PGConf.ASIA 2017

Logical Replication Internals

Noriyoshi Shinoda

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Speaker

Noriyoshi Shinoda

- Company
  - Hewlett-Packard Japan, Ltd
- Now
  - System design, tuning, consulting on RDBMS such as PostgreSQL, Oracle Database, Microsoft SQL Server, Vertica, Sybase ASE etc
  - Oracle ACE
  - Writing 15 books for Oracle Database
  - Investigation and verification of open source products
- URL
  - Slideshare
    - https://www.slideshare.net/noriyoshishinoda/
  - Oracle ACE
    - http://www.oracle.com/technetwork/jp/database/articles/vivadeveloper/index-1838335-ja.html

Agenda

– What is Logical Replication?

– Let’s try!

– Architecture

– Restrictions

– Trouble shooting

What is Logical Replication?

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What is Logical Replication?

What is Logical Replication?

- Is
  - PostgreSQL 10 new features
  - Replicate per table
  - Replicate per transaction
  - Updatable replication destination tables
  - Guarantee that the results of the SQL statement will be identical (= Logical)
  - Adopt Publish / Subscribe model
  - ≒ Slony-I
- Is Not
  - Re-execute SQL
  - Physical page format match

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What is Logical Replication?

Replication condition

- Conditions for replicable tables
  - Identical schema name
  - Identical table name
  - Identical column name
  - Identical data type
    - Different data types are available if implicit type conversion is possible

Let’s try it!

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Let’s try it!
Publisher instance

- Replicate data1 table of pubdb database to subdb database
- Create role with REPLICATION attribute / LOGIN attribute
  - Role connected from Subscriber instance

```
pubdb=# CREATE ROLE repusr1 PASSWORD ’Passw0rd’ LOGIN REPLICATION ;
CREATE ROLE
```

- Grant database CREATE privilege to table owner (pubusr1)

```
pubdb=# GRANT CREATE ON DATABASE pubdb TO pubusr1 ;
GRANT
```

- Modify pg_hba.conf file

```
# TYPE  DATABASE     USER       ADDRESS               METHOD
host    pubdb        repusr1    192.168.1.100/32      md5
```

  - 'DATABASE = replication' item not required

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Let’s try it!

Publisher instance

- Modify postgresql.conf file

```
wal_level = logical
```

Let’s try it!
Publisher database

– Create table for replication

```
pubdb=> CREATE TABLE data1 (c1 INT PRIMARY KEY, c2 VARCHAR(5)) ;
CREATE TABLE
```

– Grant SELECT permission to the table for connected user

```
pubdb=> GRANT SELECT ON data1 TO repusr1 ;
GRANT
```

– Create the PUBLICATION object

```
pubdb=> CREATE PUBLICATION pub1 FOR TABLE data1 ;
CREATE PUBLICATION
```

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Let’s try it!

Subscriber database

– Create table for replication

```
subdb=> CREATE TABLE data1 (c1 INT PRIMARY KEY, c2 VARCHAR(5)) ;
CREATE TABLE
```

– Create the SUBSCRIPTION object (require SUPERUSER)

```
subdb=# CREATE SUBSCRIPTION sub1 CONNECTION
  'host=pubhost1 dbname=pubdb user=repusr1 password=Passw0rd’
  PUBLICATION pub1 ;
CREATE SUBSCRIPTION
```

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Let’s try it!

Confirmation

– Publisher instance

```
pubdb=# SELECT application_name, state, sync_state FROM
        pg_stat_replication ;
 application_name |   state   | sync_state
------------------+-----------+------------
 sub1             | streaming | async
(1 row)
```

– Subscriber instance

```
subdb=> SELECT subname, received_lsn FROM pg_stat_subscription ;
 subname | received_lsn
---------+--------------
 sub1    | 0/1C8FF738
```

