Concepts in Object-Oriented Languages

Mitchell Chapter 10

History

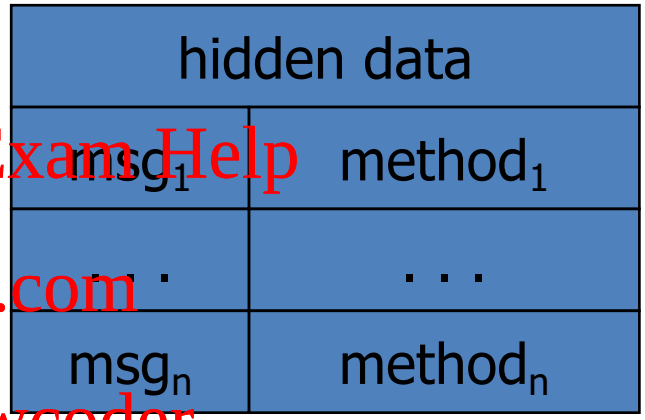
- Simula 1960's
  - Object concept used in simulation
- Smalltalk 1970's
  - Object-oriented design, systems
- C++ 1980's
  - Adapted Simula ideas to C
- Java 1990's
  - Distributed programming, internet

Varieties of Object-Oriented Languages

- class-based languages
  - behavior of object determined by its class (in Mitchell Chapter 10)
- object-based
  - objects defined directly (can be done in OCaml)
- multi-methods
  - method to execute chosen based on characteristics of the arguments

Objects

- An object consists of
  - hidden data
    - instance variables, also called member data
    - hidden functions also possible
  - public operations
    - methods or member functions
    - can also have public variables in some languages



- Object-oriented program:
  - send messages to objects

Object-Oriented Languages

- An *object-oriented language* refers to (in this chapter) a programming language that has objects and the following four features (concepts):
  - dynamic lookup
  - encapsulation (abstraction)
  - inheritance
  - subtyping
- Other topics
  - Inheritance is not Subtyping
  - A Comparison: Closures as Objects
  - A Comparison: Function-Oriented Program Organization

Dynamic Lookup

- *Dynamic lookup* means that when a message is sent to an object, the function code (or *method*) to be executed is determined by the way that the object is implemented
- Not determined by a static property of the pointer or variable used to name the object.
- In a sense, the object "chooses" how to respond to a message.
- Different objects may respond to the same message in different ways.

Dynamic Lookup

- In object-oriented programming,

  object → message (arguments)

  code depends on object and message

- In conventional programming,

  operation (operands)

  meaning of operation is always the same

Fundamental difference between abstract data types and objects

Example

- Add two numbers x → add (y)

  different add if x is integer, complex

  depends on the implementation of x

- Conventional programming: add (x, y)

  function add has fixed meaning, or

  different meanings depending on types (overloading), not on implementation

Very important distinction:

Overloading is resolved at compile time.

Dynamic lookup is resolved at run time.

(Dynamic lookup can be thought of as a run-time form of overloading.)

Encapsulation

- Builder of a concept has detailed view
- User of a concept has “abstract” view
- Encapsulation separates these two views
  - Implementation code: operate on representation
  - Client code: operate by applying fixed set of operations provided by implementer of abstraction

Comparison with Abstract Data Types

```
module type MATRIX =
 sig
  type t
  val create : unit -> t
  val update :
     t -> int -> int -> int -> unit
  val add : t -> t -> t
 end
```

```
module Matrix : MATRIX =
 struct
  type t = ...
  let create (...) : t = ...
  let update (m:t) (i:int) (j:int) (x:int) =
     ... set m(i,j) to x ...
  let add (m1:t) (m2:t) = ...
 end
```



```
class matrix
  … (representation)
  update(i,j,x) = …set(i,j) of *this* matrix
  add(m) = …add m to *this* matrix
end
```

add(x,y) vs. x → add(y)

Comparison with Abstract Data Types

```
module type MATRIX =
 sig
  type t
  val create : unit -> t
  val update :
     t -> int -> int -> int -> unit
  val add : t
 end

class
  … (r
  upda
  add(m)
end
```

```
module Matrix : MATRIX =
 struct
  type t = …
  let c
  l                                    int) (x:int) =
```


