CS 326
Specification & ADTs

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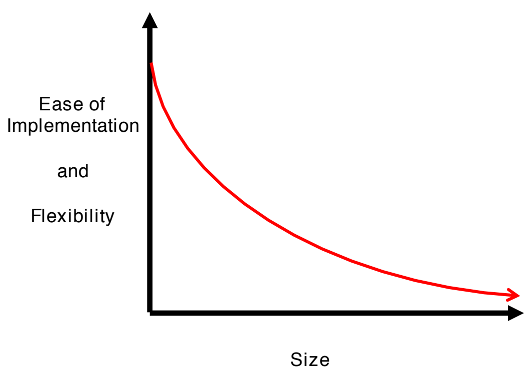
Where we are

- Basics of Reasoning about code
- Coming up
  - **Specification**: What are we supposed to build?
  - **Design**: Abstraction. Which designs are "better"?
  - **Implementation**: Building code to meet a specification
  - **Testing**: Systematically finding problems
  - **Debugging**: Systematically fixing problems
  - **Maintenance**: How does the artifact adapt over time?
  - **Documentation**: What do we need to know to do these things? How/where do we write that down?

Scaling Software Systems



Class Interface

```
class MutableList<T : Comparable> {

  var count : Int
  func get(index: Int) -> T { ... }
  func set(index: Int, to value: T) -> T { ... }
  func append(_ t : T) { ... }
  ...

  static func isSubsequence(_ part : MutableList<T>,
                            of list: MutableList<T>) -> Bool {
    ...
  }

}
```

Just Read The Code

```
static func isSubsequence(_ part : MutableList<T>,
                          of list: MutableList<T>) -> Bool {
  var partIndex = 0
  for element in list {
    if element == part.get(partIndex) {
      partIndex += 1
      if partIndex == part.count {
        return true
      }
    } else {
      partIndex = 0
    }
  }
  return false
}
```

Just Read The Comments

```
// Check whether part appears as a contiguous subsequence
// of list.
static func isSubsequence(_ part : MutableList<T>,
                          of list: MutableList<T>) -> Bool {
  var partIndex = 0
  for element in list {
    if element == part.get(partIndex) {
      partIndex += 1
      if partIndex == part.count {
        return true
      }
    } else {
      partIndex = 0
    }
  }
  return false
}
```

Write Appropriate Specification

```
// Check whether part appears as a contiguous subsequence
// of list.
```

- Document Caveats

```
// * If list is empty, always returns false
// * Results may be unexpected if partial matches
//   can happen right before a real match; e.g.,
//   (1,2,1,3) will not be identified as a
//   sub sequence of (1,2,1,2,1,3).
```

- Or Replace with More Detailed Behaviour

```
// This method scans "list" from beginning
// to end, building up a match for "part", and
// resetting that match every time that...
```

Write Better Code… (And Spec)

```
// Returns true iff there exist possibly empty
// sequences A, B where
//   list = A : part : B
// and ":" is sequence concatenation.
static func isSubsequence(_ part : MutableList<T>,
                          of list: MutableList<T>) -> Bool
  ...
}
```

Quick Help For Array.firstIndex(of:)

```
59      if let index = data.firstIndex(of: x) {
60        print(index)
```

Summary

Returns the first index where the specified value appears in the collection.

Declaration

```
func firstIndex(of element: Element) -> Int?
```

Discussion

After using `firstIndex(of:)` to find the position of a particular element in a collection, you can use it to access the element by subscripting. This example shows how you can modify one of the names in an array of students.

```
var students = ["Ben", "Ivy", "Jordell", "Maxime"]
if let i = students.firstIndex(of: "Maxime") {
    students[i] = "Max"
}
print(students)
// Prints "["Ben", "Ivy", "Jordell", "Max"]"
```

Complexity

O(*n*), where *n* is the length of the collection.

Parameters

`element` An element to search for in the collection.

Returns

The first index where `element` is found. If `element` is not found in the collection, returns `nil`.

Swift Developer Documentation

Swift 〉 Array 〉 func firstIndex(of: Element) -> Int?

Instance Method

firstIndex(of:)

Returns the first index where the specified value appears in the collection.

Declaration

```
func firstIndex(of element: Element) -> Int?
```

Parameters

`element`
An element to search for in the collection.

Return Value

The first index where `element` is found. If `element` is not found in the collection, returns `nil`.

Discussion

Swift Comments

```
/**
 Returns the first index where the specified value appears in the collection.

 After using `firstIndex(of:)` to find the position of a particular
 element in a collection, you can use it to access the element by
 subscripting. This example shows how you can modify one of the names in
 an array of students.