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Architecture

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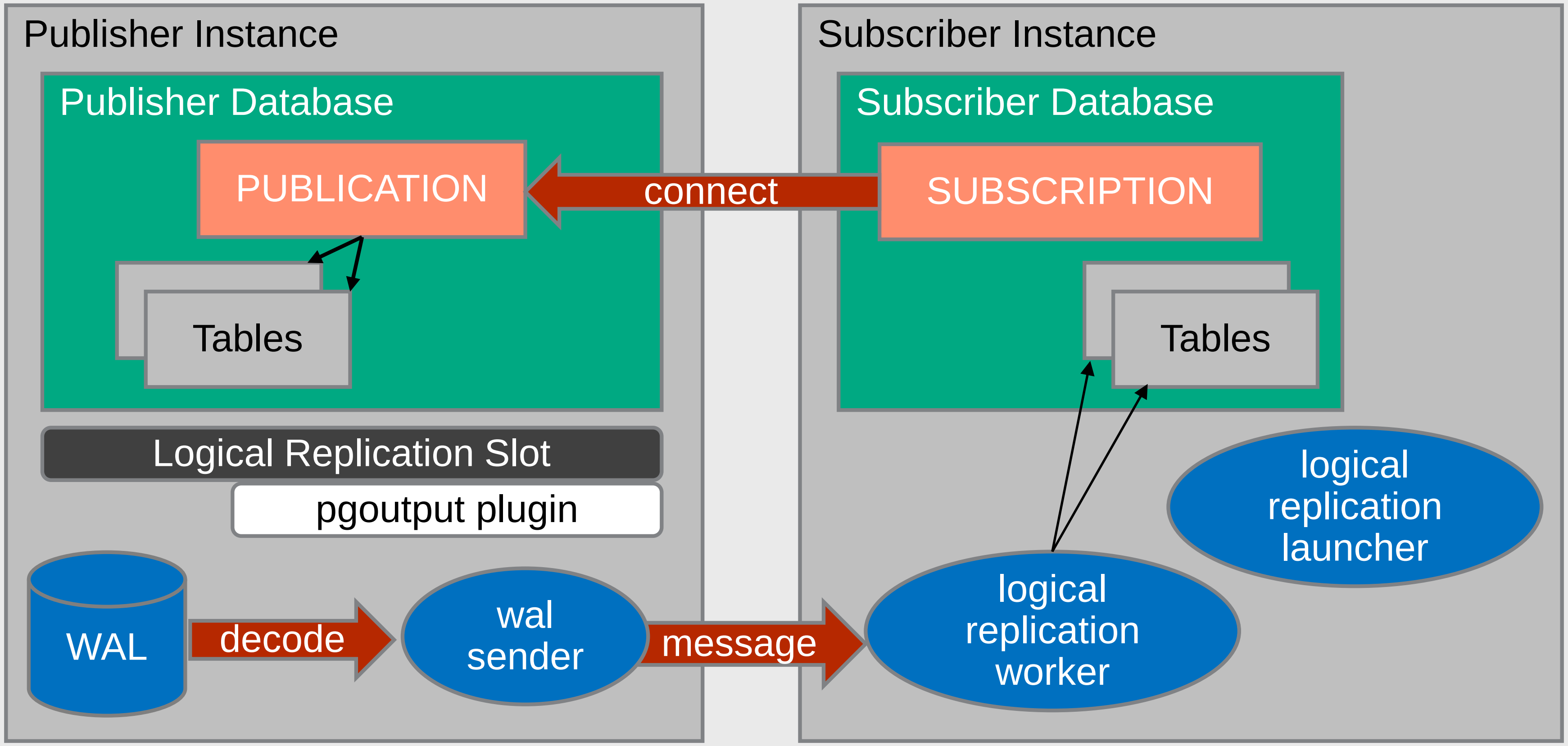
Architecture

Components



Architecture

Processes

- wal sender process {user} {client ip} {state}
  - On PUBLICATION instance
  - Send decoded WAL messages
  - Launch for each connection from SUBSCRIPTION

- bgworker: logical replication launcher
  - On PUBLICATION / SUBSCRIPTION instance
  - Start the logical replication worker process

- bgworker: logical replication worker for subscription {oid}
  - On SUBSCRIPTION instance
  - Connect to wal sender process
  - Receive decoded WAL message and update the table
  - Launch for each SUBSCRIPTION

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Architecture

Behavior when PUBLICATION is created

– Store information in the pg_publication catalog
  – PUBLICATION name
  – Which DML to replicate (INSERT / UPDATE / DELETE)
  – Whether to cover all tables (FOR ALL TABLES clause)

