INF3110 – Programming Languages
Object orientation part II

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Object Orientation and Types

Lecture I

- From predefined (simple) and user-defined (composite) types
  - via
- Abstract data types
  - to
- Classes
  - Type compatibility
  - Subtyping <> subclassing
  - Class compatibility
  - Covariance/contravariance
    - Types of parameters of redefined methods

Lecture II - Today

- Type systems
- Polymorphism
  - Generics
- Advanced oo concepts
  - Specialization of behavior?
  - Multiple inheritance - alternatives
  - Inner classes

Repetition

Remember: *syntax* (program text) and *semantics* (meaning) are two separate things.

Types and type systems help to ascribe *meaning* to programs:

- What does `"Hello" + " World"` mean?
- Which operation is called when you write `System.out.println("INF3110")`?
- What does the concept of a `Student` entail?

Repetition - What is a type?

- A set of values that have a set of operations in common
  - 32 bit integers, and the arithmetic operations on them
  - Instances of a Person class, and the methods that operate on them
- How is a type *identified*?
  - By its *name* (e.g. Int32, Person, Stack): nominal type checking
  - By its *structure* (fields, operations): structural type checking
- Does this cover everything a type might be? No.
  - Alternative definition of "type": *A piece of the program to which the type system is able to assign a label.*
  - *(but don't worry too much about this now)*

Repetition - Classification of types

- Predefined, simple types (not built from other types)
  - boolean, integer, real, ...
  - pointers, pointers to procedures
  - string
- User-defined simple types
  - enumerations, e.g. **`enum WeekDay { Mon, Tue, Wed, … }`**
- Predefined composite types
  - Arrays, lists/collections (in some languages)
- User-defined, composite types
  - Records/structs, unions, abstract data types, classes

- Evolution from simple types, via predefined composite types to user-defined types that reflect parts of the application domain.

What is a type system?

- One possible definition
  - *“A type system is a tractable syntactic method for proving the absence of certain program behaviors by classifying phrases according to the kinds of values they compute”* [Pierce, 2002]

What is a type system?

- One possible definition
  - *"A type system is a tractable syntactic method for proving the absence of certain program behaviors by classifying phrases according to the kinds of values they compute"* [Pierce, 2002]
  - We are interested in type systems in relation to *programs* and *programming languages*, and not other kinds of type systems
    - The idea of type systems (or *type theory*) predates programming languages, and type theory has other applications as well

What is a type system?

- One possible definition
  - *"A type system is a tractable syntactic method for proving the absence of certain program behaviors by classifying phrases according to the kinds of values they compute"* [Pierce, 2002]

  - The type system deals with syntactic phrases, or terms, in the language, and assigns labels (types) to them.
    - This applies to static type systems
    - Dynamic type systems, on the other hand, label and keep track of data at *runtime*.

What is a type system?

- One possible definition
  - *"A type system is a tractable syntactic method for proving the absence of certain program behaviors by classifying phrases according to the kinds of values they compute"* *[Pierce, 2002]*
  - The goal of the type system is to prove the absence of certain undesirable behaviors
    - There are hard limits to what kind of undesirable behaviors a type system can prove things about, e.g. (non)termination
  - *"The fundamental purpose of a type system is to prevent the occurrence of execution errors during the running of a program"* [Cardelli, 2004]
    - But what constitutes an execution error? ArrayIndexOutOfBounds? NullReferenceException?

What is a type system?

- One possible definition
  - *"A type system is a tractable syntactic method for proving the absence of certain program behaviors by classifying phrases according to the kinds of values they compute"* [Pierce, 2002]
  - In order to attain its goal, the type system should preferably be computationally tractable
    - Tractable = polynominal time, with regard to length of the program
    - In practice, the degree of the polynominal should not be too high

Main categories for programming language type systems

- Untyped
  - There are no types (e.g. everything is just a bit pattern)
  - Or, if you will, everything has the same single type

- Statically typed
  - Types checking is a syntactic process at compile-time
  - Rejects programs that do not type check before they can run

- Dynamically typed (or: dynamically checked)
  - Types are checked at runtime
    - By a runtime system, or
    - By code inserted by a compiler

- Categories are not mutually exclusive
  - Most “real-world” languages are somewhere in between, with elements from more than one category
  - There is a *tension* between safety and expressivity that must be resolved by the language/type system designer

Static type systems

- Types are assigned to syntactical elements of a program (prior to running it)
  - Types annotations can be specified explicitly in the source code by the programmer, “ALGOL-style”, as in Java, C++, etc
  - Or they can be inferred by the compiler, as in ML, Haskell, etc, Hindley-Milner style

- An AST is typically created from the source code using the language’s grammar
  - Some of the nodes in the tree will be declarations of types, or type annotations

- Uses the language’s semantics to establish relationships between expressions and types
  - Thus type checking the program
  - Checks *structural* or *nominal* conformance according to language semantics

```
public class C {

    int m(int i) {

        m(i);
    }
}
```

