Increased I/O Observability with `pg_stat_io`

Postgres Performance Observability Sources and Analysis Techniques

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- Open source Postgres hacking: executor, planner, storage, and statistics sub-systems
- I/O Benchmarking and Linux kernel storage performance tuning
- Recently worked on prefetching for direct I/O and I/O statistics

https://github.com/melanieplageman

Transactional Workload I/O Performance Goals

High transactions per second (TPS)

Consistent low latency

Common I/O Performance Issue Causes

Working set is not in memory

Autovacuum bottlenecked on I/O

Postgres I/O Tuning Targets

Shared buffers

Background writer

Autovacuum

Postgres I/O Statistics Views

`pg_stat_database`
- hits, reads

`pg_statio_all_tables`
- hits, reads, read time, write time

`pg_stat_bgwriter`
- backend writes, backend fsyncs

`pg_stat_statements`
- shared buffer hits, reads, writes, read time, write time
- local buffer hits, reads, writes, read time, write time

Postgres I/O Statistics Views' Gaps

- ***Writes*** = flushes + ***extends***
- ***Reads*** and ***writes*** combined for all ***backend types***
- I/O combined for all ***contexts***

pg_stat_io (pg 16)

backend_type	io_object	io_context	reads	writes	extends	op_bytes	evictions	reuses	fsyncs
autovacuum launcher	relation	bulkread	0	0		8192	0	0	
autovacuum launcher	relation	normal	1	0		8192	0		0
autovacuum worker	relation	bulkread	0	0		8192	0	0	
autovacuum worker	relation	normal	174	0	11	8192	0		0
autovacuum worker	relation	vacuum	125	0	0	8192	0	93	
client backend	relation	bulkread	891	0		8192	0	130	
client backend	relation	bulkwrite	891	0	0	8192	0	0	
client backend	relation	normal	191	0	0	8192	0		0
client backend	relation	vacuum	0	0	0	8192	0	0	
client backend	temp relation	normal	0	0	0	8192	0		
background worker	relation	bulkread	0	0		8192	0	0	
background worker	relation	bulkwrite	0	0	0	8192	0	0	
background worker	relation	normal	0	0	0	8192	0		0
background worker	relation	vacuum	0	0	0	8192	0	0	
background worker	temp relation	normal	0	0	0	8192	0		
background writer	relation	normal		0		8192			0
checkpointer	relation	normal		894		8192			248
standalone backend	relation	bulkread	0	0		8192	0	0	
standalone backend	relation	bulkwrite	0	0	8	8192	0	0	
standalone backend	relation	normal	689	983	470	8192	0		0
standalone backend	relation	vacuum	10	0	0	8192	0	0	
startup	relation	bulkread	0	0		8192	0	0	
startup	relation	bulkwrite	0	0	0	8192	0	0	
startup	relation	normal	0	0	0	8192	0		0
startup	relation	vacuum	0	0	0	8192	0	0	
walsender	relation	bulkread	0	0		8192	0	0	
walsender	relation	bulkwrite	0	0	0	8192	0	0	
walsender	relation	normal	0	0	0	8192	0		0
walsender	relation	vacuum	0	0	0	8192	0	0	
walsender	temp relation	normal	0	0	0	8192	0		

backend_type, io_object, io_context,

reads, writes, extends, evictions, reuses, fsyncs

Why Count Flushes and Extends Separately?

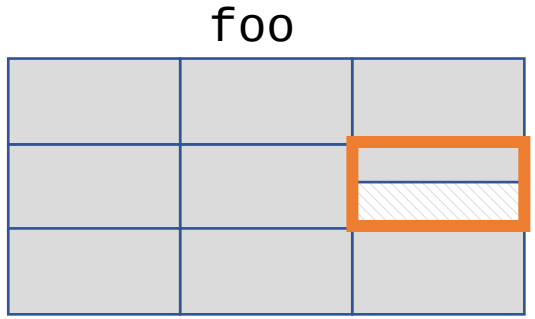
`pg_stat_io`

- ***write*** = flush
- ***extend*** = extend

Postgres UPDATE/INSERT I/O Workflow

```
INSERT INTO foo VALUES(1,1);
```

1. Find a disk block with enough space to fit the new data



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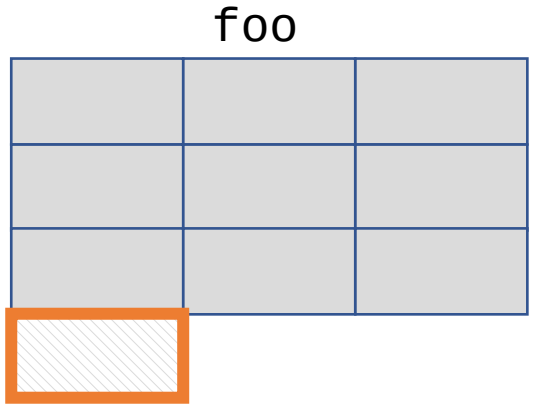

