Understanding logical decoding and replication

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About your lecturer

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Agenda

- Introduction to logical decoding
- Output decoders…
- … And logical receivers
- And then…

Introduction to logical decoding

Before coming to it…

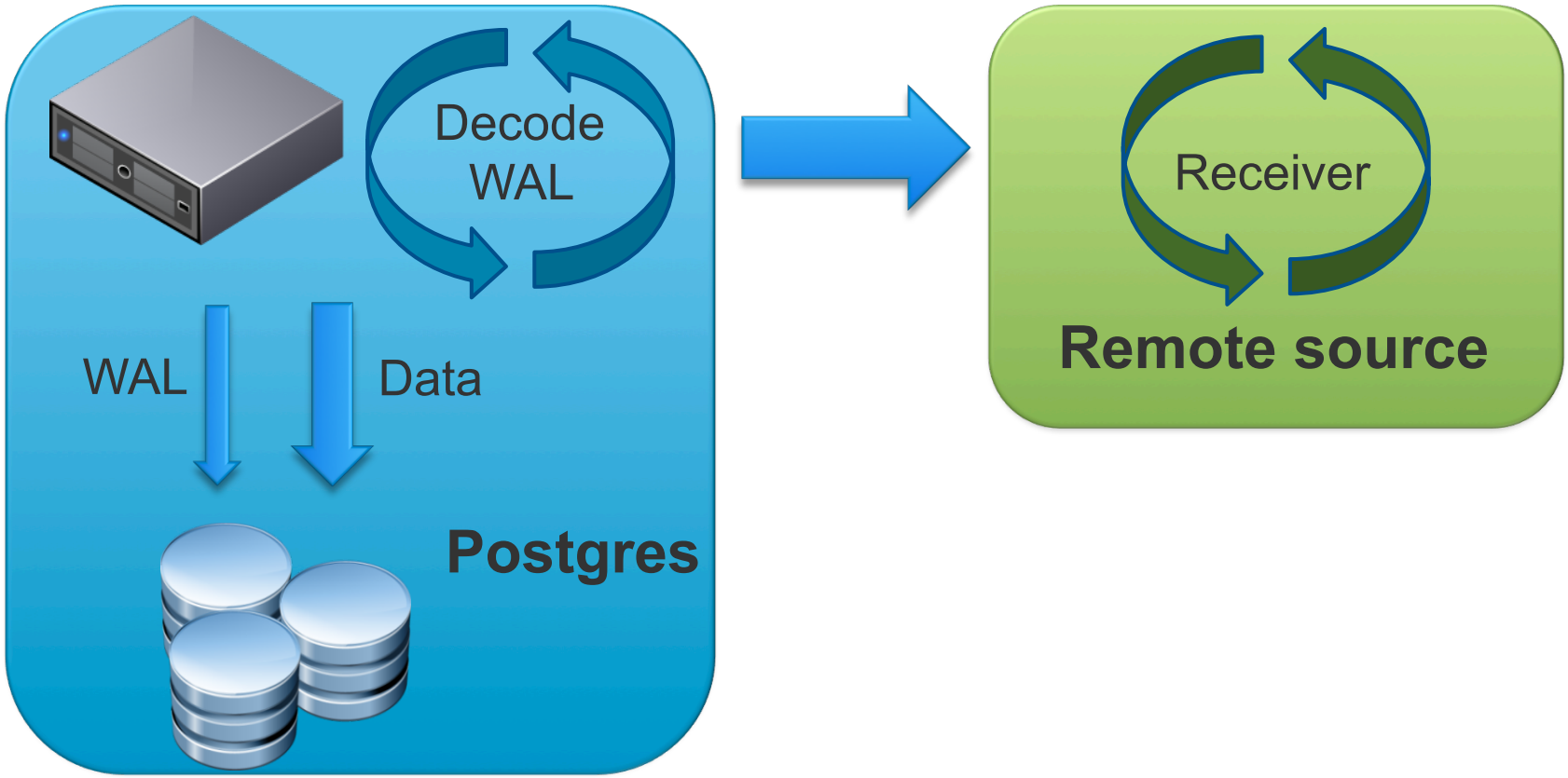
- **WAL = Write-ahead Log**
  - Internal journal of Postgres to maintain data integrity
  - Used for recovery, archives, etc.
  - LSN = Log Sequence Number, or WAL record position
  - http://www.postgresql.org/docs/9.4/static/wal-intro.html
- **WAL sender**
  - Process on root node sending WAL stream
  - On master or standby (cadcading)
- **WAL receiver**
  - Process on standby node receiving WAL stream
  - On standby
- **Replication protocol, set of commands to control replication**
  - Used internally for replication, externally as well with replication connections
  - http://www.postgresql.org/docs/devel/static/protocol-replication.html

What is logical decoding?

