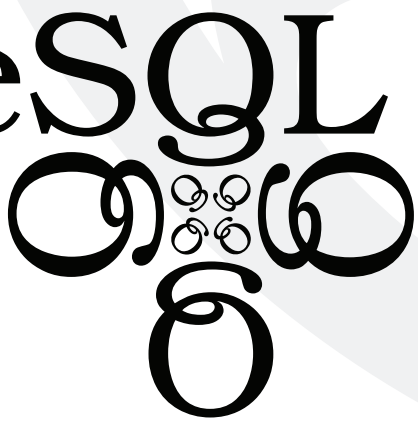
SECOND EDITION

The Art of PostgreSQL

Turn Thousands of Lines of Code into Simple Queries



by Dimitri Fontaine

1

Structured Query Language

SQL stands for *Structured Query Language*; the term defines a declarative programming language. As a user, we declare the result we want to obtain in terms of a data processing pipeline that is executed against a known database model and a dataset.

The database model has to be statically declared so that we know the type of every bit of data involved at the time the query is carried out. A query result set defines a relation, of a type determined or inferred when parsing the query.

When working with SQL, as a developer we relatedly work with a type system and a kind of relational algebra. We write code to retrieve and process the data we are interested in, in the specific way we need.

RDBMS and SQL are forcing developers to think in terms of data structure, and to declare both the data structure and the data set we want to obtain via our queries.

Some might then say that SQL forces us to be good developers:

> *I will, in fact, claim that the difference between a bad programmer and a good one is whether he considers his code or his data structures more important. Bad programmers worry about the code. Good programmers worry about data structures and their relationships.*
>
> *— Linus Torvalds*

Some of the Code is Written in SQL

If you're reading this book, then it's easy to guess that you are already maintaining at least one application that uses SQL and embeds some SQL queries into its code.

The SQLite project is another implementation of a SQL engine, and one might wonder if it is the Most Widely Deployed Software Module of Any Type?

> *SQLite is deployed in every Android device, every iPhone and iOS device, every Mac, every Windows10 machine, every Firefox, Chrome, and Safari web browser, every installation of Skype, every version of iTunes, every Dropbox client, every TurboTax and QuickBooks, PHP and Python, most television sets and set-top cable boxes, most automotive multimedia systems.*

The page goes on to say that other libraries with similar reach include:

- The original zlib implementation by Jean-loup Gailly and Mark Adler,
- The original reference implementation for *libpng*,
- *Libjpeg* from the Independent JPEG Group.

I can't help but mention that *libjpeg* was developed by Tom Lane, who then contributed to developing the specs of *PNG*. Tom Lane is a Major Contributor to the PostgreSQL project and has been for a long time now. Tom is simply one of the most important contributors to the project.

Anyway, SQL is very popular and it is used in most applications written today. Every developer has seen some `select ⋯ from ⋯ where ⋯` SQL query string in one form or another and knows some parts of the very basics from SQL-89.

The current SQL standard is SQL:2016 and it includes many advanced data processing techniques. If your application is already using the SQL programming language and SQL engine, then as a developer it's important to fully understand how much can be achieved in SQL, and what service is implemented by this runtime dependency in your software architecture.

Moreover, this service is stateful and hosts all your application user data. In most cases user data as managed by the Relational Database Management Systems that is at the heart of the application code we write, and our code means nothing if we do not have the production data set that delivers value to users.

SQL is a very powerful programming language, and it is a declarative one. It's a wonderful tool to master, and once used properly it allows one to reduce both code size and the development time for new features. This book is written so that you think of good SQL utilization as one of our greatest advantages when writing an application, coding a new business case or implementing a user story!

A First Use Case

Intercontinental Exchange provides a chart with Daily NYSE Group Volume in NYSE Listed, 2017. We can fetch the *Excel* file which is actually a *CSV* file using *tab* as a separator, remove the headings and load it into a PostgreSQL table.

Loading the Data Set

Here's what the data looks like with comma-separated thousands and dollar signs, so we can't readily process the figures as numbers:

```
2010    1/4/2010    1,425,504,460   4,628,115   $38,495,460,645
2010    1/5/2010    1,754,011,750   5,394,016   $43,932,043,406
2010    1/6/2010    1,655,507,953   5,494,460   $43,816,749,660
2010    1/7/2010    1,797,810,789   5,674,297   $44,104,237,184
```

So we create an ad-hoc table definition, and once the data is loaded we then transform it into a proper SQL data type, thanks to *alter table* commands.

```
begin;

drop table if exists factbook;

create table factbook
 (
   year    int,
   date    date,
   shares  text,
   trades  text,
   dollars text
 );

-- datestyle of the database to ISO, MDY
\copy factbook from 'factbook.csv' with delimiter E'\t' null ''

alter table factbook
   alter shares
    type bigint
```

```
    using replace(shares, ',', '')::bigint,

    alter trades
     type bigint
    using replace(trades, ',', '')::bigint,

    alter dollars
     type bigint
    using substring(replace(dollars, ',', '') from 2)::numeric;

commit;
```

We use the PostgreSQL copy functionality to stream the data from the CSV file into our table. The `\copy` variant is a *psql* specific command and initiates *client/server* streaming of the data, reading a local file and sending its content through any established PostgreSQL connection.

Application Code and SQL

Now a classic question is how to list the *factbook* entries for a given month, and because the calendar is a complex beast, we naturally pick February 2017 as our example month.

The following query lists all entries we have in the month of February 2017:

```
\set start '2017-02-01'

  select date,
         to_char(shares, '99G999G999G999') as shares,
         to_char(trades, '99G999G999') as trades,
         to_char(dollars, 'L99G999G999G999') as dollars
    from factbook
   where date >= date :'start'
     and date  < date :'start' + interval '1 month'
order by date;
```

We use the *psql* application to run this query, and *psql* supports the use of variables. The `\set` command sets the *'2017-02-01'* value to the variable *start*, and then we re-use the variable with the expression *:'start'*.

The writing `date :'start'` is equivalent to `date '2017-02-01'` and is called a *decorated literal* expression in PostgreSQL. This allows us to set the data type of the literal value so that the PostgreSQL query parser won't have to guess or infer it from the context.

This first SQL query of the book also uses the *interval* data type to compute the

end of the month. Of course, the example targets February because the end of the month has to be computed. Adding an *interval* value of *1 month* to the first day of the month gives us the first day of the next month, and we use the *less than* (<) strict operator to exclude this day from our result set.

The *to_char()* function is documented in the PostgreSQL section about Data Type Formatting Functions and allows converting a number to its text representation with detailed control over the conversion. The format is composed of *template patterns*. Here we use the following patterns:

- Value with the specified number of digits
- *L*, currency symbol (uses locale)
- *G*, group separator (uses locale)

Other template patterns for numeric formatting are available — see the PostgreSQL documentation for the complete reference.

Here's the result of our query:

```
    date    │      shares       │   trades    │      dollars
════════════╪═══════════════════╪═════════════╪═══════════════════
 2017-02-01 │ 1,161,001,502     │ 5,217,859   │ $ 44,660,060,305
 2017-02-02 │ 1,128,144,760     │ 4,586,343   │ $ 43,276,102,903
 2017-02-03 │ 1,084,735,476     │ 4,396,485   │ $ 42,801,562,275
 2017-02-06 │   954,533,086     │ 3,817,270   │ $ 37,300,908,120
 2017-02-07 │ 1,037,660,897     │ 4,220,252   │ $ 39,754,062,721
 2017-02-08 │ 1,100,076,176     │ 4,410,966   │ $ 40,491,648,732
 2017-02-09 │ 1,081,638,761     │ 4,462,009   │ $ 40,169,585,511
 2017-02-10 │ 1,021,379,481     │ 4,028,745   │ $ 38,347,515,768
 2017-02-13 │ 1,020,482,007     │ 3,963,509   │ $ 38,745,317,913
 2017-02-14 │ 1,041,009,698     │ 4,299,974   │ $ 40,737,106,101
 2017-02-15 │ 1,120,119,333     │ 4,424,251   │ $ 43,802,653,477
 2017-02-16 │ 1,091,339,672     │ 4,461,548   │ $ 41,956,691,405
 2017-02-17 │ 1,160,693,221     │ 4,132,233   │ $ 48,862,504,551
 2017-02-21 │ 1,103,777,644     │ 4,323,282   │ $ 44,416,927,777
 2017-02-22 │ 1,064,236,648     │ 4,169,982   │ $ 41,137,731,714
 2017-02-23 │ 1,192,772,644     │ 4,839,887   │ $ 44,254,446,593
 2017-02-24 │ 1,187,320,171     │ 4,656,770   │ $ 45,229,398,830
 2017-02-27 │ 1,132,693,382     │ 4,243,911   │ $ 43,613,734,358
 2017-02-28 │ 1,455,597,403     │ 4,789,769   │ $ 57,874,495,227
(19 rows)
```

The dataset only has data for 19 days in February 2017. Our expectations might be to display an entry for each calendar day and fill it in with either matching data or a zero figure for days without data in our *factbook*.

Here's a typical implementation of that expectation, in Python:

```
#! /usr/bin/env python3

import sys
import psycopg2
import psycopg2.extras
from calendar import Calendar

CONNSTRING = "dbname=yesql application_name=factbook"


def fetch_month_data(year, month):
    "Fetch a month of data from the database"
    date = "%d-%02d-01" % (year, month)
    sql = """
  select date, shares, trades, dollars
    from factbook
   where date >= date %s
     and date  < date %s + interval '1 month'
order by date;
"""
    pgconn = psycopg2.connect(CONNSTRING)
    curs = pgconn.cursor()
    curs.execute(sql, (date, date))

    res = {}
    for (date, shares, trades, dollars) in curs.fetchall():
        res[date] = (shares, trades, dollars)

    return res


def list_book_for_month(year, month):
    """List all days for given month, and for each
    day list fact book entry.
    """
    data = fetch_month_data(year, month)

    cal = Calendar()
    print("%12s | %12s | %12s | %12s" %
          ("day", "shares", "trades", "dollars"))
    print("%12s-+-%12s-+-%12s-+-%12s" %
          ("-" * 12, "-" * 12, "-" * 12, "-" * 12))

    for day in cal.itermonthdates(year, month):
        if day.month != month:
            continue
        if day in data:
            shares, trades, dollars = data[day]
        else:
            shares, trades, dollars = 0, 0, 0
```

```
51
52          print("%12s | %12s | %12s | %12s" %
53                (day, shares, trades, dollars))
54
55
56  if __name__ == '__main__':
57      year = int(sys.argv[1])
58      month = int(sys.argv[2])
59
60      list_book_for_month(year, month)
```

In this implementation, we use the above SQL query to fetch our result set, and moreover to store it in a dictionary. The dict's key is the day of the month, so we can then loop over a calendar's list of days and retrieve matching data when we have it and install a default result set (here, zeroes) when we don't have anything.

Below is the output when running the program. As you can see, we opted for an output similar to the *psql* output, making it easier to compare the effort needed to reach the same result.

```
$ ./factbook-month.py 2017 2
         day |       shares |       trades |      dollars
-------------+--------------+--------------+-------------
  2017-02-01 |   1161001502 |      5217859 |  44660060305
  2017-02-02 |   1128144760 |      4586343 |  43276102903
  2017-02-03 |   1084735476 |      4396485 |  42801562275
  2017-02-04 |            0 |            0 |            0
  2017-02-05 |            0 |            0 |            0
  2017-02-06 |    954533086 |      3817270 |  37300908120
  2017-02-07 |   1037660897 |      4220252 |  39754062721
  2017-02-08 |   1100076176 |      4410966 |  40491648732
  2017-02-09 |   1081638761 |      4462009 |  40169585511
  2017-02-10 |   1021379481 |      4028745 |  38347515768
  2017-02-11 |            0 |            0 |            0
  2017-02-12 |            0 |            0 |            0
  2017-02-13 |   1020482007 |      3963509 |  38745317913
  2017-02-14 |   1041009698 |      4299974 |  40737106101
  2017-02-15 |   1120119333 |      4424251 |  43802653477
  2017-02-16 |   1091339672 |      4461548 |  41956691405
  2017-02-17 |   1160693221 |      4132233 |  48862504551
  2017-02-18 |            0 |            0 |            0
  2017-02-19 |            0 |            0 |            0
  2017-02-20 |            0 |            0 |            0
  2017-02-21 |   1103777644 |      4323282 |  44416927777
  2017-02-22 |   1064236648 |      4169982 |  41137731714
  2017-02-23 |   1192772644 |      4839887 |  44254446593
  2017-02-24 |   1187320171 |      4656770 |  45229398830
  2017-02-25 |            0 |            0 |            0
  2017-02-26 |            0 |            0 |            0
  2017-02-27 |   1132693382 |      4243911 |  43613734358
  2017-02-28 |   1455597403 |      4789769 |  57874495227
```

A Word about SQL Injection

An *SQL Injections* is a security breach, one made famous by the Exploits of a Mom `xkcd` comic episode in which we read about *little Bobby Tables*.

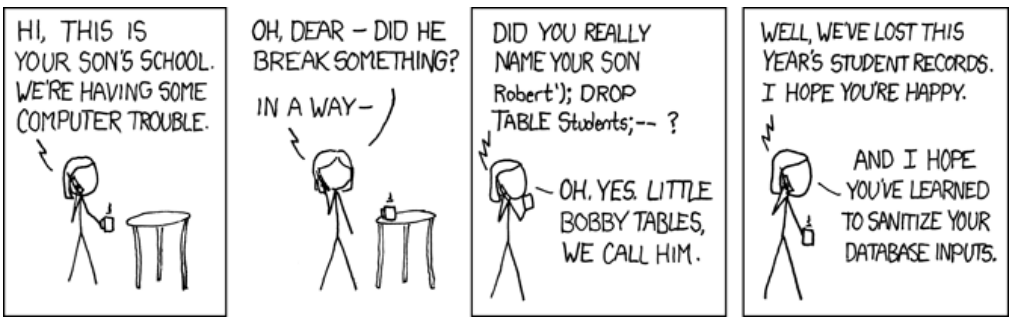


Figure 1.1: Exploits of a Mom

PostgreSQL implements a protocol level facility to send the static SQL query text separately from its dynamic arguments. An SQL injection happens when the database server is mistakenly led to consider a dynamic argument of a query as part of the query text. Sending those parts as separate entities over the protocol means that SQL injection is no longer possible.

The PostgreSQL protocol is fully documented and you can read more about *extended query* support on the Message Flow documentation page. Also relevant is the `PQexecParams` driver API, documented as part of the command execution functions of the `libpq` PostgreSQL C driver.

A lot of PostgreSQL application drivers are based on the libpq C driver, which implements the PostgreSQL protocol and is maintained alongside the main server's code. Some drivers variants also exist that don't link to any C runtime, in which case the PostgreSQL protocol has been implemented in another programming language. That's the case for variants of the JDBC driver, and the `pq` Go driver too, among others.

It is advisable that you read the documentation of your current driver and understand how to send SQL query parameters separately from the main SQL query text; this is a reliable way to never have to worry about *SQL injection* problems ever again.

In particular, *never* build a query string by concatenating your query arguments directly into your query strings, i.e. in the application client code. Never use any

library, ORM or another tooling that would do that. When building SQL query strings that way, you open your application code to serious security risk for no reason.

We were using the psycopg Python driver in our example above, which is based on `libpq`. The documentation of this driver addresses passing parameters to SQL queries right from the beginning.

When using Psycopg the SQL query parameters are interpolated in the SQL query string at the client level. It means you need to trust Psycopg to protect you from any attempt at SQL injection, and we could be more secure than that.

PostgreSQL protocol: server-side prepared statements

It is possible to send the query string and its arguments separately on the wire by using server-side prepared statements. This is a pretty common way to do it, mostly because `PQexecParams` isn't well known, though it made its debut in PostgreSQL 7.4, released November 17, 2003. To this day, a lot of PostgreSQL drivers still don't expose the `PQexecParams` facility, which is unfortunate.

Server-side Prepared Statements can be used in SQL thanks to the PREPARE and EXECUTE commands syntax, as in the following example:

```
prepare foo as
 select date, shares, trades, dollars
   from factbook
  where date >= $1::date
    and date  < $1::date + interval '1 month'
  order by date;
```

And then you can execute the prepared statement with a parameter that way, still at the `psql` console:

```
execute foo('2010-02-01');
```

We then get the same result as before, when using our first version of the Python program.

Now, while it's possible to use the prepare and execute SQL commands directly in your application code, it is also possible to use it directly at the PostgreSQL protocol level. This facility is named Extended Query and is well documented.

Reading the documentation about the protocol implementation, we see the following bits. First the PARSE message:

> In the extended protocol, the frontend first sends a Parse message, which contains a textual query string, optionally some information about data types of parameter placeholders, and the name of a destination prepared-statement object [...]

Then, the BIND message:

> Once a prepared statement exists, it can be readied for execution using a Bind message. [...] The supplied parameter set must match those needed by the prepared statement.

Finally, to receive the result set the client needs to send a third message, the EXECUTE message. The details of this part aren't relevant now though.

It is very clear from the documentation excerpts above that the query string parsed by PostgreSQL doesn't contain the parameters. The query string is sent in the BIND message. The query parameters are sent in the EXECUTE message. When doing things that way, it is impossible to have SQL injections.

Remember: SQL injection happens when the SQL parser is fooled into believing that a parameter string is in fact a SQL query, and then the SQL engine goes on and executes that SQL statement. When the SQL query string lives in your application code, and the user-supplied parameters are sent separately on the network, there's no way that the SQL parsing engine might get confused.

The following example uses the asyncpg PostgreSQL driver. It's open source and the sources are available at the MagicStack/asyncpg repository, where you can browse the code and see that the driver implements the PostgreSQL protocol itself, and uses server-side prepared statements.

This example is now safe from SQL injection by design, because the server-side prepared statement protocol sends the query string and its arguments in separate protocol messages:

```
1  import sys
2  import asyncio
3  import asyncpg
4  import datetime
5  from calendar import Calendar
6
7  CONNSTRING = "postgresql://appdev@localhost/appdev?application_name=factbook"
8
```

```
async def fetch_month_data(year, month):
    "Fetch a month of data from the database"
    date = datetime.date(year, month, 1)
    sql = """
  select date, shares, trades, dollars
    from factbook
   where date >= $1::date
     and date  < $1::date + interval '1 month'
order by date;
"""
    pgconn = await asyncpg.connect(CONNSTRING)
    stmt = await pgconn.prepare(sql)

    res = {}
    for (date, shares, trades, dollars) in await stmt.fetch(date):
        res[date] = (shares, trades, dollars)

    await pgconn.close()

    return res
```

Then, the Python function call needs to be adjusted to take into account the coroutine usage we're now making via asyncio. The function `list_book_for_month` now begins with the following lines:

```
def list_book_for_month(year, month):
    """List all days for given month, and for each
    day list fact book entry.
    """
    data = asyncio.run(fetch_month_data(year, month))
```

The rest of it is as before.

Back to Discovering SQL

Now of course it's possible to implement the same expectations with a single SQL query, without any application code being *spent* on solving the problem:

```
  select cast(calendar.entry as date) as date,
         coalesce(shares, 0) as shares,
         coalesce(trades, 0) as trades,
         to_char(
             coalesce(dollars, 0),
             'L99G999G999G999'
         ) as dollars
    from /*
          * Generate the target month's calendar then LEFT JOIN
```

```
          * each day against the factbook dataset, so as to have
          * every day in the result set, whether or not we have a
          * book entry for the day.
          */
         generate_series(date :'start',
                         date :'start' + interval '1 month'
                                       - interval '1 day',
                         interval '1 day'
         )
         as calendar(entry)
         left join factbook
                on factbook.date = calendar.entry
order by date;
```

In this query, we use several basic SQL and PostgreSQL techniques that you might be discovering for the first time:

- SQL accepts comments written either in the `-- comment` style, running from the opening to the end of the line, or C-style with a `/* comment */` style.

  As with any programming language, comments are best used to note our intentions, which otherwise might be tricky to reverse engineer from the code alone.

- *generate_series()* is a PostgreSQL set returning function, for which the documentation reads:

  > Generate a series of values, from start to stop with a step size of step

  As PostgreSQL knows its calendar, it's easy to generate all days from any given month with the first day of the month as a single parameter in the query.

- *generate_series()* is inclusive much like the *BETWEEN* operator, so we exclude the first day of the next month with the expression *- interval '1 day'*.

- The *cast(calendar.entry as date)* expression transforms the generated *calendar.entry*, which is the result of the *generate_series()* function call into the *date* data type.

  We need to *cast* here because the *generate_series()* function returns a set of *timestamp* entries and we don't care about the time parts of it.

- The *left join* in between our generated *calendar* table and the *factbook* table

will keep every calendar row and associate a *factbook* row with it only when the *date* columns of both the tables have the same value.

When the *calendar.date* is not found in *factbook*, the *factbook* columns (*year*, *date*, *shares*, *trades*, and *dollars*) are filled in with *NULL* values instead.

- COALESCE returns the first of its arguments that is not null.

  So the expression *coalesce(shares, 0) as shares* is either how many shares we found in the *factbook* table for this *calendar.date* row, or 0 when we found no entry for the *calendar.date* and the *left join* kept our result set row and filled in the *factbook* columns with *NULL* values.

Finally, here's the result of running this query:

```
    date    │   shares   │ trades  │      dollars
════════════╪════════════╪═════════╪═══════════════════
 2017-02-01 │ 1161001502 │ 5217859 │ $ 44,660,060,305
 2017-02-02 │ 1128144760 │ 4586343 │ $ 43,276,102,903
 2017-02-03 │ 1084735476 │ 4396485 │ $ 42,801,562,275
 2017-02-04 │          0 │       0 │ $               0
 2017-02-05 │          0 │       0 │ $               0
 2017-02-06 │  954533086 │ 3817270 │ $ 37,300,908,120
 2017-02-07 │ 1037660897 │ 4220252 │ $ 39,754,062,721
 2017-02-08 │ 1100076176 │ 4410966 │ $ 40,491,648,732
 2017-02-09 │ 1081638761 │ 4462009 │ $ 40,169,585,511
 2017-02-10 │ 1021379481 │ 4028745 │ $ 38,347,515,768
 2017-02-11 │          0 │       0 │ $               0
 2017-02-12 │          0 │       0 │ $               0
 2017-02-13 │ 1020482007 │ 3963509 │ $ 38,745,317,913
 2017-02-14 │ 1041009698 │ 4299974 │ $ 40,737,106,101
 2017-02-15 │ 1120119333 │ 4424251 │ $ 43,802,653,477
 2017-02-16 │ 1091339672 │ 4461548 │ $ 41,956,691,405
 2017-02-17 │ 1160693221 │ 4132233 │ $ 48,862,504,551
 2017-02-18 │          0 │       0 │ $               0
 2017-02-19 │          0 │       0 │ $               0
 2017-02-20 │          0 │       0 │ $               0
 2017-02-21 │ 1103777644 │ 4323282 │ $ 44,416,927,777
 2017-02-22 │ 1064236648 │ 4169982 │ $ 41,137,731,714
 2017-02-23 │ 1192772644 │ 4839887 │ $ 44,254,446,593
 2017-02-24 │ 1187320171 │ 4656770 │ $ 45,229,398,830
 2017-02-25 │          0 │       0 │ $               0
 2017-02-26 │          0 │       0 │ $               0
 2017-02-27 │ 1132693382 │ 4243911 │ $ 43,613,734,358
 2017-02-28 │ 1455597403 │ 4789769 │ $ 57,874,495,227
(28 rows)
```

When ordering the book package that contains the code and the data set, you can find the SQL queries *02-intro/02-usecase/02.sql* and *02-intro/02-usecase/04.sql*, and the Python script *02-intro/02-usecase/03_factbook-month.py*, and run them against the pre-loaded database *yesql*.

Note that we replaced 60 lines of Python code with a simple enough SQL query. Down the road, that's less code to maintain and a more efficient implementation too. Here, the Python is doing an *Hash Join Nested Loop* where PostgreSQL picks a *Merge Left Join* over two ordered relations. Later in this book, we see how to get and read the PostgreSQL *execution plan* for a query.

Computing Weekly Changes

The analytics department now wants us to add a weekly difference for each day of the result. More specifically, we want to add a column with the evolution as a percentage of the *dollars* column in between the day of the value and the same day of the previous week.

I'm taking the "week over week percentage difference" example because it's both a classic analytics need, though mostly in marketing circles maybe, and because in my experience the first reaction of a developer will rarely be to write a SQL query doing all the math.

Also, computing weeks is another area in which the calendar we have isn't very helpful, but for PostgreSQL taking care of the task is as easy as spelling the word *week*:

```
with computed_data as
(
  select cast(date as date)   as date,
         to_char(date, 'Dy')  as day,
         coalesce(dollars, 0) as dollars,
         lag(dollars, 1)
           over(
             partition by extract('isodow' from date)
                 order by date
           )
         as last_week_dollars
    from /*
          * Generate the month calendar, plus a week before
          * so that we have values to compare dollars against
          * even for the first week of the month.
          */
         generate_series(date :'start' - interval '1 week',
```

```
                        date :'start' + interval '1 month'
                                      - interval '1 day',
                        interval '1 day'
         )
         as calendar(date)
         left join factbook using(date)
)
  select date, day,
         to_char(
             coalesce(dollars, 0),
             'L99G999G999G999'
         ) as dollars,
         case when dollars is not null
               and dollars <> 0
              then round(  100.0
                         * (dollars - last_week_dollars)
                         / dollars
                        , 2)
          end
         as "WoW %"
    from computed_data
   where date >= date :'start'
order by date;
```

To implement this case in SQL, we need *window functions* that appeared in the SQL standard in 1992 but are still often skipped in SQL classes. The last thing executed in a SQL statement are *window functions*, well after *join* operations and *where* clauses. So if we want to see a full week before the first of February, we need to extend our calendar selection a week into the past and then once again restrict the data that we issue to the caller.

That's why we use a *common table expression* — the *WITH* part of the query — to fetch the extended data set we need, including the *last_week_dollars* computed column.

The expression *extract('isodow' from date)* is a standard SQL feature that allows computing the *Day Of Week* following the *ISO* rules. Used as a *partition by* frame clause, it allows a row to be a *peer* to any other row having the same *isodow*. The *lag()* window function can then refer to the previous peer *dollars* value when ordered by date: that's the number with which we want to compare the current *dollars* value.

The *computed_data* result set is then used in the main part of the query as a relation we get data *from* and the computation is easier this time as we simply apply a classic difference percentage formula to the *dollars* and the *last_week_dollars* columns.

Here's the result from running this query:

```
    date    | day |      dollars       | WoW %
════════════╪═════╪════════════════════╪═══════
 2017-02-01 | Wed | $ 44,660,060,305   |  -2.21
 2017-02-02 | Thu | $ 43,276,102,903   |   1.71
 2017-02-03 | Fri | $ 42,801,562,275   |  10.86
 2017-02-04 | Sat | $                0 |      ¤
 2017-02-05 | Sun | $                0 |      ¤
 2017-02-06 | Mon | $ 37,300,908,120   |  -9.64
 2017-02-07 | Tue | $ 39,754,062,721   | -37.41
 2017-02-08 | Wed | $ 40,491,648,732   | -10.29
 2017-02-09 | Thu | $ 40,169,585,511   |  -7.73
 2017-02-10 | Fri | $ 38,347,515,768   | -11.61
 2017-02-11 | Sat | $                0 |      ¤
 2017-02-12 | Sun | $                0 |      ¤
 2017-02-13 | Mon | $ 38,745,317,913   |   3.73
 2017-02-14 | Tue | $ 40,737,106,101   |   2.41
 2017-02-15 | Wed | $ 43,802,653,477   |   7.56
 2017-02-16 | Thu | $ 41,956,691,405   |   4.26
 2017-02-17 | Fri | $ 48,862,504,551   |  21.52
 2017-02-18 | Sat | $                0 |      ¤
 2017-02-19 | Sun | $                0 |      ¤
 2017-02-20 | Mon | $                0 |      ¤
 2017-02-21 | Tue | $ 44,416,927,777   |   8.28
 2017-02-22 | Wed | $ 41,137,731,714   |  -6.48
 2017-02-23 | Thu | $ 44,254,446,593   |   5.19
 2017-02-24 | Fri | $ 45,229,398,830   |  -8.03
 2017-02-25 | Sat | $                0 |      ¤
 2017-02-26 | Sun | $                0 |      ¤
 2017-02-27 | Mon | $ 43,613,734,358   |      ¤
 2017-02-28 | Tue | $ 57,874,495,227   |  23.25
(28 rows)
```

The rest of the book spends some time to explain the core concepts of *common table expressions* and *window functions* and provides many other examples so that you can master PostgreSQL and issue the SQL queries that fetch exactly the result set your application needs to deal with!

We will also look at the performance and correctness characteristics of issuing more complex queries rather than issuing more queries and doing more of the processing in the application code... or in a Python script, as in the previous example.

2

Software Architecture

Our first use case in this book allowed us to compare implementing a simple feature in Python and in SQL. After all, once you know enough of SQL, lots of data related processing and presentation can be done directly within your SQL queries. The application code might then be a shell wrapper around a software architecture that is database centered.

In some simple cases, and we'll see more about that in later chapters, it is required for correctness that some processing happens in the SQL query. In many cases, having SQL do the data-related heavy lifting yields a net gain in performance characteristics too, mostly because round-trip times and latency along with memory and bandwidth resources usage depend directly on the size of the result sets.

The Art Of PostgreSQL, Volume 1 focuses on teaching SQL idioms, both the basics and some advanced techniques too. It also contains an approach to database modeling, normalization, and denormalization. That said, it does not address software architecture. The goal of this book is to provide you, the application developer, with new and powerful tools. Determining how and when to use them has to be done in a case by case basis.

Still, a general approach is helpful in deciding how and where to implement application features. The following concepts are important to keep in mind when learning advanced SQL:

- Relational Database Management System

  PostgreSQL is an RDBMS and as such its role in your software architec-

ture is to handle concurrent access to live data that is manipulated by several applications, or several parts of an application.

Typically we will find the user-side parts of the application, a front-office and a user back-office with a different set of features depending on the user role, including some kinds of reporting (accounting, finance, analytics), and often some glue scripts here and there, crontabs or the like.

- Atomic, Consistent, Isolated, Durable

  At the heart of the concurrent access semantics is the concept of a transaction. A transaction should be atomic and isolated, the latter allowing for *online backups* of the data.

  Additionally, the RDBMS is tasked with maintaining a data set that is consistent with the business rules at all times. That's why database modeling and normalization tasks are so important, and why PostgreSQL supports an advanced set of *constraints*.

  Durable means that whatever happens PostgreSQL guarantees that it won't lose any *committed* change. Your data is safe. Not even an OS crash is allowed to risk your data. We're left with disk corruption risks, and that's why being able to carry out *online backups* is so important.

- Data Access API and Service

  Given the characteristics listed above, PostgreSQL allows one to implement a data access API. In a world of containers and micro-services, PostgreSQL is the data access service, and its API is SQL.

  If it looks a lot heavier than your typical micro-service, remember that PostgreSQL implements a stateful service, on top of which you can build the other parts. Those other parts will be scalable and highly available by design, because solving those problems for *stateless* services is so much easier.

- Structured Query Language

  The data access API offered by PostgreSQL is based on the SQL programming language. It's a declarative language where your job as a developer is to describe in detail the *result set* you are interested in.

  PostgreSQL's job is then to find the most efficient way to access only the data needed to compute this result set, and execute the plan it comes up with.

- Extensible (JSON, XML, Arrays, Ranges)

  The SQL language is statically typed: every query defines a new relation that must be fully understood by the system before executing it. That's why sometimes *cast* expressions are needed in your queries.

  PostgreSQL's unique approach to implementing SQL was invented in the 80s with the stated goal of enabling extensibility. SQL operators and functions are defined in a catalog and looked up at run-time. Functions and operators in PostgreSQL support *polymorphism* and almost every part of the system can be extended.

  This unique approach has allowed PostgreSQL to be capable of improving SQL; it offers a deep coverage for composite data types and documents processing right within the language, with clean semantics.

So when designing your software architecture, think about PostgreSQL not as *storage* layer, but rather as a *concurrent data access service*. This service is capable of handling data processing. How much of the processing you want to implement in the SQL part of your architecture depends on many factors, including team size, skill set, and operational constraints.

Why PostgreSQL?

While this book focuses on teaching SQL and how to make the best of this programming language in modern application development, it only addresses the PostgreSQL implementation of the SQL standard. That choice is down to several factors, all consequences of PostgreSQL truly being *the world's most advanced open source database*:

- PostgreSQL is open source, available under a BSD like licence named the PostgreSQL licence.
- The PostgreSQL project is done completely in the open, using public mailing lists for all discussions, contributions, and decisions, and the project goes as far as self-hosting all requirements in order to avoid being influenced by a particular company.
- While being developed and maintained in the open by volunteers, most PostgreSQL developers today are contributing in a professional capacity, both in the interest of their employer and to solve real customer problems.

- PostgreSQL releases a new major version about once a year, following a *when it's ready* release cycle.
- The PostgreSQL design, ever since its Berkeley days under the supervision of Michael Stonebraker, allows enhancing SQL in very advanced ways, as we see in the data types and indexing support parts of this book.
- The PostgreSQL documentation is one of the best reference manuals you can find, open source or not, and that's because a patch in the code is only accepted when it also includes editing the parts of the documentations that need editing.
- While new NoSQL systems are offering different trade-offs in terms of operations, guarantees, query languages and APIs, I would argue that PostgreSQL is YeSQL!

In particular, the extensibility of PostgreSQL allows this 20 years old system to keep renewing itself. As a data point, this extensibility design makes PostgreSQL one of the best JSON processing platforms you can find.

It makes it possible to improve SQL with advanced support for new data types even from "userland code", and to integrate processing functions and operators and their indexing support.

We'll see lots of examples of that kind of integration in the book. One of them is a query used in the Schemaless Design in PostgreSQL section where we deal with a Magic™ The Gathering set of cards imported from a JSON data set:

```
select jsonb_pretty(data)
  from magic.cards
 where data @> '{
                 "type":"Enchantment",
                 "artist":"Jim Murray",
                 "colors":["White"]
                }';
```

The `@>` operator reads *contains* and implements JSON searches, with support from a specialized GIN index if one has been created. The *jsonb_pretty()* function does what we can expect from its name, and the query returns *magic.cards* rows that match the JSON criteria for given *type*, *artist* and *colors* key, all as a pretty printed JSON document.

PostgreSQL extensibility design is what allows one to enhance SQL in that way. The query still fully respects SQL rules, there are no tricks here. It is only functions and operators, positioned where we expect them in the *where* clause for the

searching and in the *select* clause for the projection that builds the output format.

The PostgreSQL Documentation

This book is not an alternative to the PostgreSQL manual, which in PDF for the 9.6 server weights in at 3376 pages if you choose the A4 format. The table of contents alone in that document includes from pages *iii* to *xxxiv*, that's 32 pages!

This book offers a very different approach than what is expected from a reference manual, and it is in no way to be considered a replacement. Bits and pieces from the PostgreSQL documentation are quoted when necessary, otherwise this book contains lots of links to the reference pages of the functions and SQL commands we utilize in our practical use cases. It's a good idea to refer to the PostgreSQL documentation and read it carefully.

After having spent some time as a developer using PostgreSQL, then as a PostgreSQL contributor and consultant, nowadays I can very easily find my way around the PostgreSQL documentation. Chapters are organized in a logical way, and everything becomes easier when you get used to browsing the reference.

Finally, the *psql* application also includes online help with `\h <sql command>`.

This book does not aim to be a substitute for the PostgreSQL documentation, and other forums and blogs might offer interesting pieces of advice and introduce some concepts with examples. At the end of the day, if you're curious about anything related to PostgreSQL: read the fine manual. No really... this one is fine.

3

Getting Ready to read this Book

Be sure to use the documentation for the version of PostgreSQL you are using, and if you're not too sure about that just query for it:

```
show server_version;
 server_version
----------------
 9.6.5
(1 row)
```

Ideally, you will have a database server to play along with.

- If you're using MacOSX, check out Postgres App to install a PostgreSQL server and the `psql` tool.
- For Windows check https://www.postgresql.org/download/windows/.
- If you're mainly running Linux mainly you know what you're doing already right? My experience is with Debian, so have a look at https://apt.postgresql.org and install the most recent version of PostgreSQL on your station so that you have something to play with locally. For Red Hat packaging based systems, check out https://yum.postgresql.org.

In this book, we will be using `psql` a lot and we will see how to configure it in a friendly way.

You might prefer a more visual tool such as pgAdmin or OmniDB; the key here is to be able to easily edit SQL queries, run them, edit them in order to fix them, see the *explain plan* for the query, etc.

If you have opted for either the *Full Edition* or the *Enterprise Edition* of the book, both include the SQL files. Check out the `toc.txt` file at the top of the files tree, it contains a detailed table of contents and the list of files found in each section, such as in the following example:

```
2 Introduction
  2 Structured Query Language
    2.1 Some of the Code is Written in SQL
    2.2 A First Use Case
    2.3 Loading the Data Set
        02-intro/02-usecase/03_01_factbook.sql
    2.4 Application Code and SQL
        02-intro/02-usecase/04_01.sql
        02-intro/02-usecase/04_02_factbook-month.py
    2.5 A Word about SQL Injection
    2.6 PostgreSQL protocol: server-side prepared statements
        02-intro/02-usecase/06_01.sql
        02-intro/02-usecase/06_02.sql
    2.7 Back to Discovering SQL
        02-intro/02-usecase/07_01.sql
    2.8 Computing Weekly Changes
        02-intro/02-usecase/08_01.sql
  3 Software Architecture
    3.1 Why PostgreSQL?
        02-intro/03-postgresql/01_01.sql
    3.2 The PostgreSQL Documentation
  4 Getting Ready to read this Book
      02-intro/04-postgresql/01.sql
```

To run the queries you also need the datasets, and the *Full Edition* includes instructions to fetch the data and load it into your local PostgreSQL instance. The *Enterprise Edition* comes with a PostgreSQL instance containing all the data already loaded for you, and visual tools already setup so that you can click and run the queries.

Part III

Writing Sql Queries

In this chapter, we are going to learn about how to write SQL queries. There are several ways to accomplish this this, both from the SQL syntax and semantics point of view, and that is going to be covered later. Here, we want to address how to write SQL queries as part of your application code.

Maybe you are currently using an ORM to write your queries and then have never cared about learning how to format, indent and maintain SQL queries. SQL is code, so you need to apply the same rules as when you maintain code written in other languages: indentation, comments, version control, unit testing, etc.

Also to be able to debug what happens in production you need to be able to easily spot where the query comes from, be able to replay it, edit it, and update your code with the new fixed version of the query.

Before we go into details about the specifics of those concerns, it might be a good idea to review how SQL actually helps you write software, what parts of the code you are writing in the database layer and how much you can or should be writing. The question is this: is SQL a good place to implement business logic?

Next, to get a more concrete example around The Right Way™ to implement SQL queries in your code, we are going to have a detailed look at a very simple application, so as to work with a specific code base.

After that, we will be able to have a look at those tools and habits that will help you in using SQL in your daily life as an application developer. In particular, this chapter introduces the notion of indexing strategy and explains why this is one of the tasks that the application developer should be doing.

To conclude this part of the book, Yohann Gabory shares his Django expertise with us and covers why SQL is code, which you read earlier in this chapter.

4

Business Logic

Where to maintain the *business logic* can be a hard question to answer. Each application may be different, and every development team might have a different viewpoint here, from one extreme (all in the application, usually in a *middleware* layer) to the other (all in the database server with the help of stored procedures).

My view is that every SQL query embeds some parts of the business logic you are implementing, thus the question changes from this:

- Should we have business logic in the database?

to this:

- How much of our business logic should be maintained in the database?

The main aspects to consider in terms of where to maintain the business logic are the *correctness* and the *efficiency* aspects of your code architecture and organisation.

Every SQL query embeds some business logic

Before we dive into more specifics, we need to realize that as soon as you send an SQL query to your RDBMS you are already sending *business logic* to the database. My argument is that each and every and all SQL query contains some levels of business logic. Let's consider a few examples.

In the very simplest possible case, you are still expressing some logic in the query.

In the Chinook database case, we might want to fetch the list of tracks from a given album:

```
  select name
    from track
   where albumid = 193
order by trackid;
```

What business logic is embedded in that SQL statement?

- The *select* clause only mentions the *name* column, and that's relevant to your application. In the situation in which your application runs this query, the business logic is only interested into the tracks names.
- The *from* clause only mentions the *track* table, somehow we decided that's all we need in this example, and that again is strongly tied to the logic being implemented.
- The *where* clause restricts the data output to the *albumid* 193, which again is a direct translation of our business logic, with the added information that the album we want now is the 193rd one and we're left to wonder how we know about that.
- Finally, the *order by* clause implements the idea that we want to display the track names in the order they appear on the disk. Not only that, it also incorporates the specific knowledge that the *trackid* column ordering is the same as the original disk ordering of the tracks.