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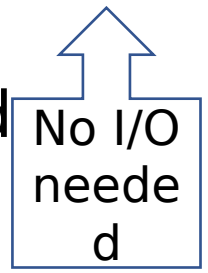
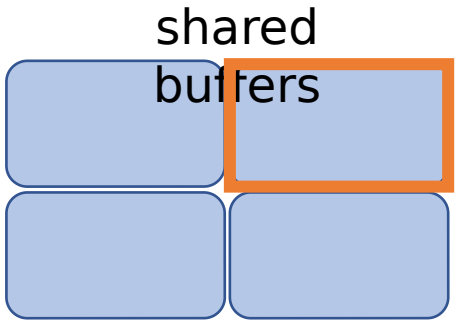
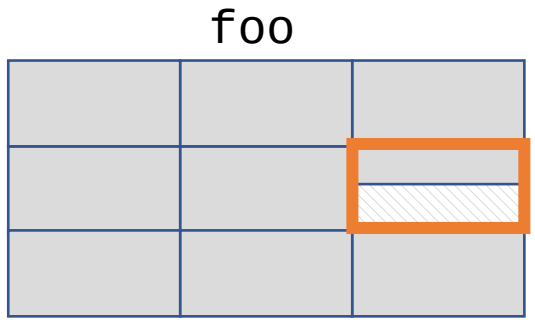
   i. If no block has enough free space, ***extend*** the file.
2. Check for the block in shared buffers.
   i. If it is already loaded cache ***hit***!







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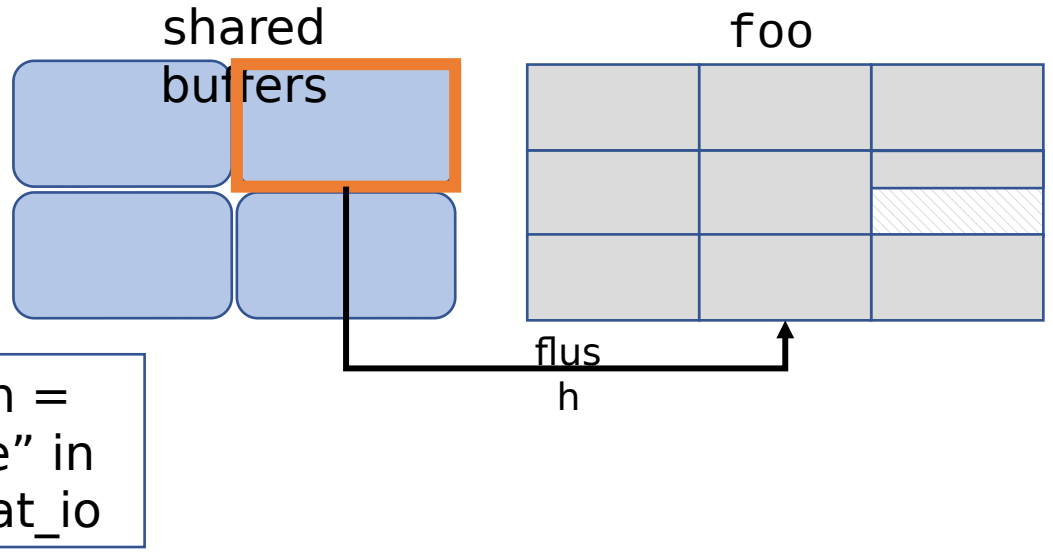
   i. If no block has enough free space, ***extend*** the file.
2. Check for the block in shared buffers.
   i. If it is already loaded, success!
3. Otherwise, find a shared buffer we can use.
   i. If it is dirty, ***flush*** it.



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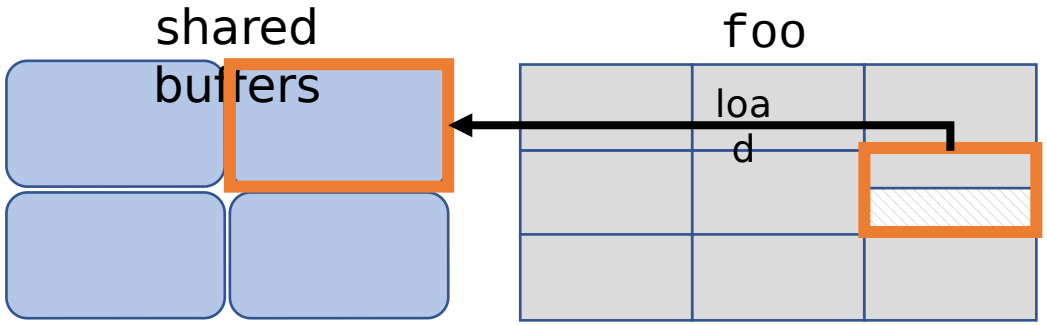

