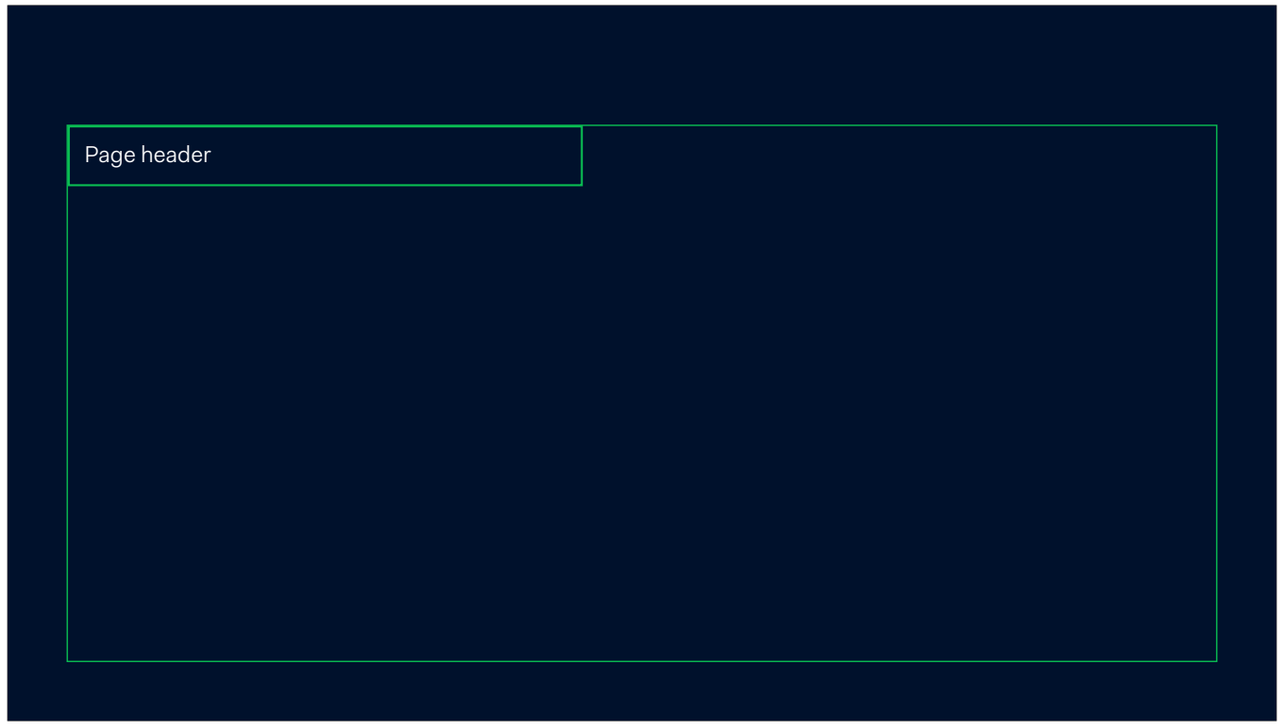
Adding small gains for maximum results

adyen

engineered
for ambition

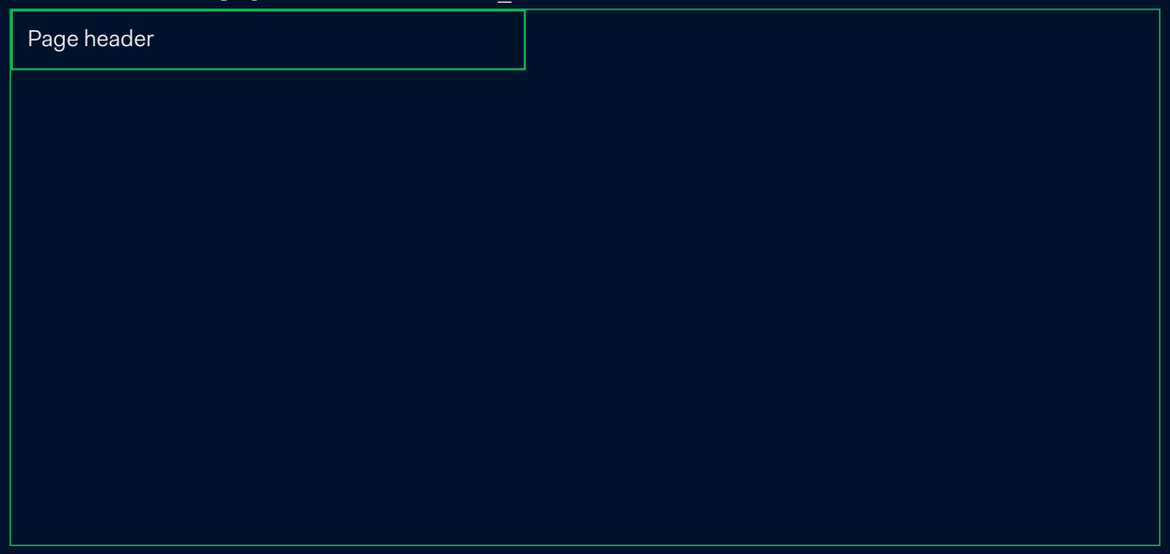


Sir David Brailsford, Team Principal, Team Sky



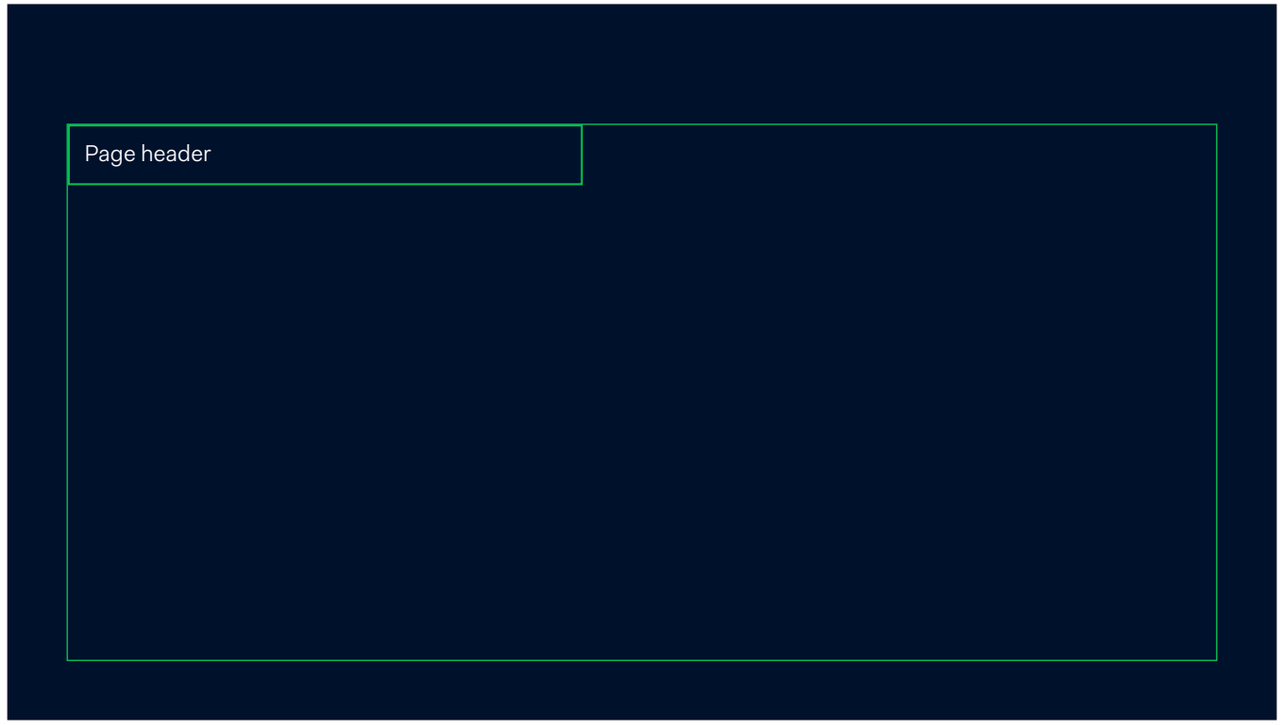

```
-- Establish row sizing: repeat('x', 700) produces a 704-byte varlena column.
-- Each full tuple is 744 bytes (24 header + 8 id + 704 text + 4 date + 4 alignment padding),
-- aligned to 8 bytes. With a 4-byte line pointer, each row consumes 748 bytes.
-- An 8192-byte page holds at most 10 such rows:
--   page header: 24 bytes
--   10 line pointers: 40 bytes  → pd_lower = 64
--   10 × 744 bytes of tuple data  → pd_upper = 8192 - 7440 = 752
--   free space: 752 - 64 = 688 bytes (not enough for an 11th row)
```

```
CREATE TABLE onepage (id bigint, t text, d date);
ALTER TABLE onepage SET (autovacuum_enabled = false);
```

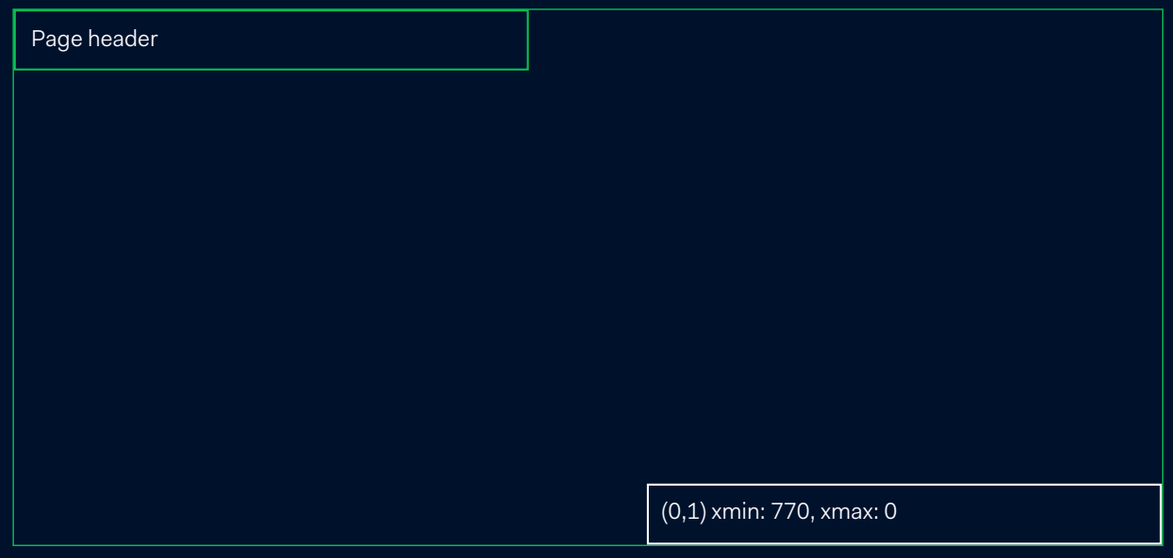



```
-- Establish row sizing: repeat('x', 700) produces a 704-byte varlena column.
-- Each full tuple is 744 bytes (24 header + 8 id + 704 text + 4 date + 4 alignment padding),
-- aligned to 8 bytes. With a 4-byte line pointer, each row consumes 748 bytes.
-- An 8192-byte page holds at most 10 such rows:
--   page header: 24 bytes
--   10 line pointers: 40 bytes  → pd_lower = 64
--   10 × 744 bytes of tuple data  → pd_upper = 8192 - 7440 = 752
--   free space: 752 - 64 = 688 bytes (not enough for an 11th row)
```