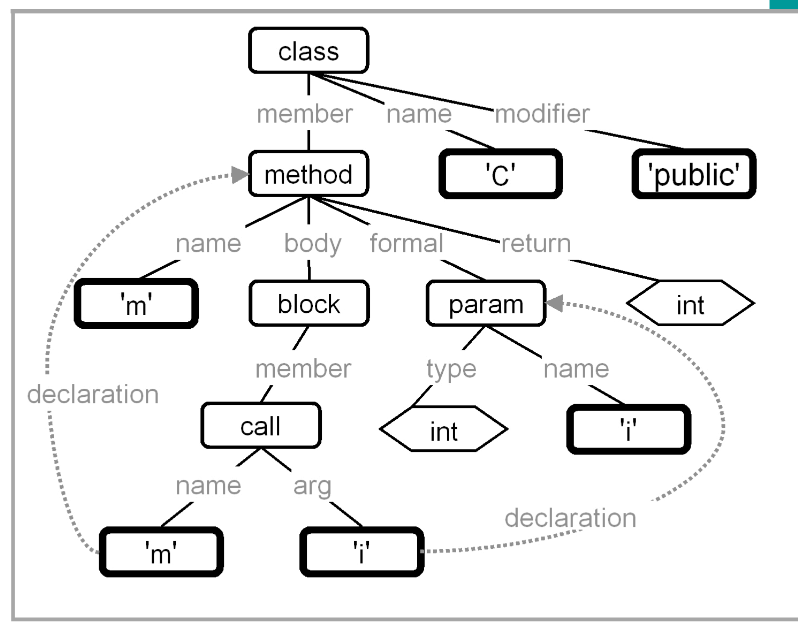


Image from JTransformer

Static type systems [cont.]

- Static type systems are always *conservative*
  - They cannot (in general) prove the presence of errors, only the absence of certain bad behaviors
  - They are therefore bound to potentially reject "correct" programs

```
if( < complex runtime condition that always evaluates to true > )
   < valid code >
else
   < type error >
```

- Mainstream languages typically concede to *tradeoffs* between flexibility and type safety
  - E.g. covariant array conversions, null-references, runtime contract checking
  - Escape hatches to circumvent the type system:
    - `Unchecked_` constructs in Ada
    - `unsafe { … }` in C#
    - `Obj.magic` in Ocaml
      - *"license to kill [the type system]"* – anonymous stackoverflow.com user
    - Foreign Function Interfaces in most languages, e.g. ML, JavaScript, Python, Java, etc

Dynamically typed languages

- Type checks at *runtime*
  - As long as the receiver supports the requested operation, everything is fine
  - Errors due to type-incorrect operations will be caught* at runtime
    - * if the language is *safe*, otherwise, anything could happen

- Never need to reject a correct program
  - But may indeed end up running many faulty ones

  - Extensive testing/TDD *may* find the errors that a compiler would otherwise have found
    - A test suite can find an *upper* bound on correctness, while (static) type systems find a *lower* bound

Dynamically typed languages [cont.]

- Freedom of expression where static type system cannot (at present?) correctly type the program
  - Can have meta-object protocols with sophisticated behavior
    - Responding to method calls or not depending on runtime environment, e.g.:

```
def methodMissing(name, args) {
   if(name.startsWith("get") && App.User.IsAuthorized())
      return OtherClass.metaClass.Invoke(name, args);
   else
       thow new MessageNotUnderstoodException();
}
```

  - Effortlessly create proxies at runtime
  - Create and cache new methods from business rules defined by users, e.g. in an internal DSL
  - Etc
- Classes and objects can be adapted at runtime
  - Add or remove methods or fields, swap out classes, etc.
  - Used a great deal by e.g. Flickr, Facebook and Gmail [Vitek 2009]

Mark Mannasse: *"The fundamental problem addressed by a type theory* [aka type system] *is to ensure that programs have meaning.*

The fundamental problem caused by a type theory is that meaningful programs may not have meanings ascribed to them.

The quest for richer type systems results from this tension."
[as quoted by Pierce 2002, p 208]

Words of wisdom?

"*Static typing is great because it keeps you out of trouble*.

Dynamic typing is great because it gets out of your way"

– Zack Grossbart (author, blogger,)

Polymorphism – a single interface usable for instances of different types

- Ad hoc polymorphism: functions/methods with the same name that can be applied to different parameter types and arities
  - Typically called *overloading*

- Parametric polymorphism: "when the type of a value contains one or more *type variables*, so that the value may adopt any type that results from substituting those variables with concrete types” [https://wiki.haskell.org/Polymorphism].
  - In OOP communities, this is typically called *generics.*
  - In FP communities, this is typically called just *polymorphism*.

- Subtype polymorphism *(subtyping)*: an instance of a subtype can be substituted where a supertype is expected
  - In OOP communities, this is often simply referred to as *polymorphism*.

Generics/parametric polymorphism

- Type constructors, of types of types
  - E.g. List<T> can be used to construct List<String>, List<Person>, etc.

- Different languages offer different degrees of expressiveness
  - What can be said about T?
  - Can we constrain what it can be?
  - Can we be sure that whatever is in our List<String> is really only strings?
  - What about subtype hierarchies?
  - To which extent is the generic type type safe?
  - Can the generic type be analyzed on its own, independently of any use-cases?

Constraining type parameters

- C++ polymorphic sort function

```
template <typename T>
void sort( int count, T* arr[] ) {
   for (int i=0; i<count-1; i++)
       for (int j=i+1; j<count-1; j++)
          if (arr[j] < arr[i])
              swap(arr[i], arr[j]);
}
```

- What parts of the implementation depend on what property of T?
  Usage, meaning and implementation of **<**

Java lists without and with generics

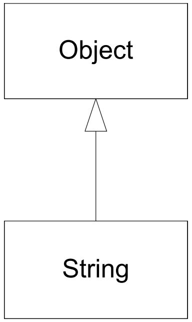
```
List myIntList = new LinkedList();
myIntList.add(new Integer(0));
Integer x = (Integer)myIntList.iterator().next()
```

```
List<Integer> myIntList = new
 LinkedList<Integer>();
myIntList.add(new Integer(0));
Integer x = myIntList.iterator().next()
```

Generics and subtyping

- String subtype of Object ~~=>~~ List<String> subtype of List<Object> ?

```
List<String> ls = new ArrayList<String>();
List<Object> lo = ls;
lo.add(new Object());
String s = ls.get(0);
```