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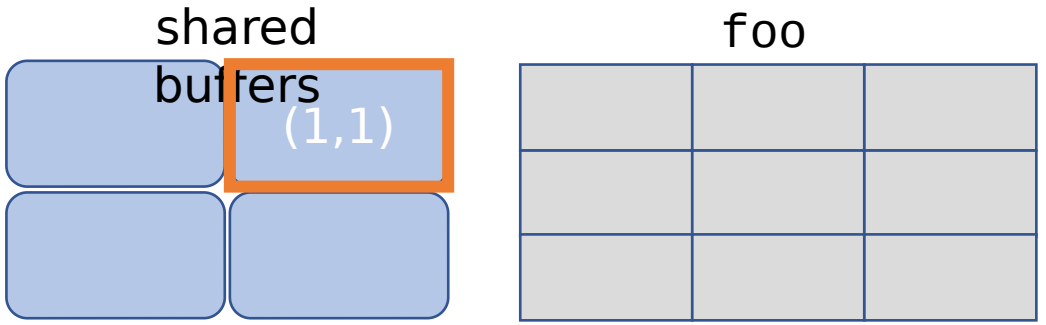
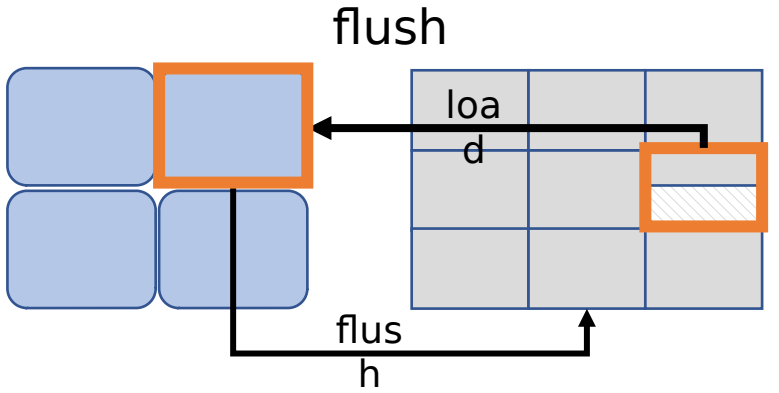
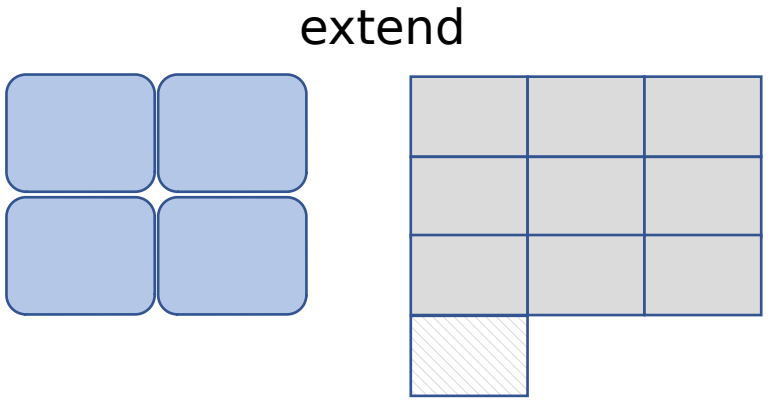
4. Read our block into the buffer.
5. Write our data into the buffer.



Why Count Flushes and Extends Separately?

- Synchronous flushes are avoidable





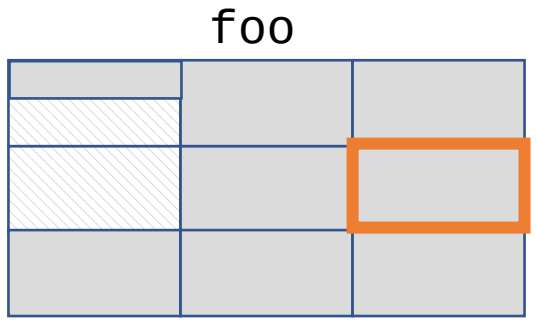
Why Track I/O Per Context or Per Backend Type?

