Finding and Repairing **Database Corruption**

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It will happen.

- Database corruption will happen to you.
- Sooner or later.
- Fortunately, it's super easy to recover!

Step 1:
Restore last-good backup

Step 2:
Receive the praise of a grateful nation.

Lunchtime yet?

Oh.

- You don't have a known-good backup?
- That's a shame.
- Sadly, even good backups can…
  - Have hidden long-term corruption.
  - be too old.
  - *(whisper it)* or PostgreSQL bugs.

For example…

- PostgreSQL 9.1 streaming replication bugs.
- Secondary could have silent corruption.
- Fail over, promote secondary, and…
  - … horrible things happened.

Let's talk about…

- Preventing corruption.
- Finding corruption.
- Fixing corruption…
  - … if you can.

Hi.

- Christophe Pettus
- Consultant with PostgreSQL Experts, Inc.
- Working with PostgreSQL since 1997.

Preventing Corruption

PostgreSQL is very trusting.

- PostgreSQL assumes the file system is perfect.
- It cannot recover from any silent bad data write (unless you are very lucky).
- With 9.3 checksums, you at least get a warning.
  - So use them.

Hardware is cheap. Data is expensive.

- Use good-quality hardware.
- Be sure your hardware properly honors fsync, end to end.
  - This is more common than you think.
- Avoid (if at all possible) network-attached devices for $PGDATA.

Backup, backup, backup.

- What only exists on one drive you do not truly possess.
- Be sure you follow the right backup protocol for your technique.
  - pg_start_backup(), etc.
- Test your backups.
  - An untested backup strategy isn't one.

Prophylactic pg_dump

- pg_dump to /dev/null.
- Reads every single row in the database.
- Great for finding lurking corruption.
- Of course, if you can save the dump file, do so!

What causes corruption?

#1: Hardware failures.

- Underlying storage failure.
  - Bad disk, bad controller.
- Garbage writes during power loss.
  - Battery backup that didn’t.
- Bad RAM.
  - Especially non-ECC RAM.

#2: Hardware “features.”

- Deferred or entirely missing fsync behavior.
  - Often done to flatter benchmark results.
- Network-attached-storage that does not handle detach gracefully.
- Soft-RAID edge conditions.

#3: PostgreSQL bugs.

- 9.x had a series of unfortunate replication bugs.
- Used to be extremely rare.
- With luck, will become extremely rare again.

#4: Operator error.

- Backups that do not include critical files.
- Backups that do not follow protocol.
- Backups that forget external tablespaces.
- rm -rf in the wrong directory.
- Bungled attempts at problem recovery.
  - Delete the wrong files to free space.

What to do?

- Buy good hardware, demand your cloud provider do so, or have multi-tier redundancy.
- Make backups, and test them.
- Stay up on PostgreSQL releases, and read the release notes.

PostgreSQL Disk Format

A quick overview.

- Full details are in the documentation…
- … or in the code.
- Enough to understand what the problems might be.

Everything's under $PGDATA.

- The heap and indexes (actual data).
- The write-ahead log (at least via symlink)
- The commit log.

base/

- Contains all “real” database data.
  - Tables, indexes.
- Subdirectories, one per database.
- Named with OID for the database.

```
total 0
drwx------   14 postgres  postgres    476 Sep 17 12:59 .
drwx------   22 postgres  postgres    748 Oct 18 14:51 ..
drwx------  238 postgres  postgres   8092 Nov  5  2013 1
drwx------  302 postgres  postgres  10268 Oct 18 14:52 108290
drwx------  238 postgres  postgres   8092 Sep 17  2013 12292
drwx------  296 postgres  postgres  10064 Oct 18 14:52 1653531
drwx------  315 postgres  postgres  10710 Sep  8 16:09 1653924
drwx------  491 postgres  postgres  16694 Oct 18 14:52 1724452
drwx------  630 postgres  postgres  21420 Oct 18 14:52 1781788
drwx------  697 postgres  postgres  23698 Oct 18 14:52 1783503
drwx------  242 postgres  postgres   8228 Oct 18 14:51 1785736
drwx------  248 postgres  postgres   8432 Oct 18 14:52 271548
drwx------  368 postgres  postgres  12512 Jul 10 13:46 90822
drwx------    2 postgres  postgres     68 Sep 14 15:35 pgsql_tmp
```

```
postgres=# select oid from pg_database where datname='silverandgold';
   oid
---------
 1653924
(1 row)
```