The operation appears to have only one argument—the matrix y that is added to the matrix x that is receiving the message add(y)

Both x and y must be matrices. If add were defined for complex numbers or integers, …, then one definition hides the other (hole in scope) or static overloading required

add(x,y) vs. x → add(y)

Comparison with Abstract Data Types

- Encapsulation via abstract data types
- Similarities with Objects (Shared Advantages)
  - Both combine functions and data
  - Both distinguish between a public interface and a private implementation
- Disadvantage as Compared to Object-Oriented Programming
  - Not extensible in the same way (see the next example)

Abstraction Example

```
module type INT_QUEUE =
 sig
  type t
  val mk_Queue : unit -> t
  val is_empty : t -> bool
  val add : int -> t -> t
  val first : t -> int
  val rest : t -> t
  val length : t -> int
 end
```

Abstraction Example: Regular Queue

```
exception Empty
module IntQueue : INT_QUEUE =
  struct
    type t = int list
    let mk_Queue () : t = []
    let is_empty (q:t) = match q with | [] -> true
                                      | _::_ -> false
    let add (x:int) (q:t) : t = q @ [x]
    let first (q:t) : int = match q with | [] -> raise Empty
                                         | x::_ -> x
    let rest (q:t) : t = match q with | [] -> raise Empty
                                      | _::l -> l
    let rec length (q:t) : int = match q with | [] -> 0
                                              | _::l -> 1 + length l
  end
```

Abstraction Example: Priority Queues

```
module IntPQueue : INT_QUEUE =
 struct
  type t = int list
  let mk_Queue () : t = []
  let is_empty (q:t) = match q with | [] -> true
                                    | _::_ -> false
  let rec add (x:int) (q:t) : t = match q with | [] -> [x]
                                               | y::l -> if x > y then x::y::l
                                                         else y::add x l
  let first (q:t) : int = match q with | [] -> raise Empty
                                       | x::_ -> x
  let rest (q:t) : t = match q with | [] -> raise Empty
                                    | _::l -> l
  let rec length (q:t) : int = match q with | [] -> 0
                                            | _::l -> 1 + length l
 end
```

Comparison with Object-Oriented

- Abstract data types guarantee invariants of data structure
  - Client code does not have access to the internal representation of data
- Limited "reuse"
  - Both Queue and PQueue have the same interface
    - same number of operations, same names of operations, same types of operations
  - Both have same implementation except for "add"
  - Cannot apply Queue code to PQueue data, even though signatures are identical
  - Cannot form list of Queues and PQueues
- Implementations can be reused in object-oriented programming
  - In queue example, 5 functions have same implementation, can use inheritance to define one from the other.
- Data abstraction is an important part of OOP, the main innovation is that it occurs in an *extensible* form

Example

Consider a hospital system with several wait queues

- The billing department's queue is first-come, first-serve
- The emergency room's queue is a priority queue, based on severity of injury or illness.
- It would be useful to treat them uniformly, for example, to calculate the total number of people currently waiting.
- Can't apply PQueue length to a Queue or vice versa

Subtyping and Inheritance

- Interface
  - The external view of an object
- Subtyping
  - Relation between interfaces
- Implementation
  - The internal representation of an object
- Inheritance
  - Relation between implementations

Subtyping in General

- In most typed languages (without subtyping), the application of a function f to an argument x requires some relation between the type of f and the type of x.
  - Common case: f is a function of type A→B and x is an expression of type A. In the implementation of the type checker, find a type A→ B for f, find a type C for x, and check for equality: A = C.
- In languages with subtyping, subtyping is a relation on types based on *substitutivity*: if C is a subtype of A (written C <: A), then any expression of type C may be used without type error in any context that requires an expression of type A.
  - Subtyping case: Find a type A→ B for f, find a type C for x, and check that C <: A.

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  - Subtyping case: Find a type A→ B for f, find a type C for x, and check that C <: A.

C can be used in any context that requires an expression of type A. Example: A is int and C is nat (natural numbers which include 0 and positive integers).

