

Using Combine

Joseph Heck

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About This Book

Supporting this effort

This is a work in progress.

The book is being made available at no cost. The content for this book, including sample code and tests is available on GitHub at <https://github.com/heckj/swiftui-notes>.

If you want to report a problem (typo, grammar, or technical fault), please [Open an issue](#) in GitHub. If you are so inclined, feel free to fork the project and send me [pull requests](#) with updates or corrections.

I am working through how to make it available to the widest audience while also generating a small amount of money to support the creation of this book, from technical authoring and review through copy editing.

Author Bio

Joe Heck has broad software engineering development and management experience crossing startups and large companies. He works across all the layers of solutions, from architecture, development, validation, deployment, and operations.

Joe has developed projects ranging from mobile and desktop application development to cloud-based distributed systems. He has established teams, development processes, CI and CD pipelines, and developed validation and operational automation. Joe also builds and mentors people to learn, build, validate, deploy and run software services and infrastructure.

Joe works extensively with and in open source, contributing and collaborating with a wide variety of open source projects. He writes online across a variety of topics at <https://rhonabwy.com/>.



Where to get this book

The contents of this book are available as [HTML](#), [PDF](#), and [ePub](#).

There is also an Xcode project ([SwiftUI-Notes.xcodeproj](#)) [available on GitHub](#). The project includes tests, snippets, and trials used in creating this work.

Download the project

The project associated with this book requires Xcode v11 (which has been released as beta3 as of this writing) and MacOS 10.14 or later.



Welcome to Xcode

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	FlyoverKit		Apr 2, 2019, 10:13 AM	SvenTiigi
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	Guise		Dec 5, 2018, 1:37 PM	ollieatkinson
	InverseKinematics		May 14, 2019, 9:23 AM	roberthein
	ios-snapshot-test-case		Jun 3, 2019, 9:05 AM	uber
	kube-ops-view		Jun 5, 2019, 10:10 AM	hjacobs
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Introduction to Combine

In Apple's words, Combine is:

a declarative Swift API for processing values over time.

Combine is Apple's take on a functional reactive programming library, akin to [RxSwift](#). RxSwift itself is a port of [ReactiveX](#). Apple's framework uses many of the same functional reactive concepts that can be found in other languages and libraries, applying the statically-typed nature of Swift to their solution.



If you are already familiar with RxSwift there is [a pretty good cheat-sheet for translating the specifics between Rx and Combine](#), built and inspired by the data collected at <https://github.com/freak4pc/rxswift-to-combine-cheatsheet>.

Another good one is a post [Combine: Where's the Beef?](#) by Casey Liss describing how Combine maps back to RxSwift and RxCocoa's concepts, and where it is different.

Functional reactive programming

[Functional reactive programming](#), also known as data-flow programming, builds on the concepts of [functional programming](#). Where functional programming applies to lists of elements, functional reactive programming is applied to streams of elements. The kinds of functions in functional programming, such as [map](#), [filter](#), and [reduce](#) all have analogues that can be applied to streams. In addition, functional reactive programming includes functions to split streams, create pipelines of operations to transform the data within a stream, and merge streams.

There are many parts of the systems we program that can be viewed as asynchronous streams of information - events, objects, or pieces of data. Programming practices defined the Observer pattern for watching a single object, getting notified of changes and updates. If you view this over time, these updates make up a stream of objects. Functional reactive programming, or Combine in this case, allows you to create code that describes what happens when getting data in a stream.

You may want to create logic to watch more than one element that is changing. You may also want to include logic that does additional asynchronous operations, some of which may fail. You may also want to change the content of the streams based on timing, or change the timing of the content. Handling the flow of these event streams, the timing, errors when they happen, and coordinating how a system responds to all those events is at the heart of this kind of programming.

A solution based on functional reactive programming is particularly effective when programming user interfaces. Or more generally for creating pipelines that process data from external sources or rely on asynchronous APIs.

Combine specifics

Applying these concepts to a strongly typed language like Swift is part of what Apple has created in

Combine. Combine embeds the concept of back-pressure, which allows the subscriber to control how much information it gets at once and needs to process. In addition, it supports efficient operation with the notion of streams that are cancellable and driven primarily by the subscriber.

Combine is set up to be composed, and includes affordances to integrate existing code to incrementally support adoption.

Combine is supported by a couple of Apple's other frameworks. SwiftUI is the obvious example that has the most attention, with both subscriber and publisher elements. RealityKit also has publishers that you can use to react to events. And Foundation has a number of Combine specific additions including NotificationCenter, URLSession, and Timer as publishers.

Any asynchronous operation API *can* be leveraged with Combine. For example, you could use some of the APIs in the Vision framework, composing data flowing to it, and from it, by leveraging Combine.

In this work, I'm going to call a set of composed operations in Combine a **pipeline**. Pipeline is not a term that Apple is (yet?) using in its documentation.

When to use Combine

Combine fits most naturally when you want to set up a something that is "immediately" reactive to a variety of inputs. User interfaces fit very naturally into this pattern.

The classic examples in functional reactive programming and user interfaces frequently show form validation, where user events such as changing text fields, taps, or mouse-clicks on UI elements make up the data being streamed. Combine takes this quite a bit further, enabling watching of properties, binding to objects, sending and receiving higher level events from UI controls, and supporting integration with almost all of Apple's existing API ecosystem.

Some things you can do with Combine include:

- You can set up pipelines to enable the button for submission only when values entered into the fields are valid.
- A pipeline can also do asynchronous actions (such as checking with a network service) and using the values returned to choose how and what to update within a view.
- Pipelines can also be used to react to a user typing dynamically into a text field and updating the user interface view based on what they're typing.

Combine is not limited to user interfaces. Any sequence of asynchronous operations can be effective as a pipeline, especially when the results of each step flow to the next step. An example of such might be a series of network service requests, followed by decoding the results.

Combine can also be used to define how to handle errors from asynchronous operations. Combine supports doing this by setting up pipelines and merging them together. One of Apple's examples with Combine include a pipeline to fall back to getting a lower-resolution image from a network service when the local network is constrained.

Many of the pipelines you create with Combine will only be a few operations. Even with just a few operations, Combine can still make it much easier to view and understand what's happening when you compose a pipeline.

Apple's Documentation



The [online documentation for Combine](https://developer.apple.com/documentation/combine) can be found at <https://developer.apple.com/documentation/combine>. Apple's developer documentation is hosted at <https://developer.apple.com/documentation/>.

WWDC content

Apple provides video, slides, and some sample code in sessions it's developer conferences. Details on Combine are primarily from [WWDC 2019](#).

A number of these introduce and go into some depth on Combine:

- [Introducing Combine](#)
 - [PDF of presentation notes](#)
- [Combine in Practice](#)
 - [PDF of presentation notes](#)

A number of additional WWDC19 sessions mention Combine:

- [Modern Swift API Design](#)
- [Data Flow Through SwiftUI](#)
- [Introducing Combine and Advances in Foundation](#)
- [Advances in Networking, Part 1](#)
- [Building Collaborative AR Experiences](#)
- [Expanding the Sensory Experience with Core Haptics](#)

Core Concepts

Publisher, Subscriber

Two key concepts, described in swift with protocols, are [publisher](#) and [subscriber](#).

A publisher provides data. It is described with two associated types: one for Output and one for Failure. A subscriber requests data. It is also described with two associated types, one for Input and one for Failure. When you connect a subscriber to a publisher, both types must match: Output to Input, and Failure to Failure. You can view this as a series of operations on two types in parallel.

Publisher source	Subscriber
+-----+	+-----+
<Output> --> <Input>	
<Failure> --> <Failure>	
+-----+	+-----+

Operators are classes that adopt both the [Subscriber protocol](#) and [Publisher protocol](#). They support subscribing to a publisher, and sending results to any subscribers.

You can create chains of these together, for processing, reacting, and transforming the data provided by a publisher, and requested by the subscriber.

I'm calling these composed sequences **pipelines**.

Publisher source	Operator	Subscriber
+-----+	+-----+	+-----+
<Output> --> <Input>	map <Output> --> <Input>	
<Failure> --> <Failure>	function <Failure> --> <Failure>	
+-----+	+-----+	+-----+

Operators can be used to transform types - both the Output and Failure type. Operators may also split or duplicate streams, or merge streams together. Operators must always be aligned by the combination of Output/Failure types. The compiler will enforce the matching types, so getting it wrong will result in a compiler error (and sometimes a useful *fixit* snippet.)

A simple pipeline, using Combine, might look like:

```

let _ = Just(5) ①
  .map { value -> String in ②
    // do something with the incoming value here
    // and return a string
    return "a string"
  }
  .sink { receivedValue in ③
    // sink is the subscriber and terminates the pipeline
    print("The end result was \(receivedValue)")
  }

```

- ① The pipeline starts with the publisher **Just**, which responds with the value that its defined with (in this case, the Integer 5). The output type is <Integer>, and the failure type is <Never>.
- ② the pipeline then has a **map** operator, which is transforming the value. In this example it is ignoring the published input and returning a string. This is also transforming the output type to <String>, and leaving the failure type still set as <Never>
- ③ The pipeline then ends with a **sink** subscriber.

When you are viewing a pipeline, or creating one, you can think of it as a sequence of operations linked by the types. This pattern will come in handy when you start constructing your own pipelines. When creating pipelines, you are often selecting operators to help you transform the types, to achieve your end goal. That end goal might be enabling or disabling a user interface element, or it might be retrieving some piece of data to be displayed.

Many combine operators are specifically created to help with these transformations. Some operators require conformance to an input or failure type. Other operators may change either or both the failure and output types. For example, there are a number of operators that have a similar operator prefixed with **try**, which indicates they return an <Error> failure type.

An example of this is **map** and **tryMap**. The **map** operator allows for any combination of Output and Failure type and passes them through. **tryMap** accepts any Input, Failure types, and allows any Output type, but will always output an <Error> failure type.

Operators like **map** allow you to define the output type being returned by inferring the type based on what you return in a closure provided to the operator. In the example above, the **map** operator is returning a String output type since that it what the closure returns.

To illustrate the the example of changing types more concretely, we expand upon the logic to use the values being passed. This example still starts with a publisher providing the types <Int>, <Never> and end with a subscription taking the types <String>, <Never>.

```

let _ = Just(5) ①
  .map { value -> String in ②
    switch value {
    case _ where value < 1:
      return "none"
    case _ where value == 1:
      return "one"
    case _ where value == 2:
      return "couple"
    case _ where value == 3:
      return "few"
    case _ where value > 8:
      return "many"
    default:
      return "some"
    }
  }
  .sink { receivedValue in ③
    print("The end result was \(receivedValue)")
  }

```

- ① Just is a publisher that creates an `<Int>`, `<Never>` type combination, provides a single value and then completes.
- ② the closure provided to the `.map()` function takes in an `<Int>` and transforms it into a `<String>`. Since the failure type of `<Never>` is not changed, it is passed through.
- ③ `sink`, the subscriber, receives the `<String>`, `<Never>` combination.

When you are creating pipelines in Xcode and don't match the types, the error message from Xcode may include a helpful *fixit*. In some cases, such as the example above, the compiler is unable to infer the return types of closure provided to `map` without specifying the return type. Xcode (11 beta 2 and beta 3) displays this as the error message: `Unable to infer complex closure return type; add explicit type to disambiguate`. In the example above, we explicitly specified the type being returned with the line `value -> String in`.

You can view Combine publishers, operators, and subscribers as having two parallel types that both need to be aligned - one for the functional case and one for the error case. Designing your pipeline is frequently choosing how to convert one or both of those types and the associated data with it.

More examples, and some common tasks, are detailed in the [section on patterns](#).

Lifecycle of Publishers and Subscribers

The data flow in Combine is driven by, and starts from, the subscriber. This is how Combine supports the concept of back pressure.

Internally, Combine supports this with the enumeration [Demand](#). When a subscriber is communicating with a publisher, it requests data based on demand. This request is what drives calling all the closures up the composed pipeline.

Because subscribers drive the closure execution, it also allows Combine to support cancellation. Cancellation can be triggered by the subscriber.

This is all enabled by subscribers and publishers communicating in a well defined sequence, or lifecycle.

1. When the subscriber is attached to a publisher, it starts with a call to `.subscribe(Subscriber)`.
2. The publisher in turn acknowledges the subscription calling `receive(subscription)`.
 - After the subscription has been acknowledged, the subscriber requests N values with `request(_ : Demand)`.
 - The publisher may then (as it has values) sending N (or fewer) values: `receive(_ : Input)`. A publisher should never send **more** than the demand requested.
 - Also after the subscription has been acknowledged, the subscriber can send a [cancellation](#) with `.cancel()`
3. A publisher may optionally send [completion](#): `receive(completion:)` which is also how errors are propagated.

Publishers

The publisher is the provider of data. The [publisher protocol](#) has a strict contract returning values when asked from subscribers, and possibly terminating with an explicit completion enumeration.

[Just](#) and [Future](#) are extremely common sources to start your own publisher from a value or function. Combine provides a number of additional convenience publishers:

Just	Future	Published
Publishers.Once	Publishers.Optional	Publishers.Sequence
Publishers.Empty	Publishers.Fail	Publishers.Deferred

A number of Apple APIs outside of Combine provide publishers as well.

- SwiftUI provides `@ObjectBinding` which can be used to create a publisher.
- Foundation
 - [URLSession.dataTaskPublisher](#)
 - `.publisher` on KVO instance

- `NotificationCenter .publisher`
- `Timer .publish` and `Timer.TimerPublisher`
- `RealityKit .Scene .publisher()`

Operators

Operators are a convenient name for a number of pre-built functions that are included under Publisher in Apple's reference documentation. These functions are all meant to be composed into pipelines. Many will accept one or more closures from the developer to define the business logic of the operator, while maintaining the adherence to the publisher/subscriber lifecycle.

Some operators support bringing together outputs from different pipelines, or splitting to send to multiple subscribers. Operators may also have constraints on the types they will operate on. Operators can also help with error handling and retry logic, buffering and prefetch, controlling timing, and supporting debugging.