`pg_stat_io`

- ***backend_type***
- ***io_context***

Postgres Autovacuum Workflow

1. Identify the next block to vacuum.

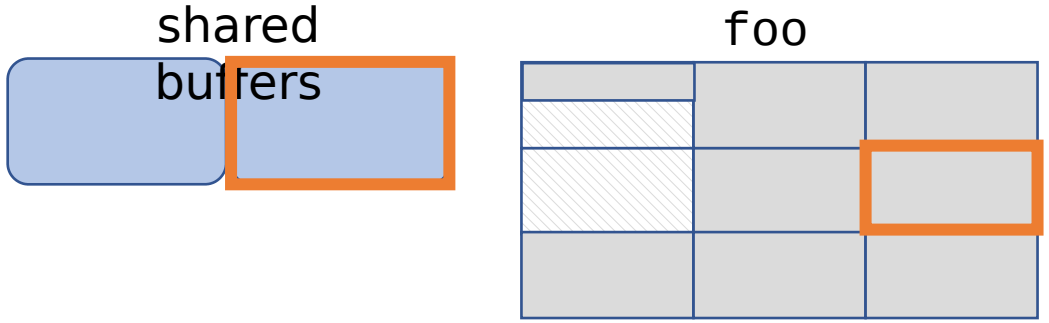


Postgres Autovacuum Workflow

1. Identify the next block to vacuum.

```
( 0, 3, 5, 6 )
```

2. Check for the block in shared buffers.
   i. If it is, vacuum it! (cache ***hit***)



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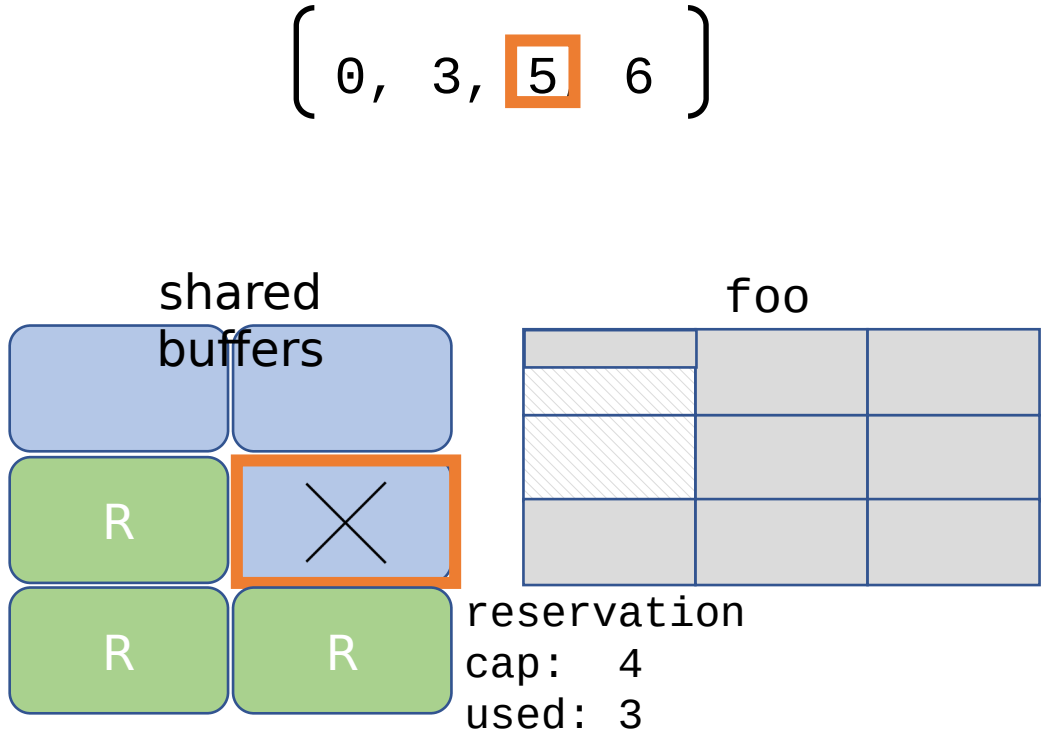

