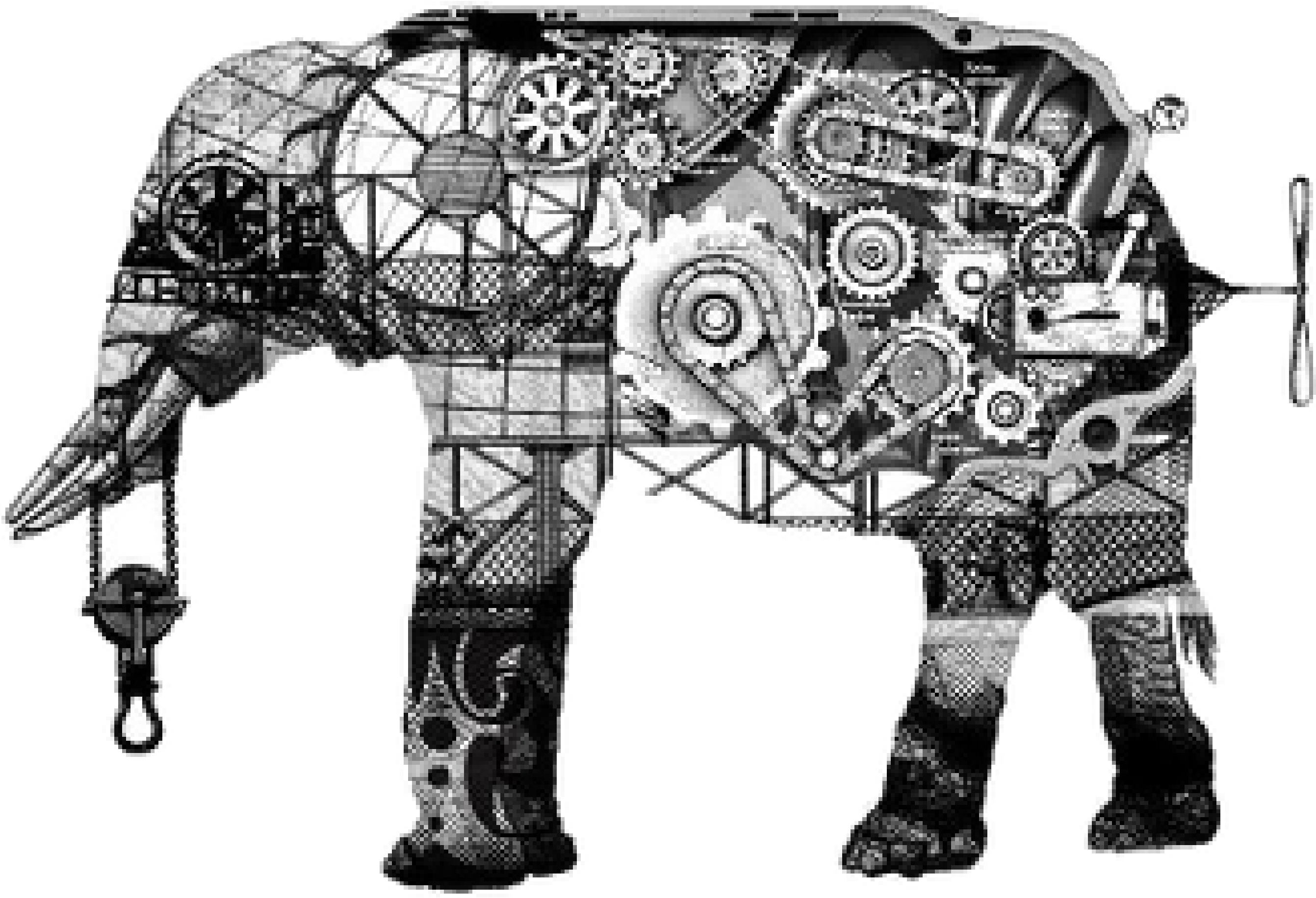
The Internals of PostgreSQL

for database administrators and system developers



Chapter 10

Base Backup & Point-in-Time Recovery

Online database backup can be roughly classified into two categories: logical and physical backups. While both of them have advantages and disadvantages, there is one disadvantage in logical backup; taking too much time for its performance. In particular, it requires a fairy long time to make the backup of a large database, and even more time to restore such a database from backup data. On the contrary, physical backup makes it possible to backup and to restore large databases in a relatively short time so that it is a very important and useful feature in practical systems.

