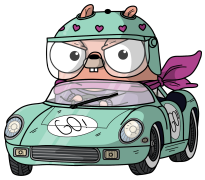
The Ultimate Guide To Building Database-Intensive Apps with Go



Gophers by Ashley McNamara

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Table of Contents

Introduction	2
What is database/sql?	3
Your First database/sql Program	5
Using a sql.DB	7
Fetching Result Sets	11
Modifying Data With db.Exec()	17
Using Prepared Statements	19
Working with Transactions	23
Working With a Single Connection	26
Error Handling	27
Using Built-In Interfaces	28
Monitoring, Tracing, Observability	31
Working With Context	33
Database Drivers	34
Common Pitfalls	35
Conclusions	37

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Introduction

Congratulations! You've discovered the ultimate resource for writing database-intensive applications in the Go programming language.

What is Go, and who uses it? Go is a modern language in the C family. It is elegant, simple, and clear, making it maintainable. It includes a garbage collector to manage memory for you. Its built-in features make it easy to write concurrent programs. These include goroutines, which you can think of as lightweight threads, and mechanisms to communicate amongst goroutines. At the same time, Go is strongly typed and compiles to self-contained binaries free of external dependencies, and is high-performance and efficient in terms of CPU and memory usage.

Using Go to access databases brings you all the benefits of Go itself, plus an elegant database interface and a vibrant community of users and developers writing high-quality, open-source database drivers for you to use.

Go's `database/sql` library has excellent documentation and source code but leaves a lot of learning to the user. Fortunately, you've found this book, which will save you time and mistakes! This book has years of collected wisdom from many experienced programmers, distilled to just what you need to know, when you need to know it.

Go is an excellent choice for systems programming, where you might otherwise choose Java, C or C++ for performance reasons. And it's not a stretch to say that Go is one of the main languages of cloud computing, with a strong presence in distributed systems and microservices architectures. Here are some key use cases for choosing Go:

- Building high performance networked applications. Go is great for building API servers, microservices, and all types of HTTP services among other things. It's not limited to HTTP, of course, it's equally capable of speaking protocols like RPC and interchanging data in every format you can think of.
- Building heavy-duty systems applications. A number of databases—including distributed high-performance databases—have been written in Go recently. In decades past, most of those would have been written in C or C++.
- Cloud migrations. A lot of companies undertake a rewrite at the same time they move to the cloud, instead of just lift-and-shift. Go is a popular language for this because of its simplicity, making it highly productive. A common joke is that you get a Go programmer by letting a Java programmer use Go and they never want to write in any other language again.
- Anywhere high-throughput, high-concurrency, low-latency, low-variability

performance is desired for great customer experience. This typically is a good fit for applications whose workload is directly user-facing at scale, where real people are expecting interactive responsiveness from your application, and will be dissatisfied otherwise.

Go is also popular for tasks where you would otherwise use dynamic scripting languages such as Python and Ruby, which give you simplicity, clarity and flexibility but not high performance. Go gives you many of the best features of these languages, and some properties not present in any of them.

We use Go extensively at VividCortex. It's the language that powers all of our public- and internal-facing services, which typically speak either HTTP or RPC to communicate with each other, and ingest more than half a billion data points a minute—and growing fast. It also powers our distributed time series database, a custom-built backend database that uses MySQL under the hood as a storage engine. And we use it for lots of utilities too, such as programs to take backups.

Go includes a standard library of code for tasks such as encryption, networking, filesystem access, and database access. The database access library is called `database/sql`, and like the rest of Go, is elegant and minimal, with just enough batteries included. It does heavy lifting and repetitive tasks for you, such as connection pooling and retries on errors. But it doesn't bury its internals in abstractions, so your code remains explicit and magic-free.

Congratulations on choosing Go and `database/sql`, and on finding this book, which covers up to Go version 1.12. Let's get started right away!

What is database/sql?

`database/sql` is a package of functionality that's included in Go's standard library. It is the idiomatic, official way to communicate with a row-oriented database. Loosely speaking, it is designed for databases that are SQL or relational, or similar to relational databases (many non-relational databases work just fine with it too).

`database/sql` provides much the same functionality for Go that you'd find in ODBC, Perl's DBI, Java's JDBC, and similar. However, it is not designed exactly the same as those, and you should be careful not to assume your knowledge of other database interfaces applies directly in Go.

The `database/sql` package handles non-database-specific aspects of database communication. These are tasks that have to be handled in common across many database technologies, so they're factored out into a uniform interface for you to use.

Database-specific functionality is provided by drivers, which aren't part of the standard library. Many excellent drivers are available in open-source form, and I will discuss those later.

To a large extent, `database/sql` is database-agnostic. The benefits of using it are that your code will be as decoupled from the underlying database as possible, enabling easier portability and ensuring your code doesn't get cluttered. This leads to better maintainability and understandability.

The `database/sql` package is very idiomatic and Go-ish, following the Go philosophy of not hiding things behind too much abstraction. As a programmer, you'll be in direct control over resource management, including memory management (although, like other things in Go, that is a very small burden due to the language design).

What is it not? The primary thing is that it definitely isn't an ORM (object-relational mapper) or other similar abstraction. Go, as a language, isn't really oriented towards the type of programming that ORMs provide, and although there are some third-party libraries that attempt to provide ORM-like functionality and convenience helpers (e.g. populating structs with rows from the database), all of them fall short for various reasons.

The `database/sql` package provides several types for you, each of which represents a concept or set of concepts:

- **DB**. The `sql.DB` type represents a database. Unlike in many other programming languages, it doesn't represent a connection to a database, but rather the database as an object you can manipulate. Connections are managed in an internal connection pool. This lets you use databases that are actually connectionless, such as shared-memory or embedded databases, through the same abstraction without worrying about exactly how you communicate with them. You can access them directly via a `sql.Conn` type.
- **Results**. There are several data types that embody the results of database interactions: a `sql.Rows` for fetching multi-row results from a query, a `sql.Row` for a single-row result, and `sql.Result` for examining the effects of statements that modify the database.
- **Statements**. A `sql.Stmt` represents a statement such as DDL, DML, and the like. You can interact with them directly as prepared statements, or indirectly by using convenience functions on the `sql.DB` variable itself.
- **Transactions and Connections**. A `sql.Tx` represents a transaction with specific properties, in exchange for bypassing many of the usual conveniences such as the connection pool. A `sql.Conn` gives you access to a connection, managed by a driver.

You'll see how to use all these data types, and the abstractions they present, in the following sections. Let's get started with a quick-start: a "hello, world" program!

Your First database/sql Program

This section presents a quick introduction to the major functionality of database/sql in the form of a fully functioning Go program! Before you begin, ensure you have access to a MySQL database, as I'll use MySQL for examples in this book. If you don't have an instance of MySQL that's appropriate for testing, you can get one in seconds with the MySQL Sandbox utility.