Mapping elements		
<code>scan</code>	<code>tryScan</code>	<code>setFailureType</code>
<code>map</code>	<code>tryMap</code>	<code>flatMap</code>

Filtering elements		
<code>compactMap</code>	<code>tryCompactMap</code>	<code>replaceEmpty</code>
<code>filter</code>	<code>tryFilter</code>	<code>replaceError</code>
<code>removeDuplicates</code>	<code>tryRemoveDuplicates</code>	

Reducing elements		
<code>collect</code>	<code>collectByCount</code>	<code>collectByTime</code>
<code>reduce</code>	<code>tryReduce</code>	<code>ignoreOutput</code>

Mathematic operations on elements		
<code>comparison</code>	<code>tryComparison</code>	<code>count</code>

Applying matching criteria to elements		
<code>allSatisfy</code>	<code>tryAllSatisfy</code>	<code>contains</code>
<code>containsWhere</code>	<code>tryContainsWhere</code>	

Applying sequence operations to elements		
<code>firstWhere</code>	<code>tryFirstWhere</code>	<code>first</code>
<code>lastWhere</code>	<code>tryLastWhere</code>	<code>last</code>
<code>dropWhile</code>	<code>tryDropWhile</code>	<code>dropUntilOutput</code>
<code>concatenate</code>	<code>drop</code>	<code>prefixUntilOutput</code>

prefixWhile	tryPrefixWhile	output
-----------------------------	--------------------------------	------------------------

Combining elements from multiple publishers		
combineLatest	tryCombineLatest	merge
zip		

Handling errors		
catch	tryCatch	assertNoFailure
retry	mapError	

Adapting publisher types		
switchToLatest	eraseToAnyPublisher	

Controlling timing		
debounce	delay	measureInterval
throttle	timeout	

Encoding and decoding		
encode	decode	

Working with multiple subscribers		
multicast		

Debugging		
breakpoint	handleEvents	print

Subjects

Subjects are a special case of publisher that also adhere to the [subject](#) protocol. This protocol requires subjects to have a [.send\(\)](#) method to allow the developer to send specific values to a subscriber (or pipeline).

Subjects can be used to "inject" values into a stream, by calling the subject's [.send\(\)](#) method. This is useful for integrating existing imperative code with Combine.

A subject can also broadcast values to multiple subscribers. If multiple subscribers are connected to a subject, it will fan out values to the multiple subscribers when [send\(\)](#) is invoked.

There are two built-in subjects with Combine: [currentValueSubject](#) and [PassthroughSubject](#). They act similarly, the primary difference being [currentValueSubject](#) remembers and provides an initial state value for any subscribers, where [passthroughSubject](#) does not. Both will provide updated values to any subscribers when [.send\(\)](#) is invoked.

Both `CurrentValueSubject` and `PassthroughSubject` are also useful for creating publishers from objects conforming to the `BindableObject` protocol within SwiftUI.

Subscribers

While `subscriber` is the protocol used to receive data throughout a pipeline, *the Subscriber* typically refers to the end of a pipeline.

There are two subscribers built-in to Combine: `assign` and `sink`.

Subscribers can support cancellation, which terminates a subscription and shuts down all the stream processing prior to any Completion sent by the publisher. Both `Assign` and `Sink` conform to the `cancellable` protocol.

`assign` applies values passed down from the publisher to an object defined by a keypath. The keypath is set when the pipeline is created. An example of this in swift might look like:

```
.assign(to: \.isEnabled, on: signupButton)
```

`sink` accepts a closure that receives any resulting values from the publisher. This allows the developer to terminate a pipeline with their own code. This subscriber is also extremely helpful when writing unit tests to validate either publishers or pipelines. An example of this in swift might look like:

```
.sink { receivedValue in
    print("The end result was \(String(describing: receivedValue))")
}
```

Most other subscribers are part of other Apple frameworks. For example, nearly every control in SwiftUI can act as a subscriber. The `.onReceive(publisher)` function is used on SwiftUI views to act as a subscriber, taking a closure akin to `.sink()` that can manipulate `@State` or `@Bindings` within SwiftUI.

An example of that in swift might look like:

```
struct MyView : View {

    @State private var currentStatusValue = "ok"
    var body: some View {
        Text("Current status: \(currentStatusValue)")
    }
    .onReceive(MyPublisher.currentStatusPublisher) { newStatus in
        currentStatusValue = newStatus
    }
}
```

For any type of UI object (UIKit, AppKit, or SwiftUI), `.assign` can be used with pipelines to manipulate properties.

When you are storing a reference to your own subscriber in order to clean up later, you generally want a reference to cancel the subscription. `AnyCancellable` provides a type-erased reference that converts any subscriber to the type `AnyCancellable`, allowing the use of `.cancel()` on that reference, but not access to the subscription itself (which could, for instance, request more data).

Swift types and exposing pipelines or subscribers

When you compose pipelines within swift, the chaining is interpreted as nesting generic types to the compiler. If you expose a pipeline as a publisher, subscriber, or subject the exposed type can be exceptionally complex.

For example, if you created a publisher from a `PassthroughSubject` such as:

```
let x = PassthroughSubject<String, Never>()
    .flatMap { name in
        return Future<String, Error> { promise in
            promise(.success(""))
        }.catch { _ in
            Just("No user found")
        }.map { result in
            return "\(result) foo"
        }
    }
```

The resulting type would reflect that composition:

```
Publishers.FlatMap<Publishers.Map<Publishers.Catch<Future<String, Error>, Just<String>>, String>, PassthroughSubject<String, Never>>
```

When you want to expose the code, all of that composition detail can be very distracting and make your publisher, subject, or subscriber) harder to use. To clean up that interface, and provide a nice API boundary, the three major protocols all support methods that do type erasure. This cleans up the exposed type to a simpler generic form.

These three methods are:

- `.eraseToAnyPublisher()`
- `.eraseToAnySubscriber()`
- `.eraseToAnySubject()`

If you updated the above code to add `.eraseToAnyPublisher()` at the end of the pipeline:

```

let x = PassthroughSubject<String, Never>()
    .flatMap { name in
        return Future<String, Error> { promise in
            promise(.success(""))
        }.catch { _ in
            Just("No user found")
        }.map { result in
            return "\\(result) foo"
        }
    }
}.eraseToAnyPublisher()

```

The resulting type would simplify to:

```
AnyPublisher<String, Never>
```

Pipelines and threads

Combine is not just a single threaded construct. Combine allows for publishers to specify the scheduler used when either receiving from an upstream publisher (in the case of operators), or when sending to a downstream subscriber. This is critical when working with a subscriber that updates UI elements, as that should always be called on the main thread.

You may see this in code as an operator, for example:

```
.receive(on: RunLoop.main)
```

Patterns and Recipes

Included are a series of patterns and examples of Publishers, Subscribers, and pipelines. These examples are meant to illustrate how to use the Combine framework to accomplish various tasks.



Since this is a work in progress: if you have a suggestion for a pattern or recipe, I'm happy to consider it.

Please [Open an issue](#) in GitHub to request something.

Creating a subscriber with sink

Goal

- To receive the output, and the errors or completion messages, generated from a publisher or through a pipeline, you can create a subscriber with `sink`.

References

- [sink](#)

See also

- [Creating a subscriber with assign](#)
- [Testing a publisher with XCTestExpectation](#)
- [Testing a subscriber with a PassthroughSubject](#)

Code and explanation

Sink creates an all-purpose subscriber to capture or react the data from a Combine pipeline, while also supporting cancellation and the [publisher subscriber lifecycle](#).

simple sink

```
let cancellablePipeline = publishingSource.sink { someValue in ①
    // do what you want with the resulting value passed down
    // be aware that depending on the data type being returned, you may get this
    closure invoked
    // multiple times.
    print(".sink() received \(someValue)")
}
```

- ① The simple version of a sink is very compact, with a single trailing closure that only receives data when presented through the pipeline.

```
let cancellablePipeline = publishingSource.sink(receiveCompletion: { completion in ❶
    switch completion {
    case .finished:
        // no associated data, but you can react to knowing the request has been
        completed
        break
    case .failure(let anError):
        // do what you want with the error details, presenting, logging, or hiding as
        appropriate
        print("received the error: ", anError)
        break
    }
}, receiveValue: { someValue in
    // do what you want with the resulting value passed down
    // be aware that depending on the data type being returned, you may get this
    closure invoked
    // multiple times.
    print(".sink() received \(someValue)")
})

cancellablePipeline.cancel() ❷
```

- ❶ Sinks are created by chaining the code from a publisher or pipeline, and terminate the pipeline. When the sink is created or invoked on a publisher, it implicitly starts [the lifecycle](#) with the [subscribe](#) and will request unlimited data.
- ❷ Creating a sink is cancellable subscriber, so at any time you can take the reference that terminated with sink and invoke [.cancel\(\)](#) on it to invalidate and shut down the pipeline.

Creating a subscriber with assign

Goal

- To use the results of a pipeline to set a value, often a property on a user interface view or control, but any KVO compliant object can be the target

References

- [assign](#)
- [receive](#)

See also

- [Creating a subscriber with sink](#)

Code and explanation

Assign is a subscriber that's specifically designed to apply data from a publisher or pipeline into a property, updating that property whenever it receives data. Like sink, it activates when created and requests an unlimited data updates. Assign requires the failure type to be specified as `<Never>`, so if your pipeline could fail (such as using an operator like tryMap) you will need to [convert or handle the failure cases](#) before using `.assign`.

simple sink

```
let cancellablePipeline = publishingSource ①
    .receive(on: RunLoop.main) ②
    .assign(to: \.isEnabled, on: yourButton) ③

cancellablePipeline.cancel() ④
```

- ① `.assign` is typically chained onto a publisher when you create it, and the return value is cancellable.
- ② If `.assign` is being used to update a user interface element, you need to make sure that it is being updated on the main thread. This call makes sure the subscriber is received on the main thread.
- ③ Assign references the property being updated using a [key path](#), and a reference to the object being updated.
- ④ At any time you can terminate and invalidate pipelines with `cancel()`. Frequently, you cancel the pipelines when you deactivate the objects (such as a viewController) that are getting updated from the pipeline.

Making a network request with `dataTaskPublisher`

Goal

- One of the common use cases is requesting JSON data from a URL and decoding it.

References

- [URLSession.dataTaskPublisher](#)
- [map](#)
- [decode](#)
- [sink](#)
- [subscribe](#)

See also

- [Stricter request processing with dataTaskPublisher](#)
- [Using catch to handle errors in a one-shot pipeline](#)
- [Retrying in the event of a temporary failure](#)

Code and explanation

This can be readily accomplished with Combine using [URLSession.dataTaskPublisher](#) followed by a series of operators that process the data. Minimally, this is [map](#) and [decode](#) before going into your subscriber.

[dataTaskPublisher](#) on [URLSession](#).

The simplest case of using this might be:


```

let myURL = URL(string: "https://postman-echo.com/time/valid?timestamp=2016-10-10")
// checks the validity of a timestamp - this one returns {"valid":true}
// matching the data structure returned from https://postman-echo.com/time/valid
fileprivate struct PostmanEchoTimeStampCheckResponse: Decodable, Hashable { ❶
    let valid: Bool
}

let remoteDataPublisher = URLSession.shared.dataTaskPublisher(for: myURL!) ❷
// the dataTaskPublisher output combination is (data: Data, response: URLResponse)
.map { $0.data } ❸
.decode(type: PostmanEchoTimeStampCheckResponse.self, decoder: JSONDecoder()) ❹

let cancellableSink = remoteDataPublisher.sink
    .sink(receiveCompletion: { completion in
        print(".sink() received the completion", String(describing: completion))
        switch completion {
            case .finished: ❺
                break
            case .failure(let anError): ❻
                print("received error: ", anError)
        }
    }, receiveValue: { someValue in ❼
        print(".sink() received \(someValue)")
    })

```

- ❶ Commonly you'll have a struct defined that supports at least [Decodable](#) (if not the full [Codable protocol](#)). This struct can be defined to only pull the pieces you're interested in from the JSON provided over the network.
- ❷ `dataTaskPublisher` is instantiated from `URLSession`. You can configure your own options on `URLSession`, or use the general shared session as you require.
- ❸ The data that is returned down the pipeline is a tuple: `(data: Data, response: URLResponse)`. The `map` operator is used to get the data and drop the URL response, returning just `Data` down the pipeline.
- ❹ `decode` is used to load the data and attempt to transform it into the struct defined. Decode can throw an error itself if the decode fails. If it succeeds, the object passed down the pipeline will be the struct from the JSON data.
- ❺ If the decoding happened without errors, the finished completion will be triggered, and the value will also be passed to the `receiveValue` closure.
- ❻ If the a failure happened (either with the original network request or the decoding), the error will be passed into with the `.failure` completion.
- ❼ Only if the data succeeded with request and decoding will this closure get invoked, and the data format received will be an instance of the struct `PostmanEchoTimeStampCheckResponse`.

Stricter request processing with dataTaskPublisher

Goal

- When URLSession makes a connection, it only reports an error if the remote server doesn't respond. You may want to consider a number of responses, based on status code, to be errors. To accomplish this, you can use tryMap to inspect the http response and throw an error in the pipeline.

References

- [URLSession.dataTaskPublisher](#)
- [tryMap](#)
- [decode](#)
- [sink](#)
- [subscribe](#)

See also

- [Making a network request with dataTaskPublisher](#)
- [Using catch to handle errors in a one-shot pipeline](#)
- [Retrying in the event of a temporary failure](#)

Code and explanation

To have more control over what is considered a failure in the URL response, use a `tryMap` operator on the tuple response from dataTaskPublisher. Since dataTaskPublisher returns both the response data and the URLResponse into the pipeline, you can immediately inspect the response and throw an error of your own if desired.

An example of that might look like:

```

let myURL = URL(string: "https://postman-echo.com/time/valid?timestamp=2016-10-10")
// checks the validity of a timestamp - this one returns {"valid":true}
// matching the data structure returned from https://postman-echo.com/time/valid
fileprivate struct PostmanEchoTimeStampCheckResponse: Decodable, Hashable {
    let valid: Bool
}

enum testFailureCondition: Error {
    case invalidServerResponse
}

let remoteDataPublisher = URLSession.shared.dataTaskPublisher(for: myURL!)
    .tryMap { data, response -> Data in ①
        guard let httpResponse = response as? HTTPURLResponse, ②
            httpResponse.statusCode == 200 else { ③
            throw testFailureCondition.invalidServerResponse ④
        }
        return data ⑤
    }
    .decode(type: PostmanEchoTimeStampCheckResponse.self, decoder: JSONDecoder())

let cancellableSink = remoteDataPublisher.sink
    .sink(receiveCompletion: { completion in
        print(".sink() received the completion", String(describing: completion))
        switch completion {
            case .finished:
                break
            case .failure(let anError):
                print("received error: ", anError)
        }
    }, receiveValue: { someValue in
        print(".sink() received \(someValue)")
    })

```

Where the [previous pattern](#) used a [map](#) operator, this uses `tryMap`, which allows us to identify and throw errors in the pipeline based on what was returned.