Advantages

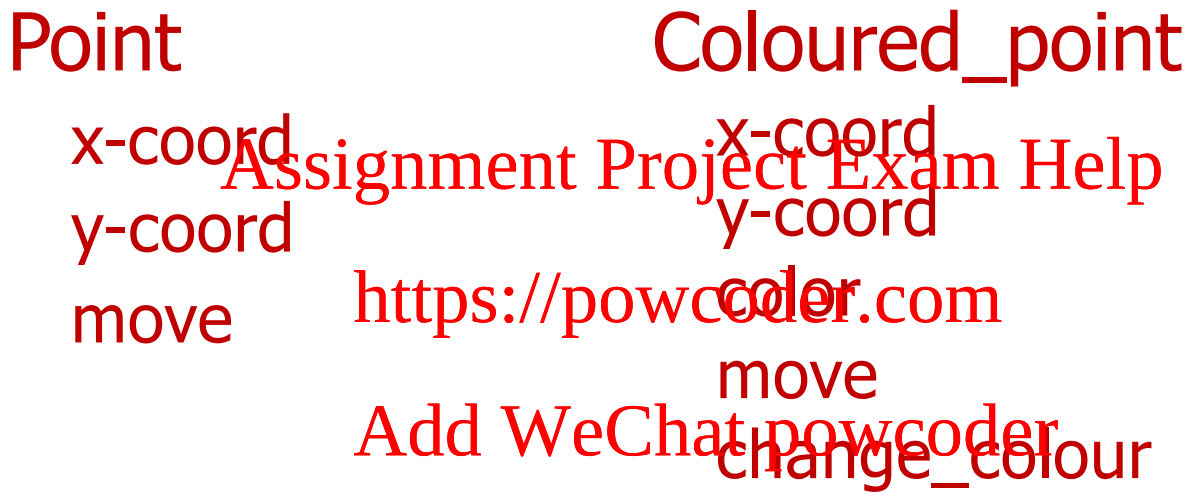
- Permits uniform operations over various types of data
  - Makes it possible, for example, to have heterogeneous data structures that contain data that belong to different subtypes of some common type
  - Example:
    - A queue containing various bank accounts to be balanced. The "balance" operation is on bank accounts, which has subtypes such as saving, chequing, investment, etc.
    - A queue of type `bank_account*` can contain all types of accounts.
- In object-oriented languages:
  - allows functionality to be added for subclasses without modifying the general parts of a system defined in the general class.

Object Interfaces

- Interface
  - The messages understood by an object
- Example: point
  - x-coord : returns x-coordinate of a point
  - y-coord : returns y-coordinate of a point
  - move : method for changing location
- The interface of an object is its *type*

Subtyping

- If interface B contains all of interface A, then B objects can also be used as A objects.



- Coloured_point interface contains Point
  - Coloured_point is a *subtype* of Point

Inheritance

- Implementation mechanism
- New objects may be defined by reusing implementations of other objects
- Advantage: saves the effort of duplicating (or reading duplicated) code:
  - When one class is implemented by inheriting from another, changes to one affect the other
  - This has significant impact on code maintenance and modification
    - Only need to change in one place
    - Must be aware of what classes are affected by the change (all those that inherit the code)

Example

```
class Point
    private
        float x, y
    public
        point move (float dx, float dy);
class Coloured_point
    private
        float x, y
        colour c
    public
        point move (float dx, float dy);
        point change_colour (colour newc);
```


- Subtyping
  - Coloured points can be used in place of points
  - Property used by client program
- Inheritance
  - Coloured points can be implemented by reusing Point implementation
  - Property used by implementer of classes

OO Program Structure

- Group together relevant data and functions
- Class
  - Defines behavior of all objects that are instances of the class
- Subtyping
  - Place similar data in related classes
- Inheritance
  - Avoid re-implementing functions that are already defined

Real World OCaml

Chapters 11 and 12

Five Fundamental Properties of OO Programming

In Mitchell, Chapter 10, 4 features/concepts are described. Real World OCaml includes a fifth. Quoting:

- Abstraction

  The details of the implementation are hidden in the object, and the external interface is just the set of publicly accessible methods.

