Object-Oriented Programming
Java

Goals

1. Java Language
2. Object-Oriented Programming
3. Inheritance and Polymorphism
4. Static Members
5. Interfaces and Abstract Classes
6. Exceptions and Nested Classes
7. Threads
8. GUI Programming
9. Collections and Generics

Module 1
Java language

Java language

- History
- Java technology: JDK, JRE, JVM
- Properties
- 'Hello world' application
- Garbage Collection

Short History

- 1991 - Green Project for consumer electronics market (Oak language → Java)
- 1994 – HotJava Web browser
- 1995 – Sun announces Java
- 1996 – JDK 1.0
- 1997 – JDK 1.1 *RMI, AWT, Servlets*
- 1998 – Java 1.2 *Reflection, Swing, Collections*
- 2004 – J2SE 1.5 (Java 5) *Generics, enums*
- 2014 – Java 8 *Lambdas*

Java technology

- JDK – Java Development Kit
- JRE – Java Runtime Environment
- JVM – Java Virtual Machine

Properties

- Object-oriented
- Interpreted
- Portable
- Secure and robust
- Scalable
- Multi-threaded
- Dynamic language
- Distributed

Hello World Application

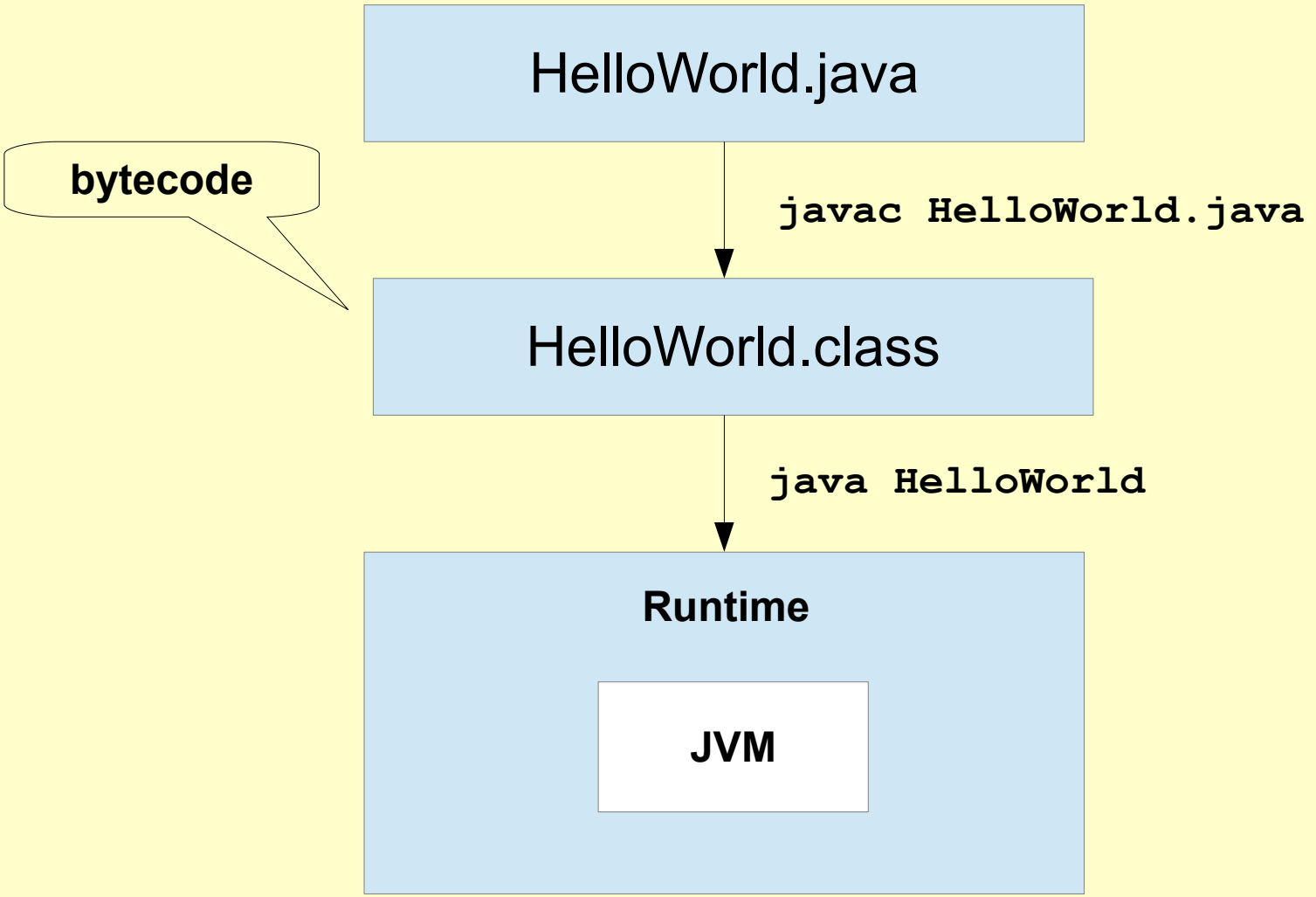
1. Write the source code: HelloWorld.java

```
public class HelloWorld{
    public static void main( String args[] ){
        System.out.println("Hello world");
    }
 }
```

2. Compile: **`javac HelloWorld.java`**

3. Run: **`java HelloWorld`**

Hello World Application



Garbage Collection

- Dynamically **allocated memory**
- **Deallocation**
  - Programmer's responsibility (C/C++)
  - System responsibility (Java):
    - Is done automatically (system-level thread)
    - Checks for and frees memory no longer needed

Remember

- JVM, JRE, JDK
- Compilers vs. interpreters
- Portability
- Dynamic typing (dynamic language)

Module 2
Object-Oriented Programming

Object-oriented programming
Classes and Objects

- **Class**
  - Attributes and methods
- **Object** (instance)
- **Information hiding**
- **Encapsulation**
- **Constructors**
- **Packages**

Class

- Is a **user-defined** type
  - Describes the *data* **(attributes)**
  - Defines the *behavior* (**methods**)

} **members**

- Instances of a class are **objects**

Declaring Classes

- **Syntax**

```
<modifier>* class <class_name>{
   <attribute_declaration>*
   <constructor_declaration>*
   <method_declaration>*
}
```

- **Example**

```
public class Counter{
   private int value;
   public void inc(){
      ++value;
   }
   public int getValue(){
      return value;
   }
}
```

Declaring Attributes

- **Syntax**

```
<modifier>* <type> <attribute_name>[= <initial_value>];
```

- **Examples**

```
public class Foo{
   private int x;
   private float f = 0.0;
   private String name =”Anonymous”;
}
```

Declaring Methods

- **Syntax**

```
<modifier>* <return_type> <method_name>( <argument>* ){

    <statement>*

}
```

- **Examples**

```
public class Counter{
   public static final int MAX = 100;
   private int value;

   public void inc(){
      if( value < MAX ){
         ++value;
      }
   }
   public int getValue(){
      return value;
   }
}
```

Accessing Object Members

- **Syntax**

  <object>.<member>

- **Examples**

```
public class Counter{
   public static final int MAX = 100;
   private int value;

   public void inc(){
      if( value < MAX ){
         ++value;
      }
   }
   public int getValue(){
      return value;
   }
}
```

```
c.inc();
int i = c.getValue();
```

Information Hiding

- **The problem:**

  Client code has direct access to internal data

```
/* C language */
struct Date {
   int year, month, day;
};
```

```
Date d;
d.day = 32; //invalid day

d.month = 2; d.day = 30;
// invalid data

d.day = d.day + 1;
// no check
```