- ① `tryMap` still gets the tuple of `(data: Data, response: URLResponse)`, and is defined here as returning just the type of `Data` down the pipeline.
- ② Within the closure for `tryMap`, we can cast the response to `HTTPURLResponse` and dig deeper into it, including looking at the specific status code.
- ③ In this case, we want to consider **anything** other than a 200 response code as a failure. `HTTPURLResponse.status_code` is an `Int` type, so you could also have logic such as `httpResponse.statusCode > 300`.
- ④ If the predicates aren't met, then we can throw an instance of an error of our choosing, `invalidServerResponse` in this case.
- ⑤ If no error has occurred, then we simply pass down `Data` for further processing.

When an error is triggered on the pipeline, a `.failure` completion is sent with the error encapsulated within it, regardless of where it happened in the pipeline.

Error Handling

The examples above expected that the subscriber would handle the error conditions, if they occurred. However, you are not always able to control the subscriber - as might be the case if you're using SwiftUI view properties as the subscriber, and you're providing the publisher. In these cases, you need to build your pipeline so that the output types match the subscriber types.

For example, if you are working with SwiftUI and the you want to use `.assign` to set the `isEnabled` property on a button, the subscriber will have a few requirements:

1. the subscriber should match the type output of `<Bool>`, `<Never>`
2. the subscriber should be called on the main thread

With a publisher that can throw an error (such as `dataTaskPublisher`), you need to construct a pipeline to convert the output type, but also handle the error within the pipeline to match a failure type of `<Never>`.

How you handle the errors within a pipeline is very dependent on how the pipeline is working. If the pipeline is set up to return a single result and terminate, continue to [Using catch to handle errors in a one-shot pipeline](#). If the pipeline is set up to continually update, the error handling needs to be a little more complex. Jump ahead to [Using flatMap with catch to handle errors](#).

Verifying a failure hasn't happened using `assertNoFailure`

Goal

- Verify no error has occurred within a pipeline

References

- [assertNoFailure](#)

See also

- << link to other patterns >>

Code and explanation

Useful in testing invariants in pipelines, the `assertNoFailure` operator also converts the failure type to `<Never>`. The operator will cause the application to terminate (and tests to crash to a debugger) if the assertion is triggered.

This is useful for verifying the invariant of having dealt with an error. If you are sure you handled the errors and need to map a pipeline which technically can generate a failure type of `<Error>` to a subscriber that requires a failure type of `<Never>`.

It is far more likely that you want to handle the error with and not have the application terminate. Look forward to [Using catch to handle errors in a one-shot pipeline](#) and [Using flatMap with catch to handle errors](#) for patterns of how to provide logic to handle errors in a pipeline.

Using catch to handle errors in a one-shot pipeline

Goal

- If you need to handle a failure within a pipeline, for example before using the `assign` operator or another operator that requires the failure type to be `<Never>`, you can use `catch` to provide the appropriate logic.

References

- [catch](#)
- [Just](#)

See also

- [Retrying in the event of a temporary failure](#)
- [Using flatMap with catch to handle errors](#)
- [Requesting data from an alternate URL when the network is constrained](#)

Code and explanation

`catch` handles errors by replacing the upstream publisher with another publisher that you provide as a return in a closure.



Be aware that this effectively terminates the earlier portion of the pipeline. If you're using a one-shot publisher (one that doesn't create more than a single event), then this is fine.

For example, `dataTaskPublisher` is a one-shot publisher and you might use `catch` with it to ensure that you get a response, returning a placeholder in the event of an error. Extending our previous example to provide a default response:

```
struct IPInfo: Codable {
    // matching the data structure returned from ip.jsontest.com
    var ip: String
}

let myURL = URL(string: "http://ip.jsontest.com")
// NOTE(heckj): you'll need to enable insecure downloads in your Info.plist for this
// example
// since the URL scheme is 'http'

let remoteDataPublisher = URLSession.shared.dataTaskPublisher(for: myURL!)
// the dataTaskPublisher output combination is (data: Data, response: URLResponse)
.map({ (inputTuple) -> Data in
    return inputTuple.data
})
.decode(type: IPInfo.self, decoder: JSONDecoder()) ①
.catch { err in ②
    return Publishers.Just(IPInfo(ip: "8.8.8.8"))③
}
.eraseToAnyPublisher()
```

- ① Often, a catch operator will be placed after several operators that could fail, in order to provide a fallback or placeholder in the event that any of the possible previous operations failed.
- ② When using catch, you get the error type in and can inspect it to choose how you provide a response.
- ③ The Just publisher is frequently used to either start another one-shot pipeline or to directly provide a placeholder response in the event of failure.

A possible problem with this technique is that if the original publisher generates more values to which you wish to react, the original pipeline has been ended. If you are creating a pipeline that reacts to a `@Published` property, then after any failed value that activates the catch operator, the pipeline will cease to react further. See [catch](#) for more illustration and examples of how this works.

If you want to continue to respond to errors and handle them, see [Using flatMap with catch to handle errors](#) for an example of how to do that using `flatMap`

Retrying in the event of a temporary failure

Goal

- The `retry` operator can be included in a pipeline to retry a subscription when a `.failure` completion occurs.

References

- [catch](#)
- [retry](#)

See also

- [Using catch to handle errors in a one-shot pipeline](#)
- [Using flatMap with catch to handle errors](#)

Code and explanation

When you specify this operator in a pipeline and it receives a subscription, it first tries to request a subscription from its upstream publisher. If the response to that subscription fails, then it will retry the subscription to the same publisher.

The retry operator can be specified with a number of retries to attempt. If no number of retries is specified, it will attempt to retry indefinitely until it receives a `.finished` completion from its subscriber. If the number of retries is specified and all requests fail, then the `.failure` completion is passed down to the subscriber of this operator.

In practice, this is mostly commonly desired when attempting to request network resources with an unstable connection. If you use a retry operator, you should add a specific number of retries so that the subscription doesn't effectively get into an infinite loop.

An example of the above example using retry in combination with a delay:

```
let remoteDataPublisher = urlSession.dataTaskPublisher(for: self.mockURL!)
    .delay(for: DispatchQueue.SchedulerTimeType.Stride(integerLiteral: Int.random(in:
1..<5)), scheduler: backgroundQueue) ❶
    .retry(3) ❷
    .tryMap { data, response -> Data in ❸
        guard let httpResponse = response as? HTTPURLResponse,
            httpResponse.statusCode == 200 else {
            throw testFailureCondition.invalidServerResponse
        }
        return data
    }
    .decode(type: PostmanEchoTimeStampCheckResponse.self, decoder: JSONDecoder())
    .subscribe(on: backgroundQueue)
    .eraseToAnyPublisher()
```

- ❶ the delay operator will delay further processing on the pipeline, in this case for a random selection of 1 to 5 seconds. By adding delay here in the pipeline, it will always occur, even if the original request is successful.

- ② `retry` is specified as trying 3 times. If you specify `retry` without any options, it will retry infinitely, and may cause your pipeline to never resolve any values or completions.
- ③ `tryMap` is being used to investigate errors after the `retry` so that `retry` will only re-attempt the request when the site didn't respond.



When using the `retry()` operator with `dataTaskPublisher`, verify that the URL you are requesting isn't going to have negative side effects if requested repeatedly or with a `retry`. Ideally such requests are expected to be idempotent.

Using flatMap with catch to handle errors

Goal

- The `flatMap` operator can be used with `catch` to continue to handle errors on new published values.

References

- [flatMap](#)
- [Just](#)
- [Publishers.Once](#)
- [catch](#)

See also

- [Using catch to handle errors in a one-shot pipeline](#)
- [Retrying in the event of a temporary failure](#)

Code and explanation

The `flatMap` operator is the operator to use in handling errors on a continual flow of events.

You provide a closure to `flatMap` that can read in the value that was provided, and creates a one-shot closure that does the possibly failing work. An example of this is requesting data from a network and then decoding the returned data. You can include a `catch` operator to capture any errors and provide any appropriate value.

This is a perfect mechanism for when you want to maintain updates up an upstream publisher, as it creates one-shot publisher or short pipelines that send a single value and then complete for every incoming value. The completion from the created one-shot publishers terminates in the `flatMap` and isn't passed to downstream subscribers.

An example of this with a `dataTaskPublisher`:

```

let remoteDataPublisher = Just(self.testURL!) ①
    .flatMap { url in ②
        URLSession.shared.dataTaskPublisher(for: url) ③
        .tryMap { data, response -> Data in ④
            guard let httpResponse = response as? HTTPURLResponse,
                httpResponse.statusCode == 200 else {
                throw testFailureCondition.invalidServerResponse
            }
            return data
        }
        .decode(type: PostmanEchoTimeStampCheckResponse.self, decoder: JSONDecoder())
    } ⑤
    .catch { _ in ⑥
        return Just(PostmanEchoTimeStampCheckResponse(valid: false))
    }
    .subscribe(on: self.myBackgroundQueue!)
    .eraseToAnyPublisher()

```

- ① Just starts this publisher as an example by passing in a URL.
- ② flatMap takes the URL as input and the closure goes on to create a one-shot publisher chain.
- ③ dataTaskPublisher uses the input url
- ④ which flows to tryMap to parse for additional errors
- ⑤ and finally decode to attempt to refine the returned data into a local type
- ⑥ if any of these have failed, catch will convert the error into a placeholder sample, in this case an object with a preset `valid = false` property.

Requesting data from an alternate URL when the network is constrained

Goal

- From Apple's WWDC 19 presentation [Advances in Networking, Part 1](#), a sample pattern was provided using `tryCatch` and `tryMap` operators to react to the specific error of having the network be constrained.

References

- [URLSession.dataTaskPublisher](#)
- [tryCatch](#)
- [tryMap](#)

See also

- [Using catch to handle errors in a one-shot pipeline](#)
- [Retrying in the event of a temporary failure](#)

Code and explanation



This sample is originally from the WWDC session. The API and example is evolving with the beta releases of Combine since that presentation. `tryCatch` was missing in the beta2 release, and has returned in beta3.

```
// Generalized Publisher for Adaptive URL Loading
func adaptiveLoader(regularURL: URL, lowDataURL: URL) -> AnyPublisher<Data, Error> {
    var request = URLRequest(url: regularURL) ❶
    request.allowsConstrainedNetworkAccess = false ❷
    return URLSession.shared.dataTaskPublisher(for: request) ❸
        .tryCatch { error -> URLSession.DataTaskPublisher in ❹
            guard error.networkUnavailableReason == .constrained else {
                throw error
            }
            return URLSession.shared.dataTaskPublisher(for: lowDataURL) ❺
        }.tryMap { data, response -> Data in
            guard let httpResponse = response as? HTTPURLResponse, ❻
                httpResponse.status_code == 200 else {
                throw MyNetworkingError.invalidServerResponse
            }
            return data
        }
    .eraseToAnyPublisher() ❼
}
```

This example, from Apple's WWDC, provides a function that takes two URLs - a primary and a fallback. It returns a publisher that will request data and fall back requesting a secondary URL when the network is constrained.

❶ The request starts with an attempt requesting data.

❷ Setting `request.allowsConstrainedNetworkAccess` will cause the `dataTaskPublisher` to error if the

network is constrained.

- ③ Invoke the `dataTaskPublisher` to make the request.
- ④ `tryCatch` is used to capture the immediate error condition and check for a specific error (the constrained network).
- ⑤ If it finds an error, it creates a new one-shot publisher with the fall-back URL.
- ⑥ The resulting publisher can still fail, and `tryMap` can map this a failure by throwing an error on HTTP response codes that map to error conditions
- ⑦ `eraseToAnyPublisher` will do type erasure on the chain of operators so the resulting signature of the `adaptiveLoader` function is of type `AnyPublisher<Data, Error>`

In the sample, if the error returned from the original request wasn't an issue of the network being constrained, it passes on the `.failure` completion down the pipeline. If the error is that the network is constrained, then the `tryCatch` operator creates a new request to an alternate URL.

Declarative UI updates from user input

Goal

- Querying a web based API and returning the data to be displayed in your UI

References

- The Xcode project ViewController with this code is in the github project at [UIKit-Combine/ViewController.swift](#)
- Publishers: [Published](#), [URLSession.dataTaskPublisher](#),
- Operators: [map](#), [switchToLatest](#), [receive](#), [throttle](#), [removeDuplicates](#)
- Subscribers: [assign](#)

See also

- [Using flatMap with catch to handle errors](#)
- [Using catch to handle errors in a one-shot pipeline](#)
- [Stricter request processing with dataTaskPublisher](#)

Code and explanation

One of the primary benefits of a framework like Combine is setting up a declarative structure that defines how an interface will update to user input.

A pattern for integrating UIKit is setting up a variable which will hold a reference to the updated state, and then linking that with existing UIKit or AppKit controls within IBAction.

The sample here is a portion of the code at in a larger ViewController implementation.

This example overlaps with the next pattern [Update the multiple pieces of your interface from a publisher update](#), which builds upon the initial publisher.

```

import UIKit
import Combine

class ViewController: UIViewController {

    @IBOutlet weak var github_id_entry: UITextField! ❶

    var usernameSubscriber: AnyCancellable?

    // username from the github_id_entry field, updated via IBAction
    @Published var username: String = "" ❷

    // github user retrieved from the API publisher. As it's updated, it
    // is "wired" to update UI elements
    @Published private var githubUserData: [GithubAPIUser] = []

    // MARK - Actions

    @IBAction func githubIdChanged(_ sender: UITextField) {
        username = sender.text ?? "" ❸
        print("Set username to ", username)
    }

    override func viewDidLoad() {
        super.viewDidLoad()
        // Do any additional setup after loading the view.

        usernameSubscriber = $username ❹
            .throttle(for: 0.5, scheduler: myBackgroundQueue, latest: true) ❺
            // ^^ scheduler myBackGroundQueue publishes resulting elements
            // into that queue, resulting on this processing moving off the
            // main runloop.
            .removeDuplicates() ❻
            .print("username pipeline: ") // debugging output for pipeline
            .map { username -> AnyPublisher<[GithubAPIUser], Never> in ❼
                return GithubAPI.retrieveGithubUser(username: username)
            }
            // ^^ type returned in the pipeline is a Publisher, so we use
            // switchToLatest to flatten the values out of that
            // pipeline to return down the chain, rather than returning a
            // publisher down the pipeline.
            .switchToLatest() ❽
            // using a sink to get the results from the API search lets us
            // get not only the user, but also any errors attempting to get it.
            .receive(on: RunLoop.main)
            .assign(to: \.githubUserData, on: self) ❾
    }
}

```

❶ The UITextField is the interface element which is driving the updates from user interaction.