- Dynamic lookup

  When a message is sent to an object, the method to be executed is determined by the implementation of the object, not by some static property of the program. In other words, different objects may react to the same message in different ways.

- Subtyping

  If an object a has all the functionality of an object b, then we may use a in any context where b is expected.

Five Fundamental Properties of OO Programming

- Inheritance

  The definition of one kind of object can be reused to produce a new kind of object. This new definition can override some behavior, but also share code with its parent.

- Open recursion

  An object's methods can invoke another method in the same object using a special variable (often called self or this). When objects are created from classes, these calls use dynamic lookup, allowing a method defined in one class to invoke methods defined in another class that inherits from the first.

Five Fundamental Properties of OO Programming

- Inheritance

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new

OCaml allows programming with objects without classes. It also includes classes, which are required for inheritance.

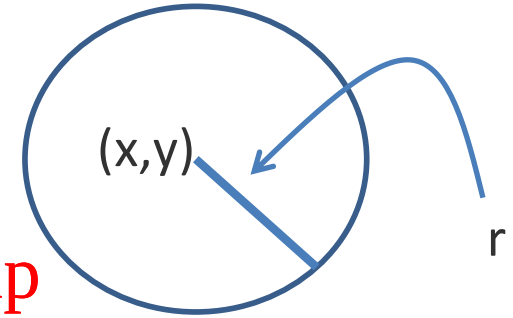
"Almost every notable modern programming language has been influenced by OOP, and you'll have run across these terms if you've ever used C++, Java, C#, Ruby, Python, or JavaScript."

Recall Data Type for Shapes

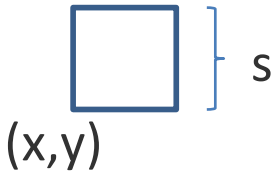
```
type point = float * float
type radius = float
type side = float

type shape =
  | Circle of point * radius
  | Square of point * side
  | Ellipse of point * radius * radius
  | RtTriangle of point * side * side
  | Polygon of point * point list
```

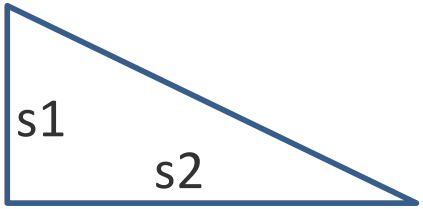

Circle (p, r) =



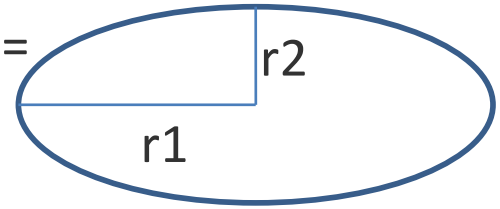
Square (p, s) =



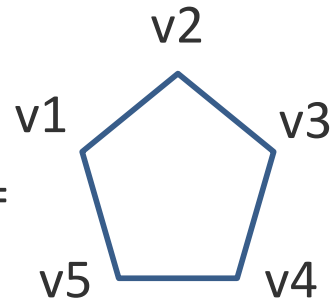
RtTriangle (p, s1, s2) =



Ellipse (p, r1, r2) =



Polygon (p, [v1; ...;v5]) =



Calculating Area

```
type point = float * float
type radius = float
type side = float

type shape =
  | Circle of point * radius
  | Square of point * side
  | Ellipse of point * radius * radius
  | RtTriangle of point * side * side
  | Polygon of point * point list
```