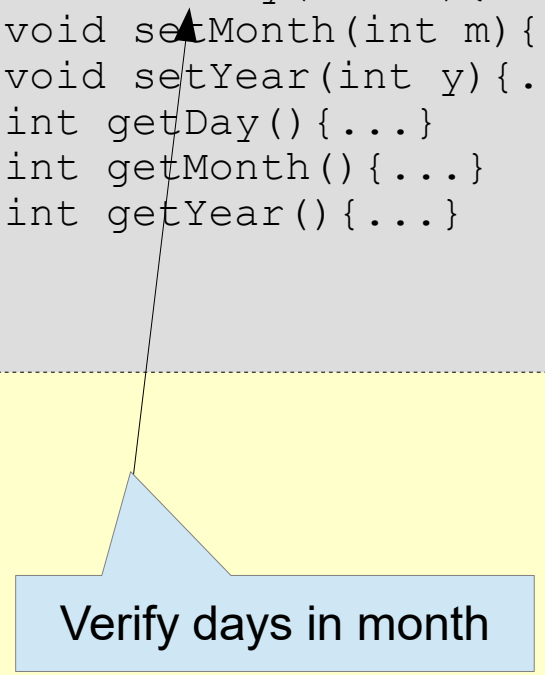
Information Hiding

- **The solution:**

Client code must use setters and getters to access internal data

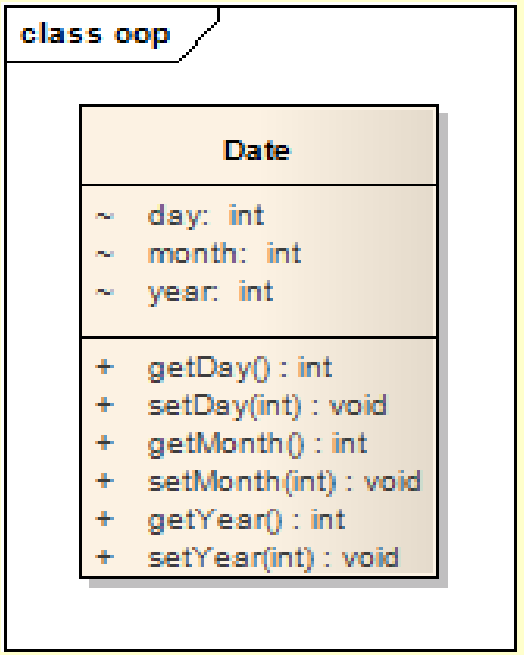
```
// Java language
public class Date {
   private int year, month, day;
   public void setDay(int d){..}
   public void setMonth(int m){..}
   public void setYear(int y){..}
   public int getDay(){...}
   public int getMonth(){...}
   public int getYear(){...}
}
```

```
Date d = new Date();
//no assignment
d.setDay(32);
// month is set
d.setMonth(2);
// no assignment
d.day = 30;
```



Encapsulation

- Hides the **implementation details** of a class
- Forces the user to use an **interface** to access data
- Makes the code more **maintainable**



Declaring Constructors

- **Syntax:**

```
[<modifier>]<class_name>( <argument>*){
   <statement>*
}
```

```
public class Date {
  private int year, month, day;

  public Date( int y, int m, int d)     {
     if( verify(y, m, d) ){
       year = y; month = m; day = d;
     }
  }

  private boolean verify(int y, int m, int d){
    //...
  }
}
```

Constructors

- Role: **object initialization**
- **Name** of the constructor must be the same as that of class name.
- Must **not** have **return type**.
- Every class should have **at least one constructor**.
  - If you don't write constructor, compiler will generate the **default constructor**.
- Constructors are usually declared **public**.
  - Constructor can be declared as private → You can't use it outside the class.
- One class can have **more than one constructors.**
  - Constructor overloading.

The Default Constructors

- There is always at least one constructor in every class.
- If the programmer does not supply any constructors, the default constructor is generated by the compiler
  - The default constructor takes no argument
  - The default constructor's body is empty

```
public class Date {
  private int year, month, day;

  public Date( ){
  }
}
```

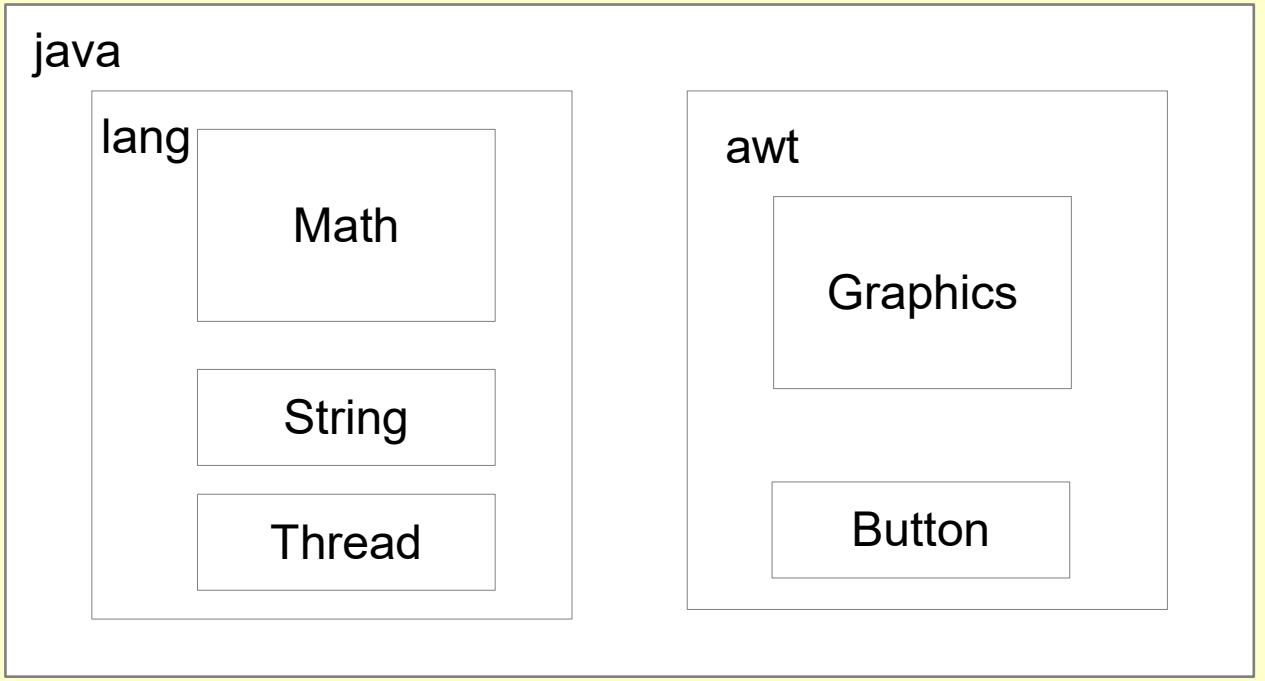
Objects

- Objects are **instances** of classes
- Are **allocated on the heap** by using the new operator
- Constructor is invoked automatically on the new object

```
Counter c = new Counter();

Date d1 = new Date( 2016, 9, 23);

Person p = new Person("John","Smith");
```

Packages

- Help manage large software systems
- Contain
  - Classes
  - Sub-packages



The `package` statement

- Syntax:

```
package <top_pkg_name>[.<sub_pkg_name>]*;
```

- Examples:

```
package java.lang;

public class  String{

...
}
```

- statement **at the beginning** of the source file
- only **one package declaration** per source file
- if **no package name** is declared → the class is placed into the **default package**

The `import` statement

- Syntax:

```
package <top_pkg_name>[.<sub_pkg_name>]*;
```

- Usage:

```
import <pkg_name>[.<sub_pkg_name>]*.*;
```

- Examples:

```
import java.util.List;
import java.io.*;
```

-precedes all class declarations
-tells the compiler **where to find classes**

Remember

- Class
- Class members:
  - attributes
  - methods
- Object, instance
- Constructor
- Package

Object-oriented programming

Types

- Primitive types
- Reference Type
- Parameter Passing
- The `this` reference
- Variables and Scope
- Casting

Java Types

- **Primitive (8)**
  - Logical: `boolean`
  - Textual: `char`
  - Integral: `byte, short, int, long`
  - Floating: `double, float`
- **Reference**
  - All others

Logical - `boolean`

- Characteristics:
  - Literals:
    - `true`
    - `false`
  - Examples:
    - `boolean cont = true;`
    - `boolean exists = false;`

Textual - `char`

- Characteristics:
  - Represents a 16-bit Unicode character
  - Literals are enclosed in single quotes (' ')
  - Examples:
    - `'a'` - the letter `a`
    - `'\t'` - the `TAB` character
    - `'\u0041'` - a specific Unicode character (`'A'`) represented by 4 hexadecimal digits

Integral – `byte, short, int, and long`

- Characteristics:
  - Use three forms:
    - Decimal: `67`
    - Octal: `0103` (`1x8^2+0x8^1+3x8^0`)
    - Hexadecimal: `0x43`
  - Default type of literal is `int`.
  - Literals with the `L` or `l` suffix are of type `long`.