Create a new Go source file, `hello_mysql.go`, with the following source code (download). You may need to adjust the connection parameters as needed to connect to your testing database. Note also that the example assumes the default test database exists and your user has rights to it:

```
package main

import (
    "database/sql"
    "log"
    _ "github.com/go-sql-driver/mysql"
)

func main() {
    db, err := sql.Open("mysql", "root:@tcp(:3306)/test")
    if err != nil {
        log.Fatal(err)
    }
    defer db.Close()

    _, err = db.Exec(
        "CREATE TABLE IF NOT EXISTS test.hello(world varchar(50))")
    if err != nil {
        log.Fatal(err)
    }
```

```
    res, err := db.Exec(
        "INSERT INTO test.hello(world) VALUES('hello world!')")
    if err != nil {
        log.Fatal(err)
    }
    rowCount, err := res.RowsAffected()
    if err != nil {
        log.Fatal(err)
    }
    log.Printf("inserted %d rows", rowCount)

    rows, err := db.Query("SELECT * FROM test.hello")
    if err != nil {
        log.Fatal(err)
    }
    for rows.Next() {
        var s string
        err = rows.Scan(&s)
        if err != nil {
            log.Fatal(err)
        }
        log.Printf("found row containing %q", s)
    }
    rows.Close()
}
```

Run your new Go program with `go run hello_mysql.go`. It's safe to run it multiple times. As you do, you should see output like the following as it continues to insert rows into the table:

```
Desktop $ go run hello_mysql.go
2014/12/16 10:57:03 inserted 1 rows
2014/12/16 10:57:03 found row containing "hello world!"
Desktop $ go run hello_mysql.go
2014/12/16 10:57:05 inserted 1 rows
2014/12/16 10:57:05 found row containing "hello world!"
```

```
2014/12/16 10:57:05 found row containing "hello world!"
Desktop $ go run hello_mysql.go
2014/12/16 10:57:07 inserted 1 rows
2014/12/16 10:57:07 found row containing "hello world!"
2014/12/16 10:57:07 found row containing "hello world!"
2014/12/16 10:57:07 found row containing "hello world!"
```

Congratulations! You've written your first program to interact with a MySQL server using Go. What might surprise you is that this is not just a toy example. It is very similar to the code you'll use in production systems under high load, including error handling. I'll explore much of this code in further sections of this book and learn more about what it does. For now, I'll just mention a few highlights:

- You imported `database/sql` and loaded a driver for MySQL.
- You created a `sql.DB` with a call to `sql.Open()`, passing the driver name and the connection string.
- You used `Exec()` to create a table and insert a row, then inspect the results.
- You used `Query()` to select the rows from the table, `rows.Next()` to iterate over them, and `rows.Scan()` to copy columns from the current row into variables.
- You used `.Close()` to clean up resources when you were finished with them.

Let's dig into each of these topics, and more, in detail. I'll begin with the `sql.DB` itself and see what it is and how it works.

Using a sql.DB

As I mentioned previously, a `sql.DB` is an abstraction of a database. (A common mistake is to think of it as a connection to a database.) It exposes a set of functions you use to interact with the database.

Internally, it manages a connection pool for you (a very important topic in this book), and handles a great deal of tedious and repetitive work for you, all in a way that's safe to use concurrently from multiple goroutines.

The intent of a `sql.DB` is that you'll create one object to represent each database you'll use, and keep it for a long time. Because it has a connection pool, it's not meant to be created and destroyed continually. You should make your single `sql.DB` available to all the code that needs it.

To create a `sql.DB`, as you saw in the previous section, you need to import a driver.

The bare-minimum imports you need in your program's main file are as follows:

```
import (
    "database/sql"
    _ "github.com/go-sql-driver/mysql"
)
```

Again, I'm using my favorite MySQL driver as an example.

You only need to import the driver once, in one file, typically `main.go` or the equivalent. If you use a custom wrapper around database functionality, you'd likely import the driver inside that wrapper library. From here on, you'll interact with the `database/sql types`, and it will interact with the library on your behalf.

I'll cover drivers in more detail later. For now it's enough to note that you don't need access to the driver directly. That's why you bind their import name to the _ anonymous variable, so their namespace isn't usable from your code. This means that you have imported the driver for side effects only. Behind the scenes, drivers use an `init()` function to register themselves with the `database/sql` package.

Now, to actually create an instance of a `sql.DB`, you usually use `sql.Open()` with two arguments. The first is the driver's name. This is the string that the driver registers with `database/sql`, and is typically the same as its package name to avoid confusion.

The second argument is the connection string, or DSN (data source name) as some people call it. This is driver-specific and has no meaning to `database/sql`. It is merely passed to the driver you identify. It might include a TCP connection endpoint, a Unix socket, username and password, a filename, or anything else you can think of. Check the driver's documentation for details.

At this point you might think you have a connection to a database, but you probably don't. You probably have only created an object in memory and associated it with a driver; it hasn't yet actually done anything like connecting to the database. This is because most drivers don't connect until you *do* something with the database. If you want to check that the connection parameters are correct, you can "ping" the database. That is what `db.Ping()` is for. Idiomatic code looks like this:

```
db, err := sql.Open("driverName", "dataSourceName")
if err != nil {
    log.Fatal(err)
}
defer db.Close()
err = db.Ping()
```

```
if err != nil {
    log.Fatal(err)
}
```

Now you know that your `db` variable is really ready to use. The above code, by the way, is not really idiomatic in one regard. Usually you'd do something more intelligent than just fatally logging an error. But in this book I'll always show `log.Fatal(err)` as a placeholder for real error handling.

An alternative way to construct a `sql.DB` is with the `sql.OpenDB()` function, which takes a `driver.Connector` as its argument. This lets you specify connection parameters more flexibly and clearly than concatenating a string together.

How The Connection Pool Works

The `database/sql` package keeps a pool of connections. The pool is initially empty, and connections are created lazily when needed. The `database/sql` package relies on the driver to create and manage individual connections.

The connection pool is vitally important to understand because it affects your program's behavior greatly. That's why I'm including details about it early in this book.

The way the pool works is fairly simple in concept. When you call a function that requires access to the underlying database, the function first asks for a connection from the pool. The pool returns a free connection if it can, or creates a new one. The connection is then owned by the function, not the pool. When the function completes, it either returns the connection to the pool, or passes ownership of the connection to an object, which will release it back to the pool when it is finished.

The specific functions[1] you can call and how they're handled follow, assuming a `sql.DB` variable named `db`:

- `db.Ping()` returns the connection to the pool immediately.
- `db.Exec()` returns the connection to the pool immediately, but the returned `Result` object has a reference to the connection, so it may be used later for inspecting the results of the `Exec()`.
- `db.Query()` passes ownership of the connection to a `sql.Rows` object, which releases it back to the pool when you've fully iterated all the rows or when `.Close()` is called.
- `db.QueryRow()` passes the connection to a `sql.Row`, which releases it when `.Scan()` is called.
- `db.Begin()` passes the connection to a `sql.Tx`, which releases it when

[1] There are also variants of each of these functions, which accept a Context object. More on this later.

`.Commit()` or `.Rollback()` is called.

A consequence of the connection pool is that you do not need to check for, or attempt to handle connection failures. If a connection fails when you perform an operation on the database, database/sql will take care of it for you. Internally, it retries up to 10 times when a connection in the pool is discovered to be dead. It simply fetches another from the pool or opens a new one. This means that your code can be clean and free of messy retry logic.

Configuring the Connection Pool

Early versions of Go didn't offer much control over the connection pool, but in Go version 1.2.1 and later, there are options to control it. These are as follows:

- `db.SetMaxOpenConns(n int)`. This sets a connection limit—the maximum number of connections the pool will open to the database. This includes connections that are in-use as well as connections that are idle in the pool. If you make a call that requests a connection from the pool, and there isn't a free one and the limit is reached, then your call will block, potentially for a long time. The default limit is 0, which means unlimited.
- `db.SetMaxIdleConns(n int)` sets the number of connections that will be kept idle in the pool after being released. The default is 0, which means that connections are not kept idle in the pool at all: they are closed when released from service. This can lead to a lot of connections being closed and opened rapidly, which is probably not what you want.
- `db.SetConnMaxLifetime(d time.Duration)` sets an expiration time on connections, so they don't get too stale. The default is for connections to live forever.

The key things to notice about the connection pool are that, depending on how you use connections and how you've configured the pool, it's possible to have a few undesired behaviors:

1. Lots of connection thrash, leading to extra work and latency.
2. Too many connections open to the database, leading to errors.
3. Blocking while waiting for a connection.
4. Operations can fail if the pool has 10 or more dead connections, due to the built-in limit of 10 retries.

Most of the time, how you use the `sql.DB` influences these behaviors more than how you configure the pool. I'll explore this throughout this book. For now, let's move on to the next topic, fetching results from the database and doing useful things with them!