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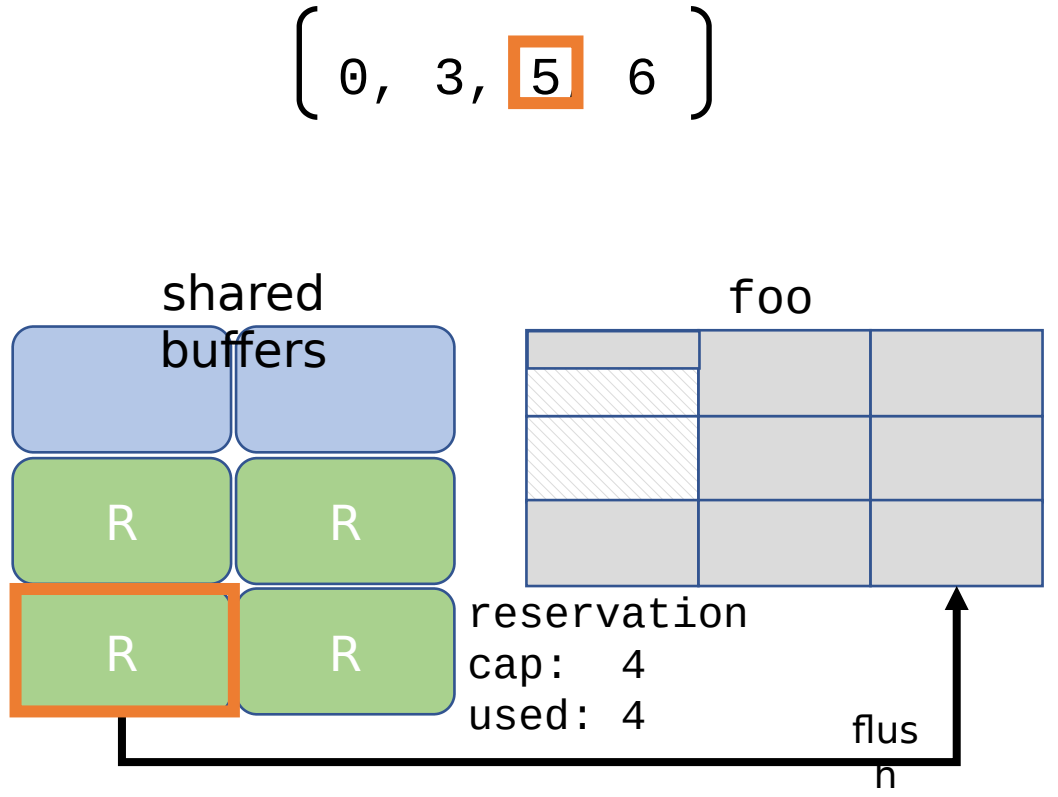

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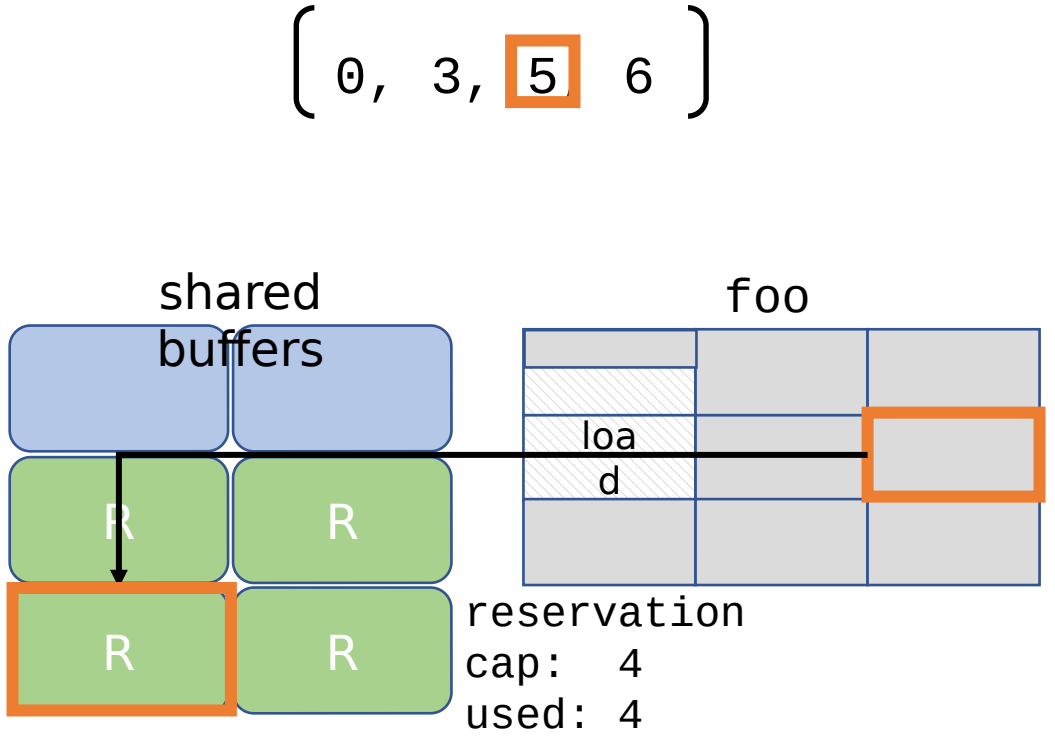