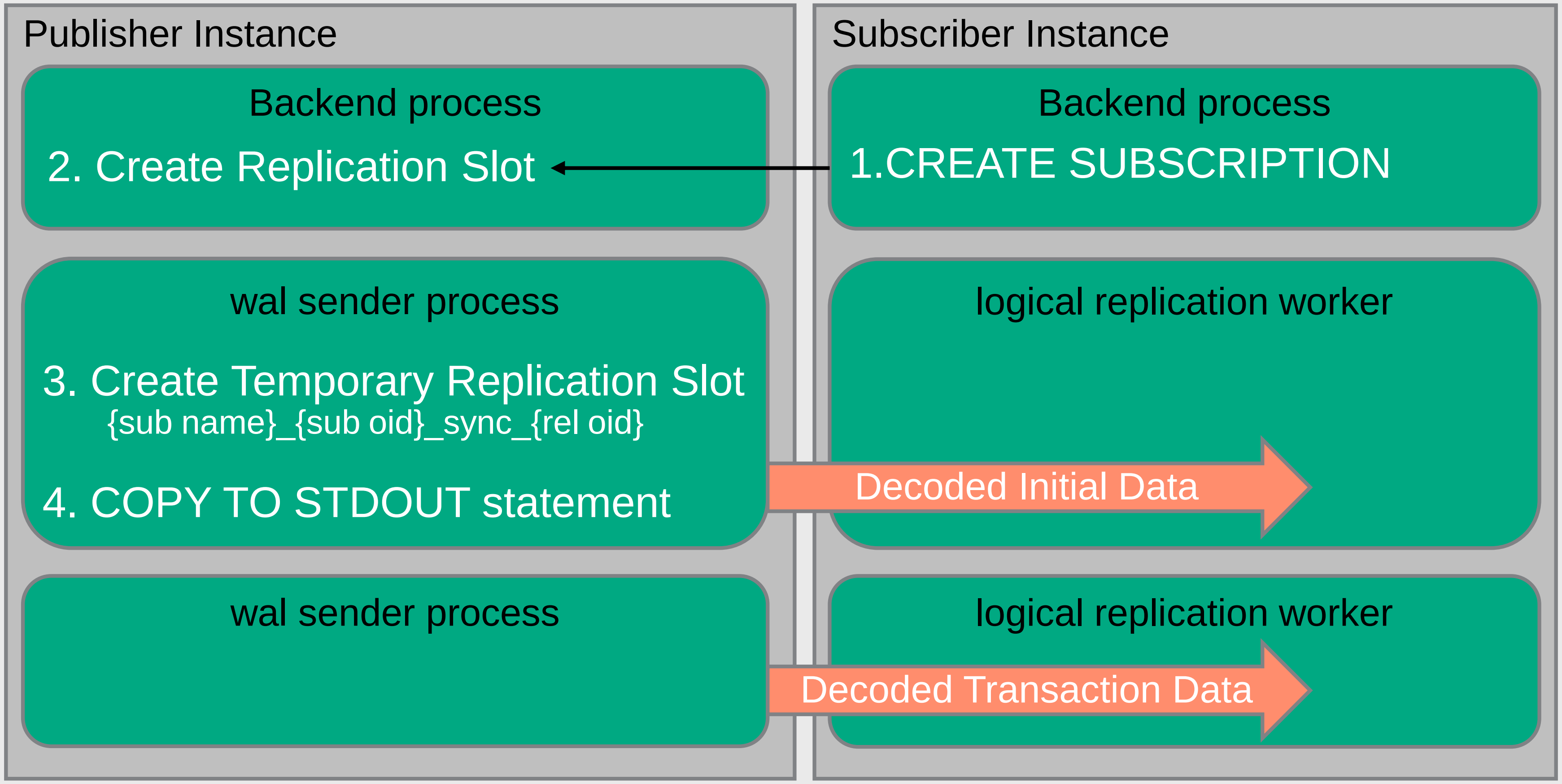
– Store information in the pg_publication_rel catalog
  – Table OID and PUBLICATION OID
  – If FOR ALL TABLES clause is specified, nothing is stored in this catalog
  – Table name can be referenced from pg_publication_tables catalog

Architecture

Behavior when SUBSCRIPTION is created

- Store information in pg_subscription catalog
  - Connected instance information
  - Replication Slot name
  - Connected PUBLICATION name
  - Synchronous / Asynchronous replication attribute
- Connect to PUBLICATION instance
  - Check REPLICATION attribute of connected user
  - Create Logical Replication Slot (default name is SUBSCRIPTION name)
  - Do not check whether PUBLICATION exists
  - Register replication target tables in pg_subscription_rel catalog
- Synchronize initial snapshot
  - Executed asynchronously
  - Existing data on SUBSCRIPTION insntance will not be deleted

Architecture
Synchronize initial snapshot


Publisher Instance
Backend process
2. Create Replication Slot
wal sender process
3. Create Temporary Replication Slot
{sub name}_{sub oid}_sync_{rel oid}
4. COPY TO STDOUT statement
wal sender process
Subscriber Instance
Backend process
1.CREATE SUBSCRIPTION
logical replication worker
Decoded Initial Data
logical replication worker
Decoded Transaction Data