Fetching Result Sets

The `database/sql` library provides specific functions intended for queries that return results: `db.Query()` and `db.QueryRow()`. We've already seen an example of the former, and I'll cover the latter in this section as well.

As described previously, executing `db.Query()` with a SQL query will do the following:

1. Get a connection from the pool
2. Execute the query
3. Transfer ownership of the connection to the result set

The result set, a `sql.Rows` variable that is traditionally called `rows` if no more descriptive name is needed, is then a cursor over the results. Each row is fetched with a call to `rows.Next()`, beginning with the first one. The cursor is initially positioned before the first row.

To repeat the earlier example:

```
rows, err := db.Query("SELECT * FROM test.hello")
if err != nil {
	log.Fatal(err)
}
for rows.Next() {
	var s string
	err = rows.Scan(&s)
	if err != nil {
		log.Fatal(err)
	}
	log.Printf("found row containing %q", s)
}
rows.Close()
```

There are a few things to know about this code, and I'll examine it outside-in, beginning with iterating over the rows with `rows.Next()`.

Iterating Over Rows In A Result

The `rows.Next()` function is designed for use in a `for` loop as shown. When it encounters an error, including `io.EOF` which signals the end of the rows has been reached, it will return `false`. In normal operation, you'll usually iterate over all the rows until the last one, which will exit the loop.

But what if you don't exit the loop normally? What if you intentionally break out of it or return from the function? If this happens, your results won't be fetched and processed completely, and the connection might not be released back to the pool. Handling rows correctly requires thinking about this possibility. Your goal should be that `rows.Close()` is always called to release its connection back to the pool. If it isn't, then the connection will never go back into the pool, and this can cause serious problems manifested as a "leakage" of connections. If you're not careful you can easily cause server problems or reach your database server's maximum number of connections, causing downtime or unavailability.

How do you prevent this? First, you'll be happy to know that if the loop terminates due to `rows.Next()` returning `false`, whether normally or abnormally, `rows.Close()` is automatically called for you, so in normal operation you won't reserve connections from the pool in these cases.

The remaining cases are an early return or breaking out of the loop. What you should do in these cases depends on the circumstances. If you will return from the enclosing function when processing ends, you should use `defer rows.Close()`. This is the idiomatic way to ensure that "must-run" code indeed always runs when the function returns. And it's also idiomatic (and important for correctness) to place such a cleanup call immediately after the resource is created. Our modified code would then look like this:

```
rows, err := db.Query("SELECT * FROM test.hello")
if err != nil {
    log.Fatal(err)
}
defer rows.Close()
```

However, if the enclosing function is long-lived and you're repeatedly querying in a loop, then you should not defer closing the rows. You should do it explicitly just before breaking out of the loop. In fact, as a general rule, you should call `rows.Close()` as early as you possibly can, to free the resources as soon as possible. This may require a little thought and analysis of your code, in more complex cases.

There are multiple reasons not to defer in a long-lived function:

1. The deferred code won't execute for a potentially long time. You need it to execute ASAP to clean up its resources right away.
2. The deferred function, and the variables it refers to, consumes memory. If the function is really long-lived then this is a memory leak.

With result set cleanup behind us, let's look at handling cases where the result set's

loop exits abnormally. We've seen that the normal reason for it to exit is when the loop encounters an `io.EOF` error, making `rows.Next()` return `false`. Anytime `rows.Next()` finds an error, it saves the error internally for later inspection, and exits the loop.

You can then examine it with `rows.Err()`. I didn't show this in the examples above, but in real production code you should always check for an error after exiting the loop:

```
for rows.Next() {
	// process the rows
}
if err = rows.Err(); err != nil {
	log.Fatal(err)
}
```

The `io.EOF` error is a special case that is handled inside `rows.Err()`. You don't need to handle this explicitly in your code; `rows.Err()` will return `nil` so you won't see it.

That's pretty much everything you need to know about looping over the rows, except for one small detail: handling errors from `rows.Close()`. Interestingly, this function *does* return an error, but it's a good question what can be done with it. If it doesn't make sense for your code to handle it (and I haven't seen a case where it does), then you can feel free to ignore it or just log it and continue.

Fetching A Single Row

Fetching a single row is a very common task that's awkward with the code shown previously. You'd have to write a loop, check that the loop actually had some rows, and so forth. Fortunately, there's `db.QueryRow()` that can do this for you. It executes a query that's expected to return zero or one rows, and returns a `sql.Row` object that is scannable. The usual idiom is to chain the query and scan together, like this:

```
var s string
err = db.QueryRow("select * from hello.world limit 1").Scan(&s)
if err != nil {
	if err == sql.ErrNoRows {
		// special case: there was no row
	} else {
		log.Fatal(err)
	}
}
log.Println("found a row", s)
```

As you can see, the idiomatic usage is a little different from before. Internally, the `sql.Row` object holds either an error from the query, or a `sql.Rows` from the query. If

there's an error, then `.Scan()` will return the deferred error. If there's none, then `.Scan()` will work as usual, except that if there was no row, it returns a special error constant, `sql.ErrNoRows`. You can check for this error to determine whether the call to `.Scan()` actually executed and copied values from the row into your destination variables.

How rows.Scan() Works

Using `rows.Scan()` and its single-row variant is actually a fairly involved subject. Under the hood, it does quite a bit of work for you. If you know what it's doing, you can use it to great effect.

The arguments to `rows.Scan()` are destinations into which the columns from the row should be stored. Often these will be straightforward pointers to variables, dereferenced with the & operator:

```
var var1, var2 string
err = rows.Scan(&var1, &var2)
```

The argument types are the empty interface, `interface{}`, which you probably already know is satisfied by any type in Go. In most cases, Go copies data[2] from the row into the destinations you give. The `database/sql` package will examine the type of the destination, and will convert values in many cases. This can help make your code, especially your error-handling code, much smaller.

For example, suppose you have a column of numbers, but for some reason it's not numeric, it is instead a VARCHAR with numbers in ASCII format. You could scan the column into a string variable, convert it into a number, and check errors at each step. But you don't need to, because `database/sql` can do it for you! If you pass, say, a float64 destination variable into the call, `Scan()` will detect that you are trying to scan a string into a number, call `strconv.ParseFloat()` for you, and return any errors.

Another special case with scanning is when values are `NULL` in the database. A `NULL` can't be scanned into an ordinary variable, and you can't pass a `nil` into `rows.Scan()`. Instead, you must use a special type as the scan destination. These types are defined in `database/sql` for many common types, such as `sql.NullFloat64` and so forth.

If you need a type that isn't defined, you can look to see whether your driver provides one, or copy/paste the source code to make your own; it's only a few lines of code. After scanning, you can check whether the value was valid or not, and get the value if

[2] There are special cases where the copy can be avoided if you want, but you have to use *sql.RawBytes types to do that, and the memory is owned by the database and has a limited lifetime of validity. If you need this behavior, you should read the documentation and the source code to learn more about how it works, but most people won't need it. Note that you can't use *sql.RawBytes with db.QueryRow().Scan() due to an internal limitation in database/sql.

it was. (If you don't care, you can just skip the validity check; reading the value will give the underlying type's zero-value.)

Putting it all together, a more complex call to `rows.Scan()` might look like this:

```
var (
	s1 string
	s2 sql.NullString
	i1 int
	f1 float64
	f2 float64
)
// Suppose the row contains ["hello", NULL, 12345, "12345.6789", "not-a-float"]
err = rows.Scan(&s1, &s2, &i1, &f1, &f2)
if err != nil {
	log.Fatal(err)
}
```

The call to `rows.Scan()` will fail with the following error, illustrating that the last column was automatically converted to a float, but it failed:

> sql: Scan error on column index 4: converting string "not-a-float" to a float64: strconv.ParseFloat: parsing "not-a-float": invalid syntax

However, since the arguments are handled in order, the rest of the scans would have succeeded, and by removing the call to `log.Fatal()` you can see that with the following lines of code:

```
err = rows.Scan(&s1, &s2, &i1, &f1, &f2)
log.Printf("%q %#v %d %f %f", s1, s2, i1, f1, f2)

// output:
// "hello" sql.NullString{String:"", Valid:false}
// 12345 12345.678900 0.000000
```

This illustrates that the `s2` variable's `Valid` field is false and its `String` field is empty, as expected. Your code could inspect this variable and handle that as desired:

```
if s2.Valid {
	// use s2.String
}
```

What If You Don't Know The Columns?

