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Concurrency by Tutorials

FIRST EDITION

Multithreading in Swift with GCD and Operations

By the raywenderlich.com Tutorial Team

Scott Grosch

Concurrency by Tutorials

By Scott Grosch

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Dedications

"This book is dedicated to my wife and daughter, as well as to my parents who always made sure a good education was a priority."

— *Scott Grosch*

About the Author

Scott Grosch is the author of this book. He has been involved with iOS app development since the first release of the public SDK from Apple. He mostly works with a small set of clients on a couple large apps. During the day, Scott is a Solutions Architect at a Fortune 500 company in the Pacific Northwest. At night, he's still working on figuring out how to be a good parent to a toddler with his wife.

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Early Access Edition

You're reading an an early access edition of *Concurrency by Tutorials*. This edition contains a sample of the chapters that will be contained in the final release.

We hope you enjoy the preview of this book, and that you'll come back to help us celebrate the full launch of *Concurrency by Tutorials* later in 2019!

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What You Need

To follow along with this book, you'll need the following:

- A Mac running **macOS Mojave** (10.14) or later. Earlier versions might work, but they're untested.
- **Xcode 10.1 or later**. Xcode is the main development tool for iOS. You'll need Xcode 10.1 or later for the tasks in this book. You can download the latest version of Xcode from Apple's developer site here: apple.co/2asi58y
- **An intermediate level knowledge of Swift**. This book teaches concurrency when building Cocoa applications (e.g. iOS, macOS, tvOS) using Swift. You could use the knowledge acquired in this book for your Objective-C codebase, but this book won't include any Objective-C examples.

If you want to try things out on a physical iOS device, you'll need a developer account with Apple, which you can obtain for free. However, all the sample projects in this book will work just fine in the iOS Simulator bundled with Xcode, so the paid developer account is completely optional.

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B Book Source Code & Forums

This book comes with the source code for the starter and completed projects for each chapter. These resources are shipped with the digital edition you downloaded from https://store.raywenderlich.com/products/concurrency-by-tutorials.

We've also set up an official forum for the book at forums.raywenderlich.com. This is a great place to ask questions about the book or to submit any errors you may find.

Section I: Getting Started with Concurrency

In this part of the book, you're going to learn about the basics of Concurrency. You're going to learn what it is, what kind of problems it solves, and why would you even use it?

Further, you will learn the basic pieces of which Concurrency comprises in Cocoa development: **Grand Central Dispatch** and **Operations**.

This section will provide you with the foundational knowledge regarding Concurrency, so be sure to read through! The upcoming sections will dive much deeper into each of these concepts individually.

Chapter 1: Introduction: Get a quick overview of what concurrency is and why you might want to use it.

Chapter 2: GCD vs. Operations: GCD vs.Operations: Concurrency can be handled by either Grand Central Dispatch (GCD) or Operations. Learn about the differences between the two and why you might choose one over the other.

Chapter 1: Introduction

Performance. Responsiveness. They're not sexy tasks. When done properly, nobody is going to thank you. When done incorrectly, app retention is going to suffer and you'll be dinged during your next yearly performance review.

There are a multitude of ways in which an app can be optimized for speed, performance and overall responsiveness. This book will focus on the topic of **concurrency**.

What is concurrency?

Wikipedia defines concurrency as "the decomposability property of a program, algorithm, or problem into order-independent or partially-ordered components or units." What this means is looking at the logic of your app to determine which pieces can run at the same time, and possibly in a random order, yet still result in a correct implementation of your data flow.

Moderns devices almost always have more than a single CPU, and Apple's iPhones have been dual core since 2011. Having more than one core means they are capable of running more than a single task at the same time. By splitting your app into logical "chunks" of code you enable the iOS device to run multiple parts of your program at the same time, thus improving overall performance.

Why use concurrency?

It's critical to ensure that your app runs as smoothly as possible and that the end user is not ever forced to wait for something to happen. A second is a minuscule amount of time for most everything not related to a computer. However, if a human has to wait a

second to see a response after taking an action on a device like an iPhone, it feels like an eternity. "It's too slow" is one of the main contributors to your app being uninstalled.

Scrolling through a table of images is one of the more common situations wherein the end user will be impacted by the lack of concurrency. If you need to download an image from the network, or perform some type of image processing before displaying it, the scrolling will stutter and you'll be forced to display multiple "busy" indicators instead of the expected image.

A beneficial side effect to using concurrency is that it helps you to spend a bit more time thinking about your app's overall architecture. Instead of just writing massive methods to "get the job done" you'll find yourself naturally writing smaller, more manageable methods that can run concurrently.

How to use concurrency

That's the focus of this book! At a high level you need to structure your app so that some tasks can run at the same time. Multiple tasks that modify the same resource (i.e., variable) can't run at the same time, unless you make them thread safe.

Tasks which access different resources, or *read-only* shared resources, can all be accessed via different threads to allow for much faster processing.

This book will focus on the two main ways that iOS provides you with the ability to run code concurrently. The first section on **Grand Central Dispatch** will cover the common scenarios where you will find yourself being able to implement concurrency. You'll learn how to run tasks in the background, how to group tasks together and how to handle restricting the number of tasks that can run at once. By the end of the first section you'll also have a strong grasp of the dangers of concurrency and how to avoid them.

In the second section you'll focus on the `Operation` class. Built on top of Grand Central Dispatch, operations allow for the handling of more complex scenarios such as reusable code to be run on a background thread, having one thread depend on another, and even canceling an operation before it's started or completed.

Most modern programming languages provide for some form of concurrency and Swift is of course no exception. Different languages use widely different mechanisms for handling concurrency. C# and Typescript, for example use an *async/await* pattern, whereas Swift uses closures to handle what runs on another thread. Swift 5 originally had plans to implement the more common *async/await* pattern but it was removed from the specification until the next release.

Where to go from here?

Well to the next page of course! Hopefully as you work through the following chapters you'll gain an appreciation for what concurrency can do for your app and why your end users will appreciate the extra effort you put into making the app perform as fast as possible. Knowing when to use Grand Central Dispatch as opposed to an `Operation` subclass early in the app lifecycle will save you hours of rework down the road.

Chapter 2: GCD & Operations

There are two APIs that you'll use when making your app concurrent: **Grand Central Dispatch**, commonly referred to as **GCD**, and **Operations**. These are neither competing technologies nor something that you have to exclusively pick between. In fact, Operations are built on top of GCD!

Grand Central Dispatch

GCD is Apple's implementation of C's **libdispatch** library. Its purpose is to queue up **tasks** — either a method or a closure — that can be run in parallel, depending on availability of resources; it then executes the tasks on an available processor core.

> **Note**: Apple's documentation sometimes refers to a **block** in lieu of **closure**, since that was the name used in Objective-C. You can consider them interchangeable in the context of concurrency.

While GCD uses threads in its implementation, you, as the developer, do not need to worry about managing them yourself. GCD's tasks are so lightweight to enqueue that Apple, in its 2009 technical brief on GCD, stated that only 15 instructions are required for implementation, whereas creating traditional threads could require several hundred instructions.

All of the tasks that GCD manages for you are placed into GCD-managed **first-in, first-out** (FIFO) queues. Each task that you submit to a queue is then executed against a pool of threads fully managed by the system.

> **Note**: There is no guarantee as to which thread your task will execute against.

Synchronous and asynchronous tasks

Work placed into the queue may either run **synchronously** or **asynchronously**. When running a task synchronously, your app will wait and block the current run loop until execution finishes before moving on to the next task. Alternatively, a task that is run asynchronously will start, but return execution to your app immediately. This way, the app is free to run other tasks while the first one is executing.

> **Note**: It's important to keep in mind that, while the queues are FIFO based, that does not ensure that tasks will finish in the order you submit them. The FIFO procedure applies to when the task *starts*, not when it finishes.

In general, you'll want to take any long-running non-UI task that you can find and make it run asynchronously in the background. GCD makes this very simple via closures with a few lines of code, like so:

```
// Class level variable
let queue = DispatchQueue(label: "com.raywenderlich.worker")

// Somewhere in your function
queue.async {
  // Call slow non-UI methods here

  DispatchQueue.main.async {
    // Update the UI here
  }
}
```

You'll learn all about `DispatchQueue` in Chapter 3, "Queues & Threads." In general, you create a queue, submit a task to it to run asynchronously on a background thread, and, when it's complete, you delegate the code back to the main thread to update the UI.

Serial and concurrent queues

The queue to which your task is submitted also has a characteristic of being either **serial** or **concurrent**. Serial queues only have a single thread associated with them and thus only allow a single task to be executed at any given time. A concurrent queue, on the other hand, is able to utilize as many threads as the system has resources for. Threads will be created and released as necessary on a concurrent queue.

> **Note**: While you can tell iOS that you'd like to use a concurrent queue, remember that there is no *guarantee* that more than one task will run at a time. If your iOS device is completely bogged down and your app is competing for resources, it may only be capable of running a single task.

Asynchronous doesn't mean concurrent

While the difference seems subtle at first, just because your tasks are *asynchronous* doesn't mean they will run *concurrently*. You're actually able to submit asynchronous tasks to either a serial queue or a concurrent queue. Being synchronous or asynchronous simply identifies whether or not the queue on which you're running the task must wait for the task to complete before it can spawn the next task.

On the other hand, categorizing something as *serial versus concurrent* identifies whether the queue has a *single* thread or *multiple* threads available to it. If you think about it, submitting three asynchronous tasks to a serial queue means that each task has to completely finish before the next task is able to start as there is only one thread available.

In other words, a task being synchronous or not speaks to the *source* of the task. Being serial or concurrent speaks to the *destination* of the task.

Operations

GCD is great for common tasks that need to be run a single time in the background. When you find yourself building functionality that should be reusable — such as image editing operations — you will likely want to encapsulate that functionality into a class. By subclassing `Operation`, you can accomplish that goal!

Operation subclassing

`Operations` are fully-functional classes that can be submitted to an `OperationQueue`, just like you'd submit a closure of work to a `DispatchQueue` for GCD. Because they're classes and can contain variables, you gain the ability to know what state the operation is in at any given point.

Operations can exist in any of the following states:

- `isReady`
- `isExecuting`

- `isCancelled`
- `isFinished`

Unlike GCD, an operation is run synchronously by default, and getting it to run asynchronously requires more work. While you can directly execute an operation yourself, that's almost never going to be a good idea due to its synchronous nature. You'll want to get it off of the main thread by submitting it to an `OperationQueue` so that your UI performance isn't impacted.

Bonus features

But wait, there's more! Operations provide greater control over your tasks as you can now handle such common needs as cancelling the task, reporting the state of the task, wrapping asynchronous tasks into an operation and specifying dependences between various tasks. Chapter 6, "Operations," will provide a more in-depth discussion of using operations in your app.

BlockOperation

Sometimes, you find yourself working on an app that heavily uses operations, but find that you have a need for a simpler, GCD-like, closure. If you don't want to also create a `DispatchQueue`, then you can instead utilize the `BlockOperation` class.

`BlockOperation` subclasses `Operation` for you and manages the concurrent execution of one or more closures on the default global queue. However, being an actual `Operation` subclass lets you take advantage of all the other features of an operation.

> **Note**: Block operations run concurrently. If you need them to run serially, you'll need to setup a dispatch queue instead.

Which should you use?

There's no clear-cut directive as to whether you should use GCD or Operations in your app. GCD tends to be simpler to work with for simple tasks you just need to execute and forget. Operations provide much more functionality when you need to keep track of a job or maintain the ability to cancel it.

If you're just working with methods or chunks of code that need to be executed, GCD is a fitting choice. If you're working with objects that need to encapsulate data and functionality then you're more likely to utilize Operations. Some developers even go to

the extreme of saying that you should always use Operations because it's built on top of GCD, and Apple's guidance says to always use the highest level of abstraction provided.

At the end of the day, you should use whichever technology makes the most sense at the time and provides for the greatest long-term sustainability of your project, or specific use-case.

In the next chapter, you'll take a deep dive into how Grand Central Dispatch works, learn about the difference between threads and queues, and identify some of the complexities that can occur when implementing concurrency in your app.

Section II: Grand Central Dispatch

In this section, you'll take a deep dive into Apple's most popular and easy-to-use mechanism to write and manage concurrent tasks — Grand Central Dispatch. You'll learn how to utilize queues and threads to control the execution of tasks in your app, as well as how togroup these tasks together. You'll also learn about common pitfalls and dangers of using concurrency, and how you can avoid them.

Chapter 3: Queues & Threads: This chapter teaches you how to use a GCD queue to offload work from the main thread. You'll also learn what a "thread" is.

Chapter 4: Groups & Semaphores: In the previous chapter you learned about how queues work. In this chapter you'll expand that knowledge to learn how to submit multiple tasks to a queue which need to run together as a "group" so that you can be notified when they have all completed. You'll also learn how to wrap an existing API so that you can call it asynchronously.

Chapter 5: Concurrency Problems: By now you know how GCD can make your app so much fater. This chapter will show you some of the dangers of concurrency if you're not careful, and how to avoid them.

Chapter 3: Queues & Threads

Dispatch queues and threads have been mentioned a couple of times now, and you're probably wondering what they are at this point. In this chapter, you'll get a much deeper understanding of what Dispatch queue and Threads are, and how to best incorporate them in your development workflow.

Threads

You've probably heard the term **multithreading** at some point, yes? A **thread** is really short for **thread of execution**, and it's how a running **process** splits tasks across resources on the system. Your iOS app is a process that runs multiple tasks by utilizing multiple threads. You can have as many threads executing at once as you have cores in your device's CPU.

There are many advantages to splitting your app's work into multiple threads:

- **Faster execution**: By running tasks on threads, it's possible for work to be done *concurrently*, which will allow it to finish faster than running everything serially.
- **Responsiveness**: If you only perform user-visible work on the main UI thread, then users won't notice that the app slows down or freezes up periodically due to work that could be performed on another thread.
- **Optimized resource consumption**: Threads are highly optimized by the OS.

Sounds great, right? More cores, more threads, faster app. I bet you're ready to learn how to create one, right? Too bad! In reality, you should never find yourself needing to create a thread explicitly. The OS will handle all thread creation for you using higher abstractions.

Apple provides the APIs necessary for thread management, but if you try to directly manage them yourself, you could in fact degrade, rather than improve, performance. The OS keeps track of many statistics to know when it should and should not allocate or destroy threads. Don't fool yourself into thinking it's as simple as spinning up a thread when you want one. For those reasons, this book will not cover direct thread management.

Dispatch queues

The way you work with threads is by creating a `DispatchQueue`. When you create a queue, the OS will potentially create and assign one or more threads to the queue. If existing threads are available, they can be reused; if not, then the OS will create them as necessary.

Creating a dispatch queue is pretty simple on your part, as you can see in the example below:

```
let label = "com.razeware.mycoolapp.networking"
let queue = DispatchQueue(label: label)
```

Phew, fairly easy, eh? Normally, you'd put the text of the label directly inside the initializer, but it's broken into separate statements for the sake of brevity.