MVCC

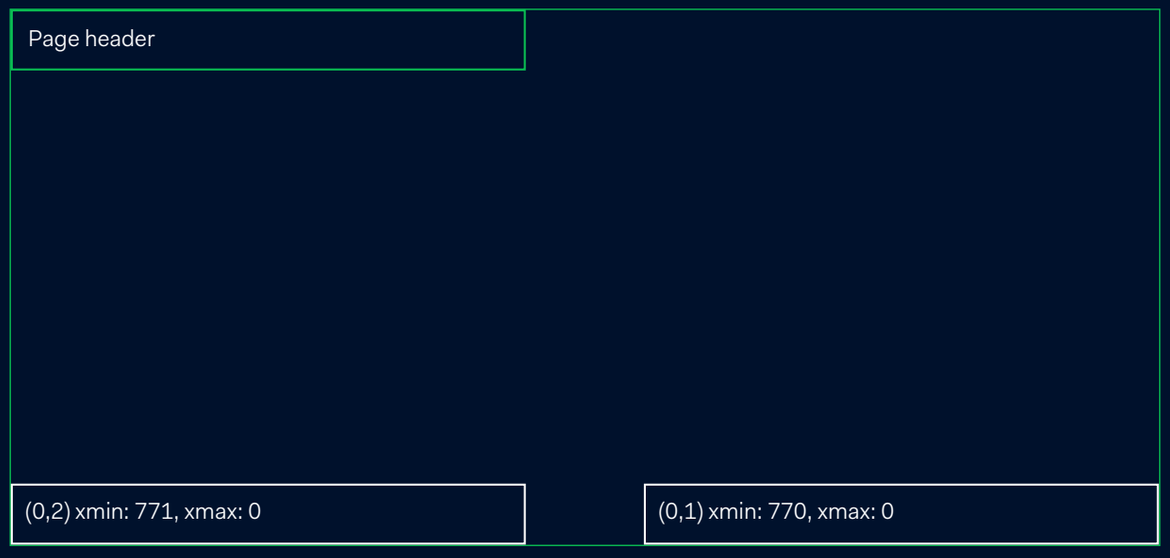

Page header

```
INSERT INTO onepage VALUES (1, repeat('x', 700), '2024-01-01');
```

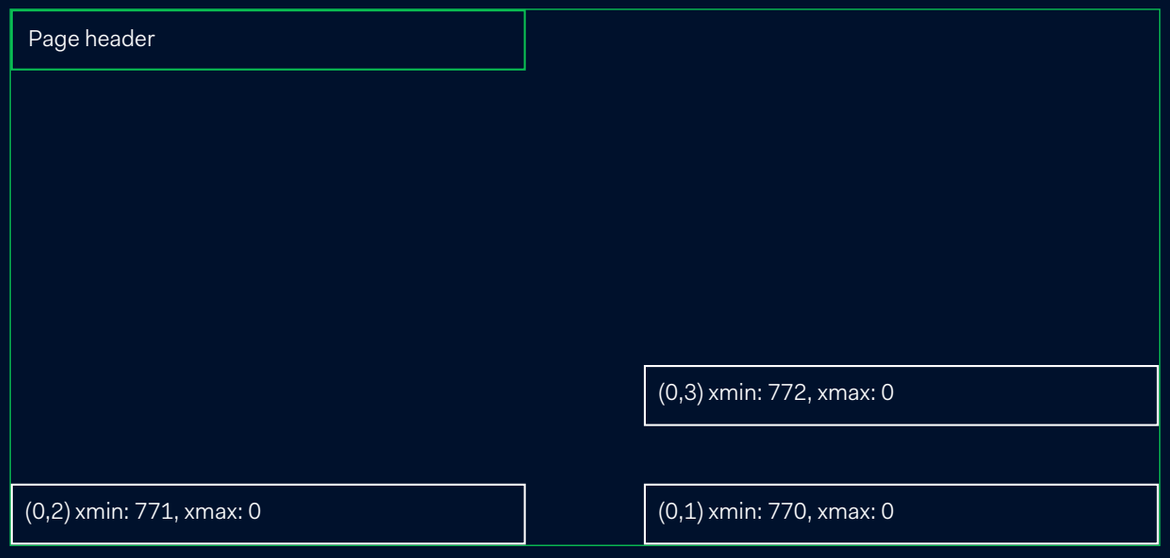



```
-- Establish row sizing: repeat('x', 700) produces a 704-byte varlena column.
-- Each full tuple is 744 bytes (24 header + 8 id + 704 text + 4 date + 4 alignment padding),
```

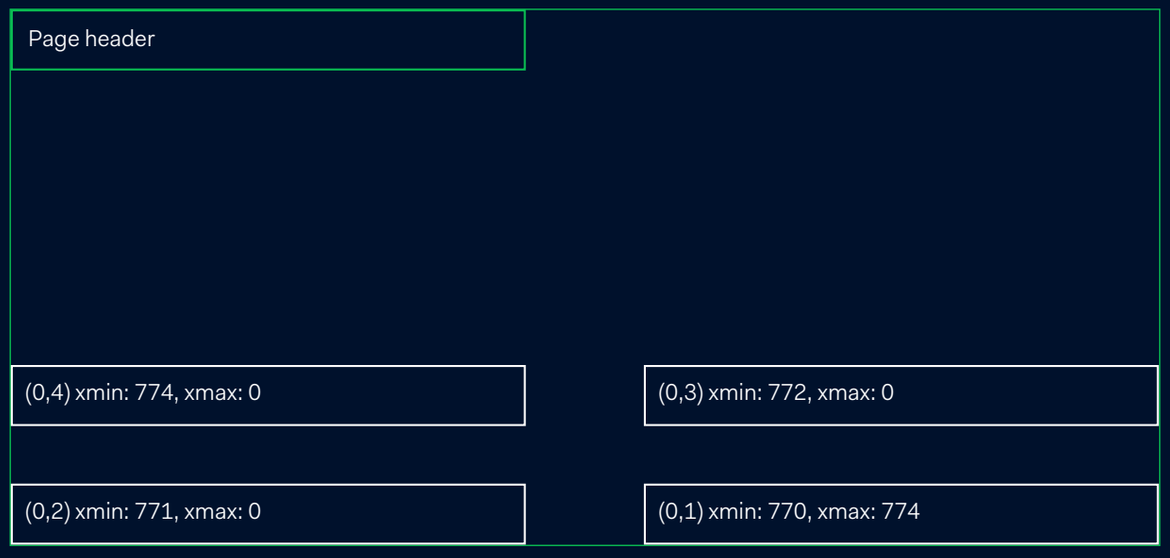
```
INSERT INTO onepage VALUES (2, repeat('x', 700), '2024-01-01');
```

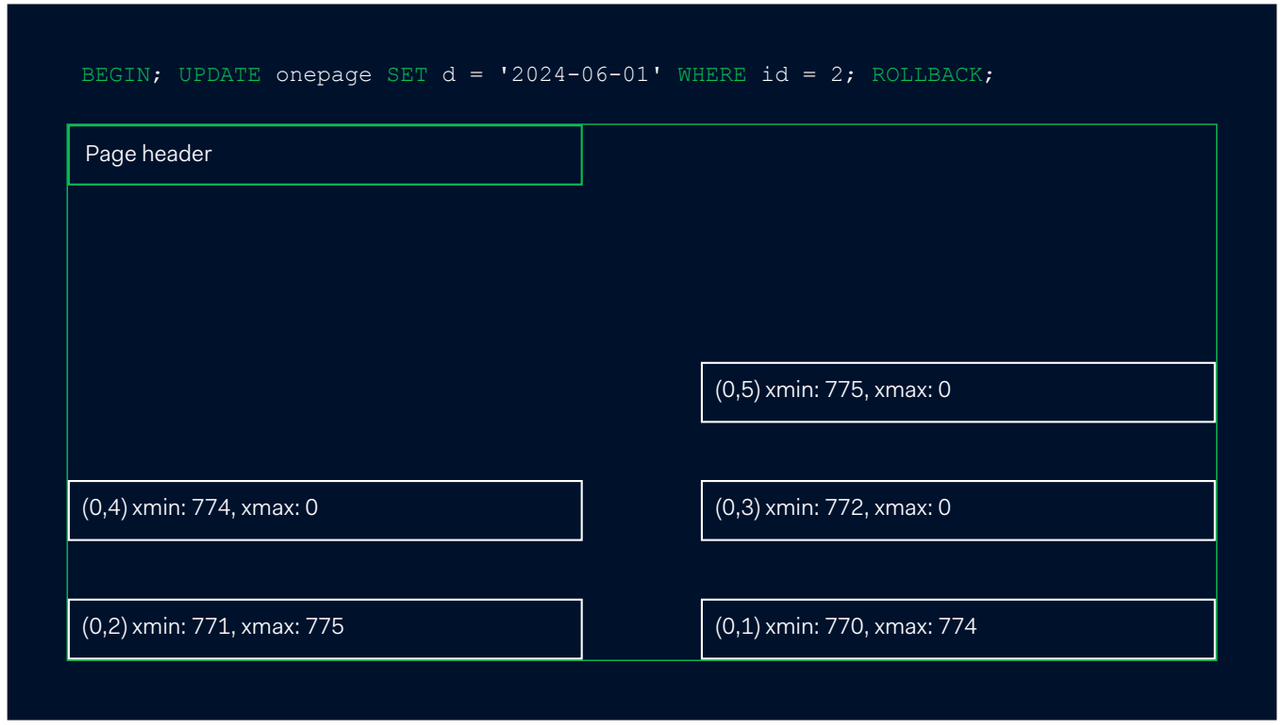


```
INSERT INTO onepage VALUES (3, repeat('x', 700), '2024-01-01');
```



```
UPDATE onepage SET d = '2024-06-01' WHERE id = 1;
```



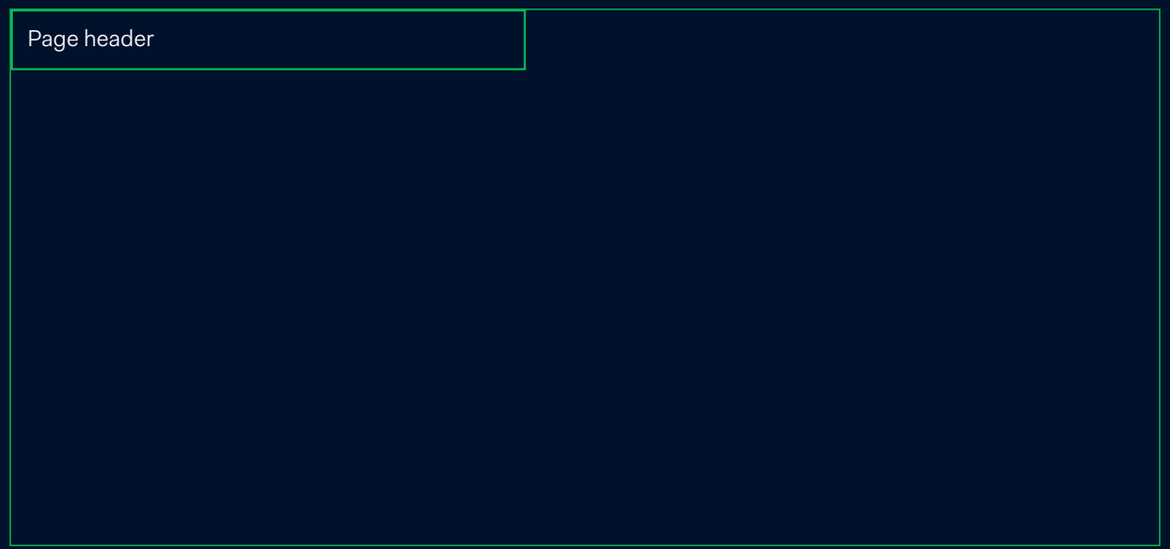


Update and abort leaves a ghost tuple. xmax of the original row is also marked as being aborted.

Why does this matter?