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Architecture
Replication Slot

– Logical Replication Slot
  – One-to-one with SUBSCRIPTION
  – Manage sent WAL
  – Provide replication plugin
  – Automatic execution of the following SQL statement when creating SUBSCRIPTION

```
pg_create_logical_replication_slot ( name, 'pgoutput' )
```

– Replication Slot name
  – SUBSCRIPTION name by default
  – Can change CREATE SUBSCRIPTION WITH (slot_name=name) statement

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Architecture
pgoutput plugin and message

- pgoutput plugin
  - Default plugin for Logical Replication
  - Used by wal sender process
  - Create Logical Replication messages from WAL
    - Convert character encoding
    - Convert text message from binary data
  - Does not support text output by pg_logical_slot_get_changes function?

- Message
  - All text data
  - Protocol
    - https://www.postgresql.org/docs/10/static/protocol-logicalrep-message-formats.html
  - When executed UPDATE / DELET statement
    - Send data specifying the update target column and updated data

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Architecture
Replica Identity

– The condition under which the UPDATE statement / DELETE statement is replicated

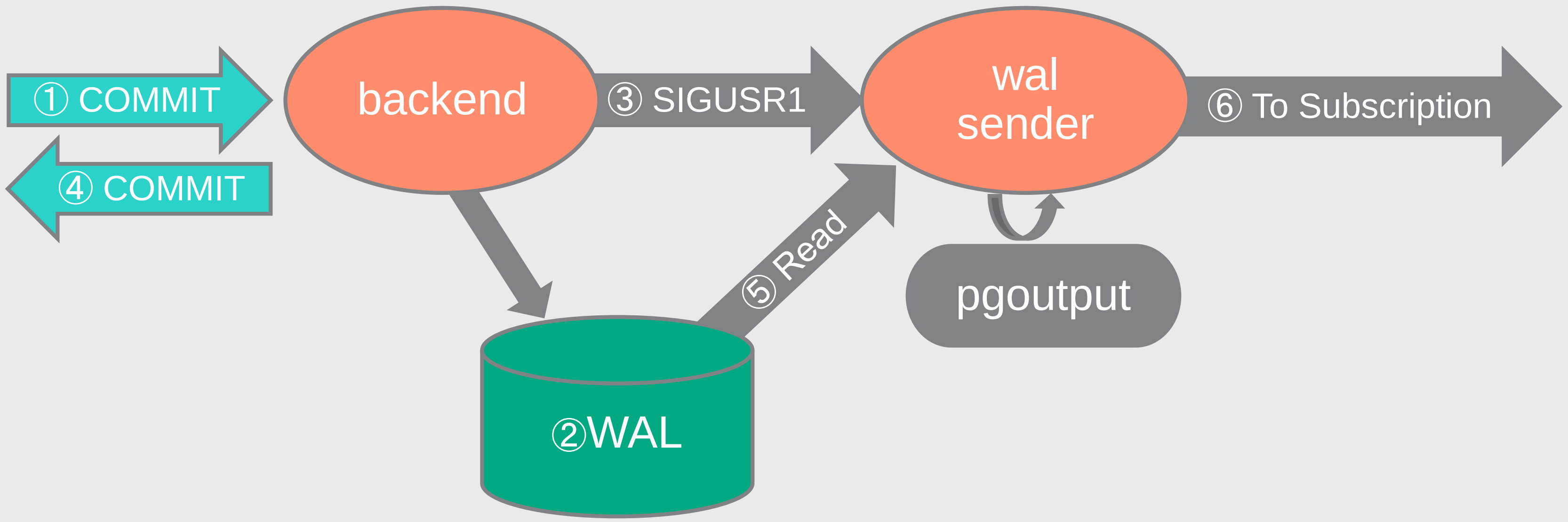
Table attribute	PUBLICATION	SUBSCRIPTION
PRIMARY KEY	Yes	Yes
REPLICA IDENTITY FULL	Yes	No
REPLICA IDENTITY USING INDEX + UNIQUE index + NOT NULL	Yes	Yes

– UPDATE / DELETE for a table without a primary key or REPLICA IDENTITY setting is an SQL execution error

```
pubdb=> UPDATE data1 SET c2='update' WHERE c1=100 ;
ERROR:  cannot update table "data1" because it does not have replica
identity and publishes updates
HINT:  To enable updating the table, set REPLICA IDENTITY using ALTER
TABLE.
```

