Object-oriented Programming

- Programs are structured in terms of objects: collections of variables ("fields") and functions ("methods")

- Invented to model discrete entities or processes, e.g.
  - Simulations (object = real-world object)
  - Graphical user interfaces (object = desktop item)

- But can be used for any programming task
OOP Characteristics

OOP languages usually support

- Dynamic dispatch
- Encapsulation
- Inheritance
- Subtyping

...but there is no precise definition of OOP
## Some important OOP languages

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<th>Static types?</th>
<th>Class-based?</th>
<th>All values are objects?</th>
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Procedures vs. Methods

Fundamental OOP control structure is method invocation.

Similar to function call in a procedural language.

But each method takes the object itself as an implicit argument, and this receiver object also helps resolve method name:

```java
s.add(x) ; OO style
Set.add(s,x) ; procedural style
```

Change in metaphor: instead of applying functions to values, we “send messages to object.”
Dynamic Dispatch

In most OOP, the receiving object itself controls how each message is processed.

This is a form of **dynamic overloading** (i.e., a certain kind of polymorphism)

```java
s1 = new ordered-list-set
s2 = new balanced-tree-set
if ... then s = s1 else s = s2
s.add(42)
```

The implementation of the `add` method is completely different in `s1` and `s2`; the choice of which one runs is determined at run time.
Classes

In OOP, we typically want to create multiple objects having the same structure (field names) and method definitions.

In most OO languages this is done by defining a class, which is a kind of template from which new objects can be created.

Different instances of the class will typically have different field values, but all will share the same method implementations.

Classes are not essential; one alternative (used by JavaScript, e.g.) is to create new objects by cloning existing prototype objects.
Encapsulation

Objects are often (though not always) designed so that their data fields can only be accessed by the object’s own methods.

This kind of encapsulation is just what is needed to implement an Abstract Data Type (ADT).

It allows the representation or implementation of an object to change without affecting client code that interacts with the object only via method send.

However, OO programmers often violate encapsulation. For example, object fields may be public, allowing them to be accessed from code outside the object’s methods.
Subtyping in general

- Types can often be naturally refined into subtypes
  - type = set of values supporting certain operations
  - subtype = subset of values supporting those operations and more

- Example: Type “Animal” supports operation “eat.” Subtype “Bird” supports operation “eat” and also operation “fly.”

- For type soundness, say B is a subtype of A if we can use a B value wherever an A value is expected.

- Informally, makes sense to say B is a subtype of A if every value of B “is a” value of A.
Subclasses

In class-based OO languages, it is common to declare immediate subtypes by defining subclasses.

- e.g. in Scala: `class Bird extends Animal`

The overall subtyping relation is automatically taken to be the reflexive, transitive closure of the immediate subclass declarations.

- e.g. if we also define `class Crow extends Bird` then automatically `Crow` is a subtype of `Animal`

This leads to a subtyping hierarchy
Heterogenous Collections

Subtyping and dynamic dispatch combine to give powerful support for manipulating heterogeneous collections:

abstract class Animal {
    def name() : String
    def eat() : String
}

class Bird extends Animal {
    def name() = "bird"
    def eat() = "chomp on insects"
}

class Bee extends Animal {
    def name() = "bee"
    def eat() = "suck nectar"
}

object Main {
    val animals : List[Animal] = List(new Bird(), new Bee())
    for (animal <- animals)
        println(animal.name() + ":" + animal.eat())
}
Inheritance

- Classes may also be related because their implementations are similar.

- To avoid writing duplicate code, we might like to inherit most of the implementation of one class from another.
  - possibly overriding some aspects of the implementation in the subclass.