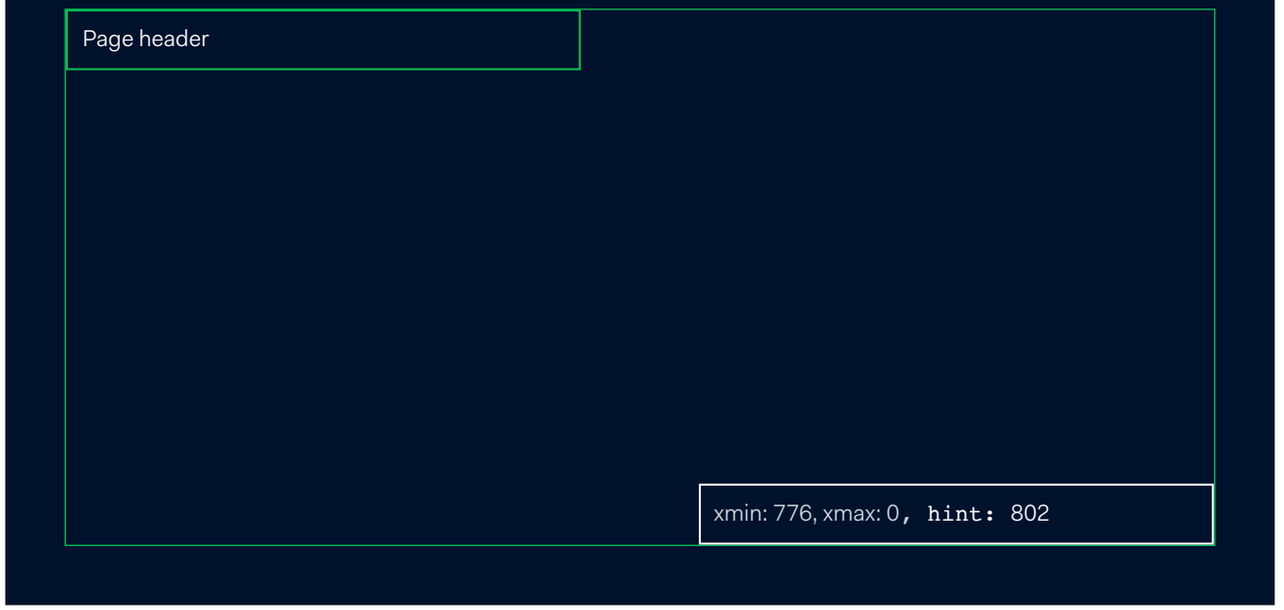
Hint bits

```
TRUNCATE onepage;
```



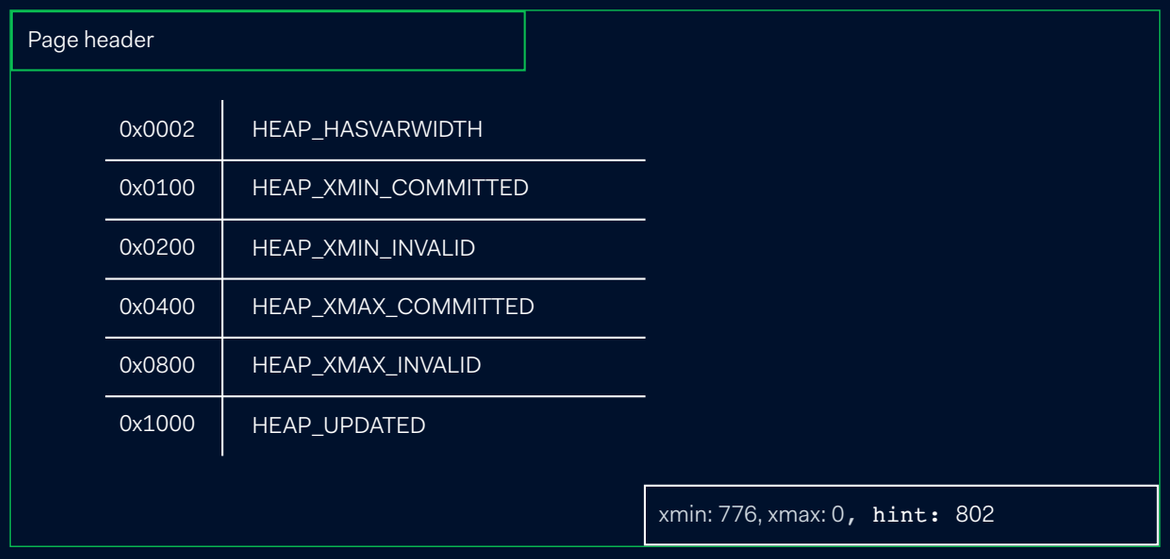
Checking whether `xmin` or `xmax` is committed requires reading the transaction status from the commit log (CLOG/pg_xact). This is a disk I/O per tuple on every visibility check — very expensive. PostgreSQL caches the result directly in the tuple's `t_infomask` field as **hint bits**, set lazily on the first read after commit.

```
INSERT INTO onepage VALUES (1, repeat('x', 700), '2024-01-01');
```

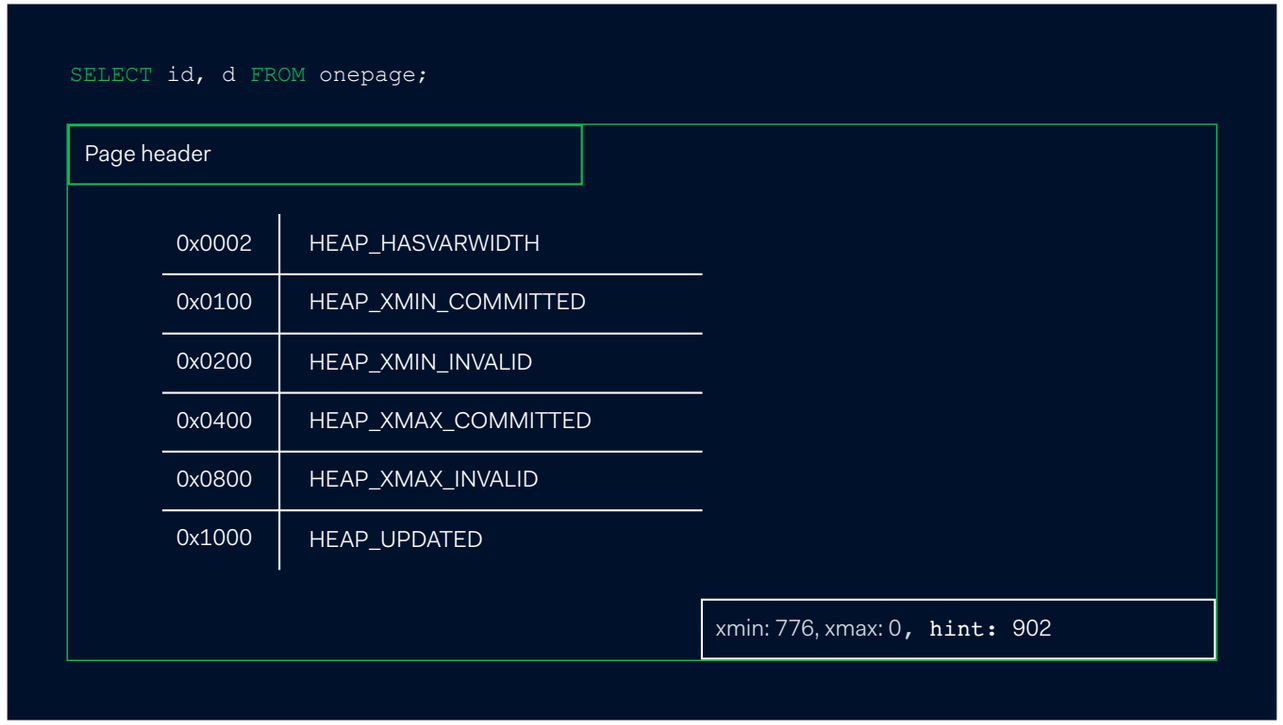


0x0002	HEAP_HASVARWIDTH
0x0100	HEAP_XMIN_COMMITTED
0x0200	HEAP_XMIN_INVALID
0x0400	HEAP_XMAX_COMMITTED
0x0800	HEAP_XMAX_INVALID
0x1000	HEAP_UPDATED

```
INSERT INTO onepage VALUES (1, repeat('x', 700), '2024-01-01');
```

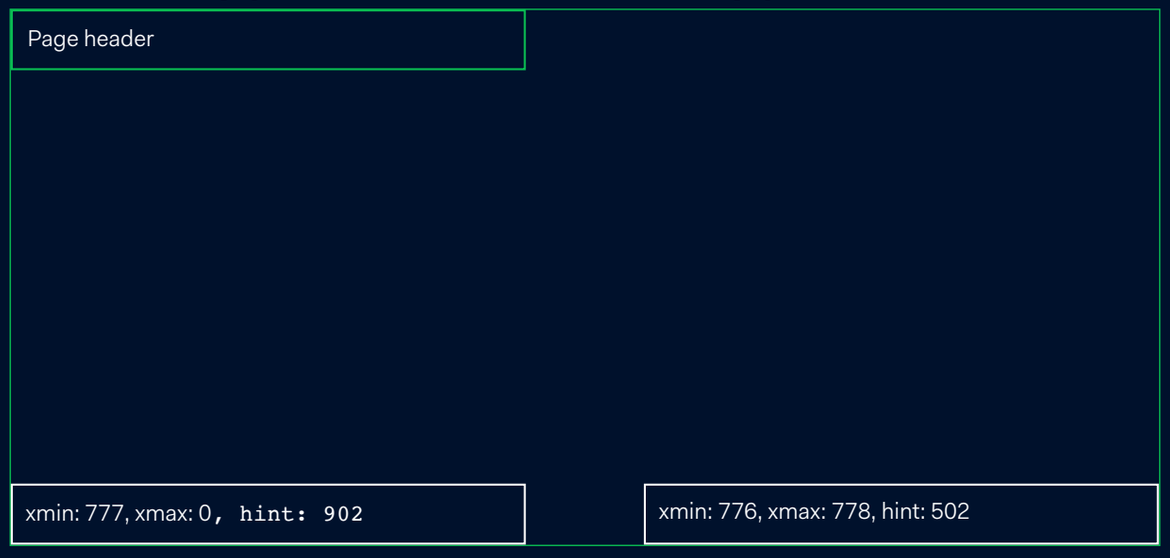


802 translates to varwidth + xmax invalid
The transaction is not listed as being committed

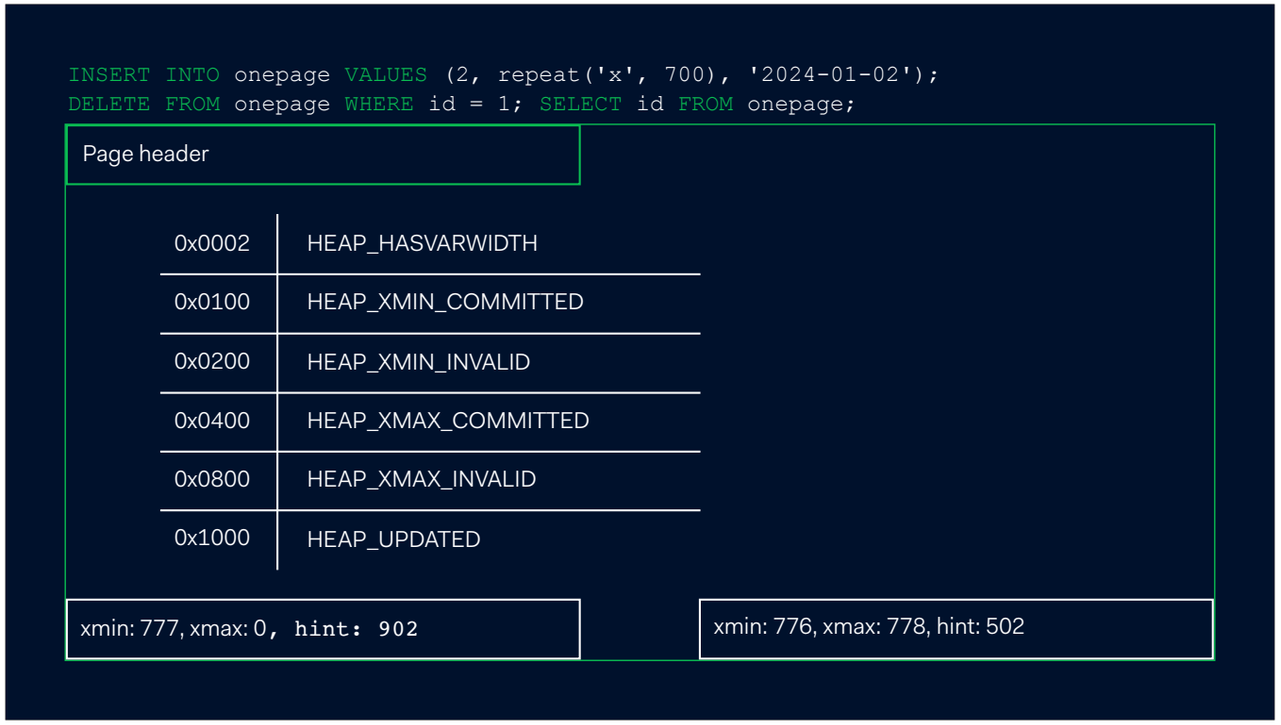


Now the hint bit is set as being committed and other transactions will rely on this information from now on.

```
INSERT INTO onepage VALUES (2, repeat('x', 700), '2024-01-02');
DELETE FROM onepage WHERE id = 1; SELECT id FROM onepage;
```



```
INSERT INTO onepage VALUES (2, repeat('x', 700), '2024-01-02');
DELETE FROM onepage WHERE id = 1; SELECT id FROM onepage;
```

