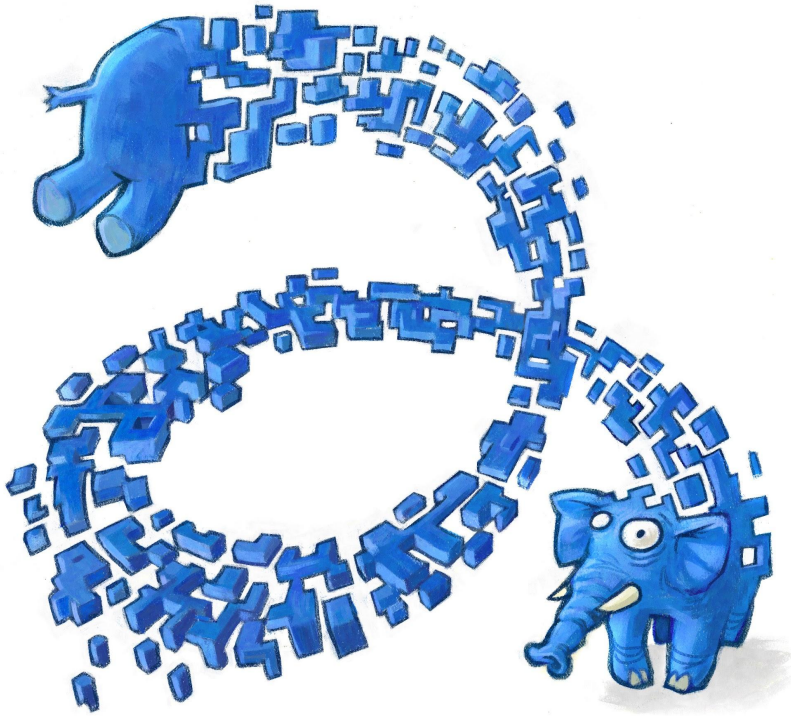
Implementing failover of logical replication slots in Patroni.



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Alexander Kukushkin
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zalando

About me

Alexander Kukushkin

Database Engineer @ZalandoTech

The Patroni guy

alexander.kukushkin@zalando.de

Twitter: @cyberdemn

Streaming replication

- Physical
  - replicates binary changes via WAL files over TCP to standby
  - can’t replicate between different major versions or platforms
- Logical
  - replicates only data objects and their changes
  - works between different major versions and platforms
  - requires the **replication slot**

Enabling logical replication

- wal_level = logical # default value is replica
- max_wal_senders = 10
- max_replication_slots = 10

Postgres restart is required!

Replication slots

- Provide guarantees that WAL segments are not removed until consumed
- Provide protection against relevant rows being removed by (auto)vacuum
- Logical replication slots are tightly coupled with particular database.

Creating a logical replication slot

- SELECT pg_create_logical_replication_slot(
  '**<slot_name>**', '**<output_plugin_name>**');

-- or --

- CREATE_REPLICATION_SLOT **<slot_name>**
  LOGICAL **<output_plugin_name>**
  - pg_recvlogical --create-slot --slot=**<slot_name>** \
    --plugin=**<plugin_name>** --dbname=**<database_name>**

Logical Decoding Plugins

- Built-in core
  - test_decoding
  - pgoutput (logical replication)
- 3rd party
  - wal2json - JSON
  - pglogical
  - Debezium decoderbufs - Protobuf
  - decoder_raw - as SQL
  - …

What is Logical Decoding?

- Extracting data changes in a “simple” format that could be interpreted by an external tool.