Sometimes you're querying something that might return an unknown number of columns with unknown names and types. Imagine that you're doing a `SELECT *` inside a backup program, for example. Or perhaps you're querying something that has different columns in different versions of the server, such as `SHOW FULL PROCESSLIST` in MySQL.

The `database/sql` package provides a way to get the column names, and thus also the number of columns. To get the column names, use `rows.Columns()`. It returns an error, so check for that as usual:

```
cols, err := rows.Columns()
if err != nil {
	log.Fatal(err)
}
```

Now you can do something useful with the results. In the simplest case, when you expect a variable number of columns to be used in different scenarios, but you know their types, you can write something like the following code. Suppose that you get at most 5 columns but in some cases fewer, and they are of type `uint64`, `string`, `string`, `string`, `uint32`. Define a slice of `interface{}` with valid variables (not `nil` pointers) that handles the largest case, then pass the appropriate sized slice of that to `Scan()`:

```
dest := []interface{}{
	new(uint64),
	new(string),
	new(string),
	new(string),
	new(uint32),
}
err = rows.Scan(dest[:len(cols)])
```

If you don't know the columns or the data types, you have two options. One is to resort to `sql.RawBytes`. After scanning, you can examine the `vals` slice. For each element you should check whether it's `nil`, and use type introspection and type assertions to figure out the type of the variable and handle it:

```
cols, err := rows.Columns()
vals := make([]interface{}, len(cols))
for i, _ := range cols {
	vals[i] = new(sql.RawBytes)
}
for rows.Next() {
	err = rows.Scan(vals...)
}
```

The resulting code (not shown!) is usually not very pretty, but there's another option in newer Go versions: using `sql.ColumnType`, which supports the following operations: `DatabaseTypeName()`, `DecimalSize()`, `Length()`, `Name()`, `Nullable()`, and `ScanType()`.

Working With Multiple Result Sets

Prior to version 1.8, the `database/sql` package has no functionality to work with a query that returns more than one result set. This can range from a non-issue to a

showstopper. A lot depends on the database and the driver implementation, but those older versions of `database/sql` were designed for a query to return a single result set, and were not capable of fetching the next result set or handling changes in columns after the first row. This had a number of consequences such as making it impossible to call stored procedures in MySQL.

Happily, Go version 1.8 introduced support for multiple result sets. After finishing iteration over a `sql.Rows` variable, you can call `rows.NextResultSet()` to advance the variable to the next result set. If the function returns `false`, there is either no next result set, or there was an error advancing; you should check `rows.Err()` to figure out what the situation is. Once you've advanced to a new result set, you need to restart your `rows.Next()` loop as usual, keeping in mind that result sets can be empty.

Modifying Data With db.Exec()

Thus far you've been working mostly with `db.Query()` and `db.QueryRow()`, but you've seen `db.Exec()` in action a few times. This is the method you should use for statements that don't return rows. Here's an example:

```
res, err := db.Exec("DELETE FROM hello.world LIMIT 1")
if err != nil {
	log.Fatal(err)
}
rowCnt, err := res.RowsAffected()
if err != nil {
	log.Fatal(err)
}
log.Println("deleted rows:", rowCnt)
```

The `db.Exec()` call returns a `sql.Result`, which you can use to get the number of rows affected, as shown. You can also use it to fetch the auto-increment ID of the last-inserted row, although support for that varies by driver and database. In PostgreSQL, for example, you should use `INSERT RETURNING` and `db.QueryRow()` to fetch the desired value as a result set.

There's a vitally important difference between `db.Exec()` and `db.Query()`, and it isn't just a matter of being pedantic. As mentioned earlier, `db.Exec()` releases its connection back to the pool right away, whereas `db.Query()` keeps it out of the pool until `rows.Close()` is called. The following code ignores the returned rows, and will cause problems:

```
_, err := db.Query("DELETE FROM hello.world LIMIT 1")
```

The problem is that although the first value returned from the method is assigned to the _ variable and is inaccessible to the program after that, it's still really assigned, with all the usual consequences. And it won't go away until it's garbage collected. Worse, the connection that's bound to it will never be returned to the connection pool. This is a common way to "leak" connections and run the server out of available connections.

In addition to the above, there are some more subtleties you should know about the `Result`. Go guarantees that the database connection that was used to create the `Result` is the same one used for `LastInsertId()` and `RowsAffected()`, and that it's taken out of the pool for these operations and locked. But beyond that, it's an interface type, and the exact behavior will be dependent on the underlying database and the driver's provided implementation. For example:

- MySQL can use a BIGINT UNSIGNED as an auto-increment column, so it's possible for the last-inserted row's column to be too large to fit in int64, the returned type defined by `LastInsertId()`.
- The MySQL driver I prefer doesn't make an extra round-trip to the database to find out the last-inserted value and number of rows affected. This information is returned from the server in the wire protocol, and stored in a struct, so there's no need for it. (The connection is still taken out of the pool and locked, then put back, even though it's not used. This is done by `database/sql`, not the driver. So even though this function doesn't access the database, it may still block waiting if its connection is busy.)
- Whether `LastInsertId()` and `RowsAffected()` return errors is driver-specific. In the MySQL driver, for example, they will never return an error. You should not rely on driver-specific details like this, though. Adhere to the contract that is publicly promised in the `database/sql` interface: functions that return errors should be checked for errors.
- Some of the behavior of these functions varies between databases or implementations. For example, suppose a database driver provides `RowsAffected()` but implements it by making a query to the underlying database (e.g. needlessly calling `SELECT LAST_INSERT_ID()` in MySQL instead of using the values returned in the protocol). As mentioned, the original connection will be used, so to that extent the behavior will be correct, but what if other work has been done on that connection in the meantime? You'd be subject to a race condition. This is an area where you'll need to know the actual implementation you're working with.

In general, the database drivers I've seen and worked with are well implemented and you don't need to worry about these finer points most of the time. But I want you to be aware of the details anyway. Now let's see how to use prepared statements!

Using Prepared Statements

Although I haven't discussed or shown it yet, `database/sql` is rather heavily oriented towards prepared statements.

What is a prepared statement? It is a statement that's sent in a partially-completed form to the server, with placeholders for values that will be filled in later. Now the statement is ready to be executed, hence the name "prepared."

The meaning of "prepared" is system-dependent, but typically the server evaluates the skeleton statement for validity and makes sure it'll be OK to execute. For example, it will usually check that all of the databases and tables mentioned exist and the user has privileges to access them, and may also partially plan the query's execution. The server then sends back a statement identifier, which is typically bound to the specific connection that was used to prepare the statement (e.g. the statement is not valid for other connections). The statement can then be executed multiple times by sending a special command with the statement identifier and any parameters to be used.

Prepared statements can be confusing sometimes, because some languages' drivers and database interfaces emulate this behavior but don't really use server-side prepared statements per se. For example, in the Perl DBI, the default behavior with the MySQL driver is to show what looks like prepared statements to the programmer, but use so-called "client-side prepared statements" instead (which are really nothing of the sort). In practice this basically means that the DBI interface is concatenating strings and quoting them before sending the full SQL to the server, and prepared statements don't enter the picture at all.

