



# Stanford CS193p

Developing Applications for iOS  
Fall 2017-18



CS193p  
Fall 2017-18



# Today

- Mostly more Swift but some other stuff too

- Quick demo of mutating protocols

- String

- NSAttributedString

- Closures (and functions as types in general)





# Data Structures

## • Four Essential Data Structure-building Concepts in Swift

class

struct

enum

protocol

## • struct

Value type (structs don't live in the heap and are passed around by copying them)

Very efficient "copy on write" is automatic in Swift

This copy on write behavior requires you to mark **mutating** methods

No inheritance (of data)

Mutability controlled via **let** (e.g. you can't add elements to an Array assigned by let)

Supports functional programming design

Examples: Card, Array, Dictionary, String, Character, Int, Double, UInt32

Let's jump over to Concentration and see what happens if we make Concentration a struct ...





# Data Structures

## • Four Essential Data Structure-building Concepts in Swift

class

struct

enum

protocol

## • protocol

A type which is a declaration of functionality only

No data storage of any kind (so it doesn't make sense to say it's a "value" or "reference" type)

Essentially provides multiple inheritance (of functionality only, not storage) in Swift

We'll "ease into" learning about protocols since it's new to most of you

Let's dive a little deeper into protocols ...





# Protocols

## • Protocols are a way to express an API more concisely

Instead of forcing the caller of an API to pass a specific class, struct, or enum, an API can let callers pass any class/struct/enum that the caller wants but can require that they implement certain methods and/or properties that the API wants. The API expresses the functions or variables it wants the caller to provide using a protocol. So a **protocol** is simply a collection of method and property declarations.

## • What are protocols good for?

Making API more flexible and expressive

Blind, structured communication between View and Controller (delegation)

Mandating behavior (e.g. the keys of a Dictionary must be hashable)

Sharing functionality in disparate types (String, Array, CountableRange are all Collections)

Multiple inheritance (of functionality, not data)





# Protocols

- A protocol is a TYPE

It can be used almost anywhere any other type is used: vars, function parameters, etc.





# Protocols

- There are three aspects to a protocol
  1. the protocol declaration (which properties and methods are in the protocol)
  2. a class, struct or enum declaration that makes the claim to implement the protocol
  3. the code in said class, struct or enum (or extension) that implements the protocol





# Protocols

## 👁 Optional methods in a protocol

Normally any protocol implementor must implement all the methods/properties in the protocol.

However, it is possible to mark some methods in a protocol **optional**

(don't get confused with the type Optional, this is a different thing).

Any protocol that has optional methods must be marked **@objc**.

And any class that implements an optional protocol must inherit from **NSObject**.

These sorts of protocols are used often in iOS for **delegation** (more later on this).

Except for delegation, a protocol with optional methods is rarely (if ever) used.

As you can tell from the @objc designation, it's mostly for backwards compatibility.





# Protocols

## 👁 Declaration of the protocol itself

```
protocol SomeProtocol : InheritedProtocol1, InheritedProtocol2 {  
    var someProperty: Int { get set }  
    func aMethod(arg1: Double, anotherArgument: String) -> SomeType  
    mutating func changeIt()  
    init(arg: Type)  
}
```





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You must specify whether a property is get only or both **get** and **set**





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Anyone that implements SomeProtocol must also implement InheritedProtocol1 and 2

You must specify whether a property is get only or both **get** and **set**

Any functions that are expected to mutate the receiver should be marked **mutating**





# Protocols

## 👁 Declaration of the protocol itself

```
protocol SomeProtocol : class, InheritedProtocol1, InheritedProtocol2 {  
    var someProperty: Int { get set }  
    func aMethod(arg1: Double, anotherArgument: String) -> SomeType  
    mutating func changeIt()  
    init(arg: Type)  
}
```

Anyone that implements SomeProtocol must also implement InheritedProtocol1 and 2

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(unless you are going to restrict your protocol to class implementers only with **class** keyword)





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Anyone that implements SomeProtocol must also implement InheritedProtocol1 and 2

You must specify whether a property is get only or both **get** and **set**

Any functions that are expected to mutate the receiver should be marked **mutating**

(unless you are going to restrict your protocol to class implementers only with **class** keyword)

You can even specify that implementers must implement a given **initializer**





# Protocols

- How an implementer says “I implement that protocol”

```
class SomeClass : SuperclassOfSomeClass, SomeProtocol, AnotherProtocol {  
    // implementation of SomeClass here  
    // which must include all the properties and methods in SomeProtocol & AnotherProtocol  
}
```