- Outside of PostgreSQL it is also known as Change Data Capture (**CDC**)

Example: creating the slot

```
localhost/testdb=# SELECT * FROM pg_create_logical_replication_slot
                   ('my_slot', 'test_decoding');
```

slot_name	lsn
my_slot	0/130694C8

(1 row)

```
localhost/testdb=# SELECT slot_name, plugin, slot_type, database, confirmed_flush_lsn
                   FROM pg_replication_slots;
```

slot_name	plugin	slot_type	database	confirmed_flush_lsn
my_slot	test_decoding	logical	testdb	0/130694C8

(1 row)

Example: peek changes without consuming

```
localhost/testdb=# CREATE TABLE replicate_me (
      id BIGINT NOT NULL GENERATED ALWAYS AS IDENTITY PRIMARY KEY,
      name TEXT);
CREATE TABLE

localhost/testdb=# INSERT INTO replicate_me (name) VALUES ('PGConf.DE');

INSERT 0 1

localhost/testdb=# SELECT * FROM pg_logical_slot_peek_changes( 'my_slot', NULL, NULL);
    lsn     | xid |                                   data
------------+-----+-----------------------------------------------------------------------
0/130694F8  | 830 | BEGIN 830
0/1309A768  | 830 | COMMIT 830
0/1309A7A0  | 831 | BEGIN 831
0/1309A808  | 831 | table public.replicate_me:  INSERT: id[bigint]:1 name[text]:'PGConf.DE'
0/1309A960  | 831 | COMMIT 831

(5 rows)
```

Example: pg_recvlogical

```
$ pg_recvlogical -h localhost -U postgres -d  testdb --slot=my_slot --start -f
-

BEGIN 830

COMMIT 830

BEGIN 831

table public.replicate_me:  INSERT: id[bigint]:1 name[text]:'PGConf.DE'

COMMIT 831

^Cpg_recvlogical: error: unexpected termination of replication stream:
```

Logical replication example

```
CREATE PUBLICATION my_publication
FOR TABLE replicate_me WITH (publish = 'insert');
```

```
CREATE SUBSCRIPTION my_sub
CONNECTION 'host=172.168.18.50 port=5432 user=repl dbname=testdb'
PUBLICATION my_publication;
```

Logical replication slots and HA

- Replication slots are not replicated!
- Logical replication slots can’t be created on standbys:

```
localhost/testdb=# SELECT * FROM

pg_create_logical_replication_slot ('my_slot', 'test_decoding');

ERROR:  logical decoding cannot be used while in recovery
```

- Consumers can’t continue work after failover/switchover.

Naive solution in Patroni

- Don’t allow incoming connections after failover/switchover before logical slots are created:
  - Patroni REST API health-check returns 503
  - Delay callbacks
  - K8s leader Service without endpoints

- Logical events could be silently lost if consumer wasn’t running or was lagging!

Can we create logical slots in the past?

- Yes, with the custom extension: https://github.com/x4m/pg_tm_aux
- **Pros:** events won't be lost
- **Cons:** It’s not always possible to install 3rd party extensions
- **Potential problems:**
  - WAL isn’t accessible
  - May fail to take a “catalog snapshot”

Can we do better?

Observation

If we restart Postgres in read-only mode, existing replication slots are still there:

```
localhost/testdb=# SELECT pg_is_in_recovery();
pg_is_in_recovery
-------------------
t

(1 row)

localhost/testdb=# SELECT slot_name, plugin, slot_type, database, confirmed_flush_lsn
                    FROM pg_replication_slots;
 slot_name |    plugin     | slot_type | database | confirmed_flush_lsn
-----------+---------------+-----------+----------+---------------------
 my_slot   | test_decoding | logical   | testdb   | 0/1309AA80
(1 row)
```

Logical replication slots can exist on replicas!

How replication slots are stored?

```
$ ls -l $PGDATA/pg_replslot/my_slot/

total 4

-rw------- 1 postgres postgres 200 Apr 11 08:15 state
```

What if we copy the slot file?

- Stop postgres on the replica
- Copy the slot file from the primary
- Start postgres on the replica
- Profit?!

Adding the secret sauce

- pg_replication_slot_advance (*slot_name* name, *upto_lsn* pg_lsn)
  - Introduced in PostgreSQL v11 (released in October 2018)
  - Works with logical slots! (must be connected to the right DB)
  - Also works on replicas!