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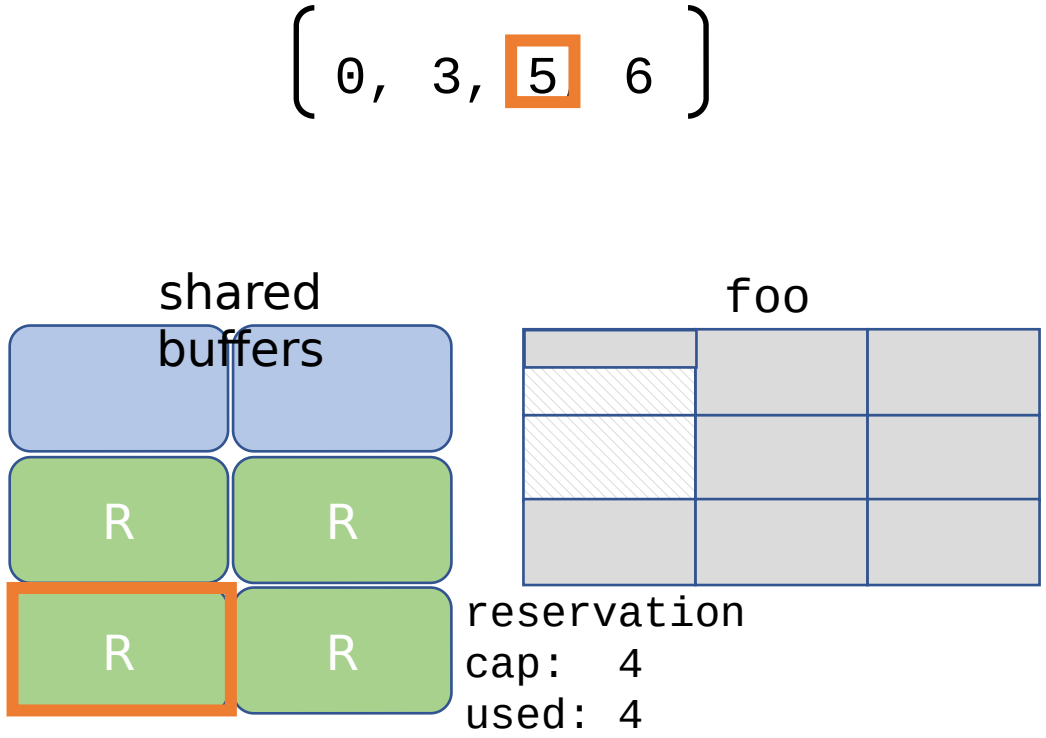

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   ii. If we are reusing a dirty, reserved buffer, flush it.
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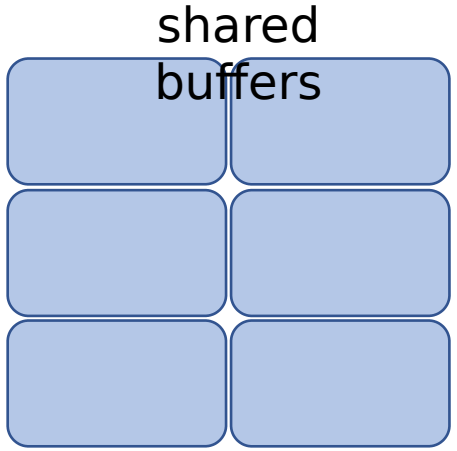
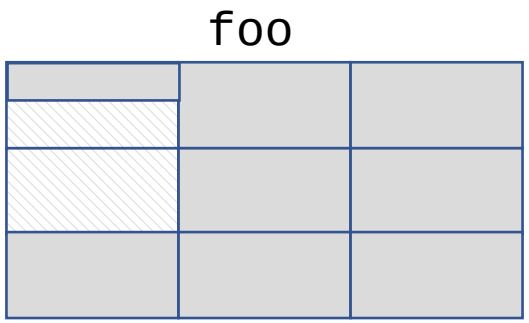
5. Vacuum the buffer and mark it dirty.
6. Upon completing vacuum cycle, return all reserved buffers.

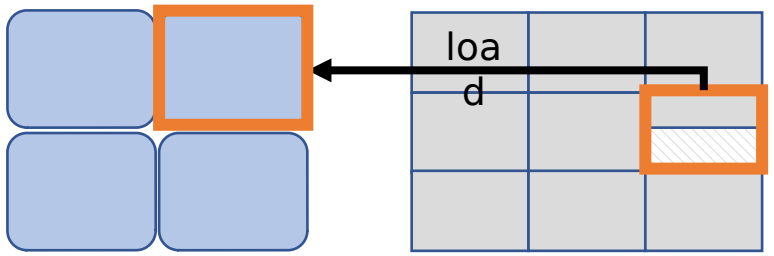




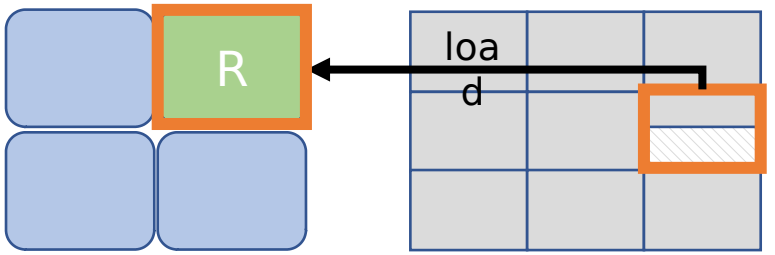
Why Track I/O Per Backend Type?