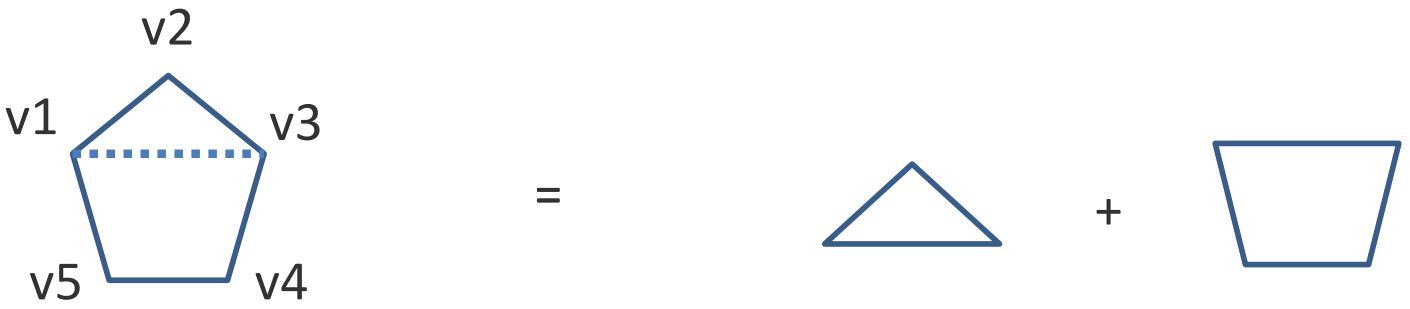
```
let area (s : shape) : float =
  match s with
  | Circle (_, r) -> pi *. r *. r
  | Square (_, s) -> s *. s
  | Ellipse (_, r1, r2)-> pi *. r1 *. r2
  | RtTriangle (_, s1, s2) -> s1 *. s2 /. 2.
  | Polygon (_, ps) -> poly_area ps
```

Area of a Polygon

```
let tri_area (p1:point) (p2:point) (p3:point) : float =
  let a = distance p1 p2 in
  let b = distance p2 p3 in
  let c = distance p3 p1 in
  let s = 0.5 *. (a +. b +. c) in
  sqrt (s *. (s -. a) *. (s -. b) *. (s -. c))
```



```
let rec poly_area (ps : point list) : float =
  match ps with
  | p1 :: p2 :: p3 :: tail ->
     tri_area p1 p2 p3 +. poly_area (p1::p3::tail)
  | _ -> 0.
```

An Object-Oriented Version

```
type point = float * float
type radius = float
type side = float

class virtual shape = object
  val mutable location : point = (0.0, 0.0)
  method get_location = location
  method set_location (xcoord:float) (ycoord:float) : unit =
    location <- (xcoord, ycoord)
  method virtual area : float
end
```

An Object-Oriented Version

```
type point = float * float
type radius = float
type side = float

class virtual shape = object
  val mutable location : point
  method get_location = location
  method set_location (xcoord, ycoord) : unit =
    location <- (xcoord, ycoord)
  method virtual area : float
end
```

Indicates an abstract class

"object…end" defines a *class type*

Variables and methods are distinguished by the keywords "val" and "method"

Indicates an abstract method in an abstract class

"<-" used for assignment to mutable instance variables or fields

Unit () is not needed here. Keyword "method" indicates that, like a function, it must be called before executing the body.

An Object-Oriented Version

```
type point = float * float
type radius = float
type side = float

class virtual shape = object
  val mutable location : point = (0.0,0.0)
  method get_location = location
  method set_location (xcoord:float) (ycoord:float) : unit =
    location <- (xcoord, ycoord)
  method virtual area : float
end

class circle = object
  inherit shape as super
  val mutable rad = 1.0
  method get_radius = rad
  method set_radius (r:radius) : unit = rad <- r
  method area = pi *. rad *. rad
end
```

An Object-Oriented Version

```
type point = float * float
type radius = float
type side = float

class virtual shape = object
  val mutable location : point = (
  method get_location = location
  method set_location (xcoord:floa                    : unit =
    location <- (xcoord, ycoo
  metho          area : fl
end

class circle = object
  inherit shape as super
  val mutable rad = 1.0
  method get_radius = r
  method set_radius (r:radius) : unit = rad <- r
  method area = pi *. rad *. rad
end
```