In each database directory…

- One big list of files.
- One or more per relation (table, index).
- The name is the relfilenode of the relation.

```
drwx------  316 postgres  postgres   10744 Oct 21 15:13 .
drwx------   14 postgres  postgres     476 Sep 17 12:59 ..
-rw-------    1 postgres  postgres  172032 Jun 29 10:04 12030
-rw-------    1 postgres  postgres   24576 Jun 29 10:04 12030_fsm
-rw-------    1 postgres  postgres    8192 Jun 29 10:04 12030_vm
-rw-------    1 postgres  postgres   16384 Jun 24 12:48 12032
-rw-------    1 postgres  postgres   24576 May 31 14:36 12032_fsm
-rw-------    1 postgres  postgres    8192 May 31 15:07 12032_vm
-rw-------    1 postgres  postgres   16384 Jun 24 12:48 12034
-rw-------    1 postgres  postgres   40960 Jun 29 10:04 12035
-rw-------    1 postgres  postgres   73728 Jun 29 10:04 12036
-rw-------    1 postgres  postgres   24576 May 31 15:07 12036_fsm
-rw-------    1 postgres  postgres    8192 May 31 14:36 12036_vm
-rw-------    1 postgres  postgres   32768 Jun 29 10:04 12038
-rw-------    1 postgres  postgres   40960 Jun 29 10:04 12039
-rw-------    1 postgres  postgres       0 May 31 14:36 12044
-rw-------    1 postgres  postgres    8192 May 31 14:36 12046
-rw-------    1 postgres  postgres    8192 May 31 14:36 12047
-rw-------    1 postgres  postgres  450560 Jun 29 10:04 12048
-rw-------    1 postgres  postgres   24576 Jun 24 12:48 12048_fsm
-rw-------    1 postgres  postgres    8192 May 31 14:36 12048_vm
-rw-------    1 postgres  postgres  155648 Jun 29 10:04 12050
```

```
silverandgold=# select relfilenode from pg_class where relname='comic_chapter';
 relfilenode
-------------
     1654288
(1 row)
```

Relation files.

- If >1 GB, divided into 1 GB segments.
  - .1, .2, .3…
- _fsm is the free space map.
- _vm is the visibility map.
  - Small / new tables might be missing one or both of these.

Inside the table files.

- Table (and index) files are divided into 8KB pages.
  - Can change this at compile time; no one does.
- Each page contains 0+ tuples.
  - Tuples do not span pages; TOAST is used for larger attributes.

Page Format.

Items.

- Each item is variable length.
- Large attributes are (usually) compressed, and then spilled to TOAST if they won't fit.
- Each item begins with a bitmap of NULL fields (if any are NULLable), then the columns in order.

A note about items.

- You cannot decode an item without access to its schema definition.
- Thus, corruption of the system catalogs can render a table unreadable.

ctids.

- Every row in a table has a ctid.
- (block number, item offset) pair.
- Can be used to select a precise row in absence of a primary key…
  - … or if corruption has rendered the primary key unusuable.

```
silverandgold=# select ctid from comic_issue;
  ctid
--------
 (0,2)
 (0,4)
 (0,6)
 (0,10)
(4 rows)
```

```
silverandgold=# select id from comic_issue where ctid='(0,6)';
 id
----
  4
(1 row)
```

Indexes.

- For B-tree indexes, the same general structure as tuple pages.
- “Items” are heap pointers (for leaf nodes), index pointers (for internal nodes).
- Other index types have their own formats, but generally follow this one.

Write-Ahead Log

- Stored in pg_xlog/
  - Can be symlinked elsewhere
- Contains a sequence of 16MB segments.
- Files are recycled and renamed when no longer required for crash protection or replication.

Yes, these files are important.

- pg_xlog bloating is a common failure condition.
  - … especially with an archive_command that is failing for some reason.
- The “log” name implies something unfortunate.

Commit Log.

- Stored in pg_clog/
- Series of files containing status of transactions.
- Stored as bitmaps, two bits per transaction.
- Be sure your backups include it!

Basic Techniques.

Save all the parts!

- Stop PostgreSQL.
- Do a full file-system level backup.
- Keep that backup safe.
- Make changes methodically, and document each step.

