Scaling WAL Performance

Eliminate replication lag and reduce startup times with `pg_prefaulter`

Joyent

What is WAL?

W Write

A Ahead

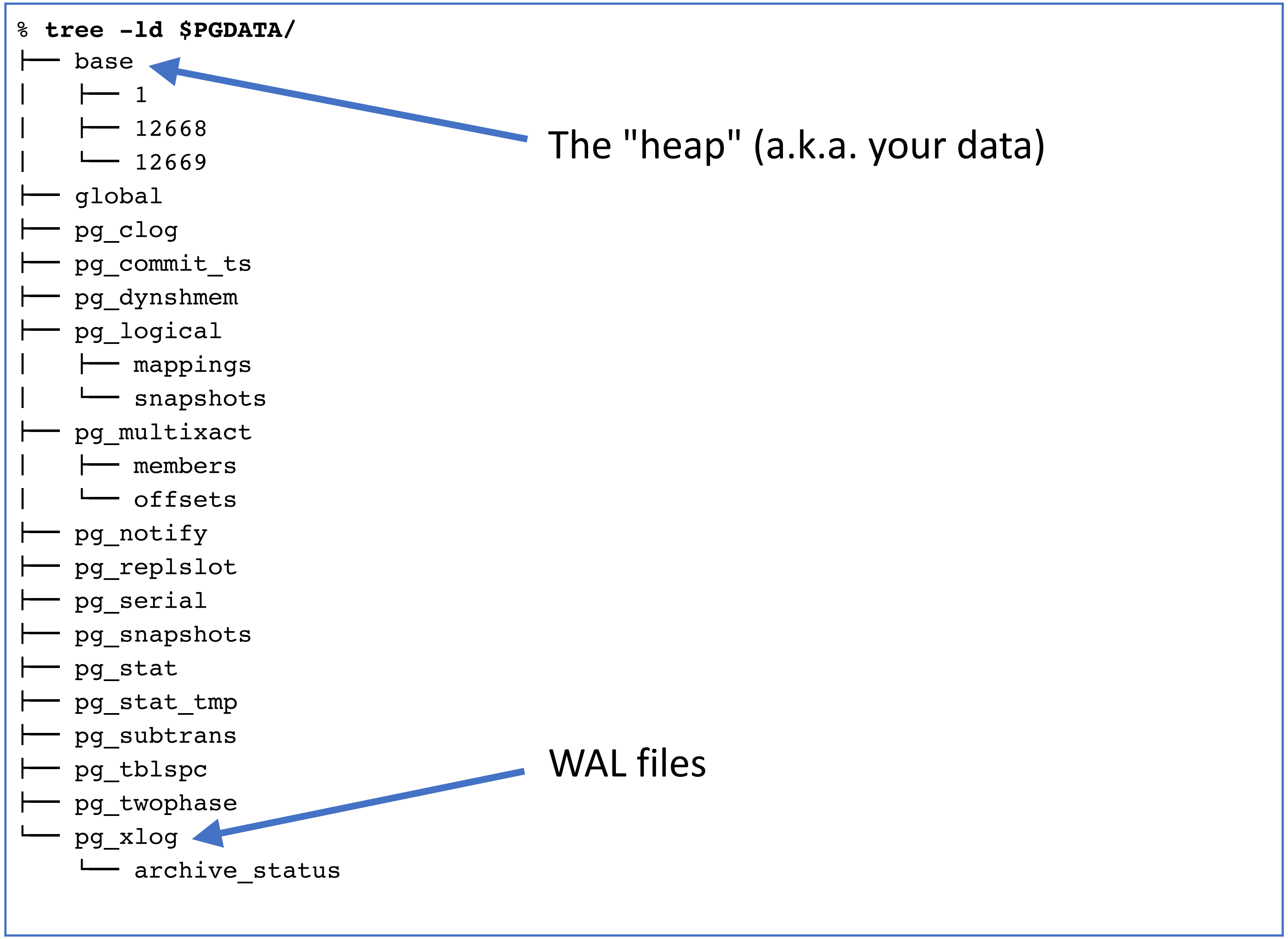
L Log

Where is WAL?

W Write

A Ahead

L Log



```
% tree -ld $PGDATA/
├── base
│   ├── 1
│   ├── 12668
│   └── 12669
├── global
├── pg_clog
├── pg_commit_ts
├── pg_dynshmem
├── pg_logical
│   ├── mappings
│   └── snapshots
├── pg_multixact
│   ├── members
│   └── offsets
├── pg_notify
├── pg_replslot
├── pg_serial
├── pg_snapshots
├── pg_stat
├── pg_stat_tmp
├── pg_subtrans
├── pg_tblspc
├── pg_twophase
└── pg_xlog
    └── archive_status
```

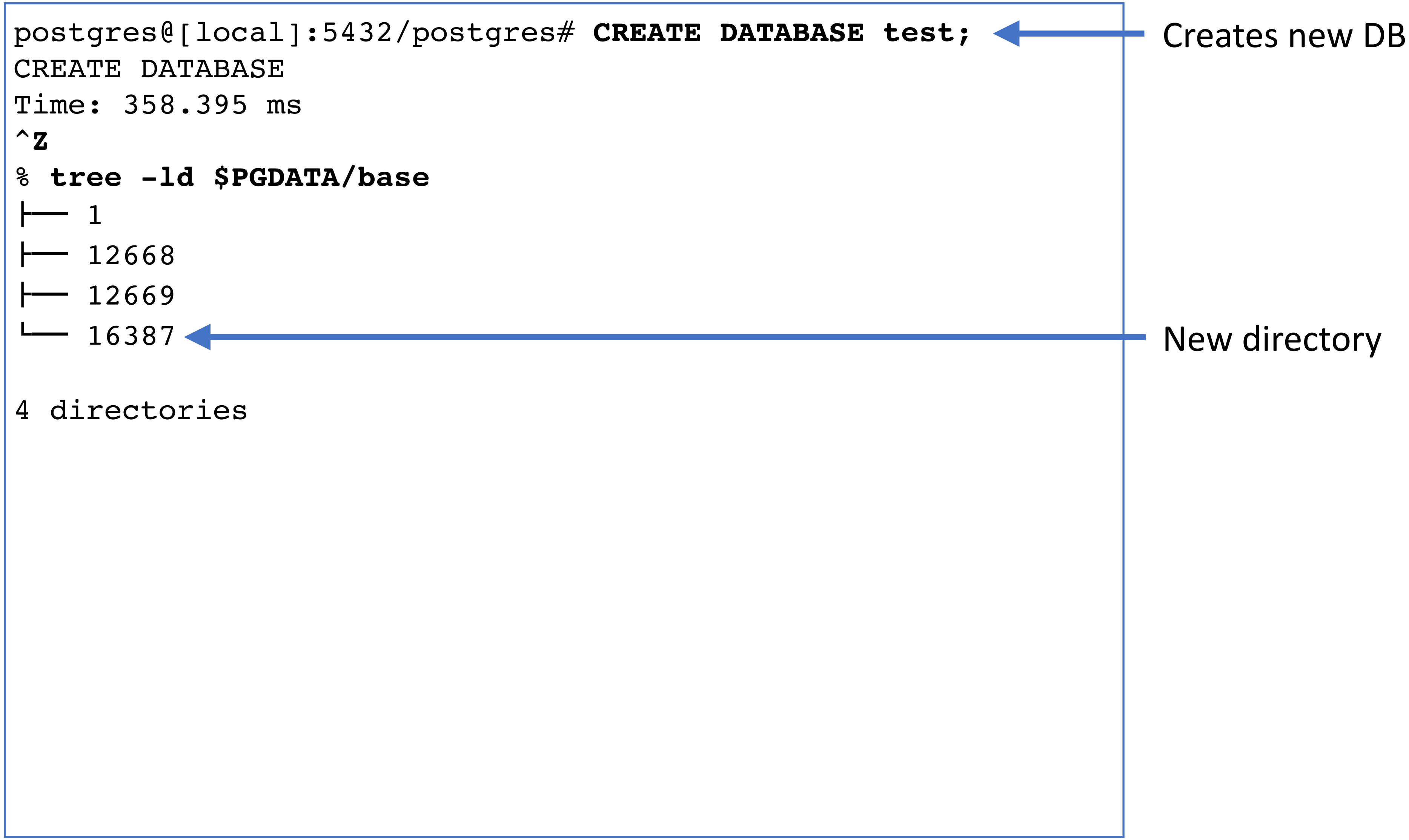
The "heap" (a.k.a. your data)

WAL files

pg_xlog/

```
% ls -lA $PGDATA/pg_xlog/
-rw-------  1 seanc  staff  16777216 May 31 12:02 $PGDATA/pg_xlog/000000010000000000000001
-rw-------  1 seanc  staff  16777216 May 31 12:02 $PGDATA/pg_xlog/000000010000000000000002
-rw-------  1 seanc  staff  16777216 May 31 12:02 $PGDATA/pg_xlog/000000010000000000000003
-rw-------  1 seanc  staff  16777216 May 31 12:02 $PGDATA/pg_xlog/000000010000000000000004
```

Heaps of SQL



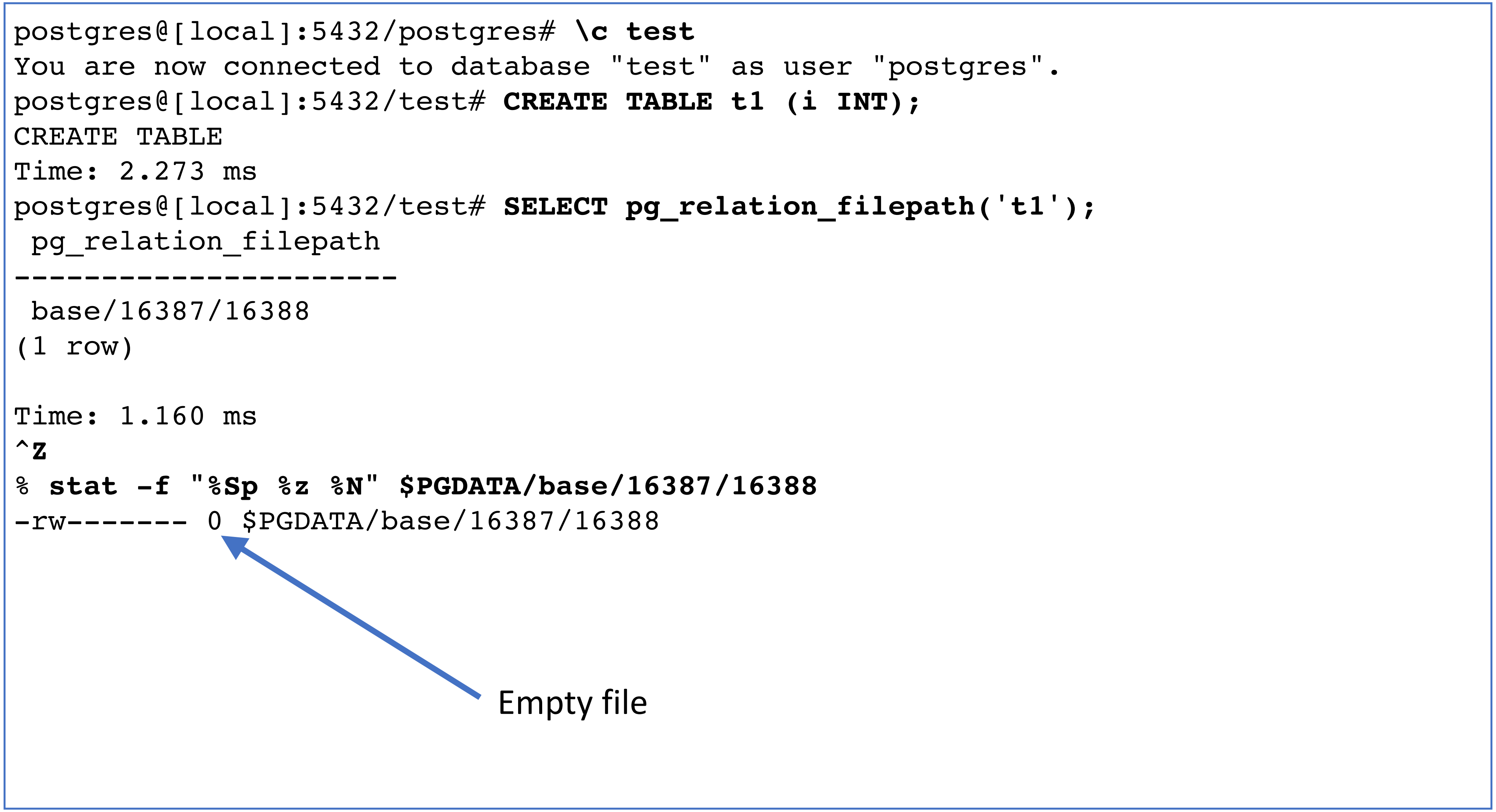
```
postgres@[local]:5432/postgres# CREATE DATABASE test;
CREATE DATABASE
Time: 358.395 ms
^Z
% tree -ld $PGDATA/base
├── 1
├── 12668
├── 12669
└── 16387

4 directories
```

Creates new DB

New directory

Table Data as Files

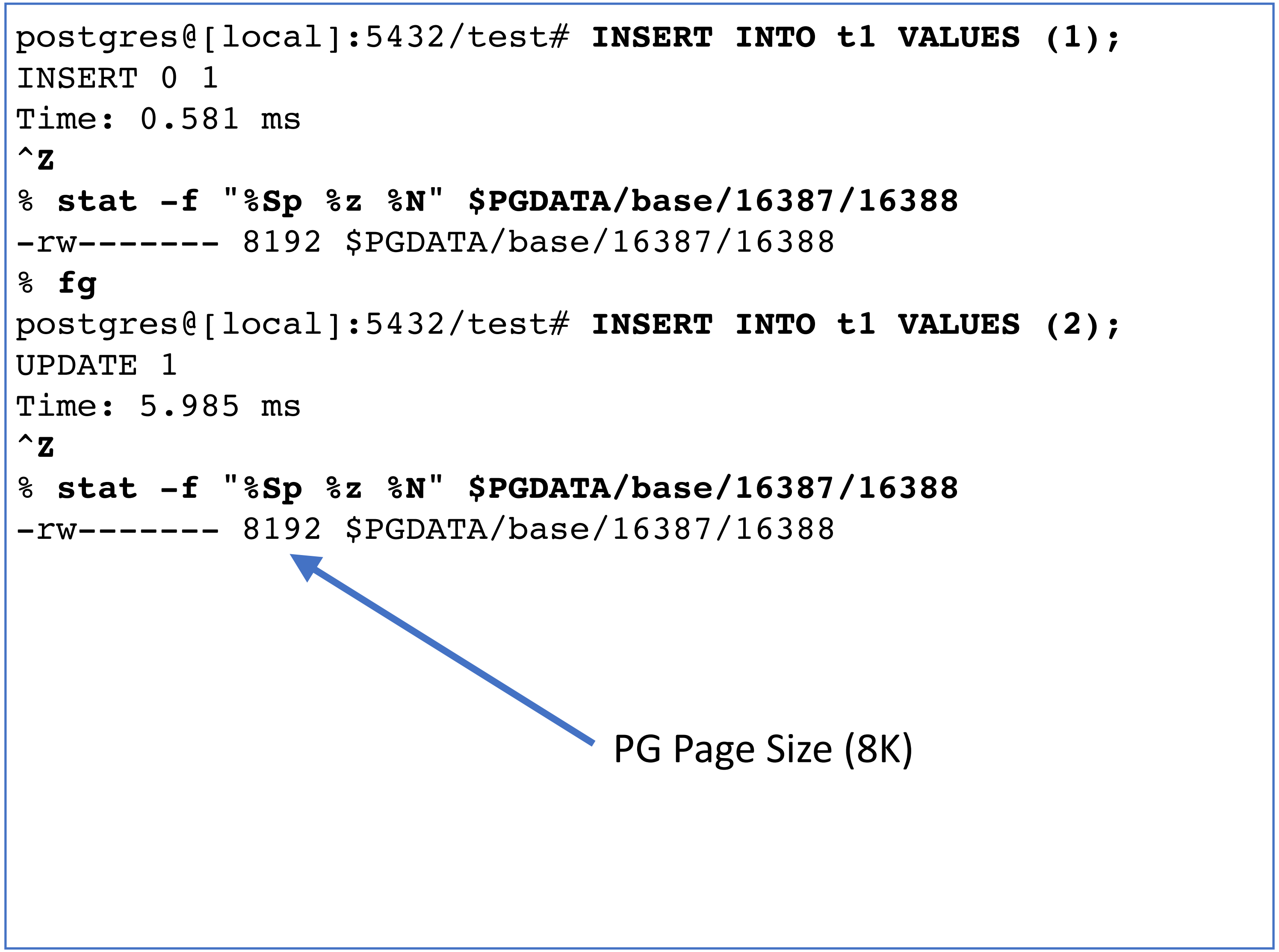


```
postgres@[local]:5432/postgres# \c test
You are now connected to database "test" as user "postgres".
postgres@[local]:5432/test# CREATE TABLE t1 (i INT);
CREATE TABLE
Time: 2.273 ms
postgres@[local]:5432/test# SELECT pg_relation_filepath('t1');
 pg_relation_filepath
----------------------
 base/16387/16388
(1 row)

Time: 1.160 ms
^Z
% stat -f "%Sp %z %N" $PGDATA/base/16387/16388
-rw------- 0 $PGDATA/base/16387/16388
```

