Java: Reflection, Cloning

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Programming Language Concepts

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- Two components involved in reflection
  - Introspection

    A program can observe, and therefore reason about its own state.
  - Intercession

    A program can modify its execution state or alter its own interpretation or meaning.

Reflection in Java

- Simple example of introspection

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Employee e = new Manager(...);
...
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- Simple example of introspection

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if (e instanceof Manager){
    ...
}
```

- What if we don't know the type that we want to check in advance?
- Suppose we want to write a function to check if two different objects are both instances of the same class?

```
public static boolean classequal(Object o1, Object o2){
  ...
  // return true iff o1 and o2 point to objects of same type
  ...
}
```

Reflection in Java . . .

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- Can't use `instanceof`
  - Will have to check across all defined classes
  - This is not even a fixed set!
- Can't use generic type variables
  - The following code is syntactically disallowed

    ```
    if (o1 instance of T) { ...}
    ```

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```

- What does `getClass()` return?
- An object of type `Class` that encodes class information

The class `Class`

- A version of `classequal` the explicitly uses this fact

```
import java.lang.reflect.*;

class MyReflectionClass{
    ...
    public static boolean classequal(Object o1, Object o2){
        Class c1, c2;
        c1 = o1.getClass();
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        return (c1 == c2);
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```

- For each currently loaded class `C`, Java creates an object of type `Class` with information about `C`
- Encoding execution state as data — reification
  - Representing an abstract idea in a concrete form

Using the `Class` object

- Can create new instances of a class at runtime

```
...
Class c = obj.getClass();
Object o = c.newInstance();
   // Create a new object of same type as obj
...
```

Using the `Class` object

- Can create new instances of a class at runtime

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Class c = obj.getClass();
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- Can also get hold of the class object using the name of the class

```
...
String s = "Manager".
Class c = Class.forName(s);
Object o = c.newInstance();
...
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...
String s = "Manager".
Class c = Class.forName(s);
Object o = c.newInstance();
...
```

- . . . , or, more compactly

```
...
Object o = Class.forName("Manager").newInstance();
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  - All three: modifiers `static`, `private` etc
- Additional classes `Constructor`, `Method`, `Field`
- Use `getConstructors()`, `getMethods()` and `getFields()` to obtain constructors, methods and fields of `C` in an array.

The class `Class` ...

- Extracting information about constructors, methods and fields

```
...
Class c = obj.getClass();
Constructor[] constructors = c.getConstructors();
Method[] methods = c.getMethods();
Field[] fields = c.getFields();
...
```

The class `Class` ...

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- `Constructor`, `Method`, `Field` in turn have functions to get further details

The class `Class` ...

- Example: Get the list of parameters for each constructor

```
...
Class c = obj.getClass();
Constructor[] constructors = c.getConstructors();
for (int i = 0; i < constructors.length; i++){
  Class params[] = constructors[i].getParameterTypes();
  ..
}
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```

- Each parameter list is a list of types
  - Return value is an array of type `Class[]`

The class `Class` ...

- We can also invoke methods and examine/set values of fields.

```
...
Class c = obj.getClass();
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Method[] methods = c.getMethods();
Object[] args = { ... }
  // construct an array  of arguments
methods[3].invoke(obj,args);
  // invoke methods[3] on obj with arguments args
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Field[] fields = c.getFields();
Object o =  fields[2].get(obj);
   // get the value of fields[2] from obj
...
fields[3].set(obj,value);
  // set the value of fields[3] in obj to value
...
```

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- Should this be allowed to all programs?
- Security issue!
- Access to private components may be restricted through external security policies

Using reflection

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- Can define and compile Java classes
- For compiled code, create object, invoke methods, examine state
- Uses reflective capabilities of Java — `BlueJ` need not internally maintain "debugging" information about each class
- See `http://www.bluej.org`

Limitations of Java reflection

- Cannot create or modify classes at run time
  - The following is not possible

    ```
    Class c = new Class(....);
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  - An environment like BlueJ must invoke Java compiler before you can use a new class

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- Contrast with Python
  - `class XYZ:` can be executed at runtime in Python

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- Contrast with Python
  - `class XYZ:` can be executed at runtime in Python
- Other OO languages like Smalltalk allow redefining methods at run time