- ② We defined a `<<reference.adoc#reference-published>` property to both hold the updates. Because its a Published property, it provides a publisher reference that we can use to attach additional combine pipelines to update other variables or elements of the interface.
- ③ We set the variable `username` from within an IBAction, which in turn triggers a data flow if the publisher `$username` has any subscribers.
- ④ We in turn set up a subscriber on the publisher `$username` that does further actions. In this case the overall flow retrieves an instance of a GithubAPIUser from Github's REST API.
- ⑤ The `throttle` is there to keep from triggering a network request on ever request. The throttle keeps it to a maximum of 1 request every half-second.
- ⑥ `removeDuplicates` is there to collapse events from the changing username so that API requests aren't made on rapidly changing values. The `removeDuplicates` prevents redundant requests from being made, should the user edit and the return the previous value.
- ⑦ `map` is used similiarly to `flatMap` in error handling here, returning an instance of a publisher. The API object returns a publisher, which this `map` is invoking. This doesn't return the value from the call, but the calling publisher itself.
- ⑧ `switchToLatest` operator takes the instance of the publisher that is the element passed down the pipeline, and pulls out the data to push the elements further down the pipeline. `switchToLatest` resolves that publisher into a value and passes that value down the pipeline, in this case an instance of `[GithubAPIUser]`.
- ⑨ And assign at the end up the pipeline is the subscriber, which assigns the value into another variable

Continue on to [Update the multiple pieces of your interface from a publisher update](#) to expand this into multiple cascading updates of various UI elements.

Update the multiple pieces of your interface from a publisher update

Goal

- Have multiple UI elements update triggered by an upstream subscriber

References

- The ViewController with this code is in the github project at [UIKit-Combine/ViewController.swift](#)
- The GithubAPI is in the github project at [UIKit-Combine/GithubAPI.swift](#)
- Publishers: [Published](#), [URLSession.dataTaskPublisher](#), [Just](#), [Publishers.Empty](#)
- Operators: [decode](#), [catch](#), [map](#), [tryMap](#), [switchToLatest](#), [filter](#), [handleEvents](#), [subscribe](#), [receive](#), [throttle](#), [removeDuplicates](#)
- Subscribers: [sink](#), [assign](#)

See also

- [Using flatMap with catch to handle errors](#)
- [Using catch to handle errors in a one-shot pipeline](#)
- [Stricter request processing with dataTaskPublisher](#)

Code and explanation

The example provided expands on a publisher updating from [Declarative UI updates from user input](#), adding additional combine pipelines to update multiple UI elements.

The general pattern of this view starts with a textfield that accepts user input:

1. We using an IBAction to update the [Published](#) username variable.
2. We have a subscriber ([usernameSubscriber](#)) attached [\\$username](#) publisher reference, which attempts to retrieve the GitHub user from the API. The resulting variable [githubUserData](#) (also [Published](#)) is a list of GitHub user objects. Even though we only expect a single value here, we use a list because we can conveniently return an empty list on failure scenarios: unable to access the API or the username isn't registered at GitHub.
3. We have a "secondary" subscriber [apiNetworkActivitySubscriber](#) which another publisher from the GithubAPI object that provides values when the GithubAPI object starts or finishes making network requests.
4. We have a another subscriber [repositoryCountSubscriber](#) attached to [\\$githubUserData](#) that pulls the repository count off the github user data object and assigns it as the count to be displayed.
5. We have a final subscriber [avatarViewSubscriber](#) attached to [\\$githubUserData](#) that attempts to retrieve the image associated with the user's avatar for display.

The empty list is useful to return because when a username is provided that doesn't resolve, we want to explicitly remove any avatar image that was previously displayed. To do this, we need the pipelines to fully resolve to some value, so that further pipelines are triggered and the relevant UI interfaces updated.

The subscribers (created with `assign` and `sink`) are stored as `AnyCancellable` variables on the `ViewController` instance. Because they are defined on the class instance, the swift compiler creates initializers and deinitializers, which will cancel and clean up the publishers when the class is torn down.



I **think** the above statement is true related to memory management and cancelling the pipelines, but I have not confirmed it. Additionally, a lot of folks comfortable with `RxSwift` operators are using a "CancelBag" object to collect cancellable references, and cancel the pipelines on tear down. An example of this can be seen at <https://github.com/tailec/CombineExamples/blob/master/CombineExamples/Shared/CancellableBag.swift>

The pipelines have been explicitly configured to work on a background queue using the `subscribe` operator. Without that additional configured, the pipelines would be invoked and run on the main runloop since they were invoked from the UI, which causes a noticable slow-down in responsiveness in the simulator. Likewise when the resulting pipelines assign or update UI elements, the `receive` operator is used to transfer that work back onto the main runloop.



If you want to have the UI continuously updated from changes propogating through `Published` properties, make sure that any configured pipelines have a `<Never>` failure type. This is required for the `assign` operator. But more importantly, it's a source of bugs when using a `sink` operator. If the pipeline from a `Published` variable terminates in a `sink` that accepts an `Error` failure type, the sink will send a termination signal if an error occurs, which stops the pipeline from further processing even when the variable is updated.

UIKit-Combine/GithubAPI.swift

```
import Foundation
import Combine

enum APIFailureCondition: Error {
    case invalidServerResponse
}

struct GithubAPIUser: Decodable { ❶
    // A very *small* subset of the content available about
    // a github API user for example:
    // https://api.github.com/users/heckj
    let login: String
    let public_repos: Int
    let avatar_url: String
}

struct GithubAPI { ❷
    // NOTE(heckj): I've also seen this kind of API access
    // object set up with with a class and static methods on the class.
    // I don't know that there's a specific benefit to make this a value
    // type/struct with a function on it.
```

```

    /// externally accessible publisher that indicates that network activity is
    /// happening in the API proxy
    static let networkActivityPublisher = PassthroughSubject<Bool, Never>() ③

    /// creates a one-shot publisher that provides a GithubAPI User
    /// object as the end result. This method was specifically designed to
    /// return a list of 1 object, as opposed to the object itself to make
    /// it easier to distinguish a "no user" result (empty list)
    /// representation that could be dealt with more easily in a Combine
    /// pipeline than an optional value. The expected return types is a
    /// Publisher that returns either an empty list, or a list of one
    /// GithubAPIUser, and with a failure return type of Never, so it's
    /// suitable for recurring pipeline updates working with a @Published
    /// data source.
    /// - Parameter username: username to be retrieved from the Github API
    static func retrieveGithubUser(username: String) -> AnyPublisher<[GithubAPIUser],
    Never> { ④

        if username.count < 3 { ⑤
            return Just([]).eraseToAnyPublisher()
            // return Publishers.Empty<GithubAPIUser, Never>()
            // .eraseToAnyPublisher()
        }
        let assembledURL = String("https://api.github.com/users/\(username)")
        let publisher = URLSession.shared.dataTaskPublisher(for: URL(string:
assembledURL)!)
            .handleEvents(receiveSubscription: { _ in ⑥
                networkActivityPublisher.send(true)
            }, receiveCompletion: { _ in
                networkActivityPublisher.send(false)
            }, receiveCancel: {
                networkActivityPublisher.send(false)
            })
            .tryMap { data, response -> Data in ⑦
                guard let httpResponse = response as? HTTPURLResponse,
                    httpResponse.statusCode == 200 else {
                    throw APIFailureCondition.invalidServerResponse
                }
                return data
            }
            .decode(type: GithubAPIUser.self, decoder: JSONDecoder()) ⑧
            .map {
                [$0] ⑨
            }
            .catch { err in ⑩
                // return Publishers.Empty<GithubAPIUser, Never>()
                // ^^ when I originally wrote this method, I was returning
                // a GithubAPIUser? optional, and then a GithubAPIUser without
                // optional. I ended up converting this to return an empty
                // list as the "error output replacement" so that I could

```

```

        // represent that the current value requested didn't *have* a
        // correct github API response. When I was returning a single
        // specific type, using Publishers.Empty was a good way to do a
        // "no data on failure" error capture scenario.
        return Just([])
    }
    .eraseToAnyPublisher() ⑪
    return publisher
}
}

```

- ① The decodable struct created here is a subset of what's returned from the GitHub API. Any pieces not defined in the struct are simply ignored when processed by the [decode](#) operator.
- ② The code to interact with the GitHub API was broken out into its own object, which I would normally have in a separate file. The functions on the API struct return publishers, and are then mixed and merged with other pipelines in the ViewController.
- ③ This struct also exposes a publisher using [PassthroughSubject](#) that have set up to trigger Boolean values when it is actively making network requests.
- ④ I first created the pipelines to return an optional GithubAPIUser instance, but found that there wasn't a convenient way to propagate "nil" or empty objects on failure conditions. The code was then recreated to return a list, even though only a single instance was ever expected, to conveniently represent an "empty" object. This was important for the use case of wanting to erase existing values in following pipelines reacting to the GithubAPIUser object "disappearing" - removing the repository count and avatar images in this case.
- ⑤ The logic here is simply to prevent extraneous network requests, returning an empty result if the username being requested has less than 3 characters. The commented out code is a bit of legacy from when I wanted to return nothing instead of an empty list.
- ⑥ the [handleEvents](#) operator here is how we are triggering updates for the network activity publisher. We define closures that trigger on subscription and finalization (both completion and cancel) that invoke [send\(\)](#) on the [PassthroughSubject](#). This is an example of how we can provide metadata about a pipeline's operation as a separate publisher.
- ⑦ [tryMap](#) adds additional checking on the API response from github to convert correct responses from the API that aren't valid User instances into a pipeline failure condition.
- ⑧ [decode](#) takes the Data from the response and decodes it into a single instance of [GithubAPIUser](#)
- ⑨ [map](#) is used to take the single instance and convert it into a list of 1 item, changing the type to a list of [GithubAPIUser](#): [\[GithubAPIUser\]](#).
- ⑩ [catch](#) operator captures the error conditions within this pipeline, and returns an empty list on failure while also converting the failure type to [Never](#).
- ⑪ [eraseToAnyPublisher](#) collapses the complex types of all the chained operators and exposes the whole pipeline as an instance of [AnyPublisher](#).

UIKit-Combine/ViewController.swift

```

import UIKit
import Combine

```

```

class ViewController: UIViewController {

    @IBOutlet weak var github_id_entry: UITextField!
    @IBOutlet weak var activityIndicator: UIActivityIndicatorView!
    @IBOutlet weak var repositoryCountLabel: UILabel!
    @IBOutlet weak var githubAvatarImageView: UIImageView!

    var repositoryCountSubscriber: AnyCancellable?
    var avatarViewSubscriber: AnyCancellable?
    var usernameSubscriber: AnyCancellable?
    var headingSubscriber: AnyCancellable?
    var apiNetworkActivitySubscriber: AnyCancellable?

    // username from the github_id_entry field, updated via IBAction
    @Published var username: String = ""

    // github user retrieved from the API publisher. As it's updated, it
    // is "wired" to update UI elements
    @Published private var githubUserData: [GithubAPIUser] = []

    // publisher reference for this is $username, of type <String, Never>
    var myBackgroundQueue: DispatchQueue = DispatchQueue(label:
"viewControllerBackgroundQueue")
    let coreLocationProxy = LocationHeadingProxy()

    // MARK - Actions

    @IBAction func githubIdChanged(_ sender: UITextField) {
        username = sender.text ?? ""
        print("Set username to ", username)
    }

    // MARK - lifecycle methods

    override func viewDidLoad() {
        super.viewDidLoad()
        // Do any additional setup after loading the view.

        let apiActivitySub = GithubAPI.networkActivityPublisher ❶
        .receive(on: RunLoop.main)
        .sink { doingSomethingNow in
            if (doingSomethingNow) {
                self.activityIndicator.startAnimating()
            } else {
                self.activityIndicator.stopAnimating()
            }
        }
        apiNetworkActivitySubscriber = AnyCancellable(apiActivitySub)

        usernameSubscriber = $username ❷
    }
}

```

```

.throttle(for: 0.5, scheduler: myBackgroundQueue, latest: true)
// ^^ scheduler myBackGroundQueue publishes resulting elements
// into that queue, resulting on this processing moving off the
// main runloop.
.removeDuplicates()
.print("username pipeline: ") // debugging output for pipeline
.map { username -> AnyPublisher<GithubAPIUser, Never> in
    return GithubAPI.retrieveGithubUser(username: username)
}
// ^^ type returned in the pipeline is a Publisher, so we use
// switchToLatest to flatten the values out of that
// pipeline to return down the chain, rather than returning a
// publisher down the pipeline.
.switchToLatest()
// using a sink to get the results from the API search lets us
// get not only the user, but also any errors attempting to get it.
.receive(on: RunLoop.main)
.assign(to: \.githubUserData, on: self)

// using .assign() on the other hand (which returns an
// AnyCancellable) *DOES* require a Failure type of <Never>
repositoryCountSubscriber = $githubUserData ③
.print("github user data: ")
.map { userData -> String in
    if let firstUser = userData.first {
        return String(firstUser.public_repos)
    }
    return "unknown"
}
.receive(on: RunLoop.main)
.assign(to: \.text, on: repositoryCountLabel)

let avatarViewSub = $githubUserData ④
// When I first wrote this publisher pipeline, the type I was
// aiming for was <GithubAPIUser?, Never>, where the value was an
// optional. The commented out .filter below was to prevent a 'nil' //
GithubAPIUser object from propagating further and attempting to
// invoke the dataTaskPublisher which retrieves the avatar image.
//
// When I updated the type to be non-optional (<GithubAPIUser?,
// Never>) the filter expression was no longer needed, but possibly
// interesting.
// .filter({ possibleUser -> Bool in
//     possibleUser != nil
// })
// .print("avatar image for user") // debugging output
.map { userData -> AnyPublisher<UIImage, Never> in
    guard let firstUser = userData.first else {
        // my placeholder data being returned below is an empty
        // UIImage() instance, which simply clears the display.
        // Your use case may be better served with an explicit