Empty file

Physical Storage of Data



```
postgres@[local]:5432/test# INSERT INTO t1 VALUES (1);
INSERT 0 1
Time: 0.581 ms
^Z
% stat -f "%Sp %z %N" $PGDATA/base/16387/16388
-rw------- 8192 $PGDATA/base/16387/16388
% fg
postgres@[local]:5432/test# INSERT INTO t1 VALUES (2);
UPDATE 1
Time: 5.985 ms
^Z
% stat -f "%Sp %z %N" $PGDATA/base/16387/16388
-rw------- 8192 $PGDATA/base/16387/16388
```

PG Page Size (8K)

How does the WAL relate to the heap?

W Write

A Ahead

L Log

1. Modifications to the heap are appended to the WAL first
2. Committed transactions in the WAL are applied in the heap during a `CHECKPOINT`
3. Crash recovery walks backwards through the WAL to the last completed `CHECKPOINT` (then rolls forward through committed transactions to prevent data loss)

Things to keep in mind

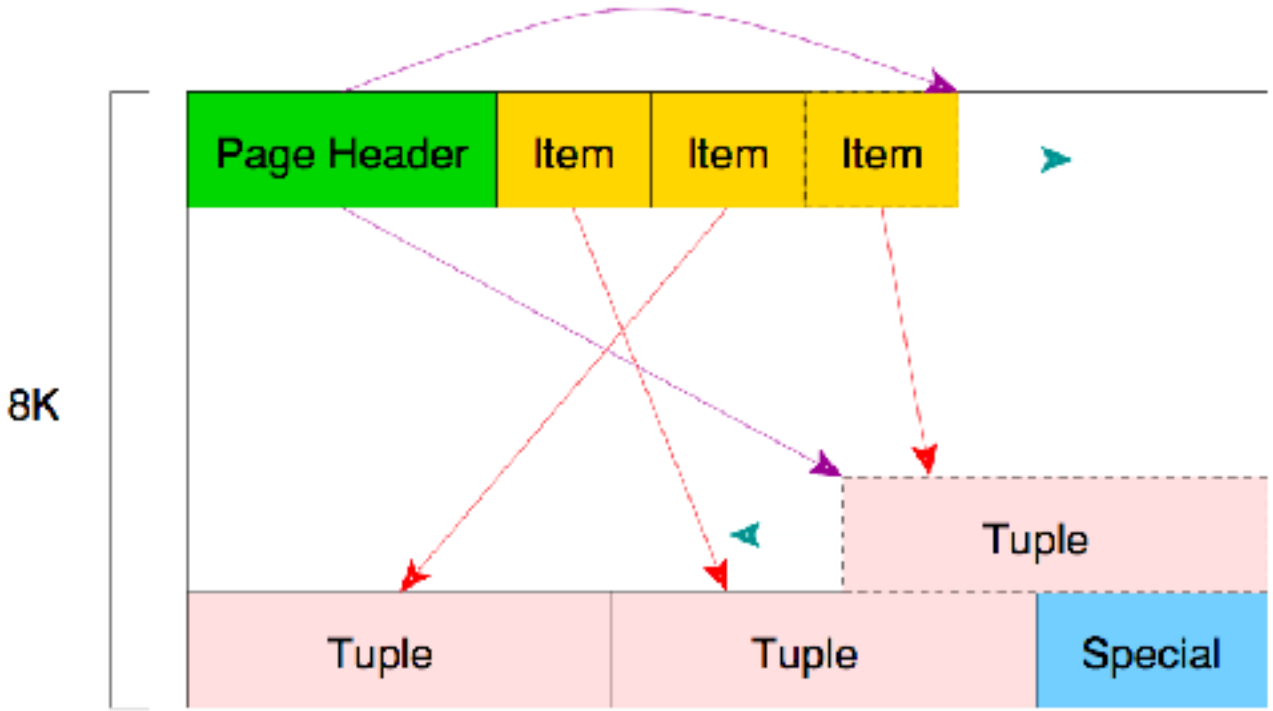
W Write

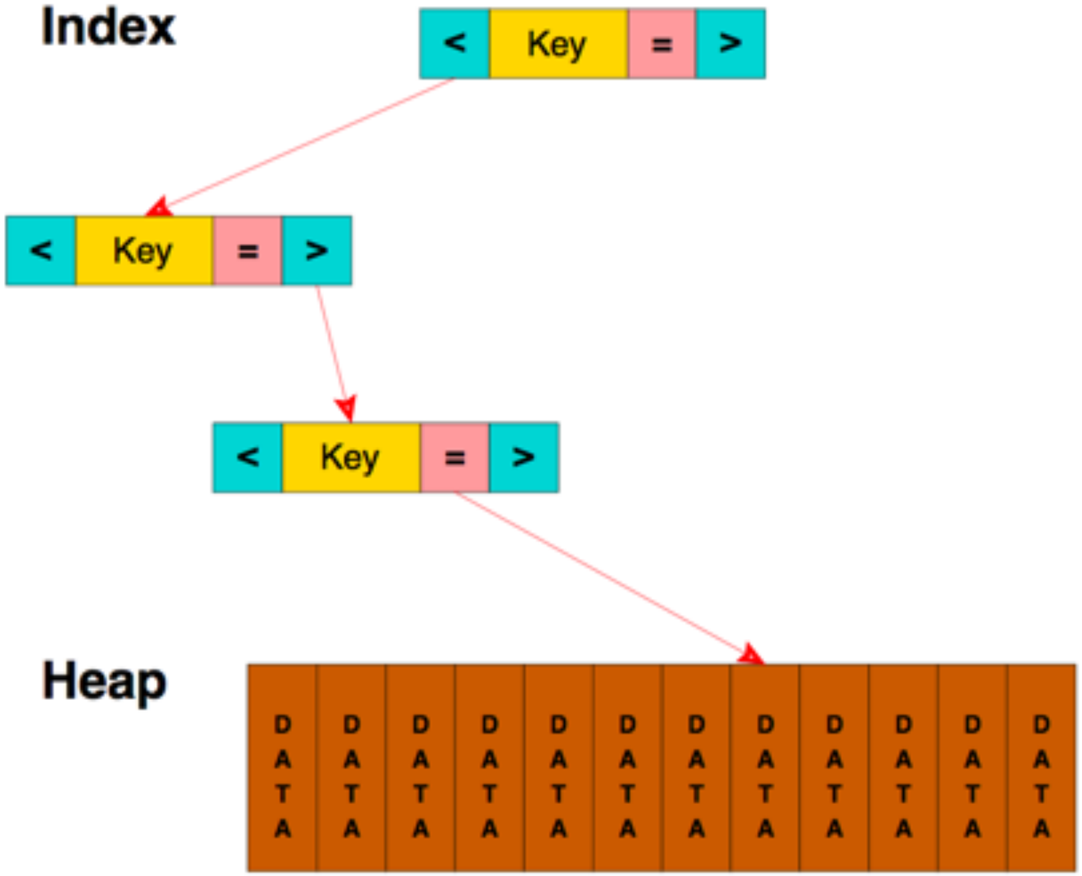
A Ahead

L Log

1. The WAL receives sequential append operations
2. WAL can be read forward and backwards
3. Recently written transaction data exists only in memory and in WAL
4. WAL is *probably* your performance friend (deferred random IO against the heap)

Tuples, Pages, Relations, and you!





https://momjian.us/main/writings/pgsql/internalpics.pdf

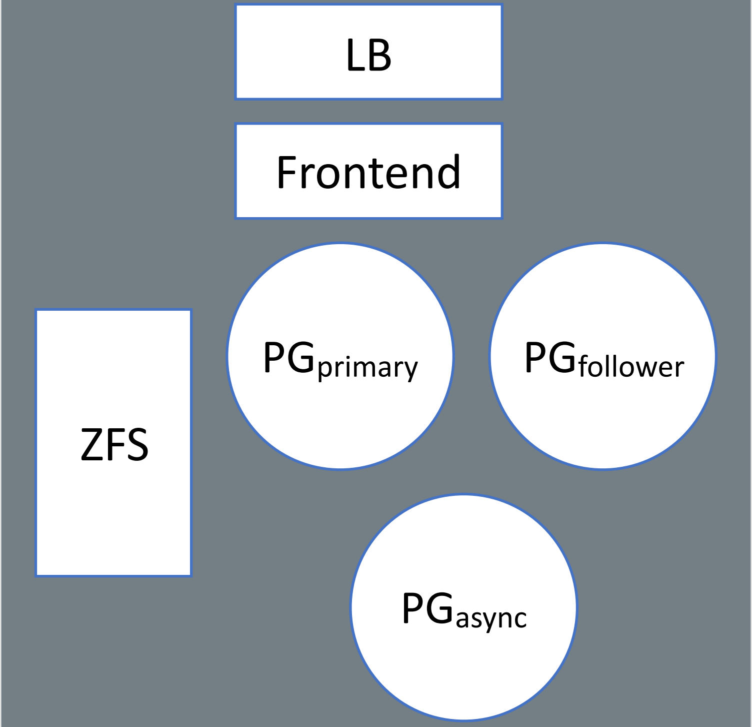
https://momjian.us/main/writings/pgsql/mvcc.pdf

https://www.postgresql.org/docs/current/static/wal.html

Why do you care about apply lag?

```
synchronous_commit="remote_write"
```

Manta is an HTTP Frontend to ZFS



- Files distributed across different ZFS storage servers
- Metadata stored in PostgreSQL

Caution: shapes in the diagram may appear more simple than they actually are

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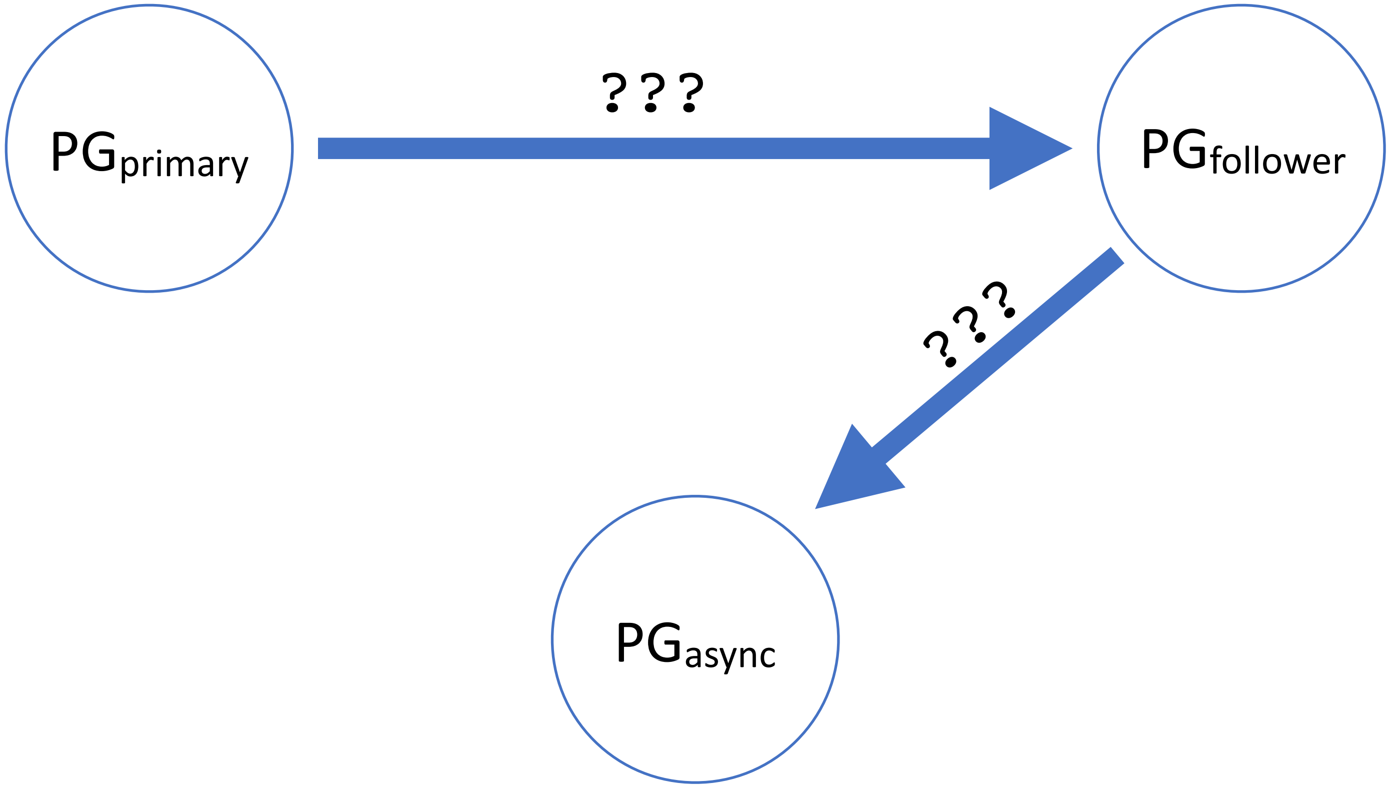
PostgreSQL Replication is Awesome

```
synchronous_commit="XXX"
```