In PostgreSQL, online physical full backup has been available since version 8.0, and a snapshot of a running whole database cluster (i.e. physical backup data) is known as a **base backup**.

Point-in-Time Recovery (PITR), which has also been available since version 8.0, is the feature to restore a database cluster to any point in time using a *base backup* and *archive logs* created by continuous archiving feature. For example, even if you made a critical mistake (e.g. truncating all tables), this feature enables you to restore the database of the point just before the mistake you have made.

In this chapter, following topics are described:

- What base backup is
- How PITR works
- What timelineId is
- What timeline history file is

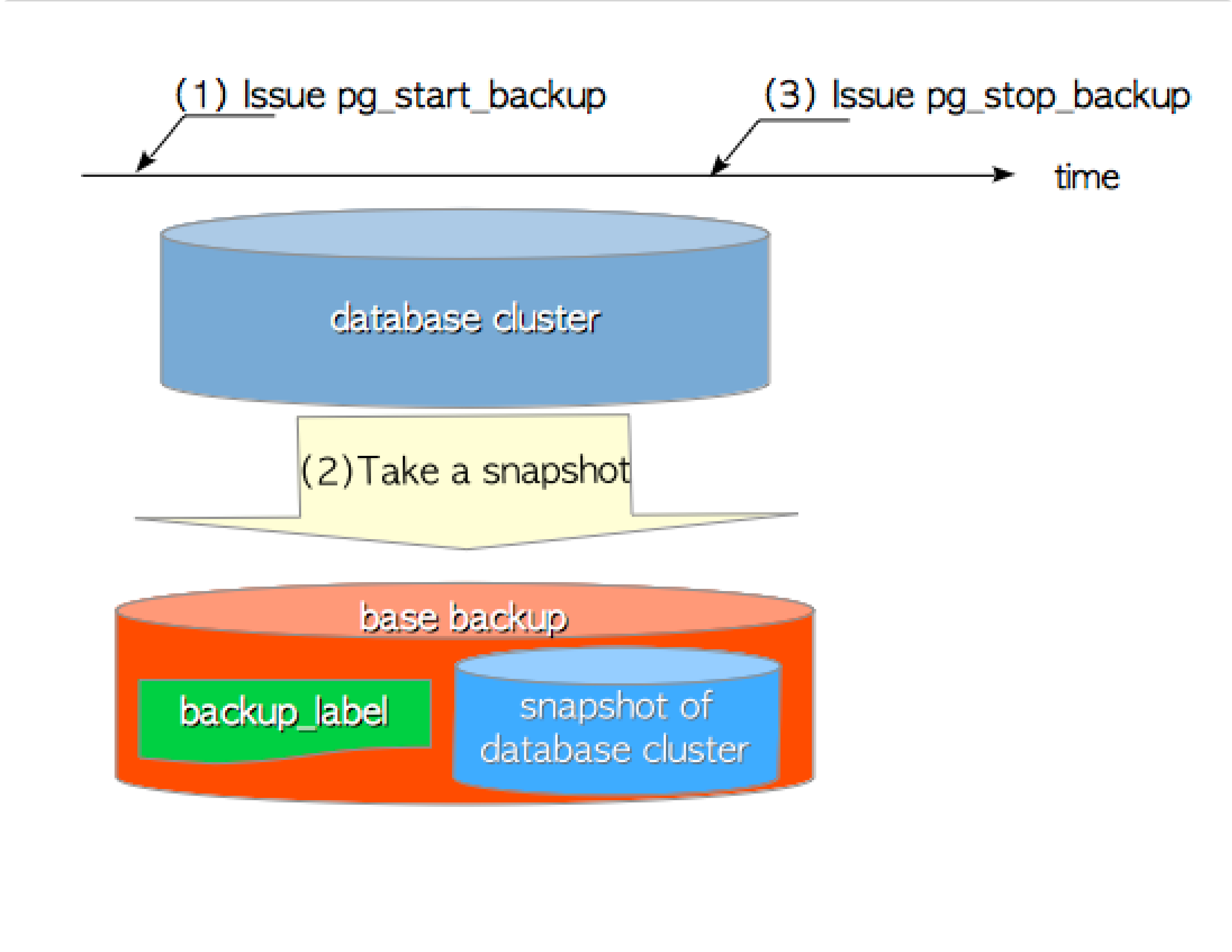
> In version 7.4 or earlier, PostgreSQL had supported only logical backups (logical full and partial backups, and data exports).

