CS 326
DispatchQueues, Equality, and Hashing

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Swift Access Levels

- **public**
  - reusable components
  - only operations for clients
- **private**
  - internal representation
  - helper methods
- **internal (default)**
  - module's internal classes/code
  - eg: Controllers specialized for single app

Multithreading

- **DispatchQueues**
  - global: general work queues
  - main: serialized UI event queue
- **Put code to run on queue:**
  - `queue.async { body }`
- **General pattern:**
  ```swift
  DispatchQueue.global.async {
    let data = ...long or blocking operation...
    DispatchQueue.main.async {
      update model and UI elements using data
    }
  }
  ```

Animation Until Some Condition

In `WindowController`:

```swift
func oneStep() {
    DispatchQueue.global.async {
        usleep(microseconds) or other time consuming work
        DispatchQueue.main.async {
            if (!timeToEnd) {
                update model and UI elements
                self?.oneStep()
            }
        }
    }
}
```

- **See AnimatedConnectTheDots** for full example
Equivalence Relation

- Reflexive: \( a = a \)
- Symmetric: \( a = b \) iff \( b = a \)
- Transitive: if \( a = b \) and \( b = c \), then \( a = c \)

Reference Equality: ===

```java
public class Duration {
    // Rep Inv: min >= 0 && 0 <= sec < 60
    public let min : Int
    public let sec : Int
    public init(_ min : Int, _ sec : Int) {
        assert(min >= 0 && 0 <= sec && sec < 60)
        self.min = min
        self.sec = sec
    }
    let d1 = Duration(3, 10)
    let d2 = Duration(3, 10)
    let d3 = d1
    d1 == d2? d1 == d3? d2 == d3?
}
```

Equatable Protocol

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

From Specification:

Equality implies substitutability—any two instances that compare equally can be used interchangeably in any code that depends on their values. To maintain substitutability, the `==` operator should take into account all visible aspects of an Equatable type...

Since equality between instances of Equatable types is an equivalence relation, any of your custom types that conform to Equatable must satisfy three conditions, for any values \( a, b, \) and \( c \):

- \( a == a \) is always true (Reflexivity)
- \( a == b \) implies \( b == a \) (Symmetry)
- \( a == b \) and \( b == c \) implies \( a == c \) (Transitivity)

Equatable Durations

```swift
public class Duration : Equatable {
    // Rep Inv: min >= 0 && 0 <= sec < 60
    public let min : Int
    public let sec : Int
    ...
    static public func ==(d1: Duration, d2: Duration) -> Bool {
        return d1.min == d2.min && d1.sec == d2.sec
    }
}
```

```swift
let d1 = Duration(3, 10)
let d2 = Duration(3, 10)
let d3 = d1
```

```swift
d1 == d2? d1 == d3? d2 == d3?
```
Equatable Durations (2)

```swift
public class Duration : Equatable {

    // Rep Inv: min >= 0 && 0 <= sec < 60
    public let min : Int
    public let sec : Int

    //

    static public func ==( _ d1: Duration, _ d2: Duration) -> Bool {
        return d1.min * 60 + d1.sec == d2.min * 60 + d2.sec
    }

    let d1 = Duration(3, 10)
    let d2 = Duration(3, 10)
    let d3 = d1

    d1 == d2?
    d1 == d3?
    d2 == d3?
}
```

Equatable Durations (3)

```swift
public class Duration : Equatable {

    // Rep Inv: min >= 0 && 0 <= sec < 60
    public let min : Int
    public let sec : Int

    ...

    static public func ==( _ d1: Duration, _ d2: Duration) -> Bool {
        return d1.min == d2.min
    }

    let d1 = Duration(3, 10)
    let d2 = Duration(3, 10)
    let d3 = d1

    d1 == d2?
    d1 == d3?
    d2 == d3?
}
```

Swift Details

- You get == for free with:
  - enums
  - structs containing Equatables
  - tuples containing Equatables

- == is a static method
  - Compile-time resolution of operand types.
  - Not like .equals in Java
    - leads to tricky run-time resolution of method calls
    - more in 334...

Subclassing and ==

```swift
public class LabelledDuration : Duration{

    public let label : String
}

let d1 = LabelledDuration(1,50,"A")
let d2 = LabelledDuration(2,50,"B")
let d3 = LabelledDuration(2,50,"C")
```

```swift
d1 == d2?
```

```swift
d1 == d3?
```

```swift
d2 == d3?
```
Subclassing and ==

```
public class ComparableDuration : Duration, Comparable {
    public static func <=(_ d1: ComparableDuration, _ d2: ComparableDuration) -> Bool {
        return d1.min < d2.min || (d1.min == d2.min && d1.sec < d2.sec)
    }
}
```

```
let d1 = ComparableDuration(1,50)
let d2 = ComparableDuration(2,50)
let d3 = ComparableDuration(2,50)
assert(d1 < d2)
assert(d2 > d1)
assert(d2 >= d3)
```