The `label` argument simply needs to be any unique value for identification purposes. While you *could* simply use a UUID to guarantee uniqueness, it's best to use a reverse-DNS style name, as shown above (e.g. `com.company.app`), since the label is what you'll see when debugging and it's helpful to assign it meaningful text.

The main queue

When your app starts, a `main` dispatch queue is automatically created for you. It's a serial queue that's responsible for your UI. Because it's used so often, Apple has made it available as a class variable, which you access via `DispatchQueue.main`. You *never* want to execute something synchronously against the main queue, unless it's related to actual UI work. Otherwise, you'll lock up your UI which could potentially degrade your app performance.

If you recall from the previous chapter, there are two types of dispatch queues: *serial* or *concurrent*. The default initializer, as shown in the code above, will create a serial queue wherein each task must complete before the next task is able to start.

In order to create a concurrent queue, simply pass in the `.concurrent` attribute, like so:

```
let label = "com.razeware.mycoolapp.networking"
let queue = DispatchQueue(label: label, attributes: .concurrent)
```

Concurrent queues are so common that Apple has provided six different global concurrent queues, depending on the **Quality of service (QoS)** the queue should have.

Quality of service

When using a concurrent dispatch queue, you'll need to tell iOS how important the tasks are that get sent to the queue so that it can properly prioritize the work that needs to be done against all the other tasks that are clamoring for resources. Remember that higher-priority work has to be performed faster, likely taking more system resources to complete and requiring more energy than lower-priority work.

If you just need a concurrent queue but don't want to manage your own, you can use the `global` class method on `DispatchQueue` to get one of the pre-defined global queues:

```
let queue = DispatchQueue.global(qos: .userInteractive)
```

As mentioned above, Apple offers six quality of service classes:

.userInteractive

The `.userInteractive` QoS is recommended for tasks that the user *directly interacts* with. UI-updating calculations, animations or anything needed to keep the UI responsive and fast. If the work doesn't happen quickly, things may appear to freeze. Tasks submitted to this queue should complete virtually instantaneously.

.userInitiated

The `.userInitiated` queue should be used when the *user* kicks off a task from the UI that needs to happen immediately, but can be done asynchronously. For example, you may need to open a document or read from a local database. If the user clicked a button, this is probably the queue you want. Tasks performed in this queue should take a few seconds or less to complete.

.utility

You'll want to use the `.utility` dispatch queue for tasks that would typically include a progress indicator such as long-running computations, I/O, networking or continuous data feeds. The system tries to balance responsiveness and performance with energy efficiency. Tasks can take a few seconds to a few minutes in this queue.

.background

For tasks that the user is not directly aware of you should use the `.background` queue. They don't require user interaction and aren't time sensitive. Prefetching, database maintenance, synchronizing remote servers and performing backups are all great examples. The OS will focus on energy efficiency instead of speed. You'll want to use this queue for work that will take significant time, on the order of minutes or more.

.default and .unspecified

There are two other possible choices that exist, but you should not use explicitly. There's a `.default` option, which falls between `.userInitiated` and `.utility` and is the default value of the `qos` argument. It's not intended for you to directly use. The second option is `.unspecified`, and exists to support legacy APIs that may opt the thread out of a quality of service. It's good to know they exist, but if you're using them, you're almost certainly doing something wrong.

> **Note**: Global queues are always concurrent and first-in, first-out.

Inferring QoS

If you create your own concurrent dispatch queue, you can tell the system what the QoS is via its initializer:

```
let queue = DispatchQueue(label: label,
                          qos: .userInitiated,
                          attributes: .concurrent)
```

However, this is like arguing with your spouse/kids/dogs/pet rock: Just because you say it doesn't make it so! The OS will pay attention to what type of tasks are being submitted to the queue and make changes as necessary.

If you submit a task with a higher quality of service than the queue has, the queue's level will increase. Not only that, but all the operations enqueued will also have their priority raised as well.

If the current context is the main thread, the inferred QoS is `.userInitiated`. You can specify a QoS yourself, but as soon as you'll add a task with a higher QoS, your queue's QoS service will be increased to match it.

Adding task to queues

Dispatch queues provide both `sync` and `async` methods to add a task to a queue. Remember that, by **task**, I simply mean, "*Whatever block of code you need to run.*" When your app starts, for example, you may need to contact your server to update the app's state. That's not user initiated, doesn't need to happen immediately and depends on networking I/O, so you should send it to the global utility queue:

```
DispatchQueue.global(qos: .utility).async { [weak self] in
  guard let self = self else { return }

  // Perform your work here
  // ...

  // Switch back to the main queue to
  // update your UI
  DispatchQueue.main.async {
    self.textLabel.text = "New articles available!"
  }
}
```

There are two key points you should take away from the above code sample. First, there's nothing special about a `DispatchQueue` that nullifies the closure rules. You still need to make sure that you're properly handling the closure's captured variables, such as `self`, if you plan to utilize them.

Strongly capturing `self` in a GCD `async` closure will not cause a reference cycle (e.g. a retain cycle) since the whole closure will be deallocated once it's completed, but it *will* extend the lifetime of `self`. For instance, if you make a network request from a view controller that has been dismissed in the meantime, the closure will still get called. If you capture the view controller weakly, it will be `nil`. However, if you capture it strongly, the view controller will remain alive until the closure finishes its work. Keep that in mind and capture weakly or strongly based on your needs.

Second, notice how updates to the UI are dispatched to the `main` queue *inside* the dispatch to the background queue. It's not only OK, but very common, to nest `async` type calls inside others.

> **Note**: You should *never* perform UI updates on any queue other than the main queue. If it's not documented what queue an API callback uses, dispatch it to the main queue!

Use extreme caution when submitting a task to a dispatch queue synchronously. If you find yourself calling the `sync` method, instead of the `async` method, think once or twice whether that's really what you should be doing. If you submit a task synchronously to

the current queue, which blocks the current queue, and your task tries to access a resource in the current queue, then your app will **deadlock**, which is explained more in Chapter 5, "Concurrency Problems." Similarly, if you call `sync` from the `main` queue, you'll block the thread that updates the UI and your app will appear to freeze up.

> **Note**: Never call `sync` from the main thread, since it would block your main thread and could even potentially cause a deadlock.

Image loading example

You've been inundated with quite a bit of theoretical concepts at this point. Time to see an actual example!

In the downloadable materials for this book, you'll find a starter project for this chapter. Open up the **Concurrency.xcodeproj** project. Build and run the app. You'll see some images slowly load from the network into a `UICollectionView`. If you try to scroll the screen while the images are loading, either nothing will happen or the scrolling will be very slow and choppy, depending on the speed of the device you are using.

Open up **CollectionViewController.swift** and take a look at what's going on. When the view loads, it just grabs a static list of image URLs to be displayed. In a production app, of course, you'd likely be making a network call at this point to generate a list of items to display, but for this example it's easier to hardcode a list of images.

The `collectionView(_:cellForItemAt:)` method is where the trouble happens. You can see that when a cell is ready to be displayed a call is made via one of `Data`'s constructors to download the image and then it's assigned to the cell. The code looks simple enough, and it is what most starting iOS developers would do to download an image, but you saw the results: a choppy, underperforming UI experience!

Unless you slept through the previous pages of explanation, you know by now that the work to download the image, which is a network call, needs to be done on a separate thread from the UI.

> **Mini-challenge**: Which queue do you think should handle the image download? Take a look back a few pages and make your decision.

Did you pick either `.userInteractive` or `.userInitiated`? It's tempting to do because the end result is directly visible to the user but the reality is if you used that logic then you'd never use any other queue. The proper choice here is to use the `.utility` queue. You've got no control over how long a network call will take to complete and you want the OS to properly balance the speed vs. battery life of the device.

Using a global queue

Create a new method in `CollectionViewController` that starts off like so:

```
private func downloadWithGlobalQueue(at indexPath: IndexPath) {
  DispatchQueue.global(qos: .utility).async { [weak self] in
  }
}
```

You'll eventually call this from `collectionView(_:cellForItemAt:)` to perform the actual image processing. Begin by determining which URL should be loaded. Since the list of URLs are part of `self`, you'll need to handle normal closure capture semantics. Add the following code *inside* the `async` closure:

```
guard let self = self else {
  return
}

let url = self.urls[indexPath.item]
```

Once you know the URL to load, you can use the same `Data` initializer you previously used. Even though it's an synchronous operation that's being performed, it is running on a separate thread and thus the UI isn't impacted. Add the following to the end of the closure:

```
guard let data = try? Data(contentsOf: url),
      let image = UIImage(data: data) else {
  return
}
```

Now that you've successfully downloaded the contents of the URL and turned it into a `UIImage`, it's time to apply it to the collection view's cell. Remember that updates to the UI can only happen on the main thread! Add this `async` call to the end of the closure:

```
DispatchQueue.main.async {
  if let cell = self.collectionView.cellForItem(at: indexPath) as?
PhotoCell {
    cell.display(image: image)
  }
}
```

Notice that the bare minimum of code is being sent back to the main thread. Do every bit of work that you can before dispatching to the main queue so that your UI remains as responsive as possible. Is the cell assignment confusing you? Why not just pass the actual `PhotoCell` to this method instead of an `IndexPath`?

Consider the nature of what you're doing here. You've offloaded the configuration of the cell to an asynchronous process. While the network download is occurring, the user is very likely doing *something* with your app. In the case of a `UITableView` or `UICollectionView`, that probably means that they're doing some scrolling. By the time the network call finishes, the cell might have been reused for another image, or it might have been disposed of completely. By calling `cellForItem(at:)`, you're grabbing the cell at the time you're ready to update it. If it still exists and if it's still on the screen, then you'll update the display. If it's not, then `nil` will be returned.

Had you instead simply passed in a `PhotoCell` and directly interacted with that object, you'd have discovered that random images are placed in random cells, and you'll see the same image repeated multiple times as you scroll around.

Now that you've got a proper image download and cell configuration method, update `collectionView(_:cellForItemAt:)` to call it. Replace everything in-between creating and returning the cell with these two lines of code:

```
cell.display(image: nil)
downloadWithGlobalQueue(at: indexPath)
```

Using built-in methods

You can see how simple the above changes were to vastly improve the performance of your app. However, it's not always necessary to grab a dispatch queue yourself. Many of the standard iOS libraries handle that for you. Add the following method to `CollectionViewController`:

```
private func downloadWithUrlSession(at indexPath: IndexPath) {
  URLSession.shared.dataTask(with: urls[indexPath.item]) {
    [weak self] data, response, error in

    guard let self = self,
          let data = data,
          let image = UIImage(data: data) else {
      return
    }

    DispatchQueue.main.async {
      if let cell = self.collectionView
        .cellForItem(at: indexPath) as? PhotoCell {
        cell.display(image: image)
      }
    }
  }.resume()
}
```

Notice how, this time, instead of getting a dispatch queue, you directly used the `dataTask` method on `URLSession`. The code is *almost* the same, but it handles the download of the data for you so that you don't have to do it yourself, nor do you need to grab a dispatch queue. Always prefer to use the system provided methods when they are available as it will make your code not only more future-proof but easier to read for other developers. A junior programmer might not understand what the dispatch queues are, but they understand making a network call.

If you call `downloadWithUrlSession(at:)` instead of `downloadWithGlobalQueue(at:)` in `collectionView(_:cellForItemAt:)` you should see the exact same result after building and running your app again.

Where to go from here?

At this point, you should have a good grasp of what dispatch queues are, what they're used for and how to use them. Play around with the code samples from above to ensure you understand how they work.

Consider passing the `PhotoCell` into the download methods instead of just passing in the `IndexPath` to see a common type of bug in practice.

The sample app is of course somewhat contrived so as to easily showcase how a `DispatchQueue` works. There are many other performance improvements that could be made to the sample app but those will have to wait for Chapter 7, "Operation Queues."

Now that you've seen the benefits, the next chapter will introduce you to the dangers of implementing concurrency in your app.

Chapter 4: Groups & Semaphores

Sometimes, instead of just tossing a job into a queue, you need to process a group of jobs. They don't all have to run at the same time, but you need to know when they have all completed. Apple provides **dispatch groups** for this exact scenario.

DispatchGroup

The aptly named `DispatchGroup` class is what you'll use when you want to track the completion of a *group* of tasks.

You start by initializing a `DispatchGroup`. Once you have one and want to track a task as part of that group, you can provide the group as an argument to the `async` method on any dispatch queue:

```
let group = DispatchGroup()

someQueue.async(group: group) { ... your work ... }
someQueue.async(group: group) { ... more work .... }
someOtherQueue.async(group: group) { ... other work ... }

group.notify(queue: DispatchQueue.main) { [weak self] in
   self?.textLabel.text = "All jobs have completed"
}
```

As seen in the example code above, groups are not hardwired to a single dispatch queue. You can use a single group, yet submit jobs to multiple queues, depending on the priority of the task that needs to be run. `DispatchGroups` provide a `notify(queue:)` method, which you can use to be notified as soon as every job submitted has finished.

> **Note**: The notification is itself asynchronous, so it's possible to submit more jobs to the group after calling notify, as long as the previously submitted jobs have not already completed.

You'll notice that the `notify` method takes a dispatch queue as a parameter. When the jobs are all finished, the closure that you provide will be executed in the indicated dispatch queue. The `notify` call shown is likely to be the version you'll use most often, but there are a couple other versions which allow you to specify a quality of service as well, for example.

Synchronous waiting

There be dragons here!

If, for some reason, you can't respond asynchronously to the group's completion notification, then you can instead use the `wait` method on the dispatch group. This is a *synchronous* method that will block the current queue until all the jobs have finished. It takes an optional parameter which specifies how long to wait for the tasks to complete. If not specified then there is an infinite wait time:

```
let group = DispatchGroup()

someQueue.async(group: group) { ... }
someQueue.async(group: group) { ... }
someOtherQueue.async(group: group) { ... }

if group.wait(timeout: .now() + 60) == .timedOut {
  print("The jobs didn't finish in 60 seconds")
}
```

> **Note**: Remember, this *blocks* the current thread; never **ever** call `wait` on the main queue.

In the above example, you're giving the tasks up to 60 seconds to complete their work before `wait` returns.

It's important to know that the jobs *will* still run, even after the timeout has happened. To see this in practice, go to the starter projects in this chapter's download materials and open the playground named **DispatchGroup.playground**.

In the playground, the code adds two jobs to a dispatch group: one that takes 10 seconds (job 1) and another one that takes two seconds to complete:

```
let group = DispatchGroup()
let queue = DispatchQueue.global(qos: .userInitiated)

queue.async(group: group) {
  print("Start job 1")
  Thread.sleep(until: Date().addingTimeInterval(10))
  print("End job 1")
}

queue.async(group: group) {
  print("Start job 2")
  Thread.sleep(until: Date().addingTimeInterval(2))
  print("End job 2")
}
```

It then synchronously waits for the group to complete:

```
if group.wait(timeout: .now() + 5) == .timedOut {
  print("I got tired of waiting")
} else {
  print("All the jobs have completed")
}
```

Run the playground and look at the output on the right side of the Xcode window. You'll immediately see messages telling you that jobs 1 and 2 have started. After two seconds, you'll see a message saying job 2 has completed, and then three seconds later a message saying, "I got tired of waiting."