Index Corruption.

- The most common kind of corruption.
- Drop the index in a transaction, and confirm that solves the problem.
- If so, rebuild the index.
- If not, it's probably not index corruption.

Take a pg_dump.

- pg_dump reads every row, and…
- … creates a logically-good snapshot.
- Restore that into a clean database.

Bad Data Page.

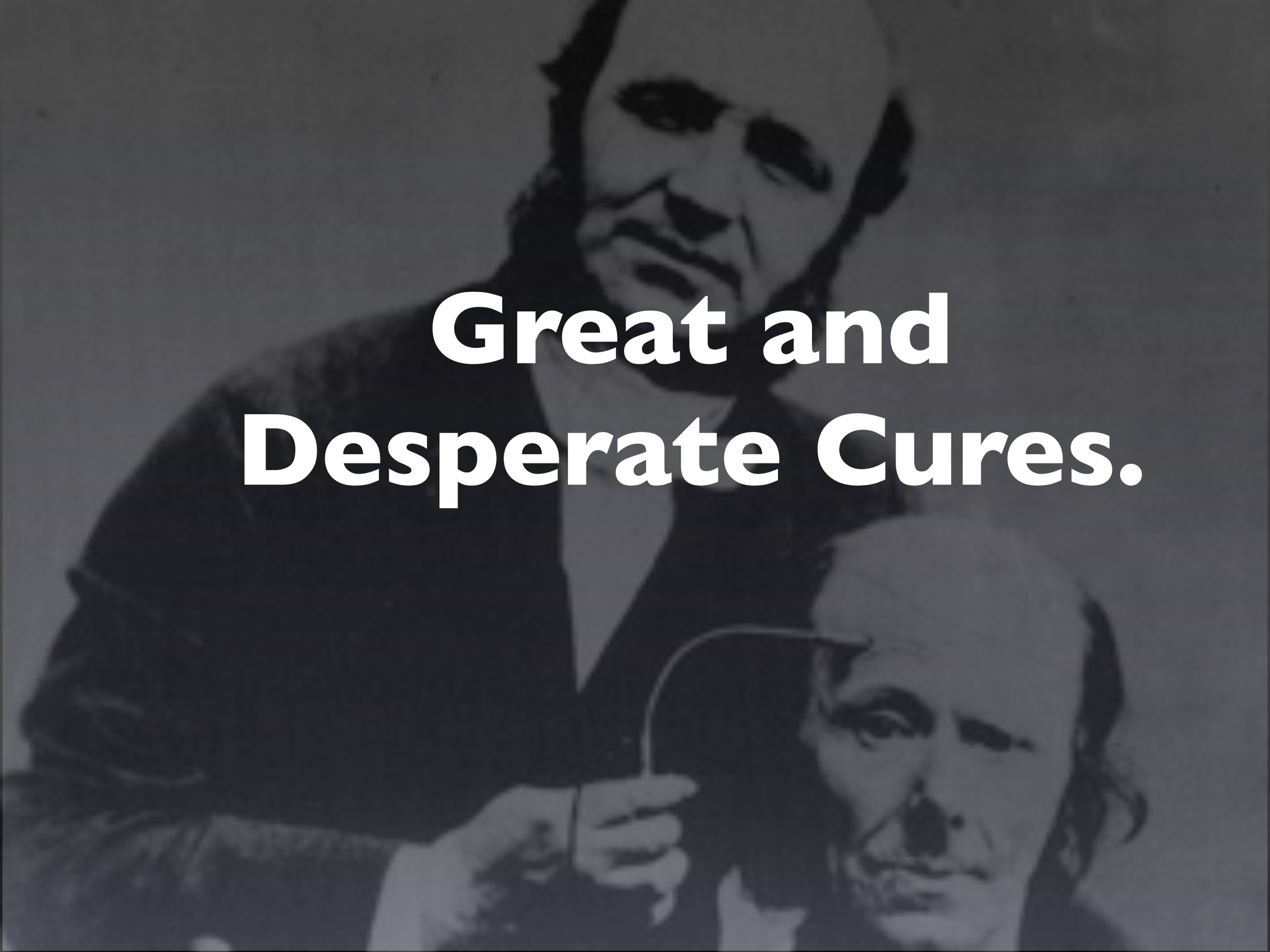
- Checksum failures, complaints about bad headers, etc.
- Can you do a pg_dump of the table?
- zero_damaged_pages = on.

