Lab 6: Performance and Concurrency

In this lab, we will cover the following topics:

- Finding slow **SQL** statements
- Finding out what makes SQL slow
- Reducing the number of rows returned
- Simplifying complex SQL queries
- Speeding up queries without rewriting them
- Discovering why a query is not using an index
- Forcing a query to use an index
- Using parallel query
- Creating time-series tables using partitioning
- Using optimistic locking to avoid long lock waits

Finding slow SQL statements

Two main kinds of slowness can manifest themselves in a database.

The first kind is a single query that can be too slow to be really usable, such as a customer information query in a **customer relationship management** (**CRM**) system running for minutes, a password check query running in tens of seconds, or a daily data aggregation query running for more than a day. These can be found by logging queries that take over a certain amount of time, either at the client end or in the database.

The second kind is a query that is run frequently (say a few thousand times a second) and used to run in single-digit **milliseconds** (**ms**) but is now running in several tens or even hundreds of milliseconds, hence slowing the system down.

One way to find slow queries is to set up PostgreSQL to log them to the server log. For example, if you decide to monitor any query that takes over 10 seconds, then use the following command:

```
postgres=# ALTER SYSTEM
          SET log_min_duration_statement = 10000;
```

Remember that the duration is in ms. After doing this, reload PostgreSQL. All queries whose duration exceeds the threshold will be logged. You should pick a threshold that is above 99% of queries so that you only get the worst outliers logged. As you progressively tune your system, you can reduce the threshold over time.

PostgreSQL log files are usually located together with other log files; for example, on Debian/Ubuntu Linux, they are in the `/var/log/postgresql/` directory.

If you set `log_min_duration_statement = 0`, then all queries would be logged, which will typically swamp the log file, causing more performance problems itself, and thus this is not recommended. A better idea would be to use the `log_min_duration_sample` parameter, available in PostgreSQL 13+, to set a limit for sampling queries. The two settings are designed to work together:

- Any query elapsed time less than `log_min_duration_sample` is not logged at all.
- Any query elapsed time higher than `log_min_duration_statement` is always logged.
- For any query elapsed time that falls between the two settings, we sample the queries and log them at a rate set by `log_statement_sample_rate (default 1.0 = all)`. Note that the sampling is blind---it is not stratified/weighted, so rare queries may not show up at all in the log.

Query logging will show the parameters that are being used for the slow query, even when `pg_stat_statements` does not.

Finding out what makes SQL slow

An SQL statement can be slow for a lot of reasons. Here, we will provide a short list of these reasons, with at least one way of recognizing each.

How to do it...

The core issues are likely to be the following:

- You're asking the SQL statement to do too much work.
- Something is stopping the SQL statement from doing the work.

This might not sound that helpful at first, but it's good to know that there's nothing really magical going on that you can't understand if you look.

In more detail, the main reasons/issues are these:

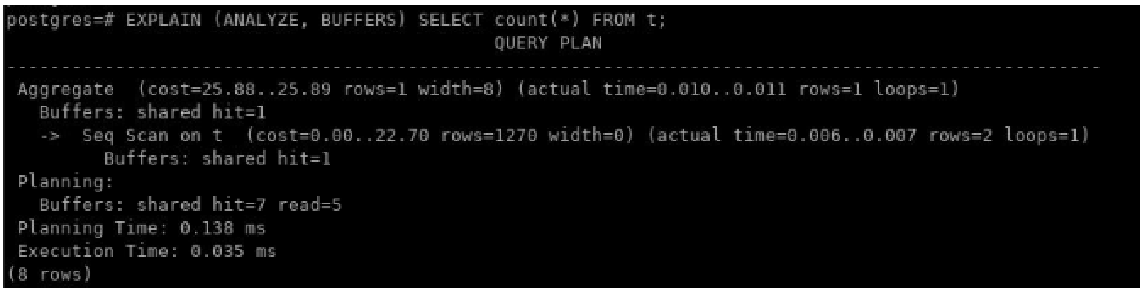
- Returning too much data.
- Processing too much data.
- Index needed.
- The wrong plan for other reasons---for example, poor estimates.
- Locking problems.
- Cache or **input/output** (**I/O**) problems. It's possible the system itself has bottlenecks such as single-core, slow **central processing units** (**CPUs**), insufficient memory, or reduced I/O throughput.

The first issue can be handled as described in the *Reducing the number of rows returned* topic. The rest of the preceding reasons can be investigated from two perspectives: the SQL itself and the objects that the SQL touches. Let's start by looking at the SQL itself by running the query with `EXPLAIN ANALYZE`. We're going to use the optional form, as follows:

```
postgres=# EXPLAIN (ANALYZE, BUFFERS) ...SQL...
```

The `EXPLAIN` command provides output to describe the execution plan of the SQL, showing access paths and costs (in abstract units). The `ANALYZE` option causes the statement to be executed (be careful), with instrumentation to show the number of rows accessed and the timings for that part of the plan. The `BUFFERS` option provides information about the number of database buffers read and the number of buffers that were hit in the cache. Taken together, we have everything we need to diagnose whether the SQL performance is reduced by one of the earlier mentioned issues:

```
postgres=# EXPLAIN (ANALYZE, BUFFERS) SELECT count(*) FROM t;
```



```
postgres=# EXPLAIN (ANALYZE, BUFFERS) SELECT count(*) FROM t;
                                              QUERY PLAN
-------------------------------------------------------------------------------------------------------
 Aggregate  (cost=25.88..25.89 rows=1 width=8) (actual time=0.010..0.011 rows=1 loops=1)
   Buffers: shared hit=1
   ->  Seq Scan on t  (cost=0.00..22.70 rows=1270 width=0) (actual time=0.006..0.007 rows=2 loops=1)
         Buffers: shared hit=1
 Planning:
   Buffers: shared hit=7 read=5
 Planning Time: 0.138 ms
 Execution Time: 0.035 ms
(8 rows)
```

Let's use this technique to look at an SQL statement that would benefit from an index.