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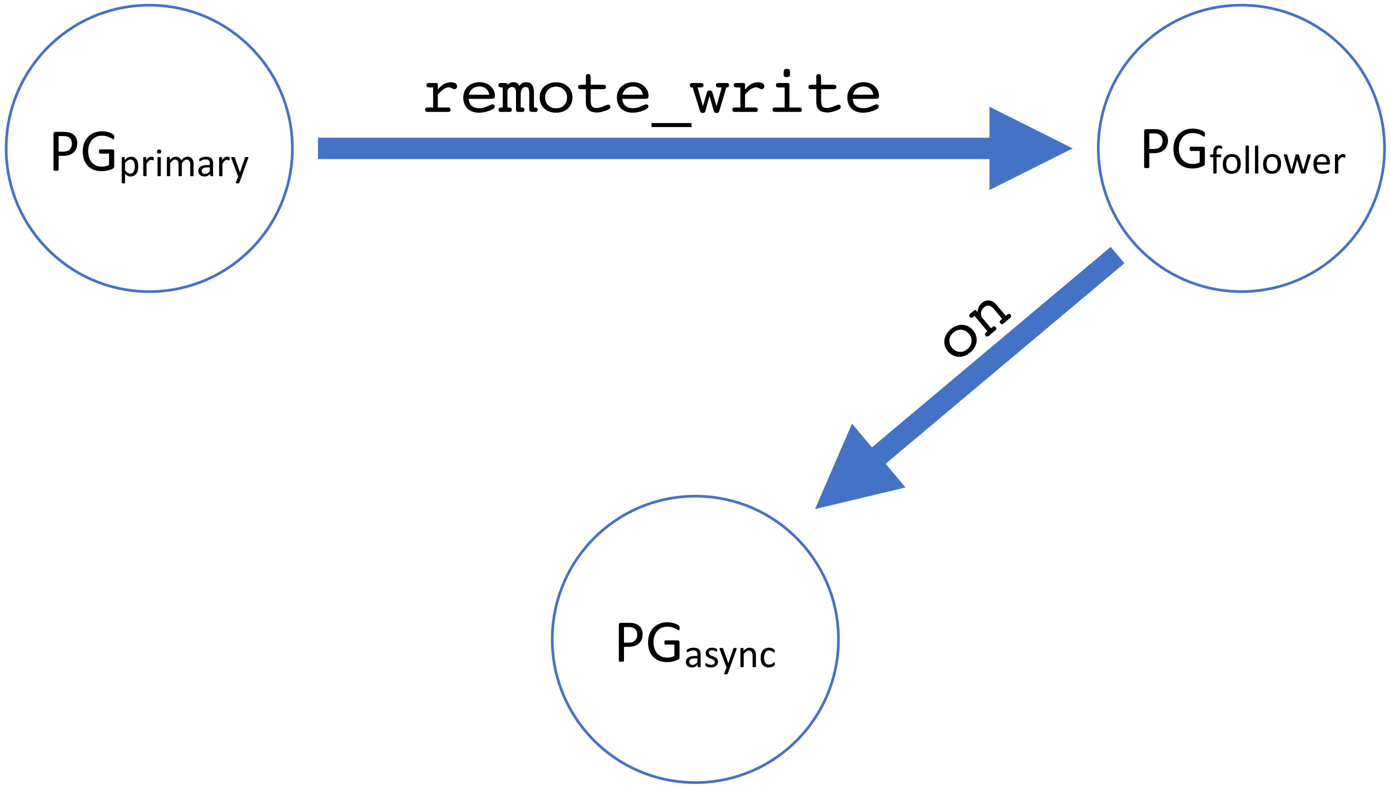
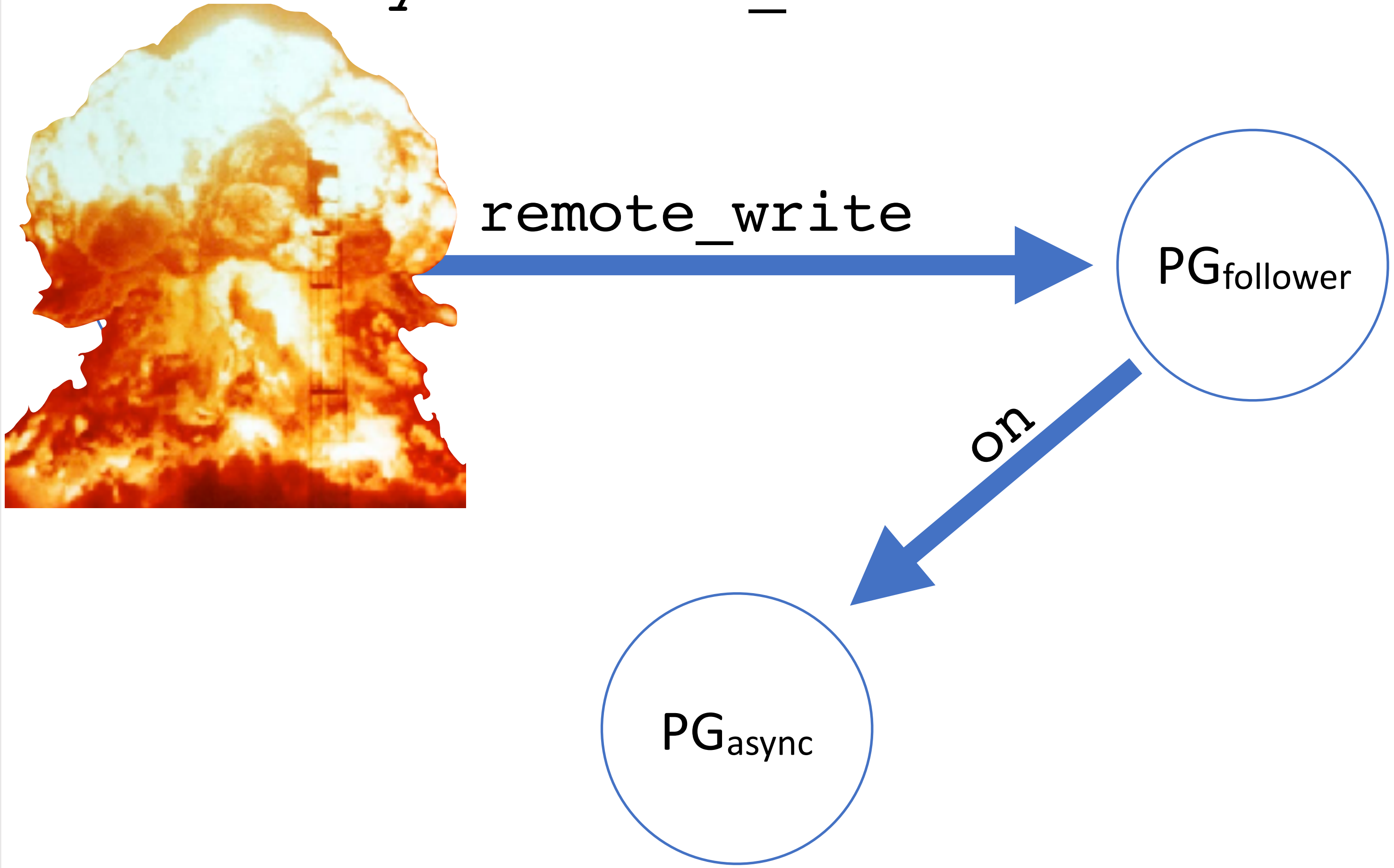
ez-mode HA Durability FTW

```
synchronous_commit="XXX"
```



Hardware fails right on time, every time

`synchronous_commit="XXX"`



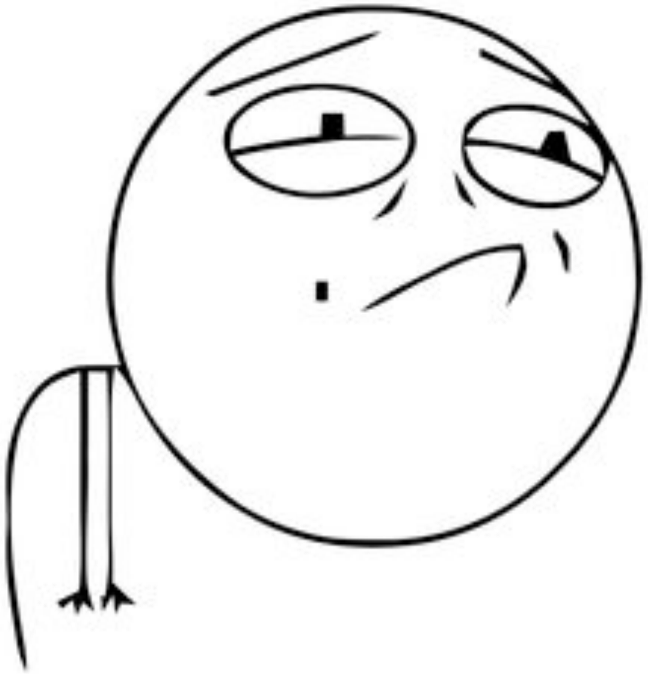
`remote_write`

PG$_{\text{follower}}$

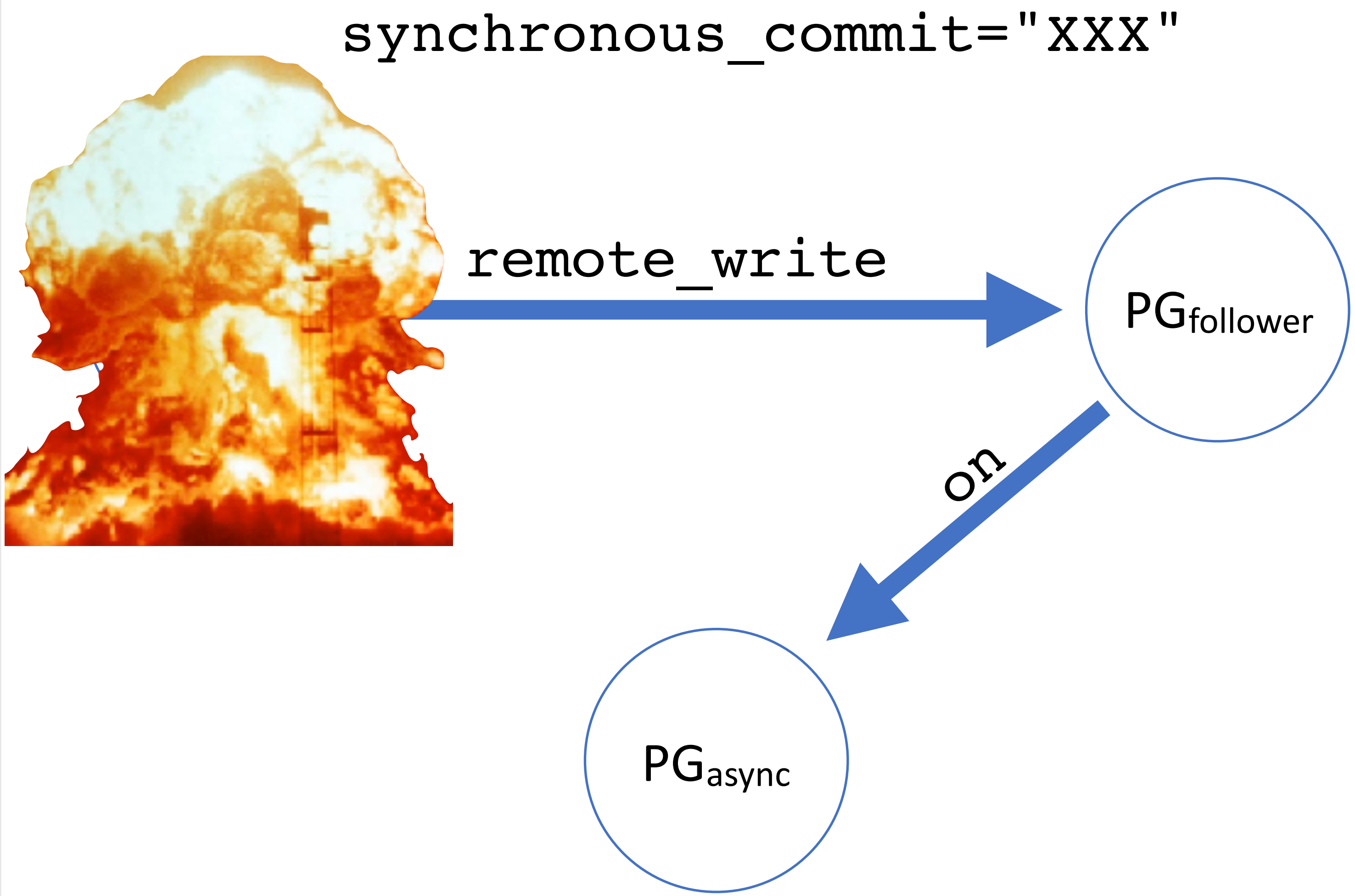
`on`

PG$_{\text{async}}$

CAP: Can haz A?



This isn't a hardware problem



synchronous_commit="XXX"

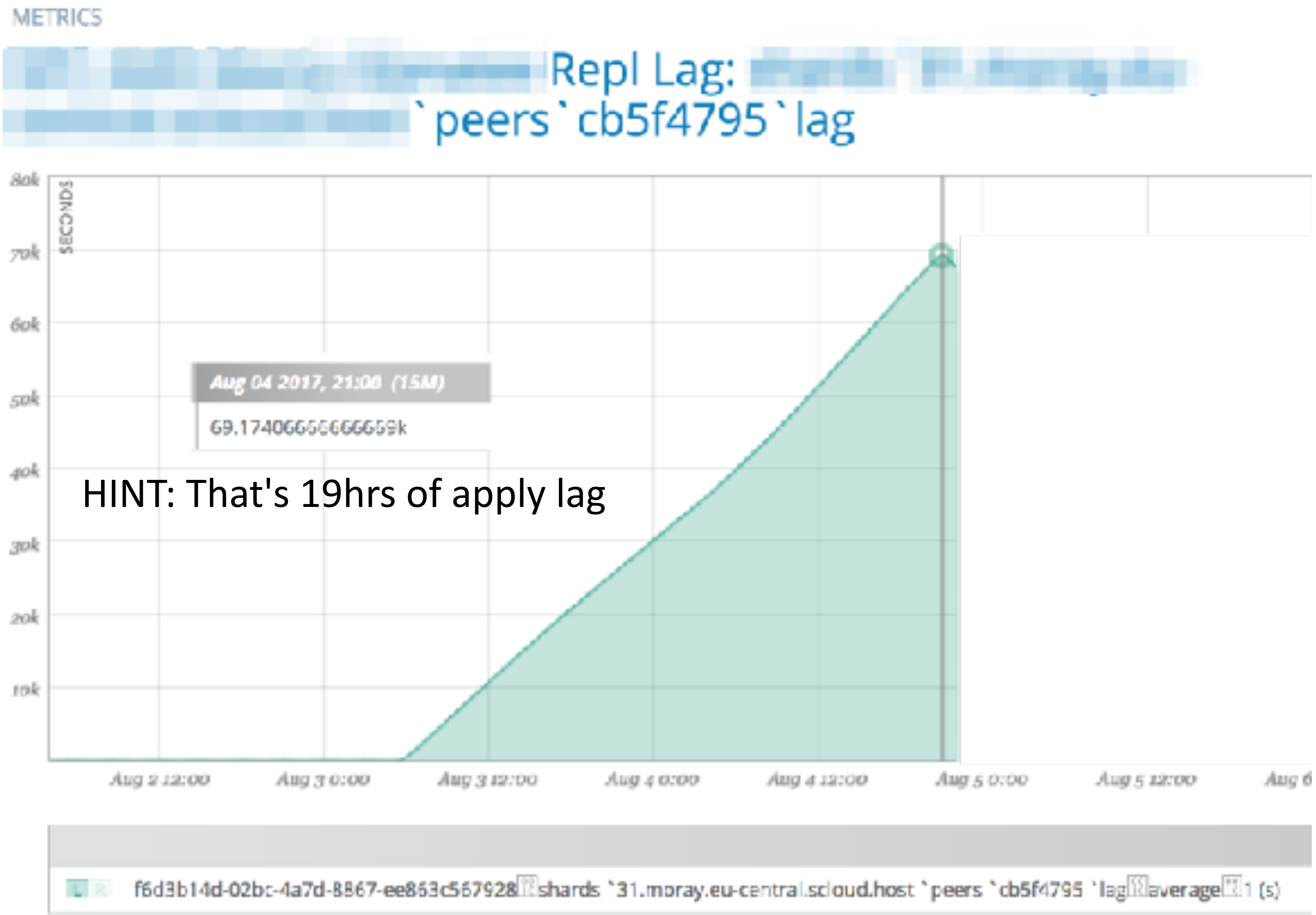
remote_write

$PG_{follower}$

on

PG_{async}

It's gunna be a while, m'kay?