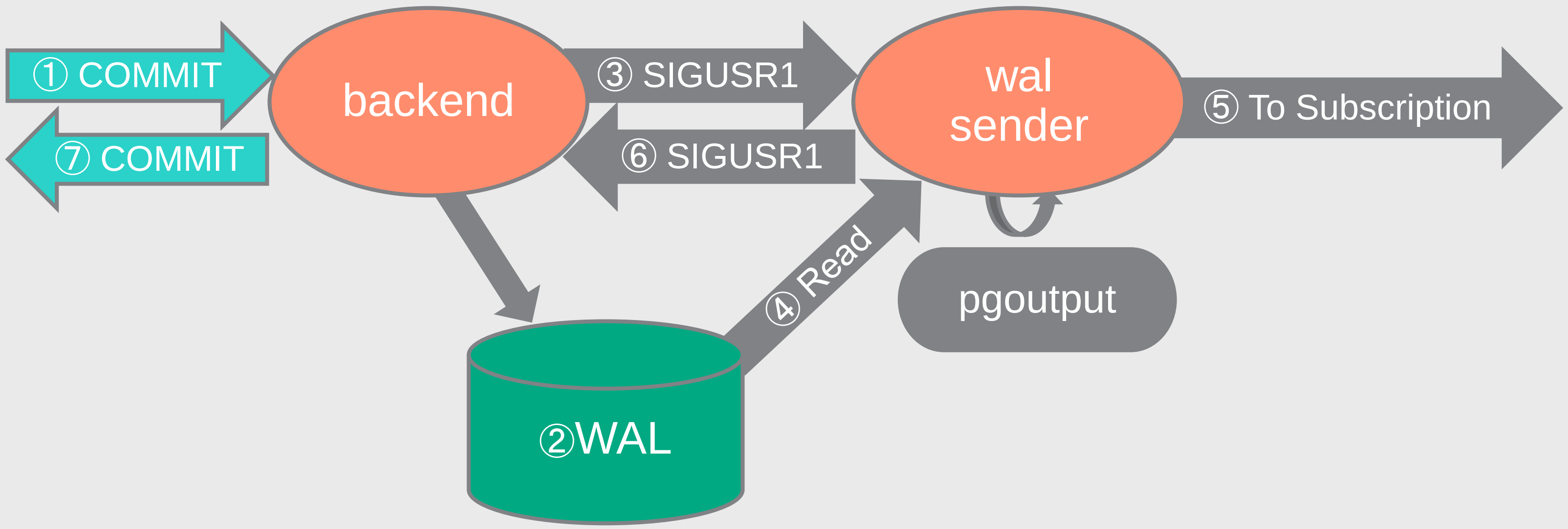
Architecture

Behavior during DML execution (asynchronous replication)



Architecture

Behavior during DML execution (synchronous replication)



Architecture
Storage

– Logical log snapshot
  – Created when wal sender process receives SIGUSR1 signal from wal writer process
  – Read the WAL file and create snapshot
  – File path

```
${PGDATA}/pg_logical/snapshots/{LSN upper}-{LSN lower}.snap
```

– Logical log snapshot when SUBSCRIPTION stop
  – Created if the SUBSCRIPTION instance is stopped and the wal sender process is restarted
  – It is deleted when the transfer is completed
  – File path

```
${PGDATA}/pg_replslot/{SLOT_NAME}/xid-{XID}-lsn-{LSN upper}-{LSN
lower}.snap
```

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Restrictions

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Restrictions

SQL statement that can not be replicated

– TRUNCATE statement

– ALTER TABLE statement

– CREATE TABLE statement

  – When executing the CREATE REPLICATION FOR ALL TABLES statement

Restrictions

Objects that can not be replicated

- Only the table can be added to PUBLICATION
  - pg_class.relkind = 'r'
- Objects that can not be replicated
  - MATERIALIZED VIEW
  - INDEX
  - SEQUENCE
  - FOREIGN TABLE
  - UNLOGGED TABLE
  - INHERIT TABLE = OK (ONLY clause)
  - Partition parent table
  - Large Object