Really Bad Data Pages.

- Can you SELECT around them?
- Do a COPY out of the good data, drop table, COPY back in.
- Or do a CREATE TABLE from the SELECT, rename appropriately.
- DELETE just the bad rows by ctid, if you can isolate them.

Finding bad data pages.

- Iterate through rows in PL/pgSQL…
- … with an exception block around the SELECT.
- Catch and log any rows that throw an exception.
- Very helpful for finding TOAST corruption.


Great and
Desperate Cures.

Known unknown knowns.

- All corruption is, by its nature, a one-off situation.
- Be sure to determine the extent of it before continuing.
- Be sure you can step backwards!


There are no recipes.

REMEMBER.

WORK ON A COPY.

First things first.

- Are there errors in demsg indicating a hardware or OS problem?
  - Is the OOM killer terminating backends?
  - Disk I/O errors?
  - Can you cp -R the data directory to /dev/null?

Very, very bad data pages.

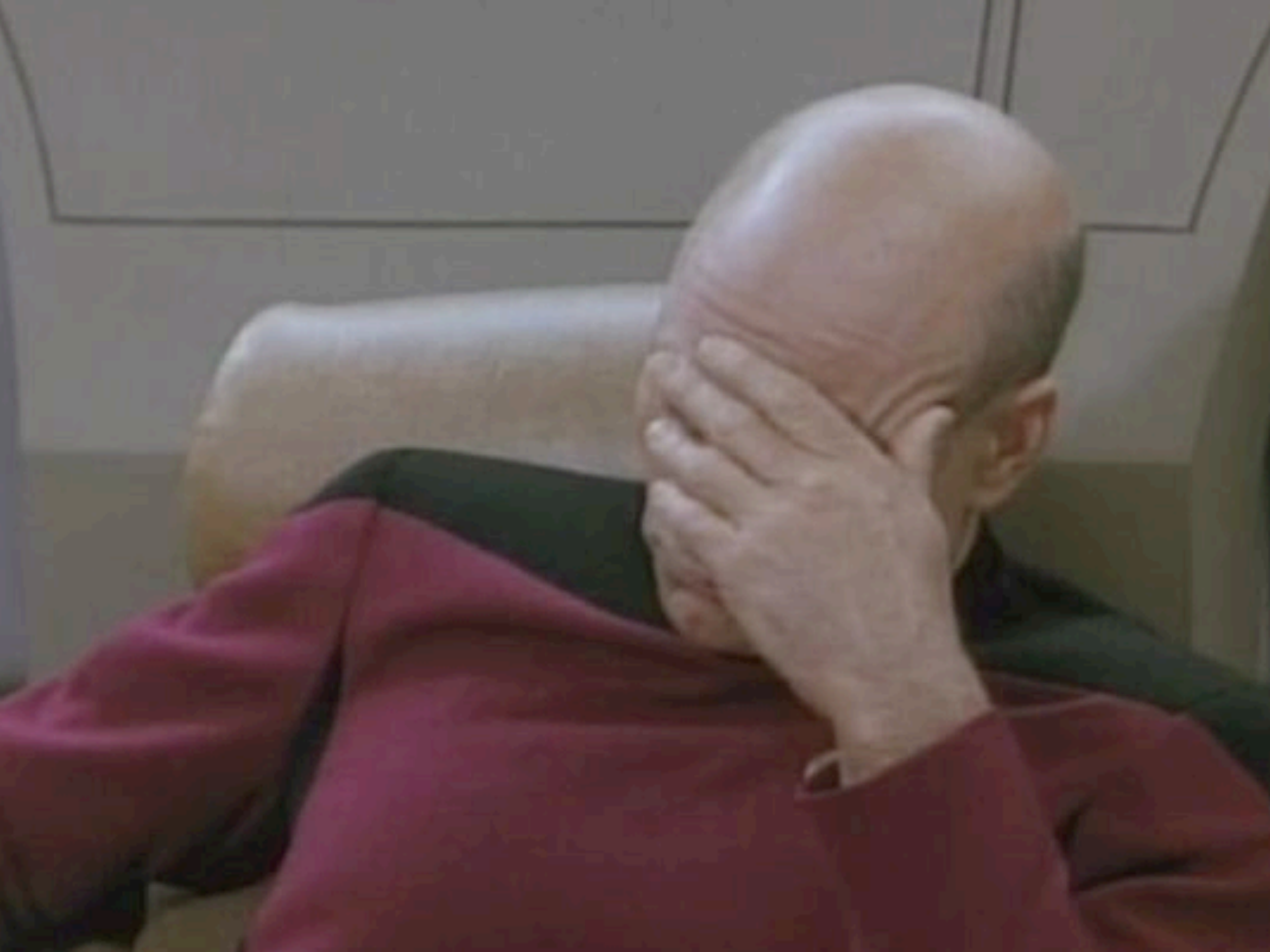
- As in, the backend crashes when it touches them.
- Isolate pages, use dd to zero out those blocks.
- Be sure to drop and recreate all indexes on the table!