(1) Issue the *pg_start_backup* command
(2) Take a snapshot of the database cluster with the archiving command you want to use
(3) Issue the *pg_stop_backup* command

This simple procedure is easy-to-use for database system administrators, because it requires no special tools but common tools such as copy command or a similar archiving tools to create a base backup. In addition, in this procedure, no table locks are required and all users can issue queries without being affected by backup operation. Those are big advantages over other major open source RDBMS.

More simple way to make a base backup is to use the *pg_basebackup* utility, but it internally issues those low-level commands.

Figure 10.1: Making a base backup



As the pair of those commands is clearly one of the key points for understanding the PITR, we will explore them in the following subsections.

The *pg_start_backup* and *pg_stop_backup* commands are defined here: src/backend/access/transam/xlogfuncs.c.

10.1.1 pg_start_backup

The *pg_start_backup* prepares for making a base backup. As discussed in Section 9.8, recovery process starts from a REDO point, so the *pg_start_backup* must do checkpoint to explicitly create a REDO point at the start of making a base backup. Moreover, the checkpoint location of its checkpoint must be saved in a file other than pg_control because regular checkpoint might be done a number of times during backup. Hence the *pg_start_backup* performs the following four operations:

1. Force into the full-page wirte mode.
2. Switch to the current WAL segment file (version 8.4 or later).
3. Do checkpoint.
4. Create a *backup_label file* – This file, created in the top level of the base directory, contains essential information about base backup itself, such as the checkpoint location of this checkpoint.

The third and fourth operations are the heart of this command; the first and second operations are performed to recover a database cluster more reliably.

A *backup_label* file contains the following five items:

- CHECKPOINT LOCATION – This is the LSN location where the checkpoint created by this command has been recorded.

- LABEL – This is the label specified at the *pg_start_backup*.

backup_label

An actual example of backup_label file is shown in the following:

```
postgres> cat /usr/local/pgsql/data/backup_label
START WAL LOCATION: 0/9000028 (file 000000010000000000000009)
CHECKPOINT LOCATION: 0/9000060
BACKUP METHOD: pg_start_backup
BACKUP FROM: master
START TIME: 2017-7-6 11:45:19 GMT
LABEL: Weekly Backup
```

As you may imagine, when you recover a database using this base backup, PostgreSQL takes the "CHECKPOINT LOCATION" out of the backup_label file to read the checkpoint record from the appropriate archive log, and then, gets the REDO point from its record and starts recovery process. (The details will be described in the next section.)

10.1.2 pg_stop_backup

The *pg_stop_backup* performs the following five operations to complete the backup.

1. Reset to *non-full-page writes* mode if it has been forcibly changed by the *pg_start_backup*.
2. Write a XLOG record of backup end.
3. Switch the WAL segment file.
4. Create a backup history file – This file contains the contents of the backup_label file and the timestamp that the *pg_stop_backup* has been executed.
5. Delete the backup_label file – The backup_label file is required for recovery from the base backup and once copied, it is not necessary in the original database cluster.