METRICS

[redacted] Repl Lag: [redacted] `peers`cb5f4795`lag

Aug 04 2017, 21:00 (15M)

69.17406666666659k

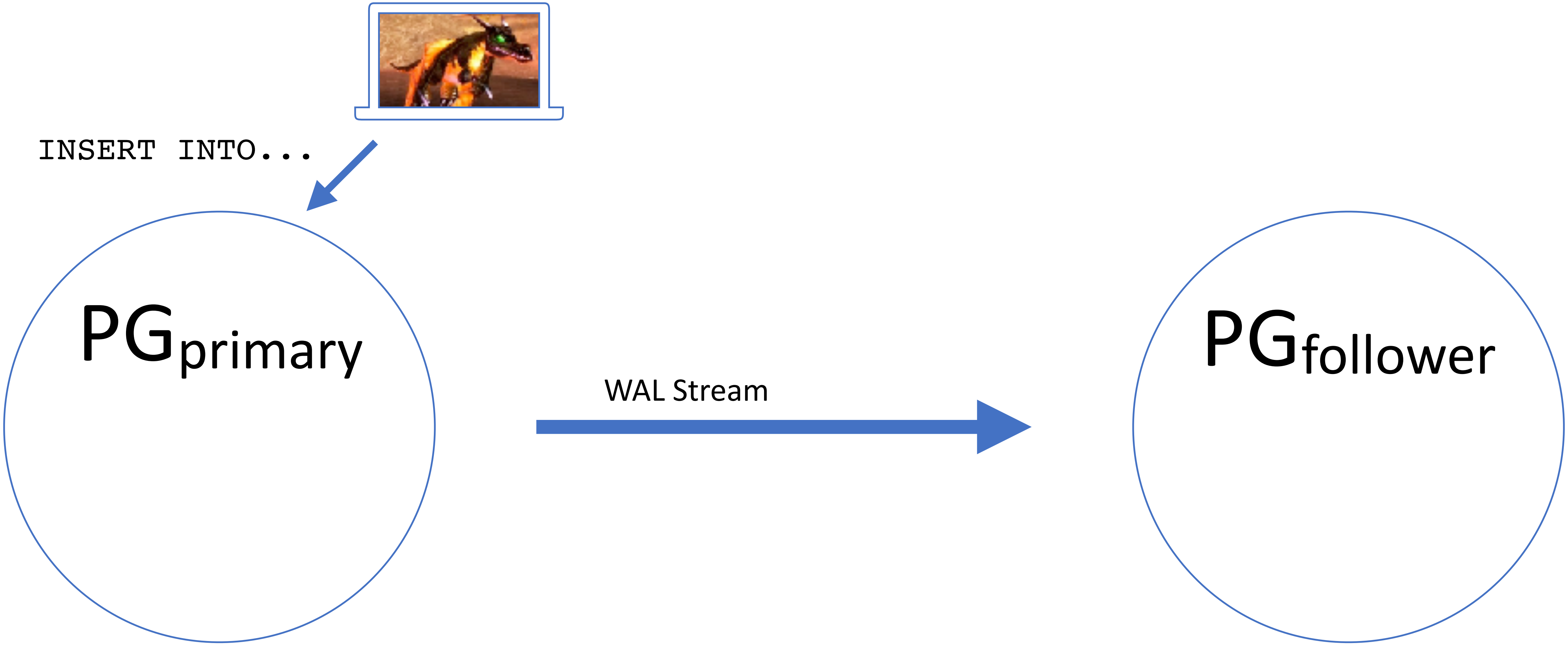
f6d3b14d-02bc-4a7d-8867-ee853c567928shards `31.moray.eu-central.scloud.host `peers `cb5f4795 `lagaverage1 (s)

HINT: That's 19hrs of apply lag

How did we get into this mess?

Cloudy with a chance of single threaded execution

Context is everything



INSERT INTO...

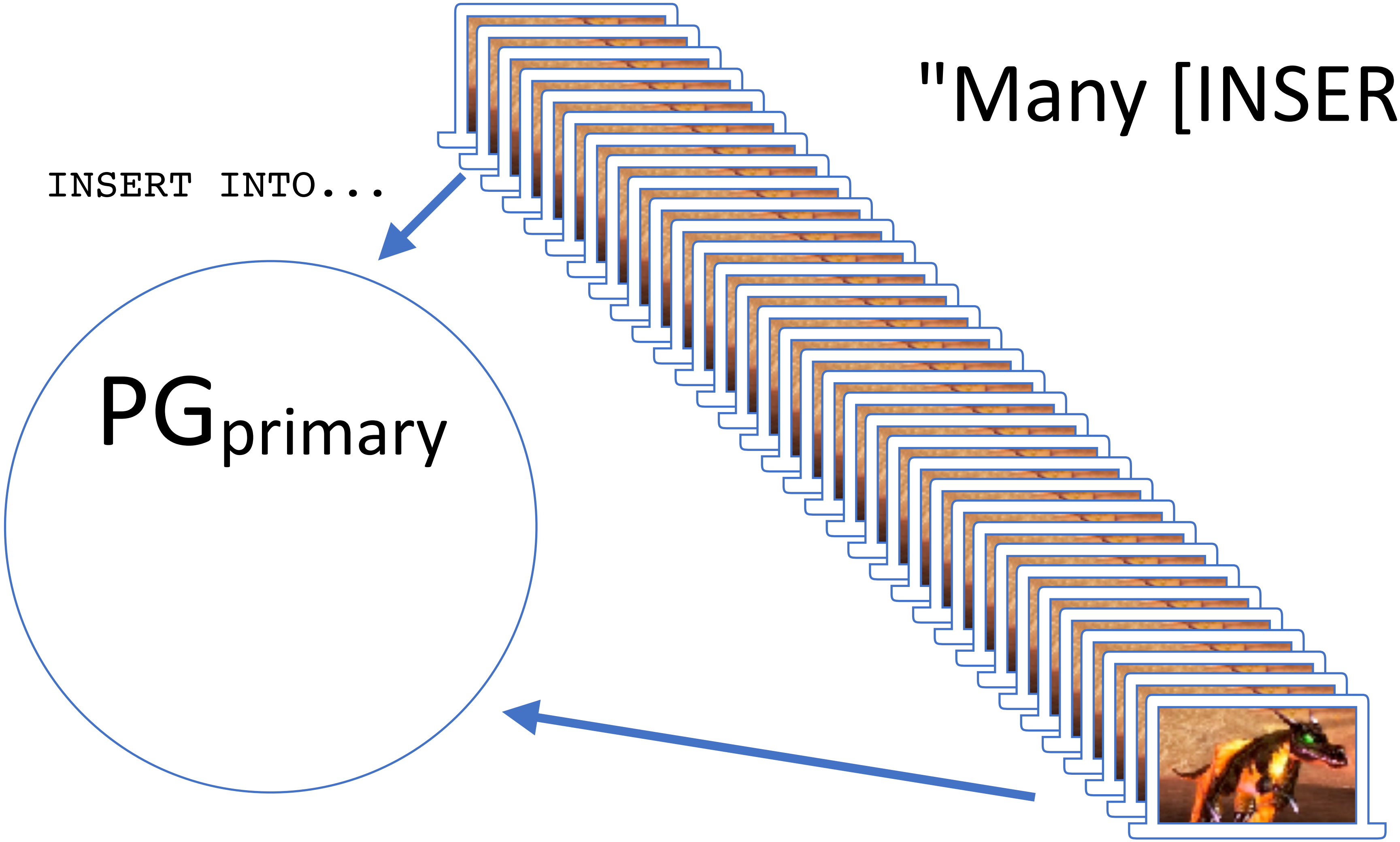
$\text{PG}_{\text{primary}}$

WAL Stream

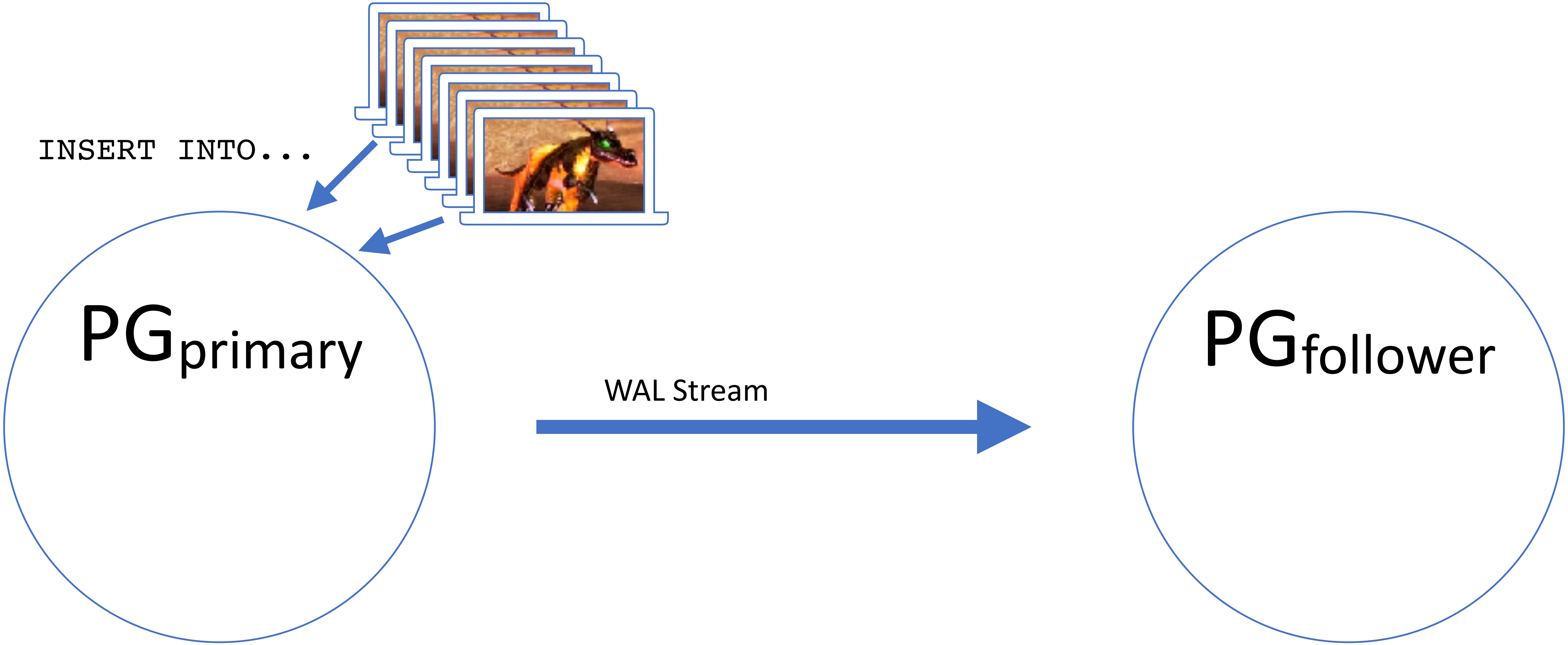
$\text{PG}_{\text{follower}}$

-50K DKP

"Many [INSERTS], handle it!"



Context is everything?



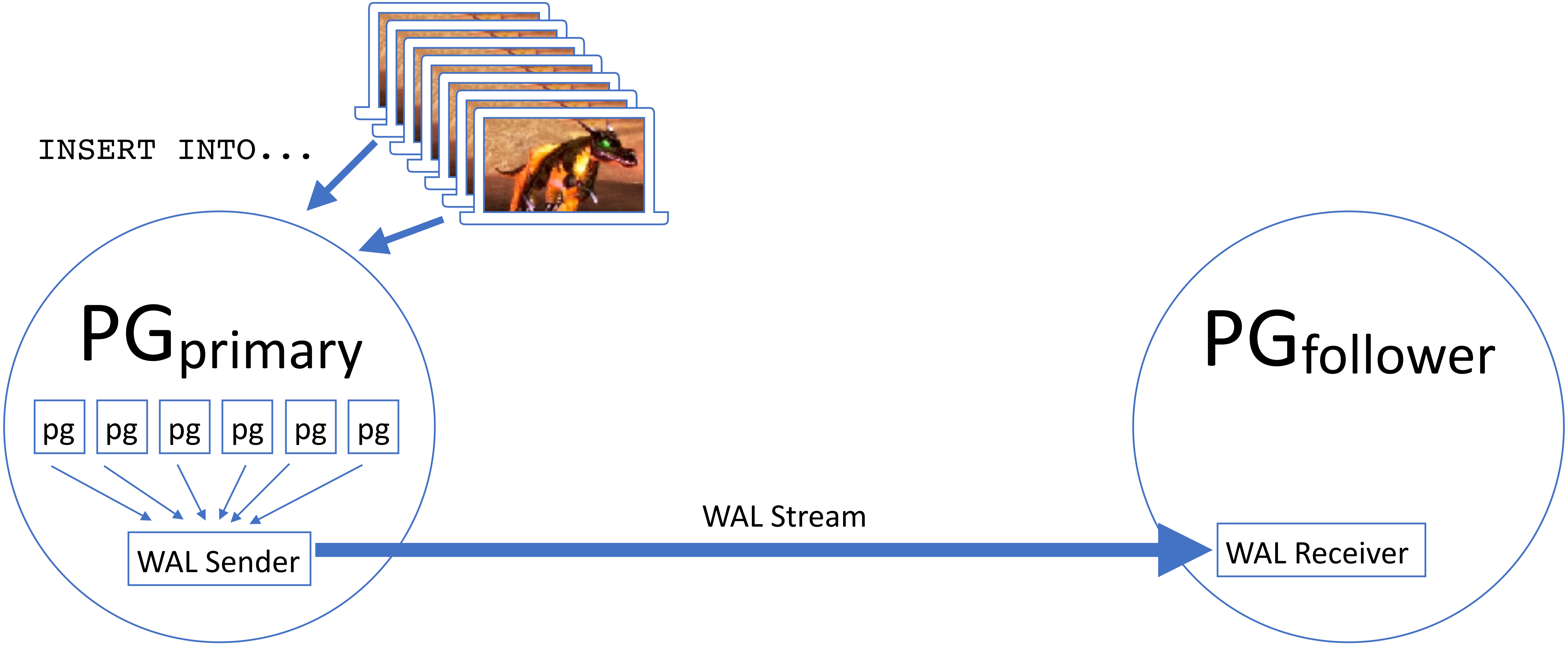
INSERT INTO...

$PG_{primary}$

WAL Stream

$PG_{follower}$

OH HAI!



INSERT INTO...