For example, if you want to get the three latest rows in a 1 million row table, run the following query:

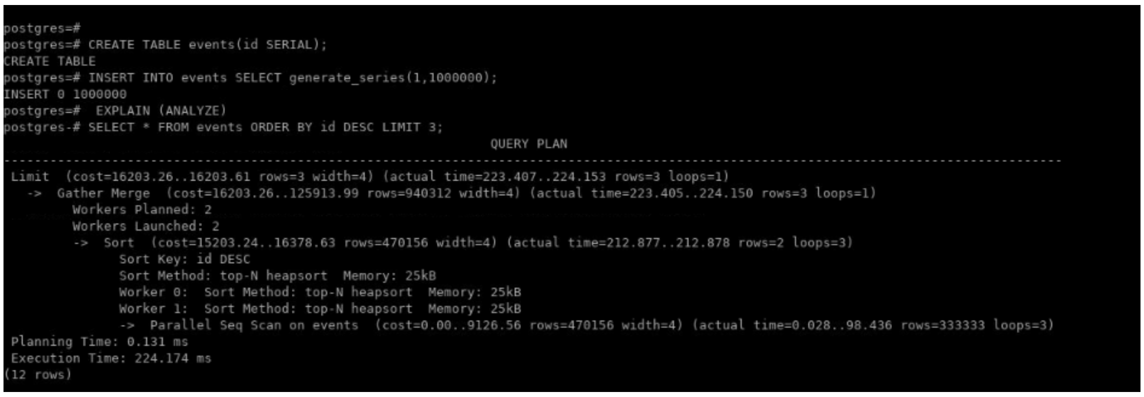
```
SELECT * FROM events ORDER BY id DESC LIMIT 3;
```

You can either read through just three rows using an index on the `id SERIAL` column or you can perform a sequential scan of all rows followed by a sort, as shown in the following code snippet. Your choice depends on whether you have a usable index on the field from which you want to get the top three rows:

```
postgres=# CREATE TABLE events(id SERIAL);


postgres=# INSERT INTO events SELECT generate_series(1,1000000);

postgres=# EXPLAIN (ANALYZE)
              SELECT * FROM events ORDER BY id DESC LIMIT 3;
```



```
postgres=#
postgres=# CREATE TABLE events(id SERIAL);
CREATE TABLE
postgres=# INSERT INTO events SELECT generate_series(1,1000000);
INSERT 0 1000000
postgres=#  EXPLAIN (ANALYZE)
postgres-# SELECT * FROM events ORDER BY id DESC LIMIT 3;
                                                              QUERY PLAN
----------------------------------------------------------------------------------------------------------------------------------------------
 Limit  (cost=16203.26..16203.61 rows=3 width=4) (actual time=223.407..224.153 rows=3 loops=1)
   ->  Gather Merge  (cost=16203.26..125913.99 rows=940312 width=4) (actual time=223.405..224.150 rows=3 loops=1)
         Workers Planned: 2
         Workers Launched: 2
         ->  Sort  (cost=15203.24..16378.63 rows=470156 width=4) (actual time=212.877..212.878 rows=2 loops=3)
               Sort Key: id DESC
               Sort Method: top-N heapsort  Memory: 25kB
               Worker 0:  Sort Method: top-N heapsort  Memory: 25kB
               Worker 1:  Sort Method: top-N heapsort  Memory: 25kB
               ->  Parallel Seq Scan on events  (cost=0.00..9126.56 rows=470156 width=4) (actual time=0.028..98.436 rows=333333 loops=3)
 Planning Time: 0.131 ms
 Execution Time: 224.174 ms
(12 rows)
```

This produces a huge difference in query runtime, even when all of the data is in the cache.

If you run the same analysis using `EXPLAIN (ANALYZE, BUFFERS)` on your production system, you'll be able to see the cache effects as well. Databases work well if the "active set" of data blocks in a database can be cached in **random-access memory** (**RAM**). The active set, also known as the working set, is a subset of the data that is accessed by queries on a regular basis. Each new index you add will increase the pressure on the cache, so it is possible to have too many indexes.

You can also look at the statistics for objects touched by queries. In `pg_stat_user_tables`, the fast growth of `seq_tup_read` means that there are lots of sequential scans occurring. The ratio of `seq_tup_read` to `seq_scan` shows how many tuples each `seqscan` reads. Similarly, the `idx_scan` and `idx_tup_fetch` columns show whether indexes are being used and how effective they are.

Locking problems

Thanks to its **multi-version concurrency control** (**MVCC**) design, PostgreSQL does not suffer from most locking problems, such as writers locking out readers or readers locking out writers, but it still has to take locks when more than one process wants to update the same row. Also, it has to hold the write lock until the current writer's transaction finishes.

So, if you have a database design where many queries update the same record, you can have a locking problem. Running **Data Definition Language** (**DDL**) will also require stronger locks that may interrupt applications.

To diagnose locking problems retrospectively, use the `log_lock_waits` parameter to generate log output for locks that are held for a long time.