- Not all I/O is for blocks that are part of the working set
- Autovacuum worker reads often are of older data

client backend read

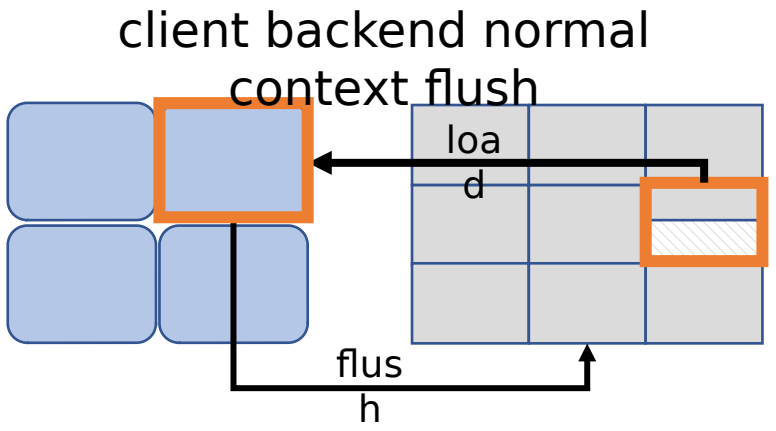


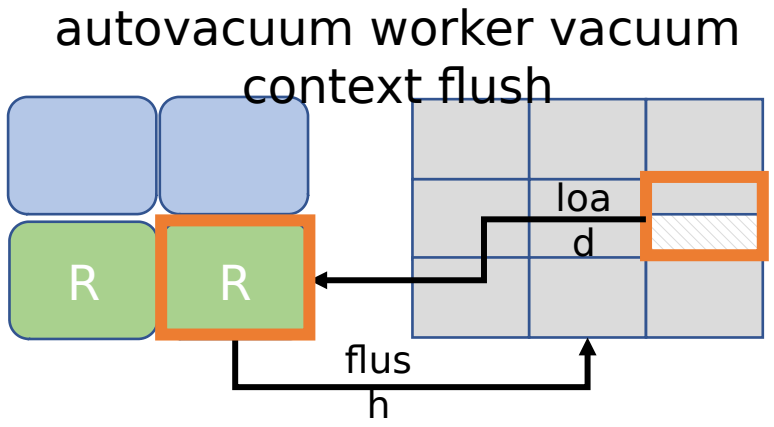
autovacuum worker read



Why Track I/O Per Context?

- Shared buffers not used for all I/O
- Vacuum I/O not in shared buffers

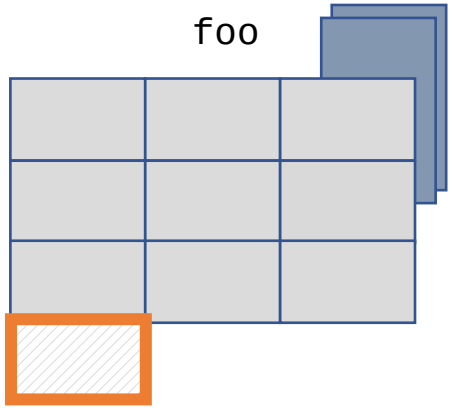




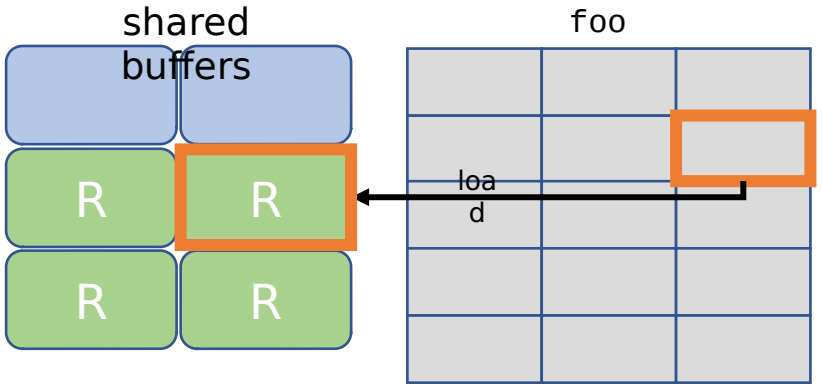
Analytic Workload I/O Characteristics

High number of extends during bulk load operations like

COPY FROM.