PG primary

pg pg pg pg pg pg

WAL Sender

WAL Stream

PG follower

WAL Receiver

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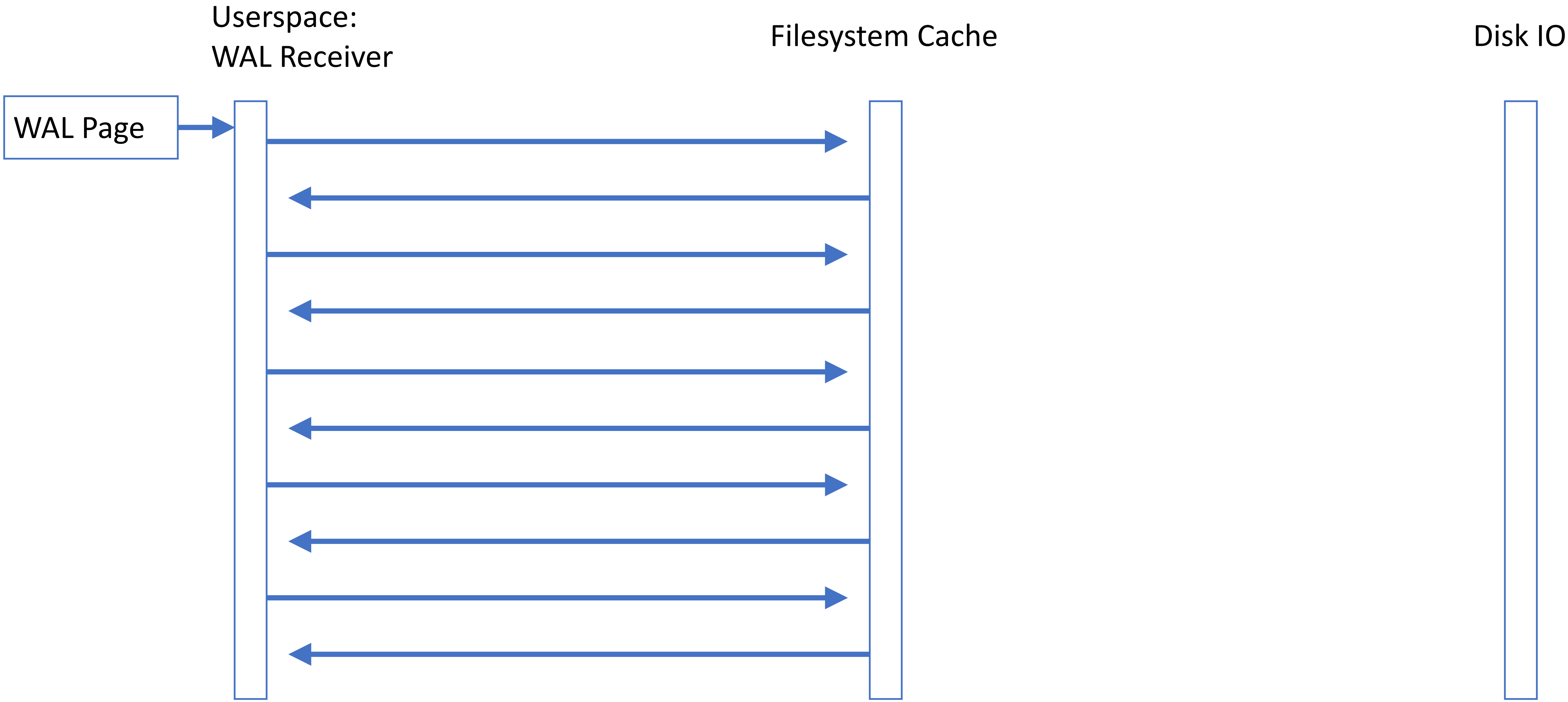
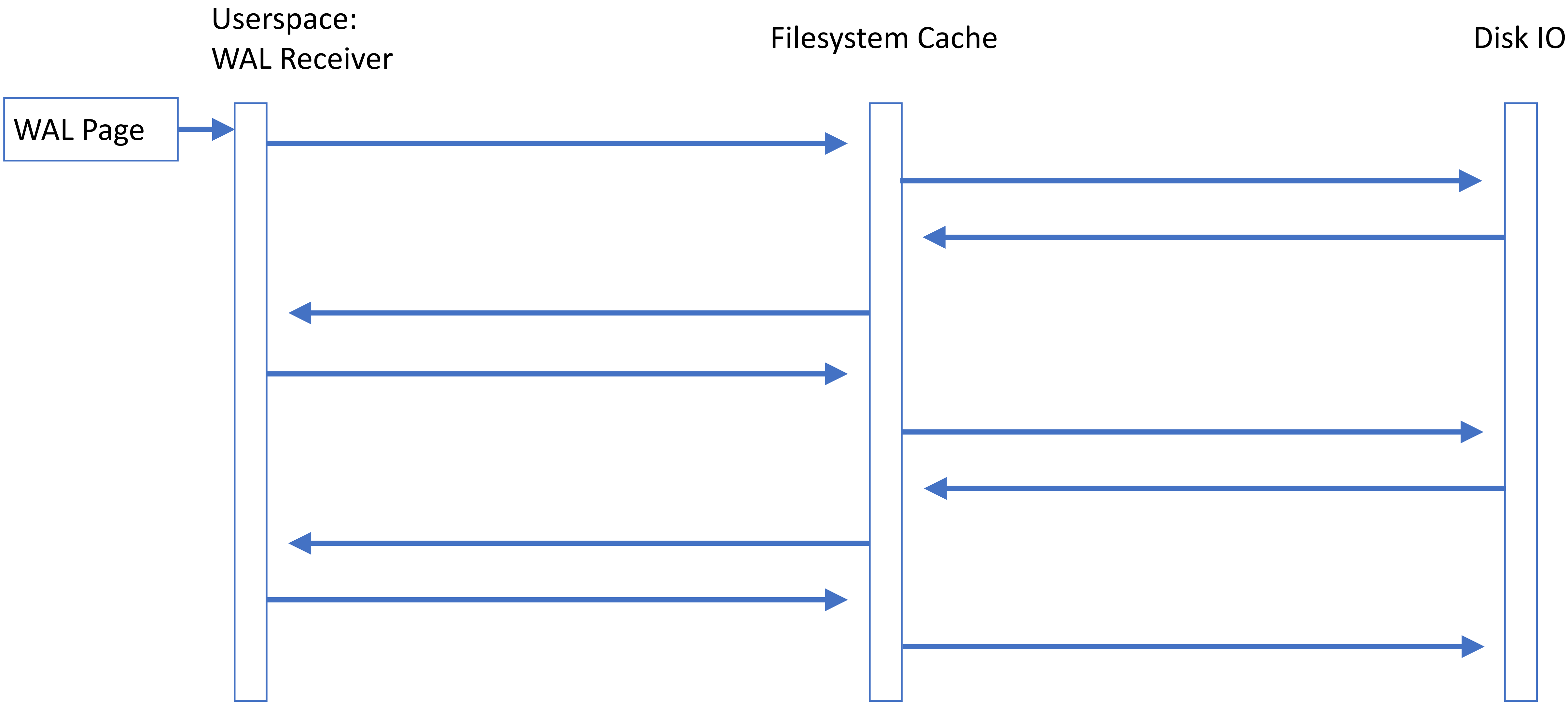
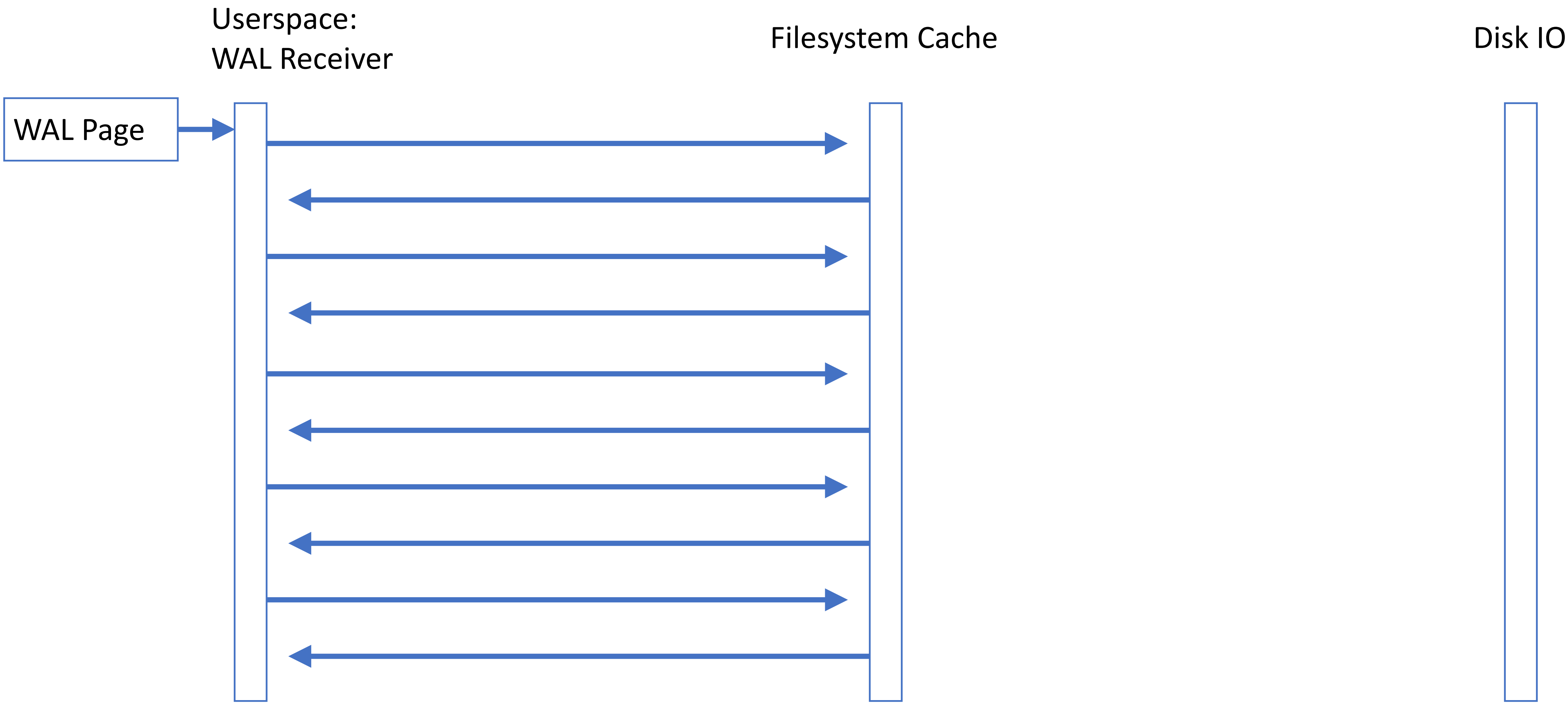
If we're lucky...



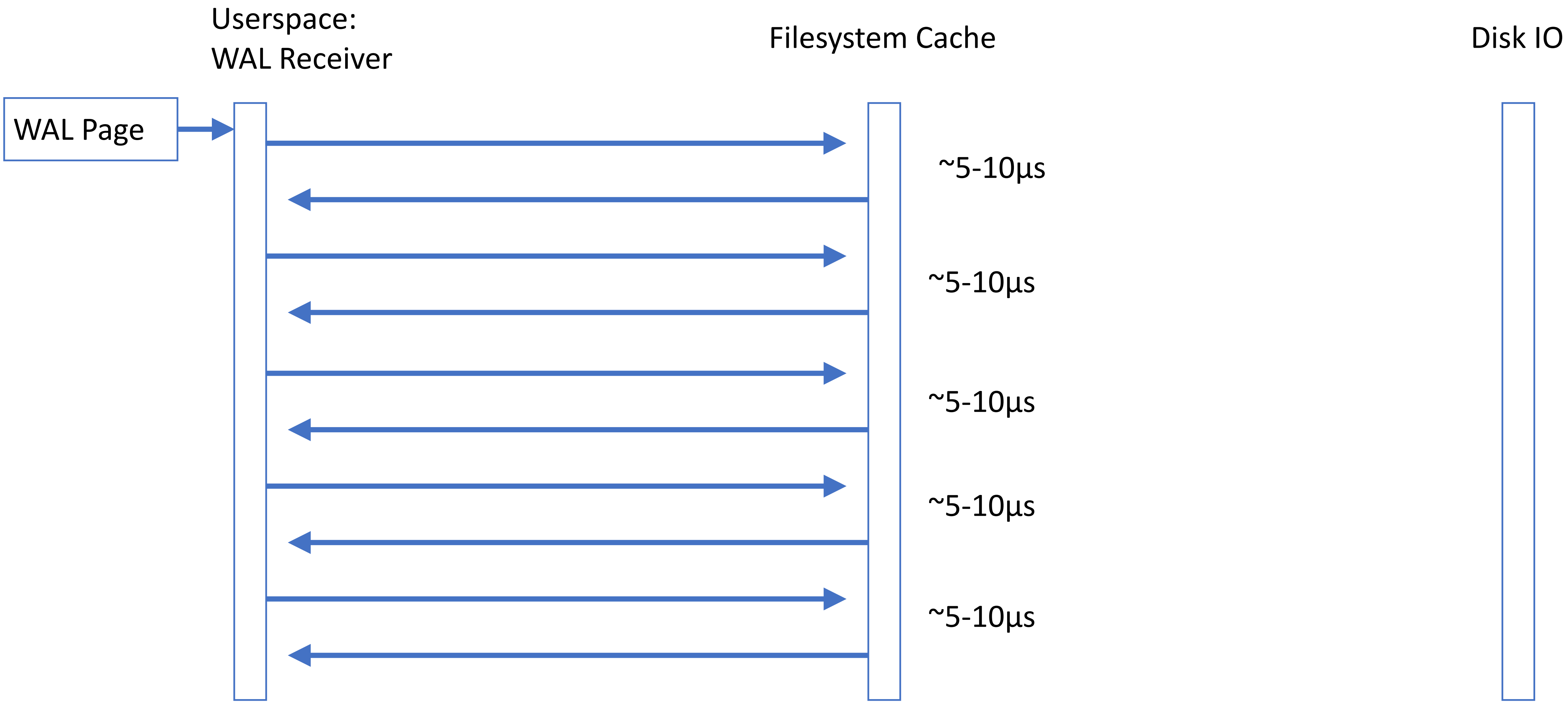
But we're not because **EREALITY**



And I lied to you. This:



...is actually this.



