Java: class hierarchy, polymorphism, abstract classes

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Programming Language Concepts

Lecture 4, 23 January 2025

A Java class

- An `Employee` class

```
public class Employee{
  private String name;
  private double salary;

  // Some Constructors ...

  // "mutator" methods
  public boolean setName(String s){ ... }
  public boolean setSalary(double x){ ... }

  // "accessor" methods
  public String getName(){ ... }
  public double getSalary(){ ... }

  // other methods
  public double bonus(float percent){
     return (percent/100.0)*salary;
  }
}
```

Subclasses

- Managers are special types of employees with extra features

```
public class Manager extends Employee{
    private String secretary;
    public boolean setSecretary(name s){ ... }
    public String getSecretary(){ ... }
}
```

class Square (Rectangle)

Subclasses

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```
public class Manager extends Employee{
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- `Manager` objects inherit other fields and methods from `Employee`
  - Every `Manager` has a `name`, `salary` and methods to access and manipulate these.

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- `Manager` objects inherit other fields and methods from `Employee`
  - Every `Manager` has a `name`, `salary` and methods to access and manipulate these.
- `Manager` is a subclass of `Employee`
  - Think of subset

Subclasses

- `Manager` objects do not automatically have access to private data of parent class.
  - Common to extend a parent class written by someone else
- How can a constructor for `Manager` set instance variables that are private to `Employee`?

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- Some constructors for `Employee`

```
public class Employee{
  ...
  public Employee(String n, double s){
    name = n; salary = s;
  }
  public Employee(String n){
    this(n,500.00);
  }
}
```

Subclasses

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  - Common to extend a parent class written by someone else
- How can a constructor for `Manager` set instance variables that are private to `Employee`?
- Some constructors for `Employee`
- A constructor for `Manager`
- Use parent class's constructor using `super`

```
public class Employee{
  ...
  public Employee(String n, double s){
     name = n; salary = s;
  }
  public Employee(String n){
     this(n,500.00);
  }
}
```

```
public class Manager extends Employee{
  ..
  public Manager(String n, double s, String sn){
     super(n,s)     /* super calls
                       Employee constructor */
     secretary = sn;
  }
}
```

Inheritance

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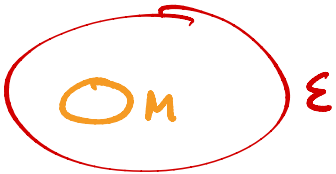
- Can use a subclass in place of a superclass

  `Employee e = new Manager(...)` ✓
- But the following will not work

  `Manager m = new Employee(...)` ✗



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  - `int[] a = new int[100];`
  - Why the seemingly redundant reference to `int` in `new`?
- One can now presumably write

  `Employee[] e = new Manager[100];`

Dynamic dispatch

- `Manager` can redefine `bonus()`

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double bonus(float percent){
   return 1.5*super.bonus(percent);
}
```
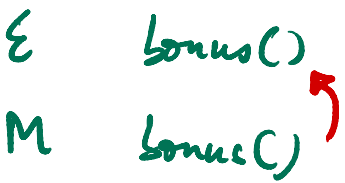

  - Uses parent class `bonus()` via `super`
  - Overrides definition in parent class



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- Consider the following assignment

```
Employee e = new Manager(...)
```

- Can we invoke `e.setSecretary()`?

Manager m = --
m.bonus()
↑ Manager bonus()

e is actually a Manager

Legal?

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- What about `e.bonus(p)`? Which `bonus()` do we use?
  - Static: Use `Employee.bonus()`
  - Dynamic: Use `Manager.bonus()`

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- What about `e.bonus(p)`? Which `bonus()` do we use?
  - Static: Use `Employee.bonus()`
  - Dynamic: Use `Manager.bonus()`
- Dynamic dispatch (dynamic binding, late method binding, ...) turns out to be more useful
  - Default in Java, optional in languages like C++ (`virtual` function)

Polymorphism

- Every `Employee` in `emparray` "knows" how to calculate its `bonus` correctly!