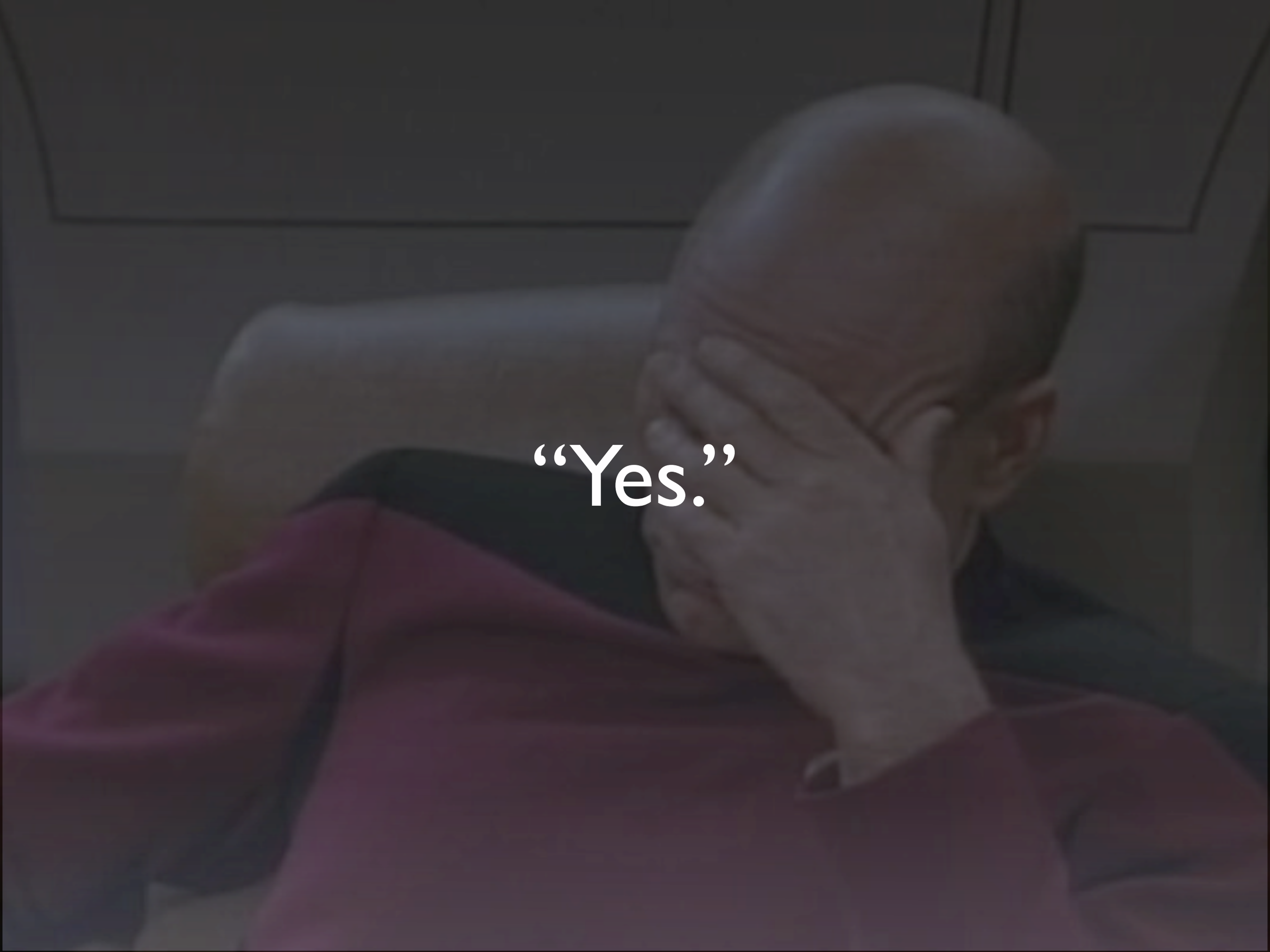
WAL files corrupt or missing.