You can see from the sample that job 2 only sleeps for two seconds and that's why it can complete. You specified five total seconds of time to wait, and that's not enough for job 1 to complete, so the timeout message was printed.

However, if you wait another five seconds — you've already waited five and job 1 takes ten seconds — you'll see the completion message for job 1.

At this point, calling a synchronous wait method like this should be a **code smell** to you, potentially pointing out other issues in your architecture. Sure, it's much easier to implement synchronously, but the entire reason you're reading this book is to learn how to make your app perform as fast as possible. Having a thread just spin and continually ask, "Is it done yet?" isn't the best use of system resources.

Wrapping asynchronous methods

A dispatch queue natively knows how to work with dispatch groups, and it takes care of signaling to the system that a job has completed for you. In this case, **completed** means that the code block has run its course. Why does that matter? Because if you call an asynchronous method inside of your closure, then the closure will *complete* before the internal asynchronous method has completed.

You've got to somehow tell the task that it's not done until those internal calls have completed as well. In such a case, you can call the provided `enter` and `leave` methods on `DispatchGroup`. Think of them like a simple count of running tasks. Every time you `enter`, the count goes up by `1`. When you `leave`, the count goes down by `1`:

```
queue.dispatch(group: group) {
  // count is 1
  group.enter()
  // count is 2
  someAsyncMethod {
    defer { group.leave() }

    // Perform your work here,
    // count goes back to 1 once complete
  }
}
```

By calling `group.enter()`, you let the dispatch group know that there's another block of code running, which should be counted towards the group's overall completion status. You, of course, have to pair that with a corresponding `group.leave()` call or you'll never be signaled of completion. Because you have to call `leave` even during error conditions, you will usually want to use a `defer` statement, as shown above, so that, no matter how you exit the closure, the `group.leave()` code executes.

In a simple case similar to the previous code sample, you can simply call the `enter` / `leave` pairs directly. If you're going to use `someAsyncMethod` frequently with dispatch groups, you should wrap the method to ensure you never forget to make the necessary calls:

```
func myAsyncAdd(
  lhs: Int,
  rhs: Int,
  completion: @escaping (Int) -> Void) {
  // Lots of cool code here
  completion(lhs + rhs)
}

func myAsyncAddForGroups(
  group: DispatchGroup,
  lhs: Int,
  rhs: Int,
```

```
  completion: @escaping (Int) -> Void) {
    group.enter()

    myAsyncAdd(first: first, second: second) { result in
      defer { group.leave() }
      completion(result)
    }
}
```

The wrapper method takes a parameter for the group that it will count against, and then the rest of the arguments should be exactly the same as that of the method you're wrapping. There's nothing special about wrapping the async method other than being 100% sure that the group `enter` and `leave` methods are properly handled.

If you write a wrapper method, then testing — you do test, right? — is simplified to a single location to validate proper pairing of `enter` and `leave` calls in all utilizations.

Downloading images

Performing a network download should always be an asynchronous operation. This book's technical editor once had an assignment that required him to download all of the player's avatars before presenting the user with a list of players and their images. A dispatch group is a perfect solution for that task.

Please switch to the playground named **Images.playground** in this chapter's startup folder. Your task is to download each image from the provided `names` array in an asynchronous manner. When complete, you should show at least one of the images and terminate the playground. Take a moment to try and write the code yourself before continuing.

How'd you do? Clearly you're going to have to loop through the images to generate a URL, so start with that:

```
for name in names {
  guard let url = URL(string: "\(base)/\(name)") else { continue }
```

Now that you've got a valid URL, call `URLSession`'s `dataTask` method. That's asynchronous already, so you'll need to handle the group's entry and exit:

```
  group.enter()

  let task = URLSession.shared.dataTask(with: url) {
    data, _, error in
```

As always, with asynchronous code, the `defer` statement is going to be your friend. Now that you've started the asynchronous task, regardless of how it exits, you've got to tell the dispatch group that the task has completed. If you don't, the app will hang forever waiting for completion:

```
    defer { group.leave() }
```

After that, it's just a matter of converting the image and adding it to the array:

```
      if error == nil, let data = data, let image = UIImage(data: data) {
        images.append(image)
      }
    }

    task.resume()
  }
```

Due to properly handling the `enter` and `leave` pairs, you no longer have to spin and wait synchronously for the groups to enter. Use the `notify(queue:)` callback method to be informed when all image downloads have completed. Add this code outside the `for` loop:

```
group.notify(queue: queue) {
  images[0]

  PlaygroundPage.current.finishExecution()
}
```

If you run the playground now and watch the sidebar, you'll see each job starting, the images downloading, and eventually the notification triggering with the first image of the bunch.

Semaphores

There are times when you really need to control how many threads have access to a shared resource. You've already seen the read/write pattern to limit access to a single thread, but there are times when you can allow more resources to be used at once while still maintaining control over the total thread count.

If you're downloading data from the network, for example, you may wish to limit how many downloads happen at once. You'll use a dispatch queue to offload the work, and you'll use dispatch groups so that you know when all the downloads have completed. However, you only want to allow four downloads to happen at once because you know the data you're getting is quite large and resource-heavy to process.

By using a `DispatchSemaphore`, you can handle exactly that use case. Before any desired use of the resource, you simply call the `wait` method, which is a synchronous function, and your thread will pause execution until the resource is available. If nothing has claimed ownership yet, you immediately get access. If somebody else has it, you'll wait until they `signal` that they're done with it.

When creating a **semaphore**, you specify how many concurrent accesses to the resource are allowed. If you wish to enable four network downloads at once, then you pass in `4`. If you're trying to lock a resource for exclusive access, then you'd just specify `1`.

Open up the playground named **Semaphores.playground** and you'll find some simple boilerplate code to set up the group and queue. After the line that assigns the dispatch queue, create a semaphore that allow four concurrent accesses:

```
let semaphore = DispatchSemaphore(value: 4)
```

You'll want to simulate performing 10 network downloads, so create a loop that dispatches onto the queue, using the group. Right after creating the semaphore, implement the loop:

```
for i in 1...10 {
  queue.async(group: group) {

  }
}
```

There shouldn't be anything surprising there as it's the same type of code you just saw. On each download thread, you now want to ask for permission to use the resource. To simulate the network download, you can just have the thread sleep for three seconds. Insert this code inside the `async` block:

```
semaphore.wait()
defer { semaphore.signal() }

print("Downloading image \(i)")

// Simulate a network wait
Thread.sleep(forTimeInterval: 3)

print("Downloaded image \(i)")
```

Just as you had to be sure to call `leave` on a dispatch group, you'll want to be sure to signal when you're done using the resource. Using a `defer` block is the best option as there's then no way to leave without letting go of the resource.

If you run the playground, you should immediately see that four **downloads** happen, then, three seconds later, another four occur. Finally, three seconds after that, the final two complete.

That's a useful example just to prove that the semaphores are doing their job of limiting access to the network. However, you need to actually download something!

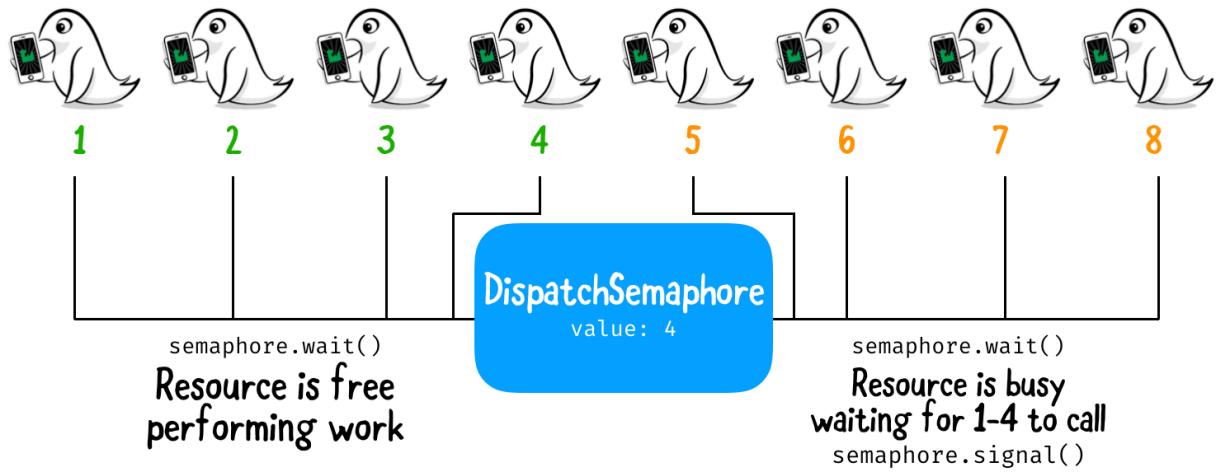
Remove everything in the playground after the creation of the `semaphore` variable and then copy the code from the **Images.playground** starting with the `let base` statement, and paste it immediately after creating the semaphore. The resource you're trying to control is the network, so you can let the URL get created in the `for` loop but, before you enter the group, you'll need to wait for an available semaphore, so add in a semaphore call just before `group.enter()`:

```
semaphore.wait()
```

You need to use both elements because the semaphore controls access to the resource, and the dispatch group is how you are tracking completion. Modify the `defer` statement as well to handle the release of the semaphore:

```
defer {
  group.leave()
  semaphore.signal()
}
```

The order of the lines doesn't really matter; I just like to have the semaphore be the **outer** element that starts and ends the task. Update the `DispatchSemaphore` to have a value of `2` instead of `4` and then run the playground. You should see it work as before, albeit slower due to the limitation of just two downloads happening at once.



Think of the semaphore itself as being some type of resource. If you have three hammers and four saws available, you'd want to create two semaphores to represent them:

```
let hammer = DispatchSemaphore(value: 3)
let saw = DispatchSemaphore(value: 4)
```

Where to go from here?

Modify the various values in the playgrounds to be sure you understand how both groups and semaphores work.

Can you think of cases in your previous or current apps that might have benefited from either one? Don't be concerned if you can't think of a use case for semaphores. They're an advanced topic that very rarely comes up in daily programming, but it's good to know they exist when you need them.

Now that you've seen how great concurrency with GCD can be, it's time to talk about some of the negative aspects.

Chapter 5: Concurrency Problems

Unfortunately, for all the benefits provided by dispatch queues, they're not a panacea for all performance issues. There are three well-known problems that you can run into when implementing concurrency in your app if you're not careful:

- Race conditions
- Deadlock
- Priority inversion

Race conditions

Threads that share the same process, which also includes your app itself, share the same address space. What this means is that each thread is trying to read and write to the same shared resource. If you aren't careful, you can run into **race conditions** in which multiple threads are trying to write to the same variable at the same time.

Consider the example where you have two threads executing, and they're both trying to update your object's `count` variable. Reads and writes are separate tasks that the computer cannot execute as a single operation. Computers work on **clock cycles** in which each tick of the clock allows a single operation to execute.

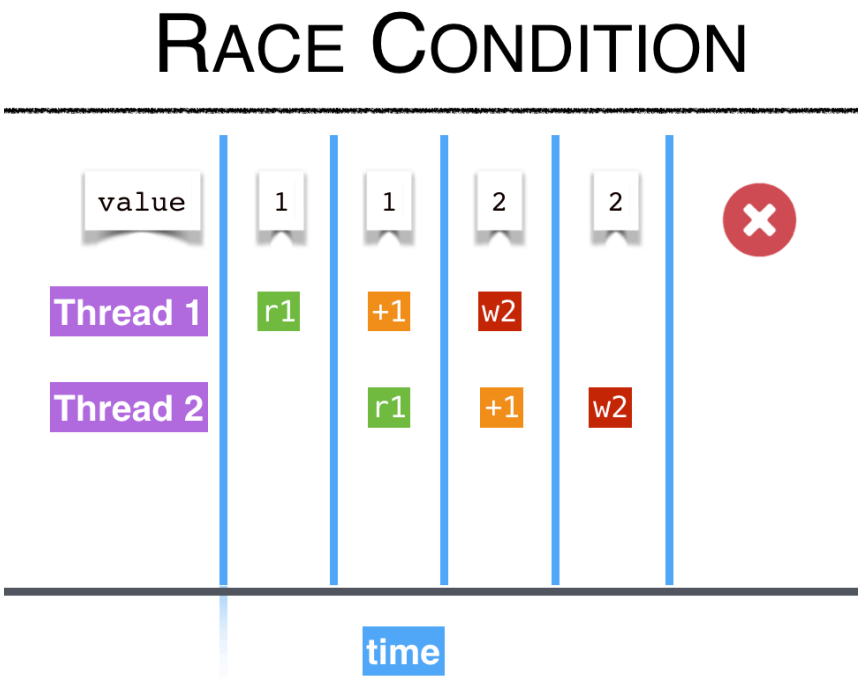
> **Note**: Do not confuse a computer's clock cycle with the clock on your watch. An iPhone XS has a 2.49 GHz processor, meaning it can perform 2,490,000,000 clock cycles per second!

Thread 1 and thread 2 both want to update the count, and so you write some nice clean code like so:

```
count += 1
```

Seems pretty innocuous, right? If you break that statement down into its component parts, adding a bit of hand-waving, what you really end up with is something like this:

1. Load value of variable `count` into memory.
2. Increment value of `count` by one in memory.
3. Write newly updated `count` back to disk.



The above graphic shows:

- Thread 1 kicked off a clock cycle before thread 2 and read the value `1` from `count`.
- On the second clock cycle, thread 1 updates the *in-memory* value to `2` and thread 2 reads the value `1` from `count`.
- On the third clock cycle, thread 1 now writes the value `2` back to the `count` variable. However, thread 2 is just now updating the *in-memory* value from `1` to `2`.
- On the fourth clock cycle, thread 2 now also writes the value `2` to `count`... except you expected to see the value `3` because two separate threads both updated the value.

This type of race condition leads to incredibly complicated debugging due to the non-deterministic nature of these scenarios. If thread 1 had started just two clock cycles earlier you'd have the value 3 as expected, but don't forget how many of these clock cycles happen per second. You might run the program 20 times and get the correct result, then deploy it and start getting bug reports.

You can usually solve race conditions with a serial queue, as long as you know they are happening. If your program has a variable that needs to be accessed concurrently, you can wrap the reads and writes with a private queue, like this:

```
private let threadSafeCountQueue = DispatchQueue(label: "...")
private var _count = 0
public var count: Int {
  get {
    return threadSafeCountQueue.sync {
      _count
    }
  }
  set {
    threadSafeCountQueue.sync {
      _count = newValue
    }
  }
}
```

Because you've not stated otherwise, the `threadSafeCountQueue` is a serial queue.