EXPLAIN options

Use the `FORMAT` option to retrieve the output of `EXPLAIN` in a different format, such as **JavaScript Object Notation** (**JSON**), **Extensible Markup Language** (**XML**), and **YAML Ain't Markup Language** (**YAML**). This could allow us to write programs to manipulate the outputs.

The following command is an example of this:

```
EXPLAIN (ANALYZE, BUFFERS, FORMAT JSON) SELECT count(*) FROM t;
```

Not enough CPU power or disk I/O capacity for the current load

These issues are usually caused by suboptimal query plans but, sometimes, your computer is just not powerful enough.

In this case, `top` is your friend. For quick checks, run the following code from the command line:

```
user@host:~$ top
```

First, watch the percentage of idle CPU from `top`. If this is in low single digits most of the time, you probably have problems with the CPU's power.

If you have a high load average with a lot of CPU idle left, you are probably out of disk bandwidth. In this case, you should also have lots of Postgres processes in the `D` status, meaning that the process is in an uninterruptible state (usually waiting for I/O).

Reducing the number of rows returned

PostgreSQL 9.5 introduced the `TABLESAMPLE` clause into SQL. This allows you to run commands much faster by using a sample of a table's rows, giving an approximate answer. In certain cases, this can be just as useful as the most accurate answer:

```
postgres=# SELECT avg(id) FROM events;
         avg
---------------------
 500000.500
(1 row)
postgres=# SELECT avg(id) FROM events TABLESAMPLE system(1);
         avg
---------------------
 507434.635
(1 row)
postgres=# EXPLAIN (ANALYZE, BUFFERS) SELECT avg(id) FROM events;
                             QUERY
PLAN
--------------------------------------------------------------------
 Aggregate (cost=16925.00..16925.01 rows=1 width=32) (actual time=204.841..204.841
rows=1 loops=1)
   Buffers: shared hit=96 read=4329
   -> Seq Scan on events (cost=0.00..14425.00 rows=1000000 width=4) (actual
time=1.272..105.452 rows=1000000 loops=1)
         Buffers: shared hit=96 read=4329
 Planning time: 0.059 ms
 Execution time: 204.912 ms
(6 rows)
postgres=# EXPLAIN (ANALYZE, BUFFERS)
          SELECT avg(id) FROM events TABLESAMPLE system(1);
                             QUERY
PLAN
--------------------------------------------------------------------
 Aggregate (cost=301.00..301.01 rows=1 width=32) (actual time=4.627..4.627 rows=1
loops=1)
   Buffers: shared hit=1 read=46
   -> Sample Scan on events (cost=0.00..276.00 rows=10000 width=4) (actual
time=0.074..2.833 rows=10622 loops=1)
         Sampling: system ('1'::real)
         Buffers: shared hit=1 read=46
Planning time: 0.066 ms
 Execution time: 4.702 ms
(7 rows)
```

Speeding up queries without rewriting them

Often, you either can't or don't want to rewrite a query. However, you can still try and speed it up through any of the techniques we will discuss here.

How to do it...

By now, we assume that you've looked at various problems already, so the following are more advanced ideas for you to try.

Increasing work_mem

For queries involving large sorts or for join queries, it may be useful to increase the amount of working memory that can be used for query execution. Try setting the following:

```
SET work_mem = '1TB';
```

Then, run `EXPLAIN` (not `EXPLAIN ANALYZE`). If `EXPLAIN` changes for the query, then it may benefit from more memory. I'm guessing that you don't have access to 1 **terabyte** (**TB**) of RAM; the previous setting was only used to prove that the query plan is dependent on available memory. Now, issue the following command:

```
RESET work_mem;
```

Now, choose a more appropriate value for production use, such as the following:

```
SET work_mem = '128MB';
```

Remember to increase `maintenace_work_mem` when creating indexes or adding **foreign keys** (**FKs**), rather than `work_mem`.

More ideas with indexes

Try to add a multicolumn index that is specifically tuned for that query.

If you have a query that, for example, selects rows from the `t1` table on the `a` column and sorts on the `b` column, then creating the following index enables PostgreSQL to do it all in one index scan:

```
CREATE INDEX t1_a_b_idx ON t1(a, b);
```

PostgreSQL 9.2 introduced a new plan type: **index-only scans**. This allows you to utilize a technique known as **covering indexes**. If all of the columns requested by the `SELECT` list of a query are available in an index, that particular index is a covering index for that query. This technique allows PostgreSQL to fetch valid rows directly from the index, without accessing the table (**heap**), so performance improves significantly. If the index is non-unique, you can just add columns onto the end of the index, like so. However, please be aware that this only works for non-unique indexes:

```
CREATE INDEX t1_a_b_c_idx ON t1(a, b, c);
```

PostgreSQL 11+ provides syntax to identify covering index columns in a way that works for both unique and non-unique indexes, like this:

```
CREATE INDEX t1_a_b_cov_idx ON t1(a, b) INCLUDE (c);
```

Another often underestimated (or unknown) feature of PostgreSQL is **partial indexes**. If you use `SELECT` on a condition, especially if this condition only selects a small number of rows, you can use a conditional index on that expression, like this:

```
CREATE INDEX t1_proc_ndx ON t1(i1)
WHERE needs_processing = TRUE;
```

The index will be used by queries that have a `WHERE` clause that includes the index clause, like so:

```
SELECT id, ... WHERE needs_processing AND i1 = 5;
```

There are many types of indexes in Postgres, so you may find that there are multiple types of indexes that can be used for a particular task and many options to choose from:

- **ID data**: `BTREE` and `HASH`
- **Categorical data**: `BTREE`
- **Text data**: `GIST` and `GIN`
- **JSONB or XML data**: `GIN`, plus selective use of `btree`
- **Time-range data**: `BRIN` (and partitioning)
- **Geographical data**: `GIST`, `SP-GIST`, and `BRIN`

Performance gains in Postgres can also be obtained with another technique: **clustering tables on specific indexes**. However, index access may still not be very efficient if the values that are accessed by the index are distributed randomly, all over the table. If you know that some fields are likely to be accessed together, then cluster the table on an index defined on those fields. For a multicolumn index, you can use the following command:

```
CLUSTER t1_a_b_ndx ON t1;
```

Clustering a table on an index rewrites the whole table in index order. This can lock the table for a long time, so don't do it on a busy system. Also, `CLUSTER` is a one-time command. New rows do not get inserted in cluster order, and to keep the performance gains, you may need to cluster the table every now and then.