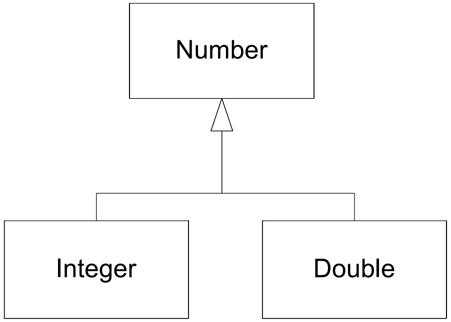


compile-time error

attempts to assign an Object to a String

- Integer subtype of Number ~~=>~~ List<Integer> subtype of List<Number> ?

```
List<Integer> ints = Arrays.asList(1,2);
List<Number> nums = ints;
nums.add(3.14);
```



compile-time error

But look out!

```
String[ ] myStrings = new String [10];
myStrings[0] = "Hello";
myStrings[1] = "World!"

Object[ ] myObjects = myStrings;   // ???
myObjects[3] = new Object(); // !!!
```

Try it out in Java and/or C#!

Unbounded polymorhpism - Wildcards - I

Write code to print the elements of any collection:

```
void printCollection(Collection c) {
  Iterator i = c.iterator();
  for (k = 0; k < c.size(); k++)
      System.out.println(i.next());
}


void printCollection(Collection<Object> c){
  for (Object e : c)
     System.out.println(e);
}


void printCollection(Collection<?> c) {
  for (Object e : c)
     System.out.println(e);
}
```

Collection<*any type*> is **not** a subtype of Collection<Object>

Collection<*any type*> is a subtype of Collection<?>

Bounded polymorhpism - Wildcards - II

```
public abstract class Shape {
  public abstract void draw(Canvas c);
}

public class Circle extends Shape {
  private int x, y, radius;
  public void draw(Canvas c) { ... }
}

public class Rectangle extends Shape {
  private int x, y, width, height;
  public void draw(Canvas c) { ... }
}

public class Canvas {
  public void draw(Shape s) { s.draw(this);}
}
```

Write code to draw a list of any kind of shape →

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Bounded polymorhpism - Wildcards - III

```
public void drawAll(List<Shape> shapes) {
  for (Shape s: shapes)
     s.draw(this);
}
```

```
public void drawAll(List<? extends Shape> shapes) {
  ...
}
```

- `List<S>` subtype of `List<? extends Shape >` for every `S` being a subtype of the (concrete) type `Shape`
- `List<S>` subtype of `List<? extends T >` for every `S` being a subtype of (the generic parameter) `T`

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Generic methods

```
static void fromArrayToColl(Object[] a, Collection<?> c) {
  for (Object o: a)
      c.add(o);     // compile time error – why?
}

static <T> void fromArrayToColl(T[] a, Collection<T> c) {
  for (T o: a)
      c.add(o); // works – why?
}

class Collections {
   public static <T> void copy(
     List<T> dest, List<? extends T> src) {…}
}
class Collections {
   public static <T, S extends T> void copy(
     List<T> dest, List<S> src) {…}
}
```

Generic parameters

```
interface Sink<T> {
  flush(T t); // flush might for instance write stuff to disk
}

// writeAll writes everything in coll to disk using sink.flush
public static <T> T writeAll(Collection<T> coll, Sink<T> snk){
  T last;
  for (T t : coll) {
    last = t;
    snk.flush(last);
   }
   return last;
}
...
Sink<Object> s = ...; // a sink that can write any object
Collection<String> cs = ... ; // can ... ngs…?
String str = writeAll(cs, s); //?
```

Illegal call

```
Sink<Object> s;
Collection<String> cs;
```

```
public static <T> T writeAll(
  Collection<? extends T>, Sink<T>){
  ...
}

String str = writeAll(cs, s); //?
```