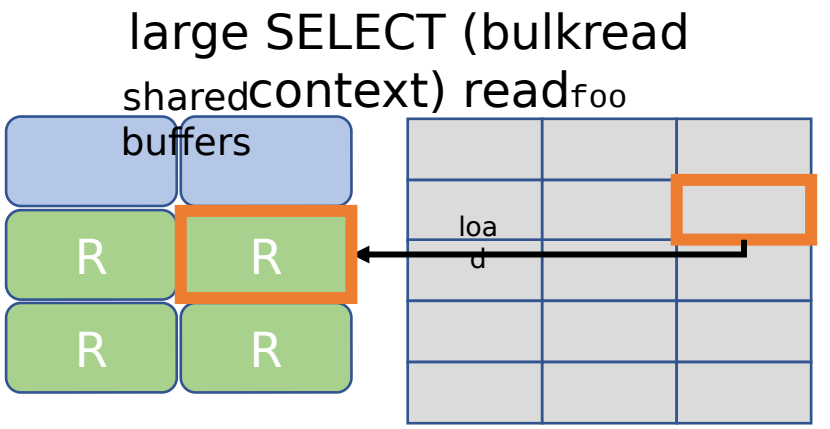


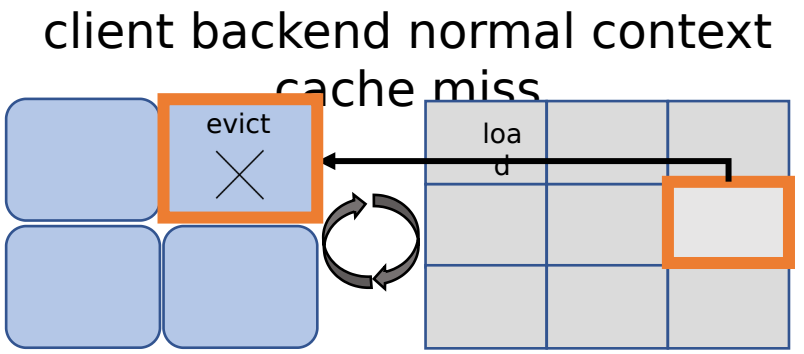
High number of reads during bulk read operations of data not in shared buffers.



Why Track I/O Per Context?

- Shared buffers not used for all I/O
- Large* SELECTs not in shared buffers

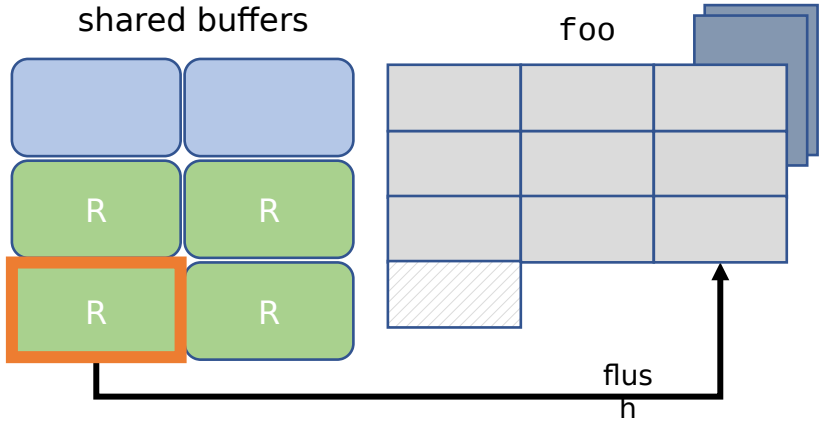




*large = table blocks > shared buffers / 4

Why Count Flushes and Extends Separately?

- COPY FROM does lots of extends
- Extends are normal for bulk writes



Data-Driven Tuning with pg_stat_io

Shared Buffers Too Small

```
  backend_type   | io_object | io_context | reads
-----------------+-----------+------------+-----------
 client backend | relation  | normal     | 128443922
```

- client_backend normal context reads high

Background Writer Too Passive

backend_type	io_object	io_context	writes
client backend	relation	normal	9986222
background writer	relation	normal	776549

- client backend normal context writes high
- background writer normal context writes high

Shared Buffers Not Too Small

```
  backend_type  | io_object | io_context | reads
----------------+-----------+------------+----------
 client backend | relation  | bulkread   |   9986222
 client backend | relation  | normal     |   210
```

- client backend normal context reads not high
- client backend bulkread context reads high

OR

- autovacuum worker vacuum context

Future additions

- I/O timing
- ”bypass” IO

Contact me:
@melanieplageman