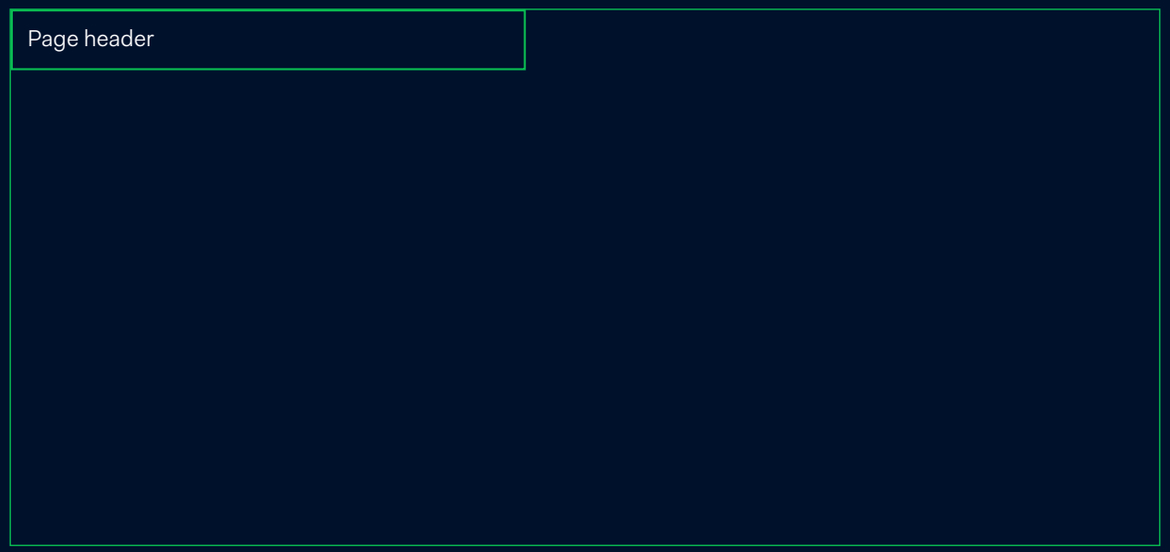


Row1 has xmin committed, xmax committed, var width
Row2 has xmin committed, xmax invalid

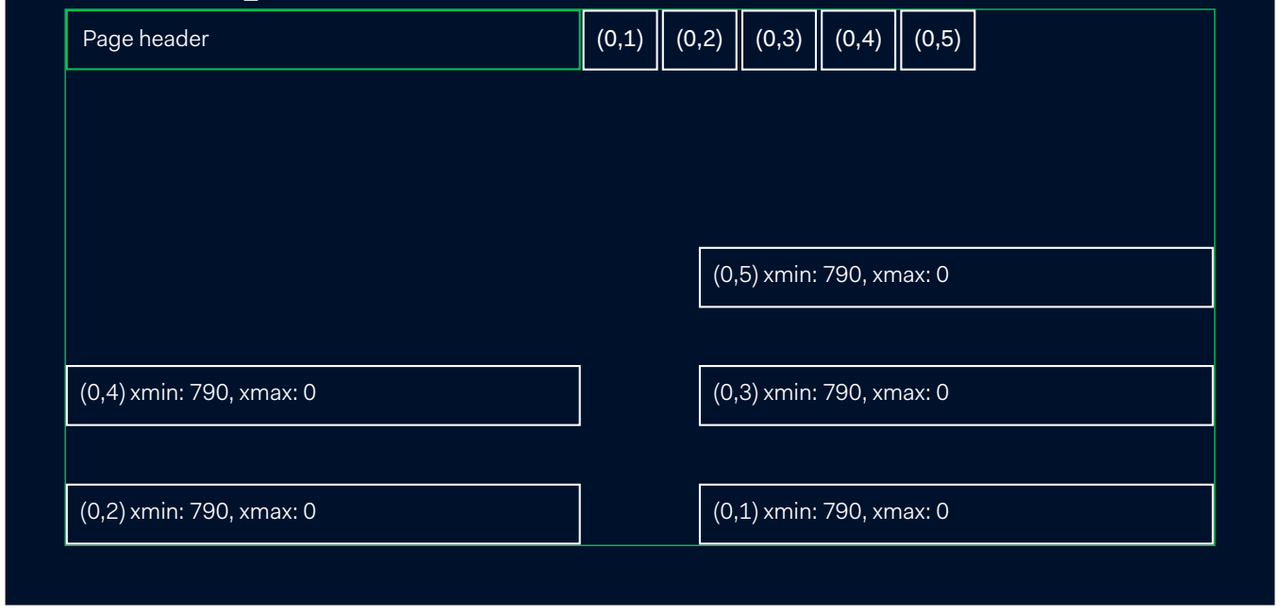
Why does this matter?

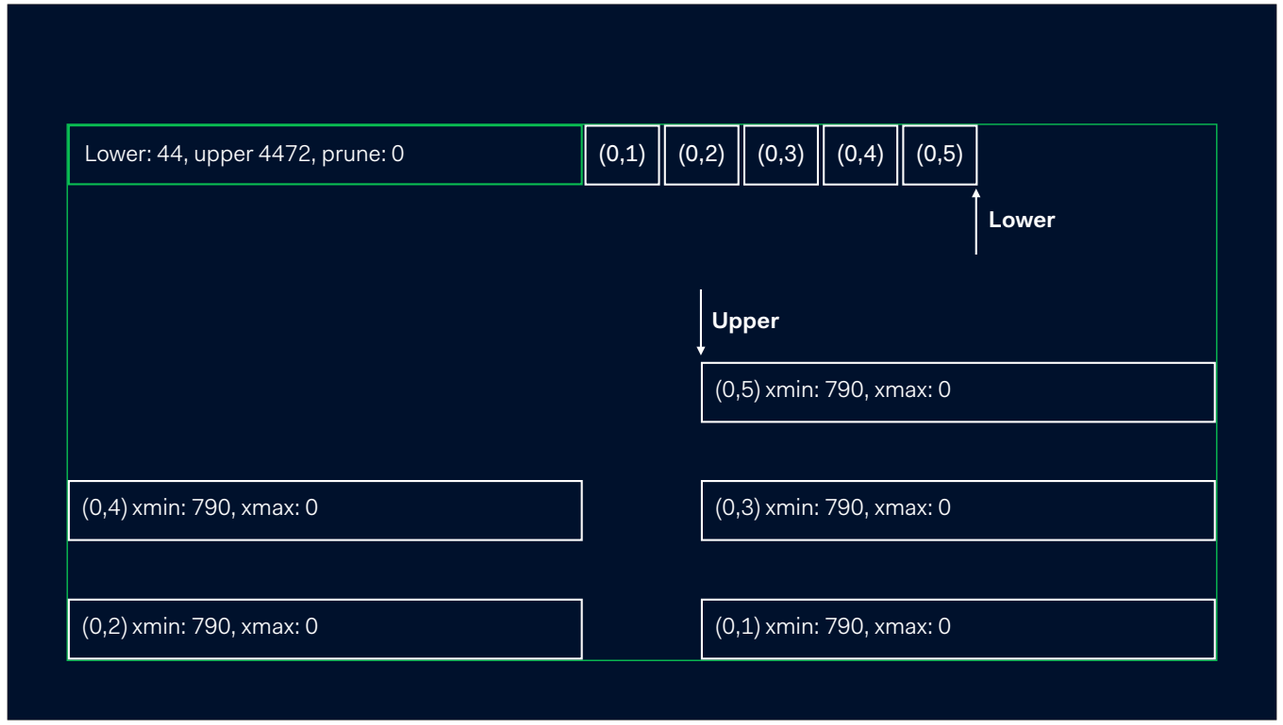
Single Page Cleanup

```
TRUNCATE onepage;
CREATE INDEX ON onepage(id);
```



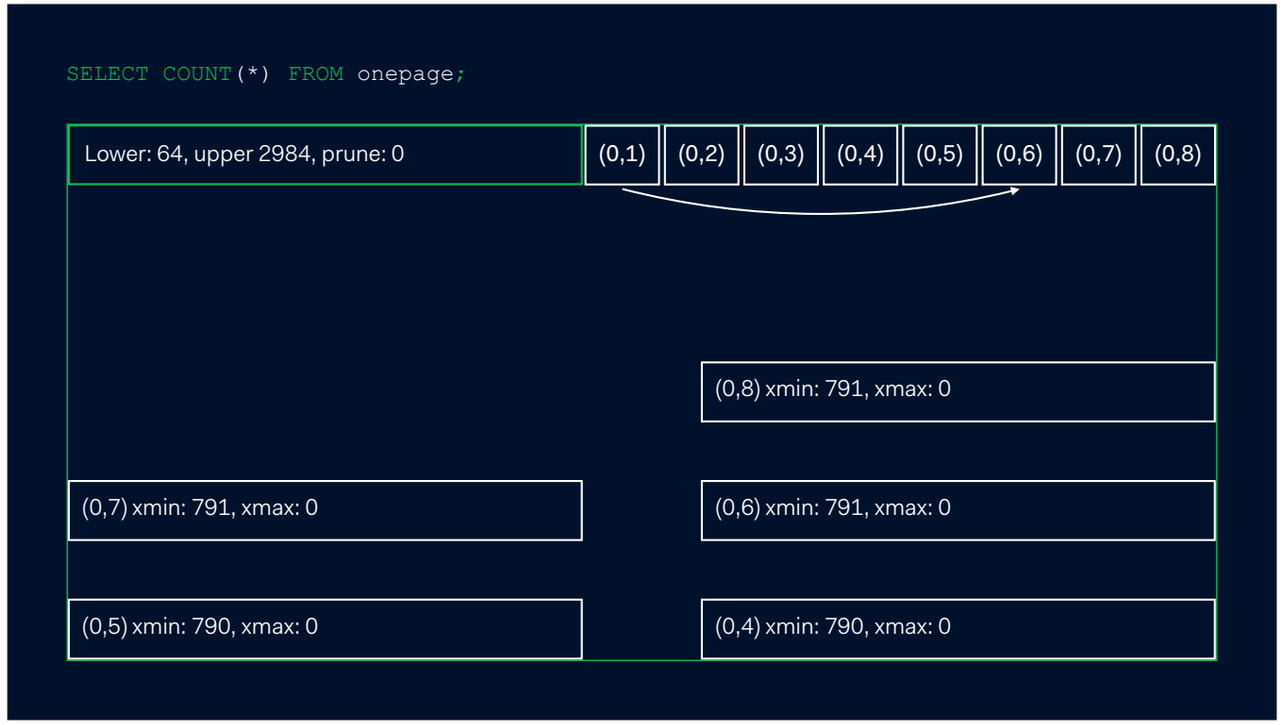
```
INSERT INTO onepage SELECT g, repeat('x', 700), '2024-01-01'::date
FROM generate_series(1, 5) g;
```