 ```
 var students = ["Ben", "Ivy", "Jordell", "Maxime"]
 if let i = students.firstIndex(of: "Maxime") {
     students[i] = "Max"
 }
 print(students)
 // Prints "["Ben", "Ivy", "Jordell", "Max"]"
 ```

 - Parameter element: An element to search for in the collection.

 - Returns: The first index where element is found. If element is
   not found in the collection, returns nil.
 */
```

CS326 Specifications

```
/**
 ...

 **Requires**: none (can omit in this case)

 **Modifies**: self

 **Effects**: Changes the first occurrence of oldValue to newValue

 - Parameter oldValue: element to replace.
 - Parameter newValue: what to replace it with.
 - Returns: The first index where oldValue is found, or nil
   if it does not occur in the list.
 */
func replace(_ oldValue: T, with newValue: T) -> Int? {
  for i in 0..<count {
    if get(i) == oldValue {
      set(i, to: newValue)
      return i
    }
  }
  return nil
}
```

CS326 Specification Pieces

- **Precondition**: constraints that hold before the method is called (if not, all bets are off)
  - **Requires**: spells out any obligations on client
- **Postcondition**: constraints that hold after the method is called (if the precondition held)
  - **Modifies**: lists objects that may be affected by method; any object not listed is guaranteed to be untouched
  - **Effects**: gives guarantees on final state of modified objects
  - Standard "Returns" tag
  - Standard "Throws": lists possible exceptions and conditions under which they are thrown (won't worry about for now)

CS326 Specifications

```
/**
 ...

 **Requires**: list1 and list2 are the same size

 **Modifies**: none

 **Effects**: none

 - Parameter list1: ...
 - Parameter list2: ...

 - Returns: A list of the same size as the parameters, where
 the ith element is the sum of the ith elements of list1 and list2
 */
static func pointwiseSum(_ list1 : MutableList<Int>,
                         _ list2 : MutableList<Int>) -> MutableList<Int> {
  let result = MutableList<Int>()
  for i in 0..<list1.count {
    result.append(list1.get(i)  + list2.get(i))
  }
  return result
}
```

CS326 Specifications

```
/**
 ...

 **Requires**: list1 and list2 are the same size

 **Modifies**: list1

 **Effects**: the ith element of other is added
              to the ith element of self

 */
func add(_ list1: MultableList<Int>,
         _ list2 : MutableList<Int>) {
  for i in 0..<count {
    list1.set(i, list1.get(i) + list2.get(i))
  }
}
```

CS326 Specifications

```
/**
 ...

 **Requires**: ??

 **Modifies**: ??

 **Effects**: ??

 */
func uniquify() {
  for i in 0..<count-1 {
    if get(i) == get(i+1) {
      remove(i)
    }
  }
}
```

Satisfaction of a Specification

- Let M be an implementation and S a specification
- **M satisfies S** if and only if
  - Every behavior of M is permitted by S
- If M does not satisfy S, either (or both!) could be "wrong"
  - Usually better to change the program than the spec

Comparing Specifications

- Specification **S1 is weaker than S2**, if for all M,

  M satisfies S2 => M satisfies S1

- A weaker specification gives greater freedom to the implementer

Which is Weaker? A or B?

```
func index(of element: Element) -> Int? {
  for i in 0..<count {
    if get(i) == element {
      return i
    }
  }
  return nil
}
```

Weaker Specification:
- Implementer: Easier to satisfy (more implementations satisfy it)
- Client: Harder to use (fewer guarantees)

Specification A
- requires: value occurs in self
- returns: `i` such that `get(i)` = `value`

Specification B
- requires: value occurs in `self`
- returns: *smallest* `i` such that `get(i)` = `value`

Which is Weaker? A or C?

```
func index(of element: Element) -> Int? {
  for i in 0..<count {
    if get(i) == element {
      return i
    }
  }
  return nil
}
```

Specification A
- requires: value occurs in `self`
- returns: `i` such that `get(i)` = `value`

Specification C
- returns: `i` such that `get(i)` = `value`, or `nil` if value is not in `self`

Weakening a Specification

- Promise Less
  - Weaker Postcondition
    - Returns clause easier to satisfy
    - More objects in modifies clause
    - Effects clause easier to satisfy
    - Fewer specific exceptions
- Ask more of client
  - Stronger Precondition
    - Requires clause harder to satisfy

(Strengthening: The Opposite)

Returns: smallest possible index of key in items
➔
Returns: index of key in items

Modifies: none
➔
Modifies: list1, list2

Effects: self.x == old(self.x) + dx
➔
Effects: self.x > old(self.x) + dx

Requires: self is not the Cartesian origin
➔
Requires: self is a Cartesian point in the first quadrant

Stronger and Weaker Specifications

- Weaker specification:
  - Implementer: Easier to satisfy (more implementations satisfy it)
  - Client: Harder to use (fewer guarantees)
- Stronger specification:
  - Implementer: Harder to satisfy
  - Client: Easier to use (more guarantees, more predictable, can make more assumptions)

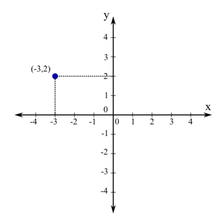
Which is Better?