Integral – `byte, short, int, and long`

- Ranges:

Type	Length	Range
`byte`	1 byte	$-2^{7}..2^{7}-1$
`short`	2 byte	$-2^{15}..2^{15}-1$
`int`	4 byte	$-2^{31}..2^{31}-1$
`long`	8 byte	$-2^{63}..2^{63}-1$

Floating Point – `float and double`

- Characteristics:
  - **Size:**
    - `float  – 4 byte`
    - `double – 8 byte`
  - Decimal point
    - `9.65` (`double`, **default type**)
    - `9.65`**`f`** or `9.65`**`F`** (`float`)
    - `9.65`**`D`** or `9.65`**`d`** (`double`)
  - Exponential notation
    - `3.41E20` (`double`)

Java ReferenceTypes

```
public class  MyDate{
    private int day = 26;
    private int month = 9;
    private int year = 2016;

    public MyDate( int day, int month, int year){
    ...
    }
}
```

```
MyDate date1 = new MyDate(20, 6, 2000);
```

Constructing and Initializing Objects

```
MyDate date1 = new MyDate(20, 6, 2000);
```

Constructing and Initializing Objects

```
MyDate date1 = new MyDate(20, 6, 2000);
```

```
new MyDate(20, 6, 2000);
```

(1) Memory is allocated for the object

(2) Explicit attribute initialization is performed

(3) A constructor is executed

(4) The **object reference** is returned by the `new` operator

Constructing and Initializing Objects

```
MyDate date1 = new MyDate(20, 6, 2000);
```

```
new MyDate(20, 6, 2000);
```

(1) Memory is allocated for the object

(2) Explicit attribute initialization is performed

(3) A constructor is executed

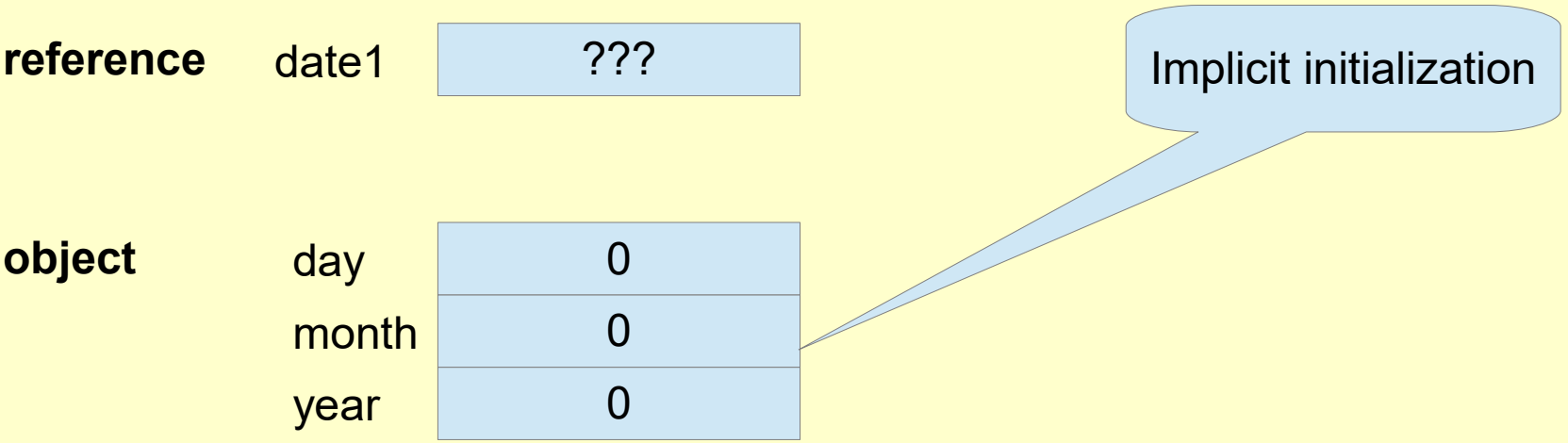
(4) The **object reference** is returned by the `new` operator

```
date1 =  object reference
```

(5)The reference is assigned to a variable

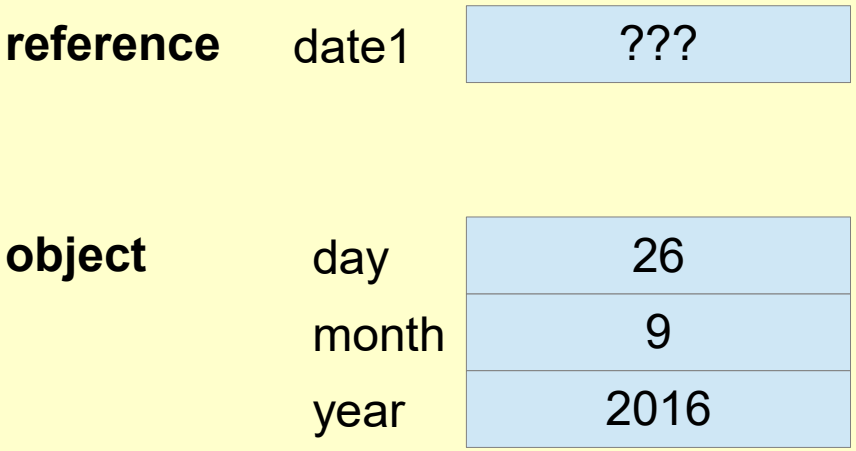
(1) Memory is allocated for the object

```
MyDate date1 = new MyDate(20, 6, 2000);
```



(2) Explicit Attribute Initialization

```
MyDate date1 = new MyDate(20, 6, 2000);
```




```
public class  MyDate{
    private int day = 26;
    private int month = 9;
    private int year = 2016;

}
```

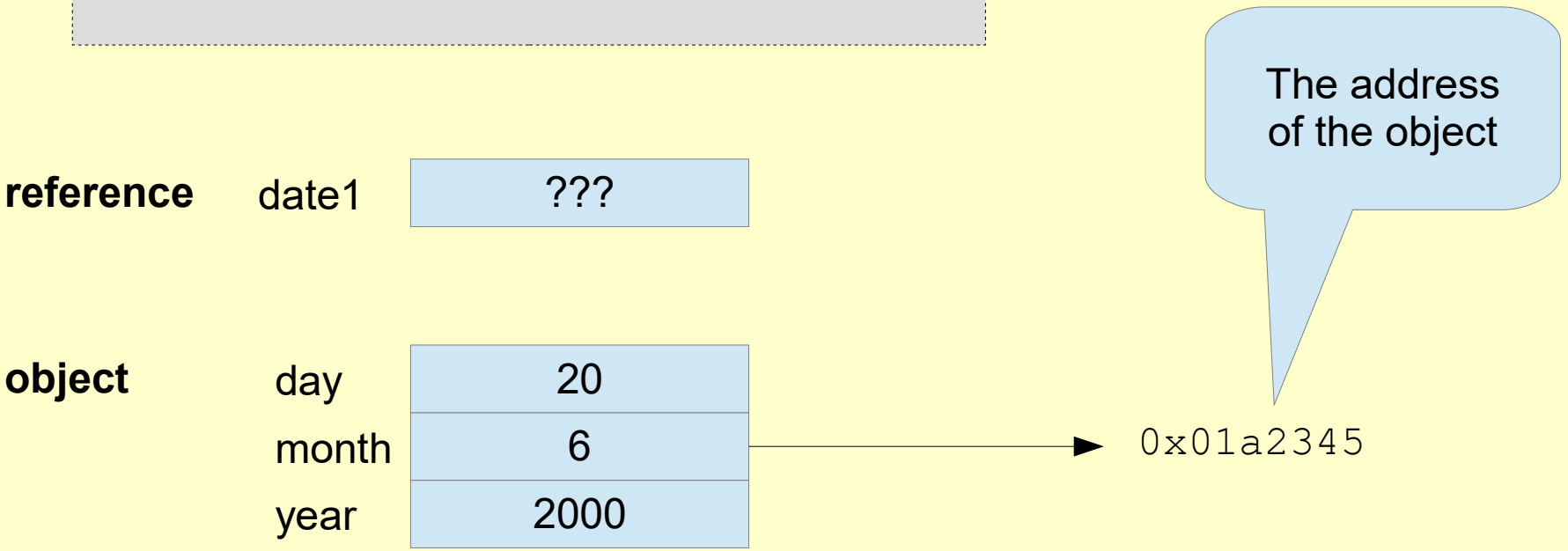
(3) Executing the constructor

```
MyDate date1 = new MyDate(20, 6, 2000);
```


```
public class  MyDate{
    private int day = 26;
    private int month = 9;
    private int year = 2016;

}
```