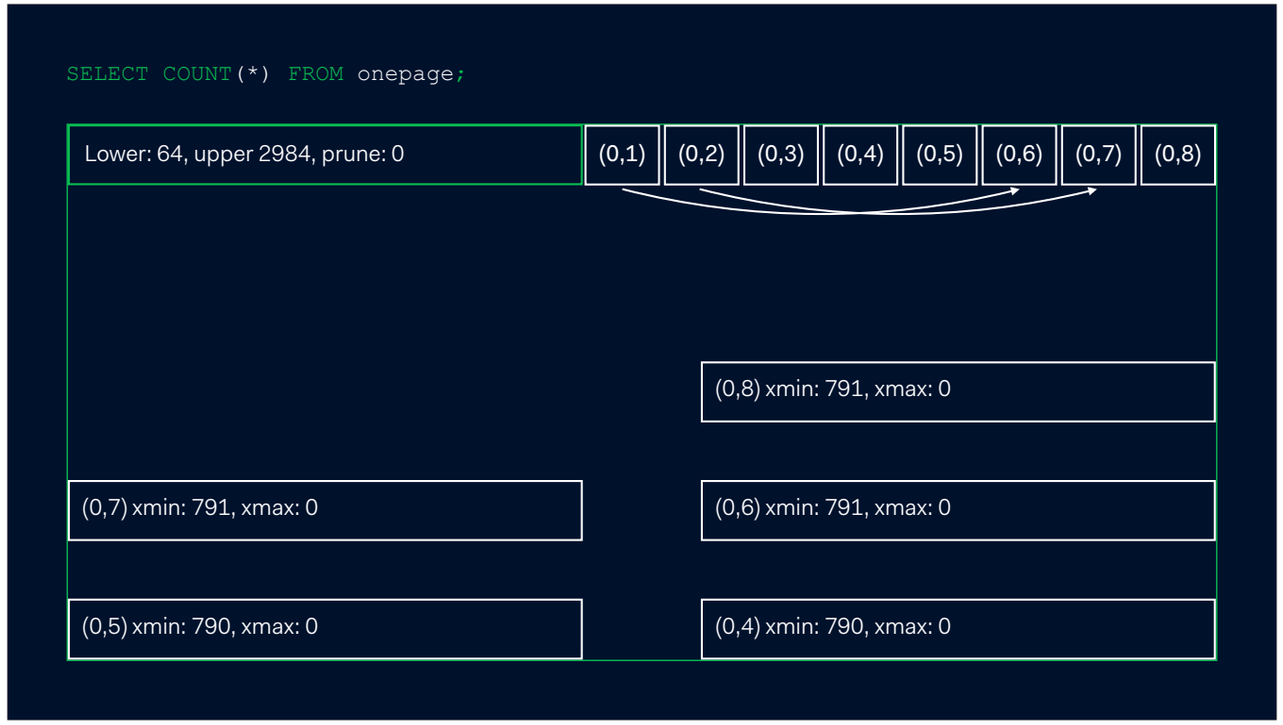


Lets take a look at the page header. It lists where the data in the page can go. We have 4472 - 44 =4.428 bytes left on this page

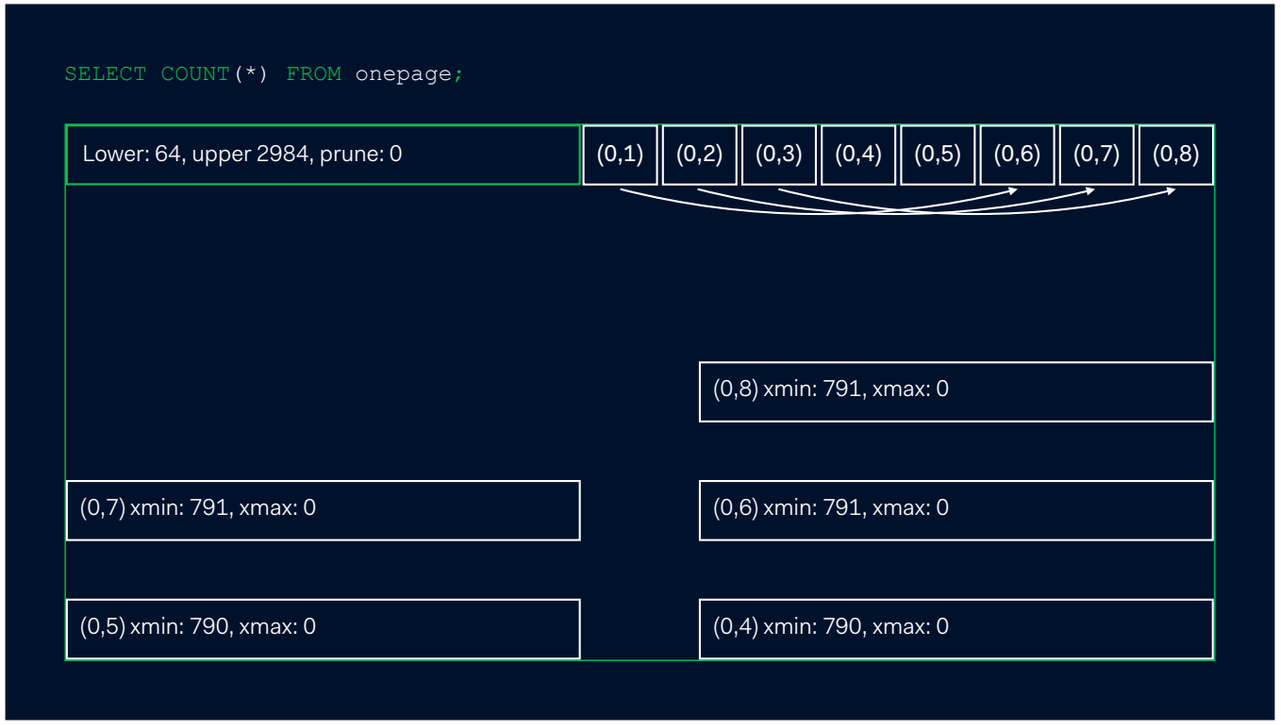
prune_txid is now set to 791, the oldest transaction id that needs information from this page.
The old versions of the updated rows still live within this page



prune_txid is now back to 0, no pruning possible



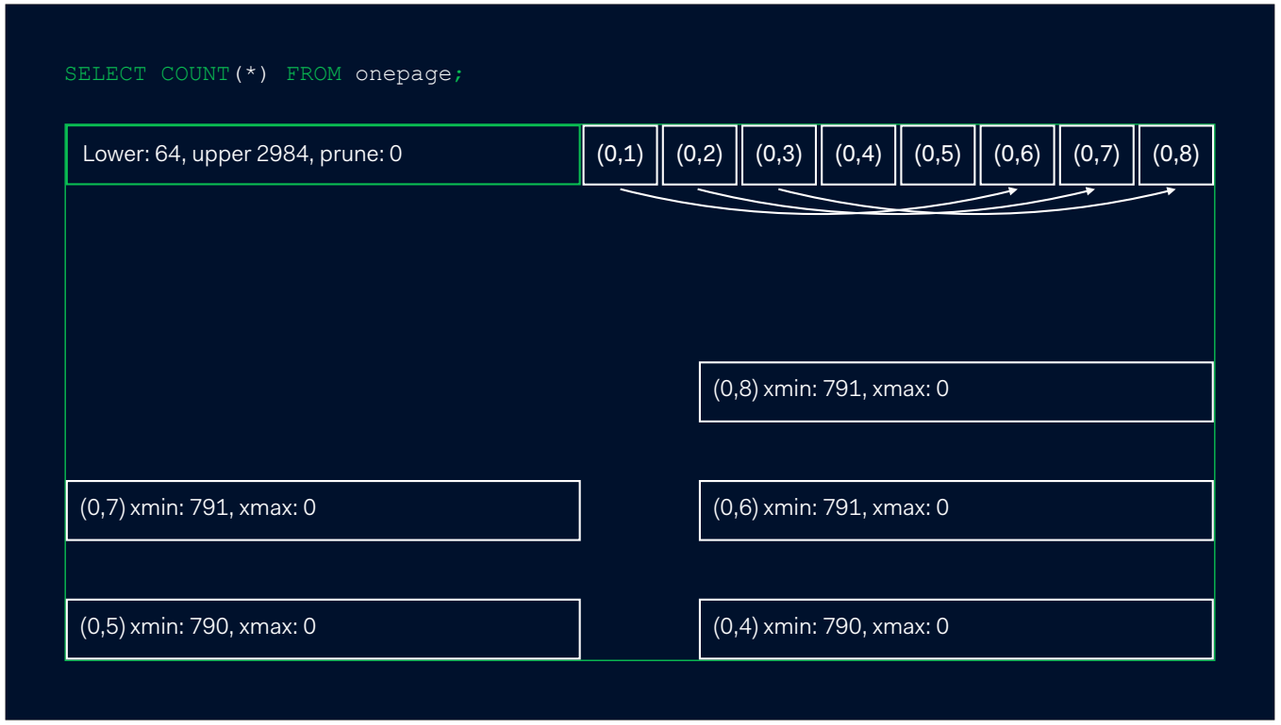
Tuple data has been removed, but line pointers remain and are not redirects to the live tuples.



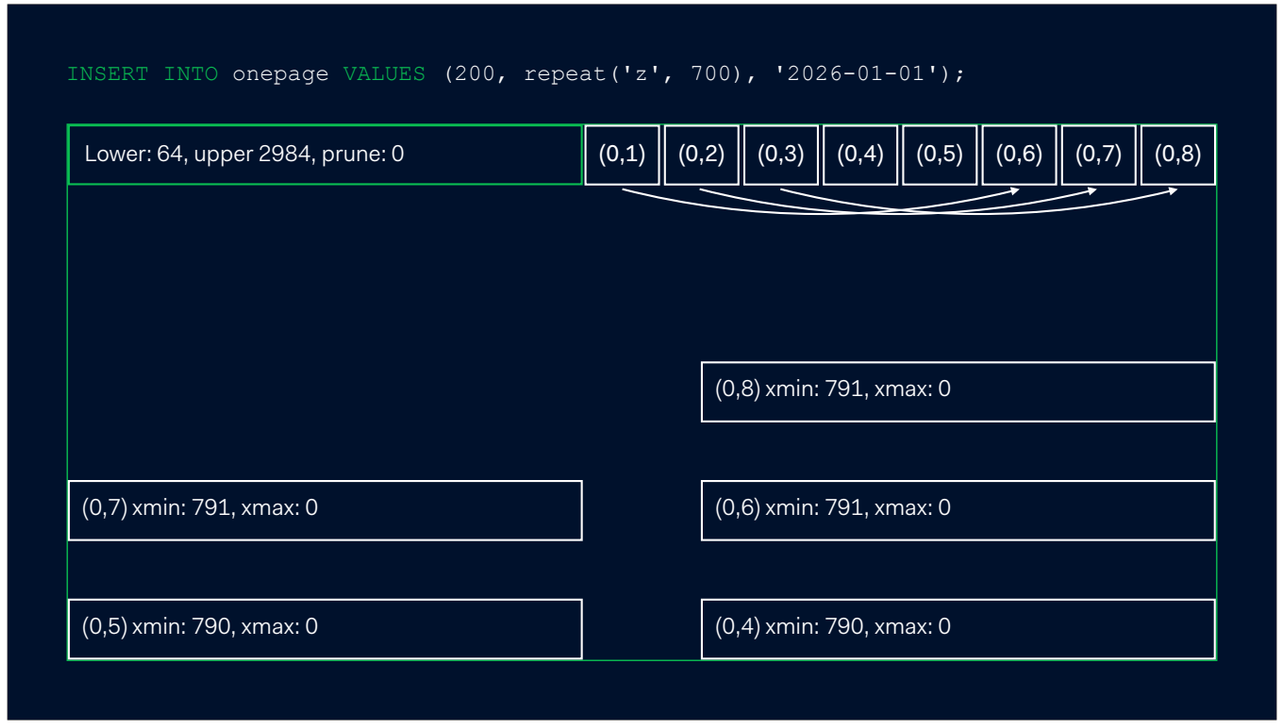
Tuple data has been removed, but line pointers remain and are not redirects to the live tuples.