```

```

        // placeholder image in the event of this error condition.
        return Just(UIImage()).eraseToAnyPublisher()
    }
    return URLSession.shared.dataTaskPublisher(for: URL(string: firstUser
.avatar_url!))

    // ^^ this hands back (Data, response) objects
    .handleEvents(receiveSubscription: { _ in
        DispatchQueue.main.async {
            self.activityIndicator.startAnimating()
        }
    }, receiveCompletion: { _ in
        DispatchQueue.main.async {
            self.activityIndicator.stopAnimating()
        }
    }, receiveCancel: {
        DispatchQueue.main.async {
            self.activityIndicator.stopAnimating()
        }
    })
    .map { $0.data }
    // ^^ pare down to just the Data object
    .map { UIImage(data: $0)!}
    // ^^ convert Data into a UIImage with its initializer
    .subscribe(on: self.myBackgroundQueue)
    // ^^ do this work on a background Queue so we don't screw
    // with the UI responsiveness
    .catch { err in
        return Just(UIImage())
    }
    // ^^ deal the failure scenario and return my "replacement"
    // image for when an avatar image either isn't available or
    // fails somewhere in the pipeline here.
    .eraseToAnyPublisher()
    // ^^ match the return type here to the return type defined
    // in the .map() wrapping this because otherwise the return
    // type would be terribly complex nested set of generics.
}

.switchToLatest()
// ^^ Take the returned publisher that's been passed down the chain
// and "subscribe it out" to the value within in, and then pass
// that further down.
.subscribe(on: myBackgroundQueue)
// ^^ do the above processing as well on a background Queue rather
// than potentially impacting the UI responsiveness
.receive(on: RunLoop.main)
// ^^ and then switch to receive and process the data on the main
// queue since we're messin with the UI

// .assign(to: \.image, on: self.githubAvatarImageView)
// this ^^ line is returning a compiler error: Type of expression
// is ambiguous without more context. I *thought* it would work,

```

```

// but it's having an issue with the keyPath that I'm trying to
// assign for the githubAvatarImageView.image.

// so instead we can use a sink to capture the data and set a value
.sink(receiveValue: { image in
    self.githubAvatarImageView.image = image
})
// convert the .sink to an `AnyCancellable` object that we have
// referenced from the implied initializers
avatarViewSubscriber = AnyCancellable(avatarViewSub)

// KVO publisher of UIKit interface element
let _ = repositoryCountLabel.publisher(for: \.text) ⑤
    .sink { someValue in
        print("repositoryCountLabel Updated to \(String(describing: someValue
)))")
    }
}
}
}

```

- ① We add a subscriber to our previous controller from that connects notifications of activity from the GithubAPI object to our activity indicator.
- ② Where the username is updated from the IBAction (from our earlier example [Declarative UI updates from user input](#)) we have the subscriber make the network request and put the results in a new variable (also [Published](#)) on our ViewController.
- ③ The first of two subscribers on the publisher `$githubUserData`, this pipeline extracts the count of repositories and updates the a UI label instance. There is a bit of logic in the middle of the pipeline to return the string "unknown" when the list is empty.
- ④ The second subscriber to the publisher `$githubUserData`, this triggers a follow on network request to request the image data for the github avatar. This is a more complex pipeline, extracting the data from the githubUser, assembling a URL, and then requesting it. As this code is in the ViewController, we can also use [handleEvents](#) operator to trigger updates to the activityIndicator in our view. We use [subscribe](#) to make the requests on a background queue, and later [receive](#) the results back onto the main thread to update the UI elements. The [catch](#) and failure handling returns an empty `UIImage` instance in the event of failure.
- ⑤ A final subscriber that doesn't do anything is attached to the UILabel itself. Any Key-Value Observable object from Foundation can also produce a publisher. In this example, we attach a publisher that triggers a print statement that the UI element was updated.



While we could simply attach pipelines to UI elements as we're updating them, it more closely couples interactions to the actual UI elements themselves. While easy and direct, it is often a good idea to make explicit state and updates to separate out actions and data for debugging and understandability. In the example above, we use two [Published](#) properties to hold the state associated with the current view. One of which is updated by an IBAction, and the second updated declaratively using a Combine publisher pipeline. All other UI elements are updated publishers hanging from those properties getting updated.

Wrapping an asynchronous call with a Future to create a one-shot publisher

Goal

- Using Future to turn an an asynchronous call into publisher to use the result in a combine pipeline.

References

- [Future](#)

See also

- [Creating a repeating publisher by wrapping a delegate based API](#)

Code and explanation

```
import Contacts
let futureAsyncPublisher = Future<Bool, Error> { promise in ❶
    CNContactStore().requestAccess(for: .contacts) { grantedAccess, err in ❷
        // err is an optional
        if let err = err { ❸
            promise(.failure(err))
        }
        return promise(.success(grantedAccess)) ❹
    }
}.eraseToAnyPublisher()
```

- ❶ Future itself has you define the return types and takes a closure. It hands in a Result object matching the type description, which you interact.
- ❷ You can invoke the async API however is relevant, including passing in it's required closure.
- ❸ Within the completion handler, you determine what would cause a failure or a success. A call to `promise(.failure(<FailureType>))` returns the failure.
- ❹ Or a call to `promise(.success(<OutputType>))` returns a value.

Sequencing operations with Combine

Goal

- To explicitly order asynchronous operations with a Combine pipeline

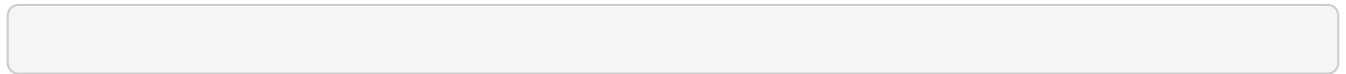
References

- [Future](#)

See also

- [Creating a repeating publisher by wrapping a delegate based API](#)

Code and explanation



Creating a repeating publisher by wrapping a delegate based API

Goal

- To use one of the Apple delegate APIs to provide values to be used in a combine pipeline.

References

- [PassthroughSubject](#)
- [currentValueSubject](#)

See also

- [Wrapping an asynchronous call with a Future to create a one-shot publisher](#)

Code and explanation

```
.eraseToAnyPublisher()
```

Responding to updates in properties with @Published

Goal

- @Published with properties and using read-only updates of those properties as publishing sources

References

- << link to reference pages>>

See also

- << link to other patterns>>

Code and explanation

```
@Published var username: String = ""

var validatedUsername: AnyPublisher<String?, Never> {
    return $username
        .debounce(for: 0.5, scheduler: RunLoop.main)
        // <String?>|<Never>
        .removeDuplicates()
        // <String?>|<Never>
        .flatMap { username in
            return Future { promise in
                self.usernameAvailable(username) { available in
                    promise(.success(available ? username : nil))
                }
            }
            // <Result<Output, Failure>>
        }
        // <String?>|<Never>
        .eraseToAnyPublisher()
}
```

validation - listening for changes to validate them together

```

@Published var password: String = ""
@Published var passwordAgain: String = ""

var validatedPassword: AnyPublisher<String?, Never> {
    return CombineLatest($password, $passwordAgain) { password, passwordAgain in
        guard password == passwordAgain, password.count > 8 else { return nil }
        return password
    }
    // <String?>|<Never>
    .map { $0 == password1 ? nil : $0 }
    // <String?>|<Never>
    .eraseToAnyPublisher()
    // <String?>|<Never>
}

```

more complex validation - bringing together substreams

```

var validatedCredentials: AnyPublisher<(String, String)?, Never> {
    return CombineLatest(validatedUsername, validatedPassword) { username, password in
        guard let uname = username, let pwd = password else { return nil }
        return (uname, pwd)
    }
    .eraseToAnyPublisher()
}

@IBOutlet var signupButton: UIButton!

var signupButtonStream: AnyCancellable?

override func viewDidLoad() {
    super.viewDidLoad()
    self.signupButtonStream = self.validatedCredentials
        .map { $0 != nil }
        .receive(on: RunLoop.main)
        .assign(to: \.isEnabled, on: signupButton)
}

```

Responding to updates from NotificationCenter

Goal

- The big "master bus" of events across a variety of Apple platforms, its where you can listen for updates and changes from controls and events across a variety of frameworks.

References

- << link to reference pages>>

See also

- << link to other patterns>>

Code and explanation

[Casey Liss](#) talks about about this (not entirely happily) based on the apple documentation [Receiving and Handling Events with Combine](#).

Using BindableObject with SwiftUI models as a publisher source

Goal

- SwiftUI includes @Binding and the BindableObject protocol, which provides a publishing source to alerts to model objects changing.

References

- << link to reference pages>>

See also

- << link to other patterns>>

Code and explanation

Testing a publisher with XCTestExpectation

Goal

- For testing a publisher (and any pipeline attached)

References

- << link to reference pages>>

See also

- << link to other patterns>>

Code and explanation

- set up an expectation (`XCTestExpectation`)
- create your publisher & relevant pipeline if so desired
- create a sink to capture the results that works on both completions and values
 - this can be separate, or just chained to the pipeline, depending on what makes most sense to you
- `wait` on the expectation to let the test "do it's thing" in the background

Testing a subscriber with a PassthroughSubject

Goal

- For testing a subscriber (how it reacts):

References

- << link to reference pages>>

See also

- << link to other patterns>>

Code and explanation

- set up your subscriber and any pipeline leading to it
- use a Subject to "inject" values
- test the results after the value is sent
- if the updates include some async/background work before data is available, use an expectation
 - add a callback to the async pieces where you can trigger the expectation, and do your asserts just prior to fulfilling the expectation

& of course you can always test using UITesting - spinning up your whole app, initializing state, and then driving and verifying the results.

(Uncertain) Mocking or faking a publisher (such as dataTaskPublisher) to validate things like using `retry()` operator * might be able to use a `Publishers.Future()`, expose as an `AnyPublisher()` (do the same with `dataTaskPublisher`) to make the the same - and in your setup, inject in the one you want to use. ** Instrument the `Future()` closure to record what gets called, and maybe set it up to return an explicit set of responses.

Debugging pipelines

Goal

- For testing a subscriber (how it reacts):

References

- << link to reference pages>>

See also

- << link to other patterns>>

Code and explanation

1. use `print()` and/or `print("prefixValue")` to get console output of what's happening in the pipeline lifecycle
 - create a `.sink()` to capture results, and drive it with a `PassthroughSubject` for specific control
2. add a `handleEvents()` operator
 - create closures to do additional poking at values or digging into more structured pieces than get exposed with a `print()`
 - allows you to ignore some sections you don't care about
 - closures on `receiveSubscription`, `receiveRequest`, `receiveCancel`, `receiveOutput`, and `receiveCompletion`
3. `breakPoint`
 - if you want to break into a debugger, add in a closure that returns true and you can inspect to your heart's content
 - closure's on `receiveSubscription`, `receiveOutput`, and `receiveCompletion`
 - might also be interesting to use `breakpointOnError()` which triggers only when a failure completion

Reference

reference preamble goes here...



This is intended to extend Apple's documentation, not replace it.

- The documentation associated with beta2 is better than beta1, but still fairly anemic.

things to potentially include for each segment

- narrative description of what the function does
 - notes on why you might want to use it, or where you may see it
 - xref back to patterns document where functions are being used
- marble/railroad diagram explaining what the transformation/operator does
- sample code showing it being used and/or tested

Publishers

For general information about Publishers, see [Publishers](#) and [Lifecycle of Publishers and Subscribers](#).

Just

Summary

Just provides a single result and then terminates, providing a publisher with a failure type of `<Never>`

🍏 docs

Just

Usage

- [Using catch to handle errors in a one-shot pipeline](#)
- [Using flatMap with catch to handle errors](#)
- [Declarative UI updates from user input](#)
- [Update the multiple pieces of your interface from a publisher update](#)

Details

Often used within a closure to [flatMap](#) in error handling, it can see a one-shot pipeline for use in error handling of continuous values.

Future

Summary

A future is initialized with a closure that eventually resolves to a single output value or failure

completion.

🍏 docs

[Future](#).

Usage

- unit tests illustrating using Future: [UsingCombineTests/FuturePublisherTests.swift](#)

Details

Future is a publisher that let's you combine in any asynchronous call and use that call to generate a value or a completion as a Publisher. It's ideal for when you want to make a single request, or get a single response, where the API you are using has a completion handler closure.

The obvious example that everyone immediately thinks about is `URLSession`. Fortunately, [URLSession.dataTaskPublisher](#) exists to make a call with a `URLSession` and return a publisher. However, if you already have an API object that wraps the direct calls to `URLSession`, then making a single request using Future can be a great way to integrate the result into a Combine pipeline.

There are a number of other APIs that exist in the Apple frameworks that use a completion closure. An example of one is requesting permission to access the contacts store in `Contacts`. An example of wrapping that request for access into a publisher using Future might be:

```
import Contacts
let futureAsyncPublisher = Future<Bool, Error> { promise in ❶
    CNContactStore().requestAccess(for: .contacts) { grantedAccess, err in ❷
        // err is an optional
        if let err = err { ❸
            promise(.failure(err))
        }
        return promise(.success(grantedAccess)) ❹
    }
}
```

- ❶ Future itself has you define the return types and takes a closure. It hands in a `Result` object matching the type description, which you interact.
- ❷ You can invoke the async API however is relevant, including passing in its required closure.
- ❸ Within the completion handler, you determine what would cause a failure or a success. A call to `promise(.failure(<FailureType>))` returns the failure.
- ❹ Or a call to `promise(.success(<OutputType>))` returns a value.

If you want to wrap an async API that could return many values over time, Future probably isn't what you want, as it only returns a single value. Instead, you should consider creating your own publisher based on [PassthroughSubject](#) or [CurrentValueSubject](#).

Published

Summary

A property wrapper that adds a Combine publisher to any property

🍏 docs

Published

Usage

- [Declarative UI updates from user input](#)
- [Update the multiple pieces of your interface from a publisher update](#)
- unit tests illustrating using Published: [UsingCombineTests/PublisherTests.swift](#)

Details

Published is part of combine, but allows you to wrap an property, enabling you to get a publisher that triggers data updates whenever the property is changed. The publisher's output type is inferred from the type of the property, and the error type of the provided publisher is <Never>.

A smaller examples of how it can be used:

```
@Published var username: String = "" ①

$username ②
    .sink { someString in
        print("value of username updated to: ", someString)
    }

$username ③
    .assign(\.text, on: myLabel)

@Published private var githubUserData: [GithubAPIUser] = [] ④
```

- ① `@Published` wraps the property, username, and will generate events whenever the property is changed. If there is a subscriber at initialization time, the subscriber will also receive the initial value being set. The publisher for the property is available at the same scope, and with the same permissions, as the property itself.
- ② The publisher is accessible as `$username`, of type `Published<String>.publisher`.
- ③ A Published property can have more than one subscriber pipeline triggering from it.
- ④ If you're publishing your own type, you may find it convenient to publish an array of that type as the property, even if you only reference a single value. This allows you represent an "Empty" result that is still a concrete result within combine pipelines, as `assign` and `sink` subscribers will only trigger updates on non-nil values.

If the publisher generated from `@Published` receives a cancellation from any subscriber, it is expected to, and will cease, reporting property changes. Because of this expectation, it is common to arrange pipelines from these publishers that have an error type of <Never> and do all error handling within the pipelines. For example, if a `sink` subscriber is set up to capture errors from a pipeline originating from a `@Published` property, when the error is received, the sink will send a `cancel` message, causing the publisher to cease generating any updates on change. This is illustrated in the test `testPublishedSinkWithError` at [UsingCombineTests/PublisherTests.swift](#)

Additional examples of how to arrange error handling for a continuous publisher like `@Published` can be found at [Using flatMap with catch to handle errors](#).