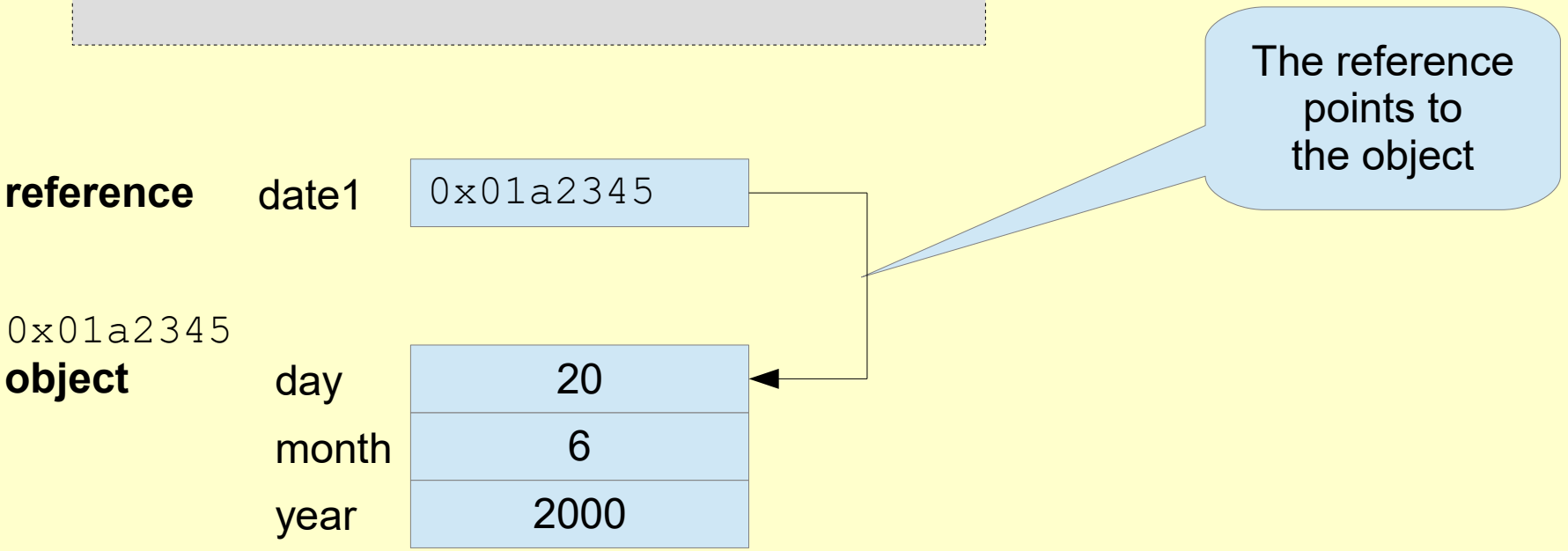
(4) The object reference is returned

```
MyDate date1 = new MyDate(20, 6, 2000);
```



(5) The reference is assigned to a variable

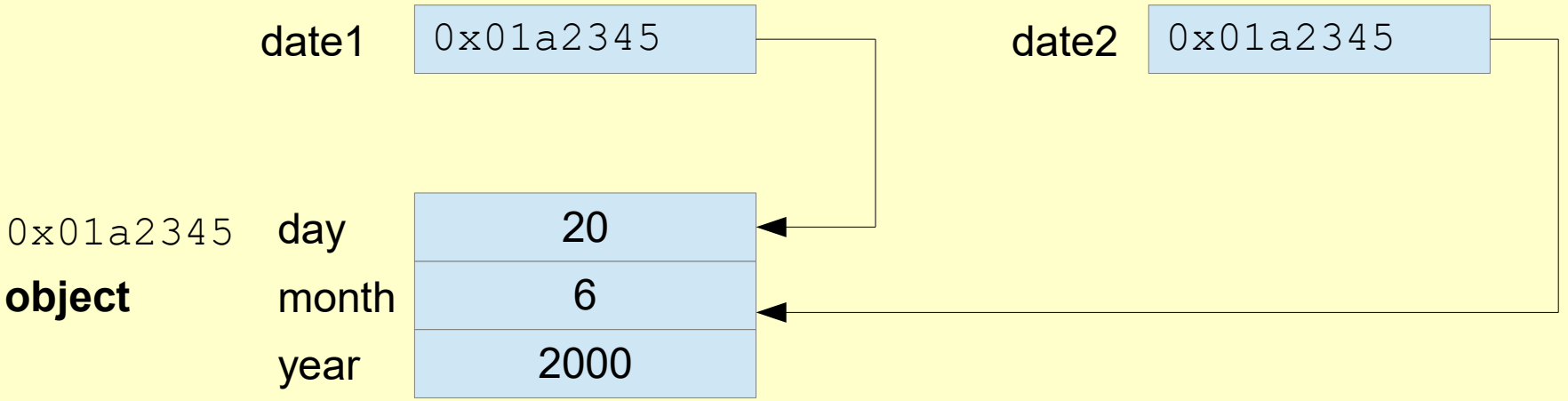
```
MyDate date1 = new MyDate(20, 6, 2000);
```



Assigning References

- Two variables refer to a single object

```
MyDate date1 = new MyDate(20, 6, 2000);
MyDate date2 = date1;
```



Parameter Passing

Pass-by-Value

```
public class  PassTest{
    public  void changePrimitive(int value){
        ++value;
    }

    public void changeReference(MyDate from, MyDate to){
        from = to;
    }

    public void changeObjectDay(MyDate date, int day){
        date.setDay( day );
    }
}
```

Parameter Passing

Pass-by-Value

```
PassTest pt = new PassTest();
int x = 100;
pt.changePrimitive( x );
System.out.println( x );

MyDate oneDate = new MyDate(3, 10, 2016);
MyDate anotherDate = new MyDate(3, 10, 2001);

pt.changeReference( oneDate, anotherDate );
System.out.println( oneDate.getYear() );

pt.changeObjectDay( oneDate, 12 );
System.out.println( oneDate.getDay() );
```

Output:
100
2016
12

The `this` Reference

Usage:

- To resolve **ambiguity** between *instance variables* and *parameters*
- To **pass** the current **object as a parameter** to another method

The `this` Reference

```
public class  MyDate{
    private int day = 26;
    private int month = 9;
    private int year = 2016;
    public MyDate( int day, int month, int year){
        this.day   = day;
        this.month = month;
        this.year  = year;
    }
    public MyDate( MyDate date){
        this.day   = date.day;
        this.month = date.month;
        this.year  = date.year;
    }
    public MyDate creteNextDate(int moreDays){
        MyDate newDate = new MyDate(this);
        //... add moreDays
        return newDate;
    }
}
```