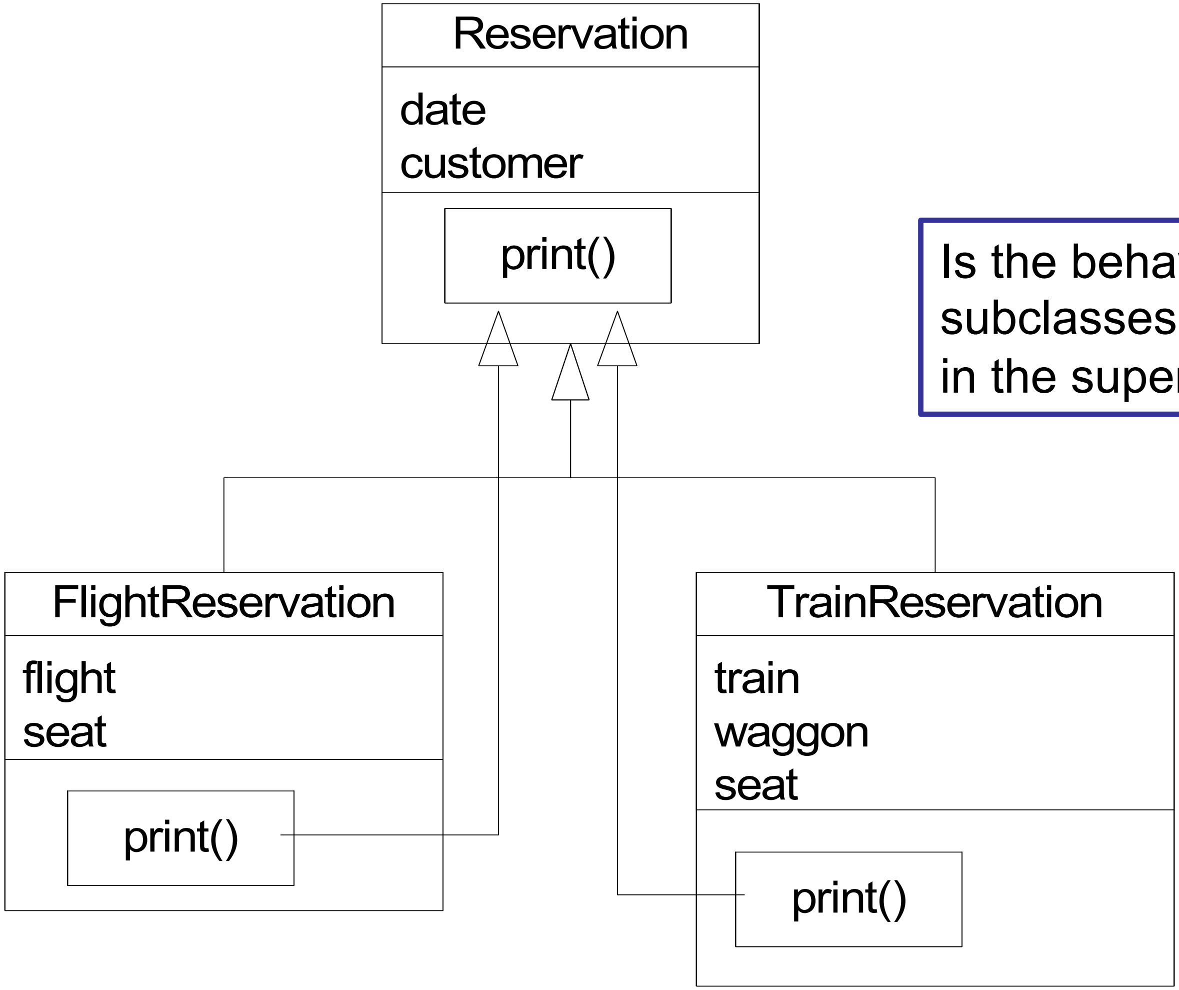
call ok, but wrong return type: T which is Object

```
public static <T> T writeAll(
  Collection<T> coll, Sink<? super T> snk){
  ...
}

String str = writeAll(cs, s); //?
```

Yes: returns T which is now String

Subtyping of behaviour specification?



Is the behavior of print in the subclasses a behavioral subtype of that in the superclass?

’Subtyping’ for behaviour – the super style

```
class Reservation {
  date . . . ;
  customer . . . ;
  void print()  {
    // print date and Customer
   }
}

class FlightReservation extends Reservation {
     flight . . .;
     seat . . .;
     void print {
       super.print();
       // print Flight and Seat
     }
}
```

We depend on the developer of FlightReservation to do the ”right thing”

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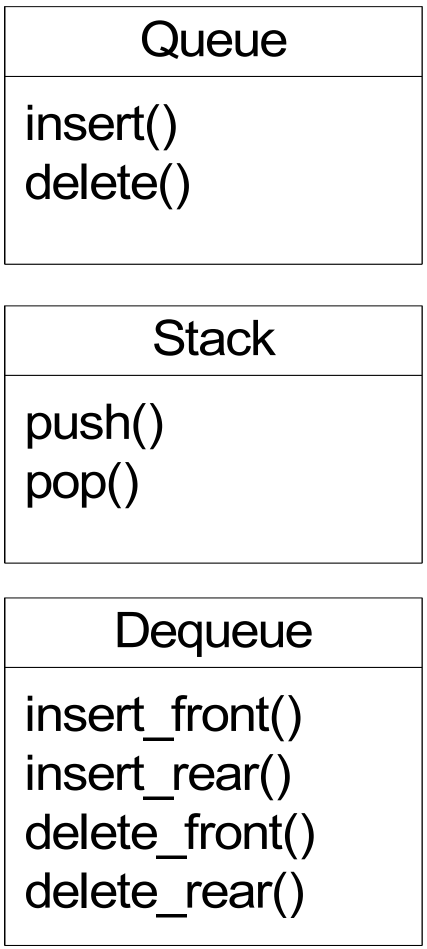
Subtyping for behaviour – the inner style