- **Newly introduced in 9.4 (release Q4 of 2014)**
- **Plugin infrastructure**
  - Customizable
  - Extensible
  - Adaptable
  - No need to modify core code
- **Use cases**
  - Replication solutions (Slony…)
  - Auditing
  - Online upgrade
- **Result of hundreds of emails**
- **Introduction of many new features and principles…**

Concept of logical decoding

- Decode WAL to get DML changes (INSERT, DELETE and UPDATE)
- Shape changes as desired and stream them
- Get changes and apply them on a remote source



Replication slots (1)

- **Store WAL as long as changes are not consumed**
- **Can be used by one single WAL sender at the same time**
- **Careful: space consumption for pg_xlog partition if used**
- **System view pg_replication_slots**
- **Physical slots**
  - System-wide, conflict resolution with oldestXmin in feedback message
  - For recovery: primary_slot_name in recovery.conf
  - Creation:
    - SELECT pg_create_physical_replication_slot('slot_name')
    - Replication protocol: CREATE_REPLICATION_SLOT foo PHYSICAL
  - Configuration: max_replication_slots > 0
  - Drop:
    - SELECT pg_drop_replication_slot('slot_name')
    - Replication protocol DROP_REPLICATION_SLOT foo

Replication slots (2)

- **Logical**
  - Attached to a database
  - Need a decoder plugin to reshape changes when requested
  - Cannot be used for recovery
  - Creation
    - pg_create_logical_replication_slot(‘slot_name’, ‘plugin_name’)
    - CREATE_REPLICATION_SLOT foo LOGICAL plugin
  - Configuration: max_replication_slots > 0 + wal_level = logical

```
=# SELECT * FROM
    pg_create_physical_replication_slot('physical_slot');
  slot_name   | xlog_position
 -----------------+---------------
  physical_slot | null
(1 row)
=# SELECT * FROM
    pg_create_logical_replication_slot('logical_slot', 'test_decoding');
  slot_name  | xlog_position
 ----------------+---------------
  logical_slot | 0/5000100
 (1 row)
```

Exported snapshots – Obtain it

- **Can be used to retrieve consistent image of database**
- **Export with replication connection**
  - In result of CREATE_REPLICATION_SLOT
  - Available for duration of replication connection
- **Export with vanilla connection**
  - SELECT pg_export_snapshot();
  - Available for duration of transaction calling function, not connection!
- **No snapshot available with pg_create_logical_replication_slot()**
- **Maintain connection/transaction for duration as long as necessary**

Exported snapshots – Dump consistent data

- **Single transaction**
- **Use with SET TRANSACTION SNAPSHOT**
- **Limitations**
  - Need to be tightly linked with application
  - pg_dump offers no real solutions in 9.4

1) Export Snapshot

```
$ psql “replication=database dbname=postgres”
=# CREATE_REPLICATION_SLOT logical_slot
    LOGICAL test_decoding;
-[ RECORD 1 ]----+-------------
 slot_name       | logical_slot
 consistent_point | 0/5000E58
 snapshot_name   | 000003F0-1
 output_plugin   | test_decoding
```

2) Fetch data

```
$ psql postgres
=# BEGIN ISOLATION LEVEL
    REPEATABLE READ;
BEGIN
=# SET TRANSACTION
    SNAPSHOT '000003F0-1’;
SET
=# [stuff]
=# COMMIT;
```

Output decoder

- **Decodes WAL from logical replication slot**
- **Plugin to be added on server side**
- **Used in WAL sender if changes streamed with replication protocol**
- **Output can be queried with SQL functions**
- **1 change per tuple modified**
  - Good for OLTP and short transactions
  - Less for warehouse, bulk writes…
- **Postgres ships one: test_decoding**
- **Can use custom options improving output granularity**
- **Documentation:**
  - http://www.postgresql.org/docs/9.4/static/logicaldecoding-output-plugin.html