Claims of conformance to protocols are listed after the superclass for a class





# Protocols

- How an implementer says “I implement that protocol”

```
enum SomeEnum : SomeProtocol, AnotherProtocol {  
    // implementation of SomeEnum here  
    // which must include all the properties and methods in SomeProtocol & AnotherProtocol  
}
```

Claims of conformance to protocols are listed after the superclass for a class  
(obviously, enums and structs would not have the superclass part)





# Protocols

- How an implementer says “I implement that protocol”

```
struct SomeStruct : SomeProtocol, AnotherProtocol {  
    // implementation of SomeStruct here  
    // which must include all the properties and methods in SomeProtocol & AnotherProtocol  
}
```

Claims of conformance to protocols are listed after the superclass for a class  
(obviously, enums and structs would not have the superclass part)





# Protocols

- How an implementer says “I implement that protocol”

```
struct SomeStruct : SomeProtocol, AnotherProtocol {  
    // implementation of SomeStruct here  
    // which must include all the properties and methods in SomeProtocol & AnotherProtocol  
}
```

Claims of conformance to protocols are listed after the superclass for a class  
(obviously, enums and structs would not have the superclass part)

Any number of protocols can be implemented by a given class, struct or enum





# Protocols

## 👁 How an implementer says “I implement that protocol”

```
class SomeClass : SuperclassOfSomeClass, SomeProtocol, AnotherProtocol {  
    // implementation of SomeClass here, including ...  
    required init(...)  
}
```

Claims of conformance to protocols are listed after the superclass for a class  
(obviously, enums and structs would not have the superclass part)

Any number of protocols can be implemented by a given class, struct or enum

In a class, `inits` must be marked `required` (or otherwise a subclass might not conform)





# Protocols

- How an implementer says “I implement that protocol”

```
extension Something : SomeProtocol {  
    // implementation of SomeProtocol here  
    // no stored properties though  
}
```

Claims of conformance to protocols are listed after the superclass for a class  
(obviously, enums and structs would not have the superclass part)

Any number of protocols can be implemented by a given class, struct or enum

In a class, `inits` must be marked `required` (or otherwise a subclass might not conform)

You are allowed to add protocol conformance via an `extension`





# Protocols

- Using protocols like the type that they are!

```
protocol Moveable {  
    mutating func move(to point: CGPoint)  
}  
  
class Car : Moveable {  
    func move(to point: CGPoint) { ... }  
    func changeOil()  
}  
  
struct Shape : Moveable {  
    mutating func move(to point: CGPoint) { ... }  
    func draw()  
}
```

```
let prius: Car = Car()  
let square: Shape = Shape()
```





# Protocols

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# Protocols

- Using protocols like the type that they are!

```
protocol Moveable {  
    mutating func move(to point: CGPoint)
```

```
}
```

```
class Car : Moveable {  
    func move(to point: CGPoint) { ... }  
    func changeOil()
```

```
}
```

```
struct Shape : Moveable {  
    mutating func move(to point: CGPoint) { ... }  
    func draw()
```

```
}
```

```
let prius: Car = Car()
```

```
let square: Shape = Shape()
```

```
var thingToMove: Moveable = prius
```





# Protocols

- Using protocols like the type that they are!

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protocol Moveable {  
    mutating func move(to point: CGPoint)  
}
```

```
class Car : Moveable {  
    func move(to point: CGPoint) { ... }  
    func changeOil()  
}
```

```
struct Shape : Moveable {  
    mutating func move(to point: CGPoint) { ... }  
    func draw()  
}
```

```
let prius: Car = Car()
```

```
let square: Shape = Shape()
```

```
var thingToMove: Moveable = prius  
thingToMove.move(to: ...)
```





# Protocols

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```
protocol Moveable {  
    mutating func move(to point: CGPoint)  
}
```

```
class Car : Moveable {  
    func move(to point: CGPoint) { ... }  
    func changeOil()  
}
```

```
struct Shape : Moveable {  
    mutating func move(to point: CGPoint) { ... }  
    func draw()  
}
```

```
let prius: Car = Car()
```

```
let square: Shape = Shape()
```

```
var thingToMove: Moveable = prius  
thingToMove.move(to: ...)  
thingToMove.changeOil()
```