```
Employee[] emparray = new Employee[2];
Employee e = new Employee(...);
Manager m = new Manager(...);

emparray[0] = e;
emparray[1] = m;

for (i = 0; i < emparray.length; i++){
  System.out.println(emparray[i].bonus(5.0))
}
```

Polymorphism

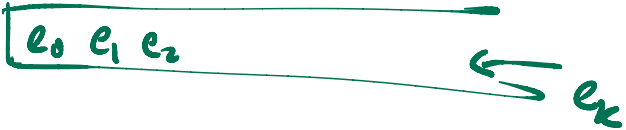
- Every `Employee` in `emparray` "knows" how to calculate its `bonus` correctly!
- Object oriented programming originated in Simula — event simulation loop

Simulation

```
Q := make-queue(first event)
repeat
  remove next event e from Q
  simulate e
  place all events generated
     by e on Q
until Q is empty
```

dynamic dispatch

Event queue



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- Also referred to as runtime polymorphism or inheritance polymorphism
- Different from structural polymorphism of Haskell etc — called generics in Java

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Functions, signatures and overloading

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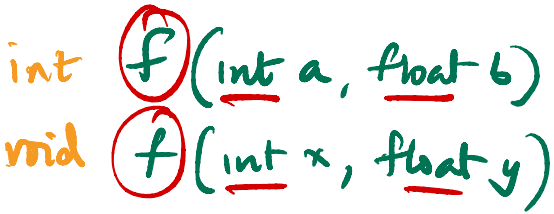

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- Java class `Arrays` has a method `sort` to sort arbitrary scalar arrays

```
double[] darr = new double[100];
int[] iarr = new int[500];
...
Arrays.sort(darr);
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- Made possible by overloaded methods defined in class `Arrays`

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class Arrays{
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- Overloading: multiple methods, different signatures, choice is static
- Overriding: multiple methods, same signature, choice is static
  - `Employee.bonus()`
  - `Manager.bonus()`
- Dynamic dispatch: multiple methods, same signature, choice made at run-time

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(t) v

⇒ "casts" variable v to type t

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- A simple example of reflection in Java
  - "Think about oneself"
- Can also use type casting for basic types

```
double d = 29.98;
long nd = (long) d;
```

From C

float f = 22/7;

Grouping together classes

- Sometimes we collect together classes under a common heading
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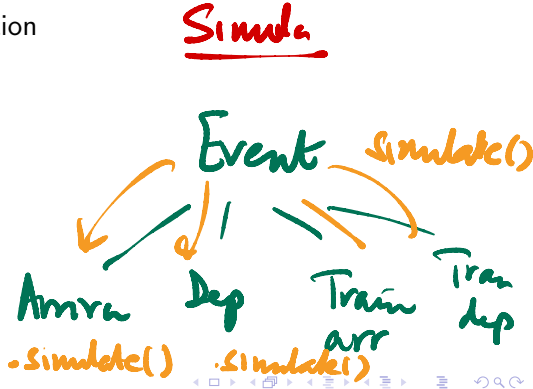

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- Could define a function in `Shape` that returns an absurd value
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- Rely on the subclass to redefine this function
- What if this doesn't happen?
  - Should not depend on programmer discipline

Abstract classes

- A better solution
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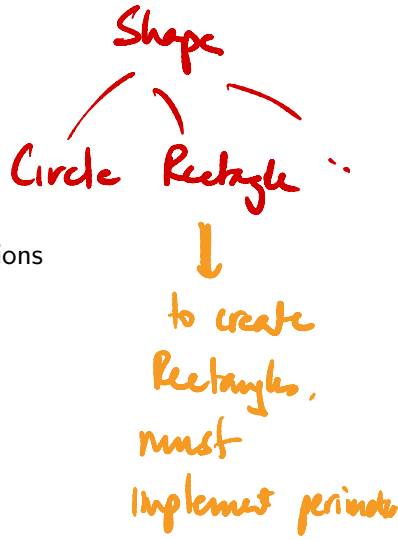

Abstract classes

- A better solution
  - Provide an abstract definition in `Shape`

    ```
    public abstract double perimeter();
    ```
- Forces subclasses to provide a concrete implementation
- Cannot create objects from a class that has abstract functions
- `Shape` must itself be declared to be `abstract`

```
public abstract class Shape{
  ...
  public abstract double perimeter();
  ...
}
```

Abstract classes . . .