A variation on the query would be the following:

```
  select track.name as track, genre.name as genre
    from      track
         join genre using(genreid)
   where albumid = 193
order by trackid;
```

This time we add a *join* clause to fetch the genre of each track and choose to return the track name in a column named *track* and the genre name in a column named *genre*. Again, there's only one reason for us to be doing that here: it's because it makes sense with respect to the business logic being implemented in our application.

Granted, those two examples are very simple queries. It is possible to argue that, barring any computation being done to the data set, then we are not actually implementing any *business logic*. It's a fair argument of course. The idea here is that those two very simplistic queries are already responsible for a *part* of the business

logic you want to implement. When used as part of displaying, for example, a per album listing page, then it actually is the whole logic.

Let's have a look at another query now. It is still meant to be of the same level of complexity (very low), but with some level of computations being done on-top of the data, before returning it to the main application's code:

```
  select name,
         milliseconds * interval '1 ms' as duration,
         pg_size_pretty(bytes) as bytes
    from track
   where albumid = 193
order by trackid;
```

This variation looks more like some sort of business logic is being applied to the query, because the columns we sent in the output contain derived values from the server's raw data set.

Business Logic Applies to Use Cases

Up to now, we have been approaching the question from the wrong angle. Looking at a query and trying to decide if it's implementing *business logic* rather than something else (*data access* I would presume) is quite impossible to achieve without a *business case* to solve, also known as a *use case* or maybe even a *user story*, depending on which methodology you are following.

In the following example, we are going to first define a business case we want to implement, and then we have a look at the SQL statement that we would use to solve it.

Our case is a simple one again: display the list of albums from a given artist, each with its total duration.

Let's write a query for that:

```
  select album.title as album,
         sum(milliseconds) * interval '1 ms' as duration
    from album
         join artist using(artistid)
         left join track using(albumid)
   where artist.name = 'Red Hot Chili Peppers'
group by album
order by album;
```

The output is:

```
          album          |           duration
═════════════════════════╪══════════════════════════
 Blood Sugar Sex Magik   | @ 1 hour 13 mins 57.073 secs
 By The Way              | @ 1 hour 8 mins 49.951 secs
 Californication         | @ 56 mins 25.461 secs
(3 rows)
```

What we see here is a direct translation from the business case (or user story if you prefer that term) into a SQL query. The SQL implementation uses joins and computations that are specific to both the data model and the use case we are solving.

Another implementation could be done with several queries and the computation in the application's main code:

1. Fetch the list of albums for the selected artist
2. For each album, fetch the duration of every track in the album
3. In the application, sum up the durations per album

Here's a very quick way to write such an application. It is important to include it here because you might recognize patterns to be found in your own applications, and I want to explain why those patterns should be avoided:

```
#! /usr/bin/env python3
# -*- coding: utf-8 -*-

import psycopg2
import psycopg2.extras
import sys
from datetime import timedelta

DEBUGSQL = False
PGCONNSTRING = "user=cdstore dbname=appdev application_name=cdstore"


class Model(object):
    tablename = None
    columns = None

    @classmethod
    def buildsql(cls, pgconn, **kwargs):
        if cls.tablename and kwargs:
            cols = ", ".join(['"%s"' % c for c in cls.columns])
            qtab = '"%s"' % cls.tablename
            sql = "select %s from %s where " % (cols, qtab)
            for key in kwargs.keys():
                sql += "\"%s\" = '%s'" % (key, kwargs[key])
            if DEBUGSQL:
                print(sql)
```

```
            return sql


    @classmethod
    def fetchone(cls, pgconn, **kwargs):
        if cls.tablename and kwargs:
            sql = cls.buildsql(pgconn, **kwargs)
            curs = pgconn.cursor(cursor_factory=psycopg2.extras.DictCursor)
            curs.execute(sql)
            result = curs.fetchone()
            if result is not None:
                return cls(*result)

    @classmethod
    def fetchall(cls, pgconn, **kwargs):
        if cls.tablename and kwargs:
            sql = cls.buildsql(pgconn, **kwargs)
            curs = pgconn.cursor(cursor_factory=psycopg2.extras.DictCursor)
            curs.execute(sql)
            resultset = curs.fetchall()
            if resultset:
                return [cls(*result) for result in resultset]


class Artist(Model):
    tablename = "artist"
    columns = ["artistid", "name"]

    def __init__(self, id, name):
        self.id = id
        self.name = name


class Album(Model):
    tablename = "album"
    columns = ["albumid", "title"]

    def __init__(self, id, title):
        self.id = id
        self.title = title
        self.duration = None


class Track(Model):
    tablename = "track"
    columns = ["trackid", "name", "milliseconds", "bytes", "unitprice"]

    def __init__(self, id, name, milliseconds, bytes, unitprice):
        self.id = id
        self.name = name
        self.duration = milliseconds
        self.bytes = bytes
```

```
        self.unitprice = unitprice


if __name__ == '__main__':
    if len(sys.argv) > 1:
        pgconn = psycopg2.connect(PGCONNSTRING)
        artist = Artist.fetchone(pgconn, name=sys.argv[1])

        for album in Album.fetchall(pgconn, artistid=artist.id):
            ms = 0
            for track in Track.fetchall(pgconn, albumid=album.id):
                ms += track.duration

            duration = timedelta(milliseconds=ms)
            print("%25s: %s" % (album.title, duration))
    else:
        print('albums.py <artist name>')
```

Now the result of this code is as following:

```
$ ./albums.py "Red Hot Chili Peppers"
    Blood Sugar Sex Magik: 1:13:57.073000
                By The Way: 1:08:49.951000
          Californication: 0:56:25.461000
```

While you would possibly not write the code in exactly that way, you might be using an application object model which provides a useful set of API entry points and you might be calling object methods that will, in turn, execute the same kind of series of SQL statements. Sometimes, adding insult to injury, your magic object model will insist on hydrating the intermediate objects with as much information as possible from the database, which translates into `select *` being used. We'll see more about why to avoid `select *` later.

There are several problems related to *correctness* and *efficiency* when this very simple use case is done within several queries, and we're going to dive into them.

Correctness

When using multiple statements, it is necessary to setup the *isolation level* correctly. Also, the connection and transaction semantics of your code should be tightly controlled. Our code snippet here does neither, using a default isolation level setting and not caring much about transactions.

The SQL standard defines four isolation levels and PostgreSQL implements three of them, leaving out *dirty reads*. The isolation level determines which side

effects from other transactions your transaction is sensitive to. The PostgreSQL documentation section entitled Transaction Isolation) is quite the reference to read here. If we try and simplify the matter, you can think of the isolation levels like this:

- Read uncommitted

  PostgreSQL accepts this setting and actually implements *read committed* here, which is compliant with the SQL standard;

- Read committed

  This is the default and it allows your transaction to see other transactions changes as soon as they are committed; it means that if you run the following query twice in your transaction but someone else added or removed objects from the stock, you will have different counts at different points in your transaction.

```
SELECT count(*) FROM stock;
```

- Repeatable read

  In this isolation level, your transaction keeps the same *snapshot* of the whole database for its entire duration, from BEGIN to COMMIT. It is very useful to have that for online backups — a straightforward use case for this feature.

- Serializable

  This level guarantees that a one-transaction-at-a-time ordering of what happens on the server exists with the exact same result as what you're obtaining with concurrent activity.

So by default, we are working in *read committed* isolation level. As most default values, it's a good one when you know how it works and what to expect from it, and more importantly when you should change it.

Each running transaction in a PostgreSQL system can have a different isolation level, so that the online backup tooling may be using *repeatable read* while most of your application is using *read committed*, possibly apart from the stock management facilities which are meant to be *serializable*.

Now, what's happening in our example? Our class `fetch*` methods are all seeing a different database *snapshot*. So what happens to our code if a concurrent user deletes an album from the database in between our *Album.fetchall* call and our

Track.fetchall call? Or, to make it sound less dramatic, reassigns an album to a different artist to fix some user input error?

What happens is that we'd get a silent empty result set with the impact of showing a duration of 0 to the end-user. In other languages or other spellings of the code, you might have a user-visible error.

Of course, the SQL based solution is immune to those problems: when using PostgreSQL every query always runs within a single consistent snapshot. The isolation level impacts reusing a snapshot from one query to the next.

Efficiency

Efficiency can be measured in a number of ways, including a static and a dynamic analysis of the code written.

The static analysis includes the time it takes a developer to come up with the solution, the maintenance burden it then represents (like the likelihood of bug fixes, the complexity of fixing those bugs), how easy it is to review the code, etc. The dynamic analysis concerns what happens at runtime in terms of the resources we need to run the code, basically revolving around the processor, memory, network, and disk.

The correct solution here is eight lines of very basic SQL. We may consider that writing this query takes a couple minutes at most and reviewing it is about as easy. To run it from the application side we need to send the query text on the network and we directly retrieve the information we need: for each album its name and its duration. This exchange is done in a single round trip. From the application side, we need to have the list of albums and their duration in memory, and we don't do any computing, so the CPU usage is limited to what needs to be done to talk to the database server and organise the result set in memory, then walk the result it to display it. We must add to that the time it took the server to compute the result for us, and computing the *sum* of the milliseconds is not free.

In the application's code solution, here's what happens under the hood:

- First, we fetch the artist from the database, so that's one network round trip and one SQL query that returns the artist id and its name

  note that we don't need the name of the artist in our use-case, so that's a useless amount of bytes sent on the network, and also in memory in the

application.

- Then we do another network round-trip to fetch a list of albums for the artistid we just retrieved in the previous query, and store the result in the application's memory.
- Now for each album (here we only have three of them, the same collection counts 21 albums for *Iron Maiden*) we send another SQL query via the network to the database server and fetch the list of tracks and their properties, including the duration in milliseconds.
- In the same loop where we fetch the tracks durations in milliseconds, we sum them up in the application's memory — we can approximate the CPU usage on the application side to be the same as the one in the PostgreSQL server.
- Finally, the application can output the fetched data.

The thing about picturing the network as a resource is that we now must consider both the latency and the bandwidth characteristics and usage. That's why in the analysis above the *round trips* are mentioned. In between an application's server and its database, it is common to see latencies in the order of magnitude of 1ms or 2ms.

So from SQL to application's code, we switch from a single network round trips to five of them. That's a lot of extra work for this simple a use case. Here, in my tests, the whole SQL query is executed in less than 1ms on the server, and the whole timing of the query averages around 3ms, including sending the query string and receiving the result set.

With queries running in one millisecond on the server, the network round-trip becomes the main runtime factor to consider. When doing very simple queries against a *primary key* column (`where id = :id`) it's quite common to see execution times around 0.1ms on the server. Which means you could do ten of them in a millisecond... unless you have to wait for ten times for about 1ms for the network transport layer to get the result back to your application's code...

Again this example is a very simple one in terms of *business logic*, still, we can see the cost of avoiding raw SQL both in terms of correctness and efficiency.

Stored Procedures — a Data Access API

When using PostgreSQL it is also possible to create server-side functions. Those SQL objects store code and then execute it when called. The naïve way to create a server-side stored procedure from our current example would be the following:

```
create or replace function get_all_albums
 (
   in  name     text,
   out album    text,
   out duration interval
 )
returns setof record
language sql
as $$
  select album.title as album,
         sum(milliseconds) * interval '1 ms' as duration
    from album
         join artist using(artistid)
         left join track using(albumid)
   where artist.name = get_all_albums.name
group by album
order by album;
$$;
```

But having to give the name of the artist rather than its *artistid* means that the function won't be efficient to use, and for no good reason. So, instead, we are going to define a better version that works with an artist id:

```
create or replace function get_all_albums
 (
   in  artistid bigint,
   out album    text,
   out duration interval
 )
returns setof record
language sql
as $$
  select album.title as album,
         sum(milliseconds) * interval '1 ms' as duration
    from album
         join artist using(artistid)
         left join track using(albumid)
   where artist.artistid = get_all_albums.artistid
group by album
order by album;
$$;
```

This function is written in *PL/SQL*, so it's basically a SQL query that accepts

parameters. To run it, simply do as follows:

```
select * from get_all_albums(127);
```

```
         album          |           duration
════════════════════════╪══════════════════════════════
 Blood Sugar Sex Magik  | @ 1 hour 13 mins 57.073 secs
 By The Way             | @ 1 hour 8 mins 49.951 secs
 Californication        | @ 56 mins 25.461 secs
(3 rows)
```

Of course, if you only have the name of the artist you are interested in, you don't need to first do another query. You can directly fetch the *artistid* from a subquery:

```
select *
  from get_all_albums(
         (select artistid
            from artist
           where name = 'Red Hot Chili Peppers')
       );
```

As you can see, the subquery needs its own set of parenthesis even as a function call argument, so we end up with a double set of parenthesis here.

Since PostgreSQL 9.3 and the implementation of the *lateral* join technique, it is also possible to use the function in a join clause:

```
select album, duration
  from artist,
       lateral get_all_albums(artistid)
 where artist.name = 'Red Hot Chili Peppers';
```

```
         album          |           duration
════════════════════════╪══════════════════════════════
 Blood Sugar Sex Magik  | @ 1 hour 13 mins 57.073 secs
 By The Way             | @ 1 hour 8 mins 49.951 secs
 Californication        | @ 56 mins 25.461 secs
(3 rows)
```

Thanks to the *lateral* join, the query is still efficient, and it is possible to reuse it in more complex use cases. Just for the sake of it, say we want to list the album with durations of the artists who have exactly four albums registered in our database:

```
with four_albums as
(
   select artistid
     from album
 group by artistid
   having count(*) = 4
```

```
)
  select artist.name, album, duration
    from four_albums
         join artist using(artistid),
         lateral get_all_albums(artistid)
order by artistid, duration desc;
```

Using stored procedure allows reusing SQL code in between use cases, on the server side. Of course, there are benefits and drawbacks to doing so.

Procedural Code and Stored Procedures

The main drawback to using stored procedure is that you must know when to use procedural code or plain SQL with parameters. The previous example can be written in a very ugly way as server-side code:

```
create or replace function get_all_albums
 (
   in  name     text,
   out album    text,
   out duration interval
 )
returns setof record
language plpgsql
as $$
declare
  rec record;
begin
  for rec in select albumid
               from album
                    join artist using(artistid)
              where album.name = get_all_albums.name
  loop
       select title, sum(milliseconds) * interval '1ms'
         into album, duration
         from album
              left join track using(albumid)
        where albumid = record.albumid
     group by title
     order by title;

    return next;
  end loop;
end;
$$;
```

What we see here is basically a re-enactment of everything we said was wrong to do in our application code example. The main difference is that this time, we

avoid network round trips, as the loop runs on the database server.

If you want to use stored procedures, please always write them in SQL, and only switch to *PLpgSQL* when necessary. If you want to be efficient, the default should be SQL.

Where to Implement Business Logic?

We saw different ways to implement a very simple use case, with business logic implemented either on the application side, in a SQL query that is part of the application's environment, or as a server-side stored procedure.

The first solution is both incorrect and inefficient, so it should be avoided. It's preferable to exercise PostgreSQL's ability to execute joins rather than play with your network latency. We had five round-trips, with a *ping* of 2 ms, that's 10 ms lost before we do anything else, and we compare that to a query that executes in less than 1 millisecond.

We also need to think in terms of concurrency and scalability. How many concurrent users browsing your album collection do you want to be able to serve? When doing five times as many queries for the same result set, we can imagine that you take a hit of about that ratio in terms of scalability. So rather than invest in an extra layer of caching architecture in front of your APIs, wouldn't it be better to write smarter and more efficient SQL?

As for stored procedures, a lot has already been said. Using them allows the developers to build a data access API in the database server and to maintain it in a transactional way with the database schema: PostgreSQL implements transactions for the *DDL* too. The *DDL* is the *data definition language* which contains the *create*, *alter* and *drop* statements.

Another advantage of using stored procedures is that you send even less data over the network, as the query text is stored on the database server.

5

A Small Application

Let's write a very basic application where we're going to compare using either classic application code or SQL to solve some common problems. Our goal in this section is to be confronted with managing SQL as part of a code base, and show when to use classic application code or SQL.

Readme First Driven Development

Before writing any code or tests or anything, I like to write the *readme* first. That's this little file explaining to the user why to care for about the application, and maybe some details about how to use it. Let's do that now.

The *cdstore* application is a very simple wrapper on top of the Chinook database. The Chinook data model represents a digital media store, including tables for artists, albums, media tracks, invoices, and customers.

The *cdstore* application allows listing useful information and reports on top of the database, and also provides a way to generate some activity.

Loading the Dataset

When I used the Chinook dataset first, it didn't support PostgreSQL, so I used the SQLite data output, which nicely fits into a small enough data file. Nowadays

you will find a PostgreSQL backup file that you can use. It's easier for me to just use pgloader though, so I will just do that.

Another advantage of using pgloader in this book is that we have the following summary output, which lists tables and how many rows we loaded for each of them. This is the first encounter with our dataset.

Here's a truncated output from the pgloader run (edited so that it can fit in the book page format):

```
$ createdb chinook
$ pgloader https://github.com/lerocha/chinook-database/raw/master ⏎
           /ChinookDatabase/DataSources                           ⏎
           /Chinook_Sqlite_AutoIncrementPKs.sqlite
           pgsql:///chinook
...
             table name     errors       rows      bytes      total time
-----------------------  ---------  ---------  ---------  --------------
                  fetch          0          0                     1.611s
        fetch meta data          0         33                     0.050s
         Create Schemas          0          0                     0.002s
       Create SQL Types          0          0                     0.008s
          Create tables          0         22                     0.092s
         Set Table OIDs          0         11                     0.017s
-----------------------  ---------  ---------  ---------  --------------
                 artist          0        275     6.8 kB          0.026s
                  album          0        347    10.5 kB          0.090s
               employee          0          8     1.4 kB          0.034s
                invoice          0        412    31.0 kB          0.059s
              mediatype          0          5     0.1 kB          0.083s
          playlisttrack          0       8715    57.3 kB          0.179s
               customer          0         59     6.7 kB          0.010s
                  genre          0         25     0.3 kB          0.019s
            invoiceline          0       2240    43.6 kB          0.090s
               playlist          0         18     0.3 kB          0.056s
                  track          0       3503   236.6 kB          0.192s
-----------------------  ---------  ---------  ---------  --------------
COPY Threads Completion          0          4                     0.335s
         Create Indexes          0         22                     0.326s
 Index Build Completion          0         22                     0.088s
        Reset Sequences          0          0                     0.049s
           Primary Keys          1         11                     0.030s
    Create Foreign Keys          0         11                     0.065s
        Create Triggers          0          0                     0.000s
       Install Comments          0          0                     0.000s
-----------------------  ---------  ---------  ---------  --------------
      Total import time          ✓      15607   394.5 kB          0.893s
```

Now that the dataset is loaded, we have to fix a badly defined primary key from the SQLite side of things:

```
> \d track
                                  Table "public.track"
    Column     |  Type   |                        Modifiers
===============+=========+=========================================================
 trackid       | bigint  | not null default nextval('track_trackid_seq'::regclass)
 name          | text    |
 albumid       | bigint  |
 mediatypeid   | bigint  |
 genreid       | bigint  |
 composer      | text    |
 milliseconds  | bigint  |
 bytes         | bigint  |
 unitprice     | numeric |
Indexes:
    "idx_51519_ipk_track" UNIQUE, btree (trackid)
    "idx_51519_ifk_trackalbumid" btree (albumid)
    "idx_51519_ifk_trackgenreid" btree (genreid)
    "idx_51519_ifk_trackmediatypeid" btree (mediatypeid)

... foreign keys ...

> alter table track add primary key using index idx_51519_ipk_track;
ALTER TABLE
```

Note that as PostgreSQL implements *group by* inference we need this primary key to exists in order to be able to run some of the following queries. This means that as soon as you've loaded the dataset, please fix the primary key so that we are ready to play with the dataset.

Chinook Database

The Chinook database includes basic music elements such as *album*, *artist*, *track*, *genre* and *mediatype* for a music collection. Also, we find the idea of a *playlist* with an association table *playlisttrack*, because any track can take part of several playlists and a single playlist is obviously made of several tracks.

Then there's a model for a customer paying for some tracks with the tables *staff*, *customer*, *invoice* and *invoiceline*.

```
pgloader# \dt chinook.
            List of relations
 Schema  |     Name      | Type  | Owner
=========+===============+=======+=======
 chinook | album         | table | dim
 chinook | artist        | table | dim
```

```
 chinook | customer      | table | dim
 chinook | genre         | table | dim
 chinook | invoice       | table | dim
 chinook | invoiceline   | table | dim
 chinook | mediatype     | table | dim
 chinook | playlist      | table | dim
 chinook | playlisttrack | table | dim
 chinook | staff         | table | dim
 chinook | track         | table | dim
(11 rows)
```

With that in mind we can begin to explore the dataset with a simple query:

```
  select genre.name, count(*) as count
    from           genre
         left join track using(genreid)
group by genre.name
order by count desc;
```

Which gives us:

```
        name         | count
═════════════════════╪═══════
 Rock                |  1297
 Latin               |   579
 Metal               |   374
 Alternative & Punk  |   332
 Jazz                |   130
 TV Shows            |    93
 Blues               |    81
 Classical           |    74
 Drama               |    64
 R&B/Soul            |    61
 Reggae              |    58
 Pop                 |    48
 Soundtrack          |    43
 Alternative         |    40
 Hip Hop/Rap         |    35
 Electronica/Dance   |    30
 Heavy Metal         |    28
 World               |    28
 Sci Fi & Fantasy    |    26
 Easy Listening      |    24
 Comedy              |    17
 Bossa Nova          |    15
 Science Fiction     |    13
 Rock And Roll       |    12
 Opera               |     1
```

```
(25 rows)
```

Music Catalog

Now, back to our application. We are going to write it in Python, to make it easy to browse the code within the book.

Using the anosql Python library it is very easy to embed SQL code in Python and keep the SQL clean and tidy in `.sql` files. We will look at the Python side of things in a moment.

The `artist.sql` file looks like this:

```
-- name: top-artists-by-album
-- Get the list of the N artists with the most albums
  select artist.name, count(*) as albums
    from           artist
         left join album using(artistid)
group by artist.name
order by albums desc
   limit :n;
```

Having `.sql` files in our source tree allows us to version control them with git, write comments when necessary, and also copy and paste the files between your application's directory and the interactive `psql` shell.

In the case of our `artist.sql` file, we see the use of the *anosql* facility to name variables and we use `limit :n`. Here's how to benefit from that directly in the PostgresQL shell:

```
> \set n 1
> \i artist.sql
    name     | albums
═════════════╪════════
 Iron Maiden |     21
(1 row)

> \set n 3
> \i artist.sql
     name     | albums
══════════════╪════════
 Iron Maiden  |     21
 Led Zeppelin |     14
 Deep Purple  |     11
(3 rows)
```

Of course, you can also set the variable's value from the command line, in case you want to integrate that into *bash* scripts or other calls:

```
psql --variable "n=10" -f artist.sql chinook
```

Albums by Artist

We might also want to include the query from the previous section and that's fairly easy to do now. Our `album.sql` file looks like the following:

```
-- name: list-albums-by-artist
-- List the album titles and duration of a given artist
  select album.title as album,
         sum(milliseconds) * interval '1 ms' as duration
    from album
         join artist using(artistid)
         left join track using(albumid)
   where artist.name = :name
group by album
order by album;
```

Later in this section, we look at the calling Python code.

Top-N Artists by Genre

Let's implement some more queries, such as the Top-N artists per genre, where we sort the artists by their number of appearances in our playlists. This ordering seems fair, and we have a classic Top-N to solve in SQL.

The following extract is our application's `genre-topn.sql` file. The best way to implement a Top-N query in SQL is using a *lateral* join, and the query here is using that technique. We will get back to this kind of join later in the book and learn more details about it. For now, we can simplify the theory down to *lateral join* allowing one to write explicit *loops* in SQL:

```
-- name: genre-top-n
-- Get the N top tracks by genre
select genre.name as genre,
       case when length(ss.name) > 15
            then substring(ss.name from 1 for 15) || '···'
            else ss.name
        end as track,
       artist.name as artist
  from genre
```

```
        left join lateral
        /*
         * the lateral left join implements a nested loop over
         * the genres and allows to fetch our Top-N tracks per
         * genre, applying the order by desc limit n clause.
         *
         * here we choose to weight the tracks by how many
         * times they appear in a playlist, so we join against
         * the playlisttrack table and count appearances.
         */
        (
           select track.name, track.albumid, count(playlistid)
             from           track
                  left join playlisttrack using (trackid)
            where track.genreid = genre.genreid
         group by track.trackid
         order by count desc
            limit :n
        )
        /*
         * the join happens in the subquery's where clause, so
         * we don't need to add another one at the outer join
         * level, hence the "on true" spelling.
         */
            ss(name, albumid, count) on true
        join album using(albumid)
        join artist using(artistid)
order by genre.name, ss.count desc;
```

Here, we loop through the musical genres we know about, and for each of them, we fetch the `n` tracks with the highest number of appearances in our registered playlists (thanks to the SQL clauses `order by count desc limit :n`). This *correlated subquery* runs for each genre and is *parameterized* with the current `genreid` thanks to the clause `where track.genreid = genre.genreid`. This *where clause* implements the correlation in between the outer loop and the inner one.

Once the inner loop is done in the lateral subquery named `ss` then we join again with the `album` and `artist` tables in order to get the artist name, through the album.

The query may look complex at this stage. The main goal of this book is to help you to find it easier to read and figure out the equivalent code we would have had to write in Python. The main reason why writing moderately complex SQL for this listing is efficiency.

To implement the same thing in application code you have to:

1. Fetch the list of genres (that's one `select name from genre` query)
2. Then for each genre fetch the Top-N list of tracks, which is the `ss` subquery before ran as many times as genres from the application
3. Then for each track selected in this way (that's n times how many genres you have), you can fetch the artist's name.

That's a lot of data to go back and forth in between your application and your database server. It's a lot of useless processing too. So we avoid all this extra work by having the database compute exactly the *result set* we are interested in, and then we have a very simple Python code that only cares about the user interface, here parsing command line options and printing out the result of our queries.

Another common argument against the seemingly complex SQL query is that you know another way to obtain the same result, in SQL, that doesn't involve a *lateral subquery*. Sure, it's possible to solve this Top-N problem in other ways in SQL, but they are all less efficient than the *lateral* method. We will cover how to read an *explain plan* in a later chapter, and that's how to figure out the most efficient way to write a query.

For now, let's suppose this is the best way to write the query. So of course that's the one we are going to include in the application's code, and we need an easy way to then maintain the query.

So here's the whole of our application code:

```
#! /usr/bin/env python3
# -*- coding: utf-8 -*-

import anosql
import psycopg2
import argparse
import sys

PGCONNSTRING = "user=cdstore dbname=appdev application_name=cdstore"

class chinook(object):
    """Our database model and queries"""
    def __init__(self):
        self.pgconn = psycopg2.connect(PGCONNSTRING)
        self.queries = None

        for sql in ['sql/genre-tracks.sql',
                    'sql/genre-topn.sql',
                    'sql/artist.sql',
                    'sql/album-by-artist.sql',
```

```
                    'sql/album-tracks.sql']:
            queries = anosql.load_queries('postgres', sql)
            if self.queries:
                for qname in queries.available_queries:
                    self.queries.add_query(qname, getattr(queries, qname))
            else:
                self.queries = queries

    def genre_list(self):
        return self.queries.tracks_by_genre(self.pgconn)

    def genre_top_n(self, n):
        return self.queries.genre_top_n(self.pgconn, n=n)

    def artist_by_albums(self, n):
        return self.queries.top_artists_by_album(self.pgconn, n=n)

    def album_details(self, albumid):
        return self.queries.list_tracks_by_albumid(self.pgconn, id=albumid)

    def album_by_artist(self, artist):
        return self.queries.list_albums_by_artist(self.pgconn, name=artist)


class printer(object):
    "print out query result data"

    def __init__(self, columns, specs, prelude=True):
        """COLUMNS is a tuple of column titles,
           Specs an tuple of python format strings
        """
        self.columns = columns
        self.specs = specs
        self.fstr = " | ".join(str(i) for i in specs)

        if prelude:
            print(self.title())
            print(self.sep())

    def title(self):
        return self.fstr % self.columns

    def sep(self):
        s = ""
        for c in self.title():
            s += "+" if c == "|" else "-"
        return s

    def fmt(self, data):
        return self.fstr % data


```

```
class cdstore(object):
    """Our cdstore command line application. """

    def __init__(self, argv):
        self.db = chinook()

        parser = argparse.ArgumentParser(
            description='cdstore utility for a chinook database',
            usage='cdstore <command> [<args>]')
        subparsers = parser.add_subparsers(help='sub-command help')

        genres = subparsers.add_parser('genres', help='list genres')
        genres.add_argument('--topn', type=int)
        genres.set_defaults(method=self.genres)

        artists = subparsers.add_parser('artists', help='list artists')
        artists.add_argument('--topn', type=int, default=5)
        artists.set_defaults(method=self.artists)

        albums = subparsers.add_parser('albums', help='list albums')
        albums.add_argument('--id', type=int, default=None)
        albums.add_argument('--artist', default=None)
        albums.set_defaults(method=self.albums)

        args = parser.parse_args(argv)
        args.method(args)

    def genres(self, args):
        "List genres and number of tracks per genre"
        if args.topn:
            p = printer(("Genre", "Track", "Artist"),
                        ("%20s", "%20s", "%20s"))

            for (genre, track, artist) in self.db.genre_top_n(args.topn):
                artist = artist if len(artist) < 20 else "%s…" % artist[0:18]
                print(p.fmt((genre, track, artist)))
        else:
            p = printer(("Genre", "Count"), ("%20s", "%s"))
            for row in self.db.genre_list():
                print(p.fmt(row))

    def artists(self, args):
        "List genres and number of tracks per genre"
        p = printer(("Artist", "Albums"), ("%20s", "%5s"))
        for row in self.db.artist_by_albums(args.topn):
            print(p.fmt(row))

    def albums(self, args):
        # we decide to skip parts of the information here
        if args.id:
            p = printer(("Title", "Duration", "Pct"),
                        ("%25s", "%15s", "%6s"))
```

```
            for (title, ms, s, e, pct) in self.db.album_details(args.id):
                title = title if len(title) < 25 else "%s…" % title[0:23]
                print(p.fmt((title, ms, pct)))

        elif args.artist:
            p = printer(("Album", "Duration"), ("%25s", "%s"))
            for row in self.db.album_by_artist(args.artist):
                print(p.fmt(row))


if __name__ == '__main__':
    cdstore(sys.argv[1:])
```

With this application code and the SQL we saw before we can now run our Top-N query and fetch the single most listed track of each known genre we have in our Chinook database:

```
$ ./cdstore.py genres --topn 1 | head
               Genre |                Track |               Artist
---------------------+----------------------+---------------------
         Alternative |        Hunger Strike |    Temple of the Dog
  Alternative & Punk |        Infeliz Natal |            Raimundos
               Blues |     Knockin On Heav… |         Eric Clapton
          Bossa Nova |       Onde Anda Você |  Toquinho & Vinícius
           Classical |     Fantasia On Gre… |  Academy of St. Mar…
              Comedy |      The Negotiation |           The Office
               Drama |           Homecoming |               Heroes
      Easy Listening |     I've Got You Un… |        Frank Sinatra
```

Of course, we can change our `--topn` parameter and have the top three tracks per genre instead:

```
$ ./cdstore.py genres --topn 3 | head
               Genre |                Track |               Artist
---------------------+----------------------+---------------------
         Alternative |        Hunger Strike |    Temple of the Dog
         Alternative |     Times of Troubl… |    Temple of the Dog
         Alternative |     Pushin Forward … |    Temple of the Dog
  Alternative & Punk |     I Fought The La… |             The Clash
  Alternative & Punk |        Infeliz Natal |            Raimundos
  Alternative & Punk |           Redundant |           Green Day
               Blues |          I Feel Free |         Eric Clapton
               Blues |     Knockin On Heav… |         Eric Clapton
```

Now if we want to change our SQL query, for example implementing another way to weight tracks and select the *top* ones per genre, then it's easy to play with the query in `psql` and replace it once you're done.

As we are going to cover in the next section of this book, writing a SQL query happens interactively using a *REPL* tool.

6

The SQL REPL — An Interactive Setup

PostgreSQL ships with an interactive console with the command line tool named psql. It can be used both for scripting and interactive usage and is moreover quite a powerful tool. Interactive features includes *autocompletion*, *readline* support (history searches, modern keyboard movements, etc), input and output redirection, formatted output, and more.

New users of PostgreSQL often want to find an advanced visual query editing tool and are confused when *psql* is the answer. Most PostgreSQL advanced users and experts don't even think about it and use *psql*. In this chapter, you will learn how to fully appreciate that little command line tool.

Intro to psql

psql implements a REPL: the famous read-eval-print loop. It's one of the best ways to interact with the computer when you're just learning and trying things out. In the case of PostgreSQL you might be discovering a schema, a data set, or just working on a query.

We often see the SQL query when it's fully formed, and rarely get to see the steps that led us there. It's the same with code, most often what you get to see is its final form, not the intermediary steps where the author tries things and refine their understanding of the problem at hand, or the environment in which to

solve it.

The process to follow to get to a complete and efficient SQL query is the same as when writing code: iterating from a very simple angle towards a full solution to the problem at hand. Having a *REPL* environment offers an easy way to build up on what you just had before.

The psqlrc Setup

Here we begin with a full setup of *psql* and in the rest of the chapter, we are going to get back to each important point separately. Doing so allows you to have a fully working environment from the get-go and play around in your PostgreSQL console while reading the book.

```
\set PROMPT1 '%~%x%# '
\x auto
\set ON_ERROR_STOP on
\set ON_ERROR_ROLLBACK interactive

\pset null '¤'
\pset linestyle 'unicode'
\pset unicode_border_linestyle single
\pset unicode_column_linestyle single
\pset unicode_header_linestyle double
set intervalstyle to 'postgres_verbose';

\setenv LESS '-iMFXSx4R'
\setenv EDITOR '/Applications/Emacs.app/Contents/MacOS/bin/emacsclient -nw'
```

Save that setup in the `~/.psqlrc` file, which is read at startup by the *psql* application. As you've already read in the PostgreSQL documentation for *psql*, we have three different settings to play with here:

- `\set [ name [ value [ ... ] ] ]`

  This sets the psql variable name to value, or if more than one value is given, to the concatenation of all of them. If only one argument is given, the variable is set with an empty value. To unset a variable, use the `\unset` command.

- `\setenv name [ value ]`

  This sets the environment variable name to value, or if the value is not supplied, unsets the environment variable.

Here we use this facility to setup specific environment variables we need from within `psql`, such as the *LESS* setup. It allows invoking the *pager* for each result set but having it take the control of the screen only when necessary.

- `\pset [ option [ value ] ]`

  This command sets options affecting the output of query result tables. *option* indicates which option is to be set. The semantics of *value* vary depending on the selected option. For some options, omitting *value* causes the option to be toggled or unset, as described under the particular option. If no such behavior is mentioned, then omitting *value* just results in the current setting being displayed.

Transactions and psql Behavior

In our case we set several psql variables that change its behavior:

- `\set ON_ERROR_STOP on`

  The name is quite a good description of the option. It allows *psql* to know that it is not to continue trying to execute all your commands when a previous one is throwing an error. It's primarily practical for scripts and can be also set using the command line. As we'll see later, we can easily invoke scripts interactively within our session with the `\i` and `\ir` commands, so the option is still useful to us now.

- `\set ON_ERROR_ROLLBACK interactive`

  This setting changes how *psql* behaves with respect to transactions. It is a very good interactive setup, and must be avoided in batch scripts.

  From the documentation: When set to on, if a statement in a transaction block generates an error, the error is ignored and the transaction continues. When set to interactive, such errors are only ignored in interactive sessions, and not when reading script files. When unset or set to off, a statement in a transaction block that generates an error aborts the entire transaction. The error rollback mode works by issuing an implicit SAVEPOINT for you, just before each command that is in a transaction block, and then rolling back to the savepoint if the command fails.

With the `\set PROMPT1 '%~%x%# '` that we are using, *psql* displays a little star in the prompt when there's a transaction in flight, so you know you need to finish the transaction. More importantly, when you want to type in anything that will have a side effect on your database (modifying the data set or the database schema), then without the star you know you need to first type in `BEGIN`.

Let's see an example output with *ON_ERROR_ROLLBACK* set to off. Here's its default value:

```
f1db# begin;
BEGIN
f1db*# select 1/0;
ERROR:  division by zero
f1db!# select 1+1;
ERROR:  current transaction is aborted, commands ignored until end of transaction bloc
f1db!# rollback;
ROLLBACK
```

We have an error in our transaction, and we notice that the star prompt is now a flag. The SQL transaction is marked invalid, and the only thing PostgreSQL will now accept from us is to finish the transaction, with either a *commit* or a *rollback* command. Both will result in the same result from the server: `ROLLBACK`.

Now, let's do the same SQL transaction again, this time with *ON_ERROR_ROLLBA* being set to *interactive*. Now, before each command we send to the server, *psql* sends a savepoint command, which allows it to then issue a rollback to savepoint command in case of an error. This *rollback to savepoint* is also sent automatically:

```
f1db# begin;
BEGIN
f1db*# select 1/0;
ERROR:  division by zero
f1db*# select 1+1;
 ?column?
══════════
        2
(1 row)

f1db*# commit;
COMMIT
```

Notice how this time not only do we get to send successful commands after the error, while still being in a transaction — also we get to be able to *COMMIT* our work to the server.

A Reporting Tool

Getting familiar with *psql* is a very good productivity enhancer, so my advice is to spend some quality time with the documentation of the tool and get used to it. In this chapter, we are going to simplify things and help you to get started.

There are mainly two use cases for *psql*, either as an interactive tool or as a scripting and reporting tool. In the first case, the idea is that you have plenty of commands to help you get your work done, and you can type in SQL right in your terminal and see the result of the query.

In the scripting and reporting use case, you have advanced formatting commands: it is possible to run a query and fetch its result directly in either *asciidoc* or *HTML* for example, given `\pset format`. Say we have a query that reports the N bests known results for a given driver surname. We can use *psql* to set dynamic variables, display tuples only and format the result in a convenient HTML output:

```
~ psql --tuples-only      \
       --set n=1          \
       --set name=Alesi   \
       --no-psqlrc        \
       -P format=html     \
       -d f1db            \
       -f report.sql
```

```
<table border="1">
  <tr valign="top">
    <td align="left">Alesi</td>
    <td align="left">Canadian Grand Prix</td>
    <td align="right">1995</td>
    <td align="right">1</td>
  </tr>
</table>
```

It is also possible to set the connection parameters as environment variables, or to use the same connection strings as in your application's code, so you can test them with copy/paste easily, there's no need to transform them into the `-d dbname -h hostname -p port -U username` syntax:

```
~ psql -d postgresql://dim@localhost:5432/f1db
f1db#

~ psql -d "user=dim host=localhost port=5432 dbname=f1db"
f1db#
```

The query in the `report.sql` file uses the `:'name'` variable syntax. Using `:name` would be missing the quotes around the literal value injected, and `:''` allows one to remedy this even with values containing spaces. *psql* also supports `:"variable"` notation for double-quoting values, which is used for dynamic SQL when identifiers are a parameter (column name or table names).

```
  select surname, races.name, races.year, results.position
    from results
         join drivers using(driverid)
         join races using(raceid)
   where drivers.surname = :'name'
         and position between 1 and 3
order by position
   limit :n;
```

When running *psql* for reports, it might be good to have a specific setup. In this example, you can see I've been using the `--no-psqlrc` switch to be sure we're not loading my usual interactive setup all with all the UTF-8 bells and whistles, and with *ON_ERROR_ROLLBACK*. Usually, you don't want to have that set for a reporting or a batch script.

You might want to set *ON_ERROR_STOP* though, and maybe some other options.

Discovering a Schema

Let's get back to the interactive features of *psql*. The tool's main task is to send SQL statements to the database server and display the result of the query, and also server notifications and error messages. On top of that *psql* provides a set of client-side commands all beginning with a *backslash* character.

Most of the provided commands are useful for discovering a database schema. All of them are implemented by doing one or several *catalog queries* against the server. Again, it's sending a SQL statement to the server, and it is possible for you to learn how to query the PostgreSQL catalogs by reviewing those queries.