# Protocols

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struct Shape : Moveable {  
    mutating func move(to point: CGPoint) { ... }  
    func draw()  
}
```

```
let prius: Car = Car()  
let square: Shape = Shape()
```

```
var thingToMove: Moveable = prius  
thingToMove.move(to: ...)  
thingToMove.changeOil()  
thingToMove = square
```





# Protocols

- Using protocols like the type that they are!

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    func move(to point: CGPoint) { ... }  
    func changeOil()  
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struct Shape : Moveable {  
    mutating func move(to point: CGPoint) { ... }  
    func draw()  
}
```

```
let prius: Car = Car()  
let square: Shape = Shape()
```

```
var thingToMove: Moveable = prius  
thingToMove.move(to: ...)  
thingToMove.changeOil()  
thingToMove = square  
let thingsToMove: [Moveable] = [prius, square]
```





# Protocols

- Using protocols like the type that they are!

```
protocol Moveable {  
    mutating func move(to point: CGPoint)  
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}  
  
struct Shape : Moveable {  
    mutating func move(to point: CGPoint) { ... }  
    func draw()  
}
```

```
let prius: Car = Car()  
let square: Shape = Shape()
```

```
var thingToMove: Moveable = prius  
thingToMove.move(to: ...)  
thingToMove.changeOil()  
thingToMove = square  
let thingsToMove: [Moveable] = [prius, square]  
  
func slide(slider: Moveable) {  
    let positionToSlideTo = ...  
    slider.move(to: positionToSlideTo)  
}  
  
slide(prius)  
slide(square)
```





# Protocols

- Using protocols like the type that they are!

```
protocol Moveable {  
    mutating func move(to point: CGPoint)  
}  
  
class Car : Moveable {  
    func move(to point: CGPoint) { ... }  
    func changeOil()  
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```

```
let prius: Car = Car()  
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```

```
var thingToMove: Moveable = prius  
thingToMove.move(to: ...)  
thingToMove.changeOil()  
thingToMove = square  
let thingsToMove: [Moveable] = [prius, square]  
  
func slide(slider: Moveable) {  
    let positionToSlideTo = ...  
    slider.move(to: positionToSlideTo)  
}  
  
slide(prius)  
slide(square)  
  
func slipAndSlide(x: Slippery & Moveable)  
slipAndSlide(prius)
```