Java Coding Conventions

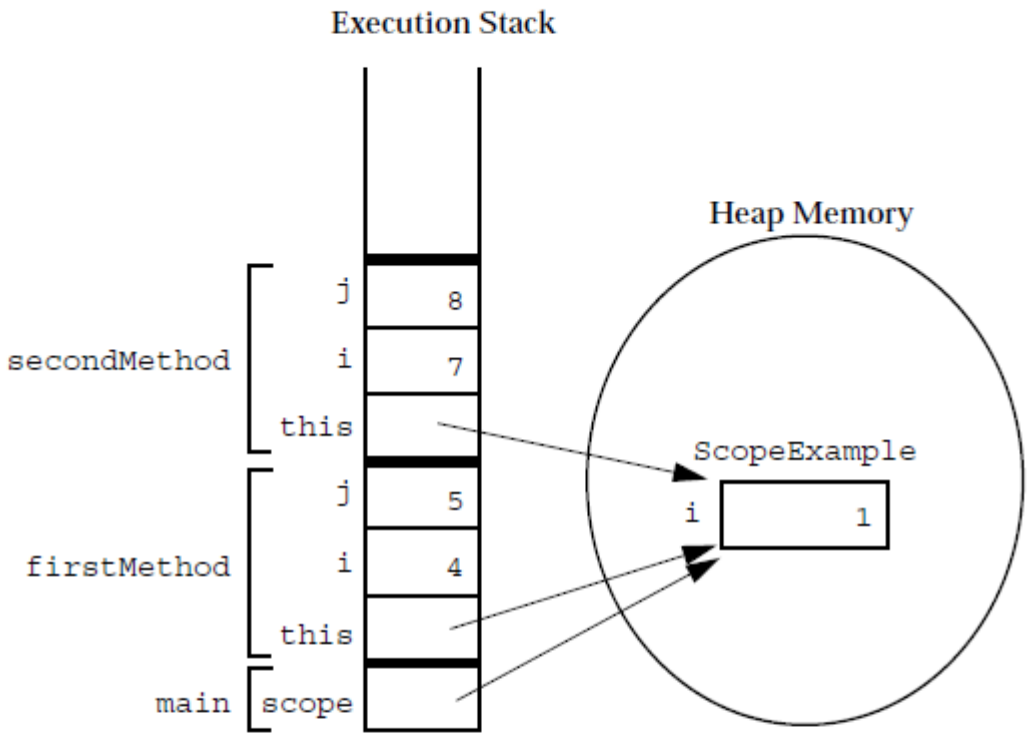
- Packages
  - `ro.sapientia.ms`
- Classes
  - `SavingsAccount`
- Methods
  - `getAmount()`
- Variables
  - `amount`
- Constants
  - `NUM_CLIENTS`

Variables and Scope

- Local variables are
  - Defined **inside a method**
  - Created when the **method is executed** and destroyed when the **method is exited**
  - **Not initialized automatically**
  - Created on the **execution stack**

Variable Scope Example

```
public class ScopeExample {
  private int i=1;

  public void firstMethod() {
    int i=4, j=5;

    this.i = i + j;
    secondMethod(7);
  }
  public void secondMethod(int i) {
    int j=8;
    this.i = i + j;
  }
}
```




```
public class TestScoping {
  public static void main(String[] args) {
    ScopeExample scope = new ScopeExample();

    scope.firstMethod();
  }
}
```

Default Initialization

- Default values for attributes:

Type	Value
`byte`	`0`
`short`	`0`
`int`	`0`
`long`	`0L`
`float`	`0.0f`
`double`	`0.0d`
`char`	`'\u0000'`
`boolean`	`false`
`refrence`	`null`

Operators

- Logical operators
- Bitwise operators (~, ^, &, |, >>, >>>, <)
- String concatenation (+)

String Types

- **`String`**
  - **Immutable –** once created can not be changed
  - Objects are stored in the **Constant String Pool**
- **`StringBuffer`**
  - **Mutable** – one can change the value of the object
  - **Thread-safe**
- **`StringBuilder`**
  - The same as `StringBuffer`
  - **Not thread-safe**

Object-oriented programming

Arrays

- Declaring arrays
- Creating arrays
- Arrays of primitive and reference type
- Initialization of elements
- Multidimensional arrays

Declaring Arrays

- What is an array?
  - **Group** of data objects of the **same type**
- Arrays of primitive types:

```
int t[];
int [] t;
```

- Arrays of reference types:

```
Point p[];
Point[] p;
```

Creating Arrays

Primitive Type

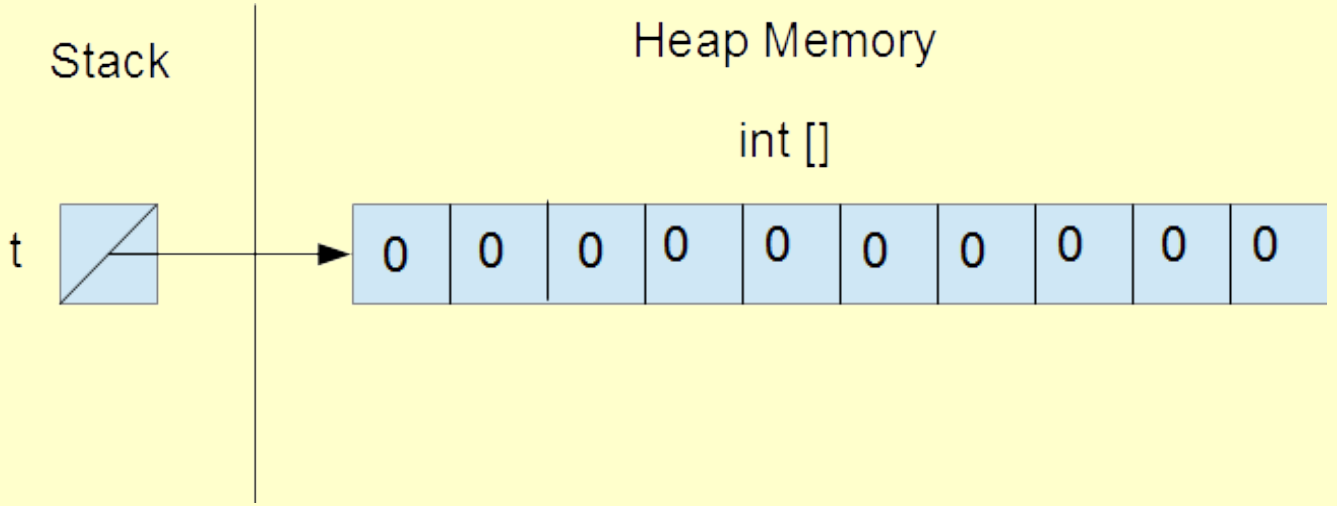
- Arrays are **objects** → are created with **new**
- Example:

```
//array declaration
int [] t;

//array creation
t = new int[10];

//print the array - enhanced for loop
for( int v: t ){
  System.out.println( v );
}
```

Creating Arrays

Primitive Type

```
//array declaration
int [] t;

//array creation
t = new int[10];
```



Creating Arrays

Reference Type

- Example:

```
//array declaration
Point [] t;

//array creation – array of references!!!
t = new Point[3];

// How many objects of type Point?
```

Creating Arrays

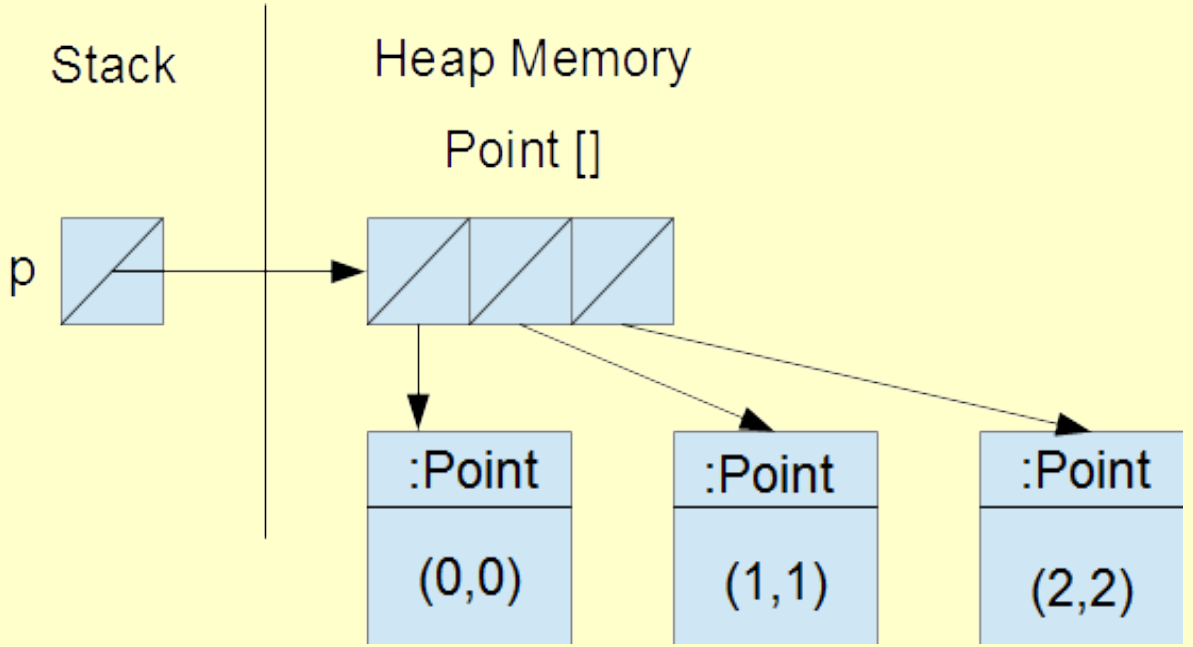
Reference Type

- Example:

```
 //array declaration
 Point [] p;

 //array creation – array of references!!!
 p = new Point[3];

 // How many objects of type Point?
 for( int i=0; i<3; ++i){
    p[i] = new Point(i, i);
 }
// How many objects of type Point?
```