Userspace:
WAL Receiver

Filesystem Cache

Disk IO

WAL Page

~5-10µs

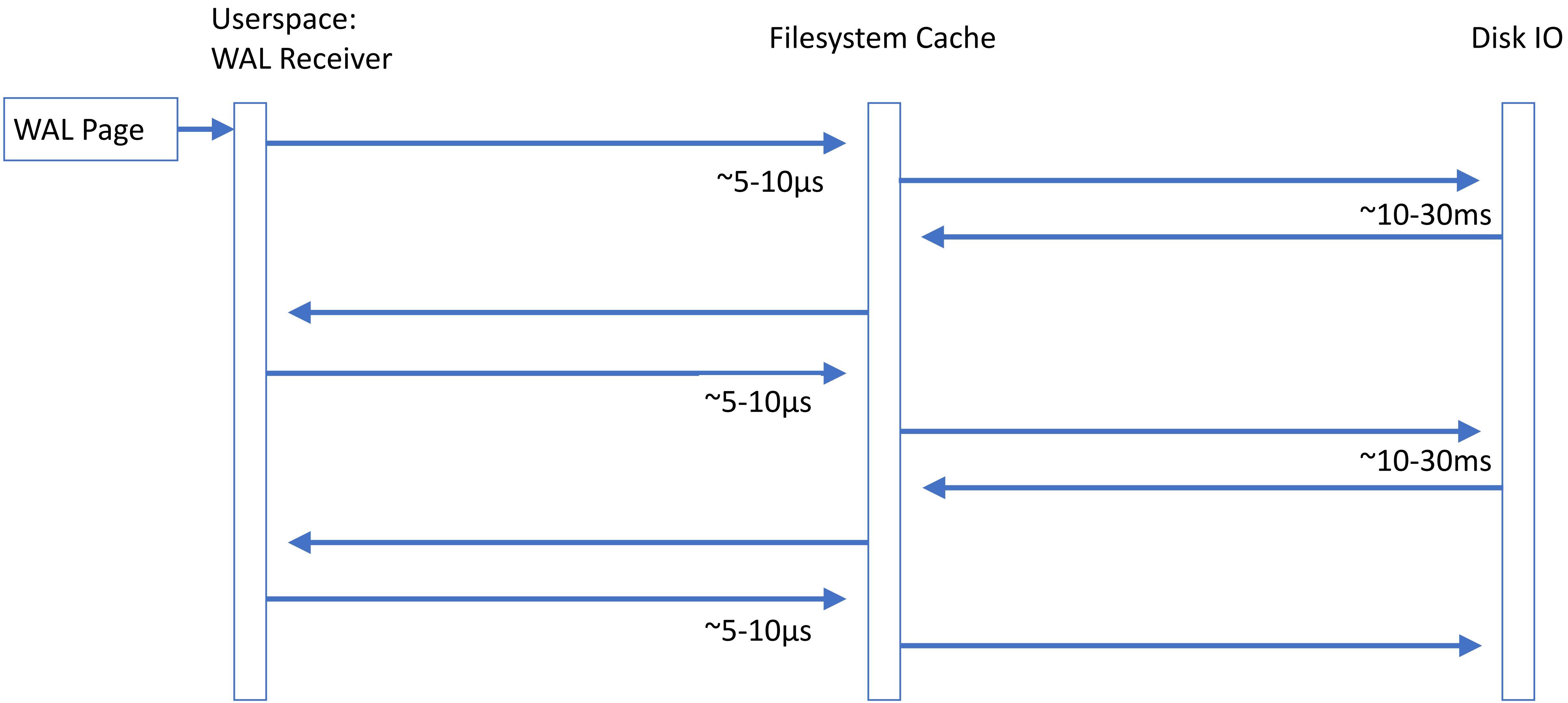
~5-10µs

~5-10µs

~5-10µs

~5-10µs

And this isn't drawn to scale...



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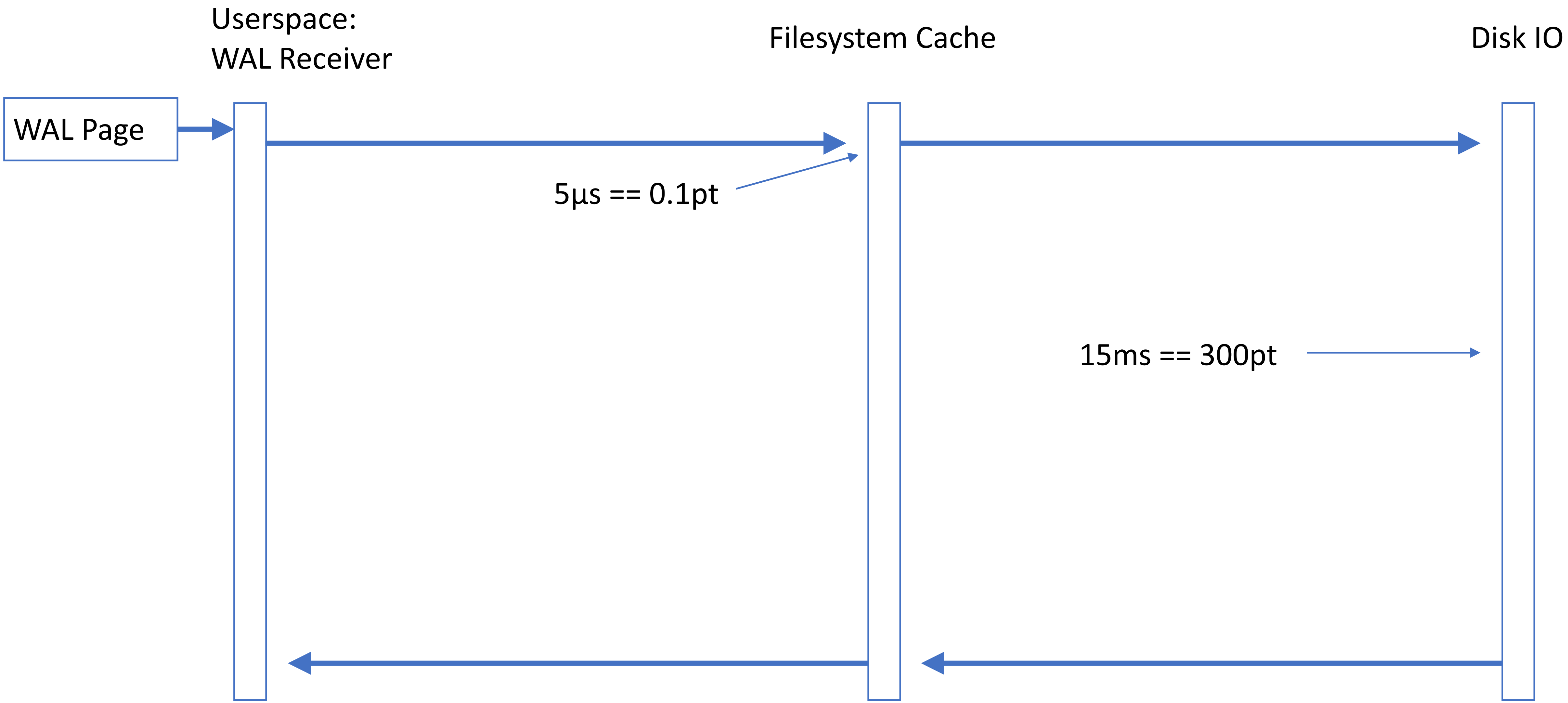
Pixel Correct Timeline



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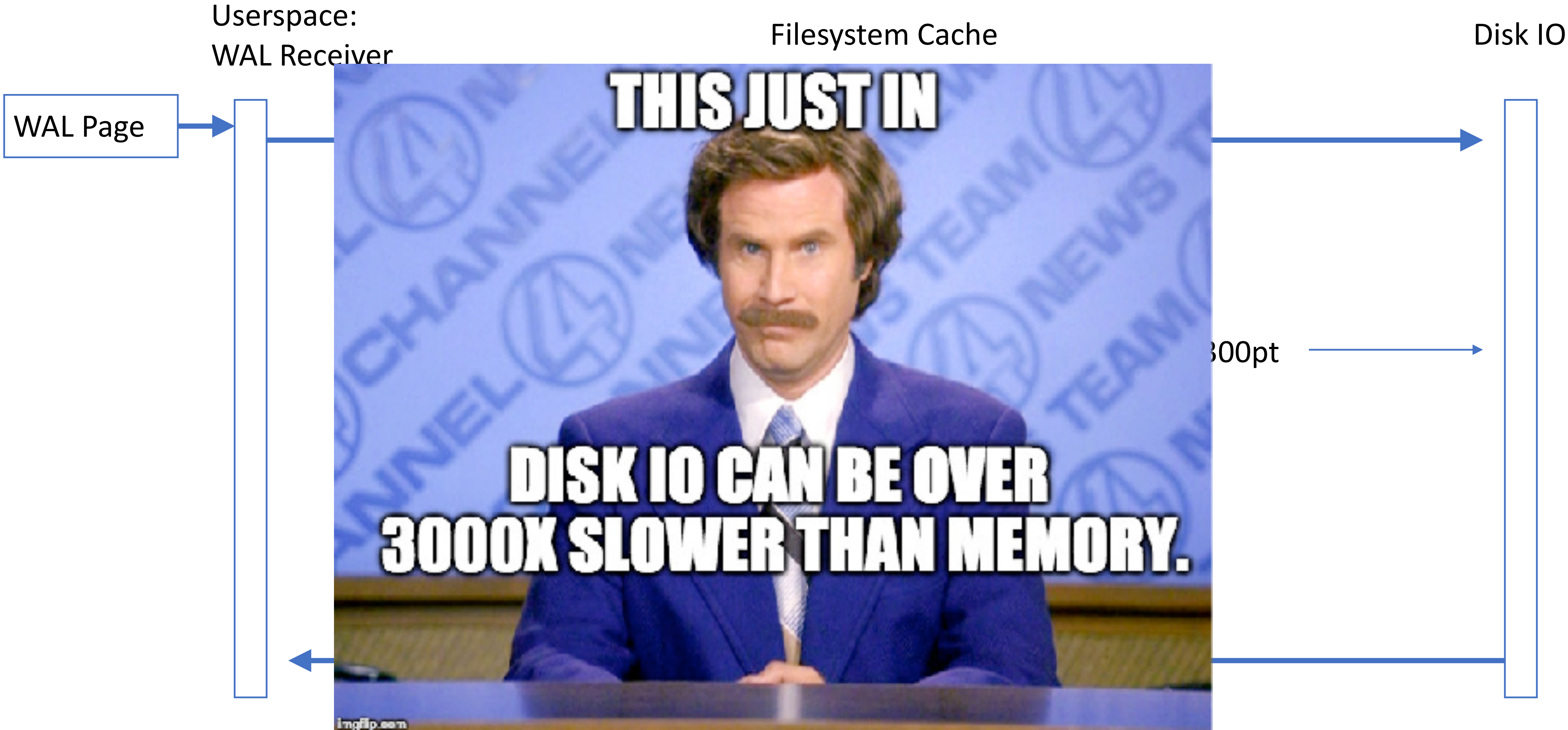
Pixel Correct Timeline



Userspace:
WAL Receiver

Filesystem Cache

Disk IO

WAL Page

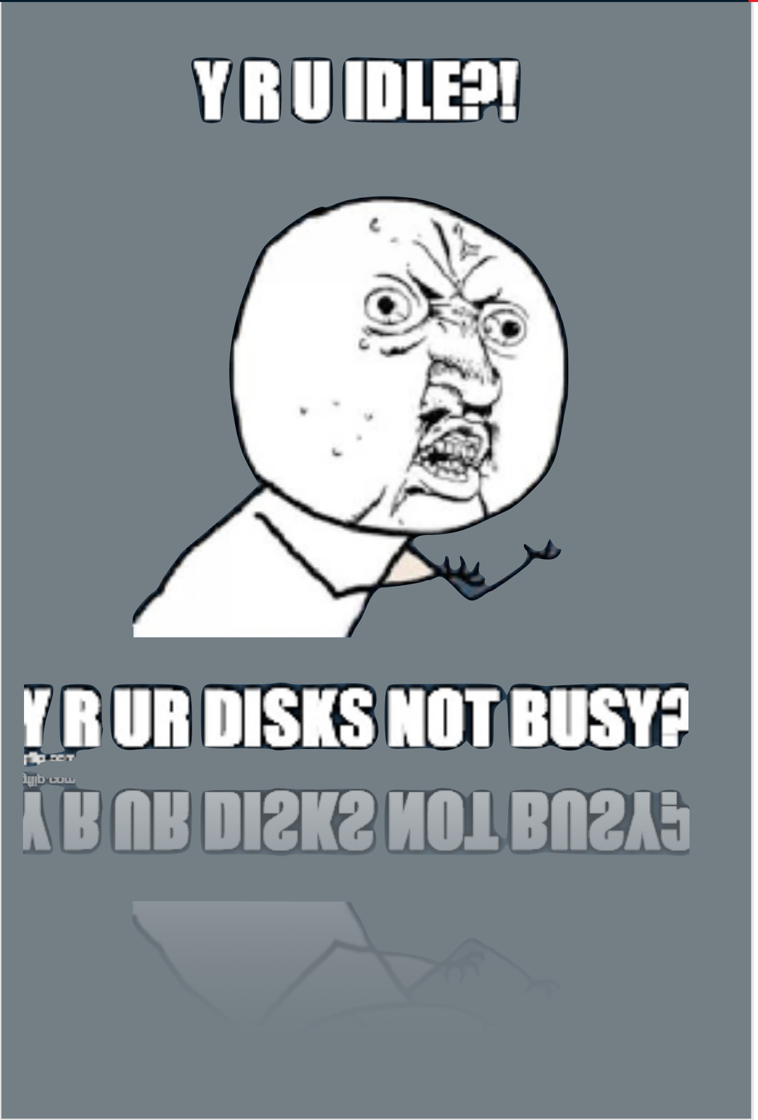
300pt

And that RAID array you have? It's Idle.

Storage math:

150 iops/disk * 16 disks = ~2400 IOPS (if perfectly scheduled)

And that RAID array you have?
It's Idle.