As of the beta3 release of Combine with the updated operating systems, `Published` doesn't always trigger updates when a struct is the holding the `@Published` variable, but it works within a class instance. The unit tests at [UsingCombineTests/PublisherTests.swift](#) illustrate this with the tests: `* testPublishedOnStructWithChange` `* testPublishedOnClassWithChange`

Publishers.Empty

Summary

`empty` never publishes any values, and optionally finishes immediately.

🍏 docs

[Publishers.Empty](#)

Usage

- [Using catch to handle errors in a one-shot pipeline](#) shows an example of using `catch` to handle errors with a one-shot publisher.
- [Using flatMap with catch to handle errors](#) shows an example of using `catch` with `flatMap` to handle errors with a continual publisher.
- [Declarative UI updates from user input](#)
- [Update the multiple pieces of your interface from a publisher update](#)
- The unit tests at [UsingCombineTests/EmptyPublisherTests.swift](#)

Details

`Empty` is useful in error handling scenarios where with publishers where the value is an optional, or where you want to resolve an error by simply not sending anything. `Empty` can be invoked to be a publisher of any output and failure type combination.

`Empty` is most commonly used where you need to return a publisher, but don't want to propagate any values (a possible error handling scenario). If you want a publisher that provides a single value, then look at [Just](#), [Publishers.Once](#), or [Publishers.Optional](#) publishers as alternatives.

When subscribed to, an instance of the `Empty` publisher will not return any values (or errors) and will immediately return a finished completion message to the subscriber.

An example of using `Empty`

```
let myEmptyPublisher = Publishers.Empty<String, Never>() ①
```

- ① Because the types are not be able to be inferred, expect to always define the types you want to return within the declaration.

Publishers.Fail

Summary

`fail` immediately terminates publishing with the specified failure.

🍏 docs

`Publishers.Fail`

Usage

n/a

Details

n/a

Publishers.Once

Summary

Generates an output to each subscriber exactly once then finishes or fails immediately.

🍏 docs

`Once`

Usage

TBD

Details

Used similiarly to `Just`, it provides a value and then completes. It is often used with `flatMap` when you want to flow have `flatMap` return a publisher that returns a publisher with an error type. Where `Just` returns a failure type of `<Never>`, `once` allows for a failure type of `<Error>`.

Publishers.Optional

Summary

generates a value exactly once for each subscriber, if the optional has a value

🍏 docs

`Publishers.Optional`

Usage

n/a

Details

n/a

Publishers.Sequence

Summary

Publishes a provided sequence of elements.

🍏 *docs*

Publishers.Sequence

Usage

n/a

Details

n/a

Publishers.Deferred

Summary

Publisher waits for a subscriber before running the provided closure to create values for the subscriber.

🍏 *docs*

Publishers.Deferred

Usage

n/a

Details

n/a

SwiftUI

- @ObjectBinding (swiftUI)
- BindableObject
- often linked with method `didChange` to publish changes to model objects
 - `@ObjectBinding var model: MyModel`

Foundation

- `NotificationCenter.publisher`
- `Timer.publish` and `Timer.TimerPublisher`
 - * `TimerPublisher`

.publisher on KVO instance

Summary

Foundation added the ability to get a publisher on any Object that can be watched with Key Value Observing.

🍏 docs

???



As of beta3, I was unable to find the documentation on the extension of NSObject. In the generated swift declaration file, it's listed as an extension on NSObject - a struct named `KeyValueObservingPublisher`

Usage

- The unit tests at `UsingCombineTests/PublisherTests.swift`

Details

Any Key Value Observing instance can produce a publisher. To create this publisher, you call the function `publisher` on the object, providing it with a single (required) KeyPath value.

For example:

```
private final class KVOAbleNSObject: NSObject {
    @objc dynamic var intValue: Int = 0
    @objc dynamic var boolValue: Bool = false
}

let foo = KVOAbleNSObject()

let _ = foo.publisher(for: \.intValue)
    .sink { someValue in
        print("value updated to: >>\(someValue)<<")
    }
```



KVO publisher access implies that with MacOS 10.15 release or IOS 13, most of Appkit and UIKit interface instances will be accessible as publishers. Relying on the interface element's state to trigger updates into pipelines can lead to your state being very tightly bound to the interface elements, rather than your model. You may be better served by explicitly creating your own state to react to from a `Published` property wrapper.

URLSession.dataTaskPublisher

Summary

Foundation's `URLSession` has a publisher specifically for requesting data from URLs: `dataTaskPublisher`

Constraints on connected publisher

- *none*

🍏 docs

`URLSession.DataTaskPublisher`

Usage

- [Making a network request with dataTaskPublisher](#)
- [Using catch to handle errors in a one-shot pipeline](#)
- [Retrying in the event of a temporary failure](#)
- [Requesting data from an alternate URL when the network is constrained](#)
- [Declarative UI updates from user input](#)
- [Update the multiple pieces of your interface from a publisher update](#)

Details

`dataTaskPublisher`, on `URLSession`, has two variants for creating a publisher. The first takes an instance of `URL`, the second `URLRequest`. The data returned from the publisher is a tuple of `(data: Data, response: URLResponse)`.

```
let request = URLRequest(url: regularURL)
return URLSession.shared.dataTaskPublisher(for: request)
```

RealityKit

- `RealityKit.Scene.publisher()`

Scene Publisher (from [RealityKit](#))

- [Scene.Publisher](#)
 - [SceneEvents](#)
 - [AnimationEvents](#)
 - [AudioEvents](#)
 - [CollisionEvents](#)

Operators

Mapping elements

scan

- scan

tryScan

- tryScan

map

Summary

map is most commonly used to convert one data type into another along a pipeline.

Constraints on connected publisher

- none

🍏 docs

<https://developer.apple.com/documentation/combine/publishers/map>

n/a

Usage

- [Making a network request with dataTaskPublisher](#)
- [Using catch to handle errors in a one-shot pipeline](#)
- [Retrying in the event of a temporary failure](#)
- [Declarative UI updates from user input](#)
- [Update the multiple pieces of your interface from a publisher update](#)
- [unit tests illustrating using map with dataTaskPublisher: UsingCombineTests/DataTaskPublisherTests.swift](#)

Details

The map operator doesn't allow for any additional failures to be thrown, and doesn't transform the failure type. If you want to throw an error within your closure, then use the [tryMap](#) operator.

map takes a single closure where you provide the logic for the map operation.

For example, the [URLSession.dataTaskPublisher](#) provides a tuple of `(data: Data, response: URLResponse)` as its output. You can use map to pass along the data, for example to use with [decode](#).

```
.map { $0.data } ①
```

① the `$0` indicates to grab the first parameter passed in, which is a tuple of `data` and `response`.

In some cases, the closure may not be able to infer what data type you are returning, so you may need to provide a definition to help the compiler. For example, if you have an object getting passed down that has a boolean property "isValid" on it, and you just want the boolean for your pipeline, you might set that up like:

```
struct myStruct {  
    isValid: bool = true  
}  
//  
Just(myStruct())  
  .map { inValue -> Bool in ①  
    inValue.isValid ②  
  }
```

- ① inValue is named as the parameter coming in, and the return type is being explicitly specified to Bool
- ② A single line is an implicit return, in this case it's pulling the isValid property off the struct and passing it down the pipeline.

tryMap

Summary

tryMap is effectively the similar to `map`, except that it also allows you to provide a closure that throws additional errors if your conversion logic is unsuccessful.

Constraints on connected publisher

- none

🍏 docs

<https://developer.apple.com/documentation/combine/publishers/trymap>

Usage

- [Stricter request processing with dataTaskPublisher](#)
- `unit tests illustrating using tryMap with dataTaskPublisher:`
`UsingCombineTests/DataTaskPublisherTests.swift`

Details

tryMap is useful when you have more complex business logic around your map and you want to indicate that the data passed in is an error, possibly handling that error later in the pipeline. If you are looking at tryMap to decode JSON, you may want to consider using the `decode` operator instead, which is set up for that common task.

```
enum myFailure: Error {
    case notBigEnough
}

//
Just(5)
.tryMap {
    if inValue < 5 { ①
        throw myFailure.notBigEnough ②
    }
    return inValue ③
}
```

- ① You can specify whatever logic is relevant to your use case within tryMap
- ② and throw an error, although throwing an Error isn't required.
- ③ If the error condition doesn't occur, you do need to pass down data for any further subscribers.

flatMap

Summary

Used with error recovery or async operations that might fail (ex: Future), flatMap will replace any incoming values with another publisher.

Constraints on connected publisher

- none

🍏 docs

flatMap

Usage

- [Using flatMap with catch to handle errors](#)
- unit tests illustrating flatMap: [UsingCombineTests/SwitchAndFlatMapPublisherTests.swift](#)

Details

Most typically used in error handling scenarios, flatMap takes a closure that allows you to read the incoming data value, and provide a publisher that returns a value to the pipeline.

In error handling, this is most frequently used to take the incoming value and create a one-shot pipeline that does some potentially failing operation, and then handling the error condition with a [catch](#) operator.

A diagram version of this pipeline construct might be:

```

one-shot-publisher(value) -> catch ( fallback )      // <- one-shot pipeline
                             ^                      \
                             |                      \
publisher -> flatMap -> ( +                + ) -> subscriber
```


In swift, this looks like:

```
.flatMap { data in
    return Just(data)
    .decode(YourType.self, JSONDecoder())
    .catch {
        return Just(YourType.placeholder)
    }
}
```

setFailureType

- setFailureType

Filtering elements

compactMap

- compactMap
 - republishes all non-nil results of calling a closure with each received element.
 - there's a variant `tryCompactMap` for use with a provided error-throwing closure.

tryCompactMap

- tryCompactMap

filter

Summary

Filter passes through all instances of the output type that match a provided closure, dropping any that don't match.

Constraints on connected publisher

- requires Failure type to be `<Never>`

🍏 docs

`filter`

Usage

- [Declarative UI updates from user input](#)
- [Update the multiple pieces of your interface from a publisher update](#)
- unit tests illustrating using filter: `UsingCombineTests/FilterPublisherTests.swift`

Details

Filter takes a single closure as a parameter that is provided the value from the previous publisher and returns a Bool value. If the return from the closure is `true`, then the operator republishes the value further down the chain. If the return from the closure is `false`, then the

operator drops the value.

If you need a variation of this that will generate an error condition in the pipeline to be handled use the [tryFilter](#) operator, which allows the closure to throw an error in the evaluation.

tryFilter

Summary

tryFilter passes through all instances of the output type that match a provided closure, dropping any that don't match, and allows generating an error during the evaluation of that closure.

Constraints on connected publisher

- none

🍏 docs

[tryFilter](#)

Usage

- unit tests illustrating using tryFilter: [UsingCombineTests/FilterPublisherTests.swift](#)

Details

Like [filter](#), tryFilter takes a single closure as a parameter that is provided the value from the previous publisher and returns a Bool value. If the return from the closure is **true**, then the operator republishes the value further down the chain. If the return from the closure is **false**, then the operator drops the value. You can additionally throw an error during the evaluation of tryFilter, which will then be propagated as the failure type down the pipeline.

removeDuplicates

Summary

removeDuplicates remembers what was previously sent in the pipeline, and only passes forward values that don't match the current value.

Constraints on connected publisher

- Available when Output of the previous publisher conforms to Equatable.

🍏 docs

[removeDuplicates](#)

Usage

- unit tests illustrating using removeDuplicates: [UsingCombineTests/debounceAndRemoveDuplicatesPublisherTests.swift](#)

Details

The default usage of removeDuplicates doesn't require any parameters, and the operator will publish only elements that don't match the previously sent element.

```
.removeDuplicates\(\)
```

A second usage of `removeDuplicates` takes a single parameter `by` that accepts a closure that allows you to determine the logic of what will be removed. The parameter version does not have the constraint on the Output type being equatable, but requires you to provide the relevant logic. If the closure returns true, the `removeDuplicates` predicate will consider the values matched and not forward a the duplicate value.

```
.removeDuplicates(by: { first, second -> Bool in
    // your logic is required if the output type doesn't conform to equatable.
    first.id == second.id
})
```

A variation of `removeDuplicates` exists that allows the predicate closure to throw an Error exists: [tryRemoveDuplicates](#)

tryRemoveDuplicates

Summary

`tryRemoveDuplicates` is a variant of [removeDuplicates](#) that allows the predicate testing equality to throw an Error, resulting in an Error completion type.

Constraints on connected publisher

- none

🍏 docs

[tryRemoveDuplicates](#)

Usage

- unit tests illustrating using `tryRemoveDuplicates:`
[UsingCombineTests/debounceAndRemoveDuplicatesPublisherTests.swift](#)

Details

`tryRemoveDuplicates` is a variant of [removeDuplicates](#) taking a single parameter that can throw an error. The parameter is a closure that allows you to determine the logic of what will be removed. If the closure returns true, `tryRemoveDuplicates` will consider the values matched and not forward a the duplicate value. If the closure throws an error, a failure completion will be propagated down the chain, and no value is sent.

```
.removeDuplicates(by: { first, second -> Bool throws in
    // your logic is required if the output type doesn't conform to equatable.
})
```

replaceEmpty

- `replaceEmpty`
 - requires Failure to be `<Never>`

replaceError

- replaceError
 - requires Failure to be **<Never>**

replaceNil

- replaceNil
 - requires Failure to be **<Never>**
 - Replaces nil elements in the stream with the provided element.