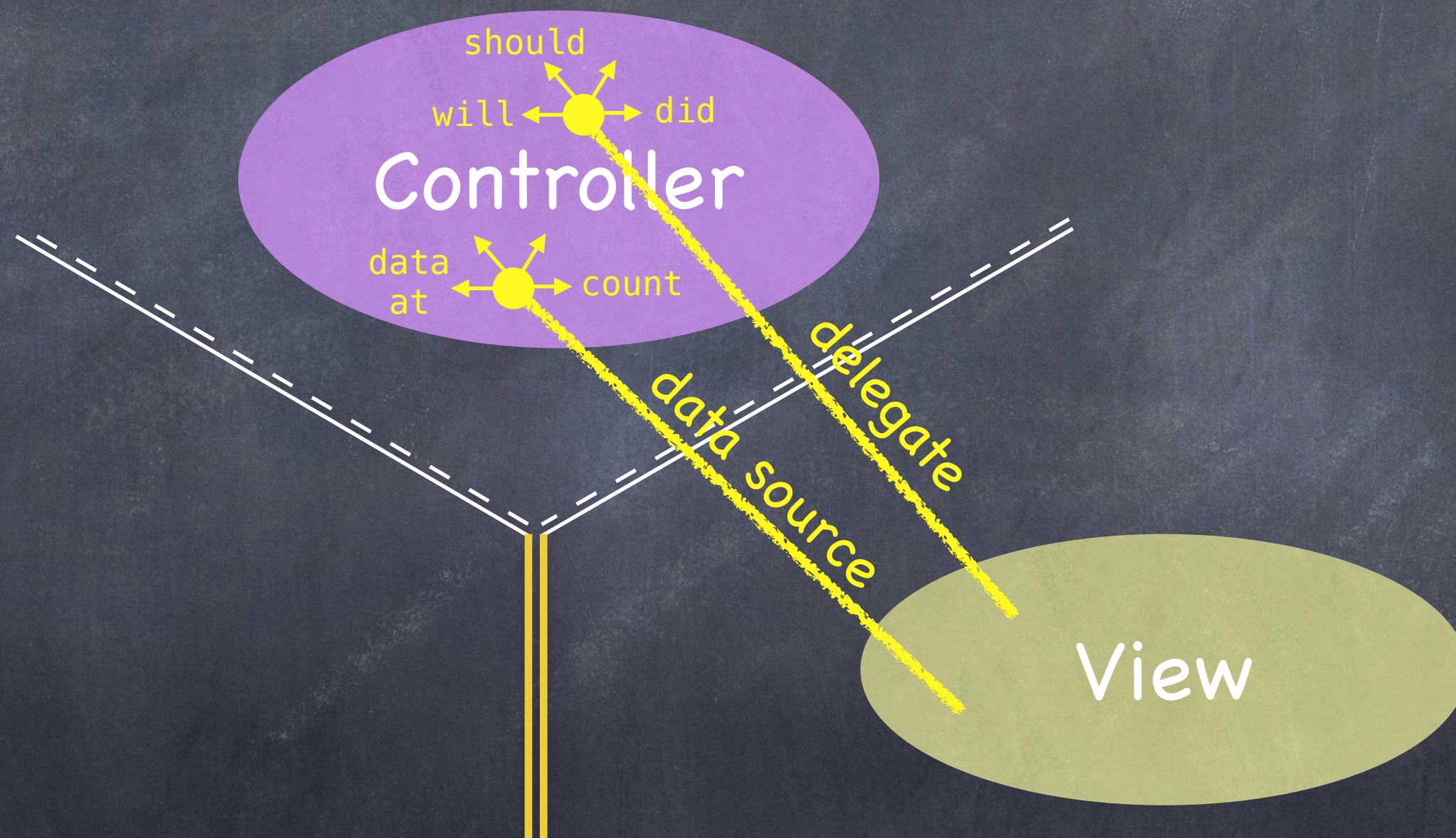




# Delegation

- A very important (simple) use of protocols

It's a way to implement "blind communication" between a View and its Controller





# Delegation

- A very important (simple) use of protocols

It's a way to implement "blind communication" between a View and its Controller

- How it plays out ...

1. A View declares a delegation protocol (i.e. what the View wants the Controller to do for it)
2. The View's API has a **weak delegate** property whose type is that delegation protocol
3. The View uses the delegate property to get/do things it can't own or control on its own
4. The Controller declares that it implements the protocol
5. The Controller sets delegate of the View to itself using the property in #2 above
6. The Controller implements the protocol (probably it has lots of optional methods in it)

- Now the View is hooked up to the Controller

But the View still has no idea what the Controller is, so the View remains generic/reusable

- This mechanism is found throughout iOS

However, it was designed pre-closures in Swift. Closures are sometimes a better option. We'll learn about closures soon.





# Delegation

## 👁 Example

UIScrollView (which we'll talk about next week) has a delegate property ...

```
weak var delegate: UIScrollViewDelegate?
```

The `UIScrollViewDelegate` protocol looks like this ...

```
@objc protocol UIScrollViewDelegate {  
    optional func scrollViewDidScroll(scrollView: UIScrollView)  
    optional func viewForZooming(in scrollView: UIScrollView) -> UIView  
    ... and many more ...  
}
```

A Controller with a UIScrollView in its View would be declared like this ...

```
class MyViewController : UIViewController, UIScrollViewDelegate { ... }
```

... probably in the @IBOutlet didSet for the scroll view, the Controller would do ...

```
scrollView.delegate = self
```

... and the Controller then would implement any of the protocol's methods it is interested in.





# Another use of Protocols

## • Being a key in a Dictionary

To be a key in a Dictionary, you have to be able to be unique.

A key in a Dictionary does this by providing an Int that is very probably unique (a hash) and then also by implementing equality testing to see if two keys are, in fact, the same.

This is enforced by requiring that a Dictionary's keys implement the Hashable protocol. Here's what that protocol looks like ...

```
protocol Hashable: Equatable {  
    var hashCode: Int { get }  
}
```

Very simple. Note, though, that Hashable inherits from Equatable ...





# Another use of Protocols

## • Being a key in a Dictionary

That means that to be Hashable, you also have to implement Equatable.