Creating Arrays

Reference Type



Initializing Arrays

- Create an array with initial values

```
String names[] = {“Anna”, “Krisztina”, “Rebekka”};
Point points[] ={ new Point(0,0), new Point(1,1)};
```

Array Bounds

```
void printElements( int t[] ){
    for( int i=0; i < t.length; ++i){
        System.out.println( t[i] );
    }
}
```

Multidimensional Arrays

- **Rectangular** arrays:

```
int [][] array = new int[3][4];
```

- **Non-rectangular** arrays:

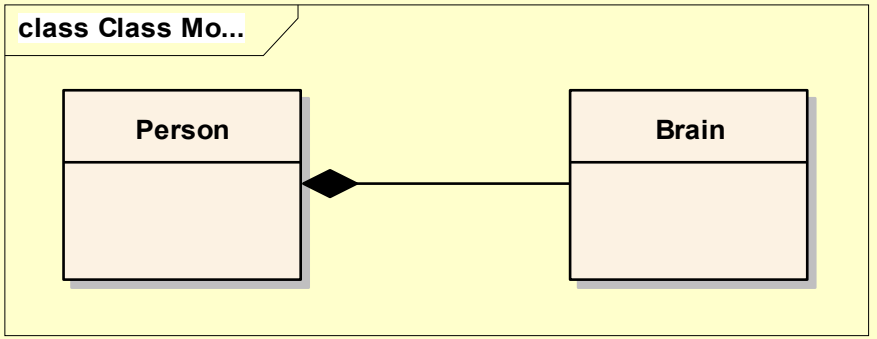
```
int [][] array;
array = new int[2][];
array[0] = new int[3];
array[1] = new int[5];
```

Remember

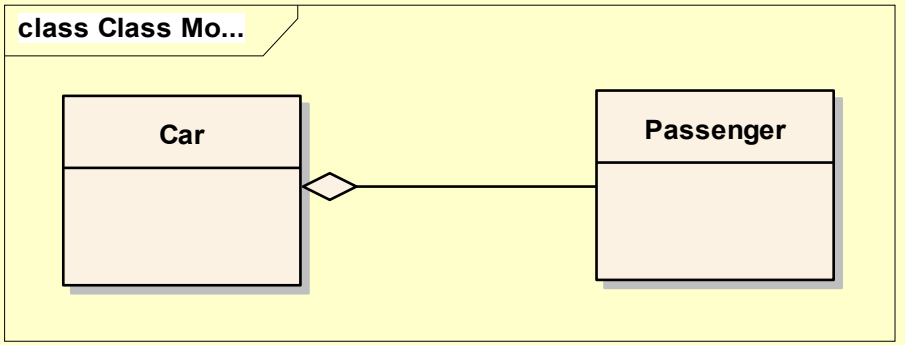
- Array declaration and creation
  - Array of primitives
  - Array of references
- Size of an array (public attribute: length)
- Initial values of array elements