REPLICA IDENTITY

- **Change information verbosity of old rows being updated or deleted**
- **Different modes**
  - DEFAULT, use PRIMARY KEY if any
  - USING INDEX index_name
    - Unique, not partial, no expression, no NOT NULL columns
    - Same as DEFAULT with PRIMARY KEY
  - ALL, old values of all columns
  - NOTHING
    - No values recorded
    - Same as DEFAULT without PRIMARY KEY
- **SQL level**
  - CREATE TABLE sets it to DEFAULT
  - ALTER TABLE to change it

Logical change receiver

- **Runs on client side**
  - Anything able to connect to Postgres node with replication protocol
  - In short, something able to fetch changes and process them
  - Can use options of decoder for custom output
- **SQL interface**
  - Textual format
    - pg_logical_slot_get_changes to consume
    - pg_logical_slot_peek_changes to look at
  - Binary format
    - pg_logical_slot_get_binary_changes to consume
    - pg_logical_slot_peek_binary_changes to look at
- **Replication connection => mainly COPY protocol**

Logical decoding and replication

- **Replication connection**
  - Extended “replication” with mode “database” in 9.4
  - Need application_name for pg_stat_replication, dbname
  - Example:
    host=$IP replication=database dbname=my_db application_name=my_app
- **Queries**
  - IDENTIFY_SYSTEM (to get current LSN write position, timeline, system ID or connected database)
  - CREATE_REPLICATION_SLOT
  - DROP_REPLICATION_SLOT
  - START_REPLICATION SLOT slot_name LOGICAL [start_pos | 0/0]
- **Position 0/0**
  - oldest LSN position available in slot.
  - Not InvalidXLogRecPtr…

Logical decoding and replication (2)

- **Use application_name in connection string**
- **standby_synchronous_names on master for synchronous receiver**
- **Feedback to master!**
  - To release WAL files on a slot
  - flush_position, write_position useful (depends on synchronous_commit)
  - Message format
    - ‘r’ for message type
    - 8 bytes for write position (XLogRecPtr)
    - 8 bytes for flush position (XLogRecPtr)
    - 8 bytes for applied/replay position (XLogRecPtr)
    - 8 bytes for timestamp
    - 1 byte to request reply from server

Output decoders…

Basics

- **Set of callback functions for events:**
  - Startup (Initialization when opening slot)
  - Shutdown
  - BEGIN
  - COMMIT
  - Tuple change triggered by INSERT, UPDATE, DELETE
- **Example with decoder generating raw queries**
- **Available as decoder_raw here (PostgreSQL license):**
  - git clone https://github.com/michaelpq/pg_plugins
  - cd pg_plugins/decoder_raw

Loading callbacks

- **Loaded by _PG_output_plugin_init**
  - Similar to _PG_init, but for decoder context
- **Startup and shutdown can be NULL**
- **Begin, commit and change mandatory**

```
Void
_PG_output_plugin_init(OutputPluginCallbacks *cb)
{
    cb->startup_cb = decoder_raw_startup;
    cb->begin_cb = decoder_raw_begin_txn;
    cb->change_cb = decoder_raw_change;
    cb->commit_cb = decoder_raw_commit_txn;
    cb->shutdown_cb = decoder_raw_shutdown;
}
```

Callback - Initialization

- Initialize context and options
- Use ctx->output_plugin_private for parameters
- Output format: OUTPUT_PLUGIN_[BINARY|TEXTUAL]_OUTPUT

```
static void
decoder_raw_startup(LogicalDecodingContext *ctx,
                    OutputPluginOptions *opt,
                    bool is_init)
{
   ListCell   *option;
   DecoderRawData *data;
   data = palloc(sizeof(TestDecodingData));
   data->context = AllocSetContextCreate(ctx->context,
                                         "Raw decoder context", …);

   /* Options */
   foreach(option, ctx->output_plugin_options)
   {
      DefElem    *elem = lfirst(option);
      […blah…]
   }
}
```

Callbacks - Shutdown

- Called each time replication connection ends…
- Or decoder context not needed
- Removal of initialization things

```
static void
decoder_raw_shutdown(LogicalDecodingContext *ctx)
{
        DecoderRawData *data = ctx->output_plugin_private;

        /* cleanup our own resources via memory context reset */
        MemoryContextDelete(data->context);
}
```