Various database abstraction layers in many languages do similar things, usually without really making it visible to the programmer. If this isn't confusing enough, there are even more confusing scenarios, such as MySQL's so-called SQL interface to prepared statements, which has caused many smart people (including driver authors) to misunderstand them.

Go's `database/sql` handles prepared statements as first-class citizens, and has a `sql.Stmt` type for them. In fact, `database/sql` prefers to use prepared statements, and a lot of the interface you've seen thus far in this book will use them if you just add parameters to your method calls. For example, let's add a parameter and placeholder to the `INSERT` from earlier:

```
res, err := db.Exec(
    "INSERT INTO test.hello(world) VALUES(?)", "hello world!")
```

See what I did there? I removed the literal `hello world!` from the SQL and put a `?` placeholder in its place, then called the method with the value as a parameter. Under the hood, Go handles this as follows:

1. It treats parameter 0 as the statement, and prepares it with the server.
2. It executes the resulting prepared statement with the rest of the parameters (in this case just one).
3. It closes the prepared statement.

Prepared statements have their benefits:

- They are convenient; they help you avoid code to quote and assemble SQL.
- They guard against SQL injection and other attacks by avoiding quoting vulnerabilities, so they enhance security.
- There may be driver-specific, protocol-specific, and database- specific performance and other enhancements. For example, in MySQL, prepared statements use the so-called binary protocol for sending parameters to the server, which can be more efficient than sending them as ASCII.
- They can reward you with additional efficiency by eliminating repeated SQL parsing, execution plan generation, and so on.

Some of these benefits apply no matter how many times statements are executed, but some are only beneficial if a statement will be repeatedly re-executed. As a result, you should be aware of the automatic use of prepared statements when you call functions such as `db.Query()` and `db.Exec()` with more than one parameter.

In addition to behind-the-scenes use of prepared statements, you can prepare statements explicitly. In fact, to reuse them and gain some of the benefits mentioned above, you must prepare them explicitly. Use the `db.Prepare()` function for that. The result is a `sql.Stmt` variable:

```
stmt, err := db.Prepare("INSERT INTO test.hello(world) VALUES(?)")
if err != nil {
      log.Fatal(err)
}
```

Now you can repeatedly execute the statement with parameters as desired. The `stmt` variable's method signatures match those you've been using thus far on the `db` variable. In this case I'll use `stmt.Exec()`:

```
for _, str := range []string{"hello1", "hello2", "hello3"} {
      res, err := stmt.Exec(str)
```

```
        if err != nil {
                log.Fatal(err)
        }
}
```

A couple of anti-patterns with prepared statements arise fairly often:

- Single-use prepared statements. This is potentially wasteful unless you really want to do it for some reason, e.g. the convenience of avoiding quoting and SQL concatenation yourself. Be aware that every one-off prepared statement at least triples the number of network round-trips you actually make to the backend database: prepare, execute, and close. As you'll see in the next section, it can be even worse than this.
- Re-preparing in a loop. This is just a magnification of the previous point. Make sure you prepare outside the loop, and execute inside of it!

Although I didn't show it in the sample code above, it's a good idea to close prepared statements when you're done with them. You can just call `stmt.Close()` when you are finished, or you can `defer stmt.Close()`. Either way, keep in mind the same types of considerations I discussed previously with `rows.Close()`.

The Relationship Between Statements And Connections

Because `database/sql` handles a connection pool for you without exposing you to connections directly, the relationship between prepared statements and connections also has to be managed for you behind the scenes. This is worth knowing about, because it has consequences for performance and resource utilization, especially at high concurrency.

When you prepare a statement with `db.Prepare()` and get a `stmt` in return, what really happens is that the statement is prepared on some connection in the pool, but the connection is then released back to the pool. The statement remembers the connection it used. When you execute the statement, it tries to get that connection, but if it's busy, it will re-prepare the statement on another connection, adding this connection to the list of remembered statements. If you re-execute the statement again and all of the connections on which it was previously prepared are busy, it'll prepare the statement on yet another connection, and so on.

So what's really happening behind the scenes is that a statement might be prepared on many different connections, and thus from the database server's point of view, the number of prepared statements may be much larger than the number of `sql.Stmt` variables you've created in your code.

This situation happens most under high load, when lots of connections are busy,

leading to lots of re-preparing. In the worst cases, I have seen statements appear to "leak" due to being re-prepared as many times as there are connections. When combined with bugs that lead to connections not being returned to the pool as previously discussed, it's even possible to exceed the maximum number of statements the server will permit to be prepared at one time.

Another subtlety of prepared statements is that it's quite likely that at least some prepared statements will be prepared and then immediately re-prepared upon execute, due to the statement's original connection being returned to the pool and grabbed by another user during the interval between `db.Prepare()` and `stmt.Exec()`. If you use a network traffic capture inspection tool such as VividCortex, you'll be able to verify this. For example, in one of the VividCortex blog posts we analyzed single-use prepared statements. Careful inspection reveals that the count of `Prepare()` actually exceeds the count of `Exec()` by a small margin, which is expected due to the phenomenon just mentioned.

Another consequence of how the pool handles connections and prepared statements is that you do not need to explicitly handle problems with prepared statements being invalidated by, for example, a failed connection that was killed or timed out server-side. The connection pool will handle this for you transparently. In other words, you shouldn't write any logic to re-prepare statements, just like you don't need to write any logic to re-connect to the database. There are up to 10 retries hidden within `database/sql`.

Avoiding Prepared Statement Usage

Sometimes it's better to send plaintext SQL to the server than to prepare statements. Why would you want to do this?

1. The statement has no parameters.
2. The statement won't be reused, so the prepare/execute/close cycle is wasteful tripling of network round-trips and extra latency for the client.
3. The database server doesn't support prepared statements. This is the case for Sphinx and MemSQL, for example, both of which support the MySQL wire protocol but not the prepared statement features of it.

Go's `database/sql` package does allow you to bypass the use of prepared statements, and send the query in a one-shot form as plain text, but the driver needs to support it too. Most drivers I'm familiar with do offer this support. The driver simply needs to implement Go's `driver.Execer` and `driver.Queryer` interfaces.

The other crucial part of avoiding prepared statements is under control of you, the programmer. To avoid prepared statements, you should do the following:

- Don't explicitly prepare a statement with `db.Prepare()`, obviously.
- Don't call functions such as `db.Query()` with more than one argument.

The latter requirement may mean that you'll have to build statements yourself by concatenating SQL and quoting values. (You might find `fmt.Sprintf()` with the `%q` placeholder to be useful for this.) If you do this, be careful to avoid SQL injection attack vectors. The best way to do this is by validating your inputs. At VividCortex, we do this with API parameter-handling frameworks that are wrappers around Go's standard flag library, so parameters are strongly typed.

Prepared Statement Parameter Syntax

Parameter syntax is up to the driver and/or the backend database by default, and `database/sql` doesn't get involved with it. It is therefore variable depending on which backend database you're using. Here's a quick list of several popular databases and how they handle it:

- MySQL uses question-mark parameters `?` that must be matched by an equal number of values during statement execution.
- PostgreSQL uses numbered parameters `$1`, `$2` and so on. These can be reused within the statement, so the number of values you pass in during execution might differ from the total number of placeholders. For example, `SELECT $1, $2, $2 FROM mytable` would be executed with only 2 values.
- Oracle uses named parameters preceded by colons, such as `:user`.
- SQLite accepts both MySQL's and PostgreSQL's syntax.

In Go version 1.8 and newer, the `database/sql` package also has support for named arguments, which you might find helpful in some situations. Look in the documentation for the `sql.NamedArg` type.

Working with Transactions

Transactions in `database/sql` are top-level data types like statements and results. And like all the others, you'll need to know how they work to avoid tripping over their subtleties. But before I dig into them, let's discuss the wrong way to work with transactions. The following code will not do the right thing:

```
_, err = db.Exec("BEGIN")
_, err = db.Exec("UPDATE account SET balance = 100 WHERE user = 83")
_, err = db.Exec("COMMIT")
```

Why? Because of the underlying connection pool. There's no guarantee those

statements were executed on the same connection. You could have started a transaction (and left it open and idle!) on one connection, updated the account table on another connection, and committed some other connection's in-flight transaction. Don't do this!