The Equatable protocol looks like this ...

```
protocol Equatable {  
    static func ==(lhs: Self, rhs: Self) -> Bool  
}
```

Types that conform to Equatable have to have a type function (note the `static`) called `==`

The arguments to `==` are both of that same type (i.e. `Self` of the type is the type itself)

The `==` operator also happens to look for such a static method to provide its implementation!





# Another use of Protocols

## 👁 Being a key in a Dictionary

Dictionary is then declared like this: `Dictionary<Key: Hashable, Value>`

This restricts keys to be things that conform to Hashable (there's no restriction on values)

Let's go make Card be Hashable.

Then we can use it directly as the key into our emoji Dictionary.

As a bonus, we'll be able to compare Cards directly since they'll be Equatable.

This will even allow us to make identifier be private in Card, which makes a lot of sense.





# Demo

## • Make Card struct Hashable and Equatable

Doing this allows us to make Card's identifier private

It also lets us look up Cards directly in a Dictionary (rather than with its identifier)

And we can use `==` to compare Cards directly

And for your homework, supporting Equatable lets you use `index(of:)` on an Array of things





# Advanced use of Protocols

## • “Multiple inheritance” with protocols

`CountableRange` implements many protocols, but here are a couple of important ones ...

`Sequence` — `makeIterator` (and thus supports `for in`)

`Collection` — subscripting (i.e. `[]`), `index(offsetBy:)`, `index(of:)`, etc.

## • Why do it this way?

Because `Array`, for example, also implements these protocols.

So now Apple can create generic code that operates on a `Collection` and it will work on both!

`Dictionary` is also a `Collection`, as is `Set` and `String`.

And they don't all just inherit the fact that they implement the methods in `Collection`,  
they actually inherit an implementation of many of the methods in `Collection`, because ...





# protocol & extension

## 👁 Using extension to provide protocol implementation

We said that protocol implementation is provided by implementing types (struct, enum, class). However, an **extension** can be used to add default implementation to a protocol. Since there's no storage, said implementation has to be in terms of other API in the protocol (and any API in any protocol that that protocol inherits from, of course).

For example, for the Sequence protocol, you really only need to implement `makeIterator`.

(An iterator implements the `IteratorProtocol` which just has the method `next()`.)

If you do, you will automatically get implementations for all these other methods in Sequence:

`contains()`, `forEach()`, `joined(separator:)`, `min()`, `max()`, even `filter()` and `map()`, et. al.

All of these are implemented via an extension to the Sequence protocol.

This extension (provided by Apple) uses only Sequence protocol methods in its implementation.

```
extension Sequence {  
    func contains(_ element: Element) -> Bool { }  
    // etc.  
}
```





# Advanced use of Protocols

## 👁 Functional Programming

By combining protocols with generics and extensions (default implementations), you can build code that focusses more on the behavior of data structures than storage.

This approach to development is called “functional programming.”

It is different than “object-oriented programming” (it’s sort of an evolution thereof).

We don’t have time to teach functional programming, but you are getting a taste of it.

What’s great about Swift is that it supports both paradigms.





# String

## 👁 The characters in a String

A String is made up of Unicodes, but there's also the concept of a **Character**. A **Character** is what a human would perceive to be a single lexical character. This is true even if a single **Character** is made up of multiple Unicodes.

For example, there is a Unicode which is "apply an accent to the previous character". But there is also a Unicode which is é (the letter e with an accent on it). So the string café might be 4 Unicodes (c-a-f-é) or 5 Unicodes (c-a-f-e-'). In either case, we perceive it as 4 **Characters**. Because of this ambiguity, the index into a String cannot be an Int. Is the p in "café pesto" at index 5 or index 6? Depends on the é. Indices into Strings are therefore of a different type ... **String.Index**. The simplest ways to get an index are **startIndex**, **endIndex** and **index(of:)**. There are other ways (see the documentation for more). To move to another index, use **index(String.Index, offsetBy: Int)**.





# String

## 👁 The characters in a String

```
let pizzaJoint = "café pesto"  
let firstCharacterIndex = pizzaJoint.startIndex // of type String.Index  
let fourthCharacterIndex = pizzaJoint.index(firstCharacterIndex, offsetBy: 3)  
let fourthCharacter = pizzaJoint[fourthCharacterIndex] // é  
  
if let firstSpace = pizzaJoint.index(of: " ") { // returns nil if " " not found  
    let secondWordIndex = pizzaJoint.index(firstSpace, offsetBy: 1)  
    let secondWord = pizzaJoint[secondWordIndex..  
pizzaJoint endIndex]  
}
```

Note the `..  
pizzaJoint endIndex` above.