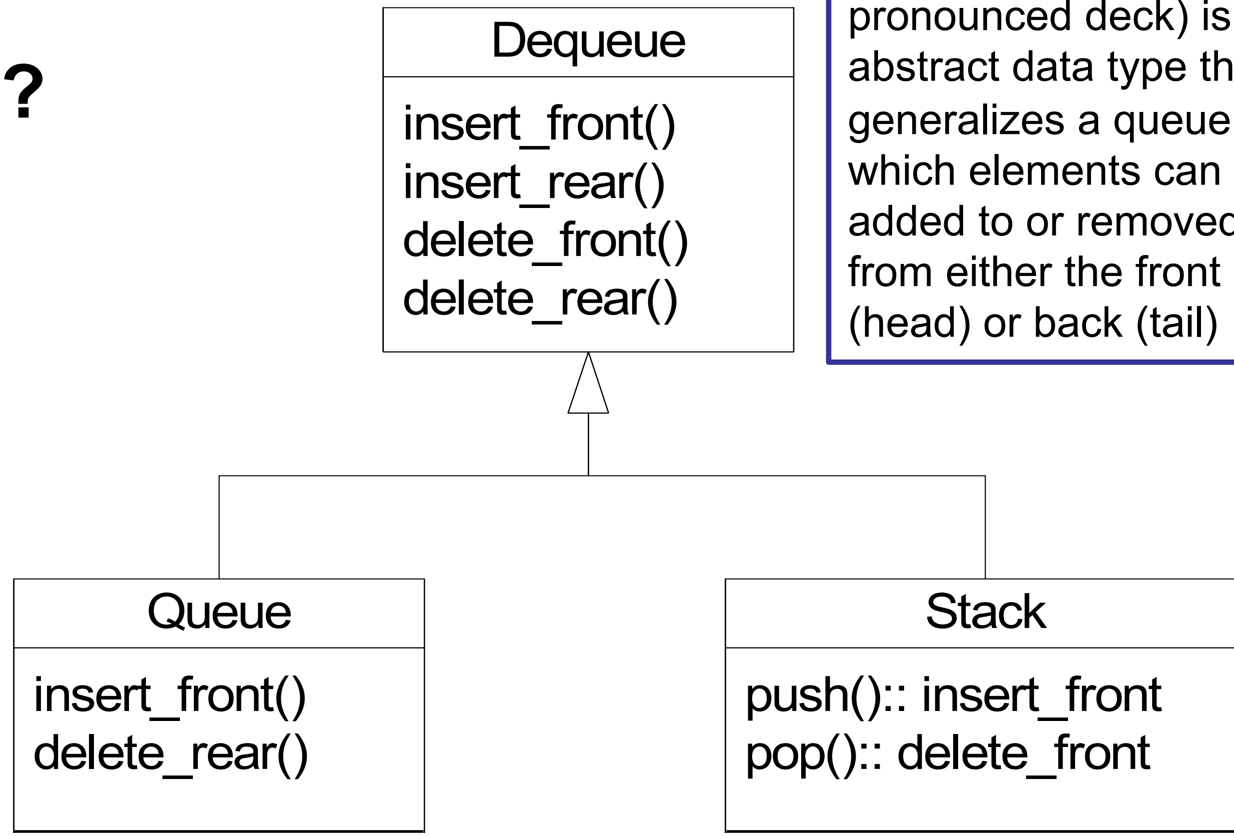
```
class Reservation {
   date . . . ;  customer . . . ;
   void print()  {
      // print Date and Customer
      inner;
   }
}

class FlightReservation
   extends Reservation {
      flight . . .;  seat . . .;
      void print  extended {
         // print flight and seat
         inner;
   }
}
```

- Does the inner style give behavioral compatibility?
- No, still only structural compatibility, but structure in terms of sequence of statements, in addition to signature (number of types of parameters)!

Subtyping = subclassing??

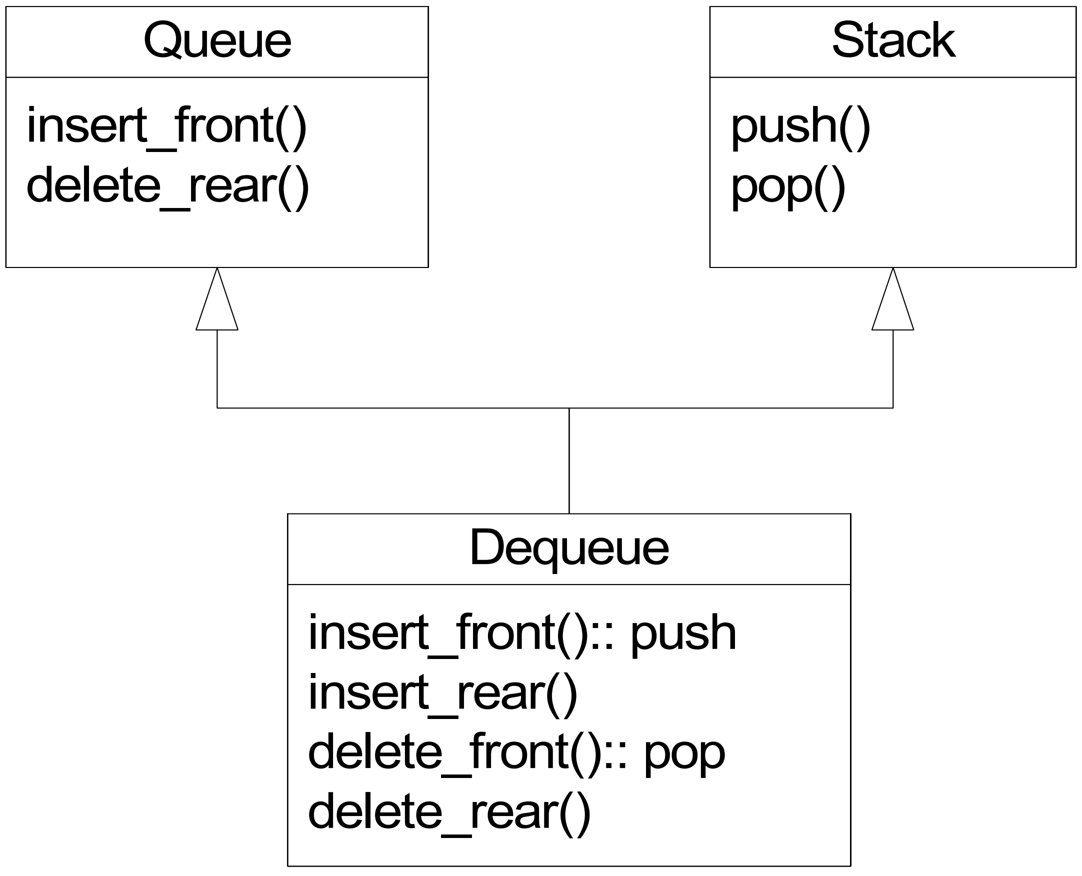


A double-ended queue (dequeue, often abbreviated to deque, pronounced deck) is an abstract data type that generalizes a queue, for which elements can be added to or removed from either the front (head) or back (tail)




```
Dequeue d; Stack s; Element e;
void f(Dequeue dp, Element ep) {
  dp.insert_front(ep); dp.insert_rear(ep) }
...
f(s, e)
```

The opposite any better?