Example: pg_replication_slot_advance()

```
localhost/testdb=# SELECT pg_is_in_recovery();

pg_is_in_recovery
-------------------
t

(1 row)


localhost/testdb=# SELECT * FROM pg_replication_slot_advance('my_slot', '0/1412FA78');

slot_name |  end_lsn
----------+-----------
my_slot   | 0/1412FA78
(1 row)
```

Is it safe?

- Copy the slot file - **Yes**
- pg_replication_slot_advance() - **Yes**
- Use replication slot after promote - **might be unsafe**

```
localhost/testdb=# SELECT slot_name, plugin, slot_type, database,
catalog_xmin, restart_lsn, confirmed_flush_lsn FROM pg_replication_slots;
```

```
slot_name |    plugin     | slot_type | database |  catalog_xmin | restart_lsn | confirmed_flush_lsn
----------+---------------+-----------+----------+---------------+-------------+---------------------
my_slot   | test_decoding | logical   | testdb   |           831 | 0/1309A768  | 0/1309AA80
(1 row)
```

catalog_xmin

- Logical decoding uses **pg_catalog** to figure out table structures
  - Needs access to old snapshots
- Race conditions:
  - Slots on replicas are usually behind
  - Autovacuum might clean up **pg_catalog** tuples required for decoding

How to protect from it?

1. Replicas must use replication slots (primary_slot_name)

2. hot_standby_feedback must be set to **on**

hot_standby_feedback = off

```
localhost/testdb=# SELECT slot_name, plugin, slot_type, database,
catalog_xmin, restart_lsn, confirmed_flush_lsn  FROM pg_replication_slots;
```

Primary:

```
 slot_name  |    plugin     | slot_type | database | catalog_xmin | restart_lsn | confirmed_flush_lsn
------------+---------------+-----------+----------+--------------+-------------+---------------------
my_slot     | test_decoding | logical   | testdb   |          864 | 0/14116228  | 0/1412E410
postgresql1 |               | physical  |          |              | 0/1412E4C0  |
(2 rows)
```

Replica:

```
slot_name |    plugin     | slot_type | database | catalog_xmin | restart_lsn | confirmed_flush_lsn
----------+---------------+-----------+----------+--------------+-------------+---------------------
my_slot   | test_decoding | logical   | testdb   |          863 | 0/140FE578  | 0/140FE5B0
(1 row)
```

hot_standby_feedback = on

```
localhost/testdb=# SELECT slot_name, plugin, slot_type, database,
catalog_xmin, restart_lsn, confirmed_flush_lsn  FROM pg_replication_slots;
```

Primary:

```
 slot_name  |    plugin     | slot_type | database | catalog_xmin | restart_lsn | confirmed_flush_lsn
------------+---------------+-----------+----------+--------------+-------------+---------------------
my_slot     | test_decoding | logical   | testdb   |          864 | 0/14116228  | 0/1412E410
postgresql1 |               | physical  |          |          863 | 0/1412E4C0  |
(2 rows)
```

Replica:

```
slot_name |    plugin     | slot_type | database | catalog_xmin | restart_lsn | confirmed_flush_lsn
----------+---------------+-----------+----------+--------------+-------------+---------------------
my_slot   | test_decoding | logical   | testdb   |          863 | 0/140FE578  | 0/140FE5B0
(1 row)
```