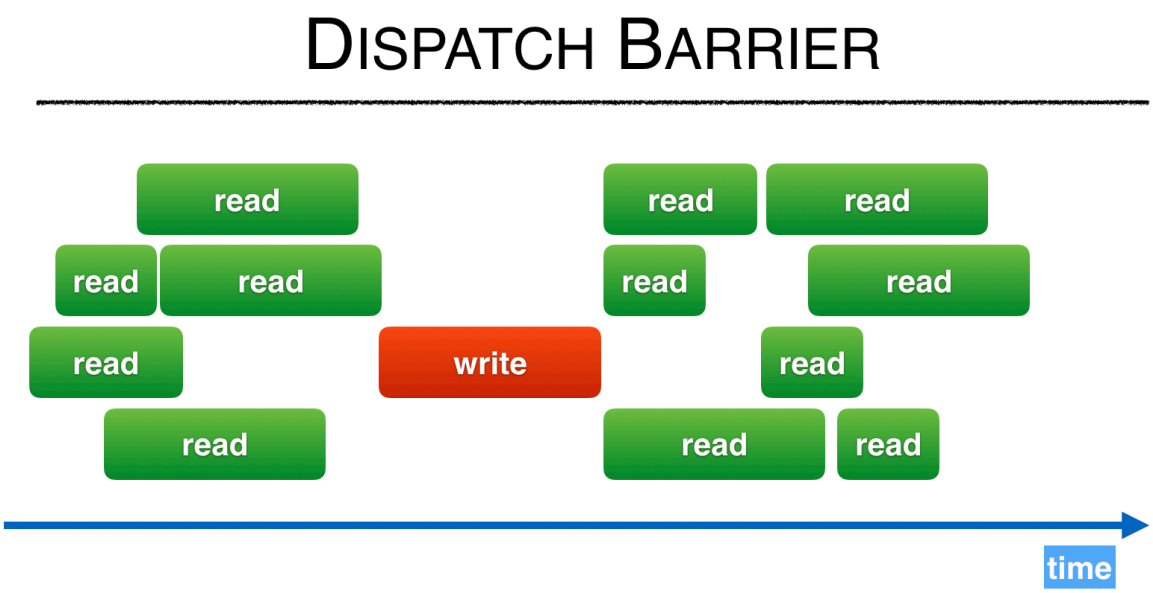
Remember, that means that only a single operation can start at a time. You're thus controlling the access to the variable and ensuring that only a single thread at a time can access the variable. If you're doing a simple read/write like the above, this is the best solution.

> **Note**: You can implement the same private queue sync for lazy variables, which might be run against multiple threads. If you don't, you could end up with two instances of the lazy variable initializer being run. Much like the variable assignment from before, the two threads could attempt to access the same lazy variable at nearly identical times. Once the second thread tries to access the lazy variable, it wasn't initialized *yet*, but it is about to be created by the access of the first thread. A classic race condition.

Thread barrier

Sometimes, your shared resource requires more complex logic in its getters and setters than a simple variable modification. You'll frequently see questions related to this online, and often they come with solutions related to locks and semaphores. Locking is very hard to implement properly. Instead, you can use Apple's **dispatch barrier** solution from GCD.

If you create a concurrent queue, you can process as many read type tasks as you want as they can all run at the same time. When the variable needs to be written to, then you need to lock down the queue so that everything already submitted completes, but no new submissions are run until the update completes.



You implement a dispatch barrier approach this way:

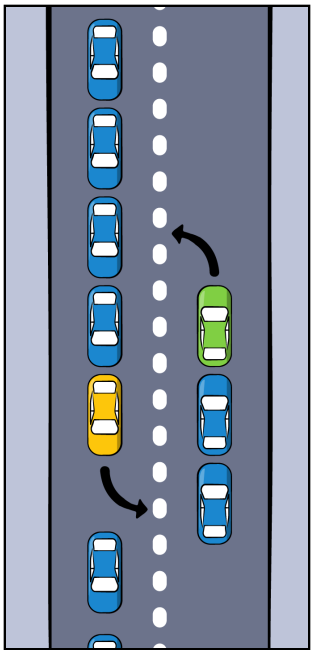
```
private let threadSafeCountQueue = DispatchQueue(label: "...",
                                                 attributes: .concurrent)
private var _count = 0
public var count: Int {
  get {
    return threadSafeCountQueue.sync {
      return _count
    }
  }
  set {
    threadSafeCountQueue.async(flags: .barrier) { [unowned self] in
      self._count = newValue
    }
  }
}
```

Notice how you're now specifying that you want a concurrent queue and that the writes should be implemented with a barrier. The barrier task won't occur until all of the previous reads have completed. Once the barrier hits, the queue pretends that it's serial and only the barrier task can run until completion. Once it completes, all tasks that were submitted after the barrier task can again run concurrently.

Deadlock

Imagine you're driving down a two-lane road on a bright sunny day and you arrive at your destination. Your destination is on the other side of the road, so you turn on the car's turn signal. You wait as tons of traffic drives in the other direction. While waiting, five cars line up behind you. You then notice a car coming the other way with its turn signal on and it also stops a few cars past you, but it is now blocked by your backup. Unfortunately, there are more cars behind the oncoming car and so the other lane backs up as well, blocking your ability to turn into your destination and clear the lane.

You've now reached **deadlock**, as you are both waiting on another task that can never complete. Neither of you can turn as cars are blocking the entrances to your destinations.



Deadlock is a pretty rare occurrence in Swift programming, unless you are using something like semaphores or other explicit locking mechanisms. Accidentally calling `sync` against the current dispatch queue is the most common occurrence of this that you'll run into.

If you're using semaphores to control access to multiple resources, be sure that you ask for resources in the same order. If thread 1 requests a hammer and then a saw, whereas thread 2 requests a saw and a hammer, you can deadlock. Thread 1 requests and receives a hammer at the same time thread 2 requests and receives a saw. Then thread 1 asks for a saw — without releasing the hammer — but thread 2 owns the resource so thread 1 must wait. Thread 2 asks for a saw, but thread 1 still owns the resource, so thread 2 must wait for the saw to become available. Both threads are now in deadlock as neither can progress until their requested resources are freed, which will never happen.

Priority inversion

Technically speaking, **priority inversion** occurs when a queue with a lower quality of service is given higher **system priority** than a queue with a higher **quality of service**, or **QoS**. If you've been playing around with submitting tasks to queues, you've probably noticed a constructor to `async`, which takes a `qos` parameter.

Back in Chapter 3, "Queues & Threads," it was mentioned that the QoS of a queue is able to change, based on the work submitted to it. Normally, when you submit work to a queue, it takes on the priority of the queue itself. If you find the need to, however, you can specify that a specific task should have higher or lower priority than normal.

If you're using a `.userInitiated` queue and a `.utility` queue, and you submit multiple tasks to the latter queue with a `.userInteractive` quality of service (having a higher priority than `.userInitiated`), you could end up in the situation in which the latter queue is assigned a higher priority by the operating system. Suddenly all the tasks in the queue, most of which are really of the `.utility` quality of service, will end up running *before* the tasks from the `.userInitiated` queue. This is simple to avoid: If you need a higher quality of service, use a different queue!

The more common situation wherein priority inversion occurs is when a higher quality of service queue shares a resource with a lower quality of service queue. When the lower queue gets a lock on the object, the higher queue now has to wait. Until the lock is released, the high-priority queue is effectively *stuck* doing nothing while low-priority tasks run.

To see priority inversion in practice, open up the playground called **PriorityInversion.playground** from the **starter** project folder in this chapter's project materials.

In the code, you'll see three threads with different QoS values, as well as a semaphore:

```
let high = DispatchQueue.global(qos: .userInteractive)
let medium = DispatchQueue.global(qos: .userInitiated)
let low = DispatchQueue.global(qos: .background)

let semaphore = DispatchSemaphore(value: 1)
```

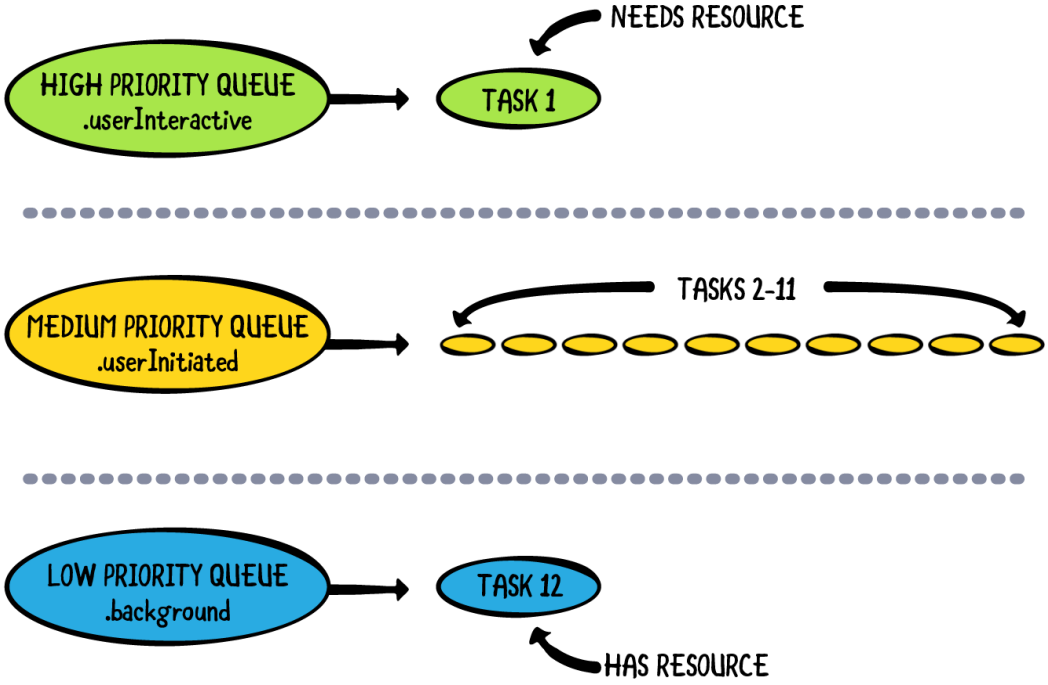
Then, various tasks are started on all queues:

```
high.async {
    // Wait 2 seconds just to be sure all the other tasks have enqueued
    Thread.sleep(forTimeInterval: 2)
    semaphore.wait()
    defer { semaphore.signal() }

    print("High priority task is now running")
}

for i in 1 ... 10 {
    medium.async {
        let waitTime = Double(exactly: arc4random_uniform(7))!
        print("Running medium task \(i)")
        Thread.sleep(forTimeInterval: waitTime)
    }
}

low.async {
    semaphore.wait()
    defer { semaphore.signal() }

    print("Running long, lowest priority task")
    Thread.sleep(forTimeInterval: 5)
}
```

If you display the console (⇧ + ⌘ + Y) and then run the playground, you'll see a different order each time you run:

```
Running medium task 7
Running medium task 6
Running medium task 1
Running medium task 4
Running medium task 2
Running medium task 8
Running medium task 5
Running medium task 3
Running medium task 9
Running medium task 10
Running long, lowest priority task
High priority task is now running
```

The end result is always the same. The high-priority task is always run *after* the medium and low-priority tasks due to priority inversion.



Section III: Operations

Even though Grand Central Dispatch provides most of the concurrency capabilties you'll need right out-of-the-box, sometimes you'll want some extra customizability. This is where Operations come into play. This section will teach you about Operations, Operation Queues, and everything in between.

Specifically, you'll learn about:

Chapter 6: Operations: In this chapter you'll switch gears and start learning about the Operations class, which allows for much more powerful control over your concurrent tasks.

Chapter 7: Operation Queues: Similar to the Dispatch Queues you learned about back in Chapter 3, the Operation class uses an OperationQueue to perform a similar function.

Chapter 8: Asynchronous Operations: Now that you can create an Operation and submit it to a queue, you'll learn how to make the operation itself asynchronous. While not something you'll do regularly, it's important to know that it's possible.

Chapter 9: Operation Dependencies: The "killer feature" of Operations is being able to tell the OS that one operation is dependant on another and shouldn't being until the dependency has finished.

Chapter 10: Canceling Operations: There are times when you need to stop an operation that is running, or has yet to start. This chapter will teach you the concepts that you need to be aware of to support cancelation.

Chapter 6: Operations

Now that you're a ninja master of Grand Central Dispatch, it's time to shift gears and take a look at **operations**. In some regards, operations act very much like GCD, and it can be confusing as to the difference when you first start utilizing concurrency.

Both GCD and operations allow you to submit a chunk of code that should be run on a separate thread; however, operations allow for greater control over the submitted task.

As mentioned at the start of the book, operations are built on top of GCD. They add extra features such as dependencies on other operations, the ability to cancel the running operation, and an object-oriented model to support more complex requirements.

Reusability

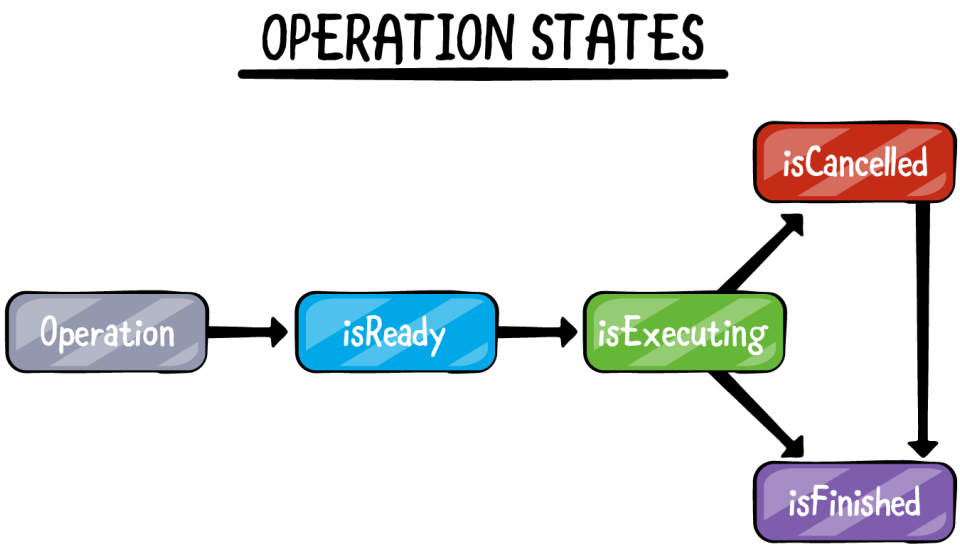
One of the first reasons you'll likely want to create an `Operation` is for reusability. If you've got a simple "fire and forget" task, then GCD is likely all you'll need.

An `Operation` is an actual Swift object, meaning you can pass inputs to set up the task, implement helper methods, etc. Thus, you can wrap up a unit of work, or task, and execute it sometime in the future, and then easily submit that unit of work more than once.

Operation states

An operation has a state machine that represents its lifecycle. There are several possible states that occur at various parts of this lifecycle:

- When it's been instantiated and is ready to run, it will transition to the `isReady` state.
- At some point, you may invoke the `start` method, at which point it will move to the `isExecuting` state.
- If the app calls the `cancel` method, then it will transition to the `isCancelled` state before moving onto the `isFinished` state.
- If it's not canceled, then it will move directly from `isExecuting` to `isFinished`.



Each of the aforementioned states are read-only Boolean properties on the `Operation` class. You can query them at any point during the execution of the task to see whether or not the task is executing.