As an example, say you want to report the size of your databases but you don't know where to look for that information. Reading the psql documentation you find that the `\l+` command can do that, and now you want to see the SQL behind it:

```
~# \set ECHO_HIDDEN true
~# \l+
```

```
********* QUERY **********
SELECT d.datname as "Name",
       pg_catalog.pg_get_userbyid(d.datdba) as "Owner",
       pg_catalog.pg_encoding_to_char(d.encoding) as "Encoding",
       d.datcollate as "Collate",
       d.datctype as "Ctype",
       pg_catalog.array_to_string(d.datacl, E'\n') AS "Access privileges",
       CASE WHEN pg_catalog.has_database_privilege(d.datname, 'CONNECT')
            THEN pg_catalog.pg_size_pretty(pg_catalog.pg_database_size(d.datname))
            ELSE 'No Access'
       END as "Size",
       t.spcname as "Tablespace",
       pg_catalog.shobj_description(d.oid, 'pg_database') as "Description"
FROM pg_catalog.pg_database d
  JOIN pg_catalog.pg_tablespace t on d.dattablespace = t.oid
ORDER BY 1;
**************************

List of databases
...
~# \set ECHO_HIDDEN false
```

So now if you only want to have the database name and its on-disk size in bytes, it is as easy as running the following query:

```
  SELECT datname,
         pg_database_size(datname) as bytes
    FROM pg_database
ORDER BY bytes desc;
```

There's not much point in this book including the publicly available documentation of all the commands available in *psql*, so go read the whole manual page to find gems you didn't know about — there are plenty of them!

Interactive Query Editor

You might have noticed that we did set the *EDITOR* environment variable early in this section. This is the command used by *psql* each time you use visual editing commands such as `\e`. This command launches your *EDITOR* on the last edited query (or an empty one) in a temporary file, and will execute the query once you end the editing session.

If you're using *emacs* or *vim* typing with a full-blown editor from within a terminal, it is something you will be very happy to do. In other cases, it is, of course, possible to set *EDITOR* to invoke your favorite IDE if your *psql* client runs locally.

7

SQL is Code

The first step here is realizing that your database engine actually is part of your application logic. Any SQL statement you write, even the simplest possible, does embed some logic: you are projecting a particular set of columns, filtering the result to only a part of the available data set (thanks to the where clause), and you want to receive the result in a known ordering. That is already is business logic. Application code is written in SQL.

We compared a simple eight-line SQL query and the typical object model code solving the same use case earlier and analyzed its correctness and efficiency issues. Then in the previous section, we approached a good way to have your SQL queries as .sql files in your code base.

Now that SQL is actually code in your application's source tree, we need to apply the same methodology that you're used to: set a minimum level of expected quality thanks to common indentation rules, code comments, consistent naming, unit testing, and code revision systems.

SQL style guidelines

Code style is mainly about following the *principle of least astonishment* rule. That's why having a clear internal style guide that every developer follows is important in larger teams. We are going to cover several aspects of SQL code style here, from indentation and to alias names.

Indenting is a tool aimed at making it easy to read the code. Let's face it: we spend more time reading code than writing it, so we should always optimize for easy to read the code. SQL is code, so it needs to be properly indented.

Let's see a few examples of bad and good style so that you can decide about your local guidelines.

```
SELECT title, name FROM album LEFT JOIN track USING(albumid) WHERE albumid = 1 ORDER
```

Here we have a run-away query all on the same line, making it more difficult than it should for a reader to grasp what the query is all about. Also, the query is using the old habit of all-caps SQL keywords. While it's true that SQL started out a long time ago, we now have color screens and syntax highlighting and we don't write all-caps code anymore... not even in SQL.

My advice is to right align top-level SQL clauses and have them on new lines:

```
  select title, name
    from album left join track using(albumid)
   where albumid = 1
order by 2;
```

Now it's quite a bit easier to understand the structure of this query at a glance and to realize that it is indeed a very basic SQL statement. Moreover, it's easier to spot a problem in the query: *order by 2*. SQL allows one to use output column number as references in some of its clauses, which is very useful at the prompt (because we are all lazy, right?). It makes refactoring harder than it should be though. If we now decide we don't want to output the album's name with each track's row in the result set, as we are actually interested in the track's title and duration, as found in the *milliseconds* column:

```
  select name, milliseconds
    from album left join track using(albumid)
   where albumid = 1
order by 2;
```

So now the ordering has changed, so you need also to change the *order by* clause, obtaining the following diff:

```
@@ -1,4 +1,4 @@
-  select title, name
+  select name, milliseconds
     from album left join track using(albumid)
    where albumid = 1
-order by 2;
+order by 1;
```

This is a very simple example, but nonetheless we can see that the review process now has to take into account why the *order by* clause is modified when what you want to achieve is changing the columns returned.

Now, the right ordering for this query might actually be to return the tracks in the order they appear on the album, which seems to be handled in the Chinook model by the *trackid* itself, so it's better to use that:

```
  select name, milliseconds
    from album left join track using(albumid)
   where albumid = 1
order by trackid;
```

This query is now about to be ready to be checked in into your application's code base, tested and reviewed. An alternative writing would require splitting the from clause into one source relation per line, having the join appearing more clearly:

```
  select name, milliseconds
    from           album
         left join track using(albumid)
   where albumid = 1
order by trackid;
```

In this style, we see that we indent the join clauses nested in the from clause, because that's the semantics of an SQL query. Also, we left align the table names that take part of the join. An alternative style consists of also entering the join clause (one of either *on* or *using*) in a separate line too:

```
  select name, milliseconds
    from           album
         left join track
             using(albumid)
   where albumid = 1
order by trackid;
```

This extended style is useful when using subqueries, so let's fetch track information from albums we get in a subquery:

```
  select title, name, milliseconds
    from (
           select albumid, title
             from      album
                  join artist using(artistid)
            where artist.name = 'AC/DC'
         )
           as artist_albums
         left join track
```

```
10              using(albumid)
11  order by trackid;
```

One of the key things to think about in terms of the style you pick is being consistent. That's why in the previous example we also split the *from* clause in the subquery, even though it's a very simple clause that's not surprising.

SQL requires using parens for subqueries, and we can put that requirement to good use in the way we indent our queries, as shown above.

Another habit that is worth mentioning here consists of writing the join conditions of inner joins in the where clause:

```
1  SELECT name, title
2    FROM artist, album
3   WHERE artist.artistid = album.artistid
4     AND artist.artistid = 1;
```

This style reminds us of the 70s and 80s before when the SQL standard did specify the join semantics and the join condition. It is extremely confusing to use such a style and doing it is frowned upon. The modern SQL spelling looks like the following:

```
1  select name, title
2    from artist
3         inner join album using(artistid)
4   where artist.artistid = 1;
```

Here I expanded the inner join to its full notation. The SQL standard introduces *noise words* in the syntax, and both *inner* and *outer* are noise words: a *left*, *right* or *full* join is always an *outer* join, and a straight join always is an *inner* join.

It is also possible to use the *natural join* here, which will automatically expand a join condition over columns having the same name:

```
1  select name, title
2    from artist natural join album
3   where artist.artistid = 1;
```

General wisdom dictates that one should avoid *natural joins*: you can (and will) change your query semantics by merely adding a column to or removing a column from a table! In the Chinook model, we have five different tables with a *name* column, none of those being part of the primary key. In most cases, you don't want to join tables on the *name* column...

Because it's fun to do so, let's write a query to find out if the Chinook data set includes cases of a track being named after another artist's, perhaps reflecting their

respect or inspiration.

```
  select artist.name as artist,
         inspired.name as inspired,
         album.title as album,
         track.name as track
    from      artist
         join track on track.name = artist.name
         join album on album.albumid = track.albumid
         join artist inspired on inspired.artistid = album.artistid
   where artist.artistid <> inspired.artistid;
```

This gives the following result where we can see two cases of a singer naming a song after their former band's name:

```
    artist     │   inspired    │       album        │     track
═══════════════╪═══════════════╪════════════════════╪═══════════════
 Iron Maiden   │ Paul D'Ianno  │ The Beast Live     │ Iron Maiden
 Black Sabbath │ Ozzy Osbourne │ Speak of the Devil │ Black Sabbath
(2 rows)
```

About the query itself, we can see we use the same table twice in the *join* clause, because in one case the artist we want to know about is the one issuing the track in one of their album, and in the other case it's the artist that had their name picked as a track's name. To be able to handle that without confusion, the query uses the SQL standard's relation aliases.

In most cases, you will see very short relation aliases being used. When I typed that query in the *psql* console, I must admit I first picked *a1* and *a2* for artist's relation aliases, because it made it short and easy to type. We can compare such a choice with your variable naming policy. I don't suppose you pass code review when using variable names such as *a1* and *a2* in your code, so don't use them in your SQL query as aliases either.

Comments

The SQL standard comes with two kinds of comments, either per line with the double-dash prefix or per-block delimited with C-style comments using `/* comment */` syntax. Note that contrary to C-style comments, SQL-style comments accept nested comments.

Let's add some comments to our previous query:

```
  -- artists names used as track names by other artists
  select artist.name as artist,
```

```
        -- "inspired" is the other artist
        inspired.name as inspired,
        album.title as album,
        track.name as track
   from      artist
        /*
         * Here we join the artist name on the track name,
         * which is not our usual kind of join and thus
         * we don't use the using() syntax. For
         * consistency and clarity of the query, we use
         * the "on" join condition syntax through the
         * whole query.
         */
        join track
          on track.name = artist.name
        join album
          on album.albumid = track.albumid
        join artist inspired
          on inspired.artistid = album.artistid
  where artist.artistid <> inspired.artistid;
```

As with code comments, it's pretty useless to explain what is obvious in the query. The general advice is to give details on what you though was unusual or difficult to write, so as to make the reader's work as easy as possible. The goal of code comments is to avoid ever having to second-guess the *intentions* of the author(s) of it. SQL is code, so we pursue the same goal with SQL.

Comments could also be used to embed the source location where the query comes from in order to make finding it easier when we have to debug it in production, should we have to. Given the PostgreSQL's *application_name* facility and a proper use of SQL files in your source code, one can wonder how helpful that technique is.

Unit Tests

SQL is code, so it needs to be tested. The general approach to unit testing code applies beautifully to SQL: given a known input a query should always return the same desired output. That allows you to change your query spelling at will and still check that the alternative still passes your tests.

Examples of query rewriting would include inlining *common table expressions* as sub-queries, expanding *or* branches in a *where* clause as *union all* branches, or maybe using *window function* rather than complex juggling with subqueries to obtain the same result. What I mean here is that there are a lot of ways to rewrite

a query while keeping the same semantics and obtaining the same result.

Here's an example of a query rewrite:

```
with artist_albums as
 (
    select albumid, title
      from      album
           join artist using(artistid)
     where artist.name = 'AC/DC'
 )
  select title, name, milliseconds
    from artist_albums
         left join track
             using(albumid)
order by trackid;
```

The same query may be rewritten with the exact same semantics (but different run-time characteristics) like this:

```
  select title, name, milliseconds
    from (
           select albumid, title
             from      album
                  join artist using(artistid)
            where artist.name = 'AC/DC'
         )
           as artist_albums
         left join track
            using(albumid)
order by trackid;
```

The PostgreSQL project includes many SQL tests to validate its query parser, optimizer and executor. It uses a framework named the *regression tests suite*, based on a very simple idea:

1. Run a SQL file containing your tests with *psql*
2. Capture its output to a text file that includes the queries and their results
3. Compare the output with the expected one that is maintained in the repository with the standard *diff* utility
4. Report any difference as a failure

You can have a look at PostgreSQL repository to see how it's done, as an example we could pick src/test/regress/sql/aggregates.sql and its matching expected result file src/test/regress/expected/aggregates.out.

Implementing that kind of regression testing for your application is quite easy, as the driver is only a thin wrapper around executing standard applications such

as *psql* and *diff*. The idea would be to always have a *setup* and a *teardown* step in your SQL test files, wherein the setup step builds a database model and fills it with the test data, and the teardown step removes all that test data.

To automate such a setup and go beyond the obvious, the tool pgTap is a suite of database functions that make it easy to write TAP-emitting unit tests in psql scripts or xUnit-style test functions. The TAP output is suitable for harvesting, analysis, and reporting by a TAP harness, such as those used in Perl applications.

When using pgTap, see the relation-testing functions for implementing unit tests based on result sets. From the documentation, let's pick a couple examples, testing against static result sets as *VALUES*:

```
SELECT results_eq(
    'SELECT * FROM active_users()',
    $$
      VALUES (42, 'Anna'),
             (19, 'Strongrrl'),
             (39, 'Theory')
    $$,
    'active_users() should return active users'
);
```

and *ARRAYS*:

```
SELECT results_eq(
    'SELECT * FROM active_user_ids()',
    ARRAY[ 2, 3, 4, 5]
);
```

As you can see your unit tests are coded in SQL too. This means you have all the SQL power to write tests at your fingertips, and also that you can also check your schema integrity directly in SQL, using PostgreSQL catalog functions.

Straight from the pg_prove command-line tool for running and harnessing pgTAP tests, we can see how it looks:

```
% pg_prove -U postgres tests/
tests/coltap.....ok
tests/hastap.....ok
tests/moretap....ok
tests/pg73.......ok
tests/pktap......ok
All tests successful.
Files=5, Tests=216,  1 wallclock secs
      ( 0.06 usr  0.02 sys +  0.08 cusr  0.07 csys =  0.23 CPU)
Result: PASS
```

You might also find it easy to integrate SQL testing in your current unit testing

solution. In Debian and derivatives operating systems, the pg_virtualenv is a tool that creates a temporary PostgreSQL installation that will exist only while you're running your tests.

If you're using Python, read the excellent article from Julien Danjou about databases integration testing strategies with Python where you will learn more tricks to integrate your database tests using the standard Python toolset.

Your application relies on SQL. You rely on tests to trust your ability to change and evolve your application. You need your tests to cover the SQL parts of your application!

Regression Tests

Regression testing protects against introducing bugs when refactoring code. In SQL too we refactor queries, either because the calling application code is changed and the query must change too, or because we are hitting problems in production and a new optimized version of the query is being checked-in to replace the previous erroneous version.

The way regression testing protects you is by registering the expected results from your queries, and then checking actual results against the expected results. Typically you would run the regression tests each time a query is changed.

The RegreSQL tool implements that idea. It finds SQL files in your code repository and allows registering plan tests against them, and then it compares the results with what's expected.

A typical output from using *RegreSQL* against our *cdstore* application looks like the following:

```
$ regresql test
Connecting to 'postgres:///chinook?sslmode=disable'··· ✓
TAP version 13
ok 1 - src/sql/album-by-artist.1.out
ok 2 - src/sql/album-tracks.1.out
ok 3 - src/sql/artist.1.out
ok 4 - src/sql/genre-topn.top-3.out
ok 5 - src/sql/genre-topn.top-1.out
ok 6 - src/sql/genre-tracks.out
```

In the following example we introduce a bug by changing the test plan without changing the expected result, and here's how it looks then:

```
$ regresql test
Connecting to 'postgres:///chinook?sslmode=disable'··· ✓
TAP version 13
ok 1 - src/sql/album-by-artist.1.out
ok 2 - src/sql/album-tracks.1.out
# Query File: 'src/sql/artist.sql'
# Bindings File: 'regresql/plans/src/sql/artist.yaml'
# Bindings Name: '1'
# Query Parameters: 'map[n:2]'
# Expected Result File: 'regresql/expected/src/sql/artist.1.out'
# Actual Result File: 'regresql/out/src/sql/artist.1.out'
#
# --- regresql/expected/src/sql/artist.1.out
# +++ regresql/out/src/sql/artist.1.out
# @@ -1,4 +1,5 @@
# -   name     | albums
# ------------+-------
# -Iron Maiden | 21
# +    name     | albums
# +-------------+-------
# +Iron Maiden  | 21
# +Led Zeppelin | 14
#
not ok 3 - src/sql/artist.1.out
ok 4 - src/sql/genre-topn.top-3.out
ok 5 - src/sql/genre-topn.top-1.out
ok 6 - src/sql/genre-tracks.out
```

The diagnostic output allows actions to be taken to fix the problem: either change the expected output (with `regresql update`) or fix the *regresql/plans/src/sql/artist.yaml* file.

A Closer Look

When something wrong happens in production and you want to understand it, one of the important tasks we are confronted with is finding which part of the code is sending a specific query we can see in the monitoring, in the logs or in the interactive activity views.

PostgreSQL implements the *application_name* parameter, which you can set in the connection string and with the *SET* command within your session. It is then possible to have it reported in the server's logs, and it's also part of the system activity view *pg_stat_activity*.

It is a good idea to be quite granular with this setting, going as low as the module or package level, depending on your programming language of choice. It's one

of those settings that the main application should have full control of, so usually external (and internal) libs are not setting it.

8

Indexing Strategy

Coming up with an *Indexing Strategy* is an important step in terms of mastering your PostgreSQL database. It means that you are in a position to make an informed choice about which indexes you need, and most importantly, which you don't need in your application.

A PostgreSQL index allows the system to have new options to find the data your queries need. In the absence of an index, the only option available to your database is a *sequential scan* of your tables. The index *access methods* are meant to be faster than a sequential scan, by fetching the data directly where it is.

Indexing is often thought of as a data modeling activity. When using PostgreSQL, some indexes are necessary to ensure data consistency (the C in ACID). Constraints such as *UNIQUE*, *PRIMARY KEY* or *EXCLUDE USING* are only possible to implement in PostgreSQL with a backing index. When an index is used as an implementation detail to ensure data consistency, then the *indexing strategy* is indeed a data modeling activity.

In all other cases, the *indexing strategy* is meant to enable methods for faster access methods to data. Those methods are only going to be exercised in the context of running a SQL query. As writing the SQL queries is the job of a developer, then coming up with the right *indexing strategy* for an application is also the job of the developer.

Indexing for Constraints

When using PostgreSQL some SQL modeling constraints can only be handled with the help of a backing index. That is the case for the primary key and unique constraints, and also for the exclusion constraints created with the PostgreSQL special syntax *EXCLUDE USING*.

In those three constraint cases, the reason why PostgreSQL needs an index is because it allows the system to implement visibility tricks with its MVCC implementation. From the PostgreSQL documentation:

> PostgreSQL provides a rich set of tools for developers to manage concurrent access to data. Internally, data consistency is maintained by using a multiversion model (Multiversion Concurrency Control, MVCC). This means that each SQL statement sees a snapshot of data (a database version) as it was some time ago, regardless of the current state of the underlying data. This prevents statements from viewing inconsistent data produced by concurrent transactions performing updates on the same data rows, providing transaction isolation for each database session. MVCC, by eschewing the locking methodologies of traditional database systems, minimizes lock contention in order to allow for reasonable performance in multiuser environments.

If we think about how to implement the *unique* constraint, we soon realize that to be correct the implementation must prevent two concurrent statements from inserting duplicates. Let's see an example with two transactions *t1* and *t2* happening in parallel:

```
t1> insert into test(id) values(1);
t2> insert into test(id) values(1);
```

Before the transactions start the table has no duplicate entry, it is empty. If we consider each transaction, both *t1* and *t2* are correct and they are not creating duplicate entries with the data currently known by PostgreSQL.

Still, we can't accept both the transactions — one of them has to be refused — because they are conflicting with the one another. PostgreSQL knows how to do that, and the implementation relies on the internal code being able to access the indexes in a non-MVCC compliant way: the internal code of PostgreSQL knows what the in-flight non-committed transactions are doing.

The way the internals of PostgreSQL solve this problem is by relying on its index data structure in a non-MVCC compliant way, and this capability is not visible to SQL level users.

So when you declare a *unique* constraint, a *primary key* constraint or an *exclusion constraint* PostgreSQL creates an index for you:

```
> create table test(id integer unique);
CREATE TABLE
Time: 68.775 ms

> \d test
     Table "public.test"
 Column |  Type   | Modifiers
--------+---------+-----------
 id     | integer |
Indexes:
    "test_id_key" UNIQUE CONSTRAINT, btree (id)
```

And we can see that the index is registered in the system catalogs as being defined in terms of a *constraint*.

Indexing for Queries

PostgreSQL automatically creates only those indexes that are needed for the system to behave correctly. Any and all other indexes are to be defined by the application developers when they need a faster access method to some tuples.

An index cannot alter the result of a query. An index only provides another access method to the data, one that is faster than a sequential scan in most cases. Query semantics and result set don't depend on indexes.

Implementing a user story (or a business case) with the help of SQL queries is the job of the developer. As the author of the SQL statements, the developer also should be responsible for choosing which indexes are needed to support their queries.

Cost of Index Maintenance

An index duplicates data in a specialized format made to optimise a certain type of searches. This duplicated data set is still *ACID* compliant: at *COMMIT;*

time, every change that is made it to the main tables of your schema must have made it to the indexes too.

As a consequence, each index adds write costs to your *DML* queries: *insert*, *update* and *delete* now have to maintain the indexes too, and in a transactional way.

That's why we have to define a global *indexing strategy*. Unless you have infinite IO bandwidth and storage capacity, it is not feasible to index everything in your database.

Choosing Queries to Optimize

In every application, we have some user side parts that require the lowest latency you can provide, and some reporting queries that can run for a little while longer without users complaining.

So when you want to make a query faster and you see that its *explain* plan is lacking index support, think about the query in terms of SLA in your application. Does this query need to run as fast as possible, even when it means that you now have to maintain more indexes?

PostgreSQL Index Access Methods

PostgreSQL implements several index *Access Methods*. An *access method* is a generic algorithm with a clean API that can be implemented for compatible data types. Each algorithm is well adapted to some use cases, which is why it's interesting to maintain several *access methods*.

The PostgreSQL documentation covers index types in the indexes chapter, and tells us that

> PostgreSQL provides several index types: B-tree, Hash, GiST, SP-GiST, GIN and BRIN. Each index type uses a different algorithm that is best suited to different types of queries. By default, the CREATE INDEX command creates B-tree indexes, which fit the most common situations.

Each index access method has been designed to solve specific use case:

- *B-Tree*, or balanced tree

Balanced indexes are the most common used, by a long shot, because they are very efficient and provide an algorithm that applies to most cases. PostgreSQL implementation of the B-Tree index support is best in class and has been optimized to handle concurrent read and write operations.

You can read more about the PostgreSQL B-tree algorithm and its theoretical background in the source code file:

src/backend/access/nbtree/README.

- *GiST*, or generalized search tree

  This access method implements an more general algorithm that again comes from research activities. The GiST Indexing Project from the University of California Berkeley is described in the following terms:

  > The GiST project studies the engineering and mathematics behind content-based indexing for massive amounts of complex content.

  Its implementation in PostgreSQL allows support for 2-dimensional data types such as the geometry *point* or the *ranges* data types. Those data types don't support a total order and as a consequence can't be indexed properly in a B-tree index.

- *SP-GiST*, or spaced partitioned gist

  SP-GiST indexes are the only PostgreSQL index access method implementation that support non-balanced disk-based data structures, such as quadtrees, k-d trees, and radix trees (tries). This is useful when you want to index 2-dimensional data with very different densities.

- *GIN*, or generalized inverted index

  GIN is designed for handling cases where the items to be indexed are composite values, and the queries to be handled by the index need to search for element values that appear within the composite items. For example, the items could be documents, and the queries could be searches for documents containing specific words.

  GIN indexes are "inverted indexes" which are appropriate for data values that contain multiple component values, such as arrays. An inverted index contains a separate entry for each component value. Such an index can

efficiently handle queries that test for the presence of specific component values.

The *GIN* access method is the foundation for the PostgreSQL Full Text Search support.

- *BRIN*, or block range indexes

  BRIN indexes (a shorthand for block range indexes) store summaries about the values stored in consecutive physical block ranges of a table. Like GiST, SP-GiST and GIN, BRIN can support many different indexing strategies, and the particular operators with which a BRIN index can be used vary depending on the indexing strategy. For data types that have a linear sort order, the indexed data corresponds to the minimum and maximum values of the values in the column for each block range.

- *Hash*

  Hash indexes can only handle simple equality comparisons. The query planner will consider using a hash index whenever an indexed column is involved in a comparison using the = operator.

  Never use a *hash* index in PostgreSQL before version 10. In PostgreSQL 10 onward, hash index are crash-safe and may be used.

- Bloom filters

  A Bloom filter is a space-efficient data structure that is used to test whether an element is a member of a set. In the case of an index access method, it allows fast exclusion of non-matching tuples via signatures whose size is determined at index creation.

  This type of index is most useful when a table has many attributes and queries test arbitrary combinations of them. A traditional B-tree index is faster than a Bloom index, but it can require many B-tree indexes to support all possible queries where one needs only a single Bloom index. Note however that Bloom indexes only support equality queries, whereas B-tree indexes can also perform inequality and range searches.

  The Bloom filter index is implemented as a PostgreSQL extension starting in PostgreSQL 9.6, and so to be able to use this *access method* it's necessary to first *create extension bloom*.

Both *Bloom* indexes and *BRIN* indexes are mostly useful when covering mut-

liple columns. In the case of *Bloom* indexes, they are useful when the queries themselves are referencing most or all of those columns in equality comparisons.

Advanced Indexing

The PostgreSQL documentation about indexes covers everything you need to know, in details, including:

- Multicolumn indexes
- Indexes and ORDER BY
- Combining multiple indexes
- Unique indexes
- Indexes on expressions
- Partial indexes
- Partial unique indexes
- Index-only scans

There is of course even more, so consider reading this PostgreSQL chapter in its entirety, as the content isn't repeated in this book, but you will need it to make informed decisions about your indexing strategy.

Adding Indexes

Deciding which indexes to add is central to your *indexing strategy*. Not every query needs to be that fast, and the requirements are mostly user defined. That said, a general system-wide analysis can be achieved thanks to the PostgreSQL extension pg_stat_statements.

Once this PostgreSQL extension is installed and deployed — this needs a PostgreSQL restart, because it needs to be registered in `shared_preload_libraries` — then it's possible to have a list of the most common queries in terms of number of times the query is executed, and the cumulative time it took to execute the query.

You can begin your indexing needs analysis by listing every query that averages out to more than 10 milliseconds, or some other sensible threshold for your application. The only way to understand where time is spent in a query is by using the EXPLAIN command and reviewing the *query plan*. From the documentation of the command:

> PostgreSQL devises a query plan for each query it receives. Choosing the right plan to match the query structure and the properties of the data is absolutely critical for good performance, so the system includes a complex planner that tries to choose good plans. You can use the EXPLAIN command to see what query plan the planner creates for any query. Plan-reading is an art that requires some experience to master, but this section attempts to cover the basics.

Here's a very rough guide to using *explain* for fixing query performances:

- use the spelling below when using *explain* to understand run time characteristics of your queries:

```
explain (analyze, verbose, buffers)
<query here>;
```

- In particular when you're new to reading *query plans*, use visual tools such as https://explain.depesz.com and PostgreSQL Explain Visualizer, or the one included in pgAdmin.
- First check for row count differences in between the *estimated* and the *effective* numbers.

  Good statistics are critical to the PostgreSQL query planner, and the collected statistics need to be reasonnably up to date. When there's a huge difference in between estimated and effective row counts (several orders of magnitude, a thousand times off or more), check to see if tables are analyzed frequently enough by the Autovacuum Daemon, then check if you should adjust your statistics target.
- Finally, check for time spent doing *sequential scans* of your data, with a *filter* step, as that's the part that a proper index might be able to optimize.

Remember Amdahl's law when optimizing any system: if some step takes 10% of the run time, then the best optimization you can reach from dealing with this step is 10% less, and usually that's by removing the step entirely.

This very rough guide doesn't take into account costly *functions* and *expressions* which may be indexed thanks to *indexes on expressions*, nor *ordering* clauses that might be derived directly from a supporting index.

Query optimisation is a large topic that is not covered in this book, and proper indexing is only a part of it. What this book covers is all the SQL capabilities that you can use to retrieve exactly the result set needed by your application.

The vast majority of slow queries found in the wild are still queries that return way too many rows to the application, straining the network and the servers memory. Returning millions of rows to an application that then displays a summary in a web browser is far too common.

The first rule of optimization in SQL, as is true for code in general, is to answer the following question:

> Do I really need to do any of that?

The very best query optimization technique consists of not having to execute the query at all. Which is why in the next chapter we learn all the SQL functionality that will allow you to execute a single query rather than looping over the result set of a first query only to run an extra query for each row retrieved.

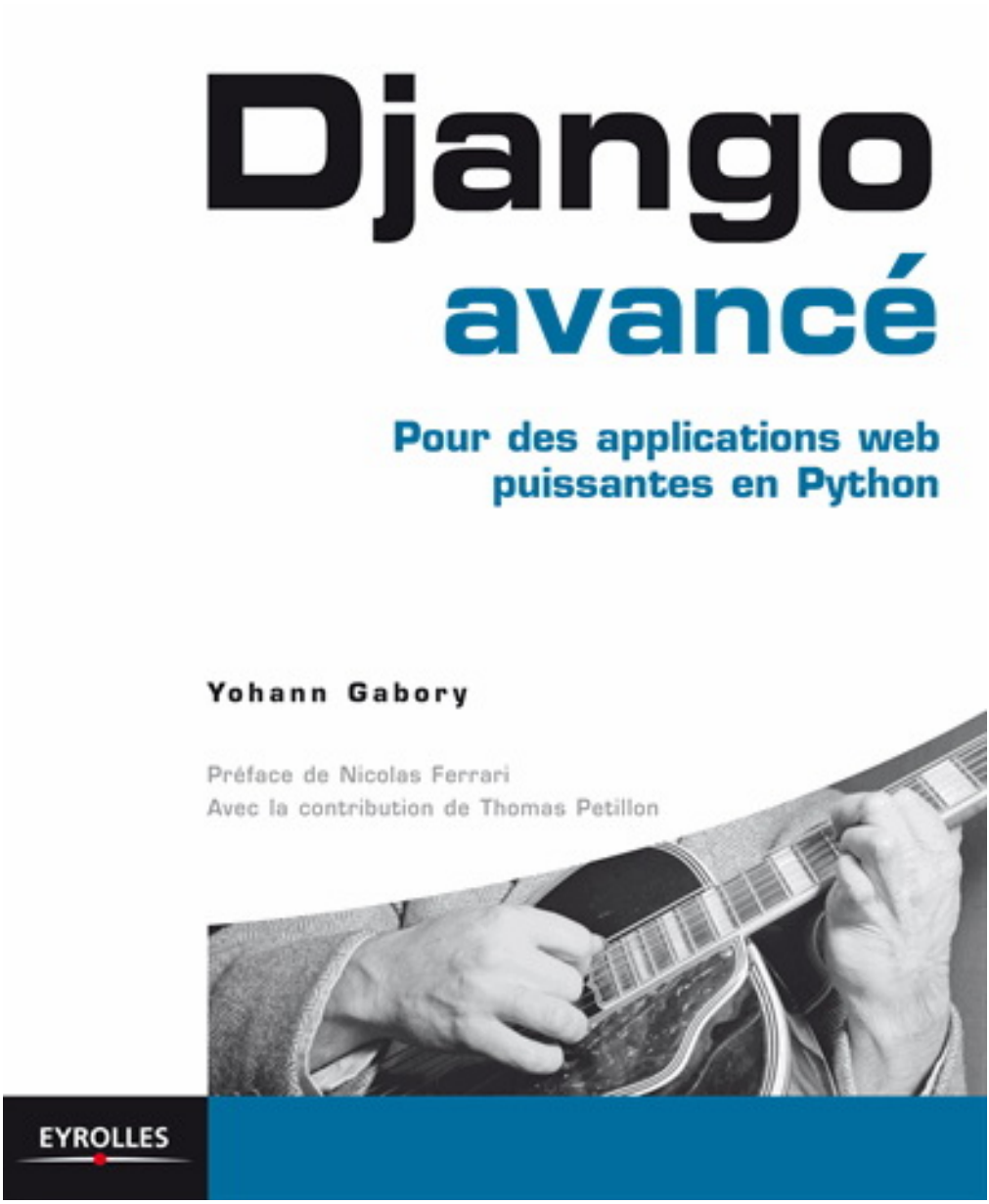


Figure 8.1: Advanced Django

9

An Interview with Yohann Gabory

Yohann Gabory, Python Django's expert, has published an "Advanced Django" book in France to share his deep understanding of the publication system with Python developers. The book really is a reference on how to use Django to build powerful applications.

As a web backend developer and Django expert, what do you expect from an RDBMS in terms of features and behavior?

> Consistency and confidence
>
> *Data is what a web application relies on. You can manage bad quality code but you cannot afford to have data loss or corruption.*
>
> *Someone might say "Hey we do not work for financials, it doesn't matter if we lose some data sometime". What I would answer to this is: if you are ready to lose some data then your data has no value. If your data has no value then there is a big chance that your app has no value either.*
>
> *So let's say you care about your customers and so you care about their data. The first thing you must guaranty is confidence. Your users must trust you when you say, "I have saved your data". They must trust you when you say, "Your data is not corrupted".*
>
> *So what is the feature I first expect?*
>
> *Don't mess up my database with invalid or corrupted data. Ensure*

that when my database says something is saved, it really is.

Code in SQL

Of course, this means that each time the coherence of my database is involved I do not rely on my framework or my Python code. I rely on SQL code.

I need my database to be able to handle code within itself — procedure, triggers, check_constraints — those are the most basic features I need from a database.

Flexible when I want, rigid when I ask

As a developer when first implementing a proof of concept or a MVC you cannot ask me to know perfectly how I will handle my data in the future. Some information that does not seem very relevant will be mandatory or something else I tough was mandatory is not after all.

So I need my database to be flexible enough to let me easily change what is mandatory and what is not.

This point is the main reason some developers fly to NoSQL databases. Because they see the schemaless *options as a way to not carefully specify their database schema.*

At first sight this can seem like a good idea. In fact, this is a terrible one. Because tomorrow you will need consistency and non-permissive schema. When it happens, you will be on your own, lost in a world of inconsistency, corrupted data and "eventually consistent" records.

I will not talk about writing consistency and relational checks in code because it reminds me of nightmares called race-conditions *and* Heisenbugs.

What I really expect from my RDBMS is to let me begin schemaless and after some time, let me specify mandatory fields, relation insurance and so on. If you think I'm asking too much, have a look at jsonb *or* hstore.

What makes you want to use PostgreSQL rather than something else in your Django projects? Are there any difficulties to be aware of when using

PostgreSQL?

> *Django lets you use a lot of different databases. You can use SQLite, MariaDB, PostgreSQL and some others. Of course, you can expect from some databases availability, consistency, isolation, and durability. This allows you to make decent applications. But there is always a time where you need more. Especially some database type that could match Python type. Think about list, dictionary, ranges, timestamp, timezone, date and datetime.*
>
> *All of this (and more) can be found in PostgreSQL. This is so true that there are now in Django some specific models fields (the Django representation of a column) to handle those great PostgreSQL fields.*
>
> *When it comes to choosing a database why someone wants to use something other than the most full-featured?*
>
> *But don't think I choose PostgreSQL only for performance, easiness of use and powerful features. It's also a really warm place to code with confidence.*
>
> *Because Django has a migration management system that can handle pure SQL I can write advanced SQL functions and triggers directly in my code. Those functions can use the most advanced features of PostgreSQL and stay right in front of me, in my Git, easily editable.*
>
> *In fact version after version, Django let you use your database more and more. You can now use SQL function like COALESCE, NOW, aggregation functions and more directly in your Django code. And those function you write are plain SQL.*
>
> *This also means that version after version your RDBMS choice is more and more important. Do you want to choose a tool that can do half the work you expect from it?*
>
> *Me neither.*

Django comes with an internal ORM that maps an object model to a relational table and allows it to handle "saving" objects and SQL query writing. Django also supports raw SQL. What is your general advice around using the ORM?

> *Well this is a tough question. Some will say ORM sucks. Some others says mixing SQL and Python code in your application is ugly.*

I think they are both right. Of course, an ORM limits you a lot. Of course writing SQL everytime you need to talk to your database is not sustainable in the long run.

When your queries are so simple you can express them with your ORM why not use it? It will generate a SQL query as good as anybody could write. It will hydrate a Django object you can use right away, in a breeze.

Think about:

```
MyModel.objects.get(id=1)
```

This is equivalent to:

```
select mymodel.id, mymodel.other_field, ...
  from mymodel
 where id=1;
```

Do you think you could write better SQL?

ORM can manage all of your SQL needs. There is also some advice to avoid the N+1 dilemma. The aggregation system relies on SQL and is fairly decent.

But if you don't pay attention, it will bite you hard.

The rule of thumb for me is to never forget what your ORM is meant for: translate SQL records into Python objects.

If you think it can handle anything more, like avoiding writing SQL, managing indexes etc... you are wrong.

The main Django ORM philosophy is to let you drive the car.

- *First always be able to translate your ORM query into the SQL counterpart, the following trick should help you with this*

```
MyModel.objects.filter(...).query.sql_with_params()
```

- *Create SQL functions and use them with the* `Func` *object*
- *Use manager methods with meticulously crafted raw sql and use those methods in your code.*

So yes, use your ORM. Not the one from Django. Yours !

What do you think of supporting several RDMS solutions in your applications?

Sorry but I have to admit that back in the days I believed in such a tale. Now as a grown-up I know two things. Santa and RDBMS agnosticism do not really exist.

What is true is that a framework like Django lets you choose a database and then stick with it.

The idea of using SQLite in development and PostgreSQL in production leads only to one thing: you will use the features of SQLite everywhere and you will not be able to use the PostgreSQL specific features.

The only way to be purely agnostic is to use only the features all the proposed RDMS provides. But think again. Do you want to drive your race car like a tractor?

Part IV

SQL Toolbox

In this chapter, we are going to add to our proficiency in writing SQL queries. The *structured query language* doesn't look like any other imperative, functional or even object-oriented programming language.

This chapter contains a long list of SQL techniques from the most basic *select* clause to advanced *lateral joins*, each time with practical examples working with a free database that you can install at home.

It is highly recommended that you follow along with a local instance of the database so that you can enter the queries from the book and play with them yourself. A key aspect of this part is that SQL queries arent' typically written in a text editor with hard thinking, instead they are interactively tried out in pieces and stitched together once the spelling is spot on.

The SQL writing process is mainly about discovery. In SQL you need to explain your problem, unlike in most programming languages where you need to focus on a solution you think is going to solve your problem. That's quite different and requires looking at your problem in another way and understanding it well enough to be able to express it in details in a single sentence.

Here's some good advice I received years and years ago, and it still applies to this day: when you're struggling to write a SQL query, first write down a single sentence —in your native language— that perfectly describes what you're trying to achieve. As soon as you can do that, then writing the SQL is going to be easier.

One of the very effective techniques in writing such a sentence is talking out loud, because apparently writing and speaking come from different parts of the brain. So it's the same as when debugging a complex program, as it helps a lot to talk about it with a colleague... or a rubber duck.

After having dealt with the basics of the language, where means basic really fundamentals, this chapter spends time on more advanced SQL concepts and PostgreSQL along with how you can benefit from them when writing your applications, making you a more effective developer.

10

Get Some Data

To be able to play with SQL queries, we first need some data. While it is possible to create a synthetic set of data and play with it, it is usually harder to think about abstract numbers that you know nothing about.

In this chapter, we are going to use the historical record of motor racing data, available publicly.

The database is available in a single download file for MySQL only. Once you have a local copy, we use pgloader to get the data set in PostgreSQL:

```
$ createdb f1db
$ pgloader mysql://root@localhost/f1db pgsql:///f1db
```

Now that we have a real data set, we can get into more details about the window function frames. To run the query as written in the following parts, you also need to tweak PostgreSQL *search_path* to include the *f1db* schema in the *f1db* database. Here's the SQL command you need for that:

```
ALTER DATABASE f1db SET search_path TO f1db, public;
```

When using the *Full Edition* or the *Enterprise Edition* of the book, the `appdev` database is already loaded with the dataset in the `f1db` schema.

11

Structured Query Language

SQL stands for *structured query language* and has been designed so that non-programmer would be able to use it for their reporting needs. Ignoring this clear attempt at getting Marketing people to stay away from the developer's desks, this explains why the language doesn't look like your normal programming language.

Apart from the aim to look like English sentences, the main aspect of the SQL language to notice and learn to benefit from is that it's a *declarative* programming language. This means that you get to *declare* or *state* the result you want to obtain, thus you need to think in term of the problem you want to solve.

This differs from most programming languages, where the developer's job is to transform his understanding of the solution into a step by step recipe for how exactly to obtain it, which means thinking in terms of the solution you decided would solve the problem at hand.

It is then quite fair to say that SQL is a very high-level programming language: even as a developer you don't need to come up with a detailed solution, rather your job is to understand the problem well enough so that you are able to translate it. After that, the RDBMS of your choice is going to figure out a plan then execute it, and hopefully return just the result set you wanted!

For some developers, not being in charge of every detail of the query plan is a source of frustration, and they prefer hiding SQL under another layer of technology that makes them feel like they are still in control.

Unfortunately, any extra layer on top of SQL is only there to produce SQL for

you, which means you have even less control over what plan is going to be executed.