- Can still declare variables whose type is an abstract class

Abstract classes . . .

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```
Shape shapearr[] = new Shape[3];
int sizearr[] = new int[3];

shapearr[0] = new Circle(...);
shapearr[1] = new Square(...);
shapearr[2] = new Rectangle(...);

for (i = 0; i < 3; i++){
  sizearr[i] = shapearr[i].perimeter();
     // each shapearr[i] calls the appropriate method
  ...
}
```

dynamic dispatch

Generic functions

- Use abstract classes to specify generic properties

```
public abstract class Comparable{
  public abstract int cmp(Comparable s);
    // return -1 if this < s,
    //         0 if this == 0,
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}
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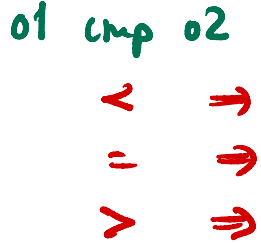

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Ord a ⇒ . .

- Now we can sort any array of objects that extend `Comparable`

```
public class SortFunctions{
  public static void quicksort(Comparable[] a){
    ...
    // Usual code for quicksort, except that
    // to compare a[i] and a[j] we use a[i].cmp(a[j])
  }
}
```

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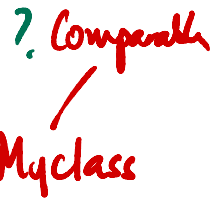
- To use this definition of `quicksort`, we write

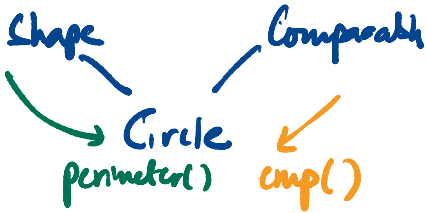
```
public class Myclass extends Comparable{
  private double size;   // quantity used for comparison

  public int cmp(Comparable s){
    if (s instanceof Myclass){
      // compare this.size and ((Myclass) s).size
      // Note the cast to access s.size
    }
  }
}
```



Multiple inheritance

- Can we sort `Circle` objects using the generic functions in `SortFunctions`?
  - `Circle` already extends `Shape`
  - Need `Circle` to also extend `Comparable`



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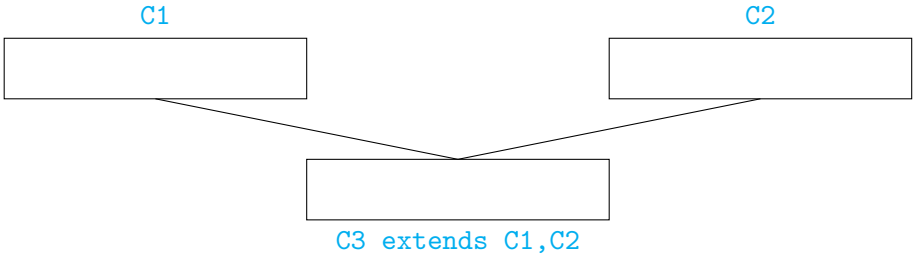

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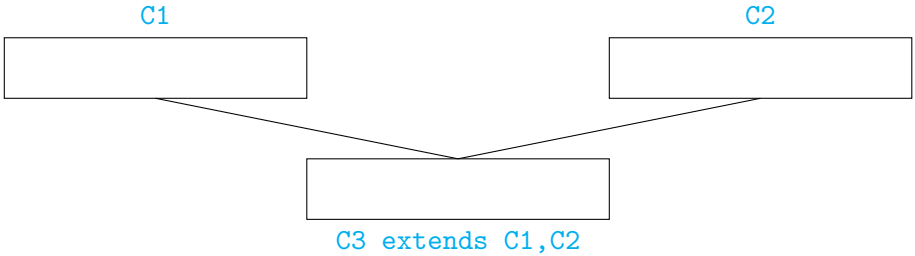