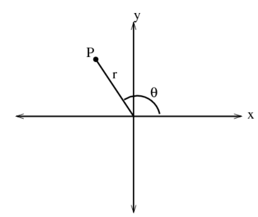
- Stronger does not always mean better!
- Weaker does not always mean better!
- Strength of specification trades off:
  - Usefulness to client
  - Ease of simple, efficient, correct implementation
  - Promotion of reuse and modularity
  - Clarity of specification itself
- "It depends"

Two Representations of Points

```
class Point {
  public float x;
  public float y;
}
```

```
class Point {
  public float r;
  public float theta;
}
```





Point ADT

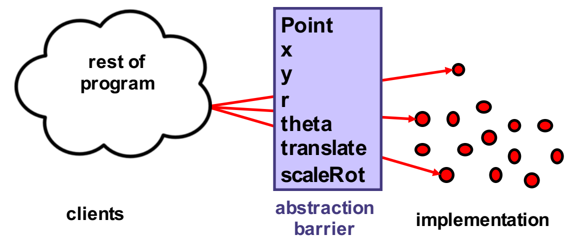
```
public class Point {
  // A 2-d point exists in the plane, ...
  public var x : Double
  public var y : Double
  public var r : Double
  public var theta : Double
  // ... can be created, ...
  public init() // new point at (0,0)
  public init(points : Set<Point>) // centroid
  // ... can be moved, ...
  public func translate(dx: Double, dy: Double)
  public func scaleAndRotate(dr: Double,
                             dTheta: Double)
}
```

Observers – may be actual or **computed** properties.

Creators/ Producers

Mutators

Abstract Data Type = Objects + Ops



Poly: Overview and Abstract State

```
/**
   A Poly is an immutable polynomial with
   integer coefficients.  A typical Poly is
     c_0 + c_1 * x + c_2 * x^2 + ...
 */
public class Poly {
```

Abstract state (specification fields)

Poly: Creators

```
/// **Effects**: makes a new Poly = 0
public init()

/// **Requires**: n >= 0
/// **Effects**: makes a new Poly = c * x^n
public init(c: Int, n: Int)
```

(Note: full specs omitted to save space; style might not be perfect either – focus on main ideas.)

Poly: Observers

```
/// The degree of self, ie largest exponent with a
/// non-zero coefficient, or 0 if self = 0.
public var degree : Int

/**
 **Requires**: d >= 0

 - Returns: The coefficient of the term of self whose
 exponent is d.
 */
public func coefficient(for d: Int) -> Int
```

Poly: Producers

```
/// - Returns: self + q, as a Poly
public func add(_ q : Poly) -> Poly

/// - Returns: self * q, as a Poly
public func mul(_ q : Poly) -> Poly

/// - Returns: -self
public func negate() -> Poly
```

```
let p = Poly(2,4)
let q = p.mul(p)
let r = q.negate()
```

Aside: Operator Overloading

```
/// - Returns: p + q
static public func +(_ p : Poly, _ q : Poly) -> Poly

/// - Returns: p * q
static public func *(_ p : Poly, _ q : Poly) -> Poly

/// - Returns: - p
static public prefix func -(_ p : Poly) -> Poly
```

```
let p = Poly(2,4)
let q = p * p
let r = -q
```

IntSet: Overview, Abs State, Creator

```
/// Overview: An IntSet is a mutable,
/// unbounded set of integers.  A typical
/// IntSet is { x1, ..., xn }.
class IntSet {

  /// **Effects**: makes a new IntSet = {}
  public init()
```

IntSet: Observers

```
/// - Returns: true if and only if element in self
public func contains(_ element: Int) -> Bool

/// Number of elements in the set
public var count : Int

/// - Returns: Some element of self.
/// - Throws: EmptyError if self is empty
public func choose() throws -> Int
```

IntSet: Mutators

```
/// **Modifies**: self
/// **Effects**: self_post = self_pre U { element }
public func add(_ element : Int)

/// **Modifies**: self
/// **Effects**: self_post = self_pre - { element }
public func remove(_ element : Int)
```