Once a table has been clustered on an index, you don't need to specify the index name in any cluster commands that follow. It is enough to type this:

```
CLUSTER t1;
```

It still takes time to rewrite the entire table, though it is probably a little faster once most of the table is in index order.

There's more...

We will complete this topic by listing four examples of query performance issues that can be addressed with a specific solution.

Time-series partitioning

Refer to the *Creating time-series tables* topic for more information on this.

Using a view that contains TABLESAMPLE

Where some queries access a table, replace that with a view that retrieves fewer rows using a `TABLESAMPLE` clause. In this example, we are using a sampling method that produces a sample of the table using a scan lasting no longer than 5 seconds; if the table is small enough, the answer is exact, otherwise progressive sampling is used to ensure that we meet our time objective:

```
CREATE EXTENSION tsm_system_time;
CREATE SCHEMA fast_access_schema;
CREATE VIEW fast_access_schema.tablename AS
 SELECT *
 FROM data_schema.tablename TABLESAMPLE system_time(5000); --5 secs
SET search_path = 'fast_access_schema, data_schema';
```

So, the application can use the new table without changing the SQL. Be careful, as some answers can change when you're accessing fewer rows (for example, `sum()`), making this particular idea somewhat restricted; the overall idea of using views is still useful.

In case of many updates, set fillfactor on the table

If you often update only some tables and can arrange your query/queries so that you don't change any indexed fields, then setting `fillfactor` to a lower value than the default of `100` for those tables enables PostgreSQL to use **heap-only tuples** (**HOT**) updates, which can be an **order of magnitude** (**OOM**) faster than ordinary updates. HOT updates not only avoid creating new index entries but can also perform a fast mini-vacuum inside the page to make room for new rows:

```
ALTER TABLE t1 SET (fillfactor = 70);
```

This tells PostgreSQL to fill only `70` % of each page in the `t1` table when performing insertions so that `30` % is left for use by in-page (HOT) updates.

Rewriting the schema -- a more radical approach

In some cases, it may make sense to rewrite the database schema and provide an old view for unchanged queries using views, triggers, rules, and functions.

One such case occurs when refactoring the database, and you would want old queries to keep running while changes are made.

Another case is an external application that is unusable with the provided schema but can be made to perform OK with a different distribution of data between tables.

Discovering why a query is not using an index

This topic explains what to do if you think your query should use an index, but it isn't.

There could be several reasons for this but, most often, the reason is that the optimizer believes that, based on the available distribution statistics, it is cheaper and faster to use a query plan that does not use that specific index.

Getting ready

First, check that your index exists, and ensure that the table has been analyzed. If there is any doubt, rerun it to be sure---though it's better to do this only on specific tables:

```
postgres=# ANALYZE;

ANALYZE
```

How to do it...

Force index usage and compare plan costs with an index and without, as follows:

```
postgres=# EXPLAIN ANALYZE SELECT count(*) FROM itable WHERE id > 500;

                         QUERY PLAN
---------------------------------------------------------------------
  Aggregate  (cost=188.75..188.76 rows=1 width=0)
            (actual time=37.958..37.959 rows=1 loops=1)
    ->  Seq Scan on itable (cost=0.00..165.00 rows=9500 width=0)
            (actual time=0.290..18.792 rows=9500 loops=1)
         Filter: (id > 500)
 Total runtime: 38.027 ms
(4 rows)

postgres=# SET enable_seqscan TO false;
SET

postgres=# EXPLAIN ANALYZE SELECT count(*) FROM itable WHERE id > 500;


                         QUERY PLAN
---------------------------------------------------------------------
  Aggregate  (cost=323.25..323.26 rows=1 width=0)
            (actual time=44.467..44.469 rows=1 loops=1)
    ->  Index Scan using itable_pkey on itable
            (cost=0.00..299.50 rows=9500 width=0)
            (actual time=0.100..23.240 rows=9500 loops=1)
         Index Cond: (id > 500)
 Total runtime: 44.556 ms
(4 rows)
```

Note that you must use `EXPLAIN ANALYZE` rather than just `EXPLAIN`. `EXPLAIN ANALYZE` shows you how much data is being requested and measures the actual execution time, while `EXPLAIN` only shows what the optimizer thinks will happen. `EXPLAIN ANALYZE` is slower, but it gives an accurate picture of what is happening.

In PostgreSQL 14, please use these `EXPLAIN (ANALYZE ON, SETTINGS ON, BUFFERS ON, WAL ON)` options rather than just using `EXPLAIN ANALYZE`. `SETTINGS` will give you information about any non-default options, while `BUFFERS` and `WAL` will give you more information about the data access for read/write.

How it works...