Callbacks - BEGIN

- Called each time decoding is done for a single record
- Somewhat similar to BEGIN transaction
- ReorderBufferTXN with information of transaction (txid, etc.)
- StringInfo of ctx->out
- OutputPluginPrepareWrite to prepare the field
- OutputPluginWrite to write change

```
static void
decoder_raw_begin_txn(LogicalDecodingContext *ctx,
                      ReorderBufferTXN *txn)
{
    OutputPluginPrepareWrite(ctx, true);
    appendStringInfoString(ctx->out, "BEGIN;");
    OutputPluginWrite(ctx, true);
}
```

Callbacks - COMMIT

- Called each time decoding is finished for a single record
- Similar to COMMIT transaction, and previous BEGIN…
- commit_lsn = WAL position of this commit

```
static void
decoder_raw_commit_txn(LogicalDecodingContext *ctx,
                       ReorderBufferTXN *txn,
                       XLogRecPtr commit_lsn)
{
    OutputPluginPrepareWrite(ctx, true);
    appendStringInfoString(ctx->out, "COMMIT;");
    OutputPluginWrite(ctx, true);
}
```

Callbacks – DML changes

- **Called each time for each tuple changed**
- **Depending on query and REPLICA IDENTITY, old and new tuple data change**
- **For decoder_raw**
  - WHERE clause of UPDATE and DELETE depends on REPLICA IDENTITY
  - Use relation->rd_rel->relreplident and relation->rd_replidindex!

```
static void
decoder_raw_change(LogicalDecodingContext *ctx, ReorderBufferTXN *txn,
                   Relation relation, ReorderBufferChange *change)
{
    old = MemoryContextSwitchTo(data->context);
    switch (change->action)
    {
        case REORDER_BUFFER_CHANGE_INSERT:
        case REORDER_BUFFER_CHANGE_UPDATE:
        case REORDER_BUFFER_CHANGE_DELETE:
    }
}
```

So now..

- **Hack your own decoders! Or contribute back.**
- **Use test_decoding in contrib/ as a base**
  - Options present as a model
  - Able to manage field values correctly
  - Reuse and abuse of it
- **Demonstration with SQL interface**
- **Remember:**
  - 1 change per tuple
  - N tuples changed => more or less N output entries for single record + 2 (BEGIN + COMMIT)

… And logical receivers

With SQL interface

- **SQL interface**
- **Primitive, maybe fine for simple cases**
- **Advantage**
  - Light
  - Do SQL operations on output, leverage decoder effort to receiver
  - Replication slot changes automatically consumed and incremented
- **Disadvantage**
  - Lack of flexibility: IDENTIFY_SYSTEM, no flush and written position control
  - No replication async or even sync

```
#!/bin/bash
psql -c “SELECT pg_create_logical_replication_slot(‘slot’, ‘decoder_raw’)”
while :
do
    psql -At –c “SELECT * FROM pg_logical_slot_get_changes(‘slot’, NULL, 1)“
    sleep 1
done
```