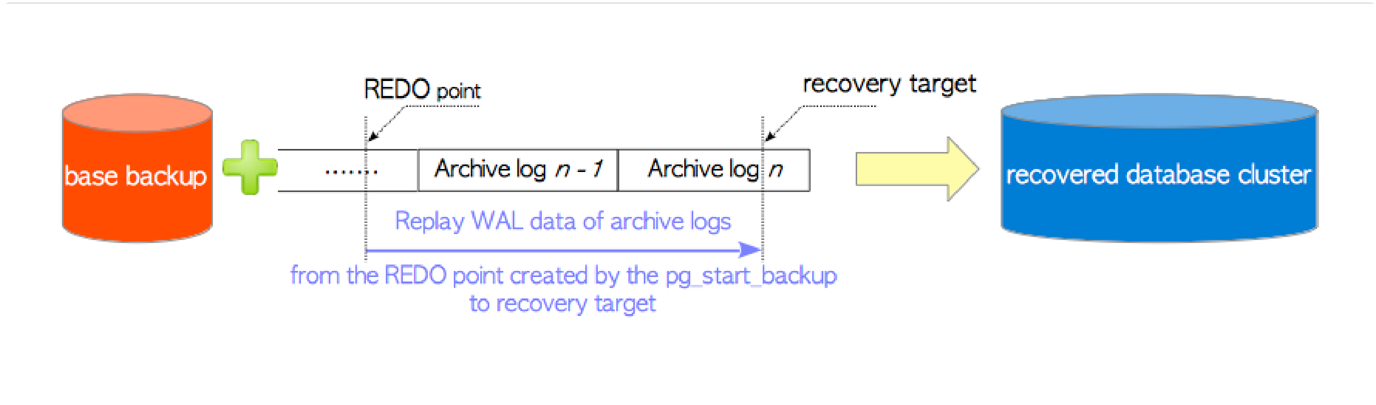
The *naming method for backup history file* is shown below.

```
{WAL segment}.{offset value at the time the base backup was started}.backup
```

10.2 How Point-in-Time recovery works

Figure 10.2 shows the basic concept of PITR. PostgreSQL in PITR-mode replays the WAL data of the archive logs on the base backup, from the REDO point created by the *pg_start_backup* up to the point you want to recover. In PostgreSQL, the point to be recovered is referred to as a **recovery target**.

Figure 10.2: Basic concept of PITR



Here is the description of how PITR works. Suppose that you made a mistake at 12:05 GMT of 6 July, 2017. You should remove the database cluster and restore the new one using the base backup you made before that. Then, create a recovery.conf file, and set the time of the parameter *recovery_target_time* within this file at the point you made the mistake (in this case, 12:05 GMT). The recovery.conf file is shown below:

```
# Place archive logs under /mnt/server/archivedir directory.
restore_command = 'cp /mnt/server/archivedir/%f %p'
recovery_target_time = "2017-7-6 12:05 GMT"
```

When PostgreSQL starts up, it enters into PITR mode if there are a *recovery.conf* and a *backup_label* in the database cluster.

PITR process is almost the same as the normal recovery process described in Chapter 9; the only differences between them are the following two points:

1. Where are WAL segments/Archive logs read from?
   - Normal recovery mode – from the pg_xlog subdirectory (in version 10 or later, pg_wal subdirectory) under the base directory.
   - PITR mode – from an archival directory set in the configuration parameter archive_command.
2. Where is the checkpoint location read from?
   - Normal recovery mode – from a *pg_control file*.
   - PITR mode – from a *backup_label file*.

The outline of PITR process is described as follows:

(1) In order to find the REDO point, PostgreSQL reads the value of *"CHECKPOINT LOCATION"* from the backup_label file with the internal function *read_backup_label*.
(2) PostgreSQL reads some values of parameters from the recovery.conf; in this example, *restore_command* and *recovery_target_time*.

recovery_target_time is set to this timestamp. If a recovery target is not set to the recovery.conf, PostgreSQL will replay until end of archiving logs.

(4) When the recovery process completes, a **timeline history file**, such as "00000002.history", is created in the pg_xlog subdirectory (in version 10 or later, pg_wal subdirectory); if archiving log feature is enabled, same named file is also created in the archival directory. The contents and role of this file are described in the following sections.

The records of commit and abort actions contain the timestamp at which each action has done (XLOG data portion of both actions are defined in xl_xact_commit and xl_xact_abort respectively). Therefore, if a target time is set to the parameter *recovery_target_time*, PostgreSQL may select whether to continue recovery or not, whenever it replays XLOG record of either commit or abort action. When XLOG record of each action is replayed, PostgreSQL compares the target time and each timestamp written in the record; and if the timestamp exceed the target time, PITR process will be finished.