This is a `Range` of `String.Index`.

`Range` is a generic type (like `Array` is). It doesn't have to be a range of `Ints`.

Another way to find the second word: `pizzaJoint.components(separatedBy: " ") [1]`  
`components(separatedBy:)` returns an `Array<String>` (might be empty, though, so careful!)





# String

## • The characters in a String

String is also a Collection (in the same sense that an Array is a Collection) of Characters  
All the indexing stuff (index(of:), etc.) is part of Collection.  
A Collection is also a Sequence, so you can do things like ...

```
for c in s { }           // iterate through all Characters in s  
let characterArray = Array(s) // Array<Character>
```

(Array has an init that takes any Sequence as an argument.)

## • A String is a value type (it's a struct)

We usually work with immutable Strings (i.e. `let s = ...`).

But there are mutating methods on String as well, for example ...

```
var s = pizzaJoint // makes a mutable copy of pizzaJoint (because it's a value type!)  
s.insert(contentsOf: " foo", at: s.index(of: " ")) // café foo pesto
```

The type of contentsOf: argument is any Collection of Character (which String is).





# String

## 👁 Other String Methods

```
func hasPrefix(String) -> Bool
```

```
func hasSuffix(String) -> Bool
```

```
var localizedCapitalized/Lowercase/Uppercase: String
```

```
func replaceSubrange(Range<String.Index>, with: Collection of Character)
```

```
e.g., s.replaceSubrange(..<s endIndex, with: "new contents")
```

Note the `.. Range appears to have no start! It defaults to the start of the String.`

And much, much more. Check out the documentation.





# Demo

## 👁️ Change our emojiChoices to be a String

It really doesn't matter either way

But it's a good opportunity to compare String and Array (which are surprisingly similar)

We'll also get a little bit of insight into the protocol-based design of the Foundation framework





# NSAttributedString

## • A String with attributes attached to each character

Conceptually, an object that pairs a String and a Dictionary of attributes for each Character.

The Dictionary's keys are things like "the font" or "the color", etc.

The Dictionary's values depend on what the key is (UIFont or UIColor or whatever).

Many times (almost always), large ranges of Characters have the same Dictionary.

Often (like in your homework), the entire NSAttributedString uses the same Dictionary.

You can put NSAttributedStrings on UILabels, UIButtons, etc.

Next week we'll also learn how to draw an NSAttributedString on the screen directly.





# NSAttributedString

## 👁 Creating and using an NSAttributedString

Here's how we'd make the flip count label have orange, outlined text ...

```
let attributes: [NSAttributedStringKey : Any] = [ // note: type cannot be inferred here
    .strokeColor : UIColor.orange,
    .strokeWidth : 5.0           // negative number here would mean fill (positive means outline)
]
let attribtext = NSAttributedString(string: "Flips: 0", attributes: attributes)
flipCountLabel.attributedText = attribtext // UIButton has attributedTitle
```





# NSAttributedString

## 👁 Peculiarities of NSAttributedString

NSAttributedString is a completely different data structure than String.

The “NS” is a clue that it is an “old style” Objective-C class.

Thus it is not really like String (for example, it’s a class, not a struct).

Since it’s not a value type, you can’t create a mutable NSAttributedString by just using var.

To get mutability, you have to use a subclass of it called **NSMutableAttributedString**.

NSAttributedString was constructed with **NSString** in mind, not Swift’s String.

NSString and String use slightly different encodings.

There is some automatic bridging between old Objective-C stuff and Swift types.

But it can be tricky with NSString to String bridging because of varying-length Unicodes.

This all doesn’t matter if the entire string has the same attributes (like in your homework).

Or if the NSAttributedString doesn’t contain “wacky” Unicode characters.

Otherwise, be careful indexing into the NSAttributedString.





# Demo

- Make flip count outlined text

Let's apply the code from the previous slide to Concentration





# Function Types

## 👁 Function types

Functions are people\* too! (\* er, types)

You can declare a variable (or parameter to a method or whatever) to be of type “function”

You’ll declare it with the types of the functions arguments (and return type) included

You can do this anywhere any other type is allowed

Example ...

```
var operation: (Double) -> Double
```

This is a var called operation

It is of type “function that takes a Double and returns a Double”

You can assign it like any other variable ...

```
operation = sqrt // sqrt is just a function that takes a Double and returns a Double
```

You can “call” this function using syntax very similar to any function call ...

```
let result = operation(4.0) // result will be 2.0
```





# Function Types

## 👁 Closures

Often you want to create the function “on the fly” (rather than already-existing like `sqrt`). You can do this “in line” using a closure.