With replication protocol (1) – Open connection

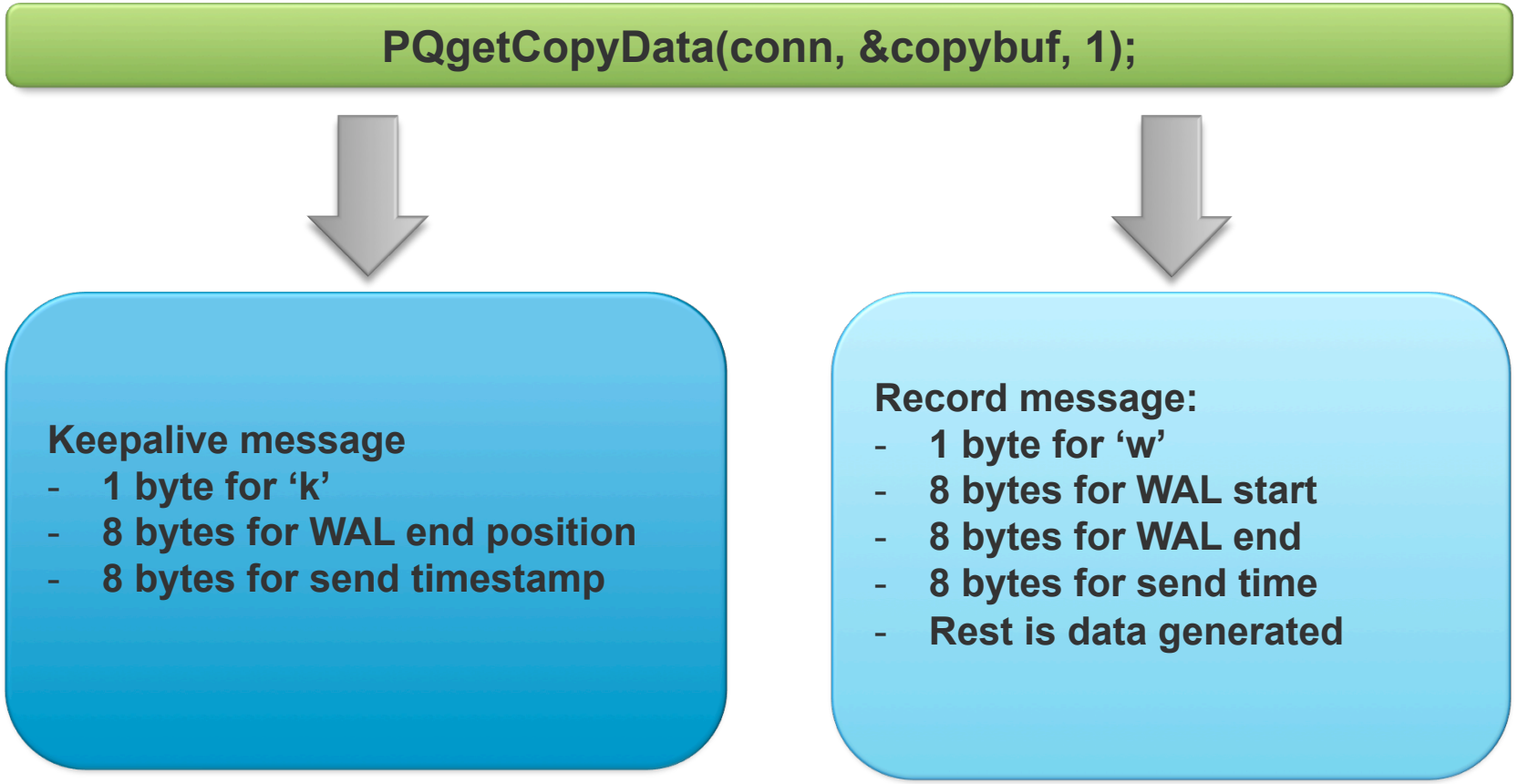
- Open replication connection
- Use PGRES_COPY_BOTH to check result validity
- Possible to pass options

```
/* Start logical replication at specified position */
appendPQExpBuffer(query, "START_REPLICATION SLOT \”slot\" LOGICAL 0/0 ”);
res = PQexec(conn, query->data);
if (PQresultStatus(res) != PGRES_COPY_BOTH)
{
    PQclear(res);
    proc_exit(1);
}

PQclear(res);
[…continue…]
```

With replication protocol (2) – Fetch changes

- **PQgetCopyData as central piece**
  - Status 0 = no data. Wait for more and continue process
  - Status -1 = End of stream. -2 = Failure when reading stream



With replication protocol (3)

- **Look at pg_recvlogical in core!**
  - Create, drop slots, fetch changes as-is
  - http://www.postgresql.org/docs/devel/static/app-pgrecvlogical.html
  - SendFeedback() is really, really important to avoid WAL file bloat
- **Demonstration with receiver_raw**
  - Fetch raw queries from decoder_raw
  - Apply them on local database
  - Need some pre-process:
    - Dump of remote schema
    - Correct REPLICA IDENTITY targets depending on application relations
  - Code
    - receiver_raw in this repo => https://github.com/michaelpq/pg_plugins
    - PostgreSQL license

And then…

- **Cool use cases**
  - Online upgrade (doable with 9.4 but tightly linked with application)
  - Auditing
  - Replication solutions: synchronous replication out-of-the-box!
- **Limitations**
  - Need advanced hacking skills
  - Consistent dumps of replication slots by pg_dump
  - No DDL yet, but event triggers perhaps showing up
  - In-core online upgrade solution not there yet
    - Drastic reduction of downtime
    - Need some pg_upgrade --online

Thanks!
Questions?