Why does this matter?

Where to insert a row?



Tuple data has been removed, but line pointers remain and are now redirects to the live tuples.



Where to insert the next incoming row —> didn't arrive at this page.
Logic for where to insert is based on the free space map. The free space map is usually not updated on Single Page Cleanup.

```
VACUUM onepage;
INSERT INTO onepage VALUES (300, repeat('z', 700), '2026-06-01');
```

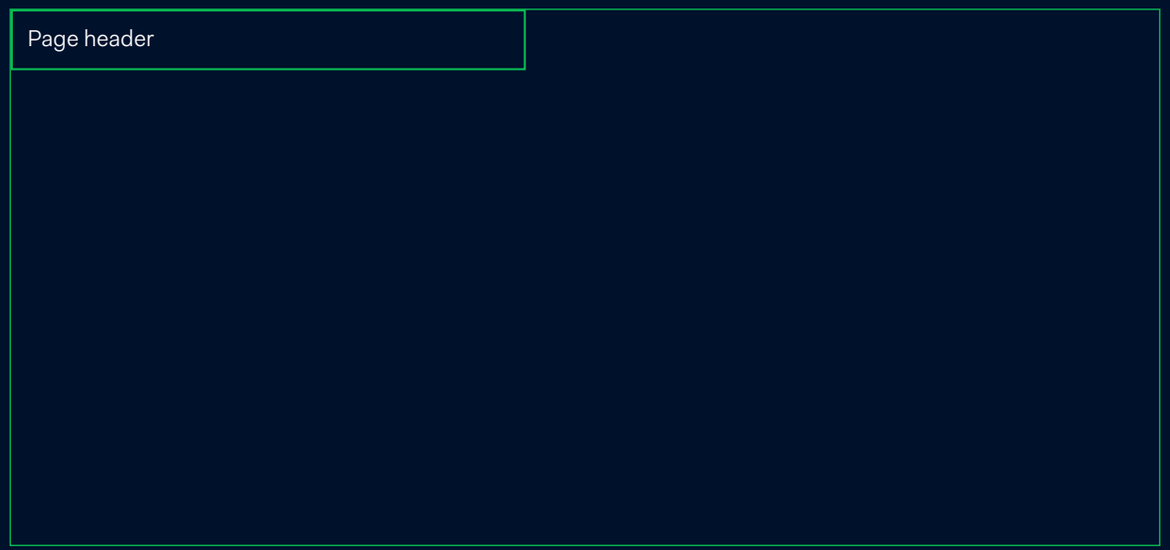
Where to insert the next incoming row —> didn't arrive at this page.
Logic for where to insert is based on the free space map. The free space map is usually not updated on Single Page Cleanup.

TODO: when does pruning update FSM
get confirmation on lp cleanup
Update lower and upper and prune values.

Why does this matter?

Fillfactor

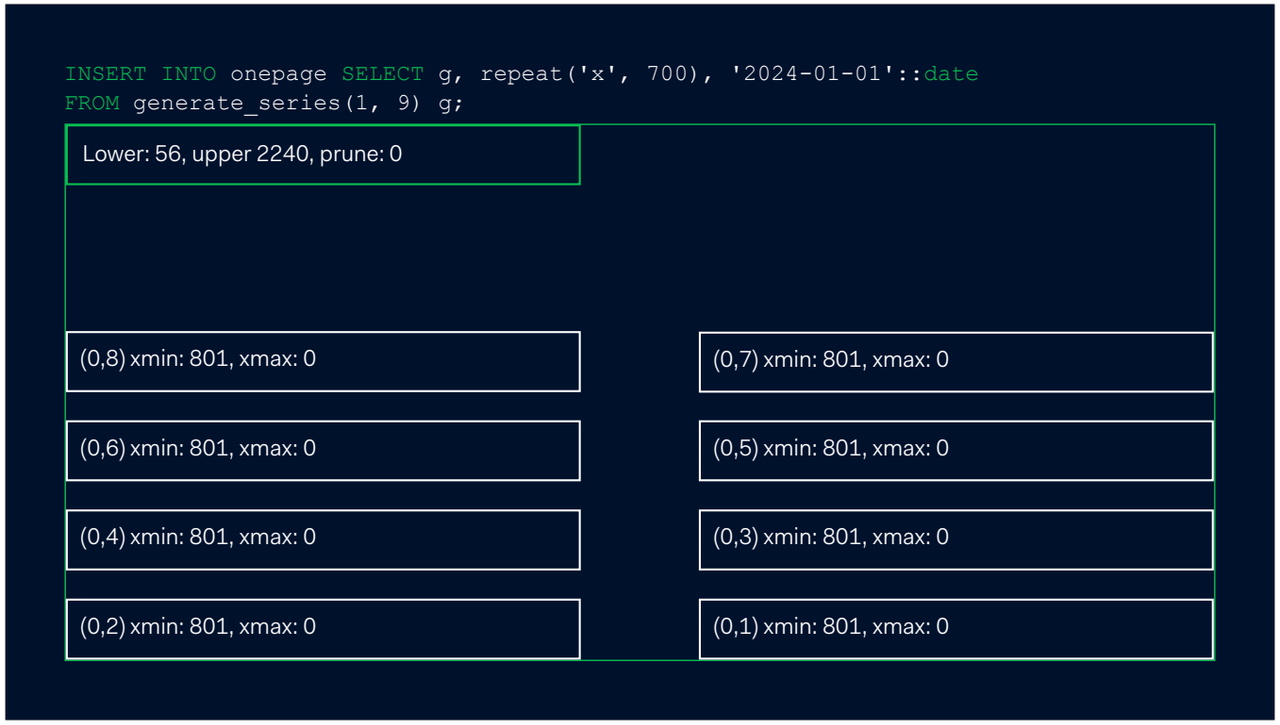
```
TRUNCATE onepage; DROP INDEX onepage_id_idx;
ALTER TABLE onepage SET (fillfactor = 75);
```



With fillfactor=75, PostgreSQL reserves 25% of each page for updates. Threshold calculation:

Available space: 8192 bytes
Reserved: 8192 × 25% = 2048 bytes minimum free space required after each INSERT
A new row needs: 748 bytes (4 LP + 744 tuple)
After 7 rows: free = 8168 – (7 × 748) = 2932 bytes → check: 2932 – 748 = 2184 ≥ 2048 → row 8 fits
After 8 rows: free = 8168 – (8 × 748) = 2184 bytes → check: 2184 – 748 = 1436 < 2048 → row 9 does NOT fit on page 0

```
INSERT INTO onepage SELECT g, repeat('x', 700), '2024-01-01'::date
FROM generate_series(1, 9) g;
```



With fillfactor=75, PostgreSQL reserves 25% of each page for updates. Threshold calculation:

Available space: 8192 bytes
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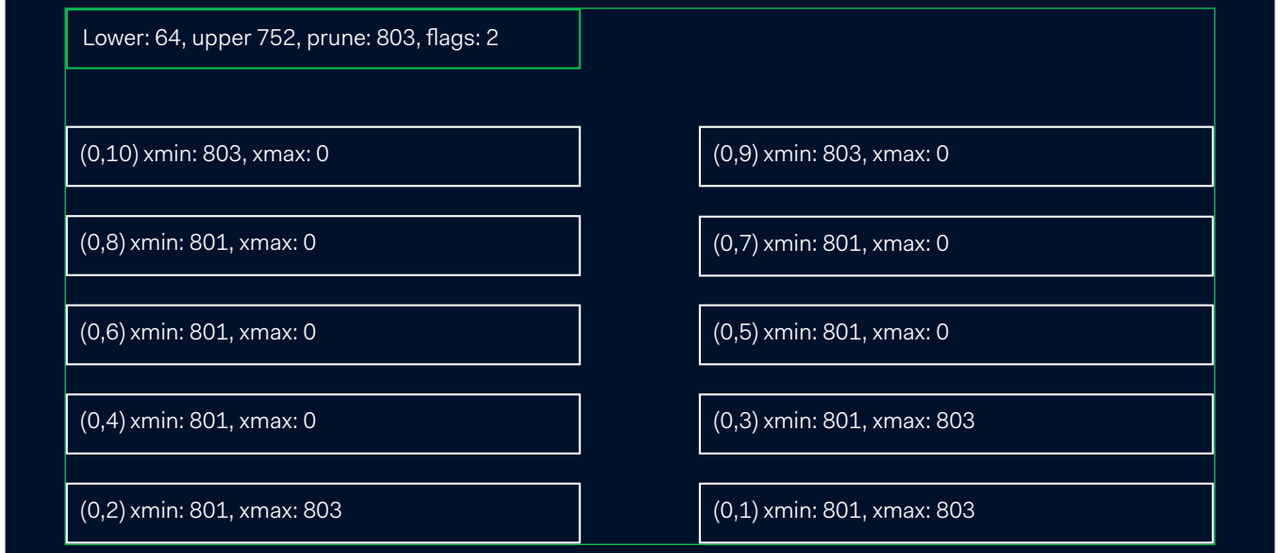
After 7 rows: free = 8168 – (7 × 748) = 2932 bytes → check: 2932 – 748 = 2184 ≥ 2048 → row 8 fits
After 8 rows: free = 8168 – (8 × 748) = 2184 bytes → check: 2184 – 748 = 1436 < 2048 → row 9 does NOT fit on page 0

```
CREATE INDEX onepage_id_idx ON onepage(id);
UPDATE onepage SET d = '2025-06-01' WHERE id IN (1, 2,3);
```



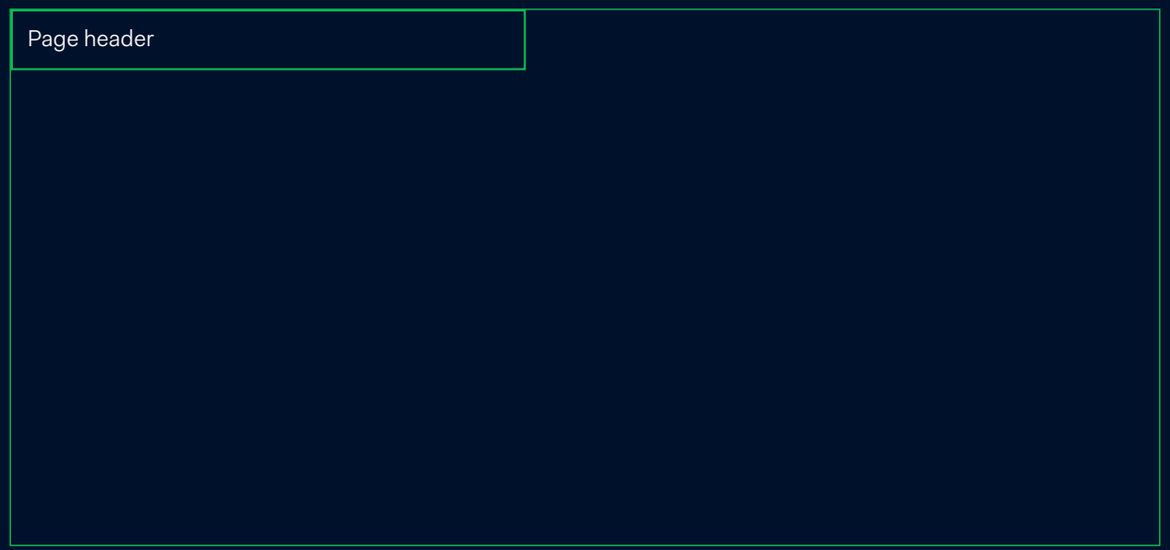
Flags 2: page full
The third update went to page 1, didn't fit this page anymore
Free space = 752 - 64 = 688; doesn't fit a 744 wide row.

This page only contains two new rows, the third row went to page 1.