Reducing elements

collect

- collect
 - multiple variants
 - buffers items
 - `collect()` Collects all received elements, and emits a single array of the collection when the upstream publisher finishes.
 - `collect(Int)` collects N elements and emits as an array
 - `collect(.byTime)` or `collect(.byTimeOrCount)`

collectByCount

- collectByCount

collectByTime

- collectByTime

ignoreOutput

- ignoreOutput

reduce

- reduce
 - A publisher that applies a closure to all received elements and produces an accumulated value when the upstream publisher finishes.
 - requires Failure to be `<Never>`
 - there's a variant `tryReduce` for use with a provided error-throwing closure.

tryReduce

- tryReduce

Mathematic operations on elements

max

- max
 - Available when Output conforms to Comparable.
 - Publishes the maximum value received from the upstream publisher, after it finishes.

min

- Publishes the minimum value received from the upstream publisher, after it finishes.
- Available when Output conforms to Comparable.

comparison

- comparison
 - republishes items from another publisher only if each new item is in increasing order from the previously-published item.
 - there's a variant `tryComparison` which fails if the ordering logic throws an error

tryComparison

- tryComparison

count

- count
 - publishes the number of items received from the upstream publisher

Applying matching criteria to elements

allSatisfy

- allSatisfy
 - Publishes a single Boolean value that indicates whether all received elements pass a given predicate.
 - there's a variant `tryAllSatisfy` when the predicate can throw errors

tryAllSatisfy

- tryAllSatisfy

contains

- contains
 - emits a Boolean value when a specified element is received from its upstream publisher.
 - variant `containsWhere` when a provided predicate is satisfied
 - variant `tryContainsWhere` when a provided predicate is satisfied but could throw errors

containsWhere

- containsWhere

tryContainsWhere

- tryContainsWhere

Applying sequence operations to elements

first

- first
 - requires Failure to be **<Never>**
 - publishes the first element to satisfy a provided predicate

firstWhere

- firstWhere

tryFirstWhere

- tryFirstWhere

last

- last
 - requires Failure to be **<Never>**
 - publishes the last element to satisfy a provided predicate

lastWhere

- lastWhere

tryLastWhere

- tryLastWhere

dropUntilOutput

- dropUntilOutput

dropWhile

- dropWhile

tryDropWhile

- tryDropWhile

concatenate

- concatenate

drop

- drop

- multiple variants
- requires Failure to be `<Never>`
- Ignores elements from the upstream publisher until it receives an element from a second publisher.
- or `drop(while: {})`

prefixUntilOutput

- `prefixUntilOutput`
 - Republishes elements until another publisher emits an element.
 - requires Failure to be `<Never>`

prefixWhile

- `prefixWhile`
 - Republishes elements until another publisher emits an element.
 - requires Failure to be `<Never>`

tryPrefixWhile

- `tryPrefixWhile`
 - Republishes elements until another publisher emits an element.
 - requires Failure to be `<Never>`

output

- `output`

Combining elements from multiple publishers

combineLatest

- combineLatest
 - brings inputs from 2 (or more) streams together
 - you provide a closure that gets the values and chooses what to publish

tryCombineLatest

- tryCombineLatest

merge

- merge
 - Combines elements from this publisher with those from another publisher of the same type, delivering an interleaved sequence of elements.
 - requires Failure to be **<Never>**
 - multiple variants that will merge between 2 and 8 different streams

zip

- zip
 - Combine elements from another publisher and deliver pairs of elements as tuples.
 - requires Failure to be **<Never>**

Handling errors

See [Error Handling](#) for more detail on how you can design error handling.

catch

Summary

The operator `catch` handles errors (completion messages of type `.failure`) from an upstream publisher by replacing the failed publisher with another publisher. The operator also transforms the Failure type to `<Never>`.

Constraints on connected publisher

- *none*

🍏 Documentation reference

`Publishers.Catch`

Usage

- [Using catch to handle errors in a one-shot pipeline](#) shows an example of using `catch` to handle errors with a one-shot publisher.
- [Using flatMap with catch to handle errors](#) shows an example of using `catch` with `flatMap` to handle errors with a continual publisher.
- [Declarative UI updates from user input](#)
- [Update the multiple pieces of your interface from a publisher update](#)

Details

Once `catch` receives a `.failure` completion, it won't send any further incoming values from the original upstream publisher. You can also view `catch` as a switch that only toggles in one direction: to using a new publisher that you define, but only when the original publisher to which it is subscribed sends an error.

This can be illustrated with the following code snippet:

```

enum testFailureCondition: Error {
    case invalidServerResponse
}

let simplePublisher = PassthroughSubject<String, Error>()

let _ = simplePublisher
    .catch { err in
        // must return a Publisher
        return Just("replacement value")
    }
    .sink(receiveCompletion: { fini in
        print(".sink() received the completion:", String(describing: fini))
    }, receiveValue: { stringValue in
        print(".sink() received \(stringValue)")
    })

simplePublisher.send("oneValue")
simplePublisher.send("twoValue")
simplePublisher.send(completion: Subscribers.Completion.failure(testFailureCondition
    .invalidServerResponse))
simplePublisher.send("redValue")
simplePublisher.send("blueValue")
simplePublisher.send(completion: .finished)

```

In this example, we are using a `PassthroughSubject` so that we can control when and what gets sent from the publisher. In the above code, we are sending two good values, then a failure, then attempting to send two more good values. The values you would see printed from our `.sink()` closures are:

```

.sink() received oneValue
.sink() received twoValue
.sink() received replacement value
.sink() received the completion: finished

```

When the failure was sent through the pipeline, `catch` intercepts it and returns "replacement value" as expected. The replacement publisher it used (`Just`) sends a single value and then sends a completion. If we want the pipeline to remain active, we need to change how we handle the errors.

tryCatch

Summary

A variant of the `catch` operator that also allows an `<Error>` failure type, and doesn't convert the failure type to `<Never>`.

Constraints on connected publisher

- *none*

Usage

- [Requesting data from an alternate URL when the network is constrained](#)

Details

`tryCatch` is a variant of `catch` that has a failure type of `<Error>` rather than `catch`'s failure type of `<Never>`. This allows it to be used where you want to immediately react to an error by creating another publisher that may also produce a failure type.

assertNoFailure

Summary

Raises a fatal error when its upstream publisher fails, and otherwise republishes all received input and converts failure type to `<Never>`.

Constraints on connected publisher

- *none*

Usage

- [Verifying a failure hasn't happened using assertNoFailure](#)

Details

If you need to verify that no error has occurred (treating the error output as an invariant), this is the operator to use. Like its namesakes, it will cause the program to terminate if the assert is violated.

Adding it into the pipeline requires no additional parameters, but you can include a string:

```
.assertNoFailure()  
// OR  
.assertNoFailure("What could possibly go wrong?")
```



I'm not entirely clear on where that string would appear if you did include it.

When trying out this code in unit tests, the tests invariably drop into a debugger at the assertion point when a `.failure` is processed through the pipeline.

If you want to convert an failure type output of `<Error>` to `<Never>`, you probably want to look at the `catch` operator.

Apple asserts this function should be primarily used for testing and verifying "internal sanity checks that are active during testing".

retry

Summary

The retry operator is used to repeat requests to a previous publisher in the event of an error.

Constraints on connected publisher

- failure type must be `<Error>`

🍏 docs

<https://developer.apple.com/documentation/combine/publishers/retry>

Usage

- [Retrying in the event of a temporary failure](#)
- unit tests illustrating using `map` with `dataTaskPublisher`: [UsingCombineTests/DataTaskPublisherTests.swift](#)
- unit tests illustrating retry: [UsingCombineTests/RetryPublisherTests.swift](#)

Details

When you specify this operator in a pipeline and it receives a subscription, it first tries to request a subscription from its upstream publisher. If the response to that subscription fails, then it will retry the subscription to the same publisher.

The retry operator accepts an optional (but recommended) single parameter that specifies a number of retries to attempt. If no number of retries is specified, it will attempt to retry indefinitely until it receives a `.finished` completion from its subscriber.



Using retry without any specific count can result in your pipeline never resolving any data or completions. If you use retry without a count, you may also want to use the [timeout](#) operator to force a completion from the pipeline.

If the number of retries is specified and all requests fail, then the `.failure` completion is passed down to the subscriber of this operator.

In practice, this is mostly commonly desired when attempting to request network resources with an unstable connection. If you use a retry operator, you should add a specific number of retries so that the subscription doesn't effectively get into an infinite loop.

```

struct IPInfo: Codable {
    // matching the data structure returned from ip.jsontest.com
    var ip: String
}
let myURL = URL(string: "http://ip.jsontest.com")
// NOTE(heckj): you'll need to enable insecure downloads in your Info.plist for this
// example
// since the URL scheme is 'http'

let remoteDataPublisher = URLSession.shared.dataTaskPublisher(for: myURL!)
// the dataTaskPublisher output combination is (data: Data, response: URLResponse)
    .retry(3)
// if the URLSession returns a .failure completion, try at most 3 times to get a
// successful response
    .map({ (inputTuple) -> Data in
        return inputTuple.data
    })
    .decode(type: IPInfo.self, decoder: JSONDecoder())
    .catch { err in
        return Publishers.Just(IPInfo(ip: "8.8.8.8"))
    }
    .eraseToAnyPublisher()

```

mapError

- mapError
 - Converts any failure from the upstream publisher into a new error.

Adapting publisher types

switchToLatest

Summary

A publisher that flattens any nested publishers, using the most recent provided publisher.

Constraints on connected publisher

- none

🍏 docs

'switchToLatest'

Usage

- Declarative UI updates from user input
- Update the multiple pieces of your interface from a publisher update
- unit tests illustrating switchToLatest:
UsingCombineTests/SwitchAndFlatMapPublisherTests.swift

Details

`switchToLatest` is akin to `flatMap`, taking in a publisher instance and returning its value (or values). The primary difference is in where it gets the publisher. In `flatMap`, the publisher is returned within the closure provided to `flatMap`, and the operator works upon that to subscribe and provide the relevant value down the pipeline. In `switchToLatest`, the publisher instance is provided **as the output type** from a previous publisher or operator.

The most common form of using this is with a one-shot publisher such as `Just`, `Publishers.Once`, or getting its value as a result of a `map` transform.

It is also commonly used when working with an API that provides a publisher. `switchToLatest` assists in taking the result of the publisher and sending that down the pipeline rather than sending the publisher itself down as the output type.

The following snippet is part of the larger example [Declarative UI updates from user input](#)

```
.map { username -> AnyPublisher<GithubAPIUser, Never> in ②
    return GithubAPI.retrieveGithubUser(username: username) ①
}
// ^^ type returned in the pipeline is a Publisher, so we use
// switchToLatest to flatten the values out of that
// pipeline to return down the chain, rather than returning a
// publisher down the pipeline.
.switchToLatest() ③
```

- ① In this example, an API instance (`GithubAPI`) has a function that returns a publisher.
- ② We are using `map` to take an earlier `String` output type and use that to invoke the API, which returns a publisher instance.
- ③ We want to use the value from that publisher, not the publisher itself, which is exactly what `switchToLatest()` provides.

Controlling timing

debounce

Summary

debounce collapses multiple values within a specified time window into a single value

Constraints on connected publisher

- *none*

🍏 docs

['debounce'](#)

Usage

- unit tests illustrating using debounce:
`UsingCombineTests/debounceAndRemoveDuplicatesPublisherTests.swift`

Details

The operator takes a minimum of two parameters, an amount of time over which to debounce the signal and a scheduler on which to apply the operations. The operator will collapse any values received within the timeframe provided to a single, last value received from the upstream publisher within the time window.

This operator is frequently used with [removeDuplicates](#) when the publishing source is bound to UI interactions, primarily to prevent an "edit and revert" style of interaction from triggering unnessecary work.

If you wish to control the value returned within the timewindow provided, you may prefer to use [throttle](#), which allows you to choose the first or last value provided.

delay

- delay
 - Delays delivery of all output to the downstream receiver by a specified amount of time on a particular scheduler.
 - requires Failure to be `<Never>`

measureInterval

- measureInterval
 - Measures and emits the time interval between events received from an upstream publisher.
 - requires Failure to be `<Never>`

throttle

Summary

Publishes either the most-recent or first element published by the upstream publisher in the specified time interval.

Constraints on connected publisher

- none

🍏 docs

['throttle'](#)

Usage

- unit tests illustrating using throttle:
`UsingCombineTests/debounceAndRemoveDuplicatesPublisherTests.swift`

Details

Throttle is akin to the [debounce](#) operator in that it collapses values. The operator will collapse any values received within the timeframe provided to a single, last value received from the upstream publisher within the time window.

The operator takes a minimum of three parameters, **for**: an amount of time over which to collapse the values received, **scheduler**: a scheduler on which to apply the operations, and **latest**: a boolean indicating if the first value or last value should be chosen and forwarded.

This operator is frequently used with [removeDuplicates](#) when the publishing source is bound to UI interactions, primarily to prevent an "edit and revert" style of interaction from triggering unnessecary work.

```
.throttle(for: 0.5, scheduler: RunLoop.main, latest: false)
```

timeout

Summary

Terminates publishing if the upstream publisher exceeds the specified time interval without producing an element.

Constraints on connected publisher

- requires Failure to be `<Never>`

🍏 docs

<https://developer.apple.com/documentation/combine/publishers/timeout>

Usage

- unit tests illustrating using retry and timeout with dataTaskPublisher:
`UsingCombineTests/DataTaskPublisherTests.swift`

Details

Timeout will force a resolution to a pipeline after a given amount of time, but does not guarantee either data or errors, only a completion. If a timeout does trigger and force a completion, it will not generate an failure completion with an error.

Timeout is specified with two parameters, a time period and a scheduler.

If you are using a specific background thread (for example, with the [subscribe](#) operator), then timeout should likely be using the same scheduler.

The time period specified will take a literal integer, but otherwise needs to conform to the protocol [SchedulerTimeIntervalConvertible](#). If you want to set a number from a Float or Int, you need to create the relevant structure, as Int or Float directly doesn't conform. For example, if you're using a DispatchQueue, you could use [DispatchQueue.SchedulerTimeType.Stride](#).

```
let remoteDataPublisher = urlSession.dataTaskPublisher(for: self.mockURL!)
    .delay(for: 2, scheduler: backgroundQueue)
    .retry(5) // 5 retries, 2 seconds each ~ 10 seconds for this to fall through
    .timeout(5, scheduler: backgroundQueue) // max time of 5 seconds before failing
    .tryMap { data, response -> Data in
        guard let httpResponse = response as? HTTPURLResponse,
              httpResponse.statusCode == 200 else {
            throw testFailureCondition.invalidServerResponse
        }
        return data
    }
    .decode(type: PostmanEchoTimeStampCheckResponse.self, decoder: JSONDecoder())
    .subscribe(on: backgroundQueue)
    .eraseToAnyPublisher()
```

Encoding and decoding

encode

Summary

Encode converts the output from upstream Encodable object using a specified TopLevelEncoder. For example, use JSONEncoder or PropertyListEncoder..

Constraints on connected publisher

- Available when Output conforms to Encodable.