The `Operation` class handles all of these state transitions for you. The only two you can directly influence are the `isExecuting` state, by starting the operation, and the `isCancelled` state, if you call the `cancel` method on the object.

BlockOperation

You can quickly create an `Operation` out of a block of code using the `BlockOperation` class. Normally, you would simply pass a closure to its initializer:

```
let operation = BlockOperation {
  print("2 + 3 = \(2 + 3)")
}
```

A `BlockOperation` manages the *concurrent* execution of one or more closures on the default global queue. This provides an object-oriented wrapper for apps that are already using an `OperationQueue` (discussed in the next chapter) and don't want to create a separate `DispatchQueue` as well.

Being an `Operation`, it can take advantage of **KVO** (Key-Value Observing) notifications, dependencies and everything else that an `Operation` provides.

What's not immediately apparent from the name of the class is that `BlockOperation` manages a **group** of closures. It acts similar to a dispatch group in that it marks itself as being finished when all of the closures have finished. The example above shows adding a single closure to the operation. You can, however, add multiple items, as you'll see in a moment.

> **Note**: Tasks in a `BlockOperation` run concurrently. If you need them to run serially, submit them to a private `DispatchQueue` or set up dependencies.

Multiple block operations

In the starter materials for this chapter, you'll find a playground named **BlockOperation.playground**. This playground provides a default `duration` function for timing your code, which you'll use in a moment.

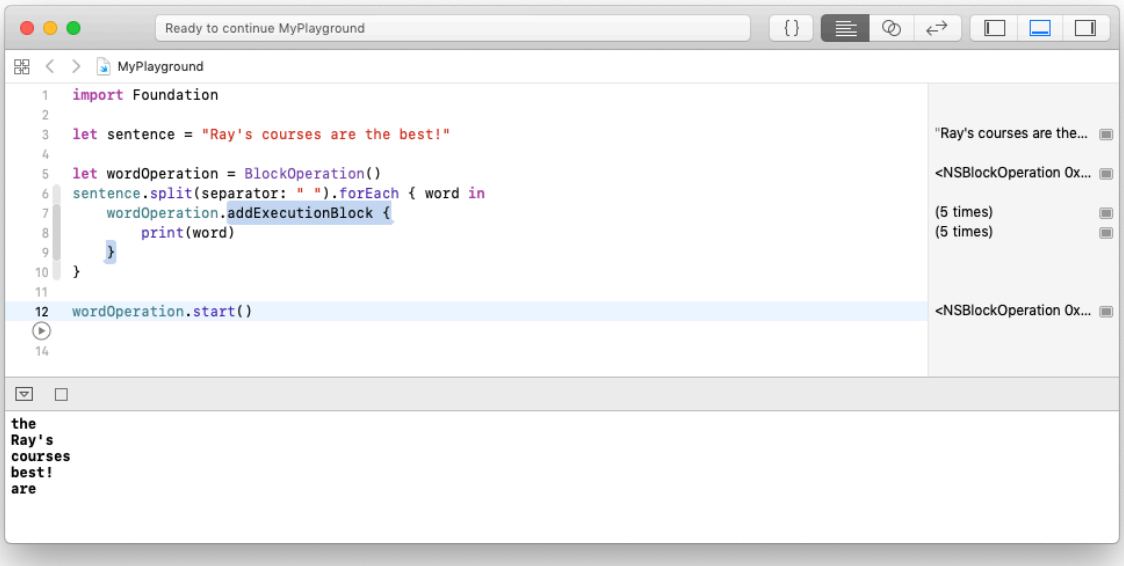
When you want to add additional closures to the `BlockOperation`, you'll call the `addExecutionBlock` method and simply pass in a new closure. Use that method to print out a public service announcement, one word at a time. Paste the following code into your Playground:

```
let sentence = "Ray's courses are the best!"
let wordOperation = BlockOperation()

for word in sentence.split(separator: " ") {
  wordOperation.addExecutionBlock {
    print(word)
  }
```

```
}

wordOperation.start()
```

The above code splits the sentence apart on spaces, so you have an array of words. For each word, another closure is added to the operation. Thus, each word is printed as part of the `wordOperation`.

Display the console (⇧ + ⌘ + Y) and then run the playground. The sentence is printed to the console, one word per line, but the order is jumbled. Remember that a `BlockOperation` runs *concurrently*, not *serially*, and thus the order of execution is not deterministic.



Time to learn a little lesson in concurrency using the `duration` helper function I mentioned earlier.

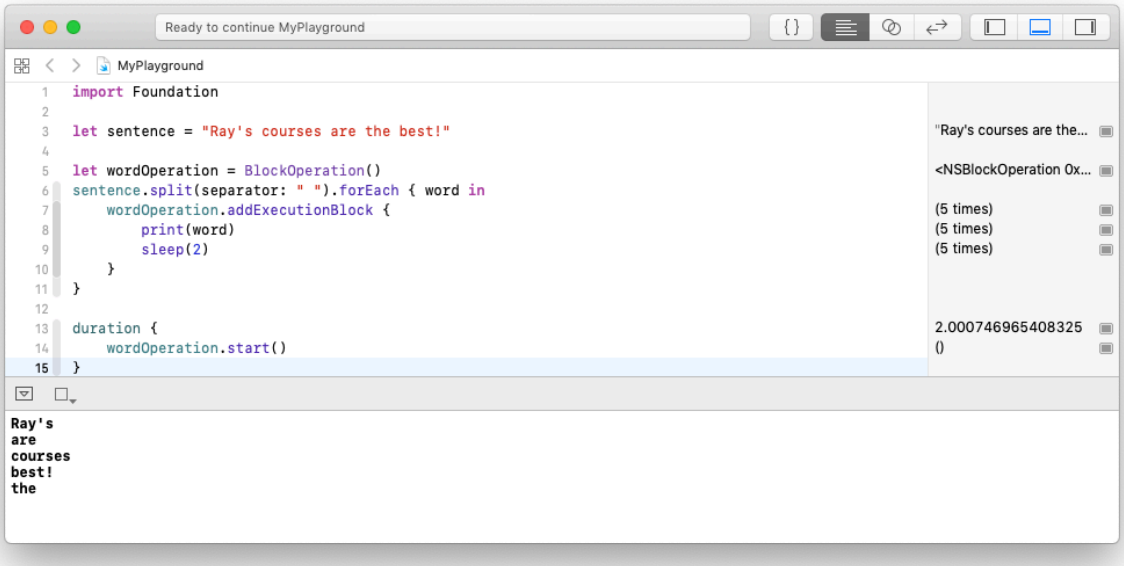
Add a delay of two seconds right after the `print` call with the following line:

```
sleep(2)
```

Next, wrap the `start` call with the provided `duration` function:

```
duration {
  wordOperation.start()
}
```

Take a look at the total time displayed on the line where you call `duration`.



Even though each operation sleeps for two seconds, the total time of the operation itself is just over two seconds, not 10 seconds (five `print`s times two seconds each).

Remember that `BlockOperation` works similar to a `DispatchGroup` — that means it's gotta be easy to know when all the operations have completed, right?

If you provide a `completionBlock` closure, then it will be executed once all of the closures added to the block operation have finished. Add this code to your playground, before you call `duration`, and run it again to see the results:

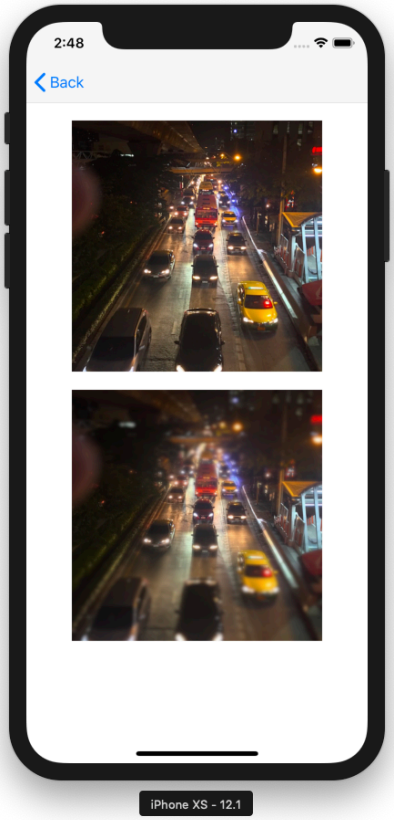
```
wordOperation.completionBlock = {
  print("Thank you for your patronage!")
}
```

Subclassing operation

The `BlockOperation` class is great for simple tasks but if performing more complex work, or for reusable components, you'll want to subclass `Operation` yourself.

Open up **Concurrency.xcodeproj** from the starter folder inside this chapter's download materials. Build and run the project and tap on the **Show Tilt Shift** button at the top of the screen.

You'll see an example of what you'll work with over the next few chapters. The image displayed at the top of the screen is the source image. After a few moments of processing, the **tilt shifted** image will appear below it.



Tilt shifting is a technique used on images to alter their depth of field. If you compare the two images, you'll see the the center of the bottom image is still in focus, but everything around it is blurred.

The example project provides a **TiltShiftFilter.swift** file, which is a subclass of `CIFilter`. Note that it works fine for educational purposes as the code is very clear and easy to follow, but it's far from optimal in terms of performance. If you need to use tilt shifting in a real application, there are far better solutions available.

If you jumped ahead and tapped on the **Show Table View** button, you were probably pretty disappointed to just get an empty table view! Time to build that out.

Tilt shift the wrong way

Since, according to Master Yoda, "The greatest teacher, failure is," you'll first implement the tilt shift the naive way most first-timers would attempt.

As mentioned earlier, you can see how the tilt shift is performed by taking a look at **TiltShiftFilter.swift**. If you're not familiar with **Core Image**, check out "Core Image Tutorial: Getting Started" at https://bit.ly/2TF8Rba. While not specifically required to continue following along, this may be helpful to understand how filters work in the examples that follow.

The sample project provides ten images in its Asset Catalog for you to use. They're simply named **0** through **9** for ease of use. Open **TiltShiftTableViewController.swift** in Xcode's editor window and add the following code to the `tableView(_:cellForRowAt:)` method, just before the `return cell` line:

```
let name = "\(indexPath.row).png"
let inputImage = UIImage(named: name)!
```

This will grab the image from the Asset Catalog. Next, add the following code to filter the image just before the `return cell` line:

```
print("Tilt shifting image \(name)")

guard let filter = TiltShiftFilter(image: inputImage, radius: 3),
      let output = filter.outputImage else {
  print("Failed to generate tilt shift image")
  cell.display(image: nil)
  return cell
}
```

You'll try to filter the image using `TiltShiftFilter`, and if everything works out, you should get an output image. If something goes wrong, you'll print out an error message. The output image is of type `CIImage`. In order to display it, you need to convert it to `UIImage`. Add the following code, still above the `return cell` statement:

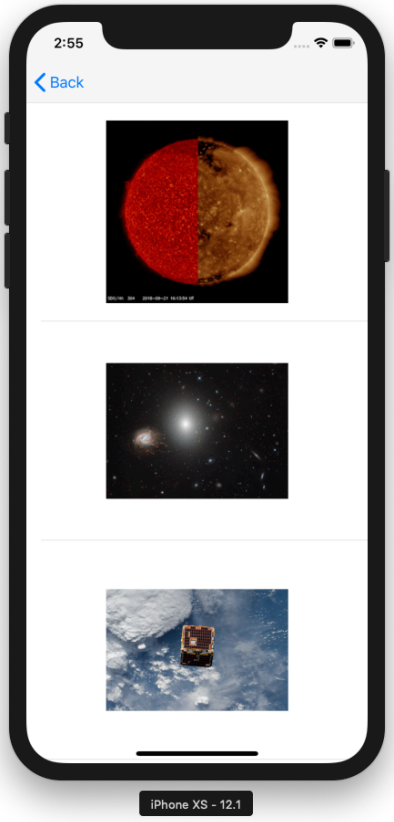
```
print("Generating UIImage for \(name)")
let fromRect = CGRect(origin: .zero, size: inputImage.size)
guard let cgImage = context.createCGImage(output, from: fromRect) else {
  print("No image generated")
  cell.display(image: nil)
  return cell
}

cell.display(image: UIImage(cgImage: cgImage))

print("Displaying \(name)")
```

You pass the output back through a `CIContext` to turn it back to a `UIImage` that you can display on the `PhotoCell`.

> **Note**: Your phone will run Core Image operations an order of magnitude faster than your Mac will. If you're running on the simulator, change the number of rows in the table view from 10 to two. I strongly suggest you test directly on your iOS device!

For the purposes of this demo, if using your Mac, those `print` statements are critical, so be sure that Xcode's console is showing (⇧ + ⌘ + Y) and then build and run the project.

Once the app starts up, tap on the **Show Table View** button and watch the console window. Depending on the speed of your device or simulator, you'll see that the filtering takes a bit of time. If you scroll the table view, you'll observe stutters while the app tries to perform the tilt shift filter.



For a smoother experience, you'll have to move the tilt shifting off the main thread and perform it in the background, so let's do that.

Tilt shift almost correctly

It should come as no surprise that the Core Image operations should be placed into an `Operation` subclass at this point. You're going to need both an input and an output image, so you'll create those two properties. The input image should never change so it makes sense to pass it to the initializer and make it private.

Create a new Swift file called **TiltShiftOperation.swift** and replace its content with the following:

```
import UIKit

final class TiltShiftOperation: Operation {
  var outputImage: UIImage?

  private let inputImage: UIImage

  init(image: UIImage) {
    inputImage = image
    super.init()
  }
}
```

In the **TiltShiftTableViewController.swift** file, it made sense to create the `context` class-level property as you only needed one instance of it. When you move to an operation class though, things change.

If you make it a simple property of `TiltShiftOperation`, you'll get a new context for every instance of `TiltShiftOperation`. `CIContext` should be reused when possible, and Apple's documentation explicitly states that the `CIContext` is thread-safe, so you can make it `static`.

Add the `context` property to your class, right at the start of the class:

```
private static let context = CIContext()
```

All that's left to do now is override the `main` method, which is the method that will be invoked when your operation starts. You can copy the code straight from the `tableView(_:cellForRowAt:)` method and just make a couple of minor tweaks:

```
override func main() {
  guard let filter = TiltShiftFilter(image: inputImage, radius: 3),
        let output = filter.outputImage else {
    print("Failed to generate tilt shift image")
    return
  }

  let fromRect = CGRect(origin: .zero, size: inputImage.size)
  guard let cgImage = TiltShiftOperation
                          .context
```

```
                              .createCGImage(output, from: fromRect) else {
      print("No image generated")
      return
    }

    outputImage = UIImage(cgImage: cgImage)
  }
```

Notice that all references to the table view cell have been removed and the `context` references the `static` property, but other than that, things work the same way. If the filter is applied successfully, then the `outputImage` will be a non-`nil` value. If anything fails, it will stay `nil`.