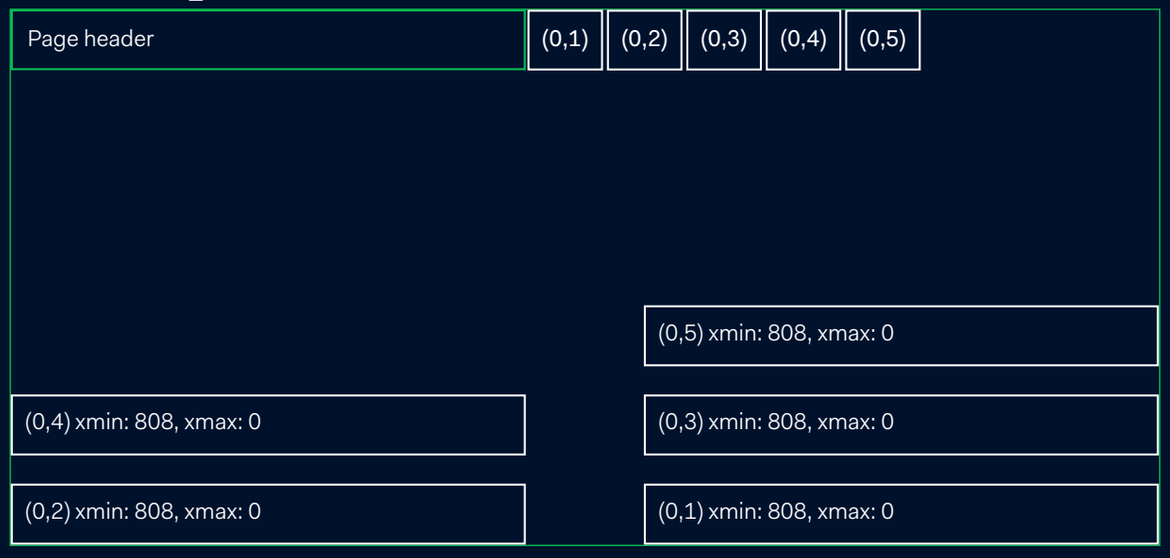
Why does this matter?

HOT Updates

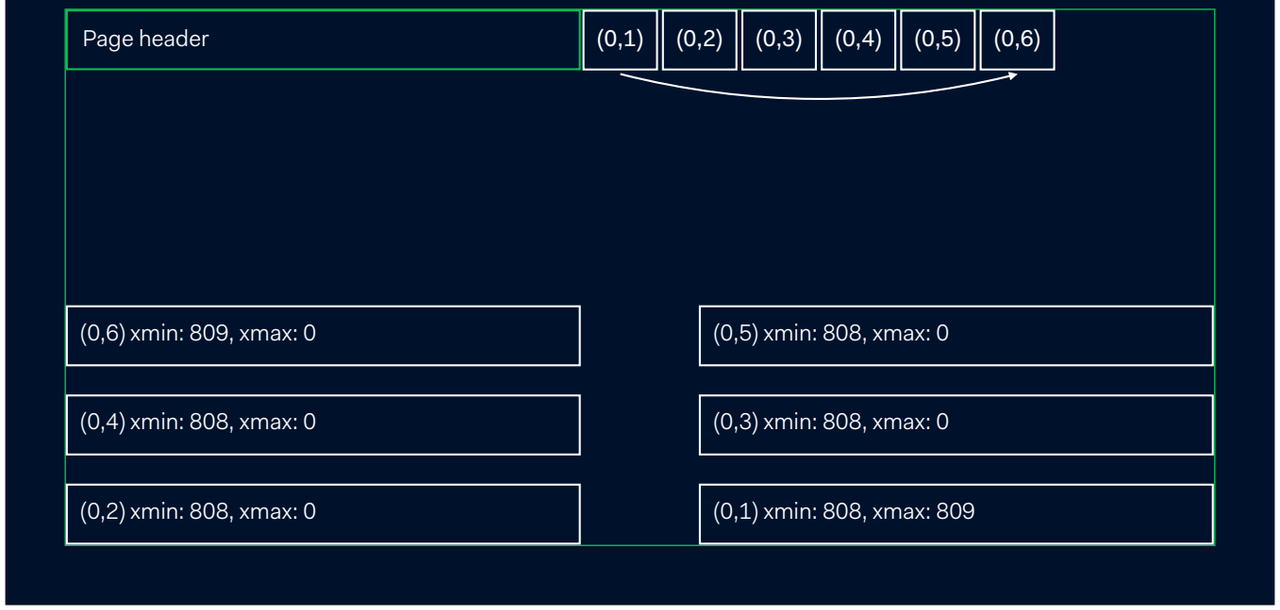
```
TRUNCATE onepage;
-- Fillfactor and index remain
```



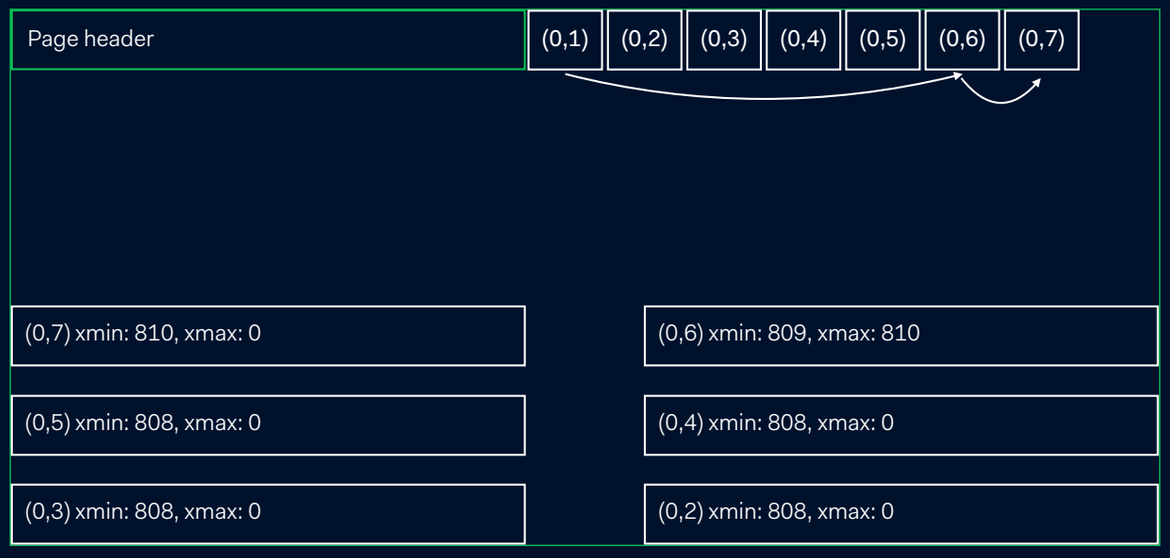
```
INSERT INTO onepage SELECT g, repeat('x', 700), '2024-01-01'::date
FROM generate_series(1, 5) g;
```



```
UPDATE onepage SET d = '2024-06-01' WHERE id = 1;
```



```
UPDATE onepage SET d = '2024-12-01' WHERE id = 1;
```

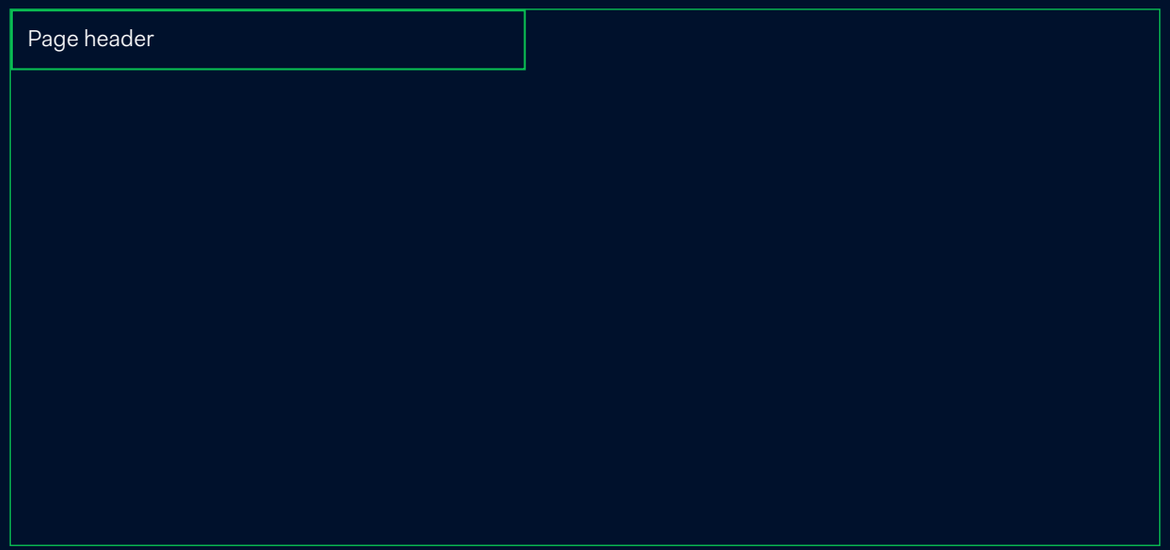


No index changes on the updates, no requirement to vacuum the index!
Number of pages changed for a single row with 10 indexes with and without HOT update
Impact of the fillfactor

Why does this matter?

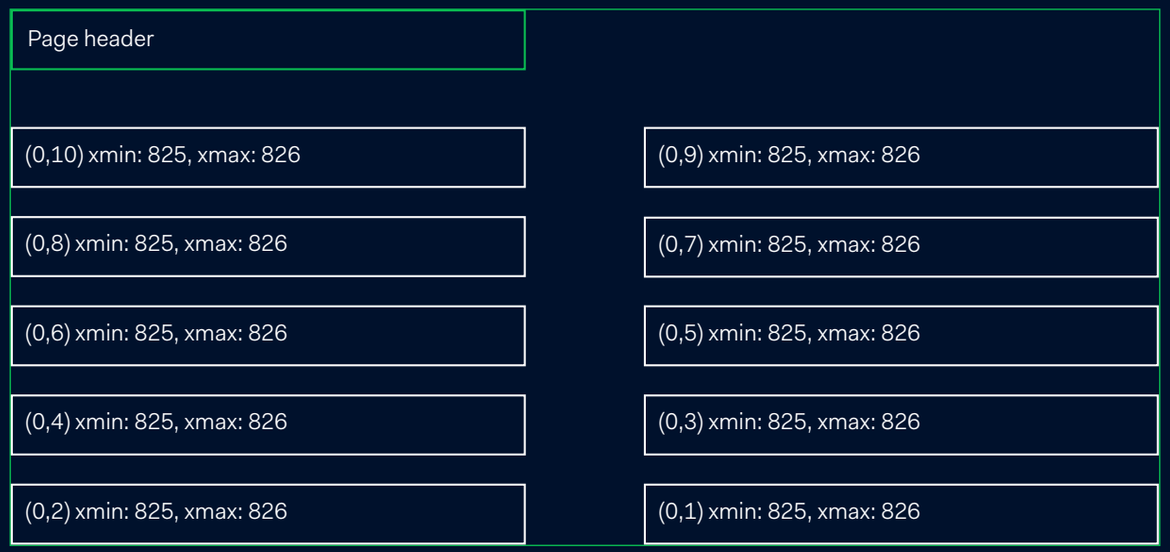
Dead rows vs bloat

```
TRUNCATE onepage; DROP INDEX onepage_id_idx;
ALTER TABLE onepage SET (fillfactor = 100);
```