Creating statefulness and binding things to a single connection is exactly what a `sql.Tx` is for, and that's what you should do instead. The essence is as follows:

- You create a `sql.Tx` with `db.Begin()`—or with its newer cousin, `db.BeginTx()`, which accepts options in a struct, letting you specify attributes like an isolation level.
- It removes exactly one connection from the pool and keeps it until it's finished.
- The driver is instructed to start a transaction on that connection.
- The connection, its transaction, and the `tx` variable are coupled, but the `tx` and the `db` are disconnected from each other.
- The lifetime of the transaction and the `tx` ends with `tx.Commit()` or `tx.Rollback()` and the variable is invalid after that.

Let's dig into these and see how transactions work. First, after you use `db.Begin()` to create the `sql.Tx`, you should operate solely on the `tx` variable, and ignore the `db` for anything that needs to work within the transaction. This is because the `db` isn't in a transaction, the `tx` is! This is a common source of confusion for programmers.

Code like the following is another buggy anti-pattern:

```
tx, err := db.Begin()
// ...
_, err = db.Exec("UPDATE account SET balance = 100 WHERE user = 83")
// ...
err = tx.Commit()
```

The programmer might not realize it, but the `UPDATE` did not happen within the context of the transaction. Instead of `db.Exec()`, the code should use `tx.Exec()`. Study this if it's confusing, because it's important. On the database server, the transaction is scoped to a single connection; in the code, the connection is bound to the `tx` variable and not available through the `db` anymore. When you call methods on the `db`, you're operating on a different connection, which doesn't participate in the transaction.

The `tx` variable, as you've seen previously with prepared statements, has all the familiar methods with the same signatures: `Query()`, `Exec()`, and so on. There's even a `tx.Prepare()` to prepare statements that are bound solely to the transaction. However, prepared statements work differently within a `tx`. A `sql.Stmt`, when associated with a `sql.Tx`, is bound to the one and only one underlying connection to the database, so there's no automatic repreparing on different connections.

To clarify this a bit further, a `stmt` that was prepared from a `db` is invalid on the `tx`, and a `stmt` that was prepared from a `tx` is valid only on the `tx`. (There is a way to "clone" a `stmt` into the scope of the `tx` by using `tx.Stmt()` but this works by the statement being reprepared even if it has already been prepared on the `tx`'s connection.)

Within the scope of a `tx`, the usual implicit logic of retrying 10 times also is disabled. You'll need to be prepared to retry statements or restart the entire transaction yourself, as appropriate for the scenario. This is meat-and-potatoes behavior for transactional databases, naturally. You've always needed to be ready to handle deadlocks and rollbacks when dealing with transactions. And of course a transaction can't be started on one connection and continued on another in most databases.

There's No Concurrency Within a Transaction

There's another thing you should know about working with a `sql.Tx`. Because there's only a single connection, you have to do all of your operations serially, finishing every database interaction before beginning a new one. This is in contrast to what you can do in the usual non-transactional connection-pooled code you might write. For example, the following excerpted code is just fine in normal usage without a transaction:

```
rows, _ := db.Query("SELECT id FROM master_table")
for rows.Next() {
	var mid, did int
	rows.Scan(&mid)
	db.QueryRow("SELECT id FROM detail_table WHERE master = ?", mid).Scan(&did)
}
```

This is okay because when you're working with a `db` variable, the inner statement will get a new connection from the pool and use it, so the loop will effectively use (at least) two connections. (Inside the loop, the first connection is busy fetching rows for the loop, so it's not available for the `QueryRow()` to use.)

In the scope of a `tx`, however, that won't work:

```
rows, _ := tx.Query("SELECT id FROM master_table")
for rows.Next() {
	var mid, did int
	rows.Scan(&mid)
	tx.QueryRow("SELECT id FROM detail_table WHERE master = ?", mid).Scan(&did)
	// **BOOM**
}
```

If you do that, you'll be trying to start a new query on the `tx`'s connection, but it's busy in row-fetching mode and that won't work. The example is rather silly and could be replaced by a `JOIN`, and doesn't even need to be in a transaction for that matter

because it's not modifying any data, but hopefully you see the point. Within the scope of a `tx`, you have to finish each statement before you start the next one.

On the other hand, a corollary also holds. If you need to do some inner-loop fetching within the context of a `tx`, but it doesn't need to participate in the transaction itself for some reason, you could use the `db` (which isn't in the transaction) to perform it instead. Just be careful that your code doesn't ambush some other programmer later!

Working With a Single Connection

Sometimes you might want the guarantee that your statements are bound to a single connection, but you don't want to actually create a transaction against the database. Why would you want this? Here are some sample reasons:

1. Connection-specific state, such as temp tables or user-defined variables, or setting the current database with `USE` or similar.
2. Limiting concurrency and avoiding unwanted connections to the database.
3. Explicit locks.
4. The use of database-specific extensions of behaviors.

In Go version 1.9 and newer, you can get a connection from the database's connection pool with `db.Conn()`. The result is a `sql.Conn` variable, which you must close with `conn.Close()` afterwards. The `sql.Conn` supports all the normal operations like execing and querying, with a caveat—it only supports the newer function signatures that accept a Context. All of these operations run against the single underlying connection to the database, just like a `sql.Tx`.

In older versions of Go, if this type of single-connection guarantee was necessary, you could take advantage of a `sql.Tx` as a way to access one and only one underlying connection. If you didn't want the transaction that comes along with it, you could commit it by calling `tx.Exec("COMMIT")` or similar.

However, I advise you not to mingle transaction-related SQL commands with `database/sql` function calls related to transactions. Whether this causes problems is dependent on your driver and backend database. Some databases communicate whether the connection has an active transaction by a signal in the network protocol, and some drivers might respect that and throw an error. It's better to upgrade to a newer Go version.

Error Handling

Idiomatic error handling in Go is to explicitly and immediately check for an error after every function call that can return an error, and it's no different in `database/sql`. However, for the sake of brevity, I've omitted some error handling in several code listings thus far.

In general, all of the method calls I've shown to this point can return an error, even when I didn't show it. There is one place, however, where you should check for an error that isn't returned by a function call: after the `rows.Next()` loop. I covered this usage of `rows.Err()` previously.

The other special consideration for error-checking is how to inspect and handle errors that the database returns. You might find yourself doing string-matching, for example, to try to catch errors such as a deadlock:

```
if strings.Contains(err.Error(), "Deadlock found") {
	// Handle the error
}
```

But what if the database's language is not set to English, and error codes are returned in Elbonian? Oops. Plus, string-matching like this is just a code smell.

The solution for this depends on the driver and the database. Although some databases return ANSI-standard error codes for some operations, these really are not specific enough for use in most applications. Instead, it's better to deal with the database's own error codes, which are usually very granular and allow you to isolate exactly what happened.

To do this, you'll have to import the driver and use a type assertion to get access to the driver-specific struct underlying the error, like this example using the MySQL driver:

```
if driverErr, ok := err.(*mysql.MySQLError); ok {
	if driverErr.Number == 1213 {
		// Handle the error
	}
}
```

That's better, but still has a code smell. What's that magic number 1213? It's much better to use a defined list of error numbers. Alas, the driver I like doesn't have such a list in it, for various reasons. Fortunately, VividCortex provides one at github.com/VividCortex/mysqlerr. Now the code can be cleaned up more:

```
if driverErr, ok := err.(*mysql.MySQLError); ok {
	if driverErr.Number == mysqlerr.ER_LOCK_DEADLOCK {
```

```
            // Handle the error
        }
}
```

Much better. In the most popular PostgreSQL driver, you can use driver-provided types and a driver-provided error list too.