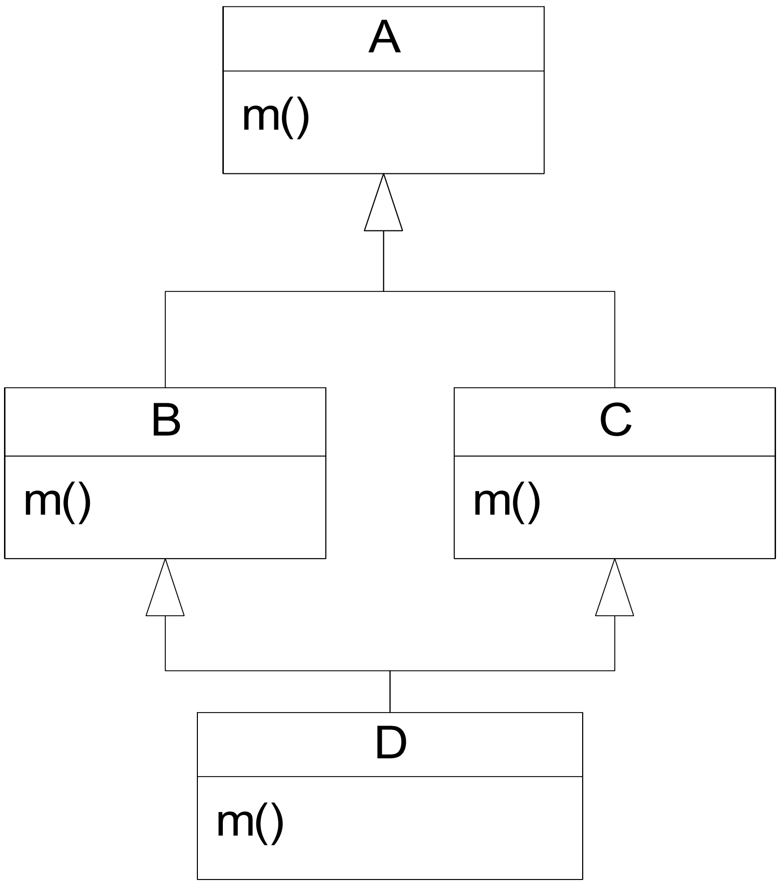


Dequeue can take the place of both a Queue and a Stack (via different references).

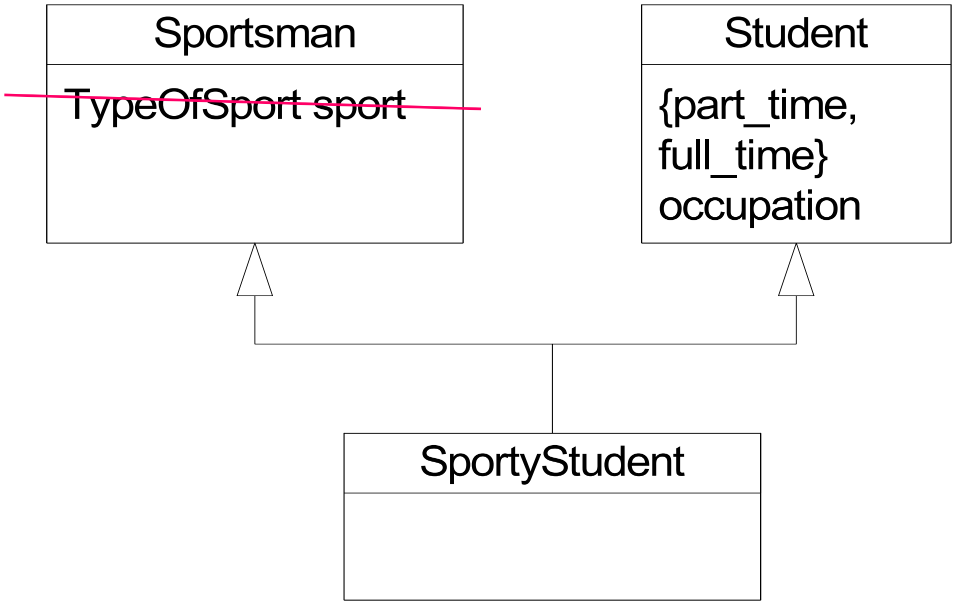
A context where it is used as a stack cannot be sure that it behaves like a stack.

Multiple inheritance I

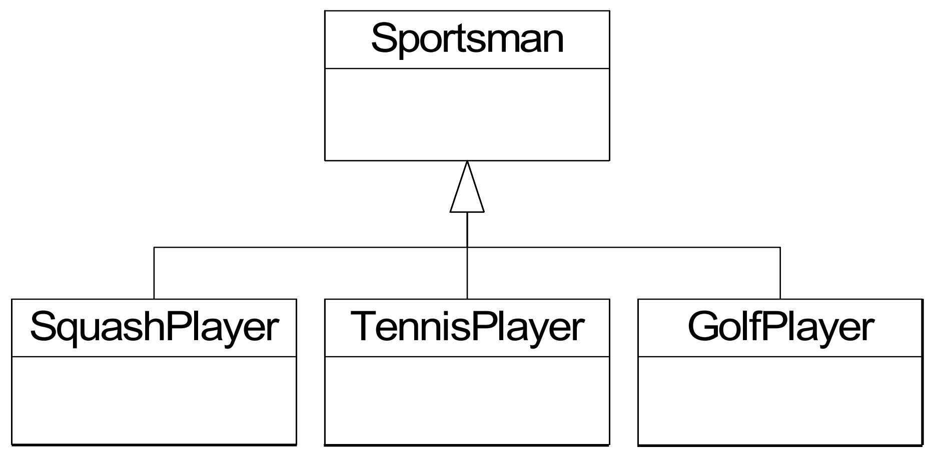
- Multiple supertypes or just multiple implementations?
- Name conflicts - m(), what to do?
  - Take the leftmost (i.e. 'B.m()')
  - Not allowed
  - Renaming
  - Explicit identification 'B.m()'
    - In definition of class D
    - In every use of m()
- One or two A's?
  - What if A has variables too? How many copies will there be?
- Overriding
  - Which one do you override?