In this section, we review important and basic parts of a SQL query. The goal is for you to be comfortable enough with writing SQL that you don't feel like you've lost control over the details of its execution plan, but instead your can rely on your RDBMS of choice for that. Of course, it's much easier to reach that level of trust when you use PostgreSQL, because it is fully open source, well documented, supports a very detailed *explain* command, and its code is very well commented, making it easy enough to read and review.

12

Queries, DML, DDL, TCL, DCL

SQL means *structured query language* and is composed of several areas, and each of them has a specific acronym and sub-language.

- *DML* stands for *data manipulation language* and it covers *insert*, *update* and *delete* statements, which are used to input data into the system.
- *DDL* stands for *data definition language* and it covers *create*, *alter* and *drop* statements, which are used to define on-disk data structures where to hold the data, and also their constraints and indexes — the things we refer to with the terms of *SQL objects*.
- *TCL* stands for *transaction control language* and includes *begin* and *commit* statements, and also *rollback*, *start transaction* and *set transaction* commands. It also includes the less well-known *savepoint*, *release savepoint*, and *rollback to savepoint* commands, and let's not forget about the two-phase commit protocol with *prepare commit*, *commit prepared* and *rollback prepared* commands.
- *DCL* stands for *data control language* and is covered with the statements *grant* and *revoke*.
- Next we have PostgreSQL maintenance commands such as *vacuum*, *analyze*, *cluster*.
- There further commands that are provided by PostgreSQL such as *prepare* and *execute*, *explain*, *listen* and *notify*, *lock* and *set*, and some more.

The *query* part of the language, which covers statements beginning with *select*, *table*, *values* and *with* keywords, is a tiny part of the available list of commands. It's also where the complexity lies and the part we are going to focus our efforts in this section.

13

Select, From, Where

Anatomy of a Select Statement

The simplest *select* statement in PostgreSQL is the following:

```
SELECT 1;
```

In other systems, the *from* clause is required and sometimes a dummy table with a single row is provided so that you can *select* from this table.

Projection (output): Select

The SQL *select* clause introduces the list of output columns. This is the list of data that we are going to send back to the client application, so it's quite important: the only reason the server is executing any query is to return a result set where each row presents the list of columns specified in the *select* clause. This is called a *projection*.

Adding a column to the *select* list might involve a lot of work, such as:

- Fetching data on-disk
- Possibly uncompressing data that is stored externally to the main table on-disk structure, and loading those uncompressed bytes into the memory of the database server
- Sending the data back over the network back to the client application.

Given that, it is usually frowned upon to use either the infamous *select star* notation or the classic *I don't know what I'm doing* behavior of some object relational mappers when they insist on always fully *hydrating* the application objects, just in case.

The following shortcut is nice to have in interactive mode only:

```
select * from races limit 1;
```

The actual standard syntax for *limit* is a little more complex:

```
select * from races fetch first 1 rows only;
```

It gives the following result:

```
-[ RECORD 1 ]----------------------------------------------------
raceid    | 1
year      | 2009
round     | 1
circuitid | 1
name      | Australian Grand Prix
date      | 2009-03-29
time      | 06:00:00
url       | http://en.wikipedia.org/wiki/2009_Australian_Grand_Prix
```

Note that rather than using this frowned upon notation, the SQL standard allows us to use this alternative, which is even more practical:

```
table races limit 1;
```

Of course, it gives the same result as the one above.

Select Star

There's another reason to refrain from using the *select star* notation in application's code: if you ever change the source relation definitions, then the same query now has a different result set data structure, and you might have to reflect that change in the application's in-memory data structures.

Let's take a very simple Java example, and I will only show the meat of it, filtering out the exception handling and resources disposal (we need to close the result set, the statement and the connection objects):

```
try {
  con = DriverManager.getConnection(url, user, password);
  st = con.createStatement();
  rs = st.executeQuery("SELECT * FROM races LIMIT 1;");

```

```
  if (rs.next()) {
      System.out.println(rs.getInt("raceid"));
      System.out.println(rs.getInt("year"));
      System.out.println(rs.getInt("round"));
      System.out.println(rs.getInt("circuitid"));
      System.out.println(rs.getString("name"));
      System.out.println(rs.getString("date"));
      System.out.println(rs.getString("time"));
      System.out.println(rs.getString("url"));
  }
} catch (SQLException ex) {
  // logger code
} finally {
  // closing code
}
```

We can use the file like this:

```
$ javac Select.java
$ java -cp .:path/to/postgresql-42.1.1.jar Select
1
2009
1
1
Australian Grand Prix
2009-03-29
06:00:00
http://en.wikipedia.org/wiki/2009_Australian_Grand_Prix
```

Even in this pretty quick example we can see that the code has to know the *races* table column list, each column name, and the data types. Of course, it's still possible to write the following code:

```
if (rs.next()) {
    for(int i=1; i<=8; i++)
        System.out.println(rs.getString(i));
}
```

But this case is only relevant when we have no processing at all to do over the data, and we still hard code the fact that the *races* table has eight column.

Now pretend we had an *extra* column in our schema definition at some point, and thus had the following line in our code to process it from the result set:

```
      System.out.println(rs.getString("extra"));
```

Once the column is no longer here (presumably following a production rollout of the schema change), then our code no longer runs:

```
Jun 29, 2017 1:17:41 PM Select main
SEVERE: The column name extra was not found in this ResultSet.
```

```
org.postgresql.util.PSQLException: The column name extra was not found in this ResultS
    at org.postgresql.jdbc.PgResultSet.findColumn(PgResultSet.java:2610)
    at org.postgresql.jdbc.PgResultSet.getString(PgResultSet.java:2484)
    at Select.main(Select.java:35)
```

That's because now our code is wrong, and code review can't help us here, because the query in both cases is a plain `select * ...`. We could have used the following code instead:

```
try {
    con = DriverManager.getConnection(url, user, password);
    st = con.createStatement();
    rs = st.executeQuery("SELECT name, date, url, extra FROM races LIMIT 1;");

    if (rs.next()) {
        System.out.println(" race: " + rs.getString("name"));
        System.out.println(" date: " + rs.getString("date"));
        System.out.println("  url: " + rs.getString("url"));
        System.out.println("extra: " + rs.getString("url"));
        System.out.println();
    }

} catch (SQLException ex) {
  // logger code
} finally {
  // closing code
}
```

Now it's quite clear that there's a direct mapping between the column names in the SQL query and what we fetch from the result set instance. We still don't know at review or compile time if the columns do currently exist in production, but at least the error message is crystal clear this time:

```
Jun 29, 2017 1:31:04 PM Select main
SEVERE: ERROR: column "extra" does not exist
  Position: 25
org.postgresql.util.PSQLException: ERROR: column "extra" does not exist
```

Again, when being explicit, the *diff* is pretty easy to review too:

```
@@ -21,18 +21,17 @@
 try {
     con = DriverManager.getConnection(url, user, password);
     st = con.createStatement();
-    rs = st.executeQuery("SELECT name, date, url, extra FROM races LIMIT 1;");
+    rs = st.executeQuery("SELECT name, date, url FROM races LIMIT 1;");

     if (rs.next()) {
         System.out.println(" race: " + rs.getString("name"));
         System.out.println(" date: " + rs.getString("date"));
```

```
11          System.out.println("  url: " + rs.getString("url"));
12  -       System.out.println("extra: " + rs.getString("extra"));
13          System.out.println();
14      }
```

To summarize, here's a review of my argument against *select star*:

- Using `select *` hides the intention of the code, while listing the columns explicitly in the code allows for declaring our thinking as a developer.
- It makes code changes easier to review when the column list is explicit in the code, and despite our previous example in Java using a string literal as a SQL query, it's even better of course when the query is found in a proper `.sql` file.
- It is not efficient to retrieve all the bytes each time even if you don't need them, some bytes are quite expensive to fetch on the server side thanks to the TOAST mechanism (The Oversized-Attribute Storage Technique), and then those bytes still need to find their way in the network and your application's memory.

The main point is about being specific about what your code is doing. It helps tremendously to never have to second guess what is happening, for example in cases of production debugging, performances analysis and optimization, onboarding of new team members, code review, and really just about anything that has to do with maintaining the code base.

Select Computed Values and Aliases

In the *SELECT* clause it is possible to return computed values and to rename columns. Here's an example of that:

```
1  select code,
2         format('%s %s', forename, surname) as fullname,
3         forename,
4         surname
5   from drivers;
```

And here are the first three drivers we get:

```
 code |    fullname     | forename | surname
======+=================+==========+==========
 HAM  | Lewis Hamilton  | Lewis    | Hamilton
 HEI  | Nick Heidfeld   | Nick     | Heidfeld
 ROS  | Nico Rosberg    | Nico     | Rosberg
(3 rows)
```

Here we are using the `format` PostgreSQL function, which mimics what is usually available in programming languages such as Python's *print* function or C's *printf*. The SQL standard gives us a concatenation operator named `||` and we could achieve the same result with a standard conforming query:

```
select code,
       forename || ' ' || surname as fullname,
       forename,
       surname
 from drivers;
```

In this book, we are going to focus on PostgreSQL rather than standard compliance, because PostgreSQL offers a lot of useful functions and gems that are nowhere to be found in the SQL standard, nor in most of the RDBMS competition.

The visibility of the *SELECT* alias is important to keep in mind. This is a topic for later in this chapter, when we learn about the *ORDER BY*, *GROUP BY*, *HAVING* and *WINDOW* clauses.

PostgreSQL Processing Functions

PostgreSQL embeds a very rich set of processing functions that can be used anywhere in the queries, even if most of them are more useful in the *SELECT* clause. Because I see a lot of code fetching only the raw data from the RDBMS and then doing all the processing in the application code, I want to show an example query processing calendar related information with PostgreSQL.

The next query is a showcase for *extract()* and *to_char()* functions, and it also uses the *CASE* construct. Read the documentation on date/time functions and operators for more details and functions on the same topic.

```
select date::date,
       extract('isodow' from date) as dow,
       to_char(date, 'dy') as day,
       extract('isoyear' from date) as "iso year",
       extract('week' from date) as week,
       extract('day' from
               (date + interval '2 month - 1 day')
              )
        as feb,
       extract('year' from date) as year,
       extract('day' from
               (date + interval '2 month - 1 day')
              ) = 29
       as leap
```

```
  from generate_series(date '2000-01-01',
                       date '2010-01-01',
                       interval '1 year')
       as t(date);
```

The *generate_series()* function returns a set of items, here all the dates of the first day of the years from the 2000s. For each of them we then compute the day of the week of this first day of the year, both in numerical and textual forms, and then the year number from the date, as defined by the ISO standard, and the week number from the ISO year, then the last day of February and a Boolean which is true for leap years.

Here's an extract from the PostgreSQL documentation about ISO years and week numbers:

> By definition, ISO weeks start on Mondays and the first week of a year contains January 4 of that year. In other words, the first Thursday of a year is in week 1 of that year.

So here's what we get:

```
    date    | dow | day | iso year | week | feb | year | leap
════════════╪═════╪═════╪══════════╪══════╪═════╪══════╪══════
 2000-01-01 |   6 | sat |     1999 |   52 |  29 | 2000 | t
 2001-01-01 |   1 | mon |     2001 |    1 |  28 | 2001 | f
 2002-01-01 |   2 | tue |     2002 |    1 |  28 | 2002 | f
 2003-01-01 |   3 | wed |     2003 |    1 |  28 | 2003 | f
 2004-01-01 |   4 | thu |     2004 |    1 |  29 | 2004 | t
 2005-01-01 |   6 | sat |     2004 |   53 |  28 | 2005 | f
 2006-01-01 |   7 | sun |     2005 |   52 |  28 | 2006 | f
 2007-01-01 |   1 | mon |     2007 |    1 |  28 | 2007 | f
 2008-01-01 |   2 | tue |     2008 |    1 |  29 | 2008 | t
 2009-01-01 |   4 | thu |     2009 |    1 |  28 | 2009 | f
 2010-01-01 |   5 | fri |     2009 |   53 |  28 | 2010 | f
(11 rows)
```

It is very easy to do complex computations on dates in PostgreSQL, and that includes taking care of time zones too. Don't even think about coding such processing yourself, as it's full of oddities.

Data sources: From

The SQL *from* clause introduces the data sources used in the query, and supports declaring how those different sources relate to each other. In the most basic form,

our query is reading a data set from a single table:

```
select code, driverref, forename, surname
  from drivers;
```

In this query *drivers* is the name of a table, so it's pretty easy to understand what's going on.

Now say we want to get the all-time top three drivers in terms of how many times they won a race. This time we need information from the *drivers* table and from the *results* table, which along with other information contains a *position* column. The winner's position is 1.

To find the all-time top three drivers, we fetch how many times each driver had *position* = *1* in the results table:

```
  select code, forename, surname,
         count(*) as wins
    from      drivers
         join results using(driverid)
   where position = 1
group by driverid
order by wins desc
limit 3;
```

This time the result is more interesting. let's have a look at our all time top three winners in the Formula One database:

```
 code | forename |  surname   | wins
══════╪══════════╪════════════╪══════
 MSC  | Michael  | Schumacher |   91
 HAM  | Lewis    | Hamilton   |   56
 ¤    | Alain    | Prost      |   51
(3 rows)
```

The query uses an *inner join* in between the *drivers* and the *results* table. In both those tables, there is a *driverid* column that we can use as a lookup reference to associate data in between the two tables.

Understanding Joins

I could spend time here and fill in the book with detailed explanations of every kind of *join* operation: *inner join*, *left* and *right outer joins*, *cross joins*, *full outer join*, *lateral join* and more. It just so happens that the PostgreSQL documentation covering the FROM clause does that very well, so please read it carefully

along with this book so that we can instead focus on more interesting and advanced examples.

Now that we know how to easily fetch the winner of a race, it is possible to also to display all the races from a quarter with their winner:

```
\set beginning '2017-04-01'
\set months 3

select date, name, drivers.surname as winner
  from races
       left join results
              on results.raceid = races.raceid
             and results.position = 1
       left join drivers using(driverid)
 where date >= date :'beginning'
   and date <  date :'beginning'
             + :months * interval '1 month';
```

And we get the following result, where we lack data for the most recent race but still display it:

```
    date    |         name          |  winner
════════════╪═══════════════════════╪══════════
 2017-04-09 | Chinese Grand Prix    | Hamilton
 2017-04-16 | Bahrain Grand Prix    | Vettel
 2017-04-30 | Russian Grand Prix    | Bottas
 2017-05-14 | Spanish Grand Prix    | Hamilton
 2017-05-28 | Monaco Grand Prix     | Vettel
 2017-06-11 | Canadian Grand Prix   | Hamilton
 2017-06-25 | Azerbaijan Grand Prix | ¤
(7 rows)
```

The reason why we are using a *left join* this time is so that we keep every race from the quarter's and display extra information only when we have it. *Left join* semantics are to keep the whole result set of the table lexically on the left of the operator, and to fill-in the columns for the table on the right of the *left join* operator when some data is found that matches the *join condition*, otherwise using NULL as the column's value.

In the example above, the *winner* information comes from the *results* table, which is lexically found at the right of the *left join* operator. The *Azerbaijan Grand Prix* has no results in the local copy of the *fidb* database used locally, so the *winner* information doesn't exists and the SQL query returns a *NULL* entry.

You can also see that the *results.position = 1* restriction has been moved directly

into the join condition, rather than being kept in the where clause. Should the condition be in the *where* clause, it would filter out races from which we don't have a result yet, and we are still interested in those.

Another way to write the query would be using an explicit subquery to build an intermediate results table containing only the winners, and then join against that:

```
select date, name, drivers.surname as winner
  from races
       left join
           ( select raceid, driverid
               from results
              where position = 1
           )
           as winners using(raceid)
       left join drivers using(driverid)
 where date >= date :'beginning'
   and date <  date :'beginning'
              + :months * interval '1 month';
```

PostgreSQL is smart enough to actually implement both SQL queries the same way, but it might be thanks to the data set being very small in the fıdb database.

Restrictions: Where

In most of the queries we saw, we already had some *where* clause. This clause acts as a filter for the query: when the filter evaluates to true then we keep the row in the result set and when the filter evaluates to false we skip that row.

Real-world SQL may have quite complex *where* clauses to deal with, and it is allowed to use *CASE* and other logic statements. That said, we usually try to keep the *where* clauses as simple as possible for PostgreSQL in order to be able to use our indexes to solve the data filtering expressions of our queries.

Some simple rules to remember here:

- In a *where* clause we can combine filters, and generally we combine them with the *and* operator, which allows short-circuit evaluations because as soon as one of the *anded* conditions evaluates to false, we know for sure we can skip the current row.
- *Where* also supports the *or* operator, which is more complex to optimize for, in particular with respect to indexes.

- We have support for both *not* and *not in*, which are completely different beasts.

  Be careful about *not in* semantics with *NULL*: the following query returns no rows...

```
select x
  from generate_series(1, 100) as t(x)
 where x not in (1, 2, 3, null);
```

Finally, as is the case just about anywhere else in a SQL query, it is possible in the *where* clause to use a subquery, and that's quite common to use when implementing the *anti-join* pattern thanks to the special feature *not exists*.

An *anti-join* is meant to keep only the rows that fail a test. If we want to list the drivers that where unlucky enough to not finish a single race in which they participated, then we can filter out those who did finish. We know that a driver finished because their *position* is filled in the *results* table: it *is not null*.

If we translate the previous sentence into the SQL language, here's what we have:

```
\set season 'date ''1978-01-01'''

  select forename,
         surname,
         constructors.name as constructor,
         count(*) as races,
         count(distinct status) as reasons

    from drivers
         join results using(driverid)
         join races using(raceid)
         join status using(statusid)
         join constructors using(constructorid)

   where date >= :season
     and date <  :season + interval '1 year'
     and not exists
         (
           select 1
             from results r
            where position is not null
              and r.driverid = drivers.driverid
              and r.resultid = results.resultid
         )
group by constructors.name, driverid
order by count(*) desc;
```

The interesting part of this query lies in the *where not exists* clause, which might

look somewhat special on a first read: what is that *select 1* doing there?

Remember that a *where* clause is a filter. The *not exists* clause is filtering based on rows that are returned by the subquery. To pass the filter, just return anything, PostgreSQL will not even look at what is selected in the subquery, it will only take into account the fact that a row was returned.

It also means that the join condition in between the main query and the *not exists* subquery is done in the *where* clause of the subquery, where you can reference the outer query as we did in *r.driverid = drivers.driverid and r.resultid = results.resultid*.

It turns out that 1978 was not a very good season based on the number of drivers who never got the chance to finish a race so we are going to show only the ten first results of the query:

```
1  │   forename   │  surname  │ constructor │ races │ reasons
2  ╞══════════════╪═══════════╪═════════════╪═══════╪═════════
3  │ Arturo       │ Merzario  │ Merzario    │    16 │       8
4  │ Hans-Joachim │ Stuck     │ Shadow      │    12 │       6
5  │ Rupert       │ Keegan    │ Surtees     │    12 │       6
6  │ Hector       │ Rebaque   │ Team Lotus  │    12 │       7
7  │ Jean-Pierre  │ Jabouille │ Renault     │    10 │       4
8  │ Clay         │ Regazzoni │ Shadow      │    10 │       5
9  │ James        │ Hunt      │ McLaren     │    10 │       6
10 │ Brett        │ Lunger    │ McLaren     │     9 │       5
11 │ Niki         │ Lauda     │ Brabham     │     9 │       4
12 │ Rolf         │ Stommelen │ Arrows      │     8 │       5
13 │(10 rows)
```

The reasons not to finish a race might be *did not qualify* or *gearbox*, or any one of the 133 different statuses found in the fidb database.

14

Order By, Limit, No Offset

Ordering with Order By

The SQL *ORDER BY* clause is pretty well-known because SQL doesn't guarantee any ordering of the result set of any query except when you use the *order by* clause.

In its simplest form the *order by* works with one column or several columns that are part of our data model, and in some cases, it might even allow PostgreSQL to return the data in the right order by following an existing index.

```
  select year, url
    from seasons
order by year desc
   limit 3;
```

This gives an expected and not that interesting result set:

```
 year │                          url
══════╪═══════════════════════════════════════════════════
 2017 │ https://en.wikipedia.org/wiki/2017_Formula_One_season
 2016 │ https://en.wikipedia.org/wiki/2016_Formula_One_season
 2015 │ http://en.wikipedia.org/wiki/2015_Formula_One_season
(3 rows)
```

What is more interesting about it is the *explain plan* of the query, where we see PostgreSQL follows the primary key index of the table in a backward direction in order to return our three most recent entries. We obtain the plan with the following query:

```
 explain (costs off)
  select year, url
    from seasons
order by year desc
   limit 3;
```

Well, this one is pretty easy to read and understand:

```
                          QUERY PLAN
═══════════════════════════════════════════════════════════
 Limit
   ->  Index Scan Backward using idx_57708_primary on seasons
(2 rows)
```

The *order by* clause can also refer to query aliases and computed values, as we noted earlier in previous queries. More complex use cases are possible: in PostgreSQL, the clause also accepts complex expression and subqueries.

As an example of a complex expression, we may use the *CASE* conditional in order to control the ordering of a race's results over the status information. Say that we order the results by position then number of laps and then by status with a special rule: the *Power Unit* failure condition is considered first, and only then the other ones.

Yes, this rule makes no sense at all, it's totally arbitrary. It could be that you're working with a constructor and he's making a study about some failing hardware and that's part of the inquiry.

```
select drivers.code, drivers.surname,
       position,
       laps,
       status
  from results
       join drivers using(driverid)
       join status using(statusid)
 where raceid = 972
order by position nulls last,
         laps desc,
         case when status = 'Power Unit'
              then 1
              else 2
          end;
```

We can almost feel we've seen the race with that result set:

```
 code │  surname   │ position │ laps │   status
══════╪════════════╪══════════╪══════╪═══════════
 BOT  │ Bottas     │        1 │   52 │ Finished
 VET  │ Vettel     │        2 │   52 │ Finished
```

```
 RAI  | Räikkönen  |        3 |   52 | Finished
 HAM  | Hamilton   |        4 |   52 | Finished
 VER  | Verstappen |        5 |   52 | Finished
 PER  | Pérez      |        6 |   52 | Finished
 OCO  | Ocon       |        7 |   52 | Finished
 HUL  | Hülkenberg |        8 |   52 | Finished
 MAS  | Massa      |        9 |   51 | +1 Lap
 SAI  | Sainz      |       10 |   51 | +1 Lap
 STR  | Stroll     |       11 |   51 | +1 Lap
 KVY  | Kvyat      |       12 |   51 | +1 Lap
 MAG  | Magnussen  |       13 |   51 | +1 Lap
 VAN  | Vandoorne  |       14 |   51 | +1 Lap
 ERI  | Ericsson   |       15 |   51 | +1 Lap
 WEH  | Wehrlein   |       16 |   50 | +2 Laps
 RIC  | Ricciardo  |        ¤ |    5 | Brakes
 ALO  | Alonso     |        ¤ |    0 | Power Unit
 PAL  | Palmer     |        ¤ |    0 | Collision
 GRO  | Grosjean   |        ¤ |    0 | Collision
(20 rows)
```

kNN Ordering and GiST indexes

Another use case for *order by* is to implement *k nearest neighbours*. The *kNN* searches are pretty well covered in the literature and is easy to implement in PostgreSQL. Let's find out the ten nearest circuits to Paris, France, which is at longitude 2.349014 and latitude 48.864716. That's a kNN search with k = 10:

```
  select name, location, country
    from circuits
order by point(lng,lat) <-> point(2.349014, 48.864716)
   limit 10;
```

Along with the following list of circuits spread around in France, we also get some tracks from Belgium and the United Kingdom:

```
            name                |     location      | country
================================+===================+=========
 Rouen-Les-Essarts              | Rouen             | France
 Reims-Gueux                    | Reims             | France
 Circuit de Nevers Magny-Cours  | Magny Cours       | France
 Le Mans                        | Le Mans           | France
 Nivelles-Baulers               | Brussels          | Belgium
 Dijon-Prenois                  | Dijon             | France
 Charade Circuit                | Clermont-Ferrand  | France
 Brands Hatch                   | Kent              | UK
```

```
 Zolder                          | Heusden-Zolder   | Belgium
 Circuit de Spa-Francorchamps    | Spa              | Belgium
(10 rows)
```

The *point* datatype is a very useful PostgreSQL addition. In our query here, the points have been computed from the raw data in the database. For a proper PostgreSQL experience, we can have a location column of point type in our circuits table and index it using GiST:

```
begin;

alter table f1db.circuits add column position point;
update f1db.circuits set position = point(lng,lat);
create index on f1db.circuits using gist(position);

commit;
```

Now the previous query can be written using the new column. We get the same result set, of course: indexes are not allowed to change the result of a query they apply to... under no circumstances. When they do, we call that a bug, or maybe it is due to data corruption. Anyway, let's have a look at the query plan now that we have a *GiST* index defined:

```
explain (costs off, buffers, analyze)
  select name, location, country
    from circuits
order by position <-> point(2.349014, 48.864716)
   limit 10;
```

The *(costs off)* option is used here mainly so that the output of the command fits in the book's page format, so try without the option at home:

```
                              QUERY PLAN
═══════════════════════════════════════════════════════════════════════
 Limit (actual time=0.039..0.061 rows=10 loops=1)
   Buffers: shared hit=7
   ->  Index Scan using circuits_position_idx on circuits
        (actual time=0.038..0.058 rows=10 loops=1)
         Order By: ("position" <-> '(2.349014,48.864716)'::point)
         Buffers: shared hit=7
 Planning time: 0.129 ms
 Execution time: 0.105 ms
(7 rows)
```

We can see that PostgreSQL is happy to be using our GiST index and even goes so far as to implement our whole kNN search query all within the index. For reference the query plan of the previous spelling of the query, the dynamic expression *point(lng,lat)* looks like this:

```
explain (costs off, buffers, analyze)
  select name, location, country
    from circuits
order by point(lng,lat) <-> point(2.349014, 48.864716)
   limit 10;
```

And here's the query plan when not using the index:

```
                              QUERY PLAN
═══════════════════════════════════════════════════════════════════════
 Limit (actual time=0.246..0.256 rows=10 loops=1)
   Buffers: shared hit=5
   ->  Sort (actual time=0.244..0.249 rows=10 loops=1)
         Sort Key: ((point(lng, lat) <-> '(2.349014,48.864716)'::point))
         Sort Method: top-N heapsort  Memory: 25kB
         Buffers: shared hit=5
         ->  Seq Scan on circuits
               (actual time=0.024..0.133 rows=73 loops=1)
                Buffers: shared hit=5
 Planning time: 0.189 ms
 Execution time: 0.344 ms
(10 rows)
```

By default, the distance operator <-> is defined only for geometric data types in PostgreSQL. Some extensions such as pg_trgm add to that list so that you may benefit from a kNN index lookup in other situations, such as in queries using the *like* operator, or even the regular expression operator ~. You'll find more on regular expressions in PostgreSQL later in this book.

Top-N sorts: Limit

It would be pretty interesting to get the list of the top three drivers in terms of races won, by decade. It is possible to do so thanks to advanced PostgreSQL date functions manipulation together with implementation of lateral joins.

The following query is a classic top-N implementation. It reports for each decade the top three drivers in terms of race wins. It is both a classic top-N because it is done thanks to a *lateral* subquery, and at the same time it's not so classic because we are joining against computed data. The decade information is not part of our data model, and we need to extract it from the *races.date* column.

```
with decades as
(
   select extract('year' from date_trunc('decade', date)) as decade
     from races
 group by decade
```

```
)
select decade,
       rank() over(partition by decade
                   order by wins desc)
       as rank,
       forename, surname, wins

  from decades
       left join lateral
       (
          select code, forename, surname, count(*) as wins
            from drivers

                 join results
                   on results.driverid = drivers.driverid
                  and results.position = 1

                 join races using(raceid)

           where   extract('year' from date_trunc('decade', races.date))
                 = decades.decade

        group by decades.decade, drivers.driverid
        order by wins desc
           limit 3
       )
       as winners on true

order by decade asc, wins desc;
```

The query extracts the decade first, in a *common table expression* introduced with the *with* keyword. This *CTE* is then reused as a data source in the *from* clause. The *from* clause is about relations, which might be hosting a dynamically computed dataset, as is the case in this example.

Once we have our list of decades from the dataset, we can fetch for each decade the list of the top three winners for each decade from the *results* table. The best way to do that in SQL is using a *lateral* join. This form of join allows one to write a subquery that runs in a loop over a data set. Here we loop over the decades and for each decade our *lateral subquery* finds the top three winners.

Focusing now on the *winners* subquery, we want to *count* how many times a driver made it to the first position in a race. As we are only interested in winning results, the query pushes that restriction in the *join condition* of the *left join results* part. The subquery should also only count victories that happened in the current decade from our loop, and that's implemented in the *where* clause, because that's how *lateral* subqueries work. Another interesting implication of

using a *left join lateral subquery* is how the join clause is then written: *on true*. That's because we inject the join condition right into the subquery as a where clause. This trick allows us to only see the results from the current decade in the subquery, which then uses a *limit* clause on top of the *order by wins desc* to report the top three with the most wins.

And here's the result of our query:

```
 decade | rank | forename  |  surname   | wins
════════╪══════╪═══════════╪════════════╪══════
   1950 |    1 | Juan      | Fangio     |   24
   1950 |    2 | Alberto   | Ascari     |   13
   1950 |    3 | Stirling  | Moss       |   12
   1960 |    1 | Jim       | Clark      |   25
   1960 |    2 | Graham    | Hill       |   14
   1960 |    3 | Jack      | Brabham    |   11
   1970 |    1 | Niki      | Lauda      |   17
   1970 |    2 | Jackie    | Stewart    |   16
   1970 |    3 | Emerson   | Fittipaldi |   14
   1980 |    1 | Alain     | Prost      |   39
   1980 |    2 | Nelson    | Piquet     |   20
   1980 |    2 | Ayrton    | Senna      |   20
   1990 |    1 | Michael   | Schumacher |   35
   1990 |    2 | Damon     | Hill       |   22
   1990 |    3 | Ayrton    | Senna      |   21
   2000 |    1 | Michael   | Schumacher |   56
   2000 |    2 | Fernando  | Alonso     |   21
   2000 |    3 | Kimi      | Räikkönen  |   18
   2010 |    1 | Lewis     | Hamilton   |   45
   2010 |    2 | Sebastian | Vettel     |   40
   2010 |    3 | Nico      | Rosberg    |   23
(21 rows)
```

No Offset, and how to implement pagination

The SQL standard offers a *fetch* command instead of the *limit* and *offset* variant that we have in PostgreSQL. In any case, using the *offset* clause is very bad for your query performances, so we advise against it:

Please take the time to read Markus Winand's Paging Through Results, as I won't explain it better than he does. Also, never use *offset* again!

As easy as it is to task you to read another article online, and as good as it is, it still seems fair to give you the main take away in this book's pages. The *offset* clause

Figure 14.1: No Offset

is going to cause your SQL query plan to read all the result anyway and then discard most of it until reaching the *offset* count. When paging through lots of results, it's less and less efficient with each additional page you fetch that way.

The proper way to implement pagination is to use index lookups, and if you have multiple columns in your ordering clause, you can do that with the *row()* construct.

To show an example of the method, we are going to paginate through the *laptimes* table, which contains every lap time for every driver in any race. For the raceid 972 that we were having a look at earlier, that's a result with 828 lines. Of course, we're going to need to paginate through it.

Here's how to do it properly, given pages of three rows at a time, to save space in this book for more interesting text. The first query is as expected:

```
    select lap, drivers.code, position,
           milliseconds * interval '1ms' as laptime
      from laptimes
           join drivers using(driverid)
     where raceid = 972
  order by lap, position
fetch first 3 rows only;
```

We are using the SQL standard spelling of the *limit* clause here, and we get the first page of lap timings for the race:

```
 lap | code | position |       laptime
═════╪══════╪══════════╪═══════════════════
   1 | BOT  |        1 | @ 2 mins 5.192 secs
   1 | VET  |        2 | @ 2 mins 7.101 secs
   1 | RAI  |        3 | @ 2 mins 10.53 secs
(3 rows)
```

The result set is important because your application needs to make an effort here and remember that it did show you the results up until *lap* = *1* and *position* = *3*.

We are going to use that so that our next query shows the next page of results:

```
     select lap, drivers.code, position,
            milliseconds * interval '1ms' as laptime
       from laptimes
            join drivers using(driverid)
      where raceid = 972
        and row(lap, position) > (1, 3)
   order by lap, position
fetch first 3 rows only;
```

And here's our second page of query results. After a first page finishing at lap 1, position 3 we are happy to find out a new page beginning at lap 1, position 4:

```
 lap | code | position |       laptime
═════╪══════╪══════════╪═══════════════════
   1 | HAM  |        4 | @ 2 mins 11.18 secs
   1 | VER  |        5 | @ 2 mins 12.202 secs
   1 | MAS  |        6 | @ 2 mins 13.501 secs
(3 rows)
```

So please, never use *offset* again if you care at all about your query time!

15

Group By, Having, With, Union All

Now that we have some of the basics of SQL queries, we can move on to more advanced topics. Up to now, queries would return as many rows as we select thanks to the *where* filtering. This filter applies against a data set that is produced by the *from* clause and its *joins* in between relations.

The *outer* joins might produce more rows than you have in your reference data set, in particular, *cross join* is a Cartesian product.

In this section, we'll have a look at aggregates. They work by computing a digest value for several input rows at a time. With aggregates, we can return a summary containing many fewer rows than passed the *where* filter.

Aggregates (aka Map/Reduce): Group By

The *group by* clause introduces aggregates in SQL, and allows implementing much the same thing as *map/reduce* in other systems: map your data into different groups, and in each group reduce the data set to a single value.

As a first example we can count how many races have been run in each decade:

```
select extract('year'
               from
               date_trunc('decade', date))
       as decade,
       count(*)
  from races
```

```
group by decade
order by decade;
```

PostgreSQL offers a rich set of date and times functions:

```
 decade | count
════════╪═══════
   1950 |    84
   1960 |   100
   1970 |   144
   1980 |   156
   1990 |   162
   2000 |   174
   2010 |   156
(7 rows)
```

The difference between each decade is easy to compute thanks to *window function*, seen later in this chapter. Let's have a preview:

```
with races_per_decade
as (
      select extract('year'
                     from
                     date_trunc('decade', date))
             as decade,
             count(*) as nbraces
        from races
      group by decade
      order by decade
   )
select decade, nbraces,
       case
         when lag(nbraces, 1)
              over(order by decade) is null
         then ''

         when nbraces - lag(nbraces, 1)
                        over(order by decade)
              < 0
         then format('-%3s',
                lag(nbraces, 1)
               over(order by decade)
               - nbraces)

         else format('+%3s',
                nbraces
              - lag(nbraces, 1)
               over(order by decade))

        end as evolution
  from races_per_decade;
```

We use a pretty complex *CASE* statement to elaborate on the exact output we want from the query. Other than that it's using the *lag() over(order by decade)* expression that allows seeing the previous row, and moreover allows us to compute the difference in between the current row and the previous one.

Here's what we get from the previous query:

```
 decade | nbraces | evolution
════════╪═════════╪═══════════
   1950 |      84 |
   1960 |     100 | + 16
   1970 |     144 | + 44
   1980 |     156 | + 12
   1990 |     162 |  + 6
   2000 |     174 | + 12
   2010 |     156 | - 18
(7 rows)
```

Now, we can also prepare the data set in a separate query that is run first, called a *common table expression* and introduced by the *with* clause. We will expand on that idea in the upcoming pages.

PostgreSQL comes with the usual aggregates you would expect such as *sum*, *count*, and *avg*, and also with some more interesting ones such as *bool_and*. As its name suggests the *bool_and* aggregate starts true and remains true only if every row it sees evaluates to true.

With that aggregate, it's then possible to search for all drivers who failed to finish any single race they participated in over their whole career:

```
with counts as
 (
   select driverid, forename, surname,
          count(*) as races,
          bool_and(position is null) as never_finished
     from drivers
          join results using(driverid)
          join races using(raceid)
 group by driverid
 )
   select driverid, forename, surname, races
     from counts
    where never_finished
 order by races desc;
```

Well, it turns out that we have a great number of cases in which it happens. The previous query gives us 202 drivers who never finished a single race they took part

in, 117 of them had only participated in a single race that said.

Not picking on anyone in particular, we can find out if some seasons were less lucky than others on that basis and search for drivers who didn't finish a single race they participated into, per season:

```
with counts as
 (
   select date_trunc('year', date) as year,
          count(*) filter(where position is null) as outs,
          bool_and(position is null) as never_finished
     from drivers
          join results using(driverid)
          join races using(raceid)
 group by date_trunc('year', date), driverid
 )
   select extract(year from year) as season,
          sum(outs) as "#times any driver didn't finish a race"
     from counts
    where never_finished
 group by season
 order by sum(outs) desc
    limit 5;
```

In this query, you can see the aggregate *filter(where ...)* syntax that allows us to update our computation only for those rows that pass the filter. Here we choose to count all race results where the position is null, which means the driver didn't make it to the finish line for some reason...

```
 season | #times any driver didn't finish a race
════════╪═════════════════════════════════════════
   1989 │                                    139
   1953 │                                     51
   1955 │                                     48
   1990 │                                     48
   1956 │                                     46
(5 rows)
```

It turns out that overall, 1989 was a pretty bad season.

Aggregates Without a Group By

It is possible to compute aggregates over a data set without using the *group by* clause in SQL. What it then means is that we are operating over a single group that contains the whole result set:

```
select count(*)
  from races;
```

This very simple query computes the count of all the races. It has built an implicit group of rows, containing everything.

Restrict Selected Groups: Having

Are you curious about the reasons why those drivers couldn't make it to the end of the race? I am too, so let's inquire about that!

```
\set season 'date ''1978-01-01'''

  select status, count(*)
    from results
         join races using(raceid)
         join status using(statusid)
   where date >= :season
     and date <  :season + interval '1 year'
     and position is null
group by status
  having count(*) >= 10
order by count(*) desc;
```

The query introduces the *having* clause. Its purpose is to filter the result set to only those groups that meet the *having* filtering condition, much as the *where* clause works for the individual rows selected for the result set.

Note that to avoid any ambiguity, the *having* clause is not allowed to reference *select* output aliases.

```
       status        | count
═════════════════════╪═══════
 Did not qualify     |    55
 Accident            |    46
 Engine              |    37
 Did not prequalify  |    25
 Gearbox             |    13
 Spun off            |    12
 Transmission        |    12
(7 rows)
```

We can see that drivers mostly do not finish a race because they didn't qualify to take part in it. Another quite common reason for not finishing is that the driver had an accident.

Grouping Sets

A restriction with classic aggregates is that you can only run them through a single group definition at a time. In some cases, you want to be able to compute aggregates for several groups in parallel. For those cases, SQL provides the *grouping sets* feature.

In the *Formula One* competition, points are given to drivers and then used to compute both the driver's champion and the constructor's champion points. Can we compute those two sums over the same points in a single query? Yes, of course, we can:

```
\set season 'date ''1978-01-01'''

    select drivers.surname as driver,
           constructors.name as constructor,
           sum(points) as points

      from results
           join races using(raceid)
           join drivers using(driverid)
           join constructors using(constructorid)

   where date >= :season
     and date <  :season + interval '1 year'

  group by grouping sets((drivers.surname),
                         (constructors.name))
    having sum(points) > 20

  order by constructors.name is not null,
           drivers.surname is not null,
           points desc;
```

And we get the following result:

```
  driver   │ constructor │ points
═══════════╪═════════════╪════════
 Andretti  │ ¤           │     64
 Peterson  │ ¤           │     51
 Reutemann │ ¤           │     48
 Lauda     │ ¤           │     44
 Depailler │ ¤           │     34
 Watson    │ ¤           │     25
 Scheckter │ ¤           │     24
 ¤         │ Team Lotus  │    116
 ¤         │ Brabham     │     69
```

```
 ¤         | Ferrari    |    65
 ¤         | Tyrrell    |    41
 ¤         | Wolf       |    24
(12 rows)
```

We see that we get *null* entries for drivers when the aggregate has been computed for a constructor's group and *null* entries for constructors when the aggregate has been computed for a driver's group.

Two other kinds of *grouping sets* are included in order to simplify writing queries. They are only syntactic sugarcoating on top of the previous capabilities.