Object-oriented programming
Relationships between classes

- **Association** (containment)
  - Strong – **Composition**

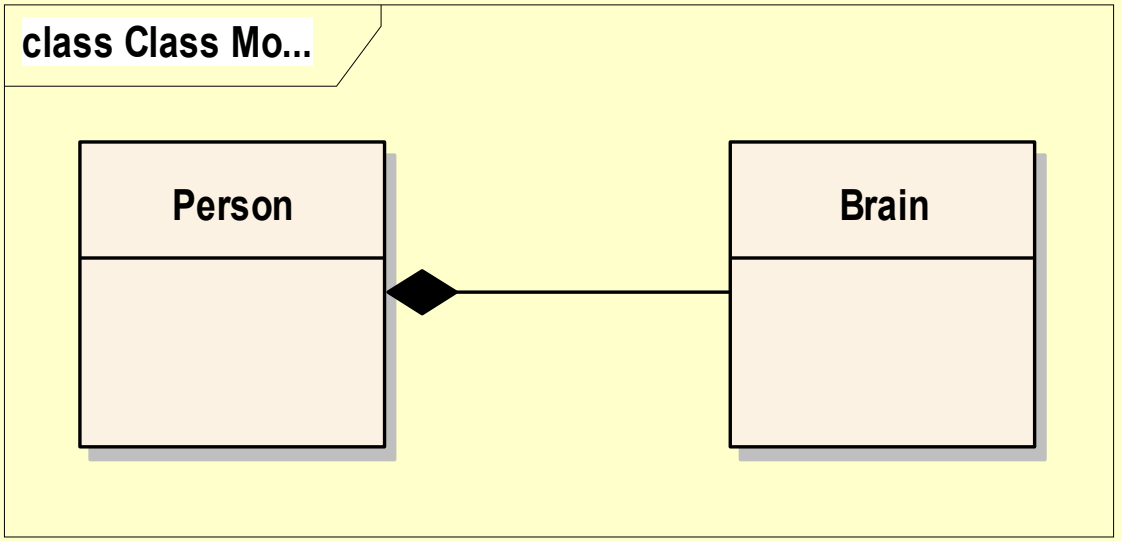


  - Weak – **Aggregation**



Relationships between classes

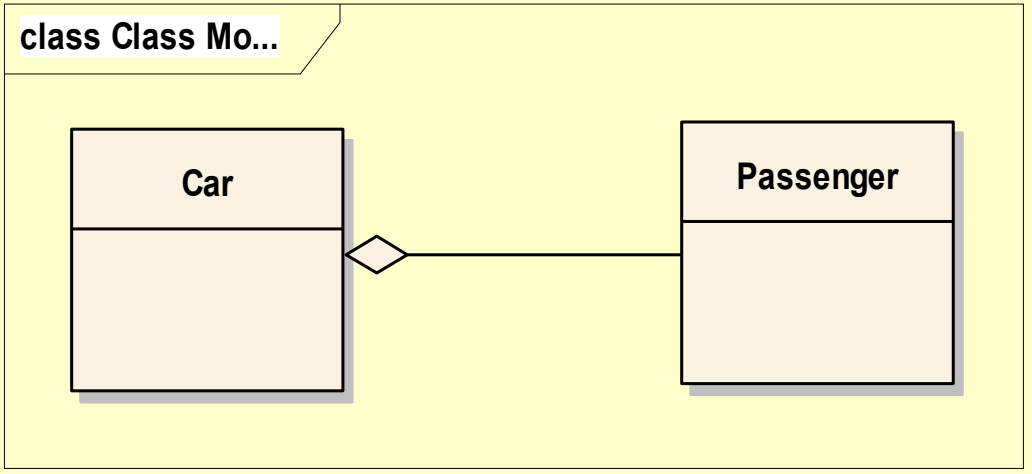
Composition



- Strong type of association
- Full ownership

Relationships between classes

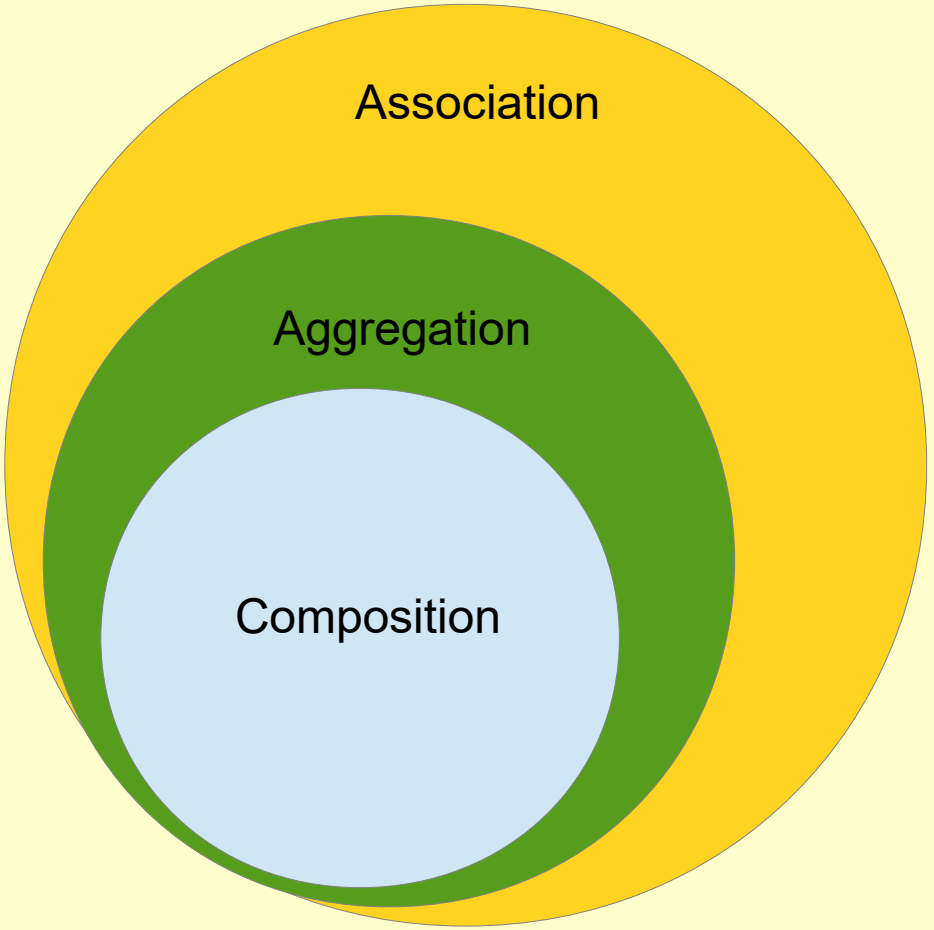
Aggregation



- Weak type of association
- Partial ownership

Relationships between classes

Association – Aggregation - Composition



Relationships between classes

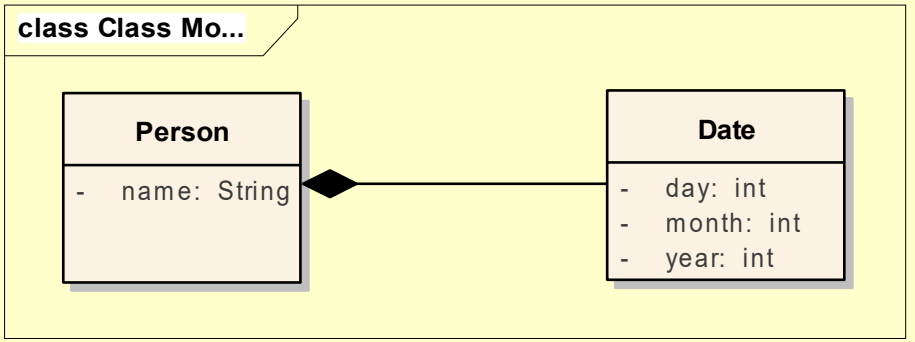
Implementing Associations (1)

```
public  class Brain{
    //...

}
```

```
public class Person{
   private Brain brain;
   //...
}
```

Relationships between classes

Implementing Associations (2)



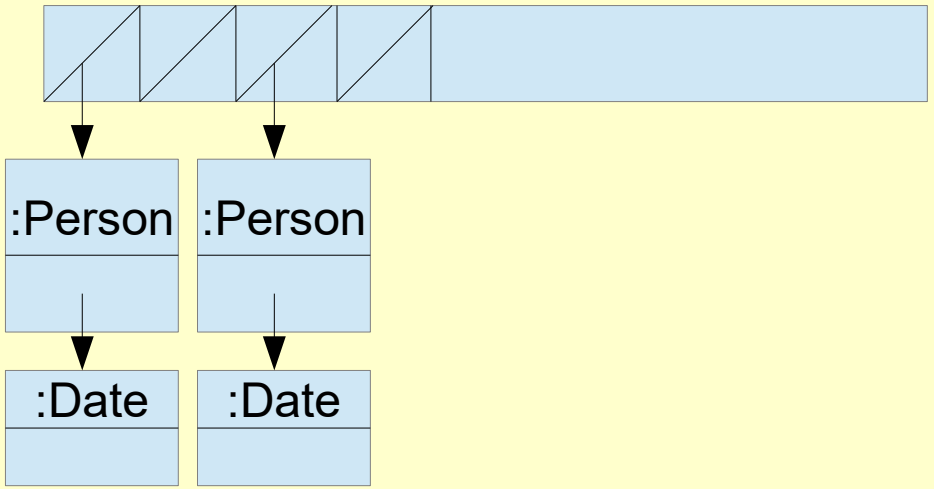

```
public  class Date{
    private int day;
    private int month;
    private int year;
    //...
}
```

```
public class Person{
    private String name;
    private Date birthDate;

    public Person(String name,
                  Date birthDate){
        this.name = name;
        this.birthDate = birthDate;
    }
    //...
}
```

Relationships between classes

Implementing Associations (3)

```
Benedek Istvan, 1990, 1, 12
Burjan  Maria, 1968, 4, 15
Dobos Hajnalka Evelin, 1986, 3, 17
...
```

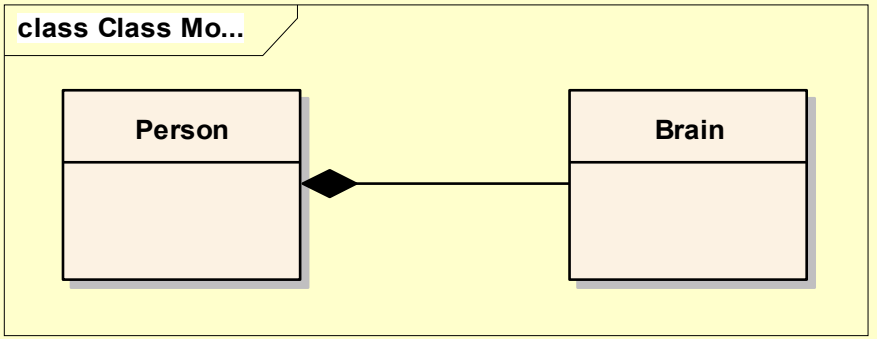


Write a program which reads the data of several persons and constructs an array of Persons.