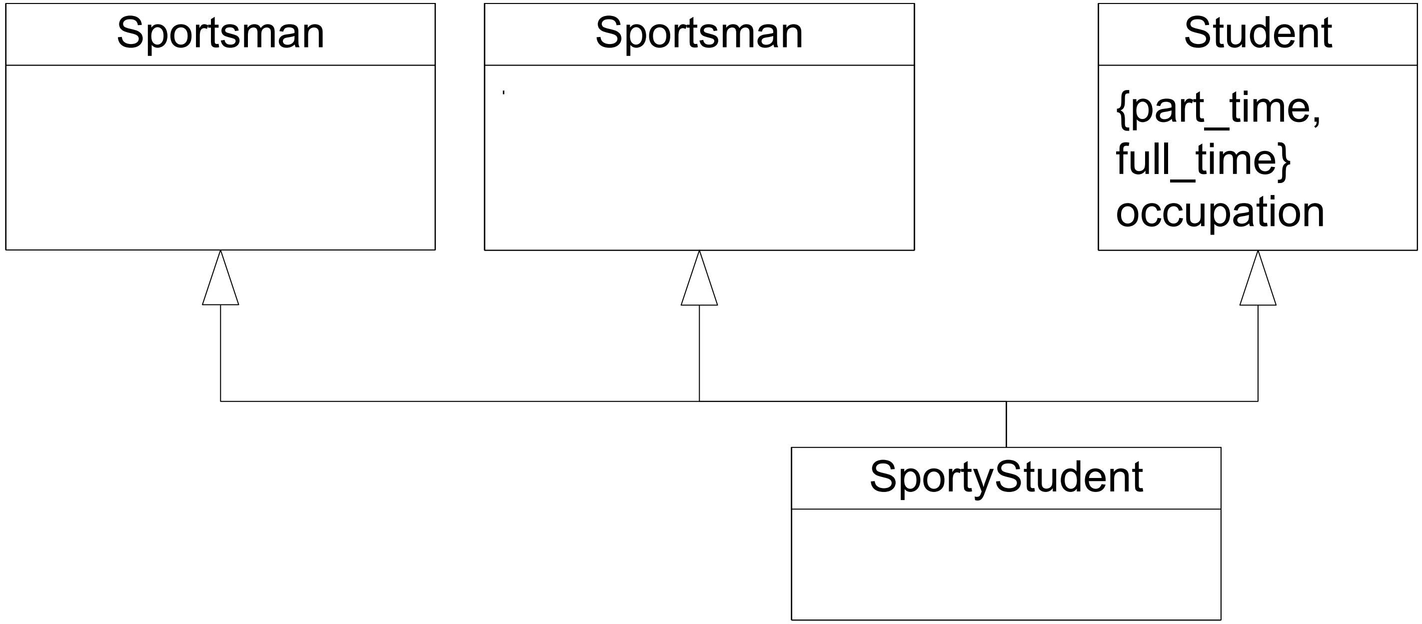
Multiple classification



Squash playing student??



Squash and Tennis playing student??



Multi-methods, ’dynamic overloading’

```
class Point { int x,y; }

class ColorPoint extends Point { Color c; }

bool equal(Point p1, Point p2) {
   return p1.x=p2.x and p1.y=p2.y };

bool equal(ColorPoint p1, ColorPoint p2) {
   return p1.x=p2.x and p1.y=p2.y and p1.c=p2.c };


equal (pt1, pt2);

           -  equal (aPoint, aPoint);
           -  equal (aPoint, aColorPoint);
           -  equal (aColorPoint, aColorPoint);
```

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Composition / Encapsulation?

```
class Apartment {
   Kitchen theKitchen = new Kitchen();
   Bathroom theBathroom = new Bathroom();
   Bedroom theBedroom = new Bedroom ();
   FamilyRoom theFamilyRoom =
      new FamilyRoom ();
   . . .
   Person Owner;
   Address theAddress = new Address()
}



...; myApartment.theKitchen.paint(); ...
```