The *rollup* clause generates permutations for each column of the *grouping sets*, one after the other. That's useful mainly for hierarchical data sets, and it is still useful in our Formula One world of champions. In the 80s Prost and Senna were all the rage, so let's dive into their results and points:

```
    select drivers.surname as driver,
           constructors.name as constructor,
           sum(points) as points

      from results
           join races using(raceid)
           join drivers using(driverid)
           join constructors using(constructorid)

     where drivers.surname in ('Prost', 'Senna')

  group by rollup(drivers.surname, constructors.name);
```

Given this query, in a single round-trip we fetch the cumulative points for Prost for each of the constructor's championship he raced for, so a total combined 798.5 points where the constructor is null. Then we do the same thing for Senna of course. And finally, the last line is the total amount of points for everybody involved in the result set.

```
 driver | constructor | points
════════╪═════════════╪════════
 Prost  | Ferrari     |    107
 Prost  | McLaren     |  458.5
 Prost  | Renault     |    134
 Prost  | Williams    |     99
 Prost  | ¤           |  798.5
 Senna  | HRT         |      0
 Senna  | McLaren     |    451
 Senna  | Renault     |      2
 Senna  | Team Lotus  |    150
```

```
 Senna   | Toleman      |     13
 Senna   | Williams     |     31
 Senna   | ¤            |    647
 ¤       | ¤            | 1445.5
(13 rows)
```

Another kind of *grouping sets* clause shortcut is named *cube*, which extends to all permutations available, including partial ones:

```
    select drivers.surname as driver,
           constructors.name as constructor,
           sum(points) as points

      from results
           join races using(raceid)
           join drivers using(driverid)
           join constructors using(constructorid)

     where drivers.surname in ('Prost', 'Senna')

  group by cube(drivers.surname, constructors.name);
```

Thanks to the cube here we can see both the total amount of points racked up by to those exceptional drivers over their entire careers. We have each driver's points by constructor, and when constructor is *NULL* we have the total amount of points for the driver. That's 798.5 points for Prost and 647 for Senna.

Also in the same query, we can see the points per constructor, independent of the driver, as both Prost and Senna raced for McLaren, Renault, and Williams at different times. And for two seasons, Prost and Senna both raced for McLaren, too.

```
 driver | constructor | points
════════╪═════════════╪════════
 Prost  | Ferrari     |    107
 Prost  | McLaren     |  458.5
 Prost  | Renault     |    134
 Prost  | Williams    |     99
 Prost  | ¤           |  798.5
 Senna  | HRT         |      0
 Senna  | McLaren     |    451
 Senna  | Renault     |      2
 Senna  | Team Lotus  |    150
 Senna  | Toleman     |     13
 Senna  | Williams    |     31
 Senna  | ¤           |    647
 ¤      | ¤           | 1445.5
 ¤      | Ferrari     |    107
```

```
 ¤       | HRT          |      0
 ¤       | McLaren      |  909.5
 ¤       | Renault      |    136
 ¤       | Team Lotus   |    150
 ¤       | Toleman      |     13
 ¤       | Williams     |    130
(20 rows)
```

Common Table Expressions: With

Earlier we saw many drivers who didn't finish the race because of accidents, and that was even the second reason listed just after *did not qualify*. This brings into question the level of danger in those Formula One races. How frequent is an accident in a Formula One competition? First we can have a look at the most dangerous seasons in terms of accidents.

```
  select extract(year from races.date) as season,
         count(*)
           filter(where status = 'Accident') as accidents

    from results
         join status using(statusid)
         join races using(raceid)

group by season
order by accidents desc
   limit 5;
```

So the five seasons with the most accidents in the history of Formula One are:

```
 season | accidents
════════╪═══════════
   1977 |        60
   1975 |        54
   1978 |        48
   1976 |        48
   1985 |        36
(5 rows)
```

It seems the most dangerous seasons of all time are clustered at the end of the 70s and the beginning of the 80s, so we are going to zoom in on this period with the following console friendly histogram query:

```
with accidents as
 (
    select extract(year from races.date) as season,
```

```
           count(*) as participants,
           count(*) filter(where status = 'Accident') as accidents
      from results
           join status using(statusid)
           join races using(raceid)
  group by season
 )
  select season,
         round(100.0 * accidents / participants, 2) as pct,
         repeat(text '■',
                ceil(100*accidents/participants)::int
               )
         as bar
    from accidents
   where season between 1974 and 1990
order by season;
```

Common table expression is the full name of the *with* clause that you see in effect in the query. It allows us to run a subquery as a prologue, and then refer to its result set like any other relation in the *from* clause of the main query. In our case, you can see that the main query is doing *from accidents*, and the *CTE* has been given that name.

In the *accidents* CTE we compute basic information such as how many participants we had overall in all the races of each season (we know this is the number of lines in the result table for the races that happened in the selected year, so that's the `count(*)` column — and we also compute how many of those participants had an accident, thanks to the *filter* clause that we introduced before.

Given the *accident* relation from the *CTE*, it is then easy to compute a percentage of accidents over race participants, and we can even get fancy and display the percentage in the form of a horizontal bar diagram by repeating a unicode black square character so that we have a fancy display:

```
 season │  pct  │       bar
════════╪═══════╪══════════════════
   1974 │  3.67 │ ■■■■
   1975 │ 14.88 │ ■■■■■■■■■■■■■■■■
   1976 │ 11.06 │ ■■■■■■■■■■■■
   1977 │ 12.58 │ ■■■■■■■■■■■■■
   1978 │ 10.19 │ ■■■■■■■■■■■
   1979 │  7.20 │ ■■■■■■■■
   1980 │  7.83 │ ■■■■■■■■
   1981 │  3.56 │ ■■■■
   1982 │  0.86 │
   1983 │  0.00 │
   1984 │  5.58 │ ■■■■■■
```

```
|  1985 |  8.87 | ■■■■■■■■
|  1986 |  6.07 | ■■■■■■
|  1987 |  5.97 | ■■■■■
|  1988 |  0.61 |
|  1989 |  0.81 |
|  1990 |  1.29 | ■
(17 rows)
```

The Formula One racing seems to be interesting enough outside of what we cover in this book and the respective database: Wikipedia is full of information about this sport. In the list of Formula One seasons, we can see a table of all seasons and their champion driver and champion constructor: the driver/constructor who won the most points in total in the races that year.

To compute that in SQL we need to first add up the points for each driver and constructor and then we can select those who won the most each season:

```
with points as
 (
    select year as season, driverid, constructorid,
           sum(points) as points
      from results join races using(raceid)
  group by grouping sets((year, driverid),
                         (year, constructorid))
    having sum(points) > 0
  order by season, points desc
 ),
 tops as
 (
    select season,
           max(points) filter(where driverid is null) as ctops,
           max(points) filter(where constructorid is null) as dtops
      from points
  group by season
  order by season, dtops, ctops
 ),
 champs as
 (
    select tops.season,
           champ_driver.driverid,
           champ_driver.points,
           champ_constructor.constructorid,
           champ_constructor.points

      from tops
           join points as champ_driver
             on champ_driver.season = tops.season
            and champ_driver.constructorid is null
            and champ_driver.points = tops.dtops

```

```
34            join points as champ_constructor
35              on champ_constructor.season = tops.season
36             and champ_constructor.driverid is null
37             and champ_constructor.points = tops.ctops
38    )
39    select season,
40           format('%s %s', drivers.forename, drivers.surname)
41              as "Driver's Champion",
42           constructors.name
43              as "Constructor's champion"
44      from champs
45           join drivers using(driverid)
46           join constructors using(constructorid)
47  order by season;
```

This time we get about a full page SQL query, and yes it's getting complex. The main thing to see is that we are *daisy chaining* the CTEs:

1. The *points* CTE is computing the sum of points for both the drivers and the constructors for each season.

   We can do that in a single SQL query thanks to the *grouping sets* feature that is covered in more details later in this book. It allows us to run aggregates over more than one group at a time within a single query scan.

2. The *tops* CTE is using the *points* one in its *from* clause and it computes the maximum points any driver and constructor had in any given season,

   We do that in a separate step because in SQL it's not possible to compute an aggregate over an aggregate:

   ERROR: aggregate function calls cannot be nested

   Thus the way to have the sum of points and the maximum value for the sum of points in the same query is by using a two-stages pipeline, which is what we are doing.

3. The *champs* CTE uses the *tops* and the *points* data to restrict our result set to the champions, that is those drivers and constructors who made as many points as the maximum.

   Additionnaly, in the *champs* CTE we can see that we use the *points* data twice for different purposes, aliasing the relation to *champ_driver* when looking for the champion driver, and to *champ_constructor* when looking for the champion constructor.

4. Finally we have the outer query that uses the *champs* dataset and formats

it for the application, which is close to what our Wikipedia example page is showing.

Here's a cut-down version of the 68 rows in the final result set:

```
 season | Driver's Champion  | Constructor's champion
========+====================+========================
   1950 | Nino Farina        | Alfa Romeo
   1951 | Juan Fangio        | Ferrari
   1952 | Alberto Ascari     | Ferrari
   1953 | Alberto Ascari     | Ferrari
   1954 | Juan Fangio        | Ferrari
   1955 | Juan Fangio        | Mercedes
   1956 | Juan Fangio        | Ferrari
   1957 | Juan Fangio        | Maserati
...
   1985 | Alain Prost        | McLaren
   1986 | Alain Prost        | Williams
   1987 | Nelson Piquet      | Williams
   1988 | Alain Prost        | McLaren
   1989 | Alain Prost        | McLaren
   1990 | Ayrton Senna       | McLaren
   1991 | Ayrton Senna       | McLaren
   1992 | Nigel Mansell      | Williams
   1993 | Alain Prost        | Williams
...
   2013 | Sebastian Vettel   | Red Bull
   2014 | Lewis Hamilton     | Mercedes
   2015 | Lewis Hamilton     | Mercedes
   2016 | Nico Rosberg       | Mercedes
```

Distinct On

Another useful PostgreSQL extension is the *distinct on* SQL form, and here's what the PostgreSQL distinct clause documentation has to say about it:

> SELECT DISTINCT ON (expression [, ...]) keeps only the first row of each set of rows where the given expressions evaluate to equal. The DISTINCT ON expressions are interpreted using the same rules as for ORDER BY (see above). Note that the "first row" of each set is unpredictable unless ORDER BY is used to ensure that the desired row appears first.

So it is possible to return the list of drivers who ever won a race in the whole

Formula One history with the following query:

```
select distinct on (driverid)
       forename, surname
  from results
       join drivers using(driverid)
 where position = 1;
```

There 107 of them, as we can check with the following query:

```
select count(distinct(driverid))
  from results
       join drivers using(driverid)
 where position = 1;
```

The classic way to have a single result per driver in SQL would be to aggregate over them, creating a group per driver:

```
  select forename, surname
    from results join drivers using(driverid)
   where position = 1
group by drivers.driverid;
```

Note that we are using the *group by* clause without aggregates. That's a valid use case for this clause, allowing us to force unique entries per group in the result set.

Result Sets Operations

SQL also includes set operations for combining queries results sets into a single one.

In our data model we have a *driverstandings* and a *constructorstandings* — they contain data that come from the *results* table that we've been using a lot, so that you can query a smaller data set... or I guess so that you can write simple SQL queries.

The set operations are *union*, *intersect* and *except*. As expected with *union* you can assemble a result set from the result of several queries:

```
(
      select raceid,
             'driver' as type,
             format('%s %s',
                    drivers.forename,
                    drivers.surname)
             as name,
             driverstandings.points
```

```
9
10          from driverstandings
11               join drivers using(driverid)
12
13         where raceid = 972
14           and points > 0
15  )
16  union all
17  (
18        select raceid,
19               'constructor' as type,
20               constructors.name as name,
21               constructorstandings.points
22
23          from constructorstandings
24               join constructors using(constructorid)
25
26         where raceid = 972
27           and points > 0
28  )
29  order by points desc;
```

Here, in a single query, we get the list of points from race 972 for drivers and constructors, well anyway all of them who got points. It is a classic of using *union*, as we are adding static column values in each branch of the query, so that we know where each line of the result set comes from:

```
1  | raceid |    type     |       name        | points
2  |========|=============|===================|========
3  |    972 | constructor | Mercedes          |    136
4  |    972 | constructor | Ferrari           |    135
5  |    972 | driver      | Sebastian Vettel  |     86
6  |    972 | driver      | Lewis Hamilton    |     73
7  |    972 | driver      | Valtteri Bottas   |     63
8  |    972 | constructor | Red Bull          |     57
9  |    972 | driver      | Kimi Räikkönen    |     49
10 |    972 | driver      | Max Verstappen    |     35
11 |    972 | constructor | Force India       |     31
12 |    972 | driver      | Daniel Ricciardo  |     22
13 |    972 | driver      | Sergio Pérez      |     22
14 |    972 | constructor | Williams          |     18
15 |    972 | driver      | Felipe Massa      |     18
16 |    972 | constructor | Toro Rosso        |     13
17 |    972 | driver      | Carlos Sainz      |     11
18 |    972 | driver      | Esteban Ocon      |      9
19 |    972 | constructor | Haas F1 Team      |      8
20 |    972 | driver      | Nico Hülkenberg   |      6
21 |    972 | constructor | Renault           |      6
22 |    972 | driver      | Romain Grosjean   |      4
```

```
|    972 | driver      | Kevin Magnussen  |      4
|    972 | driver      | Daniil Kvyat     |      2
(22 rows)
```

In our writing of the query, you may notice that we did parenthesize the branches of the *union*. It's not required that we do so, but it improves the readability of the query and makes it obvious as to what data set the *order by* clause is applied for.

Finally, we've been using *union all* in this query. That's because the way the queries are built is known to never yield duplicates in the result set. It may happen that you need to use a *union* query and then want to remove duplicates from the result set, that's what *union* (with no *all*) does.

The next query is a little convoluted and lists the drivers who received no points in race 972 (Russian Grand Prix of 2017-04-30) despite having gotten some points in the previous race (id 971, Bahrain Grand Prix of 2017-04-16):

```
(
      select driverid,
             format('%s %s',
                    drivers.forename,
                    drivers.surname)
             as name

        from results
             join drivers using(driverid)

       where raceid = 972
         and points = 0
)
except
(
      select driverid,
             format('%s %s',
                    drivers.forename,
                    drivers.surname)
             as name

        from results
             join drivers using(driverid)

       where raceid = 971
         and points = 0
)
;
```

Which gives us:

```
 driverid |       name
══════════╪══════════════════
      154 | Romain Grosjean
      817 | Daniel Ricciardo
(2 rows)
```

Here it's also possible to work with the *intersect* operator in between result sets. With our previous query, we would get the list of drivers who had no points in either race.

The *except* operator is very useful for writing test cases, as it allows us to compute a difference in between two result sets. One way to use it is to store the result of running a query against a known *fixture* or database content in an expected file. Then when you change a query, it's easy to load your expected data set into the database and compare it with the result of running the new query.

We said earlier that the following two queries are supposed to return the same dataset, so let's check that out:

```
(
      select name, location, country
        from circuits
    order by position <-> point(2.349014, 48.864716)
)
except
(
      select name, location, country
        from circuits
    order by point(lng,lat) <-> point(2.349014, 48.864716)
)
;
```

This returns 0 rows, so the index is reliable *and* the *location* column is filled with the same data as found in the *lng* and *lat* columns.

You can implement some regression testing pretty easily thanks to the *except* operator!

16

Understanding Nulls

Given its relational theory background, SQL comes with a special value that has no counterpart in a common programming language: *null*. In Python, we have *None*, in PHP we have *null*, in C we have *nil*, and about every other programming language has something that looks like a *null*.

Three-Valued Logic

The difference in SQL is that *null* introduces *three-valued logic*. Where that's very different from other languages *None* or *Null* is when comparing values. Let's have a look at the SQL *null* truth table:

```
select a::text, b::text,
       (a=b)::text as "a=b",
       format('%s = %s',
              coalesce(a::text, 'null'),
              coalesce(b::text, 'null')) as op,
       format('is %s',
              coalesce((a=b)::text, 'null')) as result
  from (values(true), (false), (null)) v1(a)
       cross join
       (values(true), (false), (null)) v2(b);
```

As you can see *cross join* is very useful for producing a truth table. It implements a Cartesian product over our columns, here listing the first value of *a* (*true*) with every value of *b* in order (*true*, then *false*, then *null*), then again with the second value of *a* (*false*) and then again with the third value of *a* (*null*).

We are using *format* and *coalesce* to produce an easier to read results table here. The *coalesce* function returns the first of its argument which is not null, with the restriction that all of its arguments must be of the same data type, here *text*. Here's the nice truth table we get:

```
   a    |   b    |  a=b  |      op       |  result
════════╪════════╪═══════╪═══════════════╪══════════
 true   | true   | true  | true = true   | is true
 true   | false  | false | true = false  | is false
 true   | ¤      | ¤     | true = null   | is null
 false  | true   | false | false = true  | is false
 false  | false  | true  | false = false | is true
 false  | ¤      | ¤     | false = null  | is null
 ¤      | true   | ¤     | null = true   | is null
 ¤      | false  | ¤     | null = false  | is null
 ¤      | ¤      | ¤     | null = null   | is null
(9 rows)
```

We can think of *null* as meaning *I don't know what this is* rather than *no value here*. Say you have in A (left hand) something (hidden) that you don't know what it is and in B (right hand) something (hidden) that you don't know what it is. You're asked if A and B are the same thing. Well, you can't know that, can you?

So in SQL *null* = *null* returns *null*, which is the proper answer to the question, but not always the one you expect, or the one that allows you to write your query and have the expected result set.

That's why we have other SQL operators to work with data that might be *null*: they are *is distinct from* and *is not distinct from*. Those two operators not only have a very long name, they also pretend that *null* is the same thing as *null*.

So if you want to pretend that SQL doesn't implement three-valued logic you can use those operators and forget about Boolean comparisons returning *null*.

We can even easily obtain the *truth table* from a SQL query directly:

```
select a::text as left, b::text as right,
       (a = b)::text as "=",
       (a <> b)::text as "<>",
       (a is distinct from b)::text as "is distinct",
       (a is not distinct from b)::text as "is not distinct from"
  from            (values(true),(false),(null)) t1(a)
       cross join (values(true),(false),(null)) t2(b);
```

With this complete result this time:

```
 left  | right |   =   |  <>   | is distinct | is not distinct from
═══════╪═══════╪═══════╪═══════╪═════════════╪══════════════════════
 true  | true  | true  | false | false       | true
 true  | false | false | true  | true        | false
 true  | ¤     | ¤     | ¤     | true        | false
 false | true  | false | true  | true        | false
 false | false | true  | false | false       | true
 false | ¤     | ¤     | ¤     | true        | false
 ¤     | true  | ¤     | ¤     | true        | false
 ¤     | false | ¤     | ¤     | true        | false
 ¤     | ¤     | ¤     | ¤     | false       | true
(9 rows)
```

You can see that we have not a single *null* in the last two columns.

Not Null Constraints

In some cases, in your data model you want the strong guarantee that a column cannot be *null*. Usually that's because it makes no sense for your application to deal with some *unknowns*, or in other words, you are dealing with a required value.

The default value for any column, unless you specify something else, is always *null*. It's only a default value though, it's not a constraint on your data model, so your application may insert a *null* value in a column with a *non null* default:

```
create table test(id serial, f1 text default 'unknown');
insert into test(f1) values(DEFAULT),(NULL),('foo');
table test;
```

This script gives the following output:

```
 id |   f1
════╪═════════
  1 | unknown
  2 | ¤
  3 | foo
```

As we can see, we have a *null* value in our test table, despite having implemented a specific default value. The way to avoid that is using a *not null* constraint:

```
drop table test;
create table test(id serial, f1 text not null default 'unknown');
insert into test(f1) values(DEFAULT),(NULL),('foo');
ERROR:  null value in column "f1" violates not-null constraint
DETAIL:  Failing row contains (2, null).
```

This time the *insert* command fails: accepting the data would violate the constraint we specified at table creation, i.e. no *null* allowed.

Outer Joins Introducing Nulls

As we saw earlier in this chapter, outer joins are meant to preserve rows from your reference relation and add to it columns from the outer relation when the join condition is satisfied. When the join condition is not satisfied, the outer joins then fill the columns from the outer relation with *null* values.

A typical example would be with calendar dates when we have not registered data at given dates yet. In our motor racing database example, we can ask for the name of the pole position's driver and the final position. As the model registers the races early, some of them won't have run yet and so the results are not available in the database:

```
  select races.date,
         races.name,
         drivers.surname as pole_position,
         results.position
    from races
         /*
          * We want only the pole position from the races
          * know the result of and still list the race when
          * we don't know the results.
          */
         left join results
                on races.raceid = results.raceid
               and results.grid = 1
         left join drivers using(driverid)
   where      date >= '2017-05-01'
         and date < '2017-08-01'
order by races.date;
```

So we can see that we only have data from races before the 25 June in the version that was used to prepare this book:

```
    date    │         name          │ pole_position │ position
════════════╪═══════════════════════╪═══════════════╪══════════
 2017-05-14 │ Spanish Grand Prix    │ Hamilton      │        1
 2017-05-28 │ Monaco Grand Prix     │ Räikkönen     │        2
 2017-06-11 │ Canadian Grand Prix   │ Hamilton      │        1
 2017-06-25 │ Azerbaijan Grand Prix │ ¤             │        ¤
 2017-07-09 │ Austrian Grand Prix   │ ¤             │        ¤
 2017-07-16 │ British Grand Prix    │ ¤             │        ¤
```

```
 2017-07-30 | Hungarian Grand Prix  | ¤              |        ¤
(7 rows)
```

With *grid* having a *not null* constraints in your database model for the *results* table, we see that sometimes we don't have the data at all. Another way to say that we don't have the data is to say that we don't know the answer to the query. In this case, SQL uses *null* in its answer.

So *null* values can be created by the queries themselves. There's basically no way to escape from having to deal with *null* values, so your application must be prepared for them and moreover understand what to do with them.

Using Null in Applications

Most programming languages come with a representation of the unknown or not yet initialized state, be it *None* in Python, *null* in Java and *C* and *PHP* and others, with varying semantics, or even the Ocaml option type or the Haskell maybe type.

Depending on your tools of choice the *null* SQL value maps quite directly to those concepts. The main thing is then to remember that you might get *null* in your results set, and you should write your code accordingly. The next main thing to keep in mind is the three-valued logic semantics when you write SQL, and remember to use `where foo is null` if that's what you mean, rather than the erroneous `where foo = null`, because `null = null is null` and then it won't be selected in your resultset:

```
select a, b
  from (values(true), (false), (null)) v1(a)
       cross join
       (values(true), (false), (null)) v2(b)
where a = null;
```

That gives nothing, as we saw before, as there's no such row where anything equals null:

```
 a | b
═══╪═══
(0 rows)
```

Now if you remember your logic, then you can instead ask the right question:

```
select a, b
  from (values(true), (false), (null)) v1(a)
```

```
       cross join
       (values(true), (false), (null)) v2(b)
where a is null;
```

You then obtain those rows for which *a is null*:

```
 a | b
═══╪═══
 ¤ | t
 ¤ | f
 ¤ | ¤
(3 rows)
```

17

Understanding Window Functions

There was SQL before window functions and there is SQL after *window functions*: that's how powerful this tool is!

The whole idea behind *window functions* is to allow you to process several values of the result set at a time: you see through the window some *peer* rows and you are able to compute a single output value from them, much like when using an *aggregate* function.

Windows and Frames

PostgreSQL comes with plenty of features, and one of them will be of great help when it comes to getting a better grasp of what's happening with *window functions*. The first step we are going through here is understanding what data the function has access to. For each input row, you have access to a frame of the data, and the first thing to understand here is that *frame*.

The `array_agg()` function is an *aggregate* function that builds an array. Let's use this tool to understand *window frames*:

```
select x, array_agg(x) over (order by x)
  from generate_series(1, 3) as t(x);
```

The *array_agg()* aggregates every value in the current frame, and here outputs the full exact content of the *windowing* we're going to process.

```
 x | array_agg
```

```
---+-----------
 1 | {1}
 2 | {1,2}
 3 | {1,2,3}
(3 rows)
```

The window definition `over (order by x)` actually means `over (order by x rows between unbounded preceding and current row)`:

```
 select x,
        array_agg(x) over (order by x
                           rows between unbounded preceding
                                    and current row)
   from generate_series(1, 3) as t(x);
```

And of course we get the same result set as before:

```
 x | array_agg
---+-----------
 1 | {1}
 2 | {1,2}
 3 | {1,2,3}
(3 rows)
```

It's possible to work with other kinds of *frame specifications* too, as in the following examples:

```
select x,
       array_agg(x) over (rows between current row
                                   and unbounded following)
  from generate_series(1, 3) as t(x);
```

```
 x | array_agg
---+-----------
 1 | {1,2,3}
 2 | {2,3}
 3 | {3}
(3 rows)
```

If no frame clause is used at all, then the default is to see the whole set of rows in each of them, which can be really useful if you want to compute sums and percentages for example:

```
select x,
       array_agg(x) over () as frame,
       sum(x) over () as sum,
       x::float/sum(x) over () as part
  from generate_series(1, 3) as t(x);
```

```
 x |  frame  | sum |       part
---+---------+-----+-------------------
 1 | {1,2,3} |   6 | 0.166666666666667
```

```
 2 | {1,2,3} |   6 | 0.333333333333333
 3 | {1,2,3} |   6 |               0.5
(3 rows)
```

Did you know you could compute both the total sum of a column and the ratio of the current value compared to the total within a single SQL query? That's the breakthrough we're talking about now with *window functions*.

Partitioning into Different Frames

Other frames are possible to define when using the clause `PARTITION BY`. It allows defining as *peer rows* those rows that share a common property with the *current row*, and the property is defined as a *partition*.

So in the *Formula One* database we have a *results* table with results from all the known races. Let's pick a race:

```
-[ RECORD 1 ]----------------------------------------------------
raceid    | 890
year      | 2013
round     | 10
circuitid | 11
name      | Hungarian Grand Prix
date      | 2013-07-28
time      | 12:00:00
url       | http://en.wikipedia.org/wiki/2013_Hungarian_Grand_Prix
```

Within that race, we can now fetch the list of competing drivers in their position order (winner first), and also their ranking compared to other drivers from the same constructor in the race:

```
select surname,
         constructors.name,
         position,
         format('%s / %s',
                row_number()
                  over(partition by constructorid
                           order by position nulls last),

                count(*) over(partition by constructorid)
               )
            as "pos same constr"
    from      results
         join drivers using(driverid)
         join constructors using(constructorid)
   where raceid = 890
order by position;
```

The *partition by* frame allows us to see *peer rows*, here the rows from *results* where the *constructorid* is the same as the current row. We use that partition twice in the previous SQL query, in the `format()` call. The first time with the `row_number()` window function gives us the position in the race with respect to other drivers from the same constructor, and the second time with `count(*)` gives us how many drivers from the same constructor participated in the race:

```
1  │    surname     │     name     │ position │ pos same constr
2  │════════════════╪══════════════╪══════════╪═════════════════
3  │ Hamilton       │ Mercedes     │        1 │ 1 / 2
4  │ Räikkönen      │ Lotus F1     │        2 │ 1 / 2
5  │ Vettel         │ Red Bull     │        3 │ 1 / 2
6  │ Webber         │ Red Bull     │        4 │ 2 / 2
7  │ Alonso         │ Ferrari      │        5 │ 1 / 2
8  │ Grosjean       │ Lotus F1     │        6 │ 2 / 2
9  │ Button         │ McLaren      │        7 │ 1 / 2
10 │ Massa          │ Ferrari      │        8 │ 2 / 2
11 │ Pérez          │ McLaren      │        9 │ 2 / 2
12 │ Maldonado      │ Williams     │       10 │ 1 / 2
13 │ Hülkenberg     │ Sauber       │       11 │ 1 / 2
14 │ Vergne         │ Toro Rosso   │       12 │ 1 / 2
15 │ Ricciardo      │ Toro Rosso   │       13 │ 2 / 2
16 │ van der Garde  │ Caterham     │       14 │ 1 / 2
17 │ Pic            │ Caterham     │       15 │ 2 / 2
18 │ Bianchi        │ Marussia     │       16 │ 1 / 2
19 │ Chilton        │ Marussia     │       17 │ 2 / 2
20 │ di Resta       │ Force India  │       18 │ 1 / 2
21 │ Rosberg        │ Mercedes     │       19 │ 2 / 2
22 │ Bottas         │ Williams     │        ¤ │ 2 / 2
23 │ Sutil          │ Force India  │        ¤ │ 2 / 2
24 │ Gutiérrez      │ Sauber       │        ¤ │ 2 / 2
25 │(22 rows)
```

In a single SQL query, we can obtain information about each driver in the race and add to that other information from the race as a whole. Remember that the *window functions* only happens after the *where* clause, so you only get to see rows from the available result set of the query.

Available Window Functions

Any and all *aggregate* function you already know can be used against a *window frame* rather than a *grouping clause*, so you can already start to use *sum*, *min*, *max*, *count*, *avg*, and the other that you're already used to using.

You might already know that with PostgreSQL it's possible to use the CREATE AGGREGATE command to register your own *custom aggregate*. Any such custom aggregate can also be given a *window frame definition* to work on.

PostgreSQL of course is included with built-in aggregate functions and a number of built-in window functions.

```
  select surname,
         position as pos,
         row_number()
           over(order by fastestlapspeed::numeric)
           as fast,
         ntile(3) over w as "group",
         lag(code, 1) over w as "prev",
         lead(code, 1) over w as "next"
    from      results
         join drivers using(driverid)
   where raceid = 890
  window w as (order by position)
order by position;
```

In this example you can see that we are reusing the same *window definition* several times, so we're giving it a name to simplify the SQL. In this query for each driver we are fetching his position in the results, his position in terms of *fastest lap speed*, a *group* number if we divide the drivers into a set of four groups thanks to the *ntile* function, the name of the previous driver who made it, and the name of the driver immediately next to the current one, thanks to the *lag* an *lead* functions:

```
    surname     | pos | fast | group | prev | next
════════════════╪═════╪══════╪═══════╪══════╪══════
 Hamilton       |   1 |   20 |     1 | ¤    | RAI
 Räikkönen      |   2 |   17 |     1 | HAM  | VET
 Vettel         |   3 |   21 |     1 | RAI  | WEB
 Webber         |   4 |   22 |     1 | VET  | ALO
 Alonso         |   5 |   15 |     1 | WEB  | GRO
 Grosjean       |   6 |   16 |     1 | ALO  | BUT
 Button         |   7 |   12 |     1 | GRO  | MAS
 Massa          |   8 |   18 |     1 | BUT  | PER
 Pérez          |   9 |   13 |     2 | MAS  | MAL
 Maldonado      |  10 |   14 |     2 | PER  | HUL
 Hülkenberg     |  11 |    9 |     2 | MAL  | VER
 Vergne         |  12 |   11 |     2 | HUL  | RIC
 Ricciardo      |  13 |    8 |     2 | VER  | VDG
 van der Garde  |  14 |    6 |     2 | RIC  | PIC
 Pic            |  15 |    5 |     2 | VDG  | BIA
 Bianchi        |  16 |    3 |     3 | PIC  | CHI
 Chilton        |  17 |    4 |     3 | BIA  | DIR
```

```
| di Resta       |  18 |   10 |     3 | CHI  | ROS
| Rosberg        |  19 |   19 |     3 | DIR  | BOT
| Sutil          |   ¤ |    2 |     3 | GUT  | ¤
| Gutiérrez      |   ¤ |    1 |     3 | BOT  | SUT
| Bottas         |   ¤ |    7 |     3 | ROS  | GUT
(22 rows)
```

And we can see that the *fastest lap speed* is not as important as one might think, as both the two fastest drivers didn't even finish the race. In SQL terms we also see that we can have two different sequences returned from the same query, and again we can reference other rows.

When to Use Window Functions

The real magic of what are called *window functions* is actually the frame of data they can see when using the `OVER ()` clause. This frame is specified thanks to the `PARTITION BY` and `ORDER BY` clauses.

You need to remember that the windowing clauses are always considered last in the query, meaning after the *where* clause. In any frame you can only see rows that have been selected for output: e.g. it's not directly possible to compute a percentage of values that you don't want to display. You would need to use a subquery in that case.

Use *window functions* whenever you want to compute values for each row of the result set and those computations depend on other rows within the same result set. A classic example is a marketing analysis of weekly results: you typically output both each day's gross sales and the variation with the same day in comparison to the previous week.

18

Understanding Relations and Joins

In the previous section, we saw some bits about data sources in SQL when introducing the *from* clause and some join operations. In this section we are going to expand this on this part and look specifically at what a relation is.

As usual, the PostgreSQL documentation provides us with some enlightenment (here in its section entitled the FROM Clause:

> A table reference can be a table name (possibly schema-qualified), or a derived table such as a subquery, a JOIN construct, or complex combinations of these. If more than one table reference is listed in the FROM clause, the tables are cross-joined (that is, the Cartesian product of their rows is formed; see below). The result of the FROM list is an intermediate virtual table that can then be subject to transformations by the WHERE, GROUP BY, and HAVING clauses and is finally the result of the overall table expression.

Relations

We already know that a relation is a set of data all having a common set of properties, that is to say a set of elements all from the same composite data type. The SQL standard didn't go as far as defining relations in terms of being a set in the mathematical way of looking at it, and that would imply that no duplicates are

allowed. We can then talk about a bag rather than a set, because duplicates are allowed in SQL relations.

The data types are defined either by the *create type* statement or by the more common *create table* statement:

```
~# create table relation(id integer, f1 text, f2 date, f3 point);
CREATE TABLE

~# insert into relation
        values(1,
               'one',
               current_date,
               point(2.349014, 48.864716)
              );
INSERT 0 1

~# select relation from relation;
                 relation
═══════════════════════════════════════════
 (1,one,2017-07-04,"(2.349014,48.864716)")
(1 row)
```

Here we created a table named *relation*. What happens in the background is that PostgreSQL created a type with the same name that you can manipulate, or reference. So the *select* statement here is returning tuples of the composite type *relation*.

SQL is a strongly typed programming language: at query planning time the data type of every column of the result set must be known. Any result set is defined in terms of being a *relation* of a known composite data type, where each and every row in the result set shares the common properties implied by this data type.

The relations can be defined in advance in *create table* or *create type* statements, or defined on the fly by the query planner when it makes sense for your query. Other statements can also create data types too, such as *create view* — more on that later.

When you use a subquery in your main query, either in the form of a *common table expression* or directly inlined in your *from* clause, you are effectively defining a relation data type. At query run time, this relation is filled with a dataset, thus you have a full-blown relation to use.

Relational algebra is thereby a formalism of what you can do with such things. In short, this means joins. The result of a join in between two relations is a relation, of course, and that relation can in-turn participates into other *join* operations.

The result of a *from* clause is a relation, with which the query planner is executing the rest of your query: the *where* clause to restrict the relation dataset to what's interesting for the query, and other clauses, up until the *window functions* and the *select* projection are computed so that we can finally construct the result set, i.e. a relation.

The PostgreSQL optimizer will then re-arrange the computations needed so they're as efficient as possible, rather than doing things in the way they are written. This is much like when *gcc* is doing its magic and you can't even recognize your intentions when reading the assembly outcome, except that with PostgreSQL you can actually make sense of the *explain plan* for your query, and relate it to the query text you wrote.

SQL Join Types

Joins are the basic operations you do with relations. The nature of a join is to build a new relation from a pair of existing ones. The most basic join is a *cross join* or Cartesian product, as we saw in the Boolean truth table, where we built a result set of all possible combinations of all entries.

Other kinds of join associate data between the two relations that participate in the operation. The association is specified precisely in the *join condition* and is usually based on some equality operator, but it is not limited to that.

We might want to count how many drivers made it to the finish behind the current one in any single race, as that's a good illustration of a non-equality join condition:

```
   select results.positionorder as position,
          drivers.code,
          count(behind.*) as behind

    from results
              join drivers using(driverid)

         left join results behind
                on results.raceid = behind.raceid
               and results.positionorder < behind.positionorder

   where results.raceid = 972
     and results.positionorder <= 3

group by results.positionorder, drivers.code
order by results.positionorder;
```

Here are our top three, with how many drivers found behind. We are using the *positionorder* column here because it attributes a position to drivers who didn't finish the race, which is useful for us in this very query:

```
 position | code | behind
══════════╪══════╪════════
        1 | BOT  |     19
        2 | VET  |     18
        3 | RAI  |     17
(3 rows)
```

In this example query, we can also see that we are using the same relation twice in the same *FROM* query, thus giving the relation different aliases. It would be tempting to name those aliases *r1* and *r2*, but much as you would not do that in your code when naming variables, it's best to give meaningful names to your the SQL objects in your queries.

Relational algebra includes set-based operations, and what we have in SQL are inner and outer joins, cross joins and lateral joins. We saw all of them in this chapter's example queries, and here's a quick summary:

- *Inner joins* are useful when you want to only keep rows that satisfy the *join condition* for both involved relation.
- *Outer joins* are useful when you want to keep a reference relation's dataset no matter what and enrich it with the dataset from the other relation when the *join condition* is satisfied.

  The relation of which you want to keep all the rows is pointed to in the name of the outer join, so it's written on the left-hand side in a *left join* and on the right-hand side in a *right join*.

  When the *join condition* is not satisfied, it means you keep some known data and must fill in the result relation with data that doesn't exist, so that's when *null* is very useful, and also why *null* is a member of every SQL data type (including the Boolean data type),
- *Full outer joins* is a special case of an outer join where you want to keep all the rows in the dataset, whether they satisfy the join condition or not.
- *Lateral joins* introduce the capability for the *join condition* to be *pushed down* into the relation on the right, allowing for new semantics such as top-N queries, thanks to being able to use *limit* in a lateral subquery.

The key here is to remember that a join takes two relations and a join condition

as input and it returns another relation. A relation here is a bag of rows that all share a common relation data type definition, known at query planning time.

19

An Interview with Markus Winand

Markus Winand is the author of the very famous book "SQL Performance explained" and he also provides both http://use-the-index-luke.com and http://modern-sql.com. Markus is a master of the SQL standard and he is a wizard in terms of how to use SQL to enable fast application delivery and solid run-time performances!

Figure 19.1: Use The Index, Luke!

Developers often say that SQL is hard to master. Do you agree? What would be your recommendations for them to improve their SQL skills?

> *I think the reason many people find SQL hard to learn is that it is a declarative programming language.*
>
> *Most people first learn imperative programming: they put a number of instructions into a particular order so that their execution delivers the desired result. An SQL statement is different because it simply defines the result. This becomes most obvious in the select clause, which literally defines the columns of the result. Most of the other*

main clauses describe which rows should be present in the result. It is important to understand that the author of an SQL statement does not instruct the database how to run the query. That's up to the database to figure out.

So I think the most important step in mastering SQL is to stop thinking in imperative terms. One recurring example I've seen in the field is how people imagine that joins work and more specifically, which indexes can help in improving join performance. People constantly try to apply their knowledge about algorithms to SQL statements, without knowing which algorithm the database actually uses. This causes a lot of problems, confusion and frustration.

First, always focus on writing a clear statement to describe each column and row of the desired result. If needed, you can take care of performance afterwards. This however, requires some understanding of database internals.

What would you say is the ideal SQL wizardry level a developer should reach to be able to do their job correctly?

Knowing everything would be best, I guess ;)

In reality, hardly any programmer is just an SQL programmer. Most are Java, C#, PHP, or whatever programmers who — more or less frequently — use SQL to interact with a database. Obviously, not all of them need to be SQL experts.

Today's programming often boils down to choosing the right tool for each problem. To do this job correctly, as you properly phrased it, programmers should at least know what their SQL database could do. Once you remember that SQL can do aggregations without group by—e.g. for running totals, moving averages, etc.—it's easy to search the Internet for the syntax. So I'd say every programmer (and even more so architects) should have a good overview of what SQL can do nowadays in order to recognize situations in which SQL offers the best solution.

Quite often, a few lines of SQL can replace dozens of lines of an imperative program. Most of the time, the SQL solution is more correct and even faster. In the vein of an old saying about shell scripts, I'd say: "Watch out or I'll replace a day's worth of your

imperative programming with a very small SQL statement".

You know the detailed behavior of many different RDBMS engines and you are used to working with them. Would you write portable SQL code in applications or pick one engine and then use it to its full capacity, writing tailored SQL (both schema and queries)?

I first aim to use standard SQL. This is just because I know standard SQL best and I believe that the semantics of standard SQL have the most rigid definitions. That means standard SQL defines a meaningful behavior, even for the most obscure corner cases. Vendor extensions have a tendency to focus on the main cases. For corner cases, they might behave in surprising and inconsistent ways — just because nobody thought about that during specification.

Sometimes, I cannot solve a problem with standard SQL — at least not in a sufficiently elegant and efficient way. That is more often because the database at hand doesn't support the standard features that I'd like to use for this problem. However, sometimes the standard just doesn't provide the required functionality. In either case I'm also happy to use a vendor extension. For me, this is really just my personal order of preference for solving a problem — it is not a limitation in any way.

When it comes to the benefits of writing portable SQL, there seems to be a common misconception in the field. Quite often, people argue that they don't need portability because they will never use another database. And I actually agree with that argument in the sense that aiming for full portability does not make any sense if you don't need to run the software on different database right now.