Inherits all instance variables and (non-abstract) methods

can add new ones

must implement abstract methods

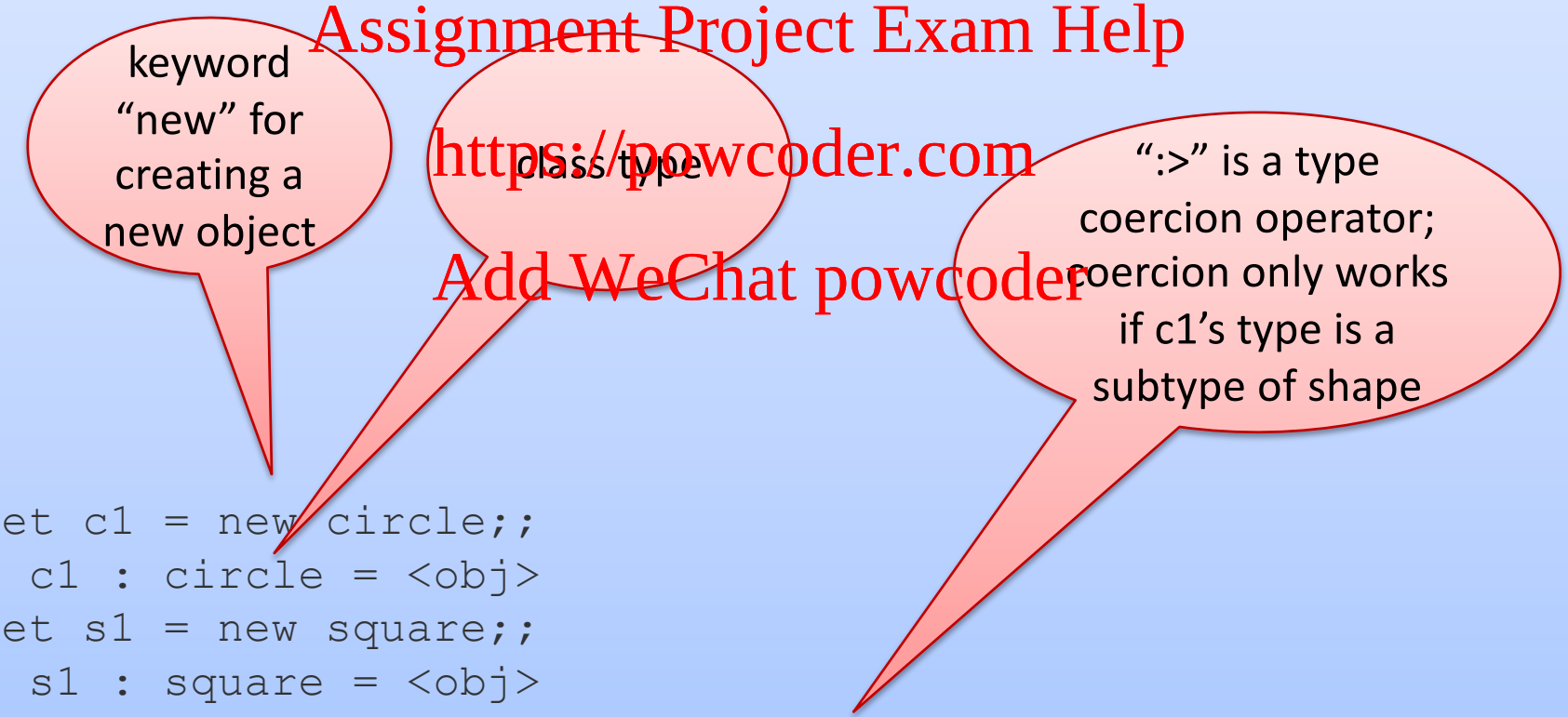
Shape Classes and Objects

```
class circle = object
  inherit shape as super
  val mutable rad = 1.0
  method get_radius = rad
  method set_radius (r:radius) : unit = rad <- r
  method area = pi *. rad *. rad
end

class square = object
  inherit shape as super
  val mutable side_length = 1.0
  method get_side = side_length
  method set_side (s:side) : unit = side_length <- s
  method area = side_length *. side_length
end

# let c1 = new circle;;
val c1 : circle = <obj>
# let s1 = new square;;
val s1 : square = <obj>
# let shape_l : shape list = (c1 :> shape)::(s1 :> shape)::[];;
val shape_l : shape list = [<obj>; <obj>]
```