- This works nicely when the inheriting class is also a subtype of the providing class.
abstract class Animal {
  def name() : String
  def eat() : String
}

class Bird extends Animal {
  def name() = "bird"
  def eat() = "chomp on insects"
}

class Crow extends Bird {
  override def name() = "crow"
}

class Bee extends Animal {
  def name() = "bee"
  def eat() = "suck nectar"
}

object Main {
  val animals : List[Animal] = List(new Bird(), new Crow(), new Bee())
  for (animal <- animals)
    println(animal.name() + "":" + animal.eat())
}
Flexibility of Dynamic Dispatch

Method calls are always dispatched to the original receiving object, so superclass code can access functionality in subclasses.

abstract class Animal {
    def name() : String
    def eat() : String
}

class Bird extends Animal {
    def name() = "bird"
    def eat() = "chomp on " + food()
    def food() = "insects"
}

class Crow extends Bird {
    override def name() = "crow"
    override def food() = "anything"
}

class Robin extends Bird {
    override def name() = "robin"
    override def food() = "worms"
}

object Main {
    val animals : List[Animal] = List(new Bird(), new Crow(), new Robin())
    for (animal <- animals)
        println(animal.name() + ":" + animal.eat())
}

Output:

bird: chomp on insects
crow: chomp on anything
robin: chomp on worms
Subtyping vs. Inheritance

Sometimes we’d like to use inheritance even when subtyping is not appropriate, e.g.:

Suppose we add bat as a new kind of animal. Since bats also eat insects, we might be tempted to make bat a subclass of bird so that it would inherit the implementation of eat().

But it is not the case that a bat “is a” bird! That is, it does not suffice to provide a bat when a bird is expected. (E.g. if bird had a method lay_eggs(), we would not be able to give an appropriate implementation of that method for bat.)

Inheritance concerns can warp design of subtyping hierarchy.
More flexible inheritance mechanisms can help.

Some languages (e.g. C++) let a class inherit from multiple super-classes. (Semantics of field inheritance can be messy.)

Java supports subtyping through multiple interfaces, which are like classes without fields.

Scala supports subtyping through traits, which are like partial class definitions that can be “mixed in” together.
Using Traits

abstract class Animal {
    def name() : String
    def eat() : String
    def reproduce() : String
}

trait Insectivorous {
    def eat() = "chomp on insects"
}

trait Oviparous {
    def reproduce() = "lay eggs"
}

class Bird extends Animal with Insectivorous with Oviparous {
    def name() = "bird"
}

class Bat extends Animal with Insectivorous {
    def name() = "bat"
    def reproduce() = "bear live young"
}

class Bee extends Animal with Oviparous {
    def name() = "bee"
    def eat() = "suck nectar"
}

object Main {
    val animals : List[Animal] = List(new Bird(), new Bat(), new Bee())
    for (animal <- animals)
        println(animal.name() + "":" + animal.eat() + ":" + animal.reproduce())
}
Representation of Objects

- An object is essentially a record (usually heap-allocated to support unlimited lifetime) containing values for the fields and code pointers for methods.

- In a dynamically-typed language, the object record fields/methods have labels that can be searched at run time (at least in a naive implementation).

- In a statically-typed language, we can (usually) compute the offset of each field/method statically, avoiding run-time search.

- In a class-based language, we usually factor the representation so that method pointers are stored in a separate class record.
Example without inheritance

class A {
    int x;
    int y;
    f() = x+y;
    g(z) = f()+z;
}
val a1:A = ...
val a2:A = ...
val w = a1.g(10)

Generated code in C-like notation

f(a) = (*a).x + (*a).y

\[ g(a, z) = (\ast(\ast(a).\text{class}).f(a)) + z \]

\[ w = (\ast(\ast(a1).\text{class}).g(a1, 10)) \]
Implementing Sub-classes

- A key observation is that sub-classes only add (or override) fields and methods to the super-class.

- So the list of contents for super-class representation is always a prefix of list for sub-class representation.

- All classes in the hierarchy can share the same offsets for the fields and methods they have in common, making run-time search unnecessary.

- (This is just an implementation trick, but the resulting efficiency was historically important for the adoption of OOP.)

- Only works for single inheritance; multiple inheritance, interfaces, or traits require more work.
Example with inheritance

class A {
    int x;
    int y;
    f() = x+y;
}
class B extends A {
    int z;
    g() = x+z;
}
val a:A = …
val b:B = …
val w = b.f()+b.g()