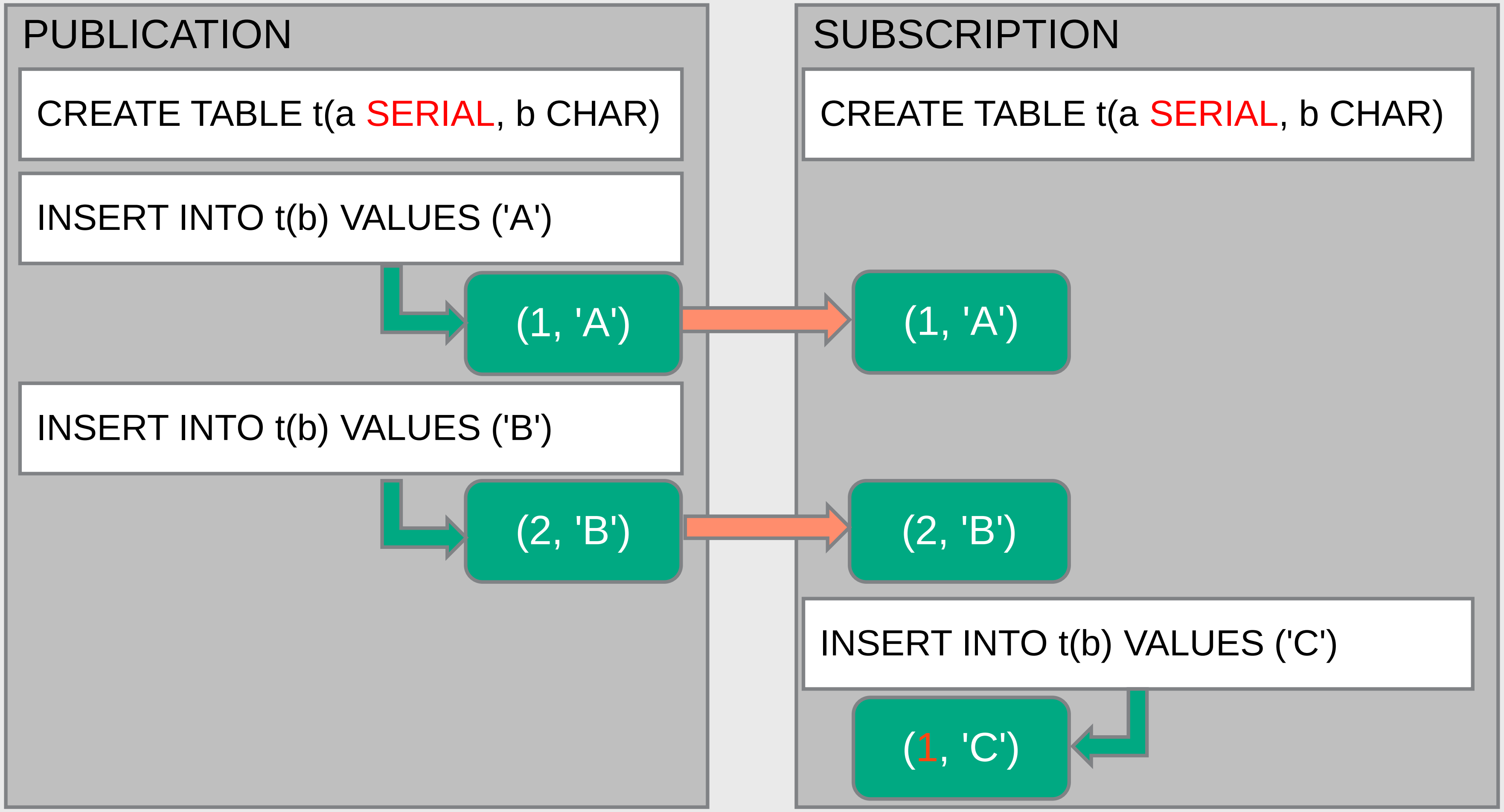
Restrictions

SERIAL column / GENERATED AS IDENTITY column

- Internally use SEQUENCE for SERIAL and GENERATED AS IDENTITY columns
- The sequence value is transferred to SUBSCRIPTION but no sequence operation is executed

Restrictions

SERIAL column / GENERATED AS IDENTITY column


PUBLICATION
CREATE TABLE t(a SERIAL, b CHAR)
INSERT INTO t(b) VALUES ('A')
(1, 'A')
INSERT INTO t(b) VALUES ('B')
(2, 'B')
SUBSCRIPTION
CREATE TABLE t(a SERIAL, b CHAR)
(1, 'A')
(2, 'B')
INSERT INTO t(b) VALUES ('C')
(1, 'C')

Restrictions

Trigger

- Partial execution
  - Only ROW TRIGGER execute
  - UPDATE OF trigger is not executed
  - STATEMENT TRIGGER is executed only at initial data transfer
- SUBSCRIPTION database
  - Require ALTER TABLE ENABLE ALWAYS or REPLICA TRIGGER statement
  - Bug on10.0 : BEFORE ROW DELETE trigger not issued
    - https://git.postgresql.org/gitweb/?p=postgresql.git;a=commitdiff;h=360fd1a7b2fe779cc9e696b813b12f6a8e83b558
    - Fixed on10.1