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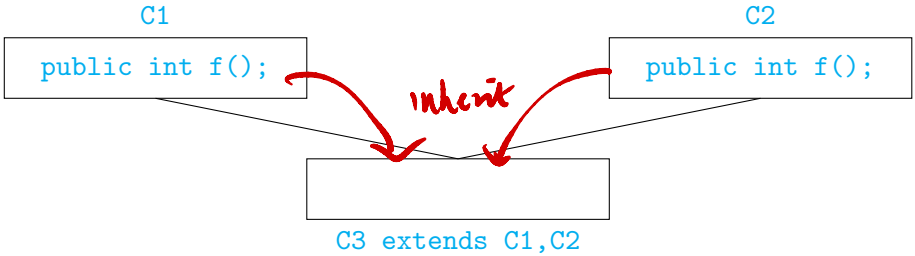

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Multiple inheritance

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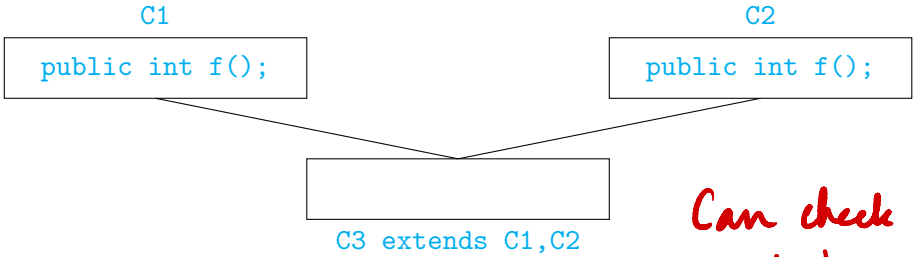

- If `f()` is not overridden, which `f()` do we use in `C3`?
- Java does not allow multiple inheritance

Can check at compile time

1. C3 overrides f()
2. No such clash

Multiple inheritance

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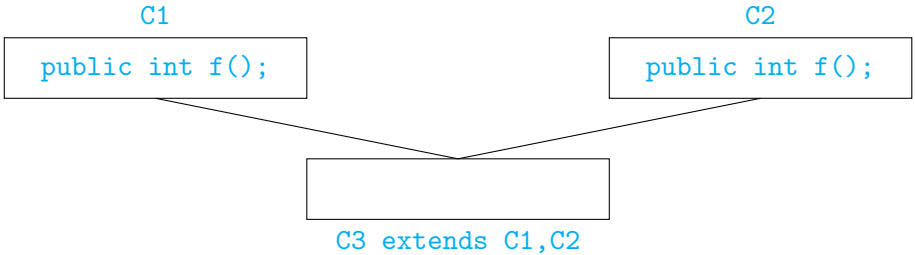

- If `f()` is not overridden, which `f()` do we use in `C3`?
- Java does not allow multiple inheritance
- C++ allows this if `C1` and `C2` have no conflict

Interfaces and Multiple inheritance

- An interface is an abstract class with no concrete components

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}
```

"Fully" abstract class

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public interface Comparable{
  public abstract int cmp(Comparable s);
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```

- A class that extends an interface is said to implement it:

```
public class Circle extends Shape implements Comparable{
  public double perimeter(){...}
  public int cmp(Comparable s){...}
     ...
}
```

extends

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- A class that extends an interface is said to implement it:

```
public class Circle extends Shape implements Comparable{
  public double perimeter(){...}
  public int cmp(Comparable s){...}
     ...
}
```

- Can extend only one class, but can implement multiple interfaces

Interfaces and Multiple inheritance

- An interface is an abstract class with no concrete components

```
public interface Comparable{
  public abstract int cmp(Comparable s);
}
```

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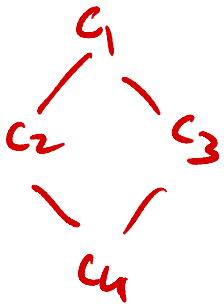
```

- Can extend only one class, but can implement multiple interfaces
- Interfaces describe relevant aspects of a class
  - Abstract functions describe a specific "slice" of capabilities
  - Another class only needs to know about these capabilities