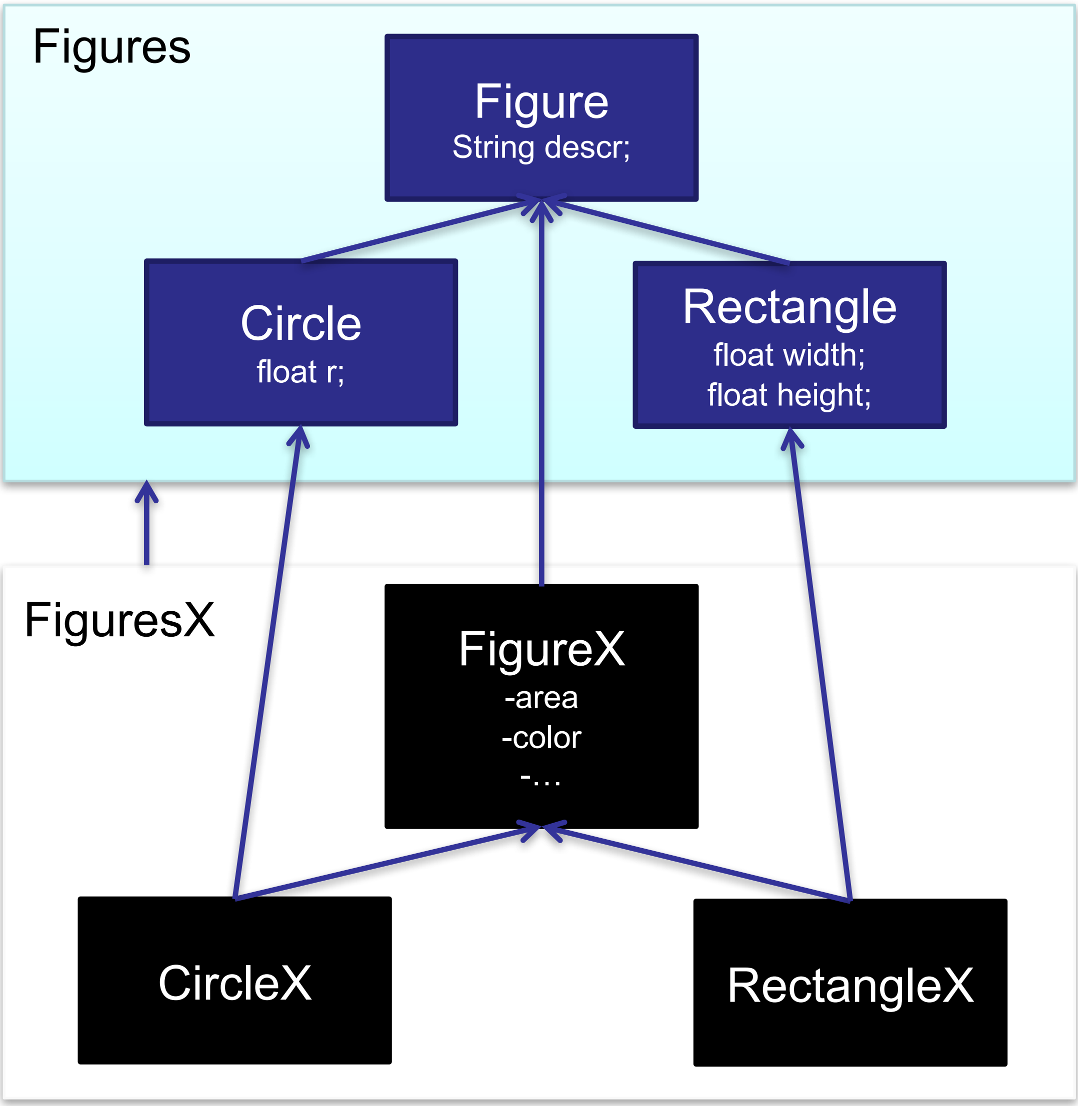
Where are Kitchen, Bathroom, Bedroom, FamiliRyoom defined?

Inner classes - locally defined classes

```
class Apartment {
   Height height;
   Kitchen theKitchen = new Kitchen();
   class ApartmentBathroom extends Bathroom {... height ...}
   ApartmentBathroom Bathroom_1 = new ApartmentBathroom ();
   ApartmentBathroom Bathroom_2 = new ApartmentBathroom ();

   Bedroom theBedroom = new Bedroom ();
   FamilyRoom theFamilyRoom = new FamilyRoom ();
   . . .
   Person Owner;
   Address theAddress = new Address()
}
```

Virtual classes



Virtual classes

```
class Apartment {
   virtual class ApartmentBathroom < Bathroom
   ...
};

class SpecialApartment extends Apartment {
   class ApartmentBathroom:: PinkBathroom
      // PinkBathroom defined somewhere else
}

class MoreSpecialApartment extends Apartment {
   class ApartmentBathroom:: PinkBathroom {...}
}
```

Singular objects (singleton class) - anonymous classes

```
...
Button btn = new Button();
btn.setText("Say 'Hello World'");
btn.setOnAction(
  new EventHandler<ActionEvent>() {
    public void handle(ActionEvent event) {
        System.out.println("Hello World!");
    }
  }
);
...
```

Anonymous class

```java
interface HelloWorld {
  public void greet();
  public void greetSomeone(String someone);
}
```

```java
HelloWorld norwegianGreeting = new
  HelloWorld() {
    String name = "Verden";
    public void greet() {
       greetSomeone("Verden");
    }
    public void greetSomeone(String someone) {
      name = someone;
      System.out.println("Hallo " + name);
    }
};
```

Anonymous class

```java
public static void printPersons(
  List<Person> roster, CheckPerson tester) {
    for (Person p : roster) {
        if (tester.test(p)) {
            p.printPerson();
        }
    }
}
```

```java
interface CheckPerson {
  boolean test(Person p);
}
```

Functional interface

```java
printPersons(
  roster,
  new CheckPerson() {
      public boolean test(Person p) {
         return p.getGender() == Person.Sex.MALE
                && p.getAge() >= 18
                && p.getAge() <= 25;
      }
  }
);
```

Anonymous class

```java
public static void printPersons(
  List<Person> roster, CheckPerson tester) {
    for (Person p : roster) {
        if (tester.test(p)) {
            p.printPerson();
        }
    }
}
```

```java
interface CheckPerson {
  boolean test(Person p);
}
```

Functional interface

```java
printPersons(
  roster,
  (Person p) ->
        p.getGender() == Person.Sex.MALE
        && p.getAge() >= 18
        && p.getAge() <= 25
);
```

Anonymous function

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Coming up!

- Two lectures on Prolog (Volker)
- Guest lecture (most likely)
- Repetition
  - Exam from last year is out with the lecture notes from last time