Erasure of generic information

- Type erasure — Java does not keep record all versions of `LinkedList<T>` as separate types
  - Cannot write

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- Or, the upper bound, if one is available
  - `LinkedList<? extends Shape>` becomes `LinkedList<Shape>`
- Since no information about `T` is preserved, cannot use `T` in expressions like

  ```
  if (o instanceof T) {...}
  ```

Erasure and overloading

- Type erasure means the comparison in following code fragment returns `True`

```
o1 = new LinkedList<Employee>();
o2 = new LinkedList<Date>();

if (o1.getClass() == o2.getClass){
   // True, so this block is executed
}
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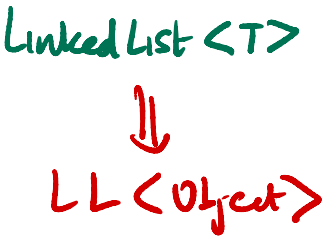

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public class Example {
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- Both functions have the same signature after type erasure

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  - If `S extends T` then `S[] extends T[]`

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  - If `S extends T` then `S[] extends T[]`
- Can lead to run time type errors

```
ETicket[] elecarr = new ETicket[10];
Ticket[] ticketarr = elecarr;  // OK. ETicket[] is a subtype of Ticket[]
...
ticketarr[5] = new Ticket();  // Not OK.  ticketarr[5] refers to an ETicket!
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- An ugly workaround . . . generates a compiler warning but works!

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Basic type	Wrapper Class
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`short`	`Short`
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- All wrapper classes other than `Boolean`, `Character` extend the class `Number`

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- Converting from basic type to wrapper class and back

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Integer myx = Integer(x);
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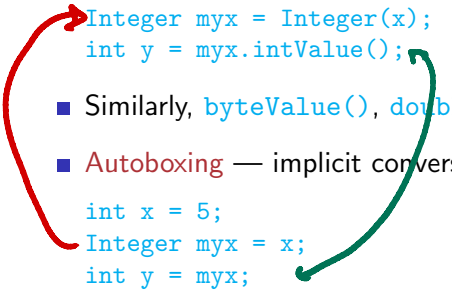

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- Use wrapper types in generic data structures

Copying an object

- Normal assignment creates two references to the same object
  - Updates via either name update the object

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

  public Employee(String n, double s){
    name = n;
    salary = s;
  }

  public void setname(String n){
    name = n;
  }
}
```


```
Employee e1 = new Employee("Dhruv", 21500.0);
Employee e2 = e1;
e2.setname("Eknath");  // e1 also updated
```

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- What if we want two separate but identical objects?
  - e2 should be initialized to a disjoint copy of e1

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- How does one make a faithful copy?

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The clone() method

- Object defines a method clone()

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The `clone()` method

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  - Cannot build up a fresh copy of `e1` from scratch

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  - Cannot build up a fresh copy of e1 from scratch
- What could go wrong with a bitwise copy?

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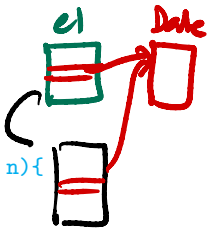
Shallow copy

- What if we add an instance variable `Date` to `Employee`?
  - Assume `update()` updates the components of a `Date` object

```
public class Employee {
  private String name;
  private double salary;
  private Date birthday;
  ...
  public void setname(String n){
    name = n;
  }

  public void setbday(int dd, int mm, int yy){
    birthday.update(dd,mm,yy);
  }
}
```



Shallow copy

- What if we add an instance variable `Date` to `Employee`?
  - Assume `update()` updates the components of a `Date` object
- Bitwise copy made by `e1.clone()` copies the reference to the embedded `Date`
  - `e2.birthday` and `e1.birthday` refer to the same object
  - `e2.setbday()` affects `e1.birthday`

```
public class Employee {
  private String name;
  private double salary;
  private Date birthday;
  ...
  public void setname(String n){
    name = n;
  }

  public void setbday(int dd, int mm, int yy){
    birthday.update(dd,mm,yy);
  }
}
...
Employee e1 = new Employee("Dhruv", 21500.0);
Employee e2 = e1.clone();
e2.setname("Eknath");  // e1 name not updated
e2.setbday(16,4,1997); // e1 bday updated!
```

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  - `e2.birthday` and `e1.birthday` refer to the same object
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- Bitwise copy is a shallow copy
  - Nested mutable references are copied verbatim

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Deep copy

- Deep copy recursively clones nested objects