Java class hierarchy

- No multiple inheritance — tree-like



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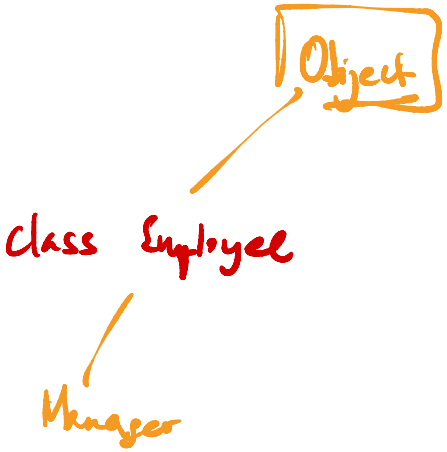

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- For Java objects `x` and `y`, `x == y` invokes `x.equals(y)`
- To print `o`, use `System.out.println(o+"");`
  - Implicitly invokes `o.toString()`

forces conversion to String

Java class hierarchy

- Can exploit the tree structure to write generic functions
  - Example: search for an element in an array

```
public int find (Object[] objarr, Object o){
  int i;
  for (i = 0; i < objarr.length(); i++){
      if (objarr[i] == o) {return i};
  }
  return (-1);
}
```

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```

Date.equals()
Object
objarr[i].equals(o)

- Recall that `==` is pointer equality, by default
- If a class overrides `equals()`, dynamic dispatch will use the redefined function instead of `Object.equals()` for `objarr[i] == o`

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- Unfortunately,
  `boolean equals(Date d)`
  does not override
  `boolean equals(Object o)`!

- Should write, instead

```
public boolean equals(Object d){
  if (d instanceof Date){
    Date myd = (Date) d;
    return ((this.day == myd.day) &&
            (this.month == myd.month) &&
            (this.year == myd.year));
  }
  return(false);
}
```

type cast

  - Note the run-time type check and the cast

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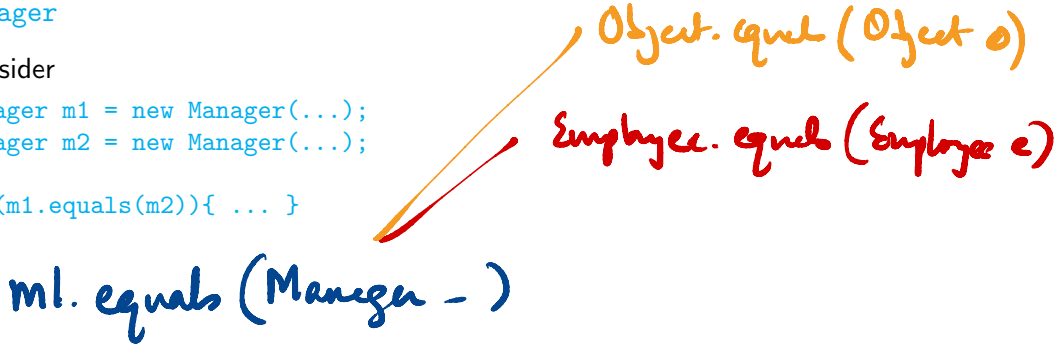

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- Use `boolean equals(Employee e)`

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  - Capabilities of the subtype are a superset of the main type
  - If `B` is a subtype of `A`, wherever we require an object of type `A`, we can use an object of type `B`
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  - `Employee e = new Manager(...);` is legal
- Inheritance
  - Subtype can reuse code of the main type
  - `B` inherits from `A` if some functions for `B` are written in terms of functions of `A`
  - `Manager.bonus()` uses `Employee.bonus()`

Subtyping vs inheritance

- Consider the following example
  - `queue`, with methods `insert-rear`, `delete-front`
  - `stack`, with methods `insert-front`, `delete-front`
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  - `deque` has more functionality than `queue` or `stack`
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- Inheritance
  - Can suppress two functions in a `deque` and use it as a `queue` or `stack`
  - Both `queue` and `stack` inherit from `deque`

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  - `B` inherits from `A` if some functions for `B` are written in terms of functions of `A`.
- Using one idea (hierarchy of classes) to implement both concepts blurs the distinction between the two