Subclassing and ==

```
public class NanoDuration : Duration {
    public let nano : Int
    public init(_ min : Int, _ sec : Int, _ nano : Int) {
        self.nano = nano
        super.init(min, sec)
    }
}
```

```
let n1 = NanoDuration(0,50,100)
let n2 = NanoDuration(0,50,200)
let n3 = NanoDuration(0,50,200)
assert(n1 == n2)
assert(n1 == n3)
assert(n2 == n3)
```

Subclassing and ==

```
public class NanoDuration : Duration {
    public let nano : Int
    public init(_ min : Int, _ sec : Int, _ nano : Int) {
        self.nano = nano
        super.init(min, sec)
    }
}
```

```
let d1 = Duration(0,50)
let d2 = NanoDuration(0,50,100)
let d3 = NanoDuration(0,50,200)
assert(d1 == d2)
assert(d1 == d3)
assert(d2 == d3)
```

But...

```
let d1 = Duration(0,50)
let d2 = NanoDuration(0,50,100)
let d3 = NanoDuration(0,50,200)
```

```
d1 == d2?
d1 == d3?
d2 == d3?
```
Composition (Delegation)

```swift
public class NanoDuration {
    public let duration : Duration
    public let nano : Int

    public static func ==(d1: NanoDuration, d2: NanoDuration) -> Bool {
        return d1.duration == d2.duration && d1.nano == d2.nano
    }
}

• Tradeoffs?
```

Hashable Protocol

- I want a set of Durations:

```swift
var x = Set<Duration>()
error: type 'Duration' does not conform to protocol 'Hashable'
```

- Protocol definition:

```swift
protocol Hashable : Equatable {
    var hashValue : Int
}
```

Hashable Protocol Spec

- You can use any type that conforms to the Hashable protocol in a set or as a dictionary key... A hash value, provided by a type's hashValue property, is an integer that is the same for any two instances that compare equally. That is, for two instances a and b of the same type, if a == b, then a.hashValue = b.hashValue. The reverse is not true: Two instances with equal hash values are not necessarily equal to each other.

- So:
  - Consistent with equality:
    - a == b ⇒ a.hashValue == b.hashValue
  - Self-consistent:
    - a == a, so a.hashValue = a.hashValue
    - ...so long as a doesn’t change between reads

Implementing hashValue

```swift
public class Duration : Equatable, Hashable {
    public static func ==(d1: Duration, d2: Duration) -> Bool {
        return d1.min == d2.min && d1.sec == d2.sec
    }

    public var hashValue : Int {
        return 1
        return min
        return min ^ sec
        return 31 * min + sec
        return 60 * min + sec
    }
}
```
Implementing hashValue (2)

```swift
public class Duration : Equatable, Hashable {
    public static func ==(_ d1: Duration, _ d2: Duration) -> Bool {
        return d1.min * 60 + d1.sec == d2.min * 60 + d2.sec
    }

    public var hashValue: Int {
        return 1
        return min
        return min ^ sec
        return 31 * min + sec
        return 60 * min + sec
    }

    }
}
```

Equality and Time

- If two immutable objects are equal now, will they always be equal?

```swift
let d1 = Duration(10, 50)
let d2 = Duration(10, 50)
assert(d1==d2)
...
assert(d1==d2)
```

- Yes! Abstract value never changes
  - Equality is forever, even if rep changes (benevolent side effect)
- **Behavioural Equivalence**: if a == b, then no sequence of operations applied to a and b can distinguish them.

Equality and Time

- If two mutable objects are equal now, will they always be equal?

```swift
let d1 = MutableDuration(10, 50)
let d2 = MutableDuration(10, 50)
assert(d1==d2)
as1.min = 5
assert(d1==d2)
```

- No! Abstract value may change
- **Observational Equivalence**: if a == b, then no sequence of observer operations can distinguish them.

Added After Lecture: Overflows

- Integer operations may crash due to overflow.

```swift
public class Pair : Hashable {
    let s1 : String
    let s2 : String

    var hashValue : Int {
        return s1.hashValue + s2.hashValue
    }
}
```

- To avoid:
  - use overflow-permitting math operators:
    - `s1.hashValue &+ s2.hashValue`
    - `31 &* value1 &+ value2`
  - xor if the values are uniformly distributed (ie, other hashValues):
    - `s1.hashValue ^ s2.hashValue`

```
Sum could be greater than Int.max or less than Int.min!
```
Observational Equivalence Pitfalls

let set = Set<MutableDuration>()
let d1 = Duration(10,50)
let d2 = Duration(20,20)
set.add(d1)
set.add(d2)
d1.min = 20
for d in set {
  print(d)
}

• Set's Rep Invariant is broken by mutation after insertion
  – How could we avoid this? Why don't we do that?

Notions of Equality

• \( a =\!\!\!= b \) iff:
  – Reference: \( a \) and \( b \) are the same object
  – Behavioral: \( a \) and \( b \) cannot be distinguished by any sequence of operations
  – Observational: \( a \) and \( b \) cannot be distinguished by any sequence of observer operations