All that's left to do now is to switch the table view to utilize your new operation. If you want to manually run an operation, you can call its `start` method. Go back to **TiltShiftTableViewController.swift** and update `tableView(_:cellForRowAt:)` to look like this:

```
  override func tableView(
    _ tableView: UITableView,
    cellForRowAt indexPath: IndexPath) -> UITableViewCell {

    let cell = tableView.dequeueReusableCell(withIdentifier: "normal",
                                             for: indexPath) as! PhotoCell

    let image = UIImage(named: "\(indexPath.row).png")!

    print("Filtering")
    let op = TiltShiftOperation(image: image)
    op.start()

    cell.display(image: op.outputImage)
    print("Done")

    return cell
  }
```

Before you build and run the app again, take a moment to consider the changes you've made and their impact on the end user's experience. Build and run, now.

Did reality meet your expectations? Were you surprised there were no performance gains between this version of the app and the previous version? When you call the `start` method directly on an operation, you're performing a **synchronous** call on the **current thread** (i.e., the main thread). So while the code has been refactored into an `Operation` subclass, you're not yet taking advantage of the concurrency opportunities provided therein.

> **Note**: Besides the fact that calling `start` runs the operation on the current thread, it can also lead to an exception if the operation is not yet ready to be started. Generally, you shouldn't call `start` manually, unless you really know what you're doing!

In the next chapter, you'll begin to truly utilize the benefits of the `Operation` class and resolve that synchronous issue.

Chapter 7: Operation Queues

The real power of operations begins to appear when you let an `OperationQueue` handle your operations. Just like with GCD's `DispatchQueue`, the `OperationQueue` class is what you use to manage the scheduling of an `Operation` and the maximum number of operations that can run simultaneously.

`OperationQueue` allows you to add work in three separate ways:

- Pass an `Operation`.
- Pass a closure.
- Pass an array of `Operations`.

If you implemented the project from the previous chapter, you saw that an operation by itself is a synchronous task. While you could dispatch it asynchronously to a GCD queue to move it off the main thread, you'll want, instead, to add it to an `OperationQueue` to gain the full concurrency benefits of operations.

OperationQueue management

The operation queue executes operations that are **ready**, according to quality of service values and any dependencies the operation has. Once you've added an `Operation` to the queue, it will run until it has completed or been canceled. you'll learn about dependencies and canceling operations in future chapters.

Once you've added an `Operation` to an `OperationQueue`, you can't add that same `Operation` to any other `OperationQueue`. `Operation` instances are **once and done** tasks, which is why you make them into subclasses so that you can execute them multiple times, if necessary.

Waiting for completion

If you look under the hood of `OperationQueue`, you'll notice a method called `waitUntilAllOperationsAreFinished`. It does exactly what its name suggests: Whenever you find yourself wanting to call that method, in your head, replace the word **wait** with **block** in the method name. Calling it blocks the current thread, meaning that you must never call this method on the main UI thread.

If you find yourself needing this method, then you should set up a private serial `DispatchQueue` wherein you can safely call this blocking method. If you don't need to wait for all operations to complete, but just a set of operations, then you can, instead, use the `addOperations(_:waitUntilFinished:)` method on `OperationQueue`.

Quality of service

An `OperationQueue` behaves like a `DispatchGroup` in that you can add operations with different quality of service values and they'll run according to the corresponding priority. If you need a refresher on the different quality of service levels, refer back to Chapter 3, "Queues & Threads."

The default quality of service level of an operation queue is `.background`. While you can set the `qualityOfService` property on the operation queue, keep in mind that it might be overridden by the quality of service that you've set on the individual operations managed by the queue.

Pausing the queue

You can pause the dispatch queue by setting the `isSuspended` property to `true`. In-flight operations will continue to run but newly added operations will not be scheduled until you change `isSuspended` back to `false`.

Maximum number of operations

Sometimes you'll want to limit the number of operations which are running at a single time. By default, the dispatch queue will run as many jobs as your device is capable of handling at once. If you wish to limit that number, simply set the `maxConcurrentOperationCount` property on the dispatch queue. If you set the `maxConcurrentOperationCount` to `1`, then you've effectively created a serial queue.

Underlying DispatchQueue

Before you add any operations to an `OperationQueue`, you can specify an existing `DispatchQueue` as the `underlyingQueue`. If you do so, keep in mind that the quality of service of the dispatch queue will override any value you set for the operation queue's quality of service.

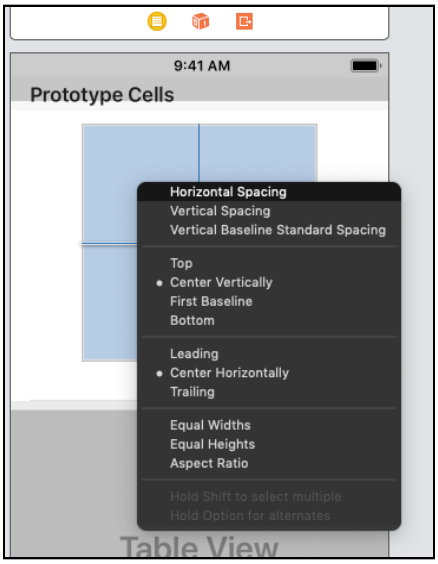
> **Note**: Do not specify the main queue as the underlying queue!

Fix the previous project

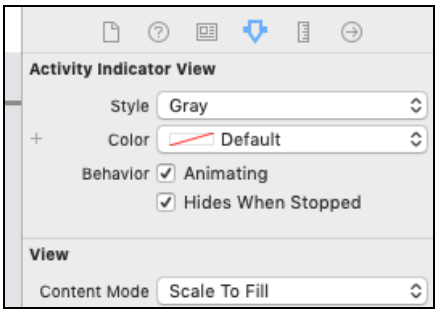
In the previous chapter, you set up an operation to handle the tilt shift, but it ran synchronously. Now that you're familiar with `OperationQueue`, you'll modify that project to work properly. You can either continue with your existing project or open up **Concurrency.xcodeproj** from this chapter's starter materials.

UIActivityIndicator

The first change you'll make is to add a `UIActivityIndicator` to clue the user that something is happening. Open up the **Main.storyboard** and choose the **Tilt Shift Table View Controller Scene**. Drag an activity indicator to the center of the image so that the crosshairs appear in both directions and place it there. Once you've done that, Control-drag from the activity indicator onto the image view in a diagonal manner. On the pop-up that appears hold down the Shift key and select both **Center Vertically** and **Center Horizontally**.



On the **Attributes inspector**, check the **Animating** and **Hides When Stopped** behaviors.



Open up **PhotoCell.swift**. Add a new `@IBOutlet`, called `activityIndicator`, and link it to the newly added activity indicator in the storyboard:

```
@IBOutlet private var activityIndicator: UIActivityIndicatorView!
```

Next, add the following computed proeprty to `PhotoCell`:

```
var isLoading: Bool {
  get { return activityIndicator.isAnimating }
  set {
    if newValue {
      activityIndicator.startAnimating()
    } else {
      activityIndicator.stopAnimating()
    }
  }
}
```

While you could make the `activityIndicator` property public and call the methods directly, It's suggested to not expose UI elements and outlets to avoid leaking UIKit-specific logic to higher layers of abstraction. For example, you may wish to replace this indicator with a custom component at some point down the road.

Updating the table

Head over to **TiltShiftTableViewController.swift**. In order to add operations to a queue, you need to create one. Add the following property to the top of the class:

```
private let queue = OperationQueue()
```

Next, replace everything in `tableView(_:cellForRowAt:)` between declaring `image` and returning the cell with the following:

```
let op = TiltShiftOperation(image: image)
op.completionBlock = {
  DispatchQueue.main.async {
    guard let cell = tableView.cellForRow(at: indexPath)
```

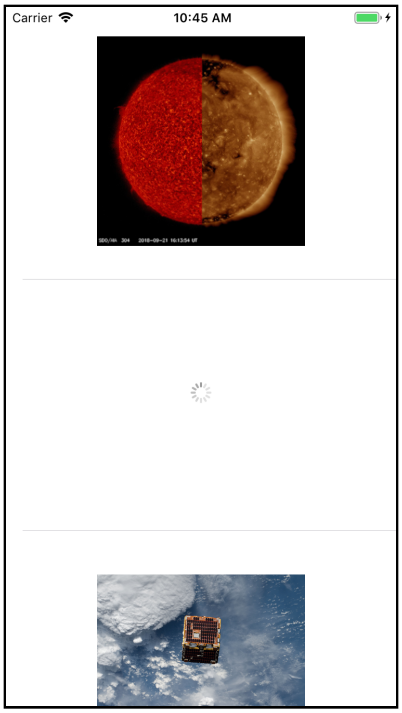
```
        as? PhotoCell else { return }

      cell.isLoading = false
      cell.display(image: op.outputImage)
    }
  }

  queue.addOperation(op)
```

Instead of manually calling `start` on the operation, you'll now add the operation to a queue that will be starting and completing it for you. Additionally, the queue runs in the background by default, so you won't be blocking the main thread anymore.

When the operation completes, the `completionBlock` is called with no arguments, and it expects no return value. You'll immediately want to dispatch your code back to the main UI thread. If you are able to get a reference to the table view cell (if it wasn't scrolled away), then you're simply turning off the activity indicator and updating the image.

As soon as you add an operation to an operation queue, the job will be scheduled. Now there's no longer a reason to call `op.start()`.

Build and run the app and try scrolling the table again.



Now that your code is running in an asynchronous manner, the table scrolling is much smoother. While making such a change doesn't do anything to improve the performance of the code being run via the operation, it does ensure that the UI isn't locked up or choppy.

You may be thinking to yourself, "How is this any different than just doing it with GCD?" Right now, there really isn't a difference. But, in the next couple of chapters, you'll expand on the power of operations, and the reason for the changes will become clear.

Where to go from here?

The table currently loads and filters every image every time the cell is displayed. Think about how you might implement a caching solution so that the performance is even better.

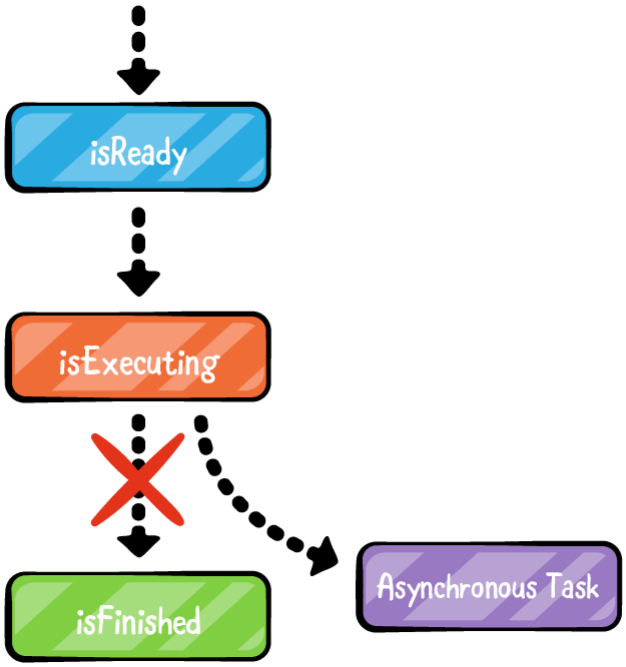
The project is coming along nicely, but it is using static images, which usually won't be the case for production-worthy projects. In the next chapter, you'll take a look at network operations.

Chapter 8: Asynchronous Operations

Up to this point, your operations have been synchronous, which works very well with the `Operation` class' state machine. When the operation transitions to the `isReady` state, the system knows that it can start searching for an available thread.

Once the scheduler has found a thread on which to run the operation, the operation will transition to the `isExecuting` state. At that point, your code executes and completes, and the state then becomes `isFinished`.

How would that work with an *asynchronous* operation, though? When the `main` method of the operation executes, it will kick off your asynchronous task, and then `main` exits. The state of the operation can't switch to `isFinished` at that point because the asynchronous method likely has yet to complete.



Asynchronous operations

It's possible to wrap an asynchronous method into an operation, but it takes a bit more work on your part. You'll need to manage the state changes manually as the operation can't determine automatically when the task has finished executing. To make matters worse, the state properties are all read-only!

If you're ready to throw in the towel, don't worry. Managing the states is actually quite simple to accomplish. In fact, you will now create a base class that all asynchronous operations you use will inherit from so you never have to do it again. No, we don't know why this class isn't part of the framework.

AsyncOperation

In the download materials for this chapter, open **AsyncAddOperation.playground** in the **starter** folder. You can ignore the compilation error as you'll resolve it in a moment when you add some code.

State tracking

Since the state of an operation is read-only, you'll first want to give yourself a way to track changes in a read-write manner, so create a `State` enumeration at the top of the file:

```
extension AsyncOperation {
  enum State: String {
    case ready, executing, finished

    fileprivate var keyPath: String {
      return "is\(rawValue.capitalized)"
    }
  }
}
```

Back in Chapter 6, "Operations," I mentioned that the `Operation` class uses **KVO notifications**. When the `isExecuting` state changes, for example, a KVO notification will be sent. The states you set yourself don't start with the '**is**' prefix though, and, per the Swift style guide, `enum` entries should be lowercased.

The `keyPath` computed property you wrote is what helps support the aforementioned KVO notifications. When you ask for the `keyPath` of your current `State`, it will capitalize the first letter of the state's value and prefix with the text **is**. Thus, when your state is set to `executing`, the `keyPath` will return `isExecuting`, which matches the property on the `Operation` base class.

Notice the `fileprivate` modifier. You thought the need to ever use that monstrosity went away with the fixes in Swift 4, didn't you? This is a case in which it's still helpful. The `keyPath` needs to be available to this entire file but not externally. If you just made it `private`, then it wouldn't be visible outside of the `enum` itself.

Be aware that the scoping is now the entire *file*, so you'll want to make sure the class lives in a file of its own for production code.

Now that you have the type of your state created, you'll need a variable to hold the state. Because you need to send the appropriate KVO notifications when you change the value, you'll attach property observers to the property. Add the following code to the `AsyncOperation` class, under `// Create state management`:

```
var state = State.ready {
  willSet {
    willChangeValue(forKey: newValue.keyPath)
    willChangeValue(forKey: state.keyPath)
  }
  didSet {
    didChangeValue(forKey: oldValue.keyPath)
    didChangeValue(forKey: state.keyPath)
```

```
    }
  }
```

By default, your `state` is `ready`. When you change the value of `state`, you'll actually end up sending four KVO notifications! Take a minute to see if you can understand what is happening and why there are four entries there instead of just two.

Consider the case in which the state is currently `ready` and you are updating to `executing`. `isReady` will become `false`, while `isExecuting` will become `true`. These four KVO notifications will be sent:

1. Will change for `isReady`.
2. Will change for `isExecuting`.
3. Did change for `isReady`.
4. Did change for `isExecuting`.

The `Operation` base class needs to know that both the `isExecuting` and `isReady` properties are changing.

Base properties

Now that you have a way to track state changes and signal that a change was in fact performed, you'll need to override the base class' instances of those methods to use your state instead. Add these three overrides to the class, below `// Override properties`:

```
override var isReady: Bool {
  return super.isReady && state == .ready
}

override var isExecuting: Bool {
  return state == .executing
}

override var isFinished: Bool {
  return state == .finished
}
```

Note: It's critical that you include a check to the base class' `isReady` method as your code isn't aware of everything that goes on while the scheduler determines whether or not it is ready to find your operation a thread to use.