- You went on vacation…
- The system ran out of disk space…
- And they called you to say that it won't start now.
- "We just deleted some log files."
- "Which ones?"

“pg_xlog”

“Is that bad?”





“Yes.”

pg_resetxlog

- Tells PostgreSQL that WAL files it needs for crash recovery… it doesn't need.
- Can get the server to start with missing log files.
  - Read the instructions carefully!
- High risk of inconsistent data! Check the database very thoroughly!

pg_clog

```
PG::InternalError: ERROR: could not
access status of transaction 2924295225
DETAIL: Could not read from file
"pg_clog/0AE4" at offset 212992:
Success.
```

pg_clog corruption.

- Good news: Rarely subtle.
- Missing file.
- Truncated file.

Patching.

- Replace a missing file with all-zeros file.
- 00 for a transaction means “in progress.”
- Previously-committed transactions can thus disappear.
- Be prepared to do more cleanup in this case.

System catalog corruption.

- The nightmare scenario.
- Very hard to recover from, unless the corruption is very small.
- Probably requires expert attention to do recovery or scavenging.

War Stories.

```
PG::InternalError: ERROR: could not
access status of transaction 2924295225
DETAIL: Could not read from file
"pg_clog/0AE4" at offset 212992:
Success.
```

So, how did we get here?

- Network connectivity issue caused secondary to be promoted to primary.
- New secondary couldn't handle load.
- Beefier primary was initialized from secondary, but…
- … on startup, these errors popped out.

What happened?

- Same network problems that began the situation caused the rsync building the primary to abort.
- No one noticed in the rush to get the primary back on line.

The fix…

- … the missing clog file could be copied from the secondary and dropped into place.
- Problem solved!
- Very lucky that clog file was available.

The moral?

- No matter how bad a disaster is…
- … rushing can make it worse.
- Make sure that you are not introducing new problems as you are repairing old ones.

```
ERROR:  missing chunk number 0 for
toast value 968442 in pg_toast_263610
```

So, how did we get here?

- New primary provisioned by promoting from secondary.
- Errors started appearing almost immediately.
- But only one row, on one table…

Spooky!

- … and only on some queries.
- Isolating the record using primary key found nothing; the record retrieved just fine.
- Reindexing the TOAST table? No help.
- Iterating through the table did find it, however.

What happened?

- Two levels of corruption.
- Bad TOAST entry, and…
- … two rows with the same primary key.
  - One referring to the “bad” row.
- Index scans only found the “good” row.
- Seq scans found both.

The fix…

- Delete the missing row by ctid.
- Iterate through all other tables to confirm no other corrupt rows.

The moral?

- Read the release notes.
- This was directly related to an existing bug in PostgreSQL.
- But the hosting provider* hadn't upgraded PostgreSQL promptly.
- * cough AWS cough

Uh, Christophe?
About that upgrade...

So, how did we get here?

- New primary provisioned by promoting from secondary.
- New primary put into service, old primary decommissioned.
- Everything looks fine for a few hours, until…

Spooky!

- Some existing rows are missing.
- Some existing rows are duplicated, as if both old and new from an UPDATE had been committed.
- No error messages.

What happened?

- PostgreSQL bug.
  - Since fixed.
  - clog values were not properly being transmitted from primary to secondary under high-write-load conditions.
  - So, some rolled back, etc.

The fix…

- Enough information in the database (date/time stamps) to delete the bad rows, and copy the missing ones from the old database.
- Hand-crafted scripts to do so.
- Never, ever want to do that again.

The moral?

- Do not exclude that it could be a PostgreSQL problem.
- Do thorough sanity checks on promoted primaries.
- Have a client or employer who understands open source software.

Thank you!

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