By setting the `enable_seqscan` parameter to `off`, we greatly increase the cost of sequential scans for the query. This setting is never recommended for production use---only use it for testing because this setting affects the whole query, not just the part of it you would like to change.

This allows us to generate two different plans, one with `SeqScan` and one without. The optimizer works by selecting the lowest-cost option available. In the preceding example, the cost of `SeqScan` is `188.75` and the cost of `IndexScan` is `323.25`, so for this specific case, `IndexScan` will not be used.

Remember that each case is different and always relates to the exact data distribution.

There's more...

Be sure that the `WHERE` clause you are using can be used with the type of index you have. For example, the `abs(val) < 2` `WHERE` clause won't use an index because you're performing a function on the column, while `val BETWEEN -2 AND 2` could use the index. With more advanced operators and data types, it's easy to get confused as to the type of clause that will work, so check the documentation for the data type carefully.

In PostgreSQL 10, join statistics were also improved by the use of FKs since they can be used in some queries to prove that joins on those keys return exactly one row.

Forcing a query to use an index

Often, we think we know better than the database optimizer. Most of the time, your expectations are wrong, and if you look carefully, you'll see that. So, recheck everything and come back later.

It is a classic error to try to get the database optimizer to use indexes when the database has very little data in it. Put some genuine data in the database first, then worry about it. Better yet, load some data on a test server first, rather than doing this in production.

Sometimes, the optimizer gets it wrong. You feel elated---and possibly angry---that the database optimizer doesn't see what you see. Please bear in mind that the data distributions within your database change over time, and this causes the optimizer to change its plans over time as well.

If you have found a case where the optimizer is wrong, this can sometimes change over time as the data changes. It might have been correct last week and will be correct again next week, or it correctly calculated that a change of plan was required, but it made that change slightly ahead of time or slightly too late. Again, trying to force the optimizer to do the right thing *now* might prevent it from doing the right thing *later*, when the plan changes again. So hinting fixes things in the short term, but in the longer term can cause problems to resurface.

In the long run, it is not recommended to try to force the use of a particular index.

Getting ready

Still here? Oh well.

If you really feel this is necessary, then your starting point is to run an `EXPLAIN` command for your query, so please read the previous topic first.

How to do it...

The most common problem is selecting too much data.

A typical point of confusion comes from data that has a few very common values among a larger group. Requesting data for very common values costs more because we need to bring back more rows. As we bring back more rows, the cost of using the index increases. Therefore, it is possible that we won't use the index for very common values, whereas we would use the index for less common values. To use an index effectively, make sure you're using the `LIMIT` clause to reduce the number of rows that are returned.

Since different index values might return more or less data, it is common for execution times to vary depending upon the exact input parameters. This could cause a problem if we are using prepared statements---the first five executions of a prepared statement are made using "custom plans" that vary according to the exact input parameters. From the sixth execution onward, the optimizer decides whether to use a "generic plan" or not, if it thinks the cost will be lower on average. Custom plans are more accurate, but the planning overhead makes them less efficient than generic plans. This heuristic can go wrong at times and you might need to override it using `plan_cache_mode  = force_generic_plan` or `force_custom_plan`.

Another technique for making indexes more usable is **partial indexes**. Instead of indexing all of the values in a column, you might choose to index only a set of rows that are frequently accessed---for example, by excluding `NULL` or other unwanted data. By making the index smaller, it will be cheaper to access and will fit within the cache better, avoiding pointless work by targeting the index at only the important data. Data statistics are kept for such indexes, so it can also improve the accuracy of query planning. Let's look at an example:

```
CREATE INDEX ON customer(id)
 WHERE blocked = false AND subscription_status = 'paid';
```

Another common problem is that the optimizer may make errors in its estimation of the number of rows returned, causing the plan to be incorrect. Some optimizer estimation errors can be corrected using `CREATE STATISTICS`. If the optimizer is making errors, it can be because the `WHERE` clause contains multiple columns. For example, queries that mention related columns such as `state` and `phone_area_code` or `city` and `zip_code` will have poor estimates because those pairs of columns have data values that are correlated.

You can define additional statistics that will be collected when you next analyze the table:

```
CREATE STATISTICS cust_stat1 ON state, area_code FROM cust;
```

The execution time of `ANALYZE` will increase to collect the additional stats information, plus there is a small increase in query planning time, so use this sparingly when you can confirm this will make a difference. If there is no benefit, use `DROP STATISTICS` to remove them again. By default, multiple types of statistics will be collected---you can fine-tune this by specifying just a few types of statistics if you know what you are doing.

Unfortunately, the `statistics` command doesn't automatically generate names, so include the table name in the statistics you create since the name is unique within the database and cannot be repeated on different tables. In future releases, we may also add cross-table statistics.

Additionally, you cannot collect statistics on individual fields within JSON documents at the moment, nor collect dependency information between them; this command only applies to whole column values at this time.

Another nudge toward using indexes is to set `random_page_cost` to a lower value---maybe even equal to `seq_page_cost`. This makes PostgreSQL prefer index scans on more occasions, but it still does not produce entirely unreasonable plans, at least for cases where data is mostly cached in shared buffers or system disk caches, or underlying disks are **solid-state drives** (**SSDs**).

The default values for these parameters are provided here:

```
random_page_cost = 4;
seq_page_cost = 1;
```

Try setting this:

```
set random_page_cost = 2;
```

See if it helps; if not, you can try setting it to `1`.

Changing `random_page_cost` allows you to react to whether data is on disk or in memory. Letting the optimizer know that more of an index is in the cache will help it to understand that using the index is actually cheaper.