Restrictions

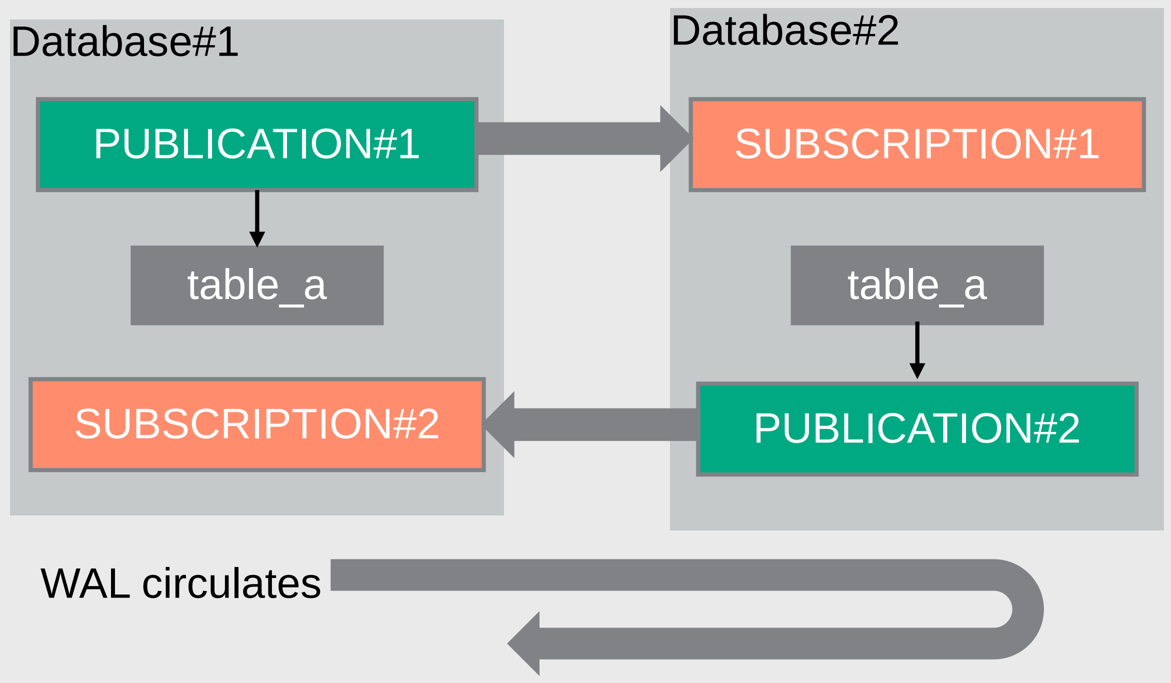
Parameter log_statement

– Even if log_statement = 'all' set, the SQL statement by replication does not be logged

Restrictions

Bidirectional replication

– Bidirectional replication can not be performed
  - It can be configured, however WAL circulates
  - Mutual replication between databases is possible if tables are different



Restrictions
Replication within instance

– Be careful to create the replication within instance
  – The CREATE SUBSCRIPTION statement hangs when trying to simply configure it
  – It is necessary to create SUBSCRIPTION and Replication Slot indivisually

– Create Logical Replication Slot manually

```
pubdb=# SELECT
   pg_create_logical_replication_slot ('sub1', 'pgoutput') ;
```

– Create SUBSCRIPTION

```
subdb=# CREATE SUBSCRIPTION sub1 CONNECTION 'dbname=pubdb' WITH
  (CONNECT=off) ;
```

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Restrictions

Combined with Streaming Replication

– Mixable with Streaming Replication environment

– Logical replication from slave instance is not possible

  – Logical Replication Slot can not be created on standby instance

  – Logical Decoding can not be executed on the standby instance

Trouble shooting

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Trouble shooting

Log of resource shortage

– max_replication_slots shortage (PUBLICATION)

```
ERROR:  could not create replication slot "sub1": ERROR:  all
replication slots are in use
```

– max_wal_senders shortage (PUBLICATION)

```
FATAL:  number of requested standby connections exceeds
max_wal_senders (currently 10)
```

– max_logical_replication_workers shortage (SUBSCRIPTION)

```
WARNING:  out of logical replication worker slots
HINT:  You might need to increase max_logical_replication_workers.
```

– max_worker_processes shortage (SUBSCRIPTION)

```
No log output
```

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Trouble shooting
Other log

– Lack of permission at the time of the initial data copy (PUBLICATION)

```
ERROR:  could not start initial contents copy for table
"public.data1": ERROR:  permission denied for relation data1
```