On the other hand, I believe that portability is not only about the code — it is also about the people. I'd say it is even more about the people. If you use standard SQL by default and only revert to proprietary syntax if needed, the SQL statements will be easier for other people to understand, especially people used to another database. On the scale of the whole industry it means that bringing new personnel on board involves less friction. Even from the personal viewpoint of a single developer, it has a big benefit: if you are used to writing standard SQL then the chances increase that you can write SQL that works on many databases. This makes you more valuable

in the job market.

However, there is one big exception and that's DDL – i.e. create statements. For DDL, I don't even aim for portability in the first place. This is pointless and too restricting. If you need to create tables, views, indexes, and the like for different databases, it is better to just maintain a separate schema definition for each of them.

How do you see PostgreSQL in the RDBMS offering?

PostgreSQL is in a very strong position. I keep on saying that from a developer's perspective, PostgreSQL's feature set is closer to that of a commercial database than to that of the open-source competitors such as MySQL/MariaDB.

I particularly like the rich standard SQL support PostgreSQL has: that means simple things like the fully featured values clause, but also `with [recursive]`, `over`, `lateral` *and arrays.*

Part V

Data Types

Reading the Wikipedia article on relations in databases article, we find the following:

> In relational database theory, a relation, as originally defined by E. F. Codd,[1] is a set of tuples (d1, d2, ..., dn), where each element dj is a member of Dj, a data domain. Codd's original definition notwithstanding, and contrary to the usual definition in mathematics, there is no ordering to the elements of the tuples of a relation.[2][3] Instead, each element is termed an attribute value. An attribute is a name paired with a domain (nowadays more commonly referred to as a type or data type). An attribute value is an attribute name paired with an element of that attribute's domain, and a tuple is a set of attribute values in which no two distinct elements have the same name. Thus, in some accounts, a tuple is described as a function, mapping names to values.

In a relational database, we deal with relations. The main property of a relation is that all the tuples that belong to a relation share a common data definition: they have the same list of attributes, and each attribute is of a specific data type. Then we might also might have some more constraints.

In this chapter, we are going to see what data types PostgreSQL makes available to us as application developers, and how to use them to enhance our application correctness, succinctness and performance.

20

Serialization and Deserialization

It's all too common to see *RDBMS* mentioned as a solution to marshaling and unmarshaling in-memory objects, and even distributed computed systems tend to talk about the *storage* parts for databases. In my opinion, we should talk about *transactional* systems rather than *storage* when we want to talk about RDBMS and other transaction technologies. That said, *storage* is a good name for distributed file systems.

On this topic, it might be interesting to realize how Lisp introduced *print readably*. In Lisp rather than working with a compiler and then running static binary files, you work with an interactive *REPL* where the *reader* and the *printer* are fully specified parts of the system. Those pieces are meant to be used by Lisp users. Here's what the common Lisp standard documentation has to say about printing *readably*:

> If *print-readably* is true, some special rules for printing objects go into effect. Specifically, printing any object O1 produces a printed representation that, when seen by the Lisp reader while the standard readtable is in effect, will produce an object O2 that is similar to O1.

In the following example code, we define a structure with *slots* of different types: string, float, and integer. Then we create an instance of that structure, with specific values for the three slots, and serialize this instance to string, only to read it back from the string:

```
1 (defpackage #:readably
2   (:use #:cl))
3
```

```
(in-package #:readably)

(defstruct foo
  (name nil :type (or nil string))
  (x    0.0 :type float)
  (n    0   :type fixnum))

(defun print-and-read ()
  (let ((instance (make-foo :name "bar" :x 1.0 :n 2)))
    (values instance
            (read-from-string
             (write-to-string instance :escape t :readably t)))))
```

The result is, as expected, a couple of very similar instances:

```
CL-USER> (readably::print-and-read)
#S(READABLY::FOO :NAME "bar" :X 1.0 :N 2)
#S(READABLY::FOO :NAME "bar" :X 1.0 :N 2)
```

The first instance is created in the application code from literal strings and numbers, and the second instance has been created by the reader from a string, which could have been read from a file or a network service somewhere.

The discovery of Lisp predates the invention of the relational model by a long shot, and Lisp wasn't unique in its capacity to read data structure in-memory from *external* storage.

It is important to understand which problem can be solved with using a database service, and to insist that storing and retrieving values out of and back into memory isn't a problem for which you need a database system.

21

Some Relational Theory

Back to relational database management systems and what they can provide to your application is:

- A service to access your data and run transactions
- A common API to guarantee consistency in between several application bases
- A transport mechanism to exchange data with the database service.

In this chapter, the focus is the C of *ACID*, i.e. data *consistency*. When your application grows, it's going to be composed of several parts: the administration panel, the customer back-office application, the public front of the application, the accounting reports, financial reporting, and maybe some more parts such as salespeople back-office and the like. Maybe some of those elements are going to be implemented using a third-party solution. Even if it's all in-house, it's often the case that different technical stacks are going to be used for different parts: a backend in Go or in Java, a frontend in Python (Django) or Ruby (on Rails), maybe PHP or Node.js, etc.

For this host of applications to work well together and respect the same set of business rules, we need a core system that enables to guaranteeing overall *consistency*. That is the main problem that a *relational database management system* is meant to solve, and that's why the relational model is so generic.

In the next chapter — Data Modeling — we are going to compare *schemaless* with the relational modeling and go more deeply into this topic. In order to be able to compare those very different approaches, we need a better understand-

ing of how the *consistency* is guaranteed by our favorite database system, PostgreSQL.

Attribute Values, Data Domains and Data Types

The Wikipedia definition for *relation* mentions *attribute values* that are part of *data domains*. A domain here is much like in mathematics, a set of values that are given a common name to. There's the data domain of natural numbers, and the data domain of rational numbers, in mathematics.

In relational theory, we can compose basic data domains into a tuple. Allow me to quote Wikipedia again, this time the tuple definition page:

> *The term originated as an abstraction of the sequence: single, double, triple, quadruple, quintuple, sextuple, septuple, octuple, ..., n-tuple, ..., where the prefixes are taken from the Latin names of the numerals.*

So by definition, a tuple is a list of T attributes, and a relation is a list of tuples that all share the same list of attributes domains: names and data type.

So the basics of the relational model is to establish consistency within your data set: we structure the data in a way that we know what we are dealing with, and in a way allowing us to enforce business constraints.

The first business constraint enforced here is dealing with proper data. For instance, the *timestamp* data type in PostgreSQL implements the Gregorian Calendar, in which there's no year zero, or month zero, or day zero. While other systems might accept "timestamp formatted" text as an attribute value, PostgreSQL actually checks that the value makes sense within the Gregorian Calendar:

```
select date '2010-02-29';
```

```
ERROR:  date/time field value out of range: "2010-02-29"
LINE 1: select date '2010-02-29';
                    ^
```

The year 2010 isn't a leap year in the Gregorian Calendar, thus the 29th of February 2010 is not a proper date, and PostgreSQL knows that. By the way, this input syntax is named a *decorated literal*: we decorate the literal with its data type so that PostgreSQL doesn't have to guess what it is.

Let's try the infamous zero-timestamp:

```
select timestamp '0000-00-00 00:00:00';
```

```
ERROR:  date/time field value out of range: "0000-00-00 00:00:00"
```

No luck, because the Gregorian Calendar doesn't have a year zero. The year 1 BC is followed by 1 AD, as we can see here:

```
select date(date '0001-01-01' + x * interval '1 day')
  from generate_series (-2, 1) as t(x);
```

```
    date
═══════════════
 0001-12-30 BC
 0001-12-31 BC
 0001-01-01
 0001-01-02
(4 rows)
```

We can see in the previous example that implementing the Gregorian calendar is not a restriction to live with, rather it's a powerful choice that we can put to good use. PostgreSQL knows all about leap years and time zones, and its *time* and *date* data types also implement nice support for meaningful values:

```
select date 'today' + time 'allballs' as midnight;
```

```
      midnight
═══════════════════════
 2017-08-14 00:00:00
(1 row)
```

The *allballs* time literal sounds like an Easter egg — its history is explained in this pgsql-docs thread.

Consistency and Data Type Behavior

A key aspect of PostgreSQL data types lies in their behavior. Comparable to an *object-oriented* system, PostgreSQL implements functions and operator polymorphism, allowing for the dispatching of code at run-time depending on the types of arguments.

If we have a closer look at a very simple SQL query, we can see lots happening under the hood:

```
select code from drivers where driverid = 1;
```

In this query, the expression *driverid* = *1* uses the = operator in between a column name and a literal value. PostgreSQL knows from its catalogs that the

driverid column is a *bigint* and parses the literal *1* as an integer. We can check that with the following query:

```
select pg_typeof(driverid), pg_typeof(1) from drivers limit 1;
```

```
 pg_typeof | pg_typeof
═══════════╪═══════════
 bigint    | integer
(1 row)
```

Now, how does PostgreSQL implements = in between an 8 bytes integer and a 4 bytes integer? Well it turns out that this decision is dynamic: the operator = dispatches to an established function depending on the types of its left and right operands. We can even have a look at the PostgreSQL catalogs to get a better grasp of this notion:

```
  select oprname, oprleft::regtype, oprcode::regproc
    from pg_operator
   where oprname = '='
     and oprleft::regtype::text ~ 'int|time|text|circle|ip'
order by oprleft;
```

This gives us a list of the following instances of the = operator:

```
 oprname |           oprleft           |         oprcode
═════════╪═════════════════════════════╪═════════════════════════
 =       | bigint                      | int84eq
 =       | bigint                      | int8eq
 =       | bigint                      | int82eq
 =       | smallint                    | int28eq
 =       | smallint                    | int2eq
 =       | smallint                    | int24eq
 =       | int2vector                  | int2vectoreq
 =       | integer                     | int48eq
 =       | integer                     | int42eq
 =       | integer                     | int4eq
 =       | text                        | texteq
 =       | abstime                     | abstimeeq
 =       | reltime                     | reltimeeq
 =       | tinterval                   | tintervaleq
 =       | circle                      | circle_eq
 =       | time without time zone      | time_eq
 =       | timestamp without time zone | timestamp_eq
 =       | timestamp without time zone | timestamp_eq_date
 =       | timestamp without time zone | timestamp_eq_timestamptz
 =       | timestamp with time zone    | timestamptz_eq_timestamp
 =       | timestamp with time zone    | timestamptz_eq
 =       | timestamp with time zone    | timestamptz_eq_date
```

```
 =       | interval                    | interval_eq
 =       | time with time zone         | timetz_eq
(24 rows)
```

The previous query limits its output to the datatype expected on the *left* of the operator. Of course, the catalogs also store the datatype expected on the *right* of it, and the result type too, which is *Boolean* in the case of equality. The *oprcode* column in the output is the name of the PostgreSQL function that is run when the operator is used.

In our case with *driverid = 1* PostgreSQL is going to use the *int84eq* function to implement our query. This is true unless there's an index on *driverid* of course, in which case PostgreSQL will walk the index to find matching rows without comparing the literal with the table's content, only with the index content.

When using PostgreSQL, data types provide the following:

- Input data representation, expected in input literal values
- Output data representation
- A set of functions working with the data type
- Specific implementations of existing functions for the new data type
- Operator specific implementations for the data type
- Indexing support for the data type

The indexing support for PostgreSQL covers several kinds of indexes: *B-tree*, *GiST*, *GIN*, *SP-GiST*, *hash* and *brin*. This book doesn't go further and cover the details of each of those index types. As an example of data type support for some indexes and the relationship in between a data type, a support function, an operator and an index, we can have a look at the *GiST* support for the *ip4r* extension data type:

```
select amopopr::regoperator
    from pg_opclass c
         join pg_am am on am.oid = c.opcmethod
         join pg_amop amop on amop.amopfamily = c.opcfamily
   where opcintype = 'ip4r'::regtype
     and am.amname = 'gist';
```

The *pg_opclass* catalog is a list of *operator class*, each of them belongs to an *operator family* as found in the *pg_opfamily* catalog. Each index type implements an *access method* represented in the *pg_am* catalog. Finally, each operator that may be used in relation to an index access method is listed in the *pg_amop* catalog.

Knowing that we can access the PostgreSQL catalogs at run-time and discover

the *ip4r* supported operators for a *GiST* indexed lookup:

```
    amopopr
═══════════════
 >>=(ip4r,ip4r)
 <<=(ip4r,ip4r)
 >>(ip4r,ip4r)
 <<(ip4r,ip4r)
 &&(ip4r,ip4r)
 =(ip4r,ip4r)
(6 rows)
```

Those catalog queries are pretty advanced material that you don't need in your daily life as an application developer. That said, it's good to have some understanding of how things work in PostgreSQL as it allows a smarter usage of the system you are already relying on for your data.

What we've seen here is that PostgreSQL implementation of data types is a completely dynamic system with function and operator dispatch, and PostgreSQL extension authors have APIs they can use to register new indexing support at run time (when you type in *create extension*).

The goal of understanding that is for you, as an application developer, to understand how much can be done in PostgreSQL thanks to the integral concept of data type.

22

PostgreSQL Data Types

PostgreSQL comes with a long list of data types. The following query limits the types to the ones directly interesting to someone who is an application developer, and still it lists 72 data types:

```
select nspname, typname
    from      pg_type t
         join pg_namespace n
           on n.oid = t.typnamespace
   where nspname = 'pg_catalog'
     and typname !~ '(^_|^pg_|^reg|_handler$)'
order by nspname, typname;
```

Let's take only a sample of those with the help of the *TABLESAMPLE* feature of PostgreSQL, documented in the select SQL from page of the documentation:

```
select nspname, typname
    from      pg_type t TABLESAMPLE bernoulli(20)
         join pg_namespace n
           on n.oid = t.typnamespace
   where nspname = 'pg_catalog'
     and typname !~ '(^_|^pg_|^reg|_handler$)'
order by nspname, typname;
```

In this run here's what I get as a random sample of about 20% of the available PostgreSQL types. If you run the same query again, you will have a different result set:

```
  nspname   |    typname
════════════╪═══════════════
 pg_catalog | abstime
 pg_catalog | anyelement
```

```
 pg_catalog | bool
 pg_catalog | cid
 pg_catalog | circle
 pg_catalog | date
 pg_catalog | event_trigger
 pg_catalog | line
 pg_catalog | macaddr
 pg_catalog | oidvector
 pg_catalog | polygon
 pg_catalog | record
 pg_catalog | timestamptz
(13 rows)
```

Our pick for the data types in this book isn't based on a *table sample* query, though. Yes, it would be some kind of fun to do it like this, but maybe not the kind you're expecting from the pages of this book...

Boolean

The Boolean data type has been the topic of the three valued logic section earlier in this book, with the SQL boolean truth table that includes the values *true*, *false* and *null*, and it's important enough to warrant another inclusion here:

```
   a    |   b   |  a=b  |      op       |  result
════════╪═══════╪═══════╪═══════════════╪═══════════
 true   | true  | true  | true = true   | is true
 true   | false | false | true = false  | is false
 true   | ¤     | ¤     | true = null   | is null
 false  | true  | false | false = true  | is false
 false  | false | true  | false = false | is true
 false  | ¤     | ¤     | false = null  | is null
 ¤      | true  | ¤     | null = true   | is null
 ¤      | false | ¤     | null = false  | is null
 ¤      | ¤     | ¤     | null = null   | is null
(9 rows)
```

You can have tuple attributes as Booleans too, and PostgreSQL includes specific aggregates for them:

```
  select year,
         format('%s %s', forename, surname) as name,
         count(*) as ran,
         count(*) filter(where position = 1) as won,
         count(*) filter(where position is not null) as finished,
         sum(points) as points
    from      races
```

```
        join results using(raceid)
        join drivers using(driverid)
group by year, drivers.driverid
  having bool_and(position = 1) is true
order by year, points desc;
```

In this query, we show the *bool_and()* aggregates that returns true when all the Boolean input values are true. Like every *aggregate* it silently bypasses *null* by default, so in our expression of *bool_and(position = 1)* we will filter F1 drivers who won all the races they finished in a specific season:

```
 year |        name         | ran | won | finished | points
══════╪═════════════════════╪═════╪═════╪══════════╪════════
 1950 | Juan Fangio         |   7 |   3 |        3 |     27
 1950 | Johnnie Parsons     |   1 |   1 |        1 |      9
 1951 | Lee Wallard         |   1 |   1 |        1 |      9
 1952 | Alberto Ascari      |   7 |   6 |        6 |   53.5
 1952 | Troy Ruttman        |   1 |   1 |        1 |      8
 1953 | Bill Vukovich       |   1 |   1 |        1 |      9
 1954 | Bill Vukovich       |   1 |   1 |        1 |      8
 1955 | Bob Sweikert        |   1 |   1 |        1 |      8
 1956 | Pat Flaherty        |   1 |   1 |        1 |      8
 1956 | Luigi Musso         |   4 |   1 |        1 |      5
 1957 | Sam Hanks           |   1 |   1 |        1 |      8
 1958 | Jimmy Bryan         |   1 |   1 |        1 |      8
 1959 | Rodger Ward         |   2 |   1 |        1 |      8
 1960 | Jim Rathmann        |   1 |   1 |        1 |      8
 1961 | Giancarlo Baghetti  |   3 |   1 |        1 |      9
 1966 | Ludovico Scarfiotti |   2 |   1 |        1 |      9
 1968 | Jim Clark           |   1 |   1 |        1 |      9
(17 rows)
```

If we want to restrict the results to drivers who finished *and* won every race they entered in a season we need to then write *having bool_and(position is not distinct from 1) is true*, and then the result set only contains those drivers who participated in a single race in the season.

The main thing about Booleans is the set of operators to use with them:

- The = doesn't work as you think it would
- Use *is* to test against literal *true*, *false* or *null* rather than =
- Remember to use the *is distinct from* and *is not distinct from* operators when you need them,
- Booleans can be aggregated thanks to *bool_and* and *bool_or*.

The main thing about Booleans in SQL is that they have three possible values:

true, *false* and *null*. Moreover the behavior with *null* is entirely ad-hoc, so either you remember it or you remember to check your assumptions. For more about this topic, you can read What is the deal with NULLs? from PostgreSQL Contributor Jeff Davis.

Character and Text

PostgreSQL knows how to deal with characters and text, and it implements several data types for that, all documented in the character types chapter of the documentation.

About the data type itself, it must be noted that *text* and *varchar* are the same thing as far as PostgreSQL is concerned, and *character varying* is an alias for *varchar*. When using *varchar(15)* you're basically telling PostgreSQL to manage a *text* column with a *check* constraint of 15 characters.

Yes PostgreSQL knows how to count characters even with Unicode encoding, more on that later.

There's a very rich set of PostgreSQL functions to process text — you can find them all in the string functions and operators documentation chapter — with functions such as *overlay()*, *substring()*, *position()* or *trim()*. Or aggregates such as *string_agg()*. There are also *regular expression* functions, including the very powerful *regexp_split_to_table()*.

For more about PostgreSQL regular expressions, read the main documentation about them in the pattern matching chapter.

Additionnaly to the classic *like* and *ilike* patterns and to the SQL standard *similar to* operators, PostgreSQL embeds support for a full-blown *regular expression* matching engine. The main operator implementing regexp is ~, and then you find the derivatives for *not matching* and *match either case*. In total, we have four operators: ~, !~, ~* and !~*.

Note that PostgreSQL also supports indexing for regular expressions thanks to its trigram extension: pg_trgm.

The *regular expression* split functions are powerful in many use cases. In particular, they are very helpful when you have to work with a messy schema, in which a single column represents several bits of information in a pseudo specified way. An example of such a dataset is available in open data: the Archives de la Planète

or "planet archives". The data is available as CSV and once loaded looks like this:

```
\pset format wrapped
\pset columns 70
table opendata.archives_planete limit 1;
```

And we get the following sample data, all in French (but it doesn't matter very much for our purposes here):

```
-[ RECORD 1 ]-------------------------------------------
id          | IF39599
inventory   | A 2 037
orig_legend | Serbie, Monastir Bitolj, Un Turc
legend      | Un Turc
location    | Monastir (actuelle Bitola), Macédoine
date        | mai 1913
operator    | Auguste Léon
...
themes      | Habillement > Habillement traditionnel,Etres ···
            |···humains > Homme,Etres humains > Portrait,Rela···
            |···tions internationales > Présence étrangère
...
collection  | Archives de la Planète
...
```

You can see that the *themes* column contains several categories for a single entry, separated with a comma. Within that comma separated list, we find another classification, this time separated with a greater than sign, which looks like a hierarchical categorization of the themes.

So this picture id *IF39599* actually is relevant to that series of themes:

```
   id    |           cat1            |           cat2
═════════╪═══════════════════════════╪═══════════════════════════
 IF39599 | Habillement               | Habillement traditionnel
 IF39599 | Etres humains             | Homme
 IF39599 | Etres humains             | Portrait
 IF39599 | Relations internationales | Présence étrangère
(4 rows)
```

The question is, how do we get that information? Also, is it possible to have an idea of the distribution of the whole data set in relation to the categories embedded in the *themes* column?

With PostgreSQL, this is easy enough to achieve. First, we are going to split the *themes* column using a regular expression:

```
select id, regexp_split_to_table(themes, ',')
```

```
  from opendata.archives_planete
 where id = 'IF39599';
```

We get the following table:

```
   id    |             regexp_split_to_table
═════════╪═══════════════════════════════════════════════
 IF39599 | Habillement > Habillement traditionnel
 IF39599 | Etres humains > Homme
 IF39599 | Etres humains > Portrait
 IF39599 | Relations internationales > Présence étrangère
(4 rows)
```

Now that we have a table with an entry per theme for the same document, we can further split each entry into the two-levels category that it looks like. We do that this time with *regexp_split_to_array()* so as to keep the categories together:

```
select id,
       regexp_split_to_array(
         regexp_split_to_table(themes, ','),
         ' > ')
       as categories
  from opendata.archives_planete
 where id = 'IF39599';
```

And now we have:

```
   id    |                     categories
═════════╪═══════════════════════════════════════════════════
 IF39599 | {Habillement,"Habillement traditionnel"}
 IF39599 | {"Etres humains",Homme}
 IF39599 | {"Etres humains",Portrait}
 IF39599 | {"Relations internationales","Présence étrangère"}
(4 rows)
```

We're almost there. For the content to be normalized we want to have the categories in their own separate columns, say *category* and *subcategory*:

```
with categories(id, categories) as
 (
   select id,
          regexp_split_to_array(
            regexp_split_to_table(themes, ','),
            ' > ')
          as categories
     from opendata.archives_planete
 )
 select id,
        categories[1] as category,
        categories[2] as subcategory
```

```
    from categories
   where id = 'IF39599';
```

And now we make sense of the open data:

```
   id    |         category          |       subcategory
═════════╪═══════════════════════════╪═══════════════════════════
 IF39599 | Habillement               | Habillement traditionnel
 IF39599 | Etres humains             | Homme
 IF39599 | Etres humains             | Portrait
 IF39599 | Relations internationales | Présence étrangère
(4 rows)
```

As a side note, cleaning up a data set after you've imported it into PostgreSQL makes the difference clear between the classic *ETL* jobs (extract, transform, load) and the powerful *ELT* jobs (extract, load, transform) where you can transform your data using a data processing language: SQL.

So, now that we know how to have a clear view of the dataset, let's inquire about the categories used in our dataset:

```
with categories(id, categories) as
  (
    select id,
           regexp_split_to_array(
             regexp_split_to_table(themes, ','),
             ' > ')
           as categories
      from opendata.archives_planete
  )
  select categories[1] as category,
         categories[2] as subcategory,
         count(*)
    from categories
group by rollup(category, subcategory);
```

That query returns 175 rows, so here's an extract only:

```
       category         |         subcategory          | count
════════════════════════╪══════════════════════════════╪═══════
 Activite économique    | Agriculture / élevage        |   138
 Activite économique    | Artisanat                    |    81
 Activite économique    | Banque / finances            |     2
 Activite économique    | Boutique / magasin           |    39
 Activite économique    | Commerce ambulant            |     5
 Activite économique    | Commerce extérieur           |     1
 Activite économique    | Cueillette / chasse          |     9
...
 Art                    | Peinture                     |    15
```

```
 Art                    | Renaissance                  |    52
 Art                    | Sculpture                    |    87
 Art                    | Théâtre                      |     7
 Art                    | ¤                            |   333
...
 Habillement            | Uniforme scolaire            |     1
 Habillement            | Vêtement de travail          |     3
 Habillement            | ¤                            |   163
 Habitat / Architecture | Architecture civile publique |    37
 Habitat / Architecture | Architecture commerciale     |    24
 Habitat / Architecture | Architecture de jardin       |    31
...
 Vie quotidienne        | Vie domestique               |     8
 Vie quotidienne        | Vie rurale                   |     5
 Vie quotidienne        | ¤                            |    64
 ¤                      | ¤                            |  4449
(175 rows)
```

Each *subcategory* appears only within the same *category* each time, and we've chosen to do a *roll up* analysis of our data set here. Other *grouping sets* are available, such as the *cube*, or manually editing the dimensions you're interested into.

In an *ELT* assignment, we would create a new *categories* table containing each entry we saw in the rollup query only once, as a catalog, and an association table in between the main *opendata.archives_planete* table and this categories catalog, where each archive entry might have several categories and subcategories assigned and each category, of course, might have several archive entries assigned.

Here, the topic is about text function processing in PostgreSQL, so we just run the query against the base data set.

Finally, when mentioning advanced string matching and the *regular expression*, we must also mention PostgreSQL's implementation of a full text search with support for *documents*, advanced *text search queries*, *ranking*, *highlighting*, *pluggable parsers*, *dictionaries* and *stemmers*, *synonyms*, and *thesaurus*. Additionally, it's possible to configure all those pieces. This is material for another book, so if you need advanced searches of documents that you manage in PostgreSQL please read the documentation about it. There are also many online resources on the topic too.

Server Encoding and Client Encoding

When addressing the text datatype we must mention encoding settings, and possibly also issues. An encoding is a particular representation of characters in bits and bytes. In the *ASCII* encoding the letter `A` is encoded as the 7-bits byte `1000001`, or 65 in decimal, or 41 in hexadecimal. All those numbers are going to be written the same way on-disk, and the letter `A` too.

The *SQL_ASCII* encoding is a trap you need to avoid falling into. To know which encoding your database is using, run the *psql* command `\l`:

```
                                  List of databases
   Name    |  Owner   | Encoding |   Collate   |    Ctype    | ···
═══════════╪══════════╪══════════╪═════════════╪═════════════╪═══
 chinook   | dim      | UTF8     | en_US.UTF-8 | en_US.UTF-8 | ···
 f1db      | dim      | UTF8     | en_US.UTF-8 | en_US.UTF-8 | ···
 pgloader  | dim      | UTF8     | en_US.UTF-8 | en_US.UTF-8 | ···
 template0 | postgres | UTF8     | en_US.UTF-8 | en_US.UTF-8 | ···
 template1 | postgres | UTF8     | en_US.UTF-8 | en_US.UTF-8 | ···
 yesql     | dim      | UTF8     | en_US.UTF-8 | en_US.UTF-8 | ···
(6 rows)
```

In this output, I've stripped down the last column of output for better integration for the page size here, so you don't get to see the *Access privileges* for those databases.

The encoding here is *UTF8* which is the best choice these days, and you can see that the collation and ctype are English based in the *UTF-8* encoding, which is good for my installation. You might, of course, pick something else.

The non-encoding *SQL_ASCII* accepts any data you throw at it, whereas the *UTF8* encoding (and some others) do check for valid input. Never use *SQL_ASCII*, as you will not be able to retrieve data in any encoding and will lose data because of that! Migrating away from *SQL_ASCII* to a proper encoding such as *UTF8* is possible but lossy and complex.

You can also have an *UTF8* encoded database and use a legacy application (or programming language) that doesn't know how to handle Unicode properly. In that case, you can ask PostgreSQL to convert all and any data on the fly between the server-side encoding and your favorite client-side encoding, thanks to the *client_encoding* setting.

```
show client_encoding;
```

Here again, we use UTF8 client side, which allows handling French accentuated characters we saw previously.

```
 client_encoding
═════════════════
 UTF8
(1 row)
```

Be aware that not all combinations of *server encoding* and *client encoding* make sense. While it is possible for PostgreSQL to communicate with your application using the *latin1* encoding on the client side if the server side dataset includes texts in incompatible encodings, PostgreSQL will issue an error. Such texts might be written using non-Latin scripts such as Cyrillic, Chinese, Japanese, Arabic or other languages.

From the Emacs facility `M-x view-hello-file`, here's a table with spelling of hello in plenty of different languages and scripts, all encoded in *UTF8*:

```
          language          │            hello
════════════════════════════╪═══════════════════════════════
 Czech (čeština)            │ Dobrý den
 Danish (dansk)             │ Hej / Goddag / Halløj
 Dutch (Nederlands)         │ Hallo / Dag
 English /ˈɪŋglɪʃ/          │ Hello
 Esperanto                  │ Saluton (Eĥoŝanĝo ĉiuĵaŭde)
 Estonian (eesti keel)      │ Tere päevast / Tere õhtust
 Finnish (suomi)            │ Hei / Hyvää päivää
 French (français)          │ Bonjour / Salut
 Georgian (ქართველი)        │ გამარჯობა
 German (Deutsch)           │ Guten Tag / Grüß Gott
 Greek (ελληνικά)           │ Γειά σας
 Greek, ancient (ἑλληνική)  │ Οὗλέ τε καὶ μέγα χαῖρε
 Hungarian (magyar)         │ Szép jó napot!
 Italian (italiano)         │ Ciao / Buon giorno
 Maltese (il-Malti)         │ Bonġu / Saħħa
 Mathematics                │ ∀ p ∈ world • hello p  □
 Mongolian (монгол хэл)     │ Сайн байна уу?
 Norwegian (norsk)          │ Hei / God dag
 Polish  (język polski)     │ Dzień dobry! / Cześć!
 Russian (русский)          │ Здра́вствуйте!
 Slovak (slovenčina)        │ Dobrý deň
 Slovenian (slovenščina)    │ Pozdravljeni!
 Spanish (español)          │ ¡Hola!
 Swedish (svenska)          │ Hej / Goddag / Hallå
 Turkish (Türkçe)           │ Merhaba
 Ukrainian (українська)     │ Вітаю
 Vietnamese (ti□ ng Việt)    │ Chào bạn
```

```
Japanese (日本語)           | こんにちは / □□□□□
Chinese (中文, 普通话, 汉语) | 你好
Cantonese (粵語, 廣東話)     | 早晨, 你好
```

Now, of course, I can't have that data sent to me in *latin1*:

```
yesql# set client_encoding to latin1;
SET
yesql# select * from hello where language ~ 'Georgian';
ERROR:  character with byte sequence 0xe1 0x83 0xa5 in encoding "UTF8" ⏎
has no equivalent in encoding "LATIN1"
yesql# reset client_encoding ;
RESET
```

So if it's possible for you, use *UTF-8* encoding and you'll have a much simpler life. It must be noted that Unicode encoding makes comparing and sorting text a rather costly operation. That said being fast and wrong is not an option, so we are going to still use unicode text!

Numbers

PostgreSQL implement multiple data types to handle numbers, as seen in the documentation chapter about numeric types:

- *integer*, 32 bits signed numbers
- *bigint*, 64 bits signed numbers
- *smallint*, 16 bits signed numbers
- *numeric*, arbitrary precision numbers
- *real*, 32 bits floating point numbers with 6 decimal digits precision
- *double precision*, 64 bits floating point numbers with 15 decimal digits precision

We mentioned before that the SQL query system is statically typed, and PostgreSQL must establish the data type of every column of a query input and result-set before being able to plan and execute it. For numbers, it means that the type of every number literal must be derived at query parsing time.

In the following query, we count how many times a driver won a race when he started in pole position, per season, and return the ten drivers having done that the most in all the records or Formula One results. The query uses integer expressions *grid = 1* and *position = 1* and PostgreSQL is left to figure out which data type does that literal value 1 belong to.

It could be an *smallint*, an *integer* or a *bigint*. It could also be a *numeric* value. Of course knowing that the *grid* and *position* columns are of type *bigint* might have an impact on the parsing choice here.

```
  select year,
         drivers.code,
         format('%s %s', forename, surname) as name,
         count(*)
    from results
         join races using(raceid)
         join drivers using(driverid)
   where grid = 1
     and position = 1
group by year, drivers.driverid
order by count desc
   limit 10;
```

Which by the way gives:

```
 year | code |        name         | count
══════╪══════╪═════════════════════╪═══════
 1992 | ¤    | Nigel Mansell       |     9
 2011 | VET  | Sebastian Vettel    |     9
 2013 | VET  | Sebastian Vettel    |     8
 2004 | MSC  | Michael Schumacher  |     8
 2016 | HAM  | Lewis Hamilton      |     7
 2015 | HAM  | Lewis Hamilton      |     7
 1988 | ¤    | Ayrton Senna        |     7
 1991 | ¤    | Ayrton Senna        |     7
 2001 | MSC  | Michael Schumacher  |     6
 2014 | HAM  | Lewis Hamilton      |     6
(10 rows)
```

Also impacting on the PostgreSQL parsing choice of a data type for the 1 literal is the = operator, which exists in three different variants when its left operand is a *bigint* value:

```
  select oprname,
         oprcode::regproc,
         oprleft::regtype,
         oprright::regtype,
         oprresult::regtype
    from pg_operator
   where oprname = '='
     and oprleft::regtype = 'bigint'::regtype;
```

We can see that PostgreSQL must support the = operator for every possible combination of its integer data types:

```
 oprname | oprcode | oprleft | oprright | oprresult
═════════╪═════════╪═════════╪══════════╪═══════════
 =       | int8eq  | bigint  | bigint   | boolean
 =       | int84eq | bigint  | integer  | boolean
 =       | int82eq | bigint  | smallint | boolean
(3 rows)
```

Short of that, we would have to use decorated literals for numbers in all our queries, writing:

```
    where grid = bigint '1' and position = bigint '1'
```

The combinatorial explosion of internal operators and support functions for comparing numbers is the reason why the PostgreSQL project has chosen to have a minimum number of numeric data types: the impacts of adding another one is huge in terms of query planning time and internal data structure sizing. That's why there are no *unsigned* numeric data types in PostgreSQL.

Floating Point Numbers

Adding to integer data type support, PostgreSQL also has support for floating point numbers. Please take some time to read What Every Programmer Should Know About Floating-Point Arithmetic before considering any serious use of floating point numbers. In short, there are some numbers that can't be represented in base 10, such as 1/3. In base 2 also, some numbers are not possible to represent, and it's a different set than in base 10. So in base 2, you can't possibly represent 1/5 or 1/10, for example.

In short, understand what you're doing when using *real* or *double precision* data types, and never use them to deal with money. Use either *numeric* which provides arbitrary precision or an *integer* based representation of the money.

Sequences and the Serial Pseudo Data Type

Other kinds of numeric data types in PostgreSQL are the *smallserial*, *serial* and *bigserial* data types. They actually are *pseudo types*: the parser recognize their syntax, but then transforms them into something else entirely. Straight from the excellent PostgreSQL documentation again:

```
CREATE TABLE tablename (
    colname SERIAL
```

```
);
```

This is equivalent to specifying:

```
CREATE SEQUENCE tablename_colname_seq;
CREATE TABLE tablename (
    colname integer NOT NULL DEFAULT nextval('tablename_colname_seq')
);
ALTER SEQUENCE tablename_colname_seq OWNED BY tablename.colname;
```

The *sequence* SQL object is covered by the SQL standard and documented in the create sequence manual entry for PostgreSQL. This object is the only one in SQL with a non-transactional behavior. Of course, that's on purpose, so that multiple sessions can get the next number from the sequence concurrently, without having to then wait until *commit;* to decide if they can keep their sequence number.

From the docs:

> Sequences are based on bigint arithmetic, so the range cannot exceed the range of an eight-byte integer (-9223372036854775808 to 9223372036854775807).

So if you have a *serial* column, its real type is going to be *integer*, and as soon as the sequence generates a number that doesn't fit into signed 4-byte representation, you're going to have errors.

In the following example, we construct the situation in which we exhaust the *id* column (an *integer*) and still use the sequence to generate the next entry:

```
create table seq(id serial);
CREATE TABLE

select setval('public.seq_id_seq'::regclass, 2147483647);
   setval
════════════
 2147483647
(1 row)

yesql# insert into public.seq values (default);
ERROR:  integer out of range
```

That could happen to your application while in production if you use *serial* rather than *bigserial*. If you need a sequence and need to restrict your column to 4-byte integers, then you need to implement a maintenance policy around the fact that the sequence is 8 bytes and the hosting column only 4.

Universally Unique Identifier: UUID

A universally unique identifier (*UUID*) is a 128-bit number used to identify information in computer systems. The term globally unique identifier (GUID) is also used. PostgreSQL implements support for UUID, both for storing and processing them, and also with the *uuid-ossp* extension, for generating them.

If you need to generate UUIDs from PostgreSQL, which we do in order to cover the topic in this book, then install the extension. The extension is part of the PostgreSQL contribs, so you need to have that OS package installed.

```
create extension "uuid-ossp";
```

Now we can have a look at those UUIDs:

```
select uuid_generate_v4()
  from generate_series(1, 10) as t(x);
```

Here's a list of locally generated UUID v4:

```
           uuid_generate_v4
═══════════════════════════════════════
 fbb850cc-dd26-4904-96ef-15ad8dfaff07
 0ab19b19-c407-410d-8684-1c3c7f978f49
 5f401a04-2c58-4cb1-b203-ae2b2a1a4a5e
 d5043405-7c03-40b1-bc71-aa1e15e1bbf4
 33c98c8a-a24b-4a04-807f-33803faa5f0a
 c68b46eb-b94f-4b74-aecf-2719516994b7
 5bf5ec69-cdbf-4bd1-a533-7e0eb266f709
 77660621-7a9b-4e59-a93a-2b33977e84a7
 881dc4f4-b587-4592-a720-81d9c7e15c63
 1e879ef4-6f1f-4835-878a-8800d5e9d4e0
(10 rows)
```

Even if you generate UUIDs from your application, managing them as a proper UUID in PostgreSQL is a good idea, as PostgreSQL actually stores the binary value of the UUID on 128 bits (or 16 bytes) rather than way more when storing the text representation of an UUID:

```
select pg_column_size(uuid 'fbb850cc-dd26-4904-96ef-15ad8dfaff07')
       as uuid_bytes,

       pg_column_size('fbb850cc-dd26-4904-96ef-15ad8dfaff07')
       as uuid_string_bytes;
```

```
 uuid_bytes │ uuid_string_bytes
════════════╪═══════════════════
```

```
3 |          16 |                37
4 | (1 row)
```

Should we use UUIDs as identifiers in our database schemas? We get back to that question in the next chapter.

Bytea and Bitstring

PostgreSQL can store and process raw binary values, which is sometimes useful. Binary columns are limited to about 1 GB in size (8 bytes of this are used in the header out of this). Those types are documented in the PostgreSQL chapter entitled Binary Data Types.

While it's possible to store large binary data that way, PostgreSQL doesn't implement a chunk API and will systematically fetch the whole content when the column is included in your queries output. That means loading the content from disk to memory, pushing it through the network and handling it as a whole in-memory on the client-side, so it's not always the best solution around.

That said, when storing binary content in PostgreSQL it is then automatically part of your online backups and recovery solution, and the online backups are transactional. So if you need to have binary content with transactional properties, *bytea* might be exactly what you need.

Date/Time and Time Zones

Handling dates and time and time zones is a very complex matter, and on this topic, you can read Erik Naggum's piece The Long, Painful History of Time.

The PostgreSQL documentation chapters with the titles Date/Time Types, Data Type Formatting Functions, and Date/Time Functions and Operators cover all you need to know about date, time, timestamps, and time zones with PostgreSQL.

The first question we need to answer here is about using timestamps with or without *time zones* from our applications. The answer is simple: always use *timestamps WITH time zones*.

A common myth is that storing time zones will certainly add to your storage and memory footprint. It's actually not the case:

```
select pg_column_size(timestamp without time zone 'now'),
       pg_column_size(timestamp with time zone 'now');
```

```
 pg_column_size | pg_column_size
════════════════╪════════════════
              8 │              8
(1 row)
```

PostgreSQL defaults to using *bigint* internally to store timestamps, and the on-disk and in-memory format are the same with or without time zone support. Here's their whole type definition in the PostgreSQL source code (in `src/include/datatype/timestamp.h`):

```
typedef int64 Timestamp;
typedef int64 TimestampTz;
```

From the PostgreSQL documentation for timestamps, here's how it works:

> For timestamp with time zone, the internally stored value is always in UTC (Universal Coordinated Time, traditionally known as Greenwich Mean Time, GMT). An input value that has an explicit time zone specified is converted to UTC using the appropriate offset for that time zone. If no time zone is stated in the input string, then it is assumed to be in the time zone indicated by the system's TimeZone parameter, and is converted to UTC using the offset for the timezone zone.