- Storage math:
  150 iops/disk * 16 disks = ~2400 IOPS

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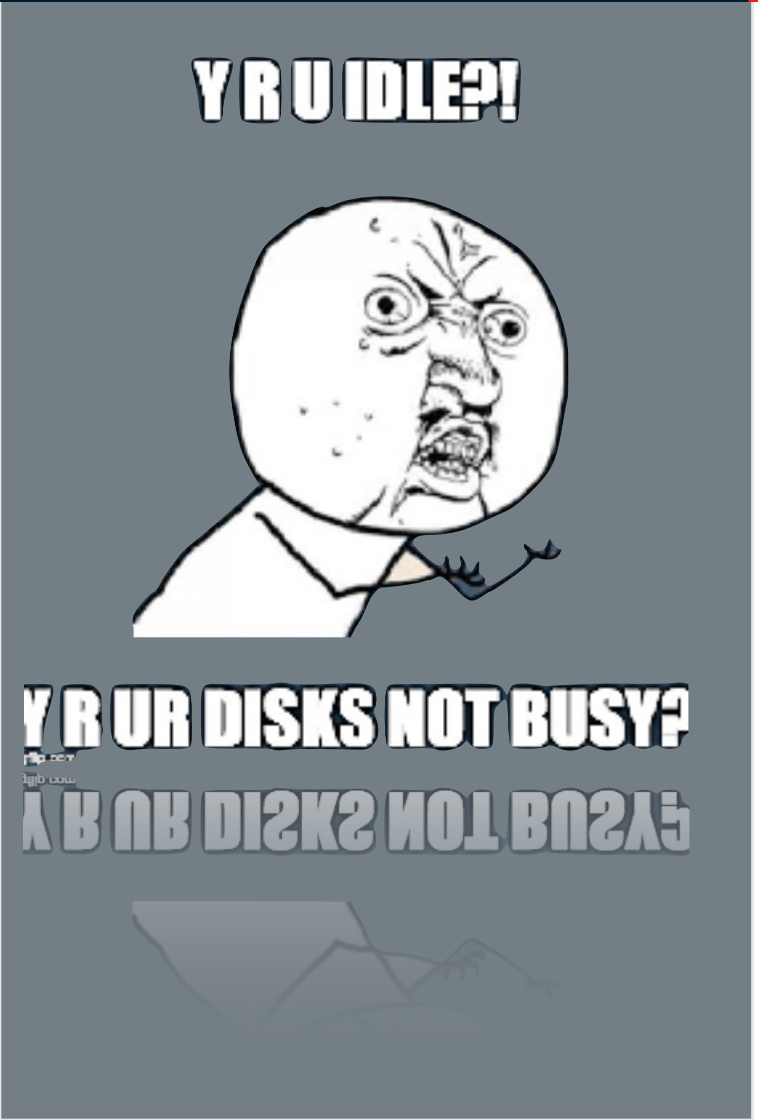
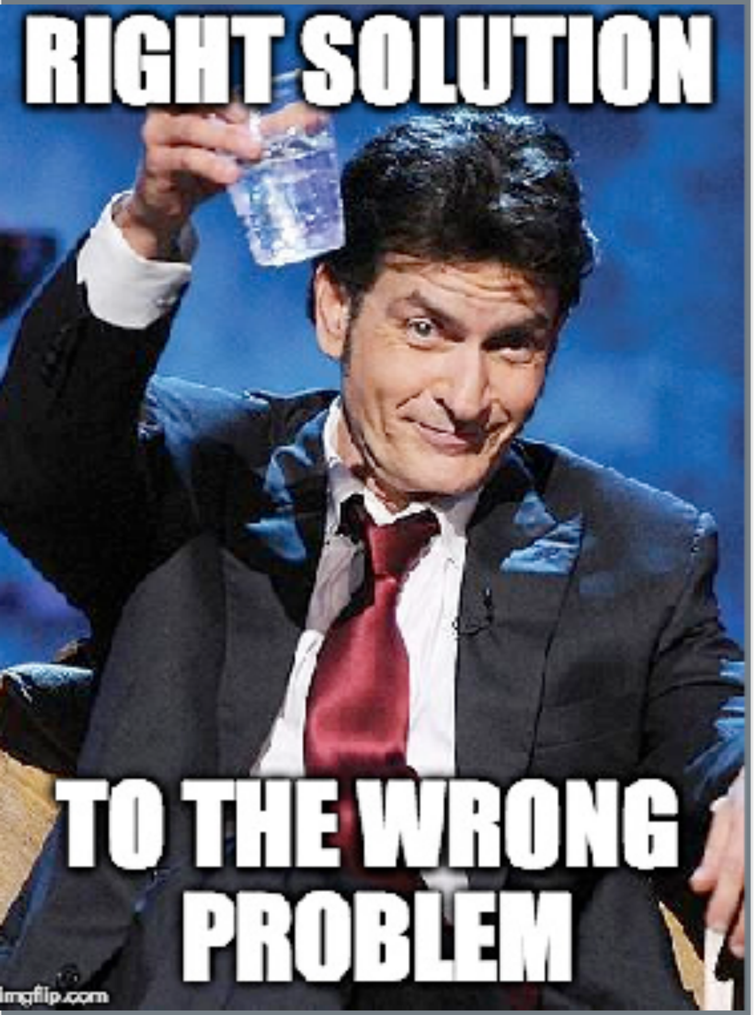
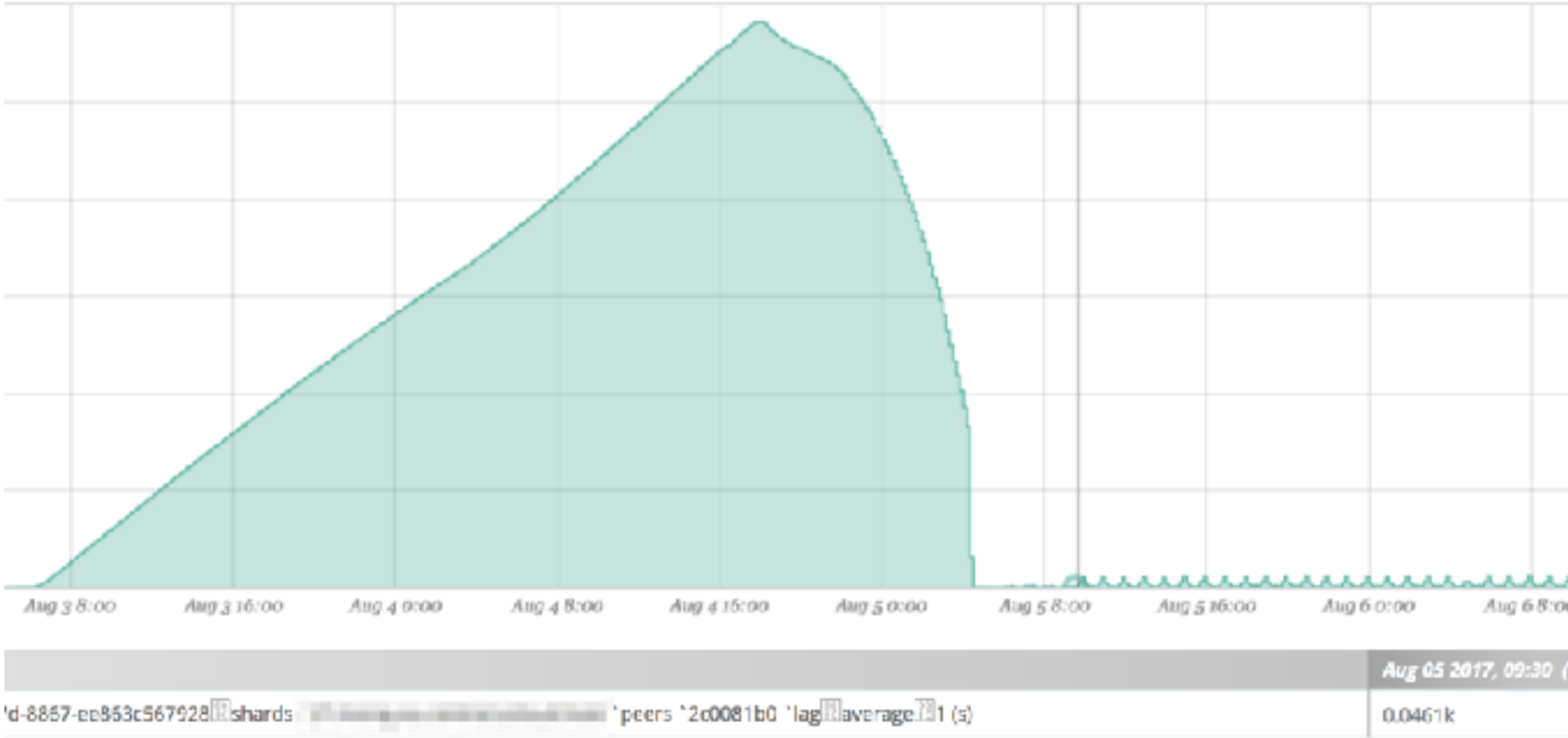
And that RAID array you have? It's Idle.



- Storage math:
  150 iops/disk * 16 disks = ~2400 IOPS
- Single WAL Receiver process issuing `pread(2)`
- Max 150 IOPS or ~6% utilization of disks
- Busy primaries will overrun followers, permanently

It's gunna be a while, m'kay?





Aug 05 2017, 09:30 (

'd-8867-ee853c567928shards [redacted] 'peers '2c0081b0 'lagaverage1 (s) 0.0461k

Fixed It

Installation

1. Install Go
2. `go get github.com/joyent/pg_prefaulter`
3. Configure
4. Run

Configuration

```
[log]
# level can be set to "DEBUG", "INFO", "WARN", "ERROR", or "FATAL"
#level = "INFO"

[postgresql]
#pgdata = "pgdata"
#database = "postgres"
#host = "/tmp"
#password = ""
#port = 5432
#user = "postgres"

[postgresql.xlog]
#pg_xlogdump-path = "/usr/local/bin/pg_xlogdump"
```

Run: Primary

```
% env PGPASSWORD=`cat .pwfile` ./pg_prefaulter run --config pg_prefaulter-primary.toml
2018-05-31T11:59:01.413991821-04:00 |DEBU| <nil> config-file=pg_prefaulter-primary.toml
2018-05-31T11:59:01.414189771-04:00 |DEBU| args: []
2018-05-31T11:59:01.414315299-04:00 |DEBU| starting gops(1) agent
2018-05-31T11:59:01.414475394-04:00 |DEBU| starting pprof endpoing agent pprof-port=4242
2018-05-31T11:59:01.414439447-04:00 |DEBU| flags postgresql.host=/tmp postgresql.pgdata=/Users/seanc/go/src/github.com/
joyent/pg_prefaulter/.pgdata_primary/ postgresql.poll-interval=1000 postgresql.port=5432 postgresql.user=postgres pos
tgresql.xlog.mode=pg postgresql.xlog.pg_xlogdump-path=/opt/local//lib/postgresql96/bin/pg_xlogdump
2018-05-31T11:59:01.415005542-04:00 |INFO| Starting pg_prefaulter pid=39865
2018-05-31T11:59:01.417634192-04:00 |DEBU| filehandle cache initialized filehandle-cache-size=2000 filehandle-cache-
ttl=300000 rlimit-nofile=7168
2018-05-31T11:59:01.426437960-04:00 |INFO| started IO worker threads io-worker-threads=3600
2018-05-31T11:59:01.454895027-04:00 |INFO| started WAL worker threads wal-worker-threads=4
2018-05-31T11:59:01.455209806-04:00 |DEBU| Starting wait
2018-05-31T11:59:01.455269901-04:00 |INFO| Starting pg_prefaulter agent commit=none date=unknown tag= version=dev
2018-05-31T11:59:01.498278613-04:00 |DEBU| established DB connection backend-pid=39867 version="PostgreSQL 9.6.3 on x86_64-
apple-darwin16.5.0, compiled by Apple LLVM version 8.1.0 (clang-802.0.42), 64-bit"
2018-05-31T11:59:01.500484662-04:00 |DEBU| found redo WAL segment from DB type=redo walfile=000000010000000000000001
2018-05-31T11:59:01.513085485-04:00 |INFO| skipping REDO record for database database=0 input="rmgr: Heap      len (rec/
tot):     14/   469, tx:          4, lsn: 0/01007750, prev 0/01007728, desc: HOT_UPDATE off 1 xmax 4 ; new off 3 x
max 0, blkref #0: rel 1664/0/1260 blk 0 FPW"
2018-05-31T11:59:01.513213488-04:00 |INFO| skipping REDO record for database database=0 input="rmgr: Heap      len (rec/
tot):      2/   337, tx:          0, lsn: 0/01007988, prev 0/01007950, desc: INPLACE off 1, blkref #0: rel 1664/0/
1262 blk 0 FPW"
2018-05-31T11:59:01.558219381-04:00 |INFO| skipping REDO record for database database=0 input="rmgr: Heap      len (rec/
tot):      3/    80, tx:         22, lsn: 0/0116B050, prev 0/0116B028, desc: INSERT+INIT off 1, blkref #0: rel 16$
4/0/1214 blk 0"
```

Run: Followers

```
% env PGPASSWORD=Kdr6zmvYOgWTKnol7HcULw91o15KhA6c ./pg_prefaulter run --config pg_prefaulter-follower.toml
--pprof-port=4243
2018-05-31T12:02:15.364191007-04:00 |DEBU| <nil> config-file=pg_prefaulter-follower.toml
2018-05-31T12:02:15.364357715-04:00 |DEBU| args: []
2018-05-31T12:02:15.364448823-04:00 |DEBU| starting gops(1) agent
2018-05-31T12:02:15.364508931-04:00 |DEBU| starting pprof endpoing agent pprof-port=4243
2018-05-31T12:02:15.364556820-04:00 |DEBU| flags postgresql.host=/tmp postgresql.pgdata=/Users/seanc/go/
src/github.com/joyent/pg_prefaulter/.pgdata_follower/ postgresql.poll-interval=1000 postgresql.port=5433
postgresql.user=postgres postgresql.xlog.mode=pg postgresql.xlog.pg_xlogdump-path=/opt/local/lib/
postgresql96/bin/pg_xlogdump
2018-05-31T12:02:15.365189238-04:00 |INFO| Starting pg_prefaulter pid=40018
2018-05-31T12:02:15.367508589-04:00 |DEBU| filehandle cache initialized filehandle-cache-size=2000
filehandle-cache-ttl=300000 rlimit-nofile=7168
2018-05-31T12:02:15.376917068-04:00 |INFO| started IO worker threads io-worker-threads=3600
2018-05-31T12:02:15.377022308-04:00 |INFO| started WAL worker threads wal-worker-threads=4
2018-05-31T12:02:15.377063872-04:00 |DEBU| Starting wait
2018-05-31T12:02:15.377104519-04:00 |INFO| Starting pg_prefaulter agent commit=none date=unknown tag=
version=dev
2018-05-31T12:02:15.413981503-04:00 |DEBU| established DB connection backend-pid=40019 version="PostgreSQL
9.6.3 on x86_64-apple-darwin16.5.0, compiled by Apple LLVM version 8.1.0 (clang-802.0.42), 64-bit"
2018-05-31T12:02:15.414627296-04:00 |DEBU| found redo WAL segment from DB type=redo
walfile=000000010000000000000004
```

What's the voodoo?

`pg_prefaulter(1)` Design

1. Find WAL files
2. Process WAL files using `pg_xlogdump(1)`
3. Read the text output from `pg_xlogdump(1)`
4. Translate output into offsets into relations (i.e. tables/indexes)
5. Dispatch `pread(2)` calls in parallel
6. Warm the OS cache before the WAL apply process faults a page in by itself
7. Dump all internal caches if process notices primary/follower change
8. Profit (or at least, fail less hard on failover or startup)

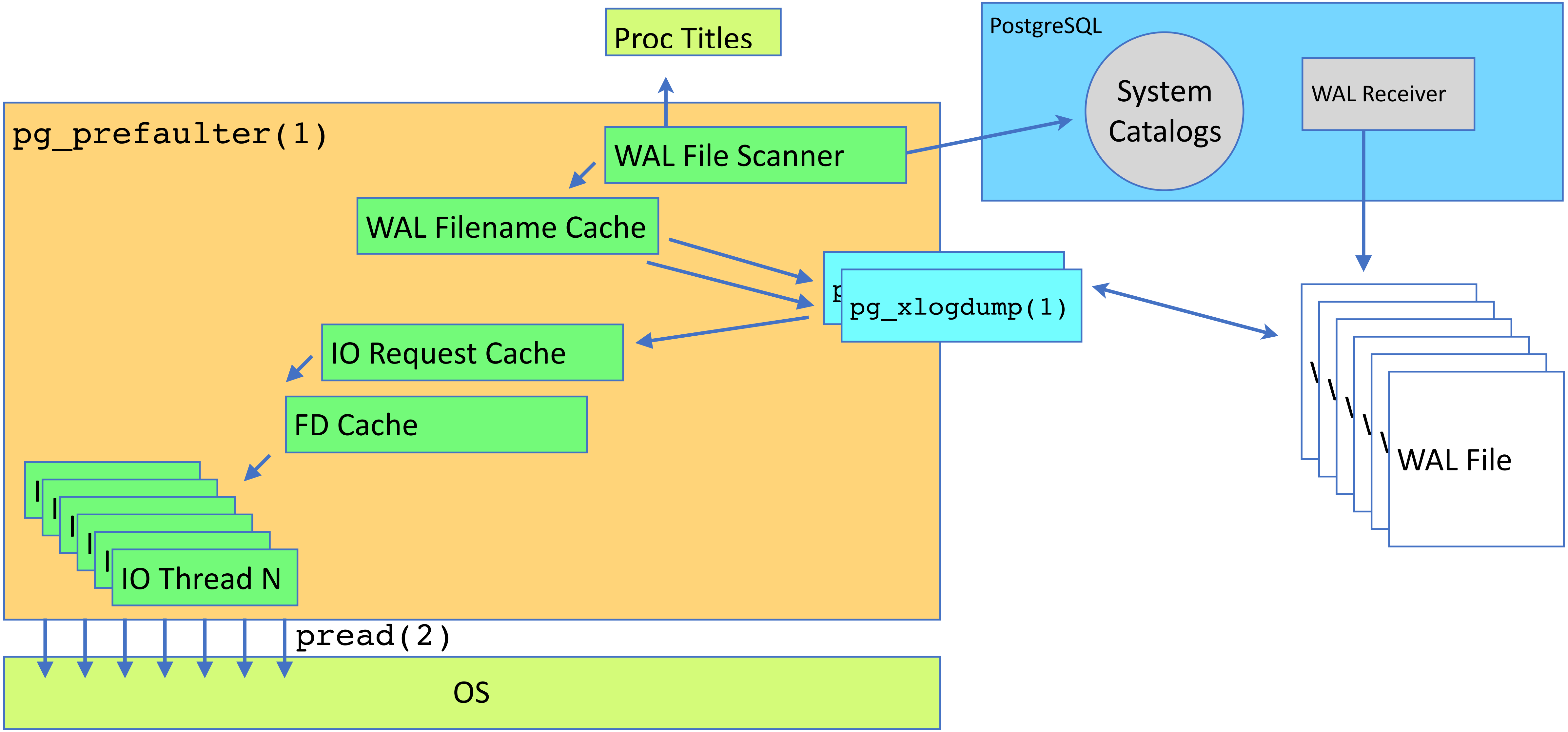
Finding WAL Files

1. Connect to PostgreSQL
2. Search for hints in process titles

:heart: `pg_xlogdump(1)`

- Platform and WAL file version agnostic way of extracting WAL information
- Elided the need for writing a customer WAL parser