Shape Classes and Objects




```
# let c1 = new circle;;
val c1 : circle = <obj>
# let s1 = new square;;
val s1 : square = <obj>
# let shape_l : shape list = (c1 :> shape)::(s1 :> shape)::[];;
val shape_l : shape list = [<obj>; <obj>]
```

Shape Processing Loop

```
let rec areas (sl: shape list) : float list =
  match sl with
  | [] -> []
  | h::t -> (h#area)::(areas t)

# let as1 = areas shape_l;;
val as1 : float list = [3.14159; 1.]
# c1#set_radius 2.0;;
- : unit = ()
# s1#set_side 3.0;;
- : unit = ()
# let as2 = areas shape_l;;
val as2 : float list = [12.56636; 9.]
```


Control “loop” or “iterator” does not know the type of each shape.

Objects (No Classes)

```
let st1 = object
    val mutable v = [0;2]
    method pop =
      match v with
      | [] -> None
      | h::t -> v <- t; Some h
    method push h =
      v <- h::v
  end

 val st1 : < pop : int option; push : int -> unit > = <obj>
# st1#pop;;
- : int option = Some 0
# st1#push 4;;
- : unit = ()
# st1#pop;;
- : int option = Some 4
```

The type of an object is its interface, which is a collection of methods and their types.

Objects Constructed by Functions

```
let stack init = object
    val mutable v = init
    method pop =
      match v with
      | [] -> None
      | h::t -> (v <- t; Some h)
    method push h =
      v <- h::v
  end

val stack : 'a list -> < pop : 'a option; push : 'a -> unit > =
  <fun>
# let st2 = stack [3;2;1];;
- : < pop : int option; push : int -> unit > = <obj>
# st2#pop;;
- : int option = Some 3
```


Finds the most general type for `stack`, which is polymorphic.

Concepts in Object-Oriented Languages

Mitchell Chapter 10 continued

Inheritance and Abstraction

- 2 views of an abstraction in ordinary modules or abstract data types:
  - the client view
  - the implementation view
- 3 views with inheritance:
  - the client view
  - the implementation view
  - the inheritance view (the view of classes that inherit from the class)
- Classes (object definitions) have 2 external clients
  - the *public interface* for the general users of the class (all the methods)
  - the *protected interface* for the inheritors (all the methods and all instance variables, i.e., data)

Subtyping Differs from Inheritance

Subtyping is a relation on interfaces; inheritance is a relation on implementations.

- Probably all class mechanisms that you are familiar with combine the two (e.g., C++, Java)
- An example that illustrates the difference (in languages that don't combine the two):
  - Queues: data structures with `insert` and `delete` operations, such that the first element inserted is the first one removed (first-in, first-out)
  - Stacks: data structures with `insert` and `delete` operations, such that the first element inserted is the last one removed (last-in, first-out)
  - Dequeues (doubly-ended queue): Data structures with two `insert` and two `delete` operations. Allows insertion and deletion form each end.

Inheritance vs. Subtyping Example

```
module type INT_DEQUEUE =
 sig
  type t
  val mk_Dequeue : unit -> t
  val insert_front : int -> t -> t
  val insert_rear : int -> t -> t
  val delete_front : int -> t -> t
  val delete_rear : int -> t -> t
  val first : t -> int
  val last : t -> int
  …
 end
```

Inheritance is Not Subtyping

Implementation using Inheritance

- Implement `dequeue` first
- Then implement `stack` from `dequeue` by restricting access to `insert_rear` and `delete_rear`, e.g., override `insert_rear` to have the same implementation as `insert_front`
- And implement `queue` from `dequeue` by restricting access to `insert_front` and `delete_rear`
- `stack` and `queue` inherit from `dequeue`
- But `stack` and `queue` are not subtypes of `dequeue` (see next page)

Inheritance is Not Subtyping

Subtyping view

- Consider a function `f` that takes a `dequeue d` as an argument and then adds an element to both ends
- If `stack` or `queue` were a subtype of `dequeue`, then function `f` should work equally well when given a `stack s` or a `queue q`.
- However, the operation performed by `f` is not legal for either.
- In fact `dequeue` is a subtype of both `stack` and `queue`; any operation on a `stack` or `queue` would be a legal operation on a `dequeue`