🍏 docs

<https://developer.apple.com/documentation/combine/publishers/encode>

Usage

- unit tests illustrating using encode and decode: `UsingCombineTests/EncodeDecodeTests.swift`

Details

The encode operator takes a single parameters:

- `encoder` an instance of an object conforming to `TopLevelEncoder`, frequently an instance of `JSONEncoder()` or `PropertyListEncoder()`.

```
fileprivate struct PostmanEchoTimeStampCheckResponse: Codable {
    let valid: Bool
}

let dataProvider = PassthroughSubject<PostmanEchoTimeStampCheckResponse, Never>()
    .encode(encoder: JSONEncoder())
    .sink { data in
        print(".sink() data received \(data)")
        let stringRepresentation = String(data: data, encoding: .utf8)
        print(stringRepresentation)
    })
```

Like the `decode` operator, the encode process can also fail and throw an error, so it returns a failure type of Error. With the compiler forcing type matching, the usual error condition is if you flow an optional value into the pipeline.

decode

Summary

A very common operation is to want to use decode (or `encode` data in a pipeline, so Combine provides an operator specifically suited to that task.

Constraints on connected publisher

- Available when Output conforms to Decodable.

Usage

- [Making a network request with dataTaskPublisher](#)
- [Stricter request processing with dataTaskPublisher](#)
- [Using catch to handle errors in a one-shot pipeline](#)
- [Retrying in the event of a temporary failure](#)
- unit tests illustrating using encode and decode: [UsingCombineTests/EncodeDecodeTests.swift](#)

Details

The decode operator takes two parameters:

- **type** which is typically a reference to a struct you've defined
- **decoder** an instance of an object conforming to [TopLevelDecoder](#), frequently an instance of [JSONDecoder\(\)](#) or [PropertyListDecoder\(\)](#).

Since decoding can fail, the operator will also return a failure type of Error. The data type returned by the operator is defined by the type you provided to decode.

```
let testUrlString = "https://postman-echo.com/time/valid?timestamp=2016-10-10"
// checks the validity of a timestamp - this one should return {"valid":true}
// matching the data structure returned from https://postman-echo.com/time/valid
fileprivate struct PostmanEchoTimeStampCheckResponse: Decodable, Hashable {
    let valid: Bool
}

let remoteDataPublisher = URLSession.shared.dataTaskPublisher(for: URL(string:
testUrlString!))
    // the dataTaskPublisher output combination is (data: Data, response: URLResponse)
    .map { $0.data }
    .decode(type: PostmanEchoTimeStampCheckResponse.self, decoder: JSONDecoder())
```

Working with multiple subscribers

multicast

- multicast

Debugging

breakpoint

- breakpoint
 - Raises a debugger signal when a provided closure needs to stop the process in the debugger.

breakpointOnError

- breakpointOnError
 - Raises a debugger signal upon receiving a failure.

handleEvents

Summary

`handleEvents` is an all purpose operator that allow you to specify closures be invoked when publisher events occur.

Constraints on connected publisher

- *none*

🍏 docs

<https://developer.apple.com/documentation/combine/publishers/handleevents>

Usage

- unit tests illustrating using `handleEvents:`
`UsingCombineTests/handleEventsPublisherTests.swift`

Details

`handleEvents` doesn't require any parameters, allowing you to specify what publisher events to which you'd like to respond. Optional closures can be provided for the following events:

- `receiveSubscription`
- `receiveOutput`
- `receiveCompletion`
- `receiveCancel`
- `receiveRequest`

All of the closures are expected to return `Void`, which makes `handleEvents` useful for intentionally creating side effects based on what is happening in the pipeline.

You could, for example, use `handleEvents` to update an `activityIndicator` UI element, triggering it on

with the receipt of the the subscription, and terminating with the receipt of either cancel or completion.

If you only want to view the information of what's happening, you might consider using the [print](#) operator instead.

```
.handleEvents(receiveSubscription: { _ in
    DispatchQueue.main.async {
        self.activityIndicator.startAnimating()
    }
}, receiveCompletion: { _ in
    DispatchQueue.main.async {
        self.activityIndicator.stopAnimating()
    }
}, receiveCancel: {
    DispatchQueue.main.async {
        self.activityIndicator.stopAnimating()
    }
})
```

print

Summary

Prints log messages for all publishing events.

Constraints on connected publisher

- *none*

🍏 docs

<https://developer.apple.com/documentation/combine/publishers/print>

Usage

- unit tests illustrating using print: [UsingCombineTests/PublisherTests.swift](#)

Details

The print operator doesn't require a parameter, but if provided will prepend any console output with the string provided.

The print is incredibly useful to see "what's happening" within a pipeline, and can be used as "printf" debugging within the pipeline to see events.

Most of the example tests illustrating the operators within this reference use a print operator to provide additional text output within the tests to show what's happening.

The print operator isn't directly integrated with Apple's OSLog unified logging, although there is an optional **to** parameter that lets you specify an instance conforming to [TextOutputStream](#) to which it will send the output.

```
let _ = foo.$username
.print(self.debugDescription)
.tryMap({ myValue -> String in
    if (myValue == "boom") {
        throw failureCondition.selfDestruct
    }
    return "mappedValue"
})
```

Scheduler and Thread handling operators

receive

Summary

Receive defines the scheduler on which to receive elements from the publisher.

Constraints on connected publisher

- *none*

🍏 docs

[receive](#)

Usage

- [Creating a subscriber with assign](#) shows an example of using assign to set an a boolean property on a UI element.
- unit tests illustrating using an assign subscriber in a pipeline from a dataTaskPublisher with subscribe and receive: [UsingCombineTests/SubscribeReceiveAssignTests.swift](#)

Details

Receive takes a single required parameter (**on:**) which accepts a scheduler, and an optional parameter (**optional:**) which can accept SchedulerOptions. [Scheduler](#) is a protocol in Combine, with the conforming types that are commonly used of [RunLoop](#), [DispatchQueue](#) and [OperationQueue](#). Receive is frequently used with [assign](#) to make sure any following pipeline invocations happen on a specific thread, such as [RunLoop.main](#) when updating user interface objects. Receive effects itself and any operators chained after it, but not previous operators. If you want to influence previously chained publishers (or operators) for where to run, use the [subscribe](#) operator.

```
examplePublisher.receive(on: RunLoop.main)
```

Receive takes a single

subscribe

Summary

Subscribe defines the scheduler on which to run operators in a pipeline.

Constraints on connected publisher

- *none*

🍏 docs

[subscribe](#)

Usage

- [Creating a subscriber with assign](#) shows an example of using assign to set an a boolean property on a UI element.

- unit tests illustrating using an assign subscriber in a pipeline from a dataTaskPublisher with subscribe and receive: [UsingCombineTests/SubscribeReceiveAssignTests.swift](#)

Details

Subscribe assigns a scheduler to any preceding pipeline invocations, and is often used to invoke a publisher on a background thread or queue. When used in this fashion, it is often used in coordination with [receive](#) to transfer data to another thread (such as the main runloop) for following operators or the subscriber.

Subscribe takes a single required parameter ([on:](#)) which accepts a scheduler, and an optional parameter ([optional:](#)) which can accept SchedulerOptions. [Scheduler](#) is a protocol in Combine, with the conforming types that are commonly used of [RunLoop](#), [DispatchQueue](#) and [OperationQueue](#).

Subscribe effects itself and any operators chained before it, but not following operators. If you want to influence chained operators after subscribe for where to run, use the [receive](#) operator. The most common example of this is receiving on [RunLoop.main](#), critical when updating user interface objects.

```
networkDataPublisher
    .subscribe(on: backgroundQueue) ①
    .receive(on: RunLoop.main) ②
    .assign(to: \.text, on: yourLabel) ③
```

- ① the [subscribe](#) call requests the publisher (and any pipeline invocations before this in a chain) be invoked on the backgroundQueue.
- ② the [receive](#) call transfers the data to the main runloop, suitable for updating user interface elements
- ③ the [assign](#) call uses the [assign](#) subscriber to update the property [text](#) on a KVO compliant object, in this case [yourLabel](#).



When creating a DispatchQueue to use with Combine publishers on background threads, it is recommended that you use a regular serial queue rather than a concurrent queue [to allow Combine to adhere to its contracts](#). That is - don't create the queue with [attributes: .concurrent](#).

Type erasure operators

eraseToAnyPublisher

- when you chain operators together in swift, the object's type signature accumulates all the various types, and it gets ugly pretty quickly.
- `eraseToAnyPublisher` takes the signature and "erases" the type back to the common type of `AnyPublisher`
- this provides a cleaner type for external declarations (framework was created prior to Swift 5's opaque types)
- `.eraseToAnyPublisher()`
- often at the end of chains of operators, and cleans up the type signature of the property getting assigned to the chain of operators

eraseToAnySubscriber

eraseToAnySubject

Subjects

General information on [Subjects](#) can be found in the Core Concepts section.

currentValueSubject

Summary

CurrentValue creates an object that can be used to integrate imperative code into a Combine pipeline, starting with an initial value.

🍏 docs

[CurrentValueSubject](#)

Usage

- [Update the multiple pieces of your interface from a publisher update](#)

Details

currentValueSubject creates an instance to which you can attach multiple subscribers. When creating a currentValueSubject, you do so with an initial value of the relevant output type for the Subject.

CurrentValue remembers the current value so that when a subscriber is attached, it immediately receives the current value. When a subscriber is connected to it and requests data, the initial value is sent. Further calls to `.send()` afterwards will then send those values to any subscribers.

PassthroughSubject

Summary

PassthroughSubject creates an object that can be used to integrate imperative code into a Combine pipeline.

🍏 docs

[PassthroughSubject](#)

Usage

- [Update the multiple pieces of your interface from a publisher update](#)

Details

PassthroughSubject creates an instance to which you can attach multiple subscribers. When it is created, only the types are defined.

When a subscriber is connected and requests data, it will not receive any values until a `.send()` call is invoked. Passthrough doesn't maintain any state, it only passes through provided values. Calls to `.send()` will then send values to any subscribers.

PassthroughSubject is commonly used in scenarios where you want to create a publisher from imperative code. One example of this might be a publisher from a delegate-callback structure, common in Apple's APIs. Another common use is to test subscribers and pipelines, providing you with imperative control of when events are sent within a pipeline. When creating tests, you can

send data (or a failure) is under test control.

Subscribers

For general information about subscribers and how they fit with publishers and operators, see [Subscribers](#).

assign

Summary

Assign creates a subscriber used to update a property on a KVO compliant object.

Constraints on connected publisher

- Failure type must be `<Never>`

🍏 docs

`assign`

Usage

- [Creating a subscriber with assign](#) shows an example of using assign to set an a boolean property on a UI element.
- unit tests illustrating using an assign subscriber in a pipeline from a dataTaskPublisher with subscribe and receive: `UsingCombineTests/SubscribeReceiveAssignTests.swift`

Details

Assign only handles data, and expects all errors or failures to be handled in the pipeline before it is invoked. The return value from setting up assign can be cancelled, and is frequently used when disabling the pipeline, such as when a viewController is disabled or deallocated. Assign is frequently used in conjunction with the `receive` operator to receive values on a specific scheduler, typically `RunLoop.main` when updating UI objects.

The type of KeyPath required for the assign operator is important. It requires a ReferenceWritableKeyPath, which is different from both WritableKeyPath and KeyPath. In particular, ReferenceWritableKeyPath requires that the object you're writing to is a reference type (an instance of a class), as well as being publicly writable. A WritableKeyPath is one that's a mutable value reference (a mutable struct), and KeyPath reflects that the object is simply readable by keypath, but not mutable.

It's not always clear (for example, while using code-completion from the editor) what a property may reflect.

If you try to assign to a property keypath and receive an error such as `Cannot convert value of type 'KeyPath<SomeObject, Bool>' to specified type 'ReferenceWritableKeyPath<SomeObject, Bool>'`, the error is because you're attempting to write to a property that is read-only.

```
examplePublisher
    .receive(on: RunLoop.main) ②
    .assign(to: \.text, on: yourLabel) ③
```

sink

Summary

Sink creates an all-purpose subscriber. At a minimum, you provide a closure to receive values, and optionally a closure that receives completions.

Constraints on connected publisher

- *none*

🍏 docs

[sink](#)

Usage

- [Creating a subscriber with sink](#) shows an example of creating a sink that receives both completion messages as well as data from the publisher.
- unit tests illustrating a sink subscriber and how it works: [UsingCombineTests/SinkSubscriberTests.swift](#)

Details

The simplest form of `.sink()` takes a single closure - by default this closure receives data (if provided by the attached publisher).

```
let examplePublisher = Just(5)

let _ = examplePublisher.sink { value in
    print(".sink() received \(String(describing: value))")
}
```

The closure you provide is invoked for every update that the publisher passes down, up until the completion. Be aware that the single closure form may be called repeatedly. How often it is called depends on the pipeline to which it is subscribing.

If you don't also include a closure to get the completion, you will not receive any information about failures. If an error or failure occurs and is handed down from the publisher the single closure form will not be called.

If you are creating a subscriber and want to receive failures, or see the completion messages at the end of pipeline, create a sink with two closures. The more complete sink has the two closures named `receiveCompletion` and `receiveValue`:

```
let examplePublisher = Just(5)

let _ = examplePublisher.sink(receiveCompletion: { err in
    print(".sink() received the completion", String(describing: err))
}, receiveValue: { value in
    print(".sink() received \(String(describing: value))")
})
```

The type that is passed into `receiveCompletion` is the enum `Subscribers.Completion`. The completion `.failure` includes an `Error` wrapped within it, providing access to the underlying cause of the failure. To get to the error within the `.failure` completion, `switch` on the returned completion to determine if it is `.finished` or `.failure`, and then pull out the error.

When you chain a `.sink` subscriber onto a publisher (or pipeline), the result is cancellable. At any time before the publisher sends a completion, the subscriber can send a cancellation and invalidate the pipeline. After a cancel is sent, no further values will be received by either closure in the sink.

```
let simplePublisher = PassthroughSubject<String, Error>()
let cancellablePipeline = simplePublisher.sink { data in
    // do what you need with the data...
}

cancellablePublisher.cancel() // this invalidates the pipeline, no further data will
be received by the sink
```

AnyCancellable

Summary

`AnyCancellable` type erases a subscriber to the general form of `Cancellable`.

🍏 docs

<https://developer.apple.com/documentation/combine/anycancellable>

Usage

- Declarative UI updates from user input
- Update the multiple pieces of your interface from a publisher update
- Creating a repeating publisher by wrapping a delegate based API

Details

This is used to provide a reference to a subscriber that allows the use of `cancel` without access to the subscription itself to request items. This is most typically used when you want a reference to a subscriber to clean it up on deallocation. Since the `assign` returns an `AnyCancellable`, this is often used when you want to save the reference to a `sink` as an `AnyCancellable`.

```
var mySubscriber: AnyCancellable?

let mySinkSubscriber = remotePublisher
    .sink { data in
        print("received ", data)
    }
mySubscriber = AnyCancellable(mySinkSubscriber)
```