pg_prefaulter(1) Architecture



Requirements

1. PostgreSQL 9.6
(an update to support 10 and 11 is coming soon)

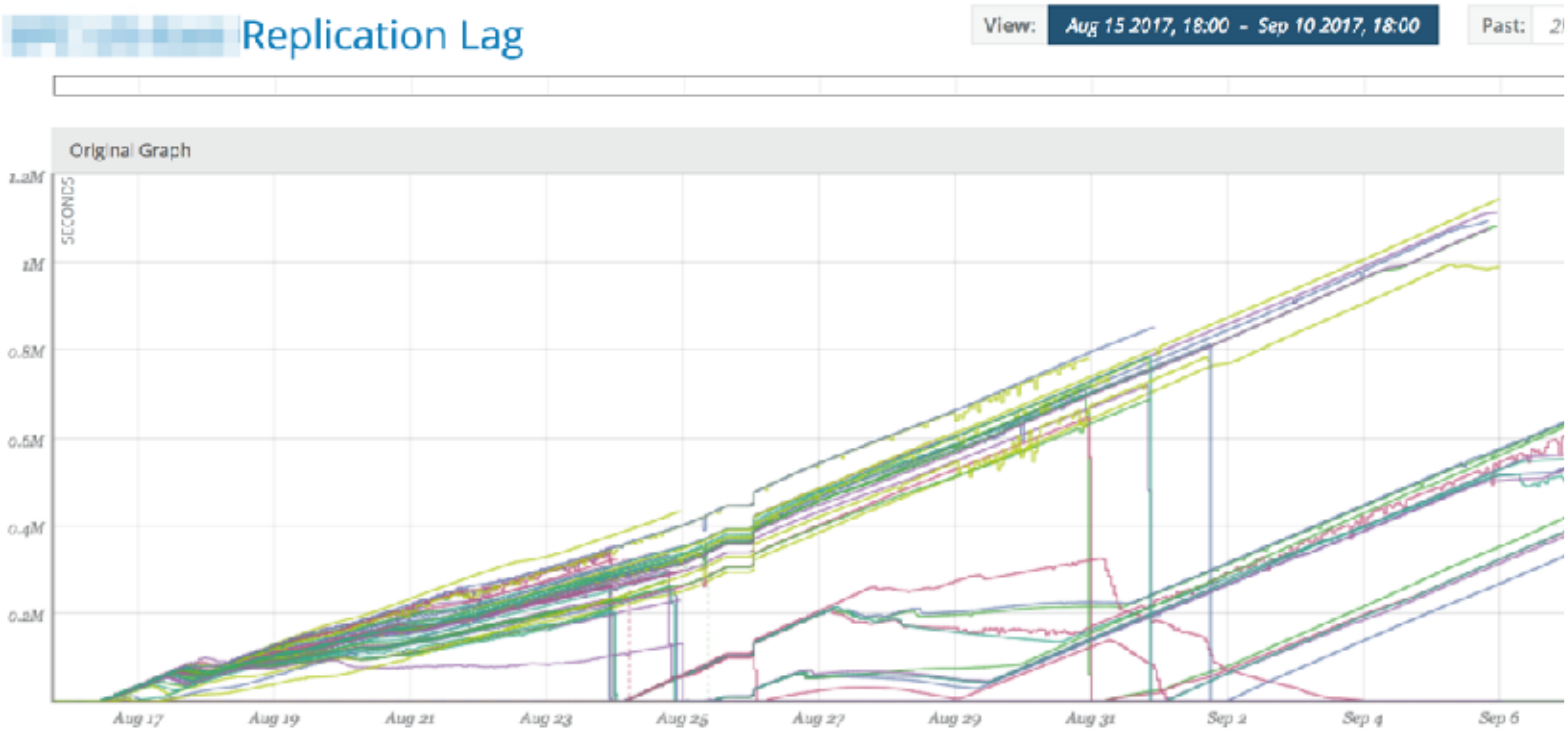
2. Go compiler to build the binary

3. `pg_xlogdump(1)`

Where to use `pg_prefaulter(1)`

1. On the primary
2. On all followers
3. Useful at startup for primaries and followers
4. Useful for promotion of followers
5. Useful on standalone PostgreSQL instances not using replication
6. Any database that you want to see start faster or where you care about availability (i.e. everywhere, on all PG instances)
7. Any PostgreSQL database that replicates and `VACUUM`s or `pg_repack(1)`s - i.e. generates lots of WAL activity

Don't be laggin' like this...



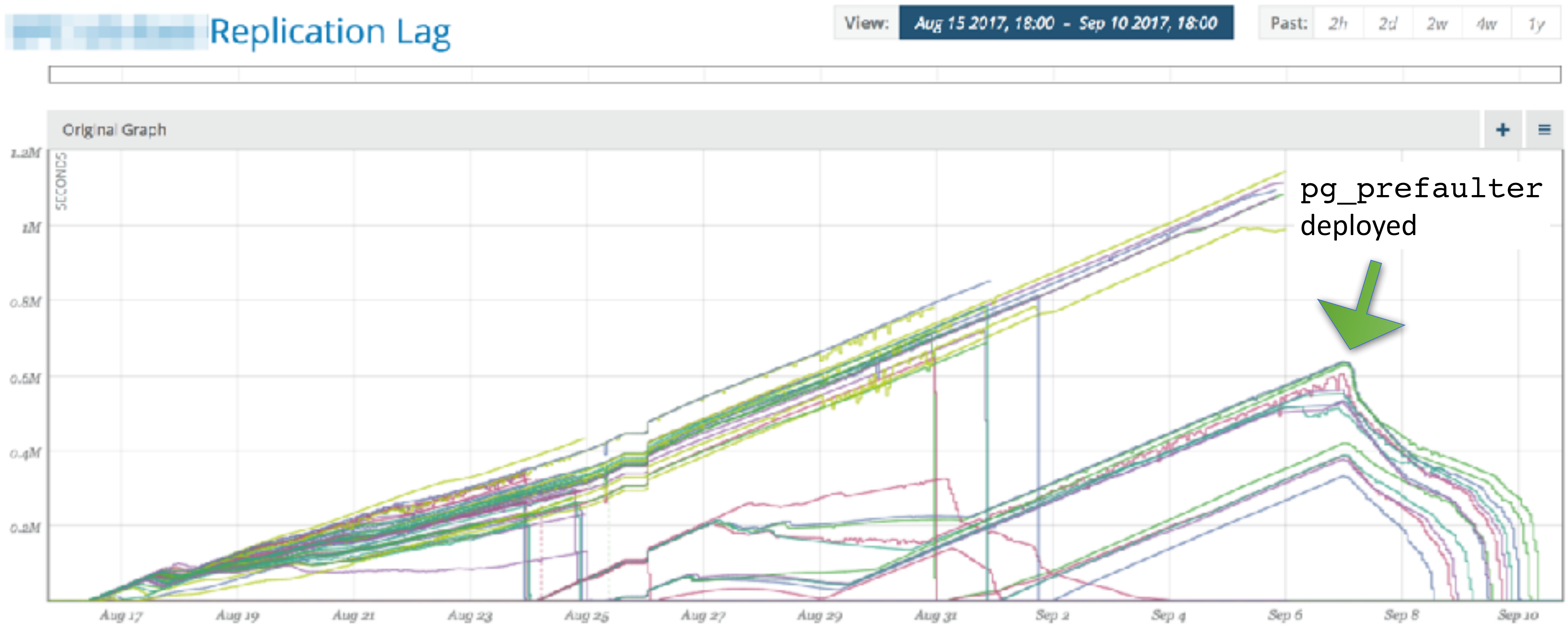
[redacted] Replication Lag

View: Aug 15 2017, 18:00 - Sep 10 2017, 18:00

Past: 2

Original Graph

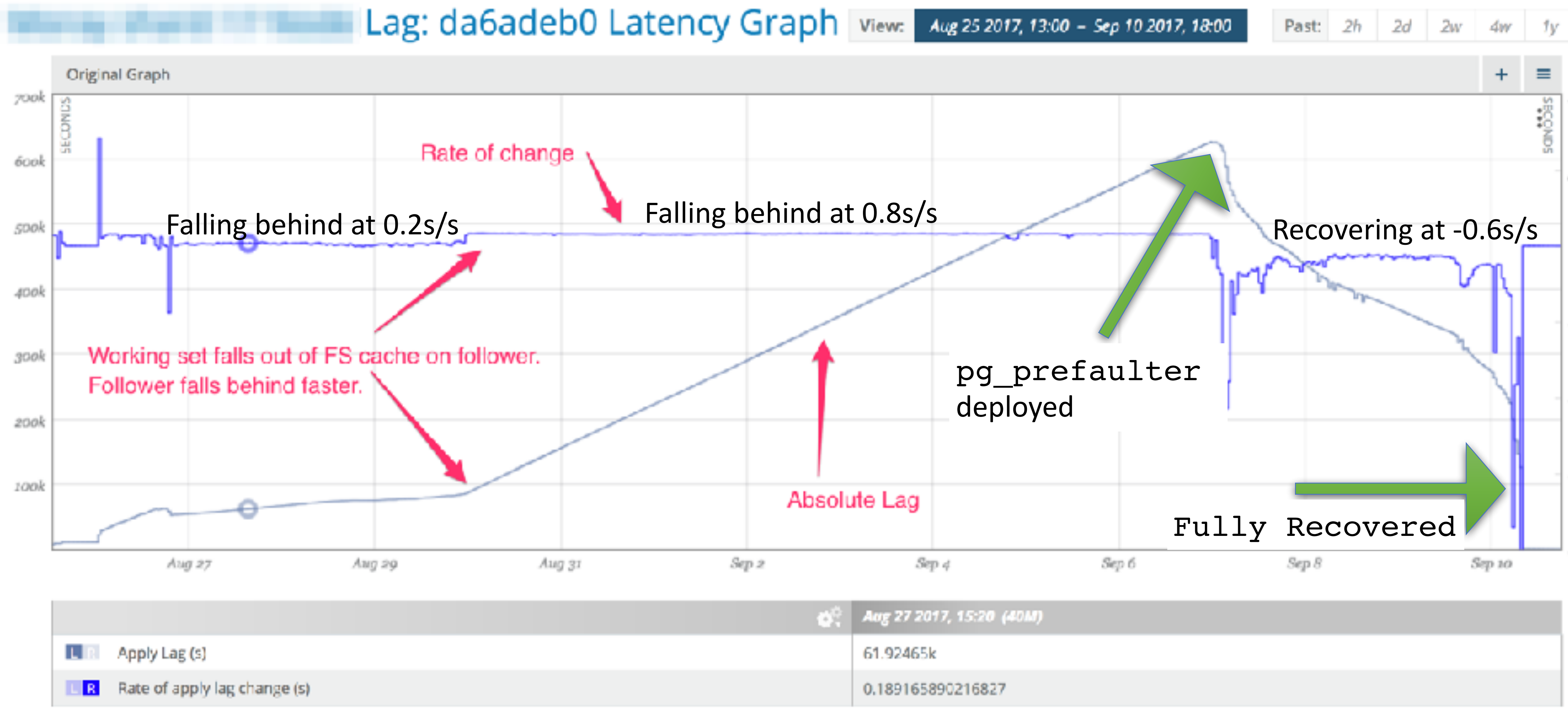
Be prefaultin' like this!



[redacted] Replication Lag

`pg_prefaulter` deployed

Recovery Visualized



[redacted] Lag: da6adeb0 Latency Graph

Rate of change

Falling behind at 0.2s/s

Falling behind at 0.8s/s

Recovering at -0.6s/s

Working set falls out of FS cache on follower.
Follower falls behind faster.

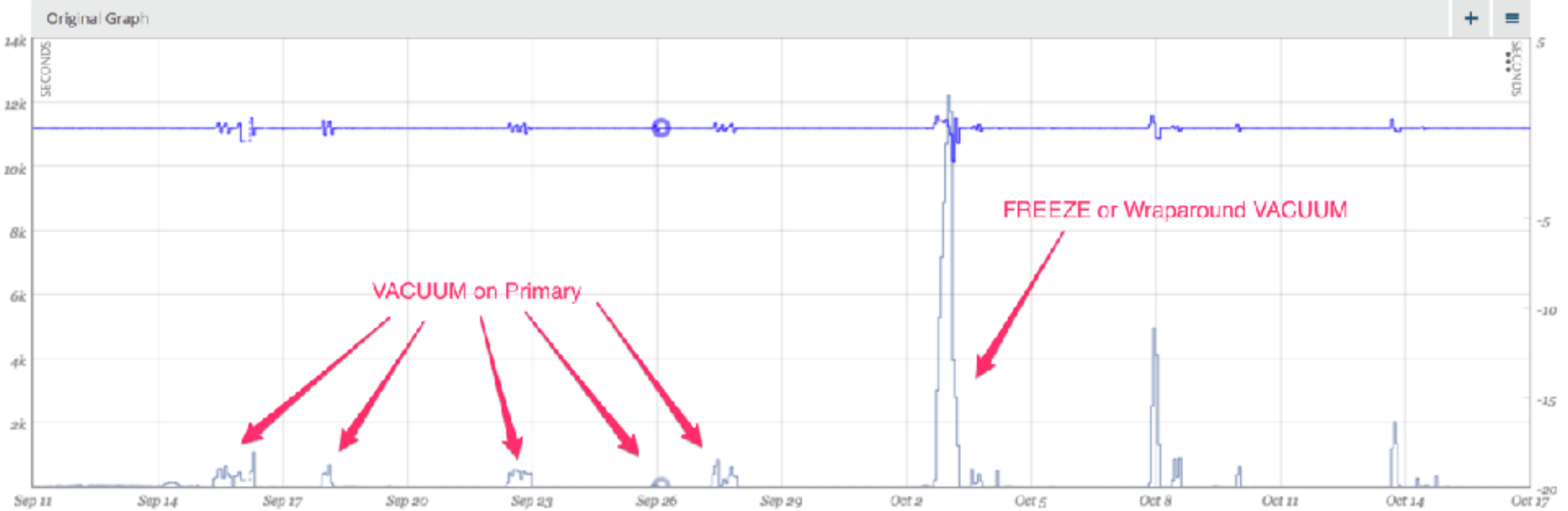
pg_prefaulter
deployed

Absolute Lag

Fully Recovered

	Aug 27 2017, 15:20 (40M)
L R Apply Lag (s)	61.92465k
L R Rate of apply lag change (s)	0.189165890216827

Steady As She Goes



VACUUM on Primary

FREEZE or Wraparound VACUUM

Thank you!

https://github.com/joyent/pg_prefaulter

We're Hiring!

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