Using Built-In Interfaces

As with all of Go's standard library, database/sql uses interfaces heavily to make the magic happen without creating tight coupling between bits of code. And these standard interfaces can be used to great advantage in your own code. There are two important interfaces involved in passing data into the database and retrieving it back:

- `driver.Valuer` influences how values are transformed as they are sent to the database.
- `sql.Scanner` influences how values are transformed upon retrieval.

You can think of these as filters you can insert into the process of reading and writing from the database.

Why would you want this? As a simple example, suppose you want to ensure that all string values of a certain type are always lowercased when sent to the database, and just in case mixed- case data is present in the database somehow, you also want to lowercase it when reading from the database. We can create a data type, let's say `LowercaseString`, that enforces these things transparently and keeps the programmer's code clean and simple. This is an overly simplistic example, but the general idea is that you're inserting a `strings.ToLower()` into the process of reading and writing the data. Now, you'd use these types in your code, instead of the string type, as parameters when inserting data and as destination variables when scanning. Here's a complete code sample you can examine (download):

```
package main

import (
        "database/sql"
        "database/sql/driver"
        "errors"
        _ "github.com/go-sql-driver/mysql"
        "log"
        "strings"
)

type LowercaseString string
```

```
// Implements driver.Valuer.
func (ls LowercaseString) Value() (driver.Value, error) {
	return driver.Value(strings.ToLower(string(ls))), nil
}

// Implements sql.Scanner. Simplistic -- only handles string and []byte
func (ls *LowercaseString) Scan(src interface{}) error {
	var source string
	switch src.(type) {
	case string:
		source = src.(string)
	case []byte:
		source = string(src.([]byte))
	default:
		return errors.New("Incompatible type for LowercaseString")
	}
	*ls = LowercaseString(strings.ToLower(source))
	return nil
}

func main() {
	db, err := sql.Open("mysql",
		"root:@tcp(:3306)/test")
	if err != nil {
		log.Fatal(err)
	}
	defer db.Close()

	_, err = db.Exec(
		"CREATE TABLE IF NOT EXISTS test.hello(world varchar(50))")
	if err != nil {
		log.Fatal(err)
	}

	_, err = db.Exec("DELETE FROM test.hello")
	if err != nil {
		log.Fatal(err)
	}

	// Insert a row that's not lowercased, and one that is.
	var normalString string = "I AM UPPERCASED NORMAL STRING"
	var lcString LowercaseString = "I AM UPPERCASED MAGIC STRING"

	_, err = db.Exec("INSERT INTO test.hello VALUES(?), (?)",
		normalString, lcString)
	if err != nil {
		log.Fatal(err)
```

```
	}

	rows, err := db.Query("SELECT * FROM test.hello")
	if err != nil {
		log.Fatal(err)
	}
	defer rows.Close()
	for rows.Next() {
		var s1 LowercaseString
		err = rows.Scan(&s1)
		if err != nil {
			log.Print(err)
		}
		log.Print(s1)
	}
}
```

If you run this code, it will print out the following:

```
$ go run lowercase.go
2014/12/17 16:08:14 i am uppercased normal string
2014/12/17 16:08:14 i am uppercased magic string
```

As you can see, both rows are apparently lowercased. But if you look in the database, you'll see a different picture:

```
mysql> select * from test.hello;
+------------------------------+
| world                        |
+------------------------------+
| I AM UPPERCASED NORMAL STRING |
| i am uppercased magic string  |
+------------------------------+
```

This is because when I inserted into the database, I used one normal string variable, which got inserted as-is, and one `LowercaseString` variable, which got lowercased on the way into the database. But while reading these rows back, I used a `LowercaseString` as a destination variable, and both of the rows were transformed to lowercase, so the program printed them out in lowercase.

This is a very simple example. Real-world examples include much more useful things, such as:

- Enforcing validation of data that must be formatted in a specific way.
- Transforming data into a uniform format.
- Compressing and decompressing data transparently.
- Encrypting and decrypting data transparently.

Here's a sample implementation of gzip compression and decompression, courtesy of

Jason Moiron's blog:

```
type GzippedText []byte

func (g GzippedText) Value() (driver.Value, error) {
       b := make([]byte, 0, len(g))
       buf := bytes.NewBuffer(b)
       w := gzip.NewWriter(buf)
       w.Write(g)
       w.Close()
       return buf.Bytes(), nil
}
func (g *GzippedText) Scan(src interface{}) error {
       var source []byte
       // let's support string and []byte
       switch src.(type) {
       case string:
              source = []byte(src.(string))
       case []byte:
              source = src.([]byte)
       default:
              return errors.New("Incompatible type for GzippedText")
       }
       reader, _ := gzip.NewReader(bytes.NewReader(source))
       defer reader.Close()
       b, err := ioutil.ReadAll(reader)
       if err != nil {
              return err
       }
       *g = GzippedText(b)
       return nil
}
```

Now the `GzippedText` type can be used just as easily as a `[]byte` in your source code. At VividCortex, we use similar techniques to transparently encrypt all of our customers' sensitive data when we insert it into our databases. You can read more about that on our blog post about encryption.

Monitoring, Tracing, Observability

The `database/sql` package does a lot for you behind the scenes, but if you have experience building large systems I'm sure you understand the value of being able to inspect that background activity. This is necessary for purposes like troubleshooting performance issues, verifying program correctness, and validating hypotheses about how configuration changes will impact behavior.

The `database/sql` package used to be hard to observe, but it's gotten steadily more instrumentation built in over time. The two primary means of observing and controlling its internals are the stats it exposes, and contexts. Contexts are discussed in the next section.

The stats interface is fairly simple: a call to `db.Stats()` will return a stats struct. The struct has added progressively more members, and at the time of writing, has the following:

- **`MaxOpenConnections`**. This is the current setting of the maximum permitted open connections. It's not a performance counter, it reports configuration.
- **`OpenConnections`**. The current total number of connections, both in use and idle.
- **`InUse`** and **`Idle`**. The breakdown of states of the open connections.
- **`WaitCount`**. The total number of times a connection was needed but not available, and a calling program had to wait.
- **`WaitDuration`**. The total amount of time such calling programs had to wait for a connection.
- **`MaxIdleClosed`** and **`MaxLifetimeClosed`**. The total number of times a connection was closed due to `SetMaxIdleConns` or `SetConnMaxLifetime`.

If you don't see all of these fields, you might have an older version of Go. You can collect these fields and turn them into metrics in your favorite monitoring system. The call to `db.Stats()` is cheap and thread-safe, so there's no reason not to collect the stats frequently if your monitoring system supports high-resolution metrics.

That covers the instrumentation that `database/sql` offers for observing its workings, but when you're building services with Go, monitoring the application/database interactions themselves is a must, too. Here's a sample of some of the important things you'll need to be able to measure in order to keep apps running reliably and with high performance:

- Are connections being opened and closed, or reused?
- Are prepared statements being repeatedly created and used just once, or created once and reused many times? Are they being closed, or left to time out and be deallocated when the connection closes?
- What are the most frequent and most time-consuming types of statements?
- Are "garbage" database interactions, such as constant needless "ping" activities, draining resources and adding latency?
- If a query takes a long time to execute, was it executing for a long time, or was the call simply blocked waiting for a free connection in the pool?

All of these questions require highly detailed observability of the *database* and the

application/database interaction, not just the application. VividCortex is second to none in this regard—for example, it's capable of analyzing statement preparation, execution, and closure separately. Instrumentation on how the database is acting is a vital set of observability signals for the application, giving engineers an irreplaceable source of truth about the behavior of their code.

In addition to database observability, it's really helpful to have distributed tracing of the application that extends into the database. Distributed apps are hard to debug otherwise. Fortunately, the OpenCensus project has a database/sql wrapper that is instrumented with OpenCensus—the leading open standard for distributed tracing. The resulting instrumentation can be ingested by any product or tool that understands the standard.