Index scan performance for larger scans can also be improved by allowing multiple asynchronous I/O operations by increasing `effective_io_concurrency`. Both `random_page_cost` and `effective_io_concurrency` can be set for specific tablespaces or for individual queries.

There's more...

PostgreSQL does not directly support hints, but they are available via an extension.

If you absolutely, positively have to use the index, then you'll want to know about an extension called `pg_hint_plan`. It is available for PostgreSQL 9.1 and later versions. For more information and to download it, go to http://pghintplan.sourceforge.jp/. Hints can be added to your application SQL using a special comment added to the start of a query, like this:

```
/*+ IndexScan(tablename indexname) */ SELECT …
```

It works but, as I said previously, try to avoid fixing things now and causing yourself pain later when the data distribution changes.

EnterpriseDB (EDB) Postgres Advanced Server (**EPAS**) also supports hints in an Oracle-style syntax to allow you to select a specific index, like this:

```
SELECT /*+ INDEX(tablename indexname) */ … rest of query …
```

EPAS has many compatibility features such as this for migrating application logic from Oracle. See https://www.enterprisedb.com/docs/epas/latest/epas_compat_ora_dev_guide/05_optimizer_hints/ for more information on this.

Using parallel query

PostgreSQL now has an increasingly effective parallel query feature.

Response times from long-running queries can be improved by the use of parallel processing. The concept is that if we divide a large task up into multiple smaller pieces then we get the answer faster, but we use more resources to do that.

Very short queries won't get faster by using parallel query, so if you have lots of those you'll gain more by thinking about better indexing strategies. Parallel query is aimed at making very large tasks faster, so it is useful for reporting and **business intelligence** (**BI**) queries.

How to do it...

Take a query that needs to do a big chunk of work, such as the following:

```
\timing
SET max_parallel_workers_per_gather = 0;
SELECT count(*) FROM big;
count
---------
1000000
(1 row)
Time: 46.399 ms
SET max_parallel_workers_per_gather = 2;
SELECT count(*) FROM big;
count
---------
1000000
(1 row)
Time: 29.085 ms
```

By setting the `max_parallel_workers_per_gather` parameter, we've improved performance using parallel query. Note that we didn't need to change the query at all. (The preceding queries were executed multiple times to remove any cache effects).

In PostgreSQL 9.6 and 10, parallel query only works for read-only queries, so only `SELECT` statements that do not contain the `FOR` clause (for example, `SELECT ... FOR UPDATE`). In addition, a parallel query can only use functions or aggregates that are marked as `PARALLEL SAFE`. No user-defined functions are marked `PARALLEL SAFE` by default, so read the docs carefully to see whether your functions can be enabled for parallelism for the current release.

How it works...

The plan for our earlier example of parallel query looks like this:

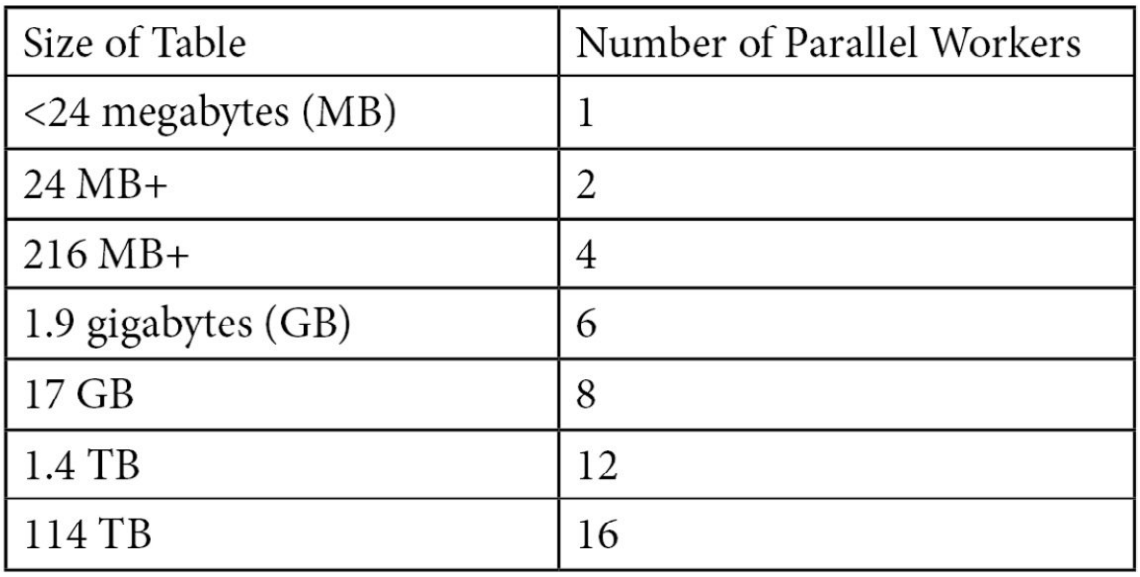
```
postgres=# EXPLAIN ANALYZE
 SELECT count(*) FROM big;
                             QUERY
PLAN
---------------------------------------------------------------------
 Finalize Aggregate  (cost=11614.55..11614.56 rows=1 width=8) (actual
time=59.810..62.074 rows=1 loops=1)
   ->  Gather  (cost=11614.33..11614.54 rows=2 width=8) (actual time=59.709..62.067
rows=3 loops=1)
         Workers Planned: 2
         Workers Launched: 2
         ->  Partial Aggregate  (cost=10614.33..10614.34 rows=1 width=8) (actual
time=56.298..56.299 rows=1 loops=3)
               ->  Parallel Seq Scan on big  (cost=0.00..9572.67 rows=416667 width=0)
(actual time=0.009..32.138 rows=333333 loops=3)
 Planning Time: 0.056 ms
 Execution Time: 62.110 ms
(8 rows)
```

By default, a query will use only one process. Parallel query is enabled by setting `max_parallel_workers_per_gather` to a value higher than zero (the default is `2`). This parameter specifies the maximum number of **additional** processes that are available if needed. So, a setting of `1` will mean you have the leader process plus one additional worker process, so two processes in total.