– Execution of DROP SUBSCRIPTION statement (normal)

```
FATAL:  terminating logical replication worker due to administrator
command
LOG:  worker process: logical replication worker for subscription
16408 (PID 77332) exited with exit code 1
```

Trouble shooting
Conflict pattern and behavior

– Conflict with the behavior that occurs in the SUBSCRIPTION database

Conflict pattern	Replication	Log output
Primary Key / Unique Key Violation	Stop	Yes
CHECK constraint violation	Stop	Yes
No UPDATE data	Continue	No
No DETETE data	Continue	No
No table	Stop	Yes
No partial columns	Stop	Yes
Data convert error	Stop	Yes
Lock table	Wait	No
Lock updated rows	Wait	No

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Trouble shooting

Conflict pattern and behavior

- Impact on applications when conflict occurs
  - Even if conflicts occur, SQL to the table does not be blocked
- Conflict detection
  - Detect from logfile
  - pg_stat_replication.flush_lag / write_lag
  - pg_replication_slots.confirmed_flush_lsn not equal pg_current_wal_lsn()
- Behavior at conflict occurrence in SUBSCRIPTION instance
  - When constraint violation is detected, the logical replication worker process stop
  - Restart after 5 seconds and restart WAL apply
  - Repeat the above until constraint violation is resolved

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Trouble shooting

Log at error occurrence

– Log of primary key violation on SUBSCRIPTION side

```
ERROR:  duplicate key value violates unique constraint "pk_data1"
DETAIL:  Key (c1)=(500) already exists.
LOG:  worker process: logical replication worker for subscription
16414 (PID 9644) exited with exit code 1
```

– Log on wal sender timeout on PUBLICATION side

```
LOG:  terminating walsender process due to replication timeout
LOG:  starting logical decoding for slot "sub1"
DETAIL:  streaming transactions committing after 0/5600ED48, reading
WAL from 0/5600ED10
```

Trouble shooting

Log at error occurrence

– Memory allocation error during WAL decoding

– Occurred when transferring bytea type

  – Text transformation according to the parameter bytea_output

  – Ensure the memory of the "record size x 2 + 1" bytes by default

– PUBLICATION side log

```
ERROR:  invalid memory alloc request size 258291203
CONTEXT:  slot "sub1", output plugin "pgoutput", in the change
callback, associated LSN 0/2B2543E8LOG:  could not send data to
client: Broken pipe FATAL:  connection to client lost
```

– SUBSCRIPTION side log

```
ERROR:  could not receive data from WAL stream:
ERROR:  invalid memory alloc request size 258291203
CONTEXT:  slot "sub1", output plugin "pgoutput", in the change
callback, associated LSN 0/2B2543E8
```

Trouble shooting

Conflict Resolution

- The conflict is not automatically resolved
- There are two ways to solve (on SUBSCRIPTION side)
  - Delete the record where the conflict occurred (resolve the constraint violation)
  - Skipping WAL where conflict has occurred (resolution of constraint violation / elimination of memory shortage)

Trouble shooting

Conflict Resolution

– Skip WAL where conflict occurred

  – Specify the LSN that starts applying WAL

– Confirm current LSN on PUBLICATION side

```
postgres=# SELECT pg_current_wal_lsn() ;
pg_current_wal_lsn
--------------------
 0/7200B4F0
(1 row)
```

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Trouble shooting
Conflict Resolution

– Confirm external_id on SUBSCRIPTION side

```
subdb=# SELECT * FROM pg_replication_origin_status ;
 local_id | external_id | remote_lsn | local_lsn
----------+-------------+------------+-----------
        1 | pg_16425    | 0/7200B068 | 0/DA0078E8
(1 row)
```

– pg_{pg_subscription.oid} is output to the external_id column

```
subdb=# SELECT oid, subname FROM pg_subscription ;
  oid  | subname
-------+---------
 16425| sub1
```

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Trouble shooting

Conflict Resolution

– Specify the start LSN on SUBSCRIPTION side

```
subdb=# SELECT
    pg_replication_origin_advance ('pg_16425', '0/7200B4F0') ;

 pg_replication_origin_advance
-------------------------------

(1 row)
```

– Sometimes it gets an error

```
subdb=# SELECT pg_replication_origin_advance('pg_16399',
'0/82708760') ;
ERROR:  replication origin with OID 1 is already active for PID 5566
```

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Thank you

noriyoshi.shinoda@hpe.com