As you'll see from reading the documentation for that wrapper, it requires you to sprinkle instrumentation into your source code, using at least a wrapper function, if not more intrusive instrumentation. Although instrumented source code is a good thing, if you can't instrument an app and you're simply trying to understand what it does to the database (and how the database and its other users impact the application in return), the approach VividCortex takes is very valuable. It can use network packet capture, for example, to understand exactly what the app and database are really exchanging with each other.

Working With Context

In Go version 1.8, the `database/sql` package was updated to add support for *context*, which is a concept that applies broadly to Go, not just database/sql. A context is a variable that can provide information code needs in order to understand and respond to what's happening outside of its scope. It can be used for things like distributed tracing and cancelling long-running operations. It helps tame a large distributed system or codebase, coordinating across its many parts. The Google team introduced the concept in a blog post on contexts.

Since version 1.8, all of the familiar database-related functions, such as `db.Query()`, have been augmented to accept a context variable. For backwards compatibility, the old methods and their signatures still exist, and new methods with Context in their names were added—such as `db.QueryContext()`. The arguments are identical, except that the first argument is a context. The old functions are now just thin wrappers around the new context-aware functions, delegating the call and adding a default context.

Contexts are used in various ways in `database/sql`. For example a context might be used only for preparing a statement, but not for executing it; you might use a different context for that. It's best to get to know the documentation to learn the nuances. At the time of writing, I personally haven't accumulated any real-world experience with contexts that would qualify me to tell you anything non-obvious about them.

Driver support for contexts varies. My favorite MySQL driver uses it for query timeouts and cancellation, but my preferred PostgreSQL driver doesn't actually implement any functionality related to contexts.

Database Drivers

I've alluded several times to third-party database drivers, but what are they, really? And what do they do? It would be great to write a manual for how to create a driver, but that's a little out of scope for this book. Instead I'll cover what they do (briefly) and how they work, and list some good open-source ones you might be interested in.

In brief, the driver's responsibilities are:

1. To open a connection to the database and communicate over it. The driver need not implement any kind of pooling or caching of connections, because `database/sql` does that itself. The connection must support preparing statements, beginning transactions, and closing.
2. To implement Rows, an iterator over an executed query's results.
3. To implement an interface for examining an executed statement's results.
4. To implement prepared statements that can be executed and closed.
5. To implement transactions that can be committed or rolled back.
6. To implement bidirectional conversions between values as provided by the database and values in Go.

Drivers can optionally implement a few nice-to-have functionalities as well, most of which signal that the driver and database support a fast-path operation for specific things (such as querying the database directly without using a prepared statement).

Drivers become available by registering themselves with `database/sql` via the `sql.Register()` call. They register under the name you'll use in `sql.Open()`. This is done with an `init()` function, similar to the following:

```
func init() {
      sql.Register("mysql", &MySQLDriver{})
}
```

This `init()` function executes when the package is imported, as shown previously in many code samples.

You can find a list of loaded drivers by calling `sql.Drivers()`, by the way. Here are some of the drivers that are good quality and idiomatic Go code:

- MySQL: github.com/go-sql-driver/mysql (godoc)
- PostgreSQL: github.com/lib/pq (godoc)

You can find more drivers on the Go wiki page for drivers.

If your application is tightly bound to the underlying database (as most are), you'll likely want to get to know your preferred driver well. For example, if you use the PostgreSQL driver I just mentioned, you might be interested in some of the extra bits it exports, such as a `NullBool` type and helpful error-handling functionality. Be sure to read your driver's documentation carefully to learn about all these little goodies.

Common Pitfalls

As you've seen, although the surface area of database/sql is pretty small, there's a lot you can do with it. That includes a lot of places you can trip up and make a mistake. This section is dedicated to all the mistakes I've made, in hopes that you won't make them yourself.

Deferring inside a loop. A long-lived function with a query inside a loop, and `defer rows.Close()` inside the loop, will cause both memory and connection usage to grow without bounds.

Opening many db objects. Make a global `sql.DB`, and don't open a new one for, say, every incoming HTTP request your API server should respond to. Otherwise you'll be opening and closing lots of TCP connections to the database. It'll cause a lot of latency, load, and TCP connections in TIME_WAIT status.

Not doing rows.Close() when done. Forgetting to close the rows variable means leaking connections. Combined with growing load on the server, this likely means running into "too many connections" errors or similar. Run `rows.Close()` as soon as you can, even if it'll later be run again (it's harmless). Chain `db.QueryRow()` and `.Scan()` together for the same reason.

Single-use prepared statements. If a prepared statement isn't going to be used more than once, consider whether it makes sense to assemble the SQL with `fmt.Sprintf()` and avoid parameters and prepared statements. This could save two network round-trips, a lot of latency, and potentially wasted work.

Prepared statement bloat. If code will be run at high concurrency, consider whether prepared statements are the right solution, since they are likely to be reprepared multiple times on different connections when connections are busy.

Cluttering the code with strconv or casts. Scan into a variable of the type you want, and let `.Scan()` convert behind the scenes for you.

Cluttering the code with error-handling and retry. Let `database/sql` handle connection pooling, reconnecting, and retry logic for you.

Forgetting to check errors after rows.Next(). Don't forget that the `rows.Next()` loop can exit abnormally.

Using db.Query() for non-SELECT queries. Don't tell Go that you want to iterate over a result set if there won't be one, or you'll leak connections. Don't use `db.Query()` when you should use `db.Exec()` instead.

Assuming that subsequent statements use the same connection. Run two statements one after another and they're likely to run on two different connections. Run `LOCK TABLES tbl1 WRITE` followed by `SELECT * FROM tbl1` and you're likely to block and wait. If you need a guarantee of a single statement being used, you need to use a transaction or a `sql.Conn`.

Accessing the db while working with a tx. A `sql.Tx` is bound to a transaction, but the `db` is not, so access to it will not participate in the transaction. This might be what you want... or not!

Being surprised by a NULL. You can't scan a `NULL` into a variable unless it is one of the `NullXXX` types provided by the `database/sql` package (or one of your own making, or provided by the driver). Examine your schema carefully, because if a column can be `NULL`, someday it will be, and what works in testing might blow up in production.

Passing a uint64 as a parameter. For some reason the `Query()`, `QueryRow()`, and `Exec()` methods don't accept parameters of type `uint64` with the most significant bit set. If you start out small and eventually your numbers get big, they could start failing unexpectedly. Convert them to strings with `fmt.Sprint()` to avoid this.

Conclusion

By now I hope you're convinced that Go is a great programming language for writing next-generation Internet-facing services (and lots of other things), and that it's adept at working with relational databases. Go continues to evolve, and I'm sure I will get a chance to write a third revision of this book at some point. (You're reading the second revision; the first was written just after Go 1.2 was released). What impresses me the most about Go is how it continually grows more powerful while remaining so simple, clear, and elegant. I am not sure what needs to be changed or improved in `database/sql` for future versions of Go, but I look forward to finding out!

I hope you've found this book enjoyable, and I hope you're able to put your new knowledge to work to build something great, and avoid many of the mistakes I've made. I certainly enjoyed writing it—almost as much as I enjoyed learning the lessons I've shared in these pages!

I didn't write this book alone. In particular I'd like to thank the team at VividCortex, who contributed *their* experiences to the book too, as well as reviewing it. Any errors in this book are mine alone, though. I'd also like to thank Ashley McNamara, who generously contributed the gophers on the cover. She draws such wonderful gophers!

If you have any suggestions or comments about this book, you can email me at baron@vividcortex.com. I'd love to hear your thoughts.

We Can Help You Build

We hope you enjoyed the second edition of *The Ultimate Guide to Building Database-Intensive Apps with Go,* and have found value in the tips we shared.

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