The query optimizer will decide whether parallel query is a useful plan based upon cost, just as with other aspects of the optimizer. Importantly, it will decide how many parallel workers to use in its plan, up to the maximum you specify.

Note that the performance increase from adding more workers isn't linear for anything other than simple plans, so there are diminishing returns from using too many workers. The biggest gains are from adding the first few extra processes.

PostgreSQL will assign a number of workers according to the size of the table compared to the `min_parallel_table_scan_size` value, using the logarithm (base 3) of the ratio. With default values this means:



Size of Table	Number of Parallel Workers
<24 megabytes (MB)	1
24 MB+	2
216 MB+	4
1.9 gigabytes (GB)	6
17 GB	8
1.4 TB	12
114 TB	16

Decreasing `min_parallel_table_scan_size` will increase the number of workers assigned.

Across the whole server, the maximum number of worker processes available is specified by the `max_parallel_workers` parameter and is set at server start only.

At execution time, the query will use its planned number of worker processes if that many are available. If worker processes aren't available, the query will run with fewer worker processes. As a result, it pays to not be too greedy, since if all concurrent users specify more workers than are available, you'll end up with variable performance as the number of concurrent parallel queries changes.

Creating time-series tables using partitioning

In many applications, we need to store data in time series. There are various mechanisms in PostgreSQL that are designed to support this.

How to do it...

If you have a huge table and a query to select only a subset of that table, then you may wish to use a **block range index** (**BRIN index**). These indexes give performance improvements when the data is naturally ordered as it is added to the table, such as `logtime` columns or a naturally ascending `OrderId` column. Adding a BRIN index is fast and very easy, and works well for the use case of time-series data logging, though it works less well under intensive updates, even with the new BRIN features in PostgreSQL 14. `INSERT` commands into BRIN indexes are specifically designed to not slow down as the table gets bigger, so they perform much better than B-tree indexes for write-heavy applications. B-trees do have faster retrieval performance but require more resources. To try BRIN, just add an index, like so:

```
CREATE TABLE measurement (
     logtime     TIMESTAMP WITH TIME ZONE NOT NULL,
     measures    JSONB NOT NULL);
CREATE INDEX ON measurement USING BRIN (logtime);
```

Partitioning syntax was introduced in PostgreSQL 10. Over the last five releases, partitioning has been very heavily tuned and extended to make it suitable for time-series logging, BI, and fast **Online Transaction Processing** (**OLTP**) `SELECT`, `UPDATE`, or `DELETE` commands.

The best reason to use partitioning is to allow you to drop old data quickly. For example, if you are only allowed to keep data for 30 days, it might make sense to store data in 30 partitions. Each day, you would add one new empty partition and detach/drop the last partition in the time series.

For example, to create a table for time-series data, you may want something like this:

```
CREATE TABLE measurement (
     logtime     TIMESTAMP WITH TIME ZONE NOT NULL,
     measures    JSONB NOT NULL
     ) PARTITION BY RANGE (logtime);
CREATE TABLE measurement_week1 PARTITION OF measurement
     FOR VALUES FROM ('2019-03-01') TO ('2019-04-01');
CREATE INDEX ON measurement_week1 USING BRIN (logtime);
CREATE TABLE measurement_week2 PARTITION OF measurement
     FOR VALUES FROM ('2019-04-01') TO ('2019-05-01');
CREATE INDEX ON measurement_week2 USING BRIN (logtime);
```

For some applications, the time taken to `SELECT` / `UPDATE` / `DELETE` from the table will increase with the number of partitions, so if you are thinking you might need more than 100 partitions, you should benchmark carefully with fully loaded partitions to check this works for your application.

You can use both BRIN indexes and partitioning at the same time so that there is less need to have a huge number of partitions. As a guide, partition size should not be larger than shared buffers, to allow the whole current partition to sit within shared buffers.

For more details on partitioning, check out https://www.postgresql.org/docs/current/ddl-partitioning.html.

How it works...

Each partition is actually a normal table, so you can refer to partitions directly in queries. A partitioned table is somewhat similar to a view, since it links all of the partitions under it together. The partition key defines which data goes into which partition so that each row lives in exactly one partition. Partitioning can also be defined with multiple levels---so, a single top-level partitioned table, then with each sub-table also having sub-sub-partitions.

B-tree performance degrades very slowly as tables get bigger, so having single tables larger than a few hundred GB may no longer be optimal. Using partitions and limiting the size of each partition will prevent any bad news as data volumes climb over time. Let me repeat the "very slowly" part---so, no need to rush around changing all of your tables when you get to 101 GB.