The plan

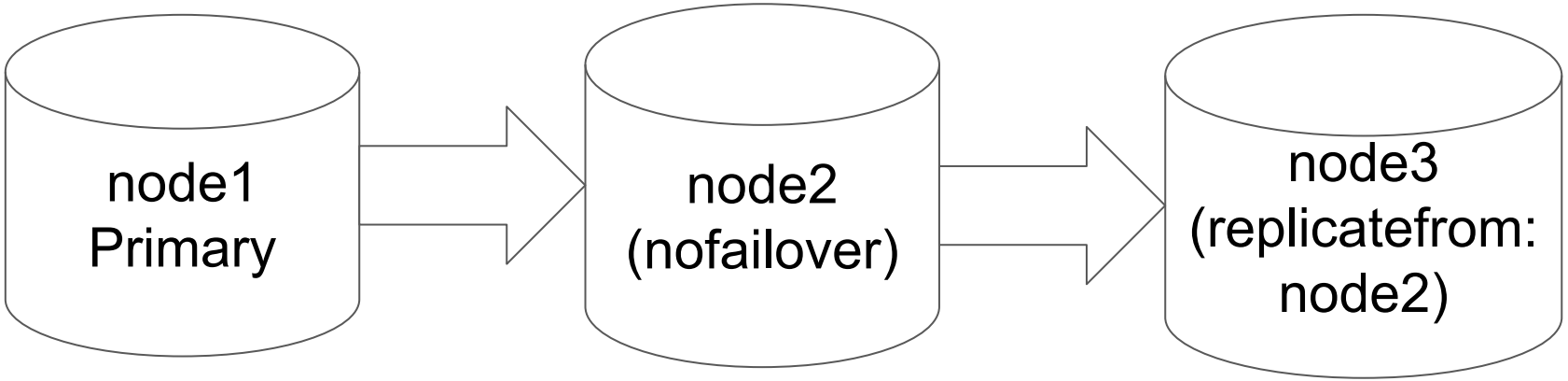
1. Copy logical slots to replicas with Postgres restart
    a. Fsync files and directories after coping!
2. Periodically call pg_replication_slot_advance()
3. Handle possible errors?

Implementation details in Patroni

- Leader: periodically publish **`confirmed_flush_lsn`** for all permanents slots to the Distributed Configuration Store (DCS)
- Replicas:
  - Use pg_read_binary_file() function to copy the slot file if it is missing on the replica
    - Requires superuser or specially configured *rewind_user*
  - Enable hot_standby_feedback

Cascading replication

The node2 doesn’t have logical slots, but must have **hot_standby_feedback** enabled (automatically configured by Patroni).



Possible problems

- Requested WAL segment pg_wal/XXX has already been removed

- The logical slot could be unsafe to use after promote if replicas physical slot didn’t reach the **catalog_xmin** of the logical slot on the old primary (Patroni shows a warning)

Configuring Patroni

```
$ patronictl edit-config
---
+++
@@ -1,6 +1,12 @@
 loop_wait: 10
 maximum_lag_on_failover: 1048576
 postgresql:
+  use_slots: true
+  parameters:
+    wal_level: logical
   use_pg_rewind: true
 retry_timeout: 10
 ttl: 30
+permanent_slots:
+  my_slot:
+    database: testdb
+    plugin: test_decoding

Apply these changes? [y/N]: y
Configuration changed
```

Logical client issues

- Clients must be prepared to receive some events for the second time after failover/switchover
- Logical replication may be ahead of physical replication that is acknowledged by synchronous replicas and see some events that didn’t survive failover.
- Debezium doesn’t correctly handle keepalive messages: DBZ-4055
    - May cause slow (or indefinite) shutdown of the primary because it keeps walsender process alive
    - “Breaks” switchover in the old (before 2.1.2) Patroni

Monitoring

```
localhost/postgres=# SELECT slot_name,
      pg_size_pretty(CASE WHEN pg_is_in_recovery() THEN pg_last_wal_replay_lsn()
                          ELSE pg_current_wal_lsn() END - confirmed_flush_lsn)
FROM pg_replication_slots WHERE slot_type = 'logical';
```

slot_name	pg_size_pretty
my_slot	5736 bytes

(1 row)

Conclusion

- Failover of logical slots is supported by Patroni starting from 2.1.0 (released in July 2021)
  - Requires PostgreSQL v11 or newer
  - The old “feature” (create logical slots after promote) is disabled.
- Used in production at Zalando for more than 30 databases
- Don’t forget about the monitoring.

Credits

- Craig Ringer

Thank you!

Questions?