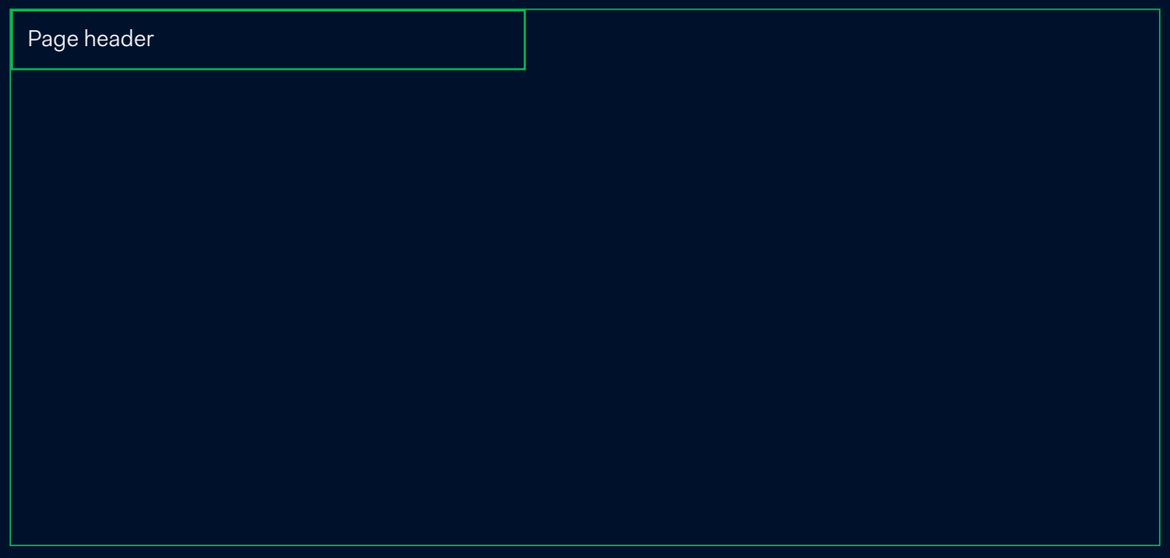
```
INSERT INTO onepage SELECT g, repeat('x', 700), '2024-01-01'::date FROM
generate_series(1,10) g;
```

```
UPDATE onepage SET d = '2025-01-01';
UPDATE onepage SET d = '2026-01-01';
```



Now the page has 10 dead rows, a row where xmax has been set;

```
SELECT * FROM onepage;
```



Now the page has 10 dead rows, a row where xmax has been set;

Page header

```
SELECT n_live_tup, n_dead_tup FROM pg_stat_user_tables
WHERE relname = 'onepage';
 n_live_tup | n_dead_tup
------------+------------
         10 |          20

SELECT pg_size_pretty(pg_relation_size('onepage'));
 pg_size_pretty
----------------
 24 kB
```

Now the page has 10 dead rows, a row where xmax has been set;

```
VACUUM onepage;
```

Page header

```
SELECT n_live_tup, n_dead_tup FROM pg_stat_user_tables
WHERE relname = 'onepage';
 n_live_tup | n_dead_tup
------------+------------
         10 |          0

SELECT pg_size_pretty(pg_relation_size('onepage'));
 pg_size_pretty
----------------
 24 kB
```

Now vacuum brings the table size back to 1 page! No need to run vacuum full.

```
UPDATE onepage SET d = '2026-04-21';
```

The next update moves all rows back to my first page

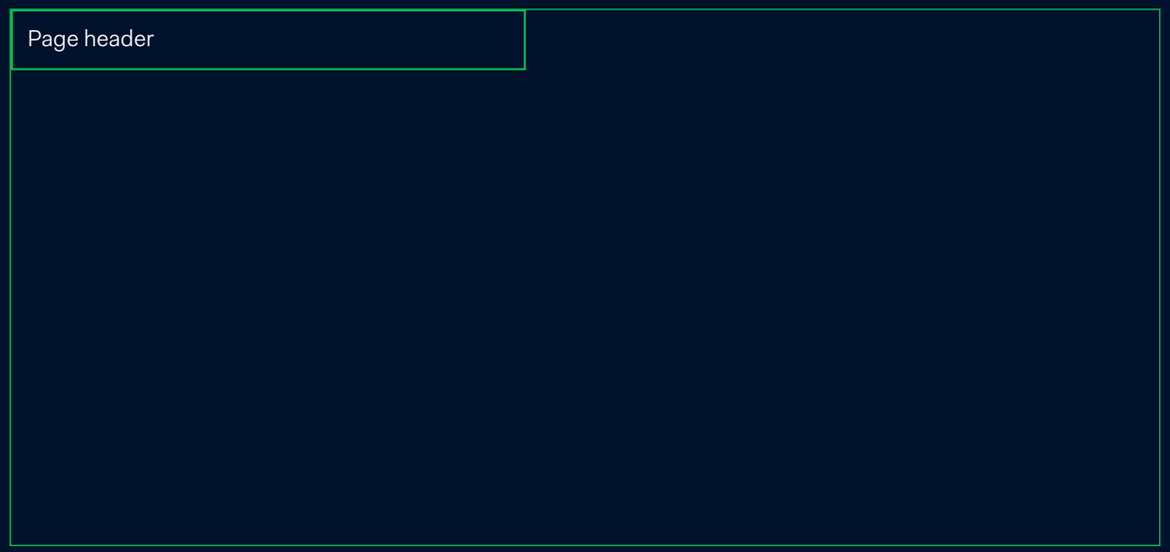
```
VACUUM onepage;
```

Page header

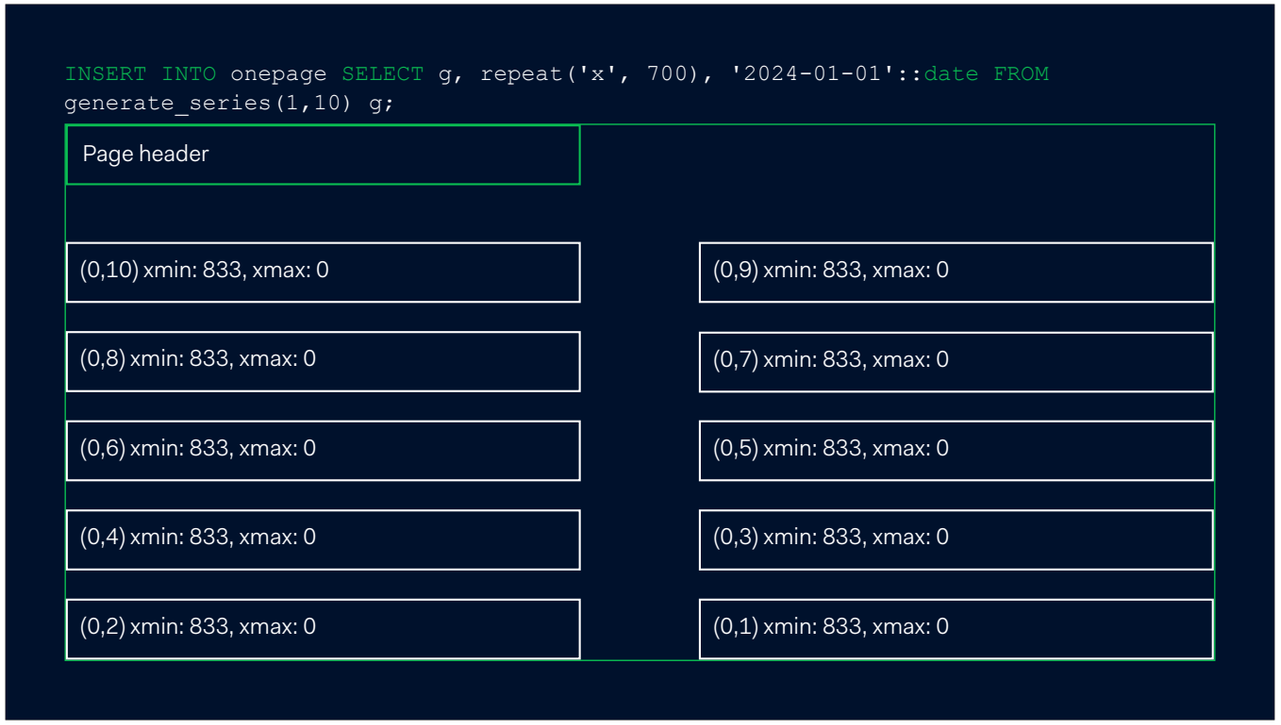
```
SELECT n_live_tup, n_dead_tup FROM pg_stat_user_tables
WHERE relname = 'onepage';
 n_live_tup | n_dead_tup
------------+------------
         10 |          0

SELECT pg_size_pretty(pg_relation_size('onepage'));
 pg_size_pretty
----------------
 8192 bytes
```

Now vacuum brings the table size back to 1 page! No need to run vacuum full.

```
TRUNCATE onepage;
```



```
INSERT INTO onepage SELECT g, repeat('x', 700), '2024-01-01'::date FROM
generate_series(1,10) g;
```



```
UPDATE onepage SET d = '2025-01-01';
UPDATE onepage SET d = '2026-01-01';
```

Now the page has 10 dead rows, a row where xmax has been set;

```
DELETE FROM onepage;
```

Page header

```
SELECT n_live_tup, n_dead_tup FROM pg_stat_user_tables
WHERE relname = 'onepage';
 n_live_tup | n_dead_tup
------------+------------
          0 |          30

SELECT pg_size_pretty(pg_relation_size('onepage'));
 pg_size_pretty
----------------
 24 kB
```

Now the page has 10 dead rows, a row where xmax has been set;

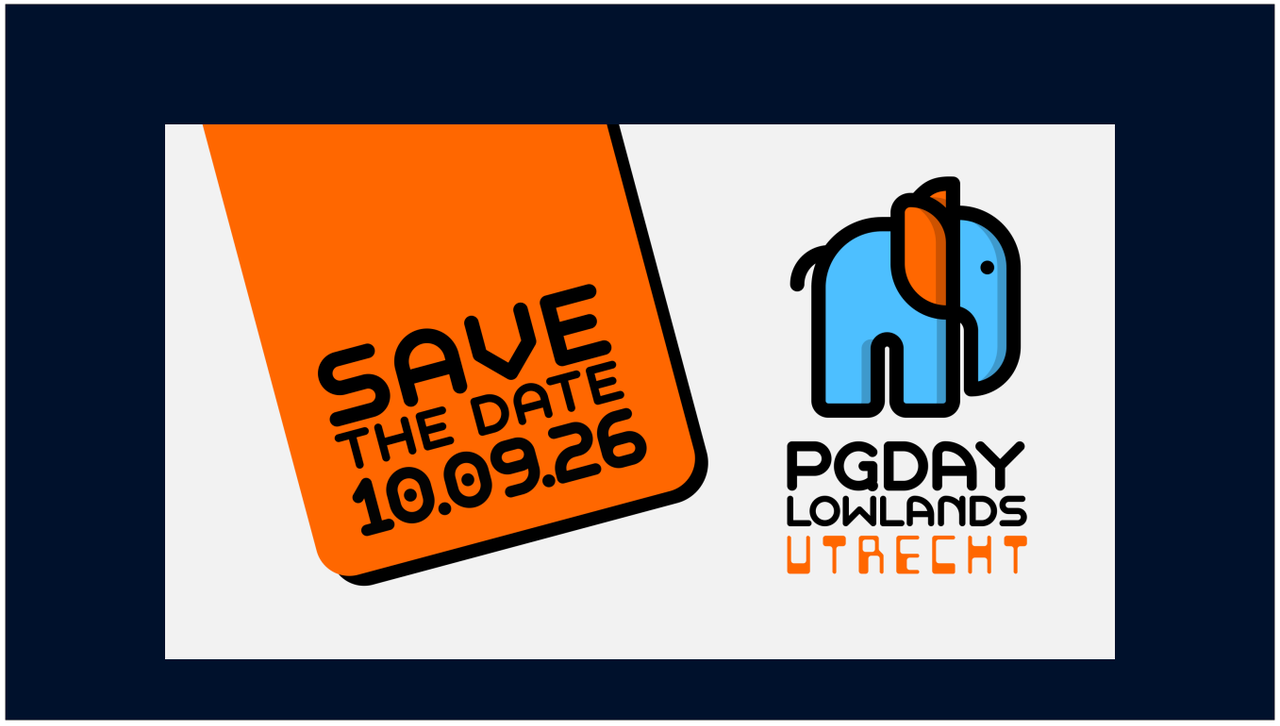
Why does this matter?

Adding small gains for maximum results

adyen

engineered
for ambition


Operational hazards of
managing PostgreSQL
DBs over 100TB


SAVE
THE DATE
10.09.26
PGDAY
LOWLANDS
UTRECHT