As of PostgreSQL 14, adding and detaching partitions are both now optimized to hold a lower level of lock, allowing `SELECT` statements to continue while those activities occur. Adding a new partition with a reduced lock level just uses the syntax shown previously. Simply dropping a partition will hold an `AccessExclusiveLock`---or, in other words, will be blocked by `SELECT` statements and will block them while it runs. Dropping a partition using a reduced lock level should be done in two steps, like this:

```
ALTER TABLE measurement
     DETACH PARTITION measurement_week2 CONCURRENTLY;
DROP TABLE measurement_week2;
```

Note that you cannot run those two commands in one transaction. If the `ALTER TABLE` command is interrupted, then you will need to run `FINALIZE` to complete the operation, like this:

```
ALTER TABLE measurement
     DETACH PARTITION measurement_week2 FINALIZE;
```

Partitioned tables also support default partitions, but I recommend against using them because of the way table locking works with that feature. If you add a new partition that partially overlaps the default partition, it will lock the default partition, scan it, and then move data to the new partition. That activity can lock out the table for some time and should be avoided on production systems. Note also that you can't use concurrent detach if you have a default partition.

There's more...

The ability to do a "partition-wise join" can be very useful for large queries when joining two partitioned tables. The join must contain all columns of the partition key and be the same data type, with a 1:1 match between the partitions. If you have multiple partitioned tables in your application, you may wish to enable the `enable_partitionwise_join = on` optimizer parameter, which defaults to `off`.

If you do large aggregates on a partitioned table, you may also want to enable another optimizer parameter, `enable_partitionwise_aggregate = on`, which defaults to `off`.

PostgreSQL 11 adds the ability to have **primary keys** (**PKs**) defined over a partitioned table, enforcing uniqueness across partitions. This requires that the partition key is the same or a subset of the columns of the PK. Unfortunately, you cannot have a unique index across an arbitrary set of columns of a partitioned table because multi-table indexes are not yet supported---and it would be very large if you did.

You can define references from a partitioned table to normal tables to enforce FK constraints. References to a partitioned table are possible in PostgreSQL 12+.

Partition tables can have before-and-after row triggers.

Partitioned tables can be used in publications and subscriptions, as well as in Postgres-**Bi-Directional Replication** (**BDR**).

Using optimistic locking to avoid long lock waits

If you perform work in one long transaction, the database will lock rows for long periods of time. Long lock times often result in application performance issues because of long lock waits:

```
BEGIN;
SELECT * FROM accounts WHERE holder_name ='BOB' FOR UPDATE;
<do some calculations here>
UPDATE accounts SET balance = 42.00 WHERE holder_name ='BOB';
COMMIT;
```

If that is happening, then you may gain some performance benefits by moving from explicit locking (`SELECT ... FOR UPDATE`) to optimistic locking.

Optimistic locking assumes that others don't update the same record, and checks this at update time, instead of locking the record for the time it takes to process the information on the client side.

How to do it...

Rewrite your application so that the SQL is transformed into two separate transactions, with a double-check to ensure that the rows haven't changed (pay attention to the placeholders):

```
SELECT A.*, (A.*::text) AS old_acc_info
FROM accounts a WHERE holder_name ='BOB';
<do some calculations here>
UPDATE accounts SET balance = 42.00
WHERE holder_name ='BOB'
AND (A.*::text) = <old_acc_info from select above>;
```

Then, check whether the `UPDATE` operation really did update one row in your application code. If it did not, then the account for `BOB` was modified between `SELECT` and `UPDATE` , and you probably need to rerun your entire operation (both transactions).

How it works...

Instead of locking Bob's row for the time that the data from the first `SELECT` command is processed in the client, PostgreSQL queries the old state of Bob's account record in the `old_acc_info` variable and then uses this value to check that the record has not changed when we eventually update.

You can also save all fields individually and then check them all in the `UPDATE` query; if you have an automatic `last_change` field, then you can use that instead. Alternatively, if you only care about a few fields changing---such as `balance` ---and are fine ignoring others---such as `email` ---then you only need to check the relevant fields in the `UPDATE` statement.

There's more...

You can also use the serializable transaction isolation level when you need to be absolutely sure that the data you are looking at is not affected by other user changes.

The default transaction isolation level in PostgreSQL is read-committed, but you can choose from two more levels---repeatable read and serializable---if you require stricter control over the visibility of data within a transaction. See http://www.postgresql.org/docs/current/static/transaction-iso.html for more information.

Another design pattern that's available in some cases is to use a single statement for the `UPDATE` clause and return data to the user via the `RETURNING` clause, as in the following example:

```
UPDATE accounts
 SET balance = balance - i_amount
WHERE username = i_username
AND balance - i_amount > - max_credit
RETURNING balance;
```

In some cases, moving the entire computation to the database function is a very good idea. If you can pass all of the necessary information to the database for processing as a database function, it will run even faster, as you save several round-trips to the database. If you use a PL/pgSQL function, you also benefit from automatically saving query plans on the first call in a session and using saved plans in subsequent calls.

Therefore, the preceding transaction is replaced by a function in the database, like so:

```
CREATE OR REPLACE FUNCTION consume_balance
( i_username text
, i_amount numeric(10,2)
, max_credit numeric(10,2)
, OUT success boolean
, OUT remaining_balance numeric(10,2)
) AS
$$
BEGIN
  UPDATE accounts SET balance = balance - i_amount
  WHERE username = i_username
  AND balance - i_amount > - max_credit
  RETURNING balance
  INTO remaining_balance;
  IF NOT FOUND THEN
    success := FALSE;
    SELECT balance
    FROM accounts
    WHERE username = i_username
    INTO remaining_balance;
  ELSE
    success := TRUE;
  END IF;
END;
$$ LANGUAGE plpgsql;
```

You can call it by simply running the following line of code from your client:

```
SELECT * FROM consume_balance ('bob', 7, 0);
```

The output will return the success variable. It tells you whether there was a sufficient balance in Bob's account. The output will also return a number, telling you the balance `bob` has left after this operation.