The final property to override is simply to specify that you are in fact using an asynchronous operation. Add the following piece of code:

```
override var isAsynchronous: Bool {
  return true
}
```

Starting the operation

All that's left to do is implement the `start` method. Whether you manually execute an operation or let the operation queue do it for you, the `start` method is what gets called first, and then it is responsible for calling `main`. Add the following code immediately below `// Override start`:

```
override func start() {
  main()
  state = .executing
}
```

> **Note**: Notice this code doesn't invoke `super.start()`. The official documentation (https://apple.co/2YcJvEh) clearly mentions that you **must not** call super at any time when overriding `start`.

Those two lines probably look backwards to you. They're really not. Because you're performing an asynchronous task, the `main` method is going to almost immediately return, thus you have to manually put the state back to `.executing` so the operation knows it is still in progress.

> **Note**: There's a piece missing from the above code. Chapter 10, "Canceling Operations," will talk about cancelable operations, and that code needs to be in any `start` method. It's left out here to avoid confusion.

If Swift had a concept of an abstract class, which couldn't be directly instantiated, you would mark this class as abstract. In other words, never directly use this class. You should always subclass `AsyncOperation`!

Math is fun!

Take a look at the rest of the code that was provided for you in the playground. Nothing should be new to you, as long as you already worked through the chapters on GCD in this book. If you run the playground with the console displayed (⇧ + ⌘ + Y), you'll see the numbers have been added together properly.

The key detail in the `AsyncSumOperation` to pay attention to is that you must manually set the `state` of the operation to `.finished` when the asynchronous task completes. If you forget to change the state then the operation will never be marked as complete, and you'll have what known as an infinite loop.

> **Note**: Be sure to always set the `state` to `.finished` when your asynchronous method completes.

Networked TiltShift

Time to get back to your image filtering. So far, you've used a hardcoded list of images. Wouldn't it be great if the images came from the network instead? Performing a network operation is simply an asynchronous task! Now that you have a way to turn an asynchronous task into an operation, let's get to it!

The starter project for this chapter, located in the **starter/Concurrency** folder, continues the project you've been building but includes two new files. If you wish to continue with your current Xcode project, please be sure to grab both files.

- **AsyncOperation.swift**: This is the asynchronous operation that you created earlier in this chapter.
- **Photos.plist**: This is a list of URLs of various images.

NetworkImageOperation

Open **Concurrency.xcodeproj** and create a new Swift file named **NetworkImageOperation.swift**. You're going to make this do more than specifically needed for the project but this way you'll have a reusable component for any other project you work on.

The general requirements for the operation are as follows:

1. Should take either a `String` representing a URL or an actual `URL`.
2. Should download the data at the specified URL.
3. If a `URLSession`-type completion handler is provided, use that instead of decoding.
4. If successful, there's no completion handler and it's an image; should set an optional `UIImage` value.

The first two requirements should be pretty obvious. The third and fourth are to give maximum flexibility to the caller. In some cases, as with this project, you just want to grab the decoded `UIImage` and be done. Other projects though may require custom processing. For example, you may care about what the specific error is, whether the HTTP header has a valid `Content-Type` header, etc.

Begin by subclassing `AsyncOperation` and declaring the variables that the class will need. Replace the content of **NetworkImageOperation.swift** with the following:

```
import UIKit

final class NetworkImageOperation: AsyncOperation {
  var image: UIImage?

  private let url: URL
  private let completion: ((Data?, URLResponse?, Error?)
                           -> Void)?

}
```

The `completion` signature is the same signature used by `URLSession` methods, just turned into an optional. To meet requirements 1 and 2, you'll need to define appropriate initializers. Add the following code inside your new class:

```
init(
  url: URL,
  completion: ((Data?, URLResponse?, Error?) -> Void)? = nil) {

  self.url = url
  self.completion = completion

  super.init()
}

convenience init?(
  string: String,
  completion: ((Data?, URLResponse?, Error?) -> Void)? = nil) {

  guard let url = URL(string: string) else { return nil }
  self.init(url: url, completion: completion)
}
```

It's probably not the normal case that someone will want to explicitly handle the HTTP return data themselves, so it makes sense to default the completion handler to `nil`. Passing an actual `URL` is the "designated initializer" and, thus, you're declaring a convenience initializer that takes a string instead. Note how that constructor is itself an optional. If you pass a string that isn't able to be converted to a URL, then the constructor will return `nil`.

Housekeeping, check! Now for the actual work of the operation. Override `main` and start a new `URLSession` task, as you would usually use `URLSession`. Add below your initializers:

```
override func main() {
  URLSession.shared.dataTask(with: url) {
    [weak self] data, response, error in

  }.resume()
}
```

Since this is an asynchronous operation, it's always possible that the object will be removed before the data download happens, so you need to be sure you can retain `self`, thus using `weak` capture group.

Now, it's time to handle the completed task. Add the following code inside the completion closure:

```
guard let self = self else { return }

defer { self.state = .finished }

if let completion = self.completion {
  completion(data, response, error)
  return
}

guard error == nil, let data = data else { return }

self.image = UIImage(data: data)
```

Using `defer` ensures that the operation is eventually marked as complete. There are already three possible exit paths in the current method, plus you never know what changes you might make in the future. Putting the `defer` statement right up front makes it bullet proof.

Meeting requirements 3 and 4 is as simple as checking for whether or not the caller has provided a completion handler. If they have provided a completion handler, you just pass the processing responsibility to it and exit. If not, then you can decode the image.

Note that there's no need to throw exceptions or return any type of error condition. If anything fails, then the `image` property will be `nil`, and the caller will know something went wrong.

Using NetworkImageFilter

Head back over to **TiltShiftTableViewController.swift**. In order to get the list of URLs that you'll be able to display, add the following code to the beginning of your view controller:

```
private var urls: [URL] = []

override func viewDidLoad() {
  super.viewDidLoad()

  guard let plist = Bundle.main.url(forResource: "Photos",
                                    withExtension: "plist"),
        let contents = try? Data(contentsOf: plist),
        let serial = try? PropertyListSerialization.propertyList(
                          from: contents,
                          format: nil),
        let serialUrls = serial as? [String] else {
    print("Something went horribly wrong!")
    return
  }

  urls = serialUrls.compactMap(URL.init)
}
```

That's the standard Swift mechanism for reading the contents of a .plist file and converting the strings to actual `URL` objects. You might not have seen `compactMap` before. It works just like `map` does, just for an array of Optional values. It excludes any `nil` items and returns only unwrapped, non-optional values. In this case, that means the `urls` array will just contain valid `URL` objects.

In `tableView(_:cellForRowAt:)`, replace the next two lines:

```
let image = UIImage(named: "\(indexPath.row).png")!
let op = TiltShiftOperation(image: image)
```

With the following:

```
let op = NetworkImageOperation(url: urls[indexPath.row])
```

The `TiltShiftOperation` class used `outputImage` as the result variable, whereas `NetworkImageOperation` uses just `image`, so replace that property by replacing the following line:

```
cell.display(image: op.outputImage)
```

With:

```
cell.display(image: op.image)
```

At this point, you can build and run the app and scroll through a large list of space-related images.

The scrolling will be nice and smooth as the UI isn't hung at any point during the network operation.

Where to go from here?

You've now got reusable components for both network image downloads as well as tilt shift filtering. Wouldn't it be nice to be able to use both at once? The next chapter will show you how to link those two together and finally provide the "*aha*" moment as to why you're using operations instead of sticking with Grand Central Dispatch.

Chapter 9: Operation Dependencies

In this chapter, you're going to learn about **dependencies** between operations. Making one operation dependent on another provides two specific benefits for the interactions between operations:

1. Ensures that the dependent operation does not begin before the prerequisite operation has completed.
2. Provides a clean way to pass data from the first operation to the second operation automatically.

Enabling dependencies between operations is one of the primary reasons you'll find yourself choosing to use an `Operation` over GCD.

Modular design

Consider the tilt shift project you've been creating. You now have an operation that will download from the network, as well as an operation that will perform the tilt shift. You could instead create a single operation that performs both tasks, but that's not a good architectural design.

Classes should ideally perform a single task, enabling reuse within and across projects. If you had built the networking code into the tilt shift operation directly, then it wouldn't be usable for an already-bundled image. While you could add many initialization parameters specifying whether or not the image would be provided or downloaded from the network, that bloats the class. Not only does it increase the long-term maintenance of the class — imagine switching from `URLSession` to Alamofire — it also increases the number of test cases which have to be designed.

Specifying dependencies

Adding or removing a dependency requires just a single method call on the **dependent** operation. Consider a fictitious example in which you'd download an image, decrypt it and then run the resultant image through a tilt shift:

```
let networkOp = NetworkImageOperation()
let decryptOp = DecryptOperation()
let tiltShiftOp = TiltShiftOperation()

decryptOp.addDependency(op: networkOp)
tiltShiftOp.addDependency(op: decryptOp)
```

If you needed to remove a dependency for some reason, you'd simply call the obviously named method, `removeDependency(op:)`:

```
tiltShiftOp.removeDependency(op: decryptOp)
```

The `Operation` class also provides a read-only property, `dependencies`, which will return an array of `Operations`, which are marked as dependencies for the given operation.

Avoiding the pyramid of doom

Dependencies have the added side effect of making the code much simpler to read. If you tried to write three chained operations together using GCD, you'd end up with a pyramid of doom. Consider the following **pseudo-code** for how you might have to represent the previous example with GCD:

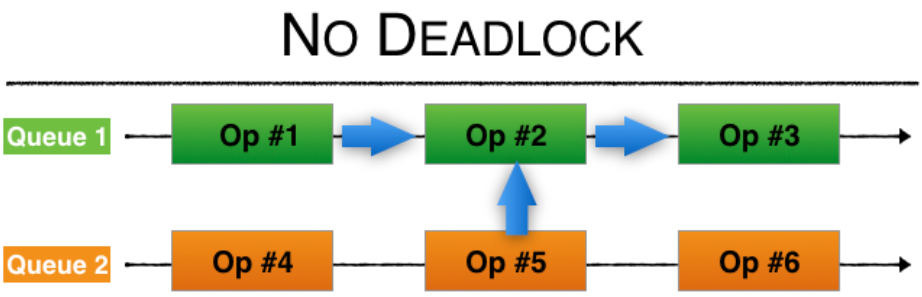
```
let network = NetworkClass()
network.onDownloaded { raw in
  guard let raw = raw else { return }

  let decrypt = DecryptClass(raw)
  decrypt.onDecrypted { decrypted in
    guard let decrypted = decrypted else { return }

    let tilt = TiltShiftClass(decrypted)
    tilt.onTiltShifted { tilted in
      guard let tilted = tilted else { return }
    }
  }
}
```

Which one is going to be easier to understand and maintain for the junior developer who takes over your project once you move on to bigger and better things? Consider also that the example provided doesn't take into account the retain cycles or error checking that real code would have to handle properly.

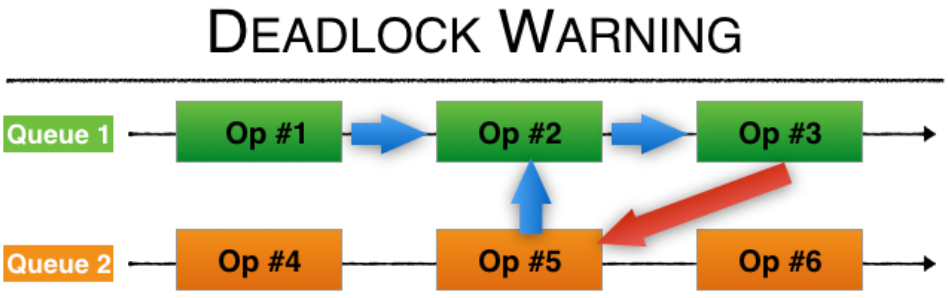
Watch out for deadlock

In Chapter 5, "Concurrency Problems," you learned about deadlock. Any time a task is dependent on another, you introduce the possibility of deadlock, if you aren't careful. Picture in your mind — better yet graph out — the dependency chain. If the graph draws a straight line, then there's no possibility of deadlock.

It's completely valid to have the operations from one operation queue depend on an operation from another operation queue. Even when you do that, as long as there are no loops, you're still safe from deadlock.



If, however, you start seeing loops, you've almost certainly run into a deadlock situation.



In the previous image, you can see where the problem lies:

- Operation 2 can't start until operation 5 is done.
- Operation 5 can't start until operation 3 is done.
- Operation 3 can't start until operation 2 is done.

If you start and end with the same operation number in a cycle, you've hit deadlock. None of the operations will ever be executed. There's no silver-bullet solution to resolve a deadlock situation, and they can be hard to find if you don't map out your dependencies. If you run into such a situation, you have no choice but to re-architect the solution you've designed.

Passing data between operations

Now that you've got a way to safely make one operation depend on another, there has to be a way to pass data between them. Enter the power of protocols. The `NetworkImageOperation` has an output property called `image`. What about the case, though, in which the property is called something else?

Part of the benefit to operations is the encapsulation and reusability they provide. You can't expect every person who writes an operation to call the output property `image`. Internally, to the class, there might have been a good reason to call it `foodImage`, for example.

Using protocols

Here's what you're really saying: "When this operation finishes, if everything went well, I will provide you with an image of type `UIImage`."

As usual, please open **Concurrency.xcodeproj** in the starter project folder that comes with this chapter's download materials and then create a new Swift file called **ImageDataProvider.swift**. Add the following code to the file:

```
import UIKit

protocol ImageDataProvider {
  var image: UIImage? { get }
}
```

Any operation that has an output of a `UIImage` should implement that protocol. In this case, the property names match one-to-one, which makes life easier. Think about your `TiltShiftOperation`, though. Following `CIFilter` naming conventions you called that one `outputImage`. Both classes should conform to the `ImageDataProvider`.

Adding extensions

Open up **NetworkImageOperation.swift** and add this code to the very bottom of the file:

```
extension NetworkImageOperation: ImageDataProvider {}
```

Since the class already contains the property exactly as defined by the protocol, there's nothing else you need to do. While you could have simply added `ImageDataProvider` to the class definition, the Swift Style Guide recommends the `extension` approach instead.

For `TiltShiftOperation`, there's a tiny bit more work to do. While you already have an output image, the name of the property isn't `image` as defined by the protocol.

Add the following code at the end of **TiltShiftOperation.swift**:

```
extension TiltShiftOperation: ImageDataProvider {
  var image: UIImage? { return outputImage }
}
```

Remember that an extension can be placed anywhere, in any file. Since you created both operations, it makes sense of course to place the extension right alongside the class. You might be using a third-party framework, however, wherein you can't edit the source. If the operation it provide gives you an image, you can add the extension to it yourself in a file within your project, like **ThirdPartyOperation+Extension.swift**.

Searching for the protocol

The `TiltShiftOperation` needs a `UIImage` as its input. Instead of just requiring the `inputImage` property be set, it can now check whether any of its dependencies provides a `UIImage` as output.