Imagine we had a function that changed the sign of its argument ...

```
func changeSign(operand: Double) -> Double { return -operand }
```

We could use it instead of `sqrt` ...

```
var operation: (Double) -> Double
```

```
operation = changeSign
```

```
let result = operation(4.0) // result will be -4.0
```





# Function Types

## 👁 Closures

Often you want to create the function “on the fly” (rather than already-existing like `sqrt`). You can do this “in line” using a closure.

Imagine we had a function that changed the sign of its argument ...

```
func changeSign(operand: Double) -> Double { return -operand }
```

We can “in line” `changeSign` simply by moving the function (without its name) below ...

```
var operation: (Double) -> Double
```

```
operation = changeSign
```

```
let result = operation(4.0) // result will be -4.0
```





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operation = (operand: Double) -> Double { return -operand }  
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A minor syntactic change: Move the first `{` to the start and replace with `in` ...

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operation = (operand: Double) -> Double { return -operand }
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Swift can infer that `operation` returns a `Double`

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Imagine we had a function that changed the sign of its argument ...

Swift can infer that `operation` returns a `Double` and that operand is a `Double`

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var operation: (Double) -> Double
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```
operation = { (operand: Double) in return -operand }
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Imagine we had a function that changed the sign of its argument ...

It also knows that `operation` returns a value, so the `return` keyword is unnecessary

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var operation: (Double) -> Double  
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Imagine we had a function that changed the sign of its argument ...

And finally, it'll let you replace the parameter names with `$0`, `$1`, `$2`, etc., and skip `in` ...

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var operation: (Double) -> Double
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operation = { -$0 }
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Imagine we had a function that changed the sign of its argument ...

That is about as succinct as possible!

```
var operation: (Double) -> Double
```

```
operation = { -$0 }
```

```
let result = operation(4.0) // result will be -4.0
```





# Closures

## 👁 Where do we use closures?

Often as arguments to methods.

Many times a method wants to know “what to do” and providing a function tells it what to do.

For example, what to do when there’s an error or when something asynchronous finishes.

Or maybe you want to ask some method to repeatedly perform a function ...





# Closures

## 👁 Where do we use closures?

Array has a method called `map` which takes a function as an argument.

It applies that function to each element of the Array to create and return a new Array.

```
let primes = [2.0, 3.0, 5.0, 7.0, 11.0]
let negativePrimes = primes.map({ -$0 }) // [-2.0, -3.0, -5.0, -7.0, -11.0]
let invertedPrimes = primes.map() { 1.0/$0 } // [0.5, 0.333, 0.2, etc.]
let primeStrings = primes.map { String($0) } // ["2.0", "3.0", "5.0", "7.0", "11.0"]
```

Note that if the last (or only) argument to a method is a closure,  
you can put it outside the method's parentheses that contain its arguments  
and if the closure was the only argument, you can skip the `()` completely if you want.





# Closures

## 👁 Closures with property initialization

You can also execute a closure to do initialization of a property if you want ...

```
var someProperty: Type = {  
    // construct the value of someProperty here  
    return <the constructed value>  
}()
```

This is especially useful with **lazy** property initialization.





# Closures

## 👁 Capturing

Closures are regular types, so they can be put in Arrays, Dictionarys, etc.

When this happens, they are stored in the heap (i.e. they are reference types).

What is more, they “capture” variables they use from the surrounding code into the heap too. Those captured variables need to stay in the heap as long as the closure stays in the heap.

```
var ltuae = 42
operation = { ltuae * $0 } // “captures” the ltuae var because it’s needed for this closure
arrayOfOperations.append(operation)
// if we later change ltuae, then the next time we evaluate operation it will reflect that
// even if we leave the scope (function or whatever) that this code is in!
```

This can create a memory cycle though.

We’ll see this later in the quarter and how to avoid that.





# Demo

## 👁 Improve `indexOfOneAndOnlyFaceUpCard` implementation

We probably used more lines of code to make `indexOfOneAndOnlyFaceUpCard` computed  
However, a better implementation using a method that takes a closure would fix that