PostgreSQL doesn't store the time zone they come from with your timestamp. Instead it converts to and from the input and output timezone much like we've seen for text with *client_encoding*.

```
begin;

drop table if exists tstz;

create table tstz(ts timestamp, tstz timestamptz);

set timezone to 'Europe/Paris';
select now();
insert into tstz values(now(), now());

set timezone to 'Pacific/Tahiti';
select now();
insert into tstz values(now(), now());

set timezone to 'Europe/Paris';
table tstz;

```

```
set timezone to 'Pacific/Tahiti';
table tstz;

commit;
```

In this script, we play with the client's setting *timezone* and change from a French value to another French value, as Tahiti is an island in the Pacific that is part of France. Here's the full output as seen when running this script, when launched with `psql -a -f tz.sql`:

```
BEGIN
...
set timezone to 'Europe/Paris';
SET
select now();
              now
═══════════════════════════════
 2017-08-19 14:22:11.802755+02
(1 row)

insert into tstz values(now(), now());
INSERT 0 1
set timezone to 'Pacific/Tahiti';
SET
select now();
              now
═══════════════════════════════
 2017-08-19 02:22:11.802755-10
(1 row)

insert into tstz values(now(), now());
INSERT 0 1
set timezone to 'Europe/Paris';
SET
table tstz;
             ts             │             tstz
════════════════════════════╪═══════════════════════════════
 2017-08-19 14:22:11.802755 │ 2017-08-19 14:22:11.802755+02
 2017-08-19 02:22:11.802755 │ 2017-08-19 14:22:11.802755+02
(2 rows)

set timezone to 'Pacific/Tahiti';
SET
table tstz;
             ts             │             tstz
════════════════════════════╪═══════════════════════════════
 2017-08-19 14:22:11.802755 │ 2017-08-19 02:22:11.802755-10
 2017-08-19 02:22:11.802755 │ 2017-08-19 02:22:11.802755-10
(2 rows)

```

```
41 commit;
42 COMMIT
```

First, we see that the *now()* function always returns the same timestamp within a single transaction. If you want to see the clock running while in a transaction, use the *clock_timestamp()* function instead.

Then, we see that when we change the *timezone* client setting, PostgreSQL outputs timestamps as expected, in the selected timezone. If you manage an application with users in different time zones and you want to display time in their own local preferred time zone, then you can *set timezone* in your application code before doing any timestamp related processing, and have PostgreSQL do all the hard work for you.

Finally, when selecting back from the *tstz* table, we see that the column *tstz* realizes that both the inserted values actually are the same point in time, but seen from different places in the world, whereas the *ts* column makes it impossible to compare the entries and realize they actually happened at exactly the same time.

As said before, even when using timestamps *with* time zone, PostgreSQL will not store the time zone in use at input time, so there's no way from our *tstz* table to know that the entries are at the same time but just from different places.

The opening of this section links to The Long, Painful History of Time, and if you didn't read it yet, maybe now is a good time. Allow me to quote a relevant part of the article here:

> *The basic problem with time is that we need to express both time and place whenever we want to place some event in time and space, yet we tend to assume spatial coordinates even more than we assume temporal coordinates, and in the case of time in ordinary communication, it is simply left out entirely. Despite the existence of time zones and strange daylight saving time regimes around the world, most people are blithely unaware of their own time zone and certainly of how it relates to standard references. Most people are equally unaware that by choosing a notation that is close to the spoken or written expression of dates, they make it meaningless to people who may not share the culture, but can still read the language. It is unlikely that people will change enough to put these issues to rest, so responsible computer people need to address the issues and resist the otherwise overpowering urge to abbreviate and drop context.*

Several options are available to input timestamp values in PostgreSQL. The easiest is to use the ISO format, so if your application's code allows that you're all set. In the following example we leave the time zone out, as usually, it's handled by the *timezone* session parameter, as seen above. If you need to, of course, you can input the time zone in the timestamp values directly:

```
select timestamptz '2017-01-08 04:05:06',
       timestamptz '2017-01-08 04:05:06+02';
```

At insert or update time, use the same literal strings without the type decoration: PostgreSQL already knows the type of the target column, and it uses that to parse the values literal in the DML statement.

Some application use-cases only need the date. Then use the *date* data type in PostgreSQL. It is of course then possible to compare a *date* and a *timestamp with time zone* in your SQL queries, and even to append a time offset on top of your date to construct a *timestamp*.

Time Intervals

PostgreSQL implements an *interval* data type along with the *time*, *date* and *timestamptz* data types. An *interval* describes a duration, like a month or two weeks, or even a millisecond:

```
set intervalstyle to postgres;

select interval '1 month',
       interval '2 weeks',
       2 * interval '1 week',
       78389 * interval '1 ms';
```

The default PostgreSQL output looks like this:

```
 interval | interval | ?column? |   ?column?
══════════╪══════════╪══════════╪═══════════════
 1 mon    | 14 days  | 14 days  | 00:01:18.389
(1 row)
```

Several *intervalstyle* values are possible, and the setting *postgres_verbose* is quite nice for interactive *psql* sessions:

```
set intervalstyle to postgres_verbose;

select interval '1 month',
       interval '2 weeks',
```

```
       2 * interval '1 week',
       78389 * interval '1 ms';
```

This time we get a user-friendly output:

```
 interval | interval  | ?column?  |      ?column?
══════════╪═══════════╪═══════════╪═══════════════════
 @ 1 mon  | @ 14 days | @ 14 days | @ 1 min 18.389 secs
(1 row)
```

How long is a month? Well, it depends on which month, and PostgreSQL knows that:

```
select d::date as month,

       (d + interval '1 month' - interval '1 day')::date as month_end,

       (d + interval '1 month')::date as next_month,

       (d + interval '1 month')::date - d::date as days

  from generate_series(
                       date '2017-01-01',
                       date '2017-12-01',
                       interval '1 month'
                      )
       as t(d);
```

When you attach an *interval* to a date or timestamp in PostgreSQL then the number of days in that interval adjusts to the specific calendar entry you've picked. Otherwise, an interval of a month is considered to be 30 days. Here we see that computing the last day of February is very easy:

```
   month    | month_end  | next_month | days
════════════╪════════════╪════════════╪══════
 2017-01-01 | 2017-01-31 | 2017-02-01 |   31
 2017-02-01 | 2017-02-28 | 2017-03-01 |   28
 2017-03-01 | 2017-03-31 | 2017-04-01 |   31
 2017-04-01 | 2017-04-30 | 2017-05-01 |   30
 2017-05-01 | 2017-05-31 | 2017-06-01 |   31
 2017-06-01 | 2017-06-30 | 2017-07-01 |   30
 2017-07-01 | 2017-07-31 | 2017-08-01 |   31
 2017-08-01 | 2017-08-31 | 2017-09-01 |   31
 2017-09-01 | 2017-09-30 | 2017-10-01 |   30
 2017-10-01 | 2017-10-31 | 2017-11-01 |   31
 2017-11-01 | 2017-11-30 | 2017-12-01 |   30
 2017-12-01 | 2017-12-31 | 2018-01-01 |   31
(12 rows)
```

PostgreSQL's implementation of the calendar is very good, so use it!

Date/Time Processing and Querying

Once the application's data, or rather the user data is properly stored as timestamp with time zone, PostgreSQL allows implementing all the processing you need to.

As an example data set this time we're playing with *git* history. The PostgreSQL and pgloader project history have been loaded into the *commitlog* table thanks to the *git log* command, with a custom format, and some post-processing — properly splitting up the commit's subjects and escaping its content. Here's for example the most recent commit registered in our local *commitlog* table:

```
  select project, hash, author, ats, committer, cts, subject
    from commitlog
   where project = 'postgresql'
order by ats desc
   limit 1;
```

The column names *ats* and *cts* respectively stand for *author commit timestamp* and *committer commit timestamp*, and the *subject* is the first line of the commit message, as per the *git log* format *%s*.

To get the most recent entry from a table we *order by* dates in *descending* order then *limit* the result set to a single entry, and we get a single line of output:

```
-[ RECORD 1 ]-----------------------------------------------------------
project   | postgresql
hash      | b1c2d76a2fcef812af0be3343082414d401909c8
author    | Tom Lane
ats       | 2017-08-19 19:39:37+02
committer | Tom Lane
cts       | 2017-08-19 19:39:51+02
subject   | Fix possible core dump in parallel restore when using a TOC list.
```

With timestamps, we can compute time-based reporting, such as how many commits each project received each year in their whole history:

```
  select extract(year from ats) as year,
         count(*) filter(where project = 'postgresql') as postgresql,
         count(*) filter(where project = 'pgloader') as pgloader
    from commitlog
group by year
order by year;
```

As we have only loaded two projects in our *commitlog* table, the output is better with a *pivot* query. We can see more than 20 years of sustained activity for the PostgreSQL project, and a less active project for pgloader:

```
 year | postgresql | pgloader
======+============+==========
 1996 |        876 |        0
 1997 |       1698 |        0
 1998 |       1744 |        0
 1999 |       1788 |        0
 2000 |       2535 |        0
 2001 |       3061 |        0
 2002 |       2654 |        0
 2003 |       2416 |        0
 2004 |       2548 |        0
 2005 |       2418 |        3
 2006 |       2153 |        3
 2007 |       2188 |       42
 2008 |       1651 |       63
 2009 |       1389 |        3
 2010 |       1800 |       29
 2011 |       2030 |        2
 2012 |       1605 |        2
 2013 |       1368 |      385
 2014 |       1745 |      367
 2015 |       1815 |      202
 2016 |       2086 |      136
 2017 |       1721 |      142
(22 rows)
```

We can also build a reporting on the repartition of commits by weekday from the beginning of the project, in order to guess if contributors are working on the project on the job only, or mostly during their free time (weekend).

```
  select extract(isodow from ats) as dow,
         to_char(ats, 'Day') as day,
         count(*) as commits,
         round(100.0*count(*)/sum(count(*)) over(), 2) as pct,
         repeat('■', (100*count(*)/sum(count(*)) over())::int) as hist
    from commitlog
   where project = 'postgresql'
group by dow, day
order by dow;
```

It seems that our PostgreSQL committers tend to work whenever they feel like it, but less so on the weekend. The project's lucky enough to have a solid team of committers being paid to work on PostgreSQL:

```
 dow │    day    │ commits │  pct  │       hist
═════╪═══════════╪═════════╪═══════╪══════════════════
   1 │ Monday    │    6552 │ 15.14 │ ■■■■■■■■■■■■■■■
   2 │ Tuesday   │    7164 │ 16.55 │ ■■■■■■■■■■■■■■■■■
   3 │ Wednesday │    6477 │ 14.96 │ ■■■■■■■■■■■■■■■
   4 │ Thursday  │    7061 │ 16.31 │ ■■■■■■■■■■■■■■■■
   5 │ Friday    │    7008 │ 16.19 │ ■■■■■■■■■■■■■■■■
   6 │ Saturday  │    4690 │ 10.83 │ ■■■■■■■■■■
   7 │ Sunday    │    4337 │ 10.02 │ ■■■■■■■■■
(7 rows)
```

Another report we can build compares the author commit timestamp with the committer commit timestamp. Those are different, but by how much?

```
with perc_arrays as
  (
       select project,
              avg(cts-ats) as average,
              percentile_cont(array[0.5, 0.9, 0.95, 0.99])
                 within group(order by cts-ats) as parr
         from commitlog
        where ats <> cts
     group by project
  )
 select project, average,
        parr[1] as median,
        parr[2] as "%90th",
        parr[3] as "%95th",
        parr[4] as "%99th"
   from perc_arrays;
```

Here's a detailed output of the time difference statistics, per project:

```
─[ RECORD 1 ]──────────────────────────────────
project │ pgloader
average │ @ 4 days 22 hours 7 mins 41.18 secs
median  │ @ 5 mins 21.5 secs
%90th   │ @ 1 day 20 hours 49 mins 49.2 secs
%95th   │ @ 25 days 15 hours 53 mins 48.15 secs
%99th   │ @ 169 days 24 hours 33 mins 26.18 secs
=[ RECORD 2 ]══════════════════════════════════
project │ postgres
average │ @ 1 day 10 hours 15 mins 9.706809 secs
median  │ @ 2 mins 4 secs
%90th   │ @ 1 hour 46 mins 13.5 secs
%95th   │ @ 1 day 17 hours 58 mins 7.5 secs
%99th   │ @ 40 days 20 hours 36 mins 43.1 secs
```

Reporting is a strong use case for SQL. Application will also send more classic

queries. We can show the commits for the PostgreSQL project for the 1st of June 2017:

```
\set day '2017-06-01'

  select ats::time,
         substring(hash from 1 for 8) as hash,
         substring(subject from 1 for 40) || '···' as subject
    from commitlog
   where project = 'postgresql'
     and ats >= date :'day'
     and ats  < date :'day' + interval '1 day'
order by ats;
```

It's tempting to use the *between* SQL operator, but we would then have to remember that *between* includes both its lower and upper bound and we would then have to compute the upper bound as the very last instant of the day. Using explicit *greater than or equal* and *less than* operators makes it possible to always compute the very first time of the day, which is easier, and well supported by PostgreSQL.

Also, using explicit bound checks allows us to use a single date literal in the query, so that's a single parameter to send from the application.

```
   ats     │   hash   │                  subject
═══════════╪══════════╪═══════════════════════════════════════════
 01:39:27 │ 3d79013b │ Make ALTER SEQUENCE, including RESTART, ···
 02:03:10 │ 66510455 │ Modify sequence catalog tuple before inv···
 04:35:33 │ de492c17 │ doc: Add note that DROP SUBSCRIPTION dro···
 19:32:55 │ e9a3c047 │ Always use -fPIC, not -fpic, when buildi···
 23:45:53 │ f112f175 │ Fix typo···
(5 rows)
```

Many data type formatting functions are available in PostgreSQL. In the previous query, although we chose to *cast* our timestamp with time zone entry down to a *time* value, we could have chosen another representation thanks to the *to_char* function:

```
set lc_time to 'fr_FR';

  select to_char(ats, 'TMDay TMDD TMMonth, HHam') as time,
         substring(hash from 1 for 8) as hash,
         substring(subject from 1 for 40) || '···' as subject
    from commitlog
   where project = 'postgresql'
     and ats >= date :'day'
     and ats  < date :'day' + interval '1 day'
order by ats;
```

And this time we have a French localized output for the time value:

```
1 │        time          │   hash   │                  subject
2 │══════════════════════╪══════════╪═══════════════════════════════════════════
3 │ Jeudi 01 Juin, 01am  │ 3d79013b │ Make ALTER SEQUENCE, including RESTART, ···
4 │ Jeudi 01 Juin, 02am  │ 66510455 │ Modify sequence catalog tuple before inv···
5 │ Jeudi 01 Juin, 04am  │ de492c17 │ doc: Add note that DROP SUBSCRIPTION dro···
6 │ Jeudi 01 Juin, 07pm  │ e9a3c047 │ Always use -fPIC, not -fpic, when buildi···
7 │ Jeudi 01 Juin, 11pm  │ f112f175 │ Fix typo···
8 │(5 rows)
```

Take some time to familiarize yourself with the time and date support that PostgreSQL comes with out of the box. Some very useful functions such as *date_trunc()* are not shown here, and you also will find more gems.

While most programming languages nowadays include the same kind of feature set, having this processing feature set right in PostgreSQL makes sense in several use cases:

- It makes sense when the SQL logic or filtering you want to implement depends on the result of the processing (e.g. grouping by week).
- When you have several applications using the same logic, it's often easier to share a SQL query than to set up a distributed service API offering the same result in XML or JSON (a data format you then have to parse).
- When you want to reduce your run-time dependencies, it's a good idea to understand how much each architecture layer is able to support in your implementation.

Network Address Types

PostgreSQL includes support for both *cidr*, *inet*, and *macaddr* data types. Again, those types are bundled with indexing support and advanced functions and operator support.

The PostgreSQL documentation chapters entitled Network Address Types and Network Address Functions and Operators cover network address types.

Web servers logs are a classic source of data to process where we find network address types and The Honeynet Project has some free samples for us to play with. This time we're using the *Scan 34* entry. Here's how to load the sample data set, once cleaned into a proper CSV file:

```
begin;

drop table if exists access_log;

create table access_log
 (
  ip      inet,
  ts      timestamptz,
  request text,
  status  integer
 );

\copy access_log from 'access.csv' with csv delimiter ';'

commit;
```

The script used to cleanse the original data into a CSV that PostgreSQL is happy about implements a pretty simple transformation from

```
211.141.115.145 - - [13/Mar/2005:04:10:18 -0500] "GET / HTTP/1.1" 403 2898 "-" "Mozill
```

into

```
"211.141.115.145";"2005-05-13 04:10:18 -0500";"GET / HTTP/1.1";"403"
```

Being mostly interested into network address types, the transformation from the Apache access log format to CSV is lossy here, we keep only some of the fields we might be interested into.

One of the things that's possible to implement thanks to the PostgreSQL *inet* data type is an analysis of */24* networks that are to be found in the logs.

To enable that analysis, we can use the *set_masklen()* function which allows us to transforms an IP address into an arbitrary CIDR network address:

```
select distinct on (ip)
       ip,
       set_masklen(ip, 24) as inet_24,
       set_masklen(ip::cidr, 24) as cidr_24
  from access_log
 limit 10;
```

And we can see that if we keep the data type as *inet*, we still get the full IP address with the */24* network notation added. To have the *.0/24* notation we need to be using *cidr*:

```
      ip       |     inet_24       |     cidr_24
═══════════════╪═══════════════════╪═════════════════
 4.35.221.243  | 4.35.221.243/24   | 4.35.221.0/24
 4.152.207.126 | 4.152.207.126/24  | 4.152.207.0/24
```

```
 4.152.207.238 | 4.152.207.238/24 | 4.152.207.0/24
 4.249.111.162 | 4.249.111.162/24 | 4.249.111.0/24
 12.1.223.132  | 12.1.223.132/24  | 12.1.223.0/24
 12.8.192.60   | 12.8.192.60/24   | 12.8.192.0/24
 12.33.114.7   | 12.33.114.7/24   | 12.33.114.0/24
 12.47.120.130 | 12.47.120.130/24 | 12.47.120.0/24
 12.172.137.4  | 12.172.137.4/24  | 12.172.137.0/24
 18.194.1.122  | 18.194.1.122/24  | 18.194.1.0/24
(10 rows)
```

Of course, note that you could be analyzing other networks than */24*:

```
select distinct on (ip)
       ip,
       set_masklen(ip::cidr, 27) as cidr_27,
       set_masklen(ip::cidr, 28) as cidr_28
  from access_log
 limit 10;
```

This computes for us the proper starting ip addresses for our CIDR notation for us, of course. After all, what's the point of using proper data types if not for advanced processing?

```
      ip       |     cidr_27      |     cidr_28
═══════════════╪══════════════════╪══════════════════
 4.35.221.243  | 4.35.221.224/27  | 4.35.221.240/28
 4.152.207.126 | 4.152.207.96/27  | 4.152.207.112/28
 4.152.207.238 | 4.152.207.224/27 | 4.152.207.224/28
 4.249.111.162 | 4.249.111.160/27 | 4.249.111.160/28
 12.1.223.132  | 12.1.223.128/27  | 12.1.223.128/28
 12.8.192.60   | 12.8.192.32/27   | 12.8.192.48/28
 12.33.114.7   | 12.33.114.0/27   | 12.33.114.0/28
 12.47.120.130 | 12.47.120.128/27 | 12.47.120.128/28
 12.172.137.4  | 12.172.137.0/27  | 12.172.137.0/28
 18.194.1.122  | 18.194.1.96/27   | 18.194.1.112/28
(10 rows)
```

Equipped with this *set_masklen()* function, it's now easy to analyze our access logs using arbitrary CIDR network definitions.

```
  select set_masklen(ip::cidr, 24) as network,
         count(*) as requests,
         array_length(array_agg(distinct ip), 1) as ipcount
    from access_log
group by network
  having array_length(array_agg(distinct ip), 1) > 1
order by requests desc, ipcount desc;
```

In our case, we get the following result:

```
    network      | requests | ipcount
═════════════════╪══════════╪═════════
 4.152.207.0/24  |      140 |       2
 222.95.35.0/24  |       59 |       2
 211.59.0.0/24   |       32 |       2
 61.10.7.0/24    |       25 |      25
 222.166.160.0/24|       25 |      24
 219.153.10.0/24 |        7 |       3
 218.78.209.0/24 |        6 |       4
 193.109.122.0/24|        5 |       5
 204.102.106.0/24|        3 |       3
 66.134.74.0/24  |        2 |       2
 219.133.137.0/24|        2 |       2
 61.180.25.0/24  |        2 |       2
(12 rows)
```

Ranges

Range types are a unique feature of PostgreSQL, managing two dimensions of data in a single column, and allowing advanced processing. The main example is the *daterange* data type, which stores as a single value a lower and an upper bound of the range as a single value. This allows PostgreSQL to implement a concurrent safe check against *overlapping* ranges, as we're going to see in the next example.

As usual, read the PostgreSQL documentation chapters with the titles Range Types and Range Functions and Operators for complete information.

The International Monetary Fund publishes exchange rate archives by month for lots of currencies. An exchange rate is relevant from its publication until the next rate is published, which makes a very good use case for our PostgreSQL range types.

The following SQL script is the main part of the *ELT* script that has been used for this book. Only missing from this book's pages is the transformation script that pivots the available *tsv* file into the more interesting format we use here:

```
begin;

create schema if not exists raw;

-- Must be run as a Super User in your database instance
-- create extension if not exists btree_gist;

```

```
drop table if exists raw.rates, rates;

create table raw.rates
 (
  currency text,
  date     date,
  rate     numeric
 );

\copy raw.rates from 'rates.csv' with csv delimiter ';'

create table rates
 (
  currency text,
  validity daterange,
  rate     numeric,

  exclude using gist (currency with =,
                      validity with &&)
 );

insert into rates(currency, validity, rate)
     select currency,
            daterange(date,
                      lead(date) over(partition by currency
                                          order by date),
                      '[)'
                     )
            as validity,
            rate
       from raw.rates
   order by date;

commit;
```

In this SQL script, we first create a target table for loading the CSV file. The file contains lines with a currency name, a date of publication, and a rate as a *numeric* value. Once the data is loaded into this table, we can transform it into something more interesting to work with from an application, the *rates* table.

The *rates* table registers the rate value for a currency and a *validity* period, and uses an exclusion constraint that guarantees non-overlapping *validity* periods for any given *currency*:

```
exclude using gist (currency with =, validity with &&)
```

This expression reads: exclude any tuple where the currency is = to an existing currency in our table *AND* where the *validity* is overlapping with (&&) any existing validity in our table. This exclusion constraint is implemented in Post-

greSQL using a *GiST* index.

By default, *GiST* in PostgreSQL doesn't support one-dimensional data types that are meant to be covered by *B-tree* indexes. With exclusion constraints though, it's very interesting to extend *GiST* support for one-dimensional data types, and so we install the *btree_gist* extension, provided in PostgreSQL contrib package.

The script then fills in the *rates* table from the *raw.rates* we'd been importing in the previous step. The query uses the *lead()* window function to implement the specification spelled out in English earlier: *an exchange rate is relevant from its publication until the next rate is published*.

Here's how the data looks, with the following query targeting Euro rates:

```
  select currency, validity, rate
    from rates
   where currency = 'Euro'
order by validity
   limit 10;
```

We can see that the validity is a range of dates, and the standard output for this type is a closed range which includes the first entry and excludes the second one:

```
 currency │        validity         │   rate
══════════╪═════════════════════════╪══════════
 Euro     │ [2017-05-02,2017-05-03) │ 1.254600
 Euro     │ [2017-05-03,2017-05-04) │ 1.254030
 Euro     │ [2017-05-04,2017-05-05) │ 1.252780
 Euro     │ [2017-05-05,2017-05-08) │ 1.250510
 Euro     │ [2017-05-08,2017-05-09) │ 1.252880
 Euro     │ [2017-05-09,2017-05-10) │ 1.255280
 Euro     │ [2017-05-10,2017-05-11) │ 1.255300
 Euro     │ [2017-05-11,2017-05-12) │ 1.257320
 Euro     │ [2017-05-12,2017-05-15) │ 1.255530
 Euro     │ [2017-05-15,2017-05-16) │ 1.248960
(10 rows)
```

Having this data set with the exclusion constraint means that we know we have at most a single rate available at any point in time, which allows an application needing the rate for a specific time to write the following query:

\index{Operators!@}

```
select rate
  from rates
```

```
  where currency = 'Euro'
    and validity @> date '2017-05-18';
```

The operator @> reads *contains*, and PostgreSQL uses the exclusion constraint's index to solve that query efficiently:

```
    rate
═══════════
 1.240740
(1 row)
```

23

Denormalized Data Types

The main idea behind the PostgreSQL project from Michael Stonebraker has been *extensibility*. As a result of that design choice, some data types supported by PostgreSQL allow bypassing relational constraint. For instance, PostgreSQL supports *arrays*, which store several values in the same attribute value. In standard SQL, the content of the *array* would be completely opaque, so the array would be considered only as a whole.

The extensible design of PostgreSQL makes it possible to enrich the SQL language with new capabilities. Specific operators are built for denormalized data types and allow addressing values contained into an *array* or a *json* attribute value, integrating perfectly with SQL.

The following data types are built-in to PostgreSQL and extend its processing capabilities to another level.

Arrays

PostgreSQL has built-in support for arrays, which are documented in the Arrays and the Array Functions and Operators chapters. As introduced above, what's interesting with PostgreSQL is its ability to process array elements from SQL directly. This capability includes indexing facilities thanks to GIN indexing.

Arrays can be used to denormalize data and avoid lookup tables. A good rule of thumb for using them that way is that you mostly use the array as a whole, even

if you might at times search for elements in the array. Heavier processing is going to be more complex than a lookup table.

A classic example of a good use case for PostgreSQL arrays is user-defined tags. For the next example, 200,000 USA geolocated tweets have been loaded into PostgreSQL thanks to the following script:

```
begin;

create table tweet
 (
   id          bigint primary key,
   date        date,
   hour        time,
   uname       text,
   nickname    text,
   bio         text,
   message     text,
   favs        bigint,
   rts         bigint,
   latitude    double precision,
   longitude   double precision,
   country     text,
   place       text,
   picture     text,
   followers   bigint,
   following   bigint,
   listed      bigint,
   lang        text,
   url         text
 );

\copy tweet from 'tweets.csv' with csv header delimiter ';'

commit;
```

Once the data is loaded we can have a look at it:

```
\pset format wrapped
\pset columns 70
table tweet limit 1;
```

Here's what it looks like:

```
-[ RECORD 1 ]-------------------------------------------------------
id        | 721318437075685382
date      | 2016-04-16
hour      | 12:44:00
uname     | Bill Schulhoff
nickname  | BillSchulhoff
bio       | Husband,Dad,GrandDad,Ordained Minister, Umpire, Poker Pla···
```

```
           |···yer, Mets, Jets, Rangers, LI Ducks, Sons of Anarchy, Surv···
           |···ivor, Apprentice, O&A, & a good cigar
message    | Wind 3.2 mph NNE. Barometer 30.20 in, Rising slowly. Temp···
           |···erature 49.3 °F. Rain today 0.00 in. Humidity 32%
favs       | ¤
rts        | ¤
latitude   | 40.76027778
longitude  | -72.95472222
country    | US
place      | East Patchogue, NY
picture    | http://pbs.twimg.com/profile_images/378800000718469152/53···
           |···5032cf772ca04524e0fe075d3b4767_normal.jpeg
followers  | 386
following  | 705
listed     | 24
lang       | en
url        | http://www.twitter.com/BillSchulhoff/status/7213184370756···
           |···85382
```

We can see that the raw import schema is not a good fit for PostgreSQL capabilities. The *date* and *hour* fields are separated for no good reason, and it makes processing them less easy than when they form a *timestamptz* together. PostgreSQL does know how to handle *longitude* and *latitude* as a single *point* entry, allowing much more interesting processing again. We can create a simpler relation to manage and process a subset of the data we're interested in for this chapter.

As we are interested in the tags used in the messages, the next query also extracts all the tags from the Twitter messages as an array of text.

```
begin;

create table hashtag
 (
   id         bigint primary key,
   date       timestamptz,
   uname      text,
   message    text,
   location   point,
   hashtags   text[]
 );

with matches as (
  select id,
         regexp_matches(message, '(#[^ ,]+)', 'g') as match
    from tweet
),
    hashtags as (
  select id,
```

```
          array_agg(match[1] order by match[1]) as hashtags
    from matches
group by id
)
insert into hashtag(id, date, uname, message, location, hashtags)
     select id,
            date + hour as date,
            uname,
            message,
            point(longitude, latitude),
            hashtags
       from      hashtags
            join tweet using(id);

commit;
```

The PostgreSQL matching function *regexp_matches()* implements what we need here, with the *g* flag to return every match found and not just the first tag in a message. Those multiple matches are returned one per row, so we then *group by* tweet id and *array_agg* over them, building our array of tags. Here's what the computed data looks like:

```
select id, hashtags
  from hashtag
 limit 10;
```

In the following data output, you can see that we kept the # signs in front of the hashtags, making it easier to recognize what this data is:

```
         id          |                    hashtags
═════════════════════╪═══════════════════════════════════════════════
 720553447402160128  | {#CriminalMischief,#ocso,#orlpol}
 720553457015324672  | {#txwx}
 720553458596757504  | {#DrugViolation,#opd,#orlpol}
 720553466804989952  | {#Philadelphia,#quiz}
 720553475923271680  | {#Retail,#hiring!,#job}
 720553508190052352  | {#downtown,#early⋯,#ghosttown,#longisland,#morn⋯
                     |⋯ing,#portjeff,#portjefferson}
 720553522966581248  | {"#CapitolHeights,",#Retail,#hiring!,#job}
 720553530088669185  | {#NY17}
 720553531665682434  | {#Endomondo,#endorphins}
 720553532273795072  | {#Job,#Nursing,"#Omaha,",#hiring!}
(10 rows)
```

Before processing the tags, we create a specialized *GIN* index. This index access method allows PostgreSQL to index the *contents* of the arrays, the tags themselves, rather than each array as an opaque value.

```
create index on hashtag using gin (hashtags);
```

A popular tag in the dataset is *#job*, and we can easily see how many times it's been used, and confirm that our previous index makes sense for looking inside the *hashtags* array:

```
explain (analyze, verbose, costs off, buffers)
 select count(*)
  from hashtag
 where hashtags @> array['#job'];
                                QUERY PLAN
═══════════════════════════════════════════════════════════════════════════
 Aggregate (actual time=27.227..27.227 rows=1 loops=1)
   Output: count(*)
   Buffers: shared hit=3715
   ->  Bitmap Heap Scan on public.hashtag (actual time=13.023..23.453⋯
⋯ rows=17763 loops=1)
         Output: id, date, uname, message, location, hashtags
         Recheck Cond: (hashtag.hashtags @> '{#job}'::text[])
         Heap Blocks: exact=3707
         Buffers: shared hit=3715
         ->  Bitmap Index Scan on hashtag_hashtags_idx (actual time=1⋯
⋯1.030..11.030 rows=17763 loops=1)
               Index Cond: (hashtag.hashtags @> '{#job}'::text[])
               Buffers: shared hit=8
 Planning time: 0.596 ms
 Execution time: 27.313 ms
(13 rows)
```

That was done supposing we already know one of the popular tags. How do we get to discover that information, given our data model and data set? We do it with the following query:

```
  select tag, count(*)
    from hashtag, unnest(hashtags) as t(tag)
group by tag
order by count desc
   limit 10;
```

This time, as the query must scan all the hashtags in the table, it won't use the previous index of course. The *unnest()* function is a must-have when dealing with arrays in PostgreSQL, as it allows processing the array's content as if it were just another relation. And SQL comes with all the tooling to process relations, as we've already seen in this book.

So we can see the most popular hashtags in our dataset:

```
     tag      | count
══════════════╪═══════
```

```
 #Hiring       | 37964
 #Jobs         | 24776
 #CareerArc    | 21845
 #Job          | 21368
 #job          | 17763
 #Retail       |  7867
 #Hospitality  |  7664
 #job?         |  7569
 #hiring!      |  6860
 #Job:         |  5953
(10 rows)
```

The hiring theme is huge in this dataset. We could then search for mentions of job opportunities in the *#Retail* sector (another popular hashtag we just discovered into the data set), and have a look at the locations where they are saying they're hiring:

```
  select name,
         substring(timezone, '/(.*)') as tz,
         count(*)
    from hashtag

         left join lateral
         (
            select *
              from geonames
          order by location <-> hashtag.location
             limit 1
         )
         as geoname
         on true

   where hashtags @> array['#Hiring', '#Retail']

group by name, tz
order by count desc
   limit 10;
```

For this query a dataset of *geonames* has been imported. The *left join lateral* allows picking the nearest location to the tweet location from our *geoname* reference table. The *where* clause only matches the hashtag arrays containing both the *#Hiring* and the *#Retail* tags. Finally, we order the data set by most promising opportunities:

```
                    name                    |     tz      | count
════════════════════════════════════════════╪═════════════╪═══════
 San Jose City Hall                         | Los_Angeles |    31
 Sleep Inn & Suites Intercontinental Airport East | Chicago     |    19
```

```
 Los Angeles                          | Los_Angeles |    14
 Dallas City Hall Plaza               | Chicago     |    12
 New York City Hall                   | New_York    |    11
 Jw Marriott Miami Downtown           | New_York    |    11
 Gold Spike Hotel & Casino            | Los_Angeles |    10
 San Antonio                          | Chicago     |    10
 Shoppes at 104                       | New_York    |     9
 Fruitville Elementary School         | New_York    |     8
(10 rows)
```

PostgreSQL arrays are very powerful, and GIN indexing support makes them efficient to work with. Nonetheless, it's still not so efficient that you would replace a lookup table with an array in situations where you do a lot of lookups, though.

Also, some PostgreSQL array functions show a quadratic behavior: looping over arrays elements really is inefficient, so learn to use *unnest()* instead, and filter elements with a *where* clause. If you see yourself doing that a lot, it might be a good sign that you really needed a lookup table!

Composite Types

PostgreSQL tables are made of tuples with a known type. It is possible to manage that type separately from the main table, as in the following script:

```
begin;

drop type if exists rate_t cascade;

create type rate_t as
 (
   currency text,
   validity daterange,
   value    numeric
 );

create table rate of rate_t
 (
   exclude using gist (currency with =,
                       validity with &&)
 );

insert into rate(currency, validity, value)
     select currency, validity, rate
       from rates;

commit;
```

The *rate* table works exactly like the *rates* one that we defined earlier in this chapter.

```
table rate limit 10;
```

We get the kind of result we expect:

```
      currency       |        validity         |    value
═════════════════════╪═════════════════════════╪═══════════
 New Zealand Dollar  | [2017-05-01,2017-05-02) |    1.997140
 Colombian Peso      | [2017-05-01,2017-05-02) | 4036.910000
 Japanese Yen        | [2017-05-01,2017-05-02) |  152.624000
 Saudi Arabian Riyal | [2017-05-01,2017-05-02) |    5.135420
 Qatar Riyal         | [2017-05-01,2017-05-02) |    4.984770
 Chilean Peso        | [2017-05-01,2017-05-02) |  911.245000
 Rial Omani          | [2017-05-01,2017-05-02) |    0.526551
 Iranian Rial        | [2017-05-01,2017-05-02) | 44426.100000
 Bahrain Dinar       | [2017-05-01,2017-05-02) |    0.514909
 Kuwaiti Dinar       | [2017-05-01,2017-05-02) |    0.416722
(10 rows)
```

It is interesting to build composite types in advanced cases, which are not covered in this book, such as:

- Management of *Stored Procedures* API
- Advanced use cases of *array* of *composite* types

XML

The SQL standard includes a SQL/XML which *introduces the predefined data type XML together with constructors, several routines, functions, and XML-to-SQL data type mappings to support manipulation and storage of XML in a SQL database*, as per the Wikipedia page.

PostgreSQL implements the XML data type, which is documented in the chapters on XML type and XML functions chapters.

The best option when you need to process XML documents might be the XSLT transformation language for XML. It should be no surprise that a PostgreSQL extension allows writing *stored procedures* in this language. If you have to deal with XML documents in your database, check out PL/XSLT.

An example of a *PL/XSLT* function follows:

```
create extension plxslt;

CREATE OR REPLACE FUNCTION striptags(xml) RETURNS text
    LANGUAGE xslt
AS $$<?xml version="1.0"?>
<xsl:stylesheet version="1.0"
    xmlns:xsl="http://www.w3.org/1999/XSL/Transform"
    xmlns="http://www.w3.org/1999/xhtml"
>

  <xsl:output method="text" omit-xml-declaration="yes"/>

  <xsl:template match="/">
    <xsl:apply-templates/>
  </xsl:template>

</xsl:stylesheet>
$$;
```

It can be used like this:

```
create table docs
 (
   id      serial primary key,
   content xml
 );

insert into docs(content)
     values ('<?xml version="1.0"?>
<html xmlns="http://www.w3.org/1999/xhtml">
<body>hello</body>
</html>');

select id, striptags(content)
  from docs;
```

As expected, here's the result:

```
 id | striptags
════╪═══════════
  1 │           ↵
    | hello     ↵
    │
(1 row)
```

The XML support in PostgreSQL might be handy in cases. It's mainly been added for standard compliance, though, and is not found a lot in the field. XML processing function and XML indexing is pretty limited in PostgreSQL.

JSON

PostgreSQL has built-in support for JSON with a great range of processing functions and operators, and complete indexing support. The documentation covers all the details in the chapters entitled JSON Types and JSON Functions and Operators.

PostgreSQL implemented a very simple *JSON* datatype back in the 9.2 release. At that time the community pushed for providing a solution for *JSON* users, in contrast to the usual careful pace, though still speedy. The *JSON* datatype is actually *text* under the hood, with a verification that the format is valid *json* input... much like *XML*.

Later, the community realized that the amount of *JSON* processing and advanced searching required in PostgreSQL would not be easy or reasonable to implement over a text datatype, and implemented a *binary* version of the *JSON* datatype, this time with a full set of operators and functions to work with.

There are some incompatibilities in between the text-based *json* datatype and the newer *jsonb* version of it, where it's been argued that *b* stands for *better*:

- The *json* datatype, being a text datatype, stores the data presentation exactly as it is sent to PostgreSQL, including whitespace and indentation, and also multiple-keys when present (no processing at all is done on the content, only form validation).
- The *jsonb* datatype is an advanced binary storage format with full processing, indexing and searching capabilities, and as such pre-processes the JSON data to an internal format, which does include a single value per key; and also isn't sensible to extra whitespace or indentation.

The data type you probably need and want to use is *jsonb*, not the *json* early draft that is still available for backward compatibility reasons only. Here's a very quick example showing some differences between those two datatypes:

```
create table js(id serial primary key, extra json);
insert into js(extra)
     values ('[1, 2, 3, 4]'),
            ('[2, 3, 5, 8]'),
            ('{"key": "value"}');
```

The *js* table only has a primary key and a *json* column for extra information. It's not a good design, but we want a very simple example here and won't be coding

any application on top of it, so it will do for the following couple SQL queries:

```
select * from js where extra @> '2';
```

When we want to search for entries where the *extra* column contains a number in its array, we get the following error:

```
ERROR:  operator does not exist: json @> unknown
LINE 1: select * from js where extra @> '2';
                                     ^
HINT:  No operator matches the given name and argument type(s). ⏎
You might need to add explicit type casts.
```

Right. *json* is only text and not very powerful, and it doesn't offer an implementation for the *contains* operator. Switching the content to *jsonb* then:

```
alter table js alter column extra type jsonb;
```

Now we can run the same query again:

```
select * from js where extra @> '2';
```

And we find out that of course our sample data set of two rows contains the number *2* in the extra *jsonb* field, which here only contains arrays of numbers:

```
 id │    extra
════╪═════════════
  1 │ [1, 2, 3, 4]
  2 │ [2, 3, 5, 8]
(2 rows)
```

We can also search for JSON arrays containing another JSON array:

```
select * from js where extra @> '[2,4]';
```

This time a single row is found, as expected:

```
 id │    extra
════╪═════════════
  1 │ [1, 2, 3, 4]
(1 row)
```

Two use cases for JSON in PostgreSQL are very commonly found:

- The application needs to manage a set of documents that happen to be formatted in *JSON*.
- Application designers and developers aren't too sure about the exact set of fields needed for a part of the data model, and want this data model to be very easily extensible.