In **TiltShiftOperation.swift**, in `main()`, change the first `guard` statement (e.g. the first line) to this:

```
let dependencyImage = dependencies
  .compactMap { ($0 as? ImageDataProvider)?.image }
  .first

guard let inputImage = inputImage ?? dependencyImage else {
  return
}
```

In the above code, you try to unwrap either the input image directly provided to the operation, the dependency chain for something that will provide us an image, making sure it gave a non-`nil` image.

If neither of those worked, simply return without performing any work.

There's one last piece to making this all work. Because you now check the dependency chain for an image, there has to be a way to initialize a `TiltShiftOperation` without providing an input image. The simplest way to handle no input is by making the current constructor default the input image to `nil`.

Adjust your initializer to look as follows:

```
init(image: UIImage? = nil) {
  inputImage = image
  super.init()
}
```

Update the table view controller

Head back over to **TiltShiftTableViewController.swift** and see if you can update it to download the image, tilt shift it, and then assign it to the table view cell.

For this to work, you'll need to add the download operation as a dependency of the tilt shift operation. In other words, the tilt shift *depends* on the download operation to get the image.

Replace the line in `tableView(_:cellForRowAt:)` where you set and declare `op` with the following code:

```
let downloadOp = NetworkImageOperation(url: urls[indexPath.row])
let tiltShiftOp = TiltShiftOperation()
tiltShiftOp.addDependency(downloadOp)
```

Instead of having a single operation, you now have two operations and a dependency between them.

Next, instead of setting `completionBlock` on the `op`, set it on the `tiltShiftOp`, because it will provide you with the image.

Replace the entire completion block with the following:

```
tiltShiftOp.completionBlock = {
  DispatchQueue.main.async {
    guard let cell = tableView.cellForRow(at: indexPath)
      as? PhotoCell else { return }
```

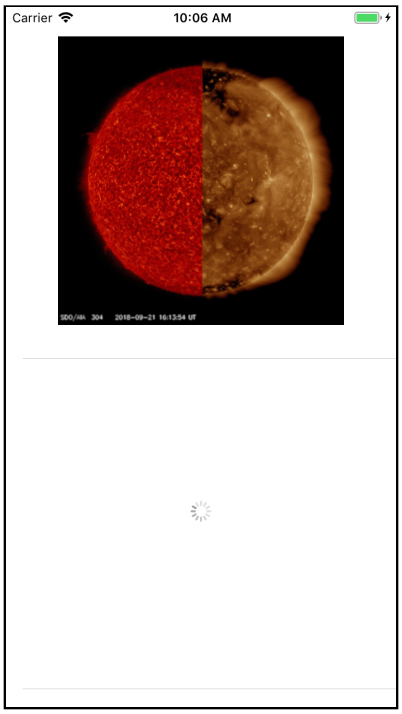
```
      cell.isLoading = false
      cell.display(image: tiltShiftOp.image)
    }
  }
```

Finally, replace the line where you add `op` to the queue with these two lines:

```
queue.addOperation(downloadOp)
queue.addOperation(tiltShiftOp)
```

Even though you said that the tilt shift depends on the download, you still need to add both operations to the queue. The queue will keep track of dependencies and only start the tilt shift operation once the download is complete.

Build and run the app. You should see a list of tilt shifted images!



Custom completion handler

The code as currently written is using the default `completionBlock` provided by the `Operation` class. You're having to do a little extra work there to grab the image and dispatch back to the main queue. In a case like this, you may want to consider adding a custom completion block. Back in **TiltShiftOperation.swift**, add a new optional class-level property at the top of the class to store a custom completion handler:

```
/// Callback which will be run *on the main thread*
/// when the operation completes.
var onImageProcessed: ((UIImage?) -> Void)?
```

Then, at the very end of the `main()` method, after assigning the `outputImage`, call that completion handler *on the main thread*:

```
if let onImageProcessed = onImageProcessed {
  DispatchQueue.main.async { [weak self] in
    onImageProcessed(self?.outputImage)
  }
}
```

If you add that extra bit of code then back in **TiltShiftTableViewController.swift**, in `tableView(_:cellForRowAt:)`, you can replace the entire completion block code with this:

```
tiltShiftOp.onImageProcessed = { image in
  guard let cell = tableView.cellForRow(at: indexPath)
    as? PhotoCell else {
    return
  }

  cell.isLoading = false
  cell.display(image: image)
}
```

While there's no functional or performance difference from those changes, it does make working with your operation a bit nicer for the caller. You've removed confusion over any possible retain cycle and ensured that they're properly working on the main UI thread automatically.

It's very important that you **document** the fact that your completion handler is being run on the main UI thread instead of the operation queue's provided thread.

The end user needs to know you're switching threads on them so they don't do something that could impact the application.

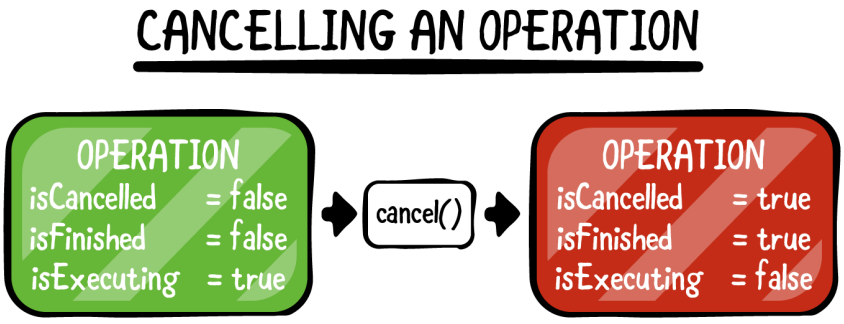
Notice how there are three `/` characters in the comment shown. If you use that syntax, then Xcode will display that comment as the summary of the property in the Quick Help Inspector. Xcode supports limited styling as well, which means that the text *on the main thread* will actually be italicized in the help display.

Chapter 10: Canceling Operations

While dependencies are the killer feature of operations, there's one more feature that's not available to Grand Central Dispatch. With an operation, you have the capability of canceling a running operation *as long as it's written properly*. This is very useful for long operations that can become irrelevant over time. For instance, the user might leave the screen or scroll away from a cell in a table view. There's no sense in continuing to load data or make complex calculations if the user isn't going to see the result.

The magic of cancel

Once you schedule an operation into an operation queue, you no longer have any control over it. The queue will schedule and manage the operation from then on. The one and only change you can make, once it's been added to the queue, is to call the `cancel` method of `Operation`.



There's nothing magical about how canceling an operation works. If you send a request to an operation to stop running, then the `isCancelled` computed property will return `true`. Nothing else happens automatically! At first, it may seem strange that iOS doesn't stop the operation automatically, but it's really not.

What does *canceling* an operation mean to the OS?

- Should the operation simply throw an exception?
- Is there cleanup that needs to take place?
- Can a running network call be canceled?
- Is there a message to send server-side to let something else know the task stopped?
- If the operation stops, will data be corrupted?

With just the small list of issues presented in the bullets above, you can see why setting a flag identifying that cancellation has been *requested* is all that's possible automatically.

The default `start` implementation of `Operation` will first check to see whether the `isCancelled` flag is `true`, and exit immediately if it is.

Cancel and cancelAllOperations

The interface to cancel an operation is quite simple. If you just want to cancel a specific `Operation`, then you can call the `cancel` method. If, on the other hand, you wish to cancel all operations that are in an operation queue, then you should call the `cancelAllOperations` method defined on `OperationQueue`.

Updating AsyncOperation

In this chapter, you'll update the app you've been working on so that a cell's operations are canceled when the user scrolls away from that cell.

In Chapter 8, "Asynchronous Operations," you built the `AsyncOperation` base class. If you recall, there was a note with that code warning you that the provided implementation wasn't entirely complete. It's time to fix that!

The start class provided was written like so:

```
override func start() {
  main()
  state = .executing
}
```

If you're going to allow your operation to be cancelable — which you should always do unless you have a *very* good reason not to — then you need to check the `isCancelled` variable at appropriate locations. Open up the starter project from this chapter's download materials and edit **AsyncOperation.swift** to update the `start` method:

```
override func start() {
  if isCancelled {
    state = .finished
    return
  }

  main()
  state = .executing
}
```

And then override the `cancel` method:

```
override func cancel() {
  state = .finished
}
```

You're probably thinking, "But `cancel` is already part of the base class," and you'd be right. However, the base class doesn't know anything about the states that you defined and thus you need to update the proper property.

It's important that when an operation is canceled, the `isExecuting` property becomes `false` and the `isFinished` property becomes `true`. Your base class now handles those requirements by evaluating the `state` property appropriately.

After the above changes, it's now possible for your operation to be canceled before it's started.

Canceling a running operation

To support the cancellation of a running operation, you'll need to sprinkle checks for `isCancelled` throughout the operation's code. Obviously, more complex operations are going to be able to check in more places than something simple like your `NetworkImageOperation`.

Open up **NetworkImageOperation.swift** and in `main`, add a new `guard` statement right after the `defer`:

```
guard !self.isCancelled else { return }
```

For the network download, there's really no other location that you'd need to make the check. In fact, it's questionable whether or not you'd really want to make the check at all.

You've already spent the time to download the image from the network. Is it better to cancel and return no image, or let the image get created? There's no right or wrong answer. It's simply an architectural decision that you'll have to make based on the requirements of the project.

Next, add a way to cancel the network request while it's in progress. First, add a new property to the class:

```
private var task: URLSessionDataTask?
```

This will hold the network task while it's being run. Next, in `main`, replace the line where you create the data task with the following line:

```
task = URLSession.shared.dataTask(with: url) { [weak self]
```

Next, remove the call to `resume` at the end of that block. Instead, you're going to call `resume` on the `task` by adding the following at the end of `main`:

```
task?.resume()
```

Finally, you need to override `cancel` to make sure the task is canceled. Add the following method to the class:

```
override func cancel() {
  super.cancel()
  task?.cancel()
}
```

Now, the downloading can be canceled at any time.

It's time to allow canceling in **TiltShiftOperation.swift**. You'll probably want to place two checks in the `main` method. Just before setting the `fromRect` variable, make the first check:

```
guard !isCancelled else { return }
```

Once you've applied the tilt shift and grabbed the output image, that's a good point to stop before you then create the `CGImage`.

Next, just before setting `outputImage`, add the same check again.

```
guard !isCancelled else { return }
```

You've got a `CGImage` at this point but there's no value in converting it to a `UIImage` if a cancellation was request. Some would argue for a third check, right after creation the `outputImage`, but that leads to the same question posed during the network operation: You've already done all the work, do you really want to stop now?

Now that you have a way to cancel the operation, it's time to hook this up to the table view so that the operations for a cell are canceled when the user scrolls away.

Open up **TiltShiftTableViewController.swift** and add the following property to the class:

```
private var operations: [IndexPath: [Operation]] = [:]
```

This is a dictionary that will hold the operations for a specific cell (both the downloading and tilt shifting). You need to store the operations because cancelling is a method on the actual operation, so you need a way to grab it to cancel it.

Add the following lines to `tableView(_:cellForRowAt:)`, right before `return cell`, to store the operations:

```
if let existingOperations = operations[indexPath] {
  for operation in existingOperations {
    operation.cancel()
  }
}

operations[indexPath] = [tiltShiftOp, downloadOp]
```

If an operation for this index path already exists, cancel it, and store the new operations for that index path.

Next, add the following method to the end of the class:

```
override func tableView(
  _ tableView: UITableView,
  didEndDisplaying cell: UITableViewCell,
  forRowAt indexPath: IndexPath) {

  if let operations = operations[indexPath] {
    for operation in operations {
      operation.cancel()
    }
  }
}
```

This implements a table view delegate method that gets called when a cell goes offscreen. At that point, you'll cancel the operations for that cell, making sure the phone's resources are only used for visible cells.

Build and run the app.

You probably won't notice a big difference, but now when you quickly scroll trough the table view the app won't load and filter an image for each cell that quickly went past the screen. The downloads for the ones that went offscreen are cancelled, saving the user's network traffic and battery life and making your app run faster.

Where to go from here?

Having to cancel an operation doesn't necessarily mean something negative happened. At times you cancel an operation because it's simply no longer necessary. If you're working with a `UITableView` or a `UICollectionView` you may want to implement the prefetching delegate methods introduced in iOS 10. When the controller is going to prefetch, you'd create the operations. If the controller cancels prefetching, you'd cancel the operations as well.

Section IV: Real-Life Concurrency

To wrap up this book, This section will be dedicated to show you how all of the knowledge you've accumulated throughout this book could be used for some real-life purposes.

In this section you'll take a deeper dive into a common case where concurrency plays a huge role — Core Data, as well as learn about Apple's Thread Sanitizer as a great tool to debug and resolve concurrency issues and confusions.

Chapter 11: Core Data: Core Data works well with concurrency as long as you keep a few simple rules in mind. This chapter will teach you how to make sure that your Core Data app is able to handle concurrency properly.

Chapter 12: Thread Sanitizer: Data races occur when multiple threads access the same memory without synchronization and at least one access is a write. This chapter will teach you how to use Apple's Thread Sanitizer to detect data races.

Chapter 11: Core Data

This is an early access release of this book. Stay tuned for this chapter in a future release!

Core Data works well with concurrency as long as you keep a few simple rules in mind. This chapter will teach you how to make sure that your Core Data app is able to handle concurrency properly.

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Dive into Concurrency in Cocoa apps!

Concurrency is the concept of multiple things, or pieces of work, running at the same time. With the addition of CPU cores in our devices, knowing how to properly utilize your customer's hardware to the maximum is absolutely a must. However, proper concurrency in Cocoa apps is one of the lesser-known topics that every developer wants to (and should) understand properly, but is usually intimidated by.

This is where Concurrency by Tutorials comes to the rescue! In this book, you'll learn everything there is to know about how to write performant and concurrent code for your Cocoa apps.

Who This Book Is For

This book is for intermediate iOS developers who already know the basics of iOS and Swift development but want to learn how to make their app efficiently perform tasks without affecting performance, and how to properly divide work to utilize hardware to the fullest extent.

Topics Covered in Concurrency by Tutorials:

- **What & Why:** Learn what is Concurrency and why would you even want to utilize it in your apps?
- **Grand Central Dispatch:** Learn about Apple's implementation of C's libdispatch, also known as GCD, it's one of the simplest ways to queue up tasks to be run in parallel.
- **Operations & Operation Queues:** When GCD doesn't quite cut it, you'll learn how to further customize and reuse your concurrent work using Operations and Operation Queues.
- **Common Concurrency Problems:** Learn about some of the problems you could face while developing concurrent applications, such as Race Conditions, Deadlocks, and more.
- **Threads & Thread Sanitizer:** Understand various threading-related concepts and how these connect to the knowledge you've accumulated throughout this book. You'll also learn how to use Thread Sanitizer to ease your debugging when things go wrong.

This book is sure to make you a pro in building concurrent and performant appllications, and finally understanding how these lower-level APIs work to the fullest, pushing your app to the top!

About Scott Grosch

Scott Grosch has been involved with iOS app development since the first release of the public SDK from Apple, and spends his days as a Solutions Architect at a Fortune 500 company in the Pacific Northwest.