```
public class Employee {
  private String name;
  private double salary;
  private Date birthday;
  ...
  public void setname(String n){...}

  public void setbday(...){...}
}
```

Deep copy

- Deep copy recursively clones nested objects
- Override the shallow `clone()` from `Object`

```
public class Employee {
  private String name;
  private double salary;
  private Date birthday;
  ...
  public void setname(String n){...}

  public void setbday(...){...}

  public Employee clone(){
    Employee newemp =
          (Employee) super.clone()
    Date newbday = birthday.clone();
    newemp.birthday = newbday;
    return newmp;
  }
}
```

Deep copy

- Deep copy recursively clones nested objects
- Override the shallow `clone()` from `Object`
- `Object.clone()` returns an `Object`
  - Cast `super.clone()`

```
public class Employee {
  private String name;
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    newemp.birthday = newbday;
    return newmp;
  }
}
```

Deep copy

- Deep copy recursively clones nested objects
- Override the shallow `clone()` from `Object`
- `Object.clone()` returns an `Object`
  - Cast `super.clone()`
- `Employee.clone()` returns an `Employee`
  - Allowed to change the return type

```
public class Employee {
  private String name;
  private double salary;
  private Date birthday;
  ...
  public void setname(String n){...}

  public void setbday(...){...}

  public Employee clone(){
    Employee newemp =
          (Employee) super.clone()
    Date newbday = birthday.clone();
    newemp.birthday = newbday;
    return newmp;
  }
}
```

Deep copy . . .

- What if `Manager` extends `Employee`?

```
public class Employee {
  private String name;
  private double salary;
  private Date birthday;
  ...
  public void setname(String n){...}

  public void setbday(...){...}

  public Employee clone(){...}
}
```

Deep copy . . .

- What if `Manager` extends `Employee`?
- New instance variable `promodate`

```
public class Employee {
  private String name;
  private double salary;
  private Date birthday;
  ...
  public void setname(String n){...}

  public void setbday(...){...}

  public Employee clone(){...}
}

public class Manager extends Employee {
  private Date promodate;
  ...
}
```

Deep copy . . .

- What if `Manager` extends `Employee`?
- New instance variable `promodate`
- `Manager` inherits deep copy `clone()` from `Employee`

```
public class Employee {
  private String name;
  private double salary;
  private Date birthday;
  ...
  public void setname(String n){...}

  public void setbday(...){...}

  public Employee clone(){...}
}

public class Manager extends Employee {
  private Date promodate;
  ...
}
```

Deep copy . . .

- What if `Manager` extends `Employee`?
- New instance variable `promodate`
- `Manager` inherits deep copy `clone()` from `Employee`
- However `Employee.clone()` does not know that it has to deep copy `promodate`!

```
public class Employee {
  private String name;
  private double salary;
  private Date birthday;
  ...
  public void setname(String n){...}

  public void setbday(...){...}

  public Employee clone(){...}
}

public class Manager extends Employee {
  private Date promodate;
  ...
}
```

Deep copy . . .

- What if `Manager` extends `Employee`?
- New instance variable `promodate`
- `Manager` inherits deep copy `clone()` from `Employee`
- However `Employee.clone()` does not know that it has to deep copy `promodate`!
- Cloning is subtle, so Java puts in some restrictions

```
public class Employee {
  private String name;
  private double salary;
  private Date birthday;
  ...
  public void setname(String n){...}

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  public Employee clone(){...}
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```

Restrictions on `clone()`

- To allow `clone()` to be used, a class has to implement `Cloneable` interface
  - Marker interface

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public class Employee implements Cloneable {
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- `clone()` in `Object` is `protected`
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- `clone()` in `Object` is `protected`
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- Redefine `clone()` as `public` to allow other classes to clone `Employee`
  - Expanding visibility from `protected` to `public` is allowed

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  - Expanding visibility from protected to public is allowed
- Object.clone() throws CloneNotSupportedException
  - Catch or report this exception
  - Call clone() in try block

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