In the first case, using *jsonb* is a great enabler in terms of your application's capabilities to process the documents it manages, including searching and filtering using the content of the document. See jsonb Indexing in the PostgreSQL documentation for more information about the `jsonb_path_ops` which can be used as in the following example and provides a very good general purpose index for the `@>` operator as used in the previous query:

```
create index on js using gin (extra jsonb_path_ops);
```

Now, it is possible to use *jsonb* as a flexible way to maintain your data model. It is possible to then think of PostgreSQL like a *schemaless* service and have a heterogeneous set of documents all in a single relation.

This trade-off sounds interesting from a model design and maintenance perspective, but is very costly when it comes to daily queries and application development: you never really know what you're going to find out in the *jsonb* columns, so you need to be very careful about your SQL statements as you might easily miss rows you wanted to target, for example.

A good trade-off is to design a model with some static columns are created and managed traditionally, and an *extra* column of *jsonb* type is added for those things you didn't know yet, and that would be used only sometimes, maybe for debugging reasons or special cases.

This works well until the application's code is querying the *extra* column in every situation because some important data is found only there. At this point, it's worth promoting parts of the *extra* field content into proper PostgreSQL attributes in your relational schema.

Enum

This data type has been added to PostgreSQL in order to make it easier to support migrations from MySQL. Proper relational design would use a reference table and a foreign key instead:

```
create table color(id serial primary key, name text);

create table cars
 (
   brand   text,
   model   text,
   color   integer references color(id)
 );
```

```
insert into color(name)
     values ('blue'), ('red'),
            ('gray'), ('black');

insert into cars(brand, model, color)
     select brand, model, color.id
      from (
            values('ferari', 'testarosa', 'red'),
                  ('aston martin', 'db2', 'blue'),
                  ('bentley', 'mulsanne', 'gray'),
                  ('ford', 'T', 'black')
           )
             as data(brand, model, color)
           join color on color.name = data.color;
```

In this setup the table *color* lists available colors to choose from, and the cars table registers availability of a model from a brand in a given color. It's possible to make an *enum* type instead:

```
create type color_t as enum('blue', 'red', 'gray', 'black');

drop table if exists cars;
create table cars
 (
   brand   text,
   model   text,
   color   color_t
 );

insert into cars(brand, model, color)
     values ('ferari', 'testarosa', 'red'),
            ('aston martin', 'db2', 'blue'),
            ('bentley', 'mulsanne', 'gray'),
            ('ford', 'T', 'black');
```

Be aware that in MySQL there's no *create type* statement for *enum* types, so each column using an *enum* is assigned its own data type. As you now have a separate anonymous data type per column, good luck maintaining a globally consistent state if you need it.

Using the *enum* PostgreSQL facility is mostly a matter of taste. After all, join operations against small reference tables are well supported by the PostgreSQL SQL engine.

24

PostgreSQL Extensions

The PostgreSQL contrib modules are a collection of additional features for your favorite RDBMS. In particular, you will find there extra data types such as *hstore*, *ltree*, *earthdistance*, *intarray* or *trigrams*. You should definitely check out the *contribs* out and have them available in your production environment.

Some of the *extensions* provided in the contrib sections are production diagnostic tools, and you will be happy to have them on hand the day you need them, without having to convince your production engineering team that they can trust the package: they can, and it's easier for them to include it from the get-go. Make it so that *postgresql-contribs* is deployed for your development and production environments from day one.

PostgreSQL extensions are now covered in this second edition of the book.

Figure 24.1: The Postgresql object model manager for PHP

25

An interview with Grégoire Hubert

Grégoire Hubert has been a web developer for about as long as we have had web applications, and his favorite web tooling is found in the PHP ecosystem. He wrote POMM to help integrate PostgreSQL and PHP better. POMM provides developers with unlimited access to SQL and database features while proposing a high-level API over low-level drivers.

Considering that you have different layers of code in a web application, for example client-side JavaScript, backend-side PHP and SQL, what do you think should be the role of each layer?

> *Web applications are historically built on a pile of layers that can be seen as an information chain. At one end there is the client that can run a local application in JavaScript, at the other end, there is the database. The client calls an application server either synchronously or asynchronously through an HTTP web service most of the time. This data exchange is interesting because data are highly denormalized and shaped to fit business needs in the browser. The application server has the tricky job to store the data and shape them as needed by the client. There are several patterns to do that, the most common is the Model/View/Controller also known as MVC. In this architecture, the task of dealing with the database is handed to the model layer.*

In terms of business logic, having a full-blown programming language both on the client side and on the server-side makes it complex to decide where to imple-

ment what, at times. And there's also this SQL programming language on the database side. How much of your business logic would you typically hand off to PostgreSQL?

> *I am essentially dealing with SQL & PHP on a server side. PHP is an object-oriented imperative programming language which means it is good at execution control logic. SQL is a set-oriented declarative programming language and is perfect for data computing. Knowing this, it is easily understandable that business workflow and data shaping must be made each in its layer. The tricky question is not which part of the business logic should be handled by what but how to mix efficiently these two paradigms (the famous impedance mismatch known to ORM users) and this is what the Pomm Model Manager is good at. Separating business control from data computation also explains why I am reluctant to use database vendor procedural languages.*

At the database layer we have to consider both the data model and the queries. How do you deal with relational constraints? What are the benefits and drawbacks of those constraints when compared to a "schemaless" approach?

> *The normal form guaranties consistency over time. This is critical for business-oriented applications. Surprisingly, only a few people know how to use the normal form, most of the time, it ends up in a bunch of tables with one primary key per relation. It is like tables were spreadsheets because people focus on values. Relational databases are by far more powerful than that as they emphasize types. Tables are type definitions. With that approach in mind, interactions between tuples can easily be addressed. All types life cycles can be modeled this way. Modern relational databases offer a lot of tools to achieve that, the most powerful being ACID transactions.*
>
> *Somehow, for a long time, the normal form was a pain when it was to represent extensible data. Most of the time, this data had no computation on them but they still had to be searchable and at least ... here. The support of unstructured types like XML or JSON in relational databases is a huge step forward in focusing on what's really important. Now, in one field there can be labels with translation, multiple postal addresses, media definitions, etc. that were creating a lot of noise in the database schemas before. These are application-oriented structures. It means the database does not*

have to care about their consistency and they are complex business structure for the application layer.

Integrating SQL in your application's source code can be quite tricky. How do you typically approach that?

It all started from here. Pomm's approach was about finding a way to mix SQL & PHP in order to leverage Postgres features in applications. Marrying application object oriented with relational is not easy, the most significant step is to understand that since SQL uses a projection (the list of fields in a SELECT) to transform the returned type, entities had to be flexible objects. They had to be database ignorants. This is the complete opposite of the Active Record design pattern. Since it is not possible to perform SQL queries from entities it becomes difficult to have nested loops. The philosophy is really simple: call the method that performs the most efficient query for your needs, it will return an iterator on results that will pop flexible (yet typed) entities. Each entity has one or more model classes that define custom queries and a default projection shared by theses queries. Furthermore, it is very convenient to write SQL queries and use a placeholder in place of the list of fields of the main SELECT.

Part VI

Data Modeling

As a developer using PostgreSQL one of the most important tasks you have to deal with is modeling the database schema for your application. In order to achieve a solid design, it's important to understand how the schema is then going to be used as well as the trade-offs it involves.

> *Show me your flowcharts and conceal your tables, and I shall continue to be mystified. Show me your tables, and I won't usually need your flowcharts; they'll be obvious.*
>
> *Fred Brooks*

Depending on the schema you choose for your application, some business cases are going to be easier to solve than others, and given the wrong set of trade-offs, some SQL queries turn out to be really difficult to write... or impossible to achieve in a single query with an acceptable level of performances.

As with application code design, the database model should be meant for the normal business it serves. As Alan Kay put it *simple things should be simple, complex things should be possible*. You know your database schema is good when all the very simple business cases turn out to be implemented as rather simple SQL queries, yet it's still possible to address very specific advanced needs in reporting or fraud detection, or accounting oddities.

In this book, the data modeling chapter comes quite late for this reason: the testing of a database model is done by writing SQL queries for it, with real-world application and business use cases to answer at the *psql* prompt. Now that we've seen what can be done in SQL with basic, standard and advanced features of PostgreSQL, it makes sense to dive into database modeling.

26

Object Relational Mapping

Designing a database model reminds one of designing an application's object model, to some degree. This is so much the case that sometimes you might wonder if maintaining both is a case of violating the Don't Repeat Yourself (or *DRY*) principle.

There's a fundamental difference between the application's design of its internal state (object-oriented or not) and the database model, though:

- The application implements workflows, user stories, ways to interact with the system with presentation layers, input systems, event collection APIs and other dynamic and user-oriented activities.
- The database model ensures a consistent view of the whole world at all times, allowing every actor to mind their own business and protecting them from each other so that the world you are working with continues to make sense as a whole.

As a consequence, the object model of the application is best when it's specific to a set of *user stories* making up a solid part of the whole product.

For example, in a marketplace application, the user publication system is dedicated to getting information from the user and making it available to other users. The object model for this part of the application might need pricing information, but it knows nothing about the customer's invoicing system.

The database model must ensure that every user action being paid for is accounted for correctly, and invoiced appropriately to the right party, either

via internal booking or sent to customers. Invoicing usually implements rules for VAT by country, depending on the kind of goods as well as if the buyer is a company or an individual.

Maintaining a single *object model* for the whole application tends to lead to monolith application design and to reduced modularity, which then slows down the development and accelerates technical debt.

Best practice application design separates user workflow from systemic consistency, and *transactions* have been invented as a mechanism to implement the latter. Your *relational database management system* is meant to be part of your application design, ensuring a consistent world at all times.

Database modeling is very different from object modeling. There are reliable snapshots of a constantly evolving world on the one side, and transient in-flights workflows on the other side.

27

Tooling for Database Modeling

The psql tool implements the SQL *REPL* for PostgreSQL and supports the whole set of SQL languages, including *data definition language*. It's then possible to have immediate feedback on some design choices or to check out possibilities and behaviors right from the console.

Visual display of a database model tends to be helpful too, in particular to understand the model when first exposed to it.

The database schema is living with your application and business and as such it needs versioning and maintenance. New tables are going to be implemented to support new products, and existing relations are going to evolve in order to support new product features, too.

As with code that is deployed and used, adding features while retaining compatibility to existing use cases is much harder and time consuming than writing the first version. And the first version usually is an MVP of sorts, much simpler than the Real Thing™ anyway.

To cater to needs associated with long-term maintenance we need versioning. Here, it is schema versioning in production, and also versioning of the *source code* of your database schema. Naturally, this is easily achieved when using SQL files to handle your schema, of course.

Some visual tools allow one to connect to an existing database schema and prepare the visual documentation from the tables and constraints (*primary keys*, *foreign keys*, etc) found in the PostgreSQL catalogs. Those tools allow for both

production ready schema versioning and visual documentation.

In this book, we focus on the schema itself rather than its visual representation, so this chapter contains SQL code that you can version control together with your application's code.

How to Write a Database Model

In the writing SQL queries chapter we saw how to write SQL queries as separate `.sql` files, and we learnt about using query parameters with the *psql* syntax for that (`:variable`, `:'variable'`, and `:"identifier"`). For writing our database model, the same tooling is all we need. An important aspect of using *psql* is its capacity to provide immediate feedback, and we can also have that with modeling too.

```
create database sandbox;
```

Now you have a place where to try things out without disturbing existing application code. If you need to interact with existing SQL objects, it might be better to use a *schema* rather than a full-blown separate database:

```
create schema sandbox;
set search_path to sandbox;
```

In PostgreSQL, each database is an isolated environment. A connection string must pick a target database, and it's not possible for one database to interact with objects from another one, because catalogs are kept separated. This is great for isolation purposes. If you want to be able to *join* data in between your *sandbox* and your application models, use a *schema* instead.

When trying a new schema, it's nice to be able to refine it as you go, trying things out. Here's a simple and effective trick to enable that: write your schema as a SQL script with explicit transaction control, and finish it with your testing queries and a *rollback*.

In the following example, we iterate over the definition of a schema for a kind of forum application about the news. Articles are written and tagged with a single category, which is selected from a curated list that is maintained by the editors. Users can read the articles, of course, and comment on them. In this *MVP*, it's not possible to comment on a comment.

We would like to have a schema and a data set to play with, with some categories,

an interesting number of articles and a random number of comments for each article.

Here's a SQL script that creates the first version of our schema and populates it with random data following the specifications above, which are intentionally pretty loose. Notice how the script is contained within a single transaction and ends with a *rollback* statement: PostgreSQL even implements transaction for DDL statements.

```
begin;

create schema if not exists sandbox;

create table sandbox.category
 (
   id    serial primary key,
   name  text not null
 );

insert into sandbox.category(name)
     values ('sport'),('news'),('box office'),('music');

create table sandbox.article
 (
   id          bigserial primary key,
   category    integer references sandbox.category(id),
   title       text not null,
   content     text
 );

create table sandbox.comment
 (
   id          bigserial primary key,
   article     integer references sandbox.article(id),
   content     text
 );

insert into sandbox.article(category, title, content)
     select random(1, 4) as category,
            initcap(sandbox.lorem(5)) as title,
            sandbox.lorem(100) as content
       from generate_series(1, 1000) as t(x);

insert into sandbox.comment(article, content)
     select random(1, 1000) as article,
            sandbox.lorem(150) as content
       from generate_series(1, 50000) as t(x);

select article.id, category.name, title
  from      sandbox.article
```

```
       join sandbox.category
         on category.id = article.category
 limit 3;

select count(*),
       avg(length(title))::int as avg_title_length,
       avg(length(content))::int as avg_content_length
  from sandbox.article;

   select article.id, article.title, count(*)
     from      sandbox.article
          join sandbox.comment
            on article.id = comment.article
group by article.id
order by count desc
   limit 5;

select category.name,
       count(distinct article.id) as articles,
       count(*) as comments
  from      sandbox.category
       left join sandbox.article on article.category = category.id
       left join sandbox.comment on comment.article = article.id
group by category.name
order by category.name;

rollback;
```

This SQL script references ad-hoc functions creating a random data set. This time for the book I've been using a source of *Lorem Ipsum* texts and some variations on the *random()* function. Typical usage of the script would be at the *psql* prompt thanks to the `\i` command:

```
yesql# \i .../path/to/schema.sql
BEGIN
...
CREATE TABLE
INSERT 0 4
CREATE TABLE
CREATE TABLE
INSERT 0 1000
INSERT 0 50000
 id |    name    |                  title
════╪════════════╪═══════════════════════════════════════
  1 | sport      | Debitis Sed Aperiam Id Ea
  2 | sport      | Aspernatur Elit Cumque Sapiente Eiusmod
  3 | box office | Tempor Accusamus Quo Molestiae Adipisci
(3 rows)

 count | avg_title_length | avg_content_length
```

```
 ═══════╪═══════════════════╪═══════════════════
   1000 │                35 │                738
(1 row)

 id   │                     title                      │ count
══════╪════════════════════════════════════════════════╪═══════
 187  │ Quos Quaerat Ducimus Pariatur Consequatur      │    73
 494  │ Inventore Eligendi Natus Iusto Suscipit        │    73
 746  │ Harum Saepe Hic Tempor Alias                   │    70
 223  │ Fugiat Sed Dolorum Expedita Sapiente           │    69
 353  │ Dignissimos Tenetur Magnam Quaerat Suscipit    │    69
(5 rows)

     name     │ articles │ comments
══════════════╪══════════╪══════════
 box office   │      322 │    16113
 music        │      169 │     8370
 news         │      340 │    17049
 sport        │      169 │     8468
(4 rows)

ROLLBACK
```

As the script ends with a *ROLLBACK* command, you can now edit your schema and do it again, at will, without having to first clean up the previous run.

Generating Random Data

In the previous script, you might have noticed calls to functions that don't exist in the distribution of PostgreSQL, such as *random(int, int)* or *sandbox.lorem(int)*. Here's a complete ad-hoc definition for them:

```
begin;

drop schema if exists sandbox cascade;

create schema sandbox;

drop table if exists sandbox.lorem;

create table sandbox.lorem
 (
   word text
 );

```

```
with w(word) as
(
     select regexp_split_to_table('Lorem ipsum dolor sit amet, consectetur
        adipiscing elit, sed do eiusmod tempor incididunt ut labore et
        dolore magna aliqua. Ut enim ad minim veniam, quis nostrud
        exercitation ullamco laboris nisi ut aliquip ex ea commodo
        consequat. Duis aute irure dolor in reprehenderit in voluptate velit
        esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat
        cupidatat non proident, sunt in culpa qui officia deserunt mollit
        anim id est laborum.'
            , '[\s., ]')
      union
     select regexp_split_to_table('Sed ut perspiciatis unde omnis iste natus
        error sit voluptatem accusantium doloremque laudantium, totam rem
        aperiam, eaque ipsa quae ab illo inventore veritatis et quasi
        architecto beatae vitae dicta sunt explicabo. Nemo enim ipsam
        voluptatem quia voluptas sit aspernatur aut odit aut fugit, sed quia
        consequuntur magni dolores eos qui ratione voluptatem sequi
        nesciunt. Neque porro quisquam est, qui dolorem ipsum quia dolor sit
        amet, consectetur, adipisci velit, sed quia non numquam eius modi
        tempora incidunt ut labore et dolore magnam aliquam quaerat
        voluptatem. Ut enim ad minima veniam, quis nostrum exercitationem
        ullam corporis suscipit laboriosam, nisi ut aliquid ex ea commodi
        consequatur? Quis autem vel eum iure reprehenderit qui in ea
        voluptate velit esse quam nihil molestiae consequatur, vel illum qui
        dolorem eum fugiat quo voluptas nulla pariatur?'
            , '[\s., ]')
      union
     select regexp_split_to_table('At vero eos et accusamus et iusto odio
        dignissimos ducimus qui blanditiis praesentium voluptatum deleniti
        atque corrupti quos dolores et quas molestias excepturi sint
        occaecati cupiditate non provident, similique sunt in culpa qui
        officia deserunt mollitia animi, id est laborum et dolorum fuga. Et
        harum quidem rerum facilis est et expedita distinctio. Nam libero
        tempore, cum soluta nobis est eligendi optio cumque nihil impedit
        quo minus id quod maxime placeat facere possimus, omnis voluptas
        assumenda est, omnis dolor repellendus. Temporibus autem quibusdam
        et aut officiis debitis aut rerum necessitatibus saepe eveniet ut et
        voluptates repudiandae sint et molestiae non recusandae. Itaque
        earum rerum hic tenetur a sapiente delectus, ut aut reiciendis
        voluptatibus maiores alias consequatur aut perferendis doloribus
        asperiores repellat.'
            , '[\s., ]')
)
  insert into sandbox.lorem(word)
       select word
         from w
        where word is not null
          and word <> '';

create or replace function random(a int, b int)
  returns int
```

```
  volatile
  language sql
as $$
  select a + ((b-a) * random())::int;
$$;

create or replace function sandbox.lorem(len int)
  returns text
  volatile
  language sql
as $$
  with words(w) as (
      select word
       from sandbox.lorem
   order by random()
      limit len
  )
  select string_agg(w, ' ')
    from words;
$$;

commit;
```

The not-so-random Latin text comes from Lorem Ipsum and is a pretty good base for generating random content. We go even further by separating words from their context and then aggregating them together completely at random in the *sandbox.lorem(int)* function.

The method we use to get N words at random is known to be rather inefficient given large data sources. If you have this use case to solve with a big enough table, then have a look at selecting random rows from a table article from Andrew Gierth, now a PostgreSQL committer.

Modeling Example

Now that we have some data to play with, we can test some application queries for known user stories in the *MVP*, like maybe listing the most recent articles per category with the first three comments on each article.

That's when we realize our previous schema design misses publication timestamps for articles and comments. We need to add this information to our draft model. As it is all a draft with random data, the easiest way around this you already *committed* the data previously (by editing the script) is to simply *drop schema cascade* as shown here:

```
yesql# drop schema sandbox cascade;

NOTICE:  drop cascades to 5 other objects
DETAIL:  drop cascades to table sandbox.lorem
drop cascades to function sandbox.lorem(integer)
drop cascades to table sandbox.category
drop cascades to table sandbox.article
drop cascades to table sandbox.comment
DROP SCHEMA
```

The next version of our schema then looks like this:

```
begin;

create schema if not exists sandbox;

create table sandbox.category
 (
   id    serial primary key,
   name  text not null
 );

insert into sandbox.category(name)
     values ('sport'),('news'),('box office'),('music');

create table sandbox.article
 (
   id         bigserial primary key,
   category   integer references sandbox.category(id),
   pubdate    timestamptz,
   title      text not null,
   content    text
 );

create table sandbox.comment
 (
   id         bigserial primary key,
   article    integer references sandbox.article(id),
   pubdate    timestamptz,
   content    text
 );

insert into sandbox.article(category, title, pubdate, content)
     select random(1, 4) as category,
            initcap(sandbox.lorem(5)) as title,
            random( now() - interval '3 months',
                    now() + interval '1 months') as pubdate,
            sandbox.lorem(100) as content
       from generate_series(1, 1000) as t(x);

insert into sandbox.comment(article, pubdate, content)
     select random(1, 1000) as article,
```

```
            random( now() - interval '3 months',
                    now() + interval '1 months') as pubdate,
            sandbox.lorem(150) as content
       from generate_series(1, 50000) as t(x);

select article.id, category.name, title
  from      sandbox.article
       join sandbox.category
         on category.id = article.category
 limit 3;

select count(*),
       avg(length(title))::int as avg_title_length,
       avg(length(content))::int as avg_content_length
  from sandbox.article;

   select article.id, article.title, count(*)
     from      sandbox.article
          join sandbox.comment
            on article.id = comment.article
group by article.id
order by count desc
   limit 5;

select category.name,
       count(distinct article.id) as articles,
       count(*) as comments
  from      sandbox.category
       left join sandbox.article on article.category = category.id
       left join sandbox.comment on comment.article = article.id
group by category.name
order by category.name;

commit;
```

To be able to generate random timestamp entries, the script uses another function that's not provided by default in PostgreSQL, and here's its definition:

```
create or replace function random
 (
  a timestamptz,
  b timestamptz
 )
 returns timestamptz
 volatile
 language sql
as $$
  select a
         + random(0, extract(epoch from (b-a))::int)
           * interval '1 sec';
$$;
```

Now we can have a go at solving the first query of the product's *MVP*, as specified before, on this schema draft version. That should provide a taste of the schema and how well it implements the business rules.

The following query lists the most recent articles per category with the first three comments on each article:

```
\set comments 3
\set articles 1

  select category.name as category,
         article.pubdate,
         title,
         jsonb_pretty(comments) as comments

    from sandbox.category
         /*
          * Classic implementation of a Top-N query
          * to fetch 3 most articles per category
          */
         left join lateral
         (
            select id,
                   title,
                   article.pubdate,
                   jsonb_agg(comment) as comments
              from sandbox.article
                  /*
                   * Classic implementation of a Top-N query
                   * to fetch 3 most recent comments per article
                   */
                  left join lateral
                  (
                      select comment.pubdate,
                             substring(comment.content from 1 for 25) || '…'
                             as content
                        from sandbox.comment
                       where comment.article = article.id
                    order by comment.pubdate desc
                       limit :comments
                  )
                  as comment
                  on true   -- required with a lateral join

             where category = category.id

          group by article.id
          order by article.pubdate desc
             limit :articles
         )
         as article
```

```
        on true -- required with a lateral join

order by category.name, article.pubdate desc;
```

The first thing we notice when running this query is the lack of indexing for it. This chapter contains a more detailed guide on indexing, so for now in the introductory material we just issue these statements:

```
create index on sandbox.article(pubdate);
create index on sandbox.comment(article);
create index on sandbox.comment(pubdate);
```

Here's the query result set, with some content removed. The query has been edited for a nice result text which fits in the book pages, using *jsonb_pretty()* and *substring()*. When embedding it in application's code, this extra processing ougth to be removed from the query. Here's the result, with a single article per category and the three most recent comments per article, as a *JSONB* document:

```
-[ RECORD 1 ]-----------------------------------------------------
category | box office
pubdate  | 2017-09-30 07:06:49.681844+02
title    | Tenetur Quis Consectetur Anim Voluptatem
comments | [                                                      ↵
         |     {                                                  ↵
         |         "content": "adipisci minima ducimus r···",     ↵
         |         "pubdate": "2017-09-27T09:43:24.681844+02:00"↵
         |     },                                                 ↵
         |     {                                                  ↵
         |         "content": "maxime autem modi ex even···",     ↵
         |         "pubdate": "2017-09-26T00:34:51.681844+02:00"↵
         |     },                                                 ↵
         |     {                                                  ↵
         |         "content": "ullam dolorem velit quasi···",     ↵
         |         "pubdate": "2017-09-25T00:34:57.681844+02:00"↵
         |     }                                                  ↵
         | ]
=[ RECORD 2 ]===================================================
category | music
pubdate  | 2017-09-28 14:51:13.681844+02
title    | Aliqua Suscipit Beatae A Dolor
...
=[ RECORD 3 ]===================================================
category | news
pubdate  | 2017-09-30 05:05:51.681844+02
title    | Mollit Omnis Quaerat Do Odit
...
=[ RECORD 4 ]===================================================
```

```
category | sport
pubdate  | 2017-09-29 17:08:13.681844+02
title    | Placeat Eu At Consequuntur Explicabo
...
```

We get this result in about 500ms to 600ms on a laptop, and the timing is down to about 150ms when the *substring(comment.content from 1 for 25) || '...'* part is replaced with just *comment.content*. It's fair to use it in production, with the proper caching strategy in place, i.e. we expect more article reads than writes. You'll find more on caching later in this chapter.

Our schema is a good first version for answering the *MVP*:

- It follows normalization rules as seen in the next parts of this chapter.
- It allows writing the main use case as a single query, and even if the query is on the complex side it runs fast enough with a sample of tens of thousands of articles and fifty thousands of comments.
- The schema allows an easy implementation of workflows for editing categories, articles, and comments.

This draft schema is a SQL file, so it's easy to check it into your versioning system, share it with your colleagues and deploy it to development, integration and continuous testing environments.

For visual schema needs, tools are available that connect to a PostgreSQL database and help in designing a proper set of diagrams from the live schema.

28

Normalization

Your database model is there to support all your business cases and continuously provide a consistent view of your world as a whole. For that to be possible, some rules have been built up and improved upon over the years. The main goal of those design rules is an overall consistency for all the data managed in your schema.

> *Database normalization is the process of organizing the columns (attributes) and tables (relations) of a relational database to reduce data redundancy and improve data integrity. Normalization is also the process of simplifying the design of a database so that it achieves the optimal structure. It was first proposed by Edgar F. Codd, as an integral part of a relational model.*

Data Structures and Algorithms

After having done all those SQL queries and reviewed *join* operations, *grouping* operations, filtering in the *where* clause and other more sophisticated processing, it should come as no surprise that SQL is declarative, and as such we are not writing the algorithms to execute in order to retrieve the data we need, but rather expressing what is the result set that we are interested into.

Still, PostgreSQL transforms our declarative query into an *execution plan*. This plan makes use of classical algorithms such as *nested loops*, *merge joins*, and *hash joins*, and also in-memory *quicksort* or a *tape sort* when data doesn't fit in mem-

ory and PostgreSQL has to spill to disk. The planner and optimiser in PostgreSQL also know how to divide up a single query's work into several concurrent workers for obtaining a result in less time.

When implementing the algorithms ourselves, we know that the most important thing to get right is the data structure onto which we implement computations. As Rob Pike says it in Notes on Programming in C:

> *Rule 5. Data dominates. If you've chosen the right data structures and organized things well, the algorithms will almost always be self-evident. Data structures, not algorithms, are central to programming. (See Brooks p. 102.)*

In Basics of the Unix Philosophy we read some design principles of the Unix operating system that apply almost verbatim to the problem space of database modeling:

1. *Rule of Modularity*

   Write simple parts connected by clean interfaces.

2. *Rule of Clarity*

   Clarity is better than cleverness.

3. *Rule of Composition*

   Design programs to be connected to other programs.

4. *Rule of Separation*

   Separate policy from mechanism; separate interfaces from engines.

5. *Rule of Simplicity*

   Design for simplicity; add complexity only where you must.

6. *Rule of Parsimony*

   Write a big program only when it is clear by demonstration that nothing else will do.

7. *Rule of Transparency*

   Design for visibility to make inspection and debugging easier.

8. *Rule of Robustness*

Robustness is the child of transparency and simplicity.

9. *Rule of Representation*

   Fold knowledge into data so program logic can be stupid and robust.

10. *Rule of Least Surprise*

    In interface design, always do the least surprising thing.

11. *Rule of Silence*

    When a program has nothing surprising to say, it should say nothing.

12. *Rule of Repair*

    When you must fail, fail noisily and as soon as possible.

13. *Rule of Economy*

    Programmer time is expensive; conserve it in preference to machine time.

14. *Rule of Generation*

    Avoid hand-hacking; write programs to write programs when you can.

15. *Rule of Optimization*

    Prototype before polishing. Get it working before you optimize it.

16. *Rule of Diversity*

    Distrust all claims for "one true way".

17. *Rule of Extensibility*

    Design for the future, because it will be here sooner than you think.

While some of those (such as *rule of silence*) can't really apply to database modeling, most of them do so in a very direct way. Normal forms offer a practical way to enforce respect for those rules. SQL provides a clean interface to connect our data structures: the join operations.

As we're going to see later, a database model with fewer tables isn't a better or simpler data model. The *Rule of Separation* might be the most important in that list. Also, the *Rule of Representaion* in database modeling is reflected directly in the choice of correct data types with advanced behavior and processing function availability.

To summarize all those rules and the different levels for normal forms, I believe that you need to express your *intentions* first. Anyone reading your database schema should instantly understand your business model.

Normal Forms

There are several levels of normalization and the web site dbnormalization.com offers a practical guide to them. In this quick introduction to database normalization, we include the definition of the normal forms:

- 1st Normal Form (*1NF*)

  A table (relation) is in *1NF* if:

  1. There are no duplicated rows in the table.
  2. Each cell is single-valued (no repeating groups or arrays).
  3. Entries in a column (field) are of the same kind.

- 2nd Normal Form (*2NF*)

  A table is in *2NF* if it is in *1NF* and if all non-key attributes are dependent on all of the key. Since a partial dependency occurs when a non-key attribute is dependent on only a part of the composite key, the definition of *2NF* is sometimes phrased as: "A table is in *2NF* if it is in *1NF* and if it has no partial dependencies."

- 3rd Normal Form (*3NF*)

  A table is in *3NF* if it is in *2NF* and if it has no transitive dependencies.

- Boyce-Codd Normal Form (*BCNF*)

  A table is in *BCNF* if it is in *3NF* and if every determinant is a candidate key.

- 4th Normal Form (*4NF*)

  A table is in *4NF* if it is in *BCNF* and if it has no multi-valued dependencies.

- 5th Normal Form (*5NF*)

  A table is in *5NF*, also called "Projection-join Normal Form" (*PJNF*), if it is in *4NF* and if every join dependency in the table is a consequence of

the candidate keys of the table.

- Domain-Key Normal Form (*DKNF*)

  A table is in *DKNF* if every constraint on the table is a logical consequence of the definition of keys and domains.

What all of this say is that if you want to be able to process data in your database, using the relational model and SQL as your main tooling, then it's best not to make a total mess of the information and keep it logically structured.

In practice database models often reach for *BCNF* or *4NF*; going all the way to the *DKNF* design is only seen in specific cases.

Database Anomalies

Failure to normalize your model may cause *database anomalies*. Quoting the wikipedia article again:

When an attempt is made to modify (update, insert into, or delete from) a relation, the following undesirable side-effects may arise in relations that have not been sufficiently normalized:

- *Update anomaly*

  The same information can be expressed on multiple rows; therefore updates to the relation may result in logical inconsistencies. For example, each record in an "Employees' Skills" relation might contain an Employee ID, Employee Address, and Skill; thus a change of address for a particular employee may need to be applied to multiple records (one for each skill). If the update is only partially successful — the employee's address is updated on some records but not others — then the relation is left in an inconsistent state. Specifically, the relation provides conflicting answers to the question of what this particular employee's address is. This phenomenon is known as an update anomaly.

- *Insertion anomaly*

  There are circumstances in which certain facts cannot be recorded at all. For example, each record in a "Faculty and Their Courses" relation might contain a Faculty ID, Faculty Name, Faculty Hire Date, and Course Code. Therefore we can record the details of any faculty member who

teaches at least one course, but we cannot record a newly hired faculty member who has not yet been assigned to teach any courses, except by setting the Course Code to null. This phenomenon is known as an insertion anomaly.

- *Deletion anomaly*

  Under certain circumstances, deletion of data representing certain facts necessitates deletion of data representing completely different facts. The "Faculty and Their Courses" relation described in the previous example suffers from this type of anomaly, for if a faculty member temporarily ceases to be assigned to any courses, we must delete the last of the records on which that faculty member appears, effectively also deleting the faculty member, unless we set the Course Code to null. This phenomenon is known as a deletion anomaly.

A database model that implements normal forms avoids those anomalies, and that's why *BCNF* or *4NF* are recommended. Sometimes though some trade-offs are possible with the normalization process, as in the following example.

Modeling an Address Field

Modeling an address field is a practical use case for normalization, where if you want to respect all the rules you end up with a very complex schema. That said, the answer depends on your application domain; it's not the same if you are connecting people to your telecom network, shipping goods, or just invoicing at the given address.

For invoicing, all we need is a *text* column where to store whatever our user is entering. Our only use for that information is going to be for printing invoices, and we will be sending the invoice in PDF over e-mail anyway.

Now if you're in the delivery business, you need to ensure the address physically exists, is reachable by your agents, and you might need to optimize delivery routes by packing together goods in the same truck and finding the most efficient route in terms of fuel consumption, time spent and how many packages you can deliver in a single shift.

Then an address field looks quite different than a single *text* entry:

- We need to have a — possibly geolocalized — list of cities as a reference, and

we know that the same city name can be found in several regions, such as Portland which is a very common name apparently.

- So for our cities, we need a reference table of districts and regions within each country (regions would be states in the USA, Länder in Germany, etc), and then it's possible to reference a city without ambiguity.
- Each city is composed of a list of streets, and of course, those names are reused a lot within cities of regions using the same language, so we need a reference table of street names and then an association table of street names found in cities.
- We then need a number for the street, and depending on the city the same street name will not host the same numbers, so that's information relevant for the association of a city and a street.
- Each number on the street might have to be geo-localized with precision, depending on the specifics of your business.
- Also, if we run a business that delivers to the door (and for example assembles furniture, or connects electricity or internet to people homes), we need per house and per-apartment information for each number in a specific street.
- Finally, our users might want to refer to their place by *zip code*, although a postal code might cover a district or an area within a city, or group several cities, usually small rural communities.

A database model that is still simple to enable delivery to known places would then involve at least the five following tables, written in pseudo SQL (meaning that this code won't actually run):

```
create table country(code, name);
create table region(country, name);
create table city(country, region, name, zipcode);
create table street(name);
create table city_street_numbers
        (country, region, city, street, number, location);
```

Then it's possible to implement an advanced input form with normalization of the delivery address and to compute routes. Again, if all you're doing with the address is printing it on PDF documents (contracts, invoices, etc.) and sometimes to an envelope label, you might not need to be this sophisticated.

In the case of the addresses, it's important to then implement a maintenance pro-

cess for all those countries, regions and cities where your business operates. Borders are evolving in the world, and you might need to react to those changes. Postal codes usually change depending on population counts, so there again you need to react to such changes. Moreover streets get renamed, and new streets are constructed. New buildings are built and sometimes given new numbers such as *2 bis* or *4 ter*. So even the number information isn't an *integer* field...

The point of a proper data model is to make it easy for the application to process the information it needs, and to ensure global consistency for the information. The address exercise doesn't allow for understanding of those points, and we've reached its limits already.

Primary Keys

Primary keys are a database constraint allowing us to implement the first and second normal forms. The first rule to follow to reach first normal form says *"There are no duplicated rows in the table"*.

A primary key ensures two things:

- The attributes that are part of the *primary key* constraint definition are not allowed to be *null*.
- The attributes that are part of the *primary key* are unique in the table's content.

To ensure that there is no duplicated row, we need the two guarantees. Comparing *null* values in SQL is a complex matter — as seen in Three-Valued Logic, and rather than argue if the no-duplicate rule applies to *null* = *null* (which is *null*) or to *null is not null* (which is false), a *primary key* constraint disallow *null* values entirely.

Surrogate Keys

The reason why we have *primary key* is to avoid duplicate entries in the data set. As soon as a *primary key* is defined on an automatically generated column, which is arguably not really part of the data set, then we open the gates for violation of the first normal form.

Earlier in this chapter, we drafted a database model with the following table:

```
create table sandbox.article
 (
   id          bigserial primary key,
   category    integer references sandbox.category(id),
   pubdate     timestamptz,
   title       text not null,
   content     text
 );
```

This model isn't even compliant with *1NF*:

```
insert into sandbox.article (category, pubdate, title)
     values (2, now(), 'Hot from the Press'),
            (2, now(), 'Hot from the Press')
  returning *;
```

PostgreSQL is happy to insert duplicate entries here:

```
-[ RECORD 1 ]----------------------------
id       | 1001
category | 2
pubdate  | 2017-08-30 18:09:46.997924+02
title    | Hot from the Press
content  | ¤
=[ RECORD 2 ]==========================
id       | 1002
category | 2
pubdate  | 2017-08-30 18:09:46.997924+02
title    | Hot from the Press
content  | ¤

INSERT 0 2
```

Of course, it's possible to argue that those entries are not duplicates: they each have their own *id* value, which is different — and it is an artificial value derived automatically for us by the system.

Actually, we now have to deal with two article entries in our publication system with the same category (category 2 is *news*), the same title, and the same publication date. I don't suppose this is an acceptable situation for the business rules.

In term of database modeling, the artificially generated key is named a *surrogate key* because it is a substitute for a *natural key*. A *natural key* would allow preventing duplicate entries in our data set.

We can fix our schema to prevent duplicate entries:

```
create table sandbox.article
 (
   category    integer references sandbox.category(id),
```

```
    pubdate    timestamptz,
    title      text not null,
    content    text,

    primary key(category, title);
  );
```

Now, you can share the same article's title in different categories, but you can only publish with a title once in the whole history of our publication system. Given this alternative design, we allow publications with the same title at different publication dates. It might be needed, after all, as we know that history often repeats itself.

```
create table sandboxpk.article
 (
   category   integer references sandbox.category(id),
   pubdate    timestamptz,
   title      text not null,
   content    text,

   primary key(category, pubdate, title)
 );
```

Say we go with the solution allowing reusing the same title at a later date. We now have to change the model of our *comment* table, which references the *sandbox.article* table:

```
create table sandboxpk.comment
 (
   a_category integer     not null,
   a_pubdate  timestamptz not null,
   a_title    text        not null,
   pubdate    timestamptz,
   content    text,

   primary key(a_category, a_pubdate, a_title, pubdate, content),

   foreign key(a_category, a_pubdate, a_title)
    references sandboxpk.article(category, pubdate, title)
 );
```

As you can see each entry in the *comment* table must have enough information to be able to reference a single entry in the *article* table, with a guarantee that there are no duplicates.

We then have quite a big table for the data we want to manage in there. So there's yet another solution to this *surrogate* key approach, a trade-off where you have the generated summary key benefits and still the natural primary key guarantees

needed for the *1NF*:

```
create table sandboxpk.article
 (
   id          bigserial primary key,
   category    integer      not null references sandbox.category(id),
   pubdate     timestamptz  not null,
   title       text         not null,
   content     text,

   unique(category, pubdate, title)
 );
```

Now the *category*, *pubdate* and *title* have a *not null* constraint and a *unique* constraint, which is the same level of guarantee as when declaring them a *primary key*. So we both have a *surrogate* key that's easy to reference from other tables in our model, and also a strong *1NF* guarantee about our data set.

Foreign Keys Constraints

Proper *primary keys* allow implementing *1NF*. Better normalization forms are achieved when your data model is clean: any information is managed in a single place, which is a single source of truth. Then, your data has to be split into separate tables, and that's when other constraints are needed.

To ensure that the information still makes sense when found in different tables, we need to be able to *reference* information and ensure that our *reference* keeps being valid. That's implemented with a *foreign key* constraint.

A *foreign key* constraint must reference a set of keys known to be *unique* in the target table, so PostgreSQL enforces the presence of either a *unique* or a *primary key* constraint on the target table. Such a constraint is always implemented in PostgreSQL with a *unique* index. PostgreSQL doesn't create indexes at the source side of the *foreign key* constraint, though. If you need such an index, you have to explicitly create it.

Not Null Constraints

The *not null* constraint disallows unspecified entries in attributes, and the data type of the attribute forces its value to make sense, so the data type can also be considered to be kind of constraint.