> The function *read_backup_label* is defined in src/backend/access/transam/xlog.c.
> The structure *xl_xact_commit* and *xl_xact_abort* are defined in src/include/access/xact.h.

> **Why can we use common archiving tools to make a base backup?**
>
> Recovery process is a process to make a database cluster in a consistent state, though the cluster is inconsistent. As PITR is based on the recovery process, it can recover the database cluster even if a base backup is a bunch of inconsistent files. This is the reason why we can use common archiving tools without a file system snapshot capability or a special tool.

10.3 timelineId and timeline history file

Timeline in PostgreSQL is used to distinguish between the original database cluster and the recovered ones, and is central concept of PITR. In this section, two things associated with the timeline are described: *timelineId* and *timeline history files*.

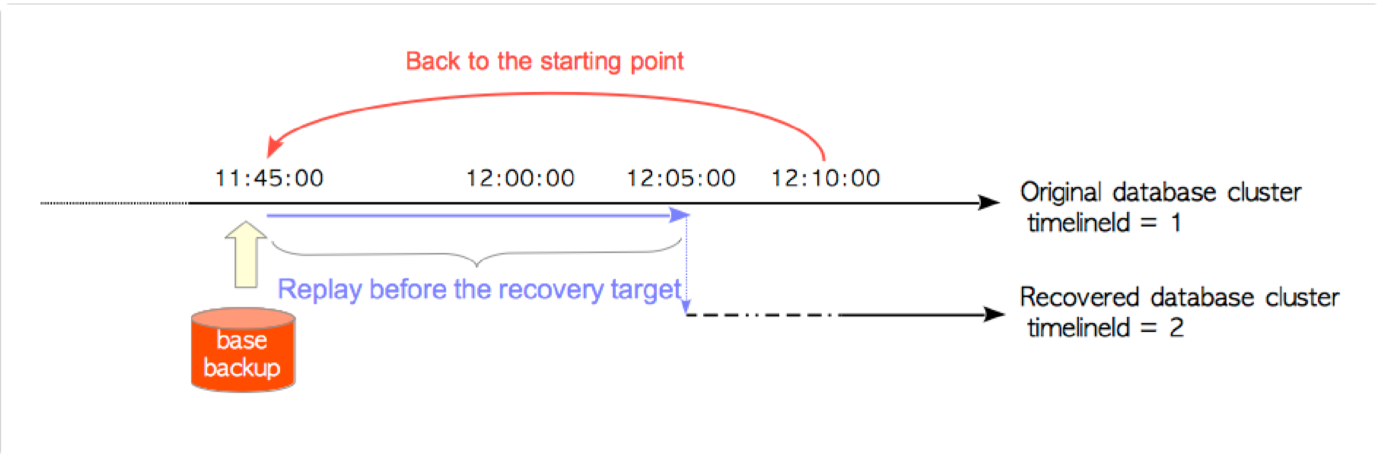
10.3.1 TimelineId

Each timeline is given a corresponding **timelineId**, a 4-byte unsigned integer starting at 1.

An individual timelineId is assigned to each database cluster. The timelineId of original database cluster created by the initdb utility is 1. Whenever database cluster recovers, timelineId will be increased by 1. For example, in the example of the previous section, the timelineId of the cluster recovered from the original one is 2.

Figure 10.3 illustrates the PITR process from the viewpoint of the timelineId. First, we remove our current database cluster and restore the base backup made in the past, in order to go back to the starting point of recovery, and such situation is represented in the red arrow curve in the figure. Next, we start the PostgreSQL server which replays WAL data in the archive logs from the REDO point created by the *pg_start_backup* until the recovery target by tracing along the initial timeline (timelineId 1), and such situation is represented in the blue arrow line in the figure. Then, a new timelineId 2 is assigned to recovered database cluster and PostgreSQL runs on the new timeline.

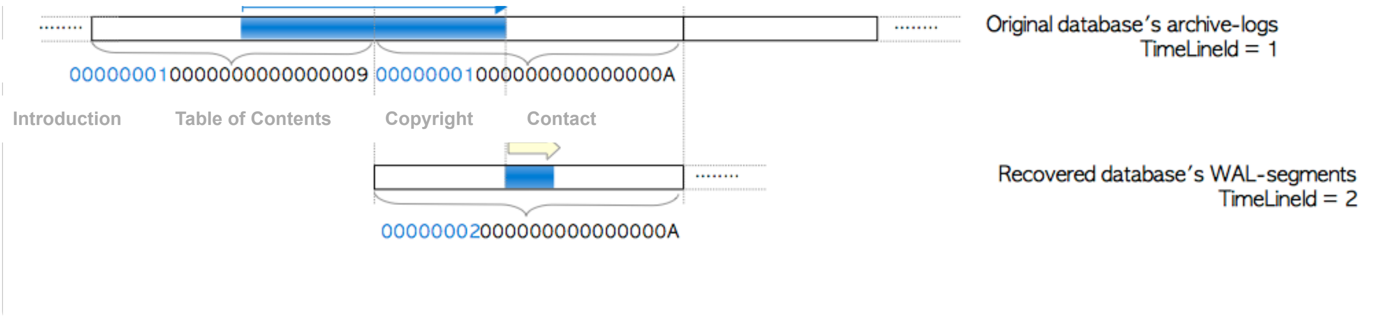
Figure 10.3: Relation of timelineId between an original and a recovered database clusters



As briefly mentioned in Chapter 9, the first 8-digit of WAL segment filename is equal to the timelineId of the database cluster created for each segment. When the timelineId is changed, WAL segment filename will also be changed.

Focusing on WAL segment files, the recovery process will be described again. Suppose that we recover the database cluster using two archive logs "000000010000000000000009" and "00000001000000000000000A". The newly recovered database cluster is assigned the timelineId 2, and PostgreSQL creates the WAL segment from "00000002000000000000000A". Figure 10.4 shows this situation.

Figure 10.4: Relation of WAL segment files between an original and a recovered database clusters



Introduction Table of Contents Copyright Contact

10.3.2 Timeline history file

When a PITR process completes, a timeline history file with names like "00000002.history" is created under the archival directory and the pg_xlog subdirectory (in version 10 or later, pg_wal subdirectory). This file records which timeline it branched off from and when.

The naming rule of this file is shown in the following:

```
"8-digit new timelineId".history
```

A timeline history file contains at least one line, and each line is composed of the following three items:

- timelineId – timelineId of the archive logs used to recover.
- LSN – LSN location where the WAL segment switches happened.
- reason – human-readable explanation of why the timeline was changed.

A specific example is shown below:

```
postgres> cat /home/postgres/archivelogs/00000002.history
1          0/A000198      before 2017-7-6 12:05:00.861324+00
```

Meaning as follows:

> The database cluster (timelineId=2) is based on the base backup whose timelineId is *1*, and is recovered in the time just *before "2017-7-6 12:05:00.861324+00"* by replaying the archive logs until the *0/A000198*.

In this way, each timeline history file tells us a complete history of the individual recovered database cluster. Moreover, it is also used to PITR process itself. The detail is explained in the next section.

The timeline history file format is changed in version 9.3. Formats of versions 9.3 or later and earlier both are shown below but not in detail.

Later version 9.3:

```
timelineId  LSN       "reason"
```

Until version 9.2:

```
timelineId  WAL_segment       "reason"
```

10.4 Point-in-Time Recovery with timeline history file

The timeline history file plays an important role in the second and subsequent PITR processes. By trying the second time recovery, we will explore how it is used.

Again, suppose that you made a mistake at 12:15:00 in the recovered database cluster whose timelineId is 2. In this case, to recover the database cluster, you should create a new recovery.conf shown below:

```
restore_command = 'cp /mnt/server/archivedir/%f %p'
recovery_target_time = "2017-7-6 12:15:00 GMT"
recovery_target_timeline = 2
```

The parameter *recovery_target_time* sets the time you made new mistake, and the *recovery_target_timeline* is set at '2', in order to recover along its timeline.

Restart the PostgreSQL server and enter PITR mode to recover the database at the target time along the timelineId 2. See Figure 10.5.

Figure 10.5: Recover the database at 12:15:00 along the timelineId 2