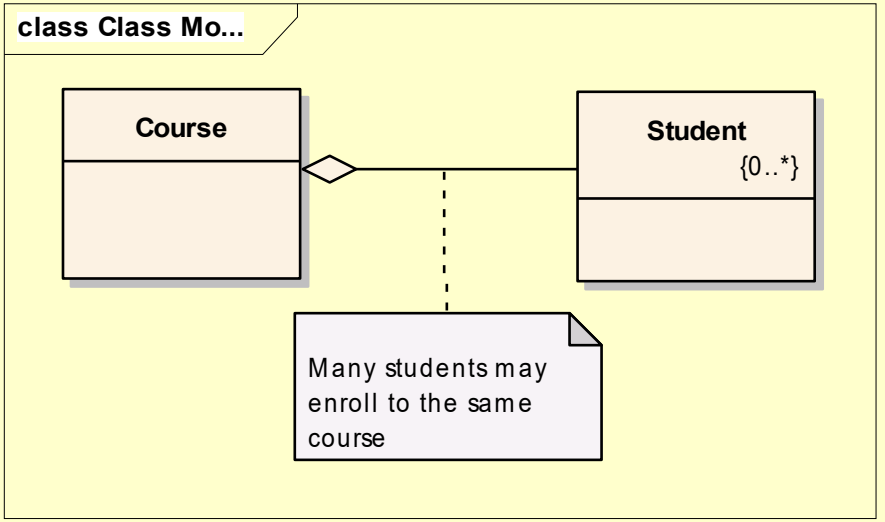
Relationships between classes

Relationship cardinality

- *One-to-one*



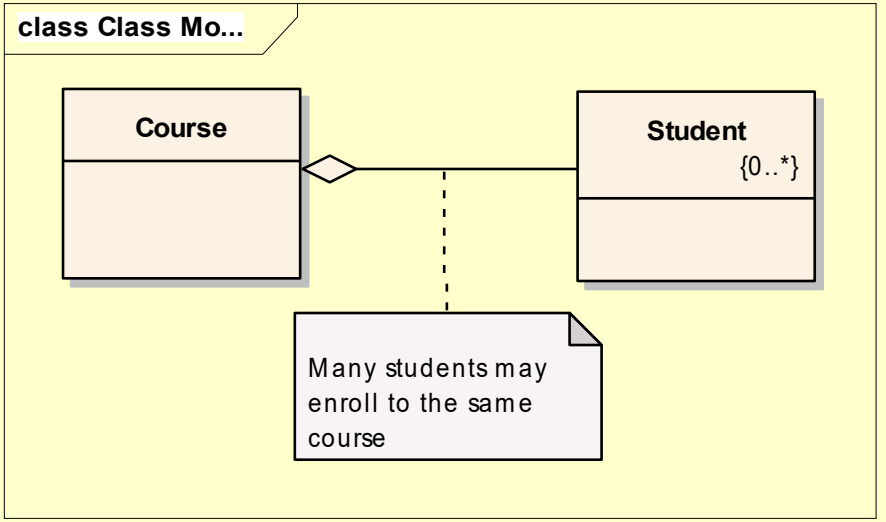
- *One-to-many*



Relationships between classes

Implementing *one-to-many* relationship (1)

```
public  class Student{
    private final long ID;
    private String firstname;
    private String lastname;
    //...
}
```




```
public  class Course{
    private final long ID;
    private String name;
    public static final int MAX_STUDENTS=100;
    private Student[] enrolledStudents;
    private int numStudents;

    //...
}
```

Relationships between classes

Implementing *one-to-many* relationship (2)

```
public  class Course{
    private final long ID;
    private String name;
    public static final int MAX_STUDENTS = 100;
    private Student[] enrolledStudents;
    private int numStudents;

    public Course( long ID, String name ){
        this.ID = ID;
        this.name = name;
        enrolledStudents = new Student[ MAX_STUDENTS ];
    }

    public void enrollStudent( Student student ){
        enrolledStudents[ numStudents ] = student;
        ++numStudents;
    }


    //...
}
```

Relationships between classes

Implementing *one-to-many* relationship (3)

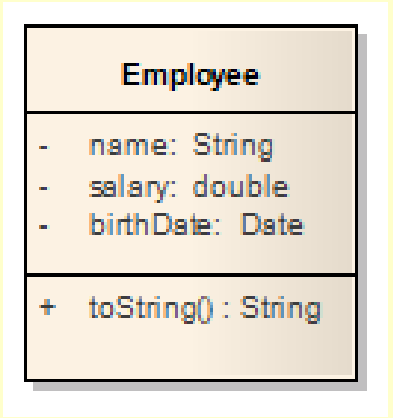
```
public  class Course{
    private final long ID;
    private String name;

    private ArrayList<Student> enrolledStudents;

    public Course( long ID, String name ){
        this.ID = ID;
        this.name = name;
        enrolledStudents = new ArrayList<Student>();
    }

    public void enrollStudent( Student student ){
        enrolledStudents.add(student);
    }


    //...
}
```

Module 3
Inheritance, Polymorphism

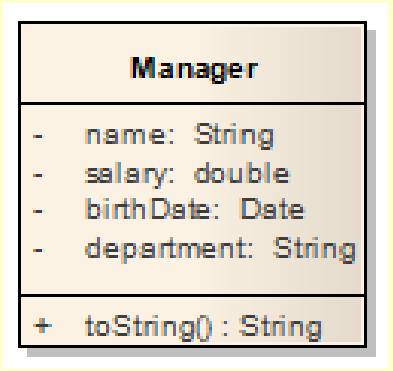
Outline

- Inheritance
  - Parent class
  - Subclass, Child class
- Polymorhism
  - Overriding methods
  - Overloading methods
  - The `instanceof` operator
  - Heterogenous collections

Problem: *repetition in implementations*

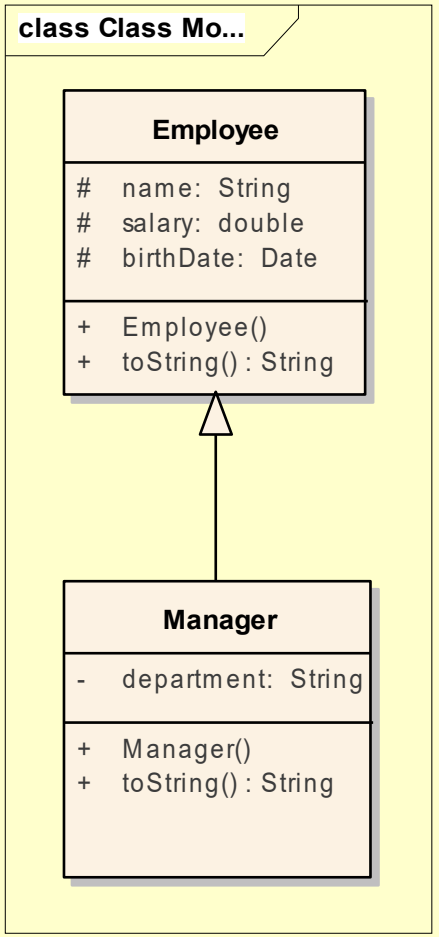



```
public  class Employee{
    private String name;
    private double salary;
    private Date birthDate;

    public String toString(){
       //...
     }
}
```




```
public  class Manager{
    private String name;
    private double salary;
    private Date birthDate;
    private String department;

    public String toString(){
       //...
     }
}
```

Solution: *inheritance*




```
public  class Employee{
    protected String name;
    protected double salary;
    protected Date birthDate;
    public Employee( … ){
        // …
    }
    public String toString(){
       //...
    }
}
```

```
public  class Manager extends Employee{
    private String department;

    public Manager( … ){
        // …
    }
    public String toString(){
       // …
    }
}
```

Inheritance - syntax

```
<modifier> class <name> extends <superclass>{
    <declaration*>
}
```

```
public  class Manager extends Employee{

}
```

The subclass

- **Inherits** the **data** and **methods** of the **parent class**
- **Does not inherit the constructors** of the **parent class**
- Opportunities:

  (1) add new data

  (2) add new methods

  (3) override inherited methods (polymorphism)

The subclass

- Opportunities:
  - (1) add new data → `department`
  - (2) add new methods → e.g. `getDepartment()`
  - (3) override inherited methods → `toString()`

Invoking Parent Class Constructors

```
public  class Employee{
    protected String name;
    protected double salary;
    protected Date birthDate;
    public Employee( String name, double salary, Date birthDate){
        this.name = name;
        this.salary = salary;
        this.birthDate = birthDate;
    }
    //...
}
```

```
public  class Manager extends Employee{
    private String department;
    public Manager( String name, double salary, Date birthDate,
                                                String department){
        super(name, salary, bityhDate);
        this.department = department;
    }
    //...
}
```

Access Control

Modifier	Same Class	Same Package	Subclass	Universe
`private`	`Yes`			
default	`Yes`	`Yes`		
`protected`	`Yes`	`Yes`	`Yes`	
`public`	`Yes`	`Yes`	`Yes`	`Yes`

Polymorphism - Overriding Methods

- A subclass can modify the **behavior** inherited from a parent class
- A subclass can create a method with different functionality than the parent's method but with the:
  - same **name**
  - same **argument list**
  - almost the same **return type**

(can be a subclass of the overriden return type)

Overriding Methods

```
public  class Employee{
     protected String name;
     protected double salary;
     protected Date birthDate;
     public Employee( … ){
          // …
     }
     public String toString(){
          return "Name: "+name+" Salary: "+salary+" B. Date:"+birthDate;
     }
}
```

```
public  class Manager extends Employee{
     private String department;
     public Manager( … ){
          // …
     }
     @Override
     public String toString(){
          return "Name: "+name+" Salary: "+salary+" B. Date:"+birthDate
                         +" department: "+department;
     }
}
```

Invoking Overriden Methods

```
public  class Employee{
     protected String name;
     protected double salary;
     protected Date birthDate;
     public Employee( … ){
          // …
     }
     public String toString(){
          return "Name: "+name+" Salary: "+salary+" B. Date:"+birthDate;
     }
}
```

```
public  class Manager extends Employee{
     private String department;
     public Manager( … ){
          // …
     }
     public String toString(){
          return super.toString() + " department: "+department;
     }
}
```

Overridden Methods Cannot Be Less Accessible

```
public  class Parent{
   public void foo(){}
}

public class Child extends Parent{
   private void foo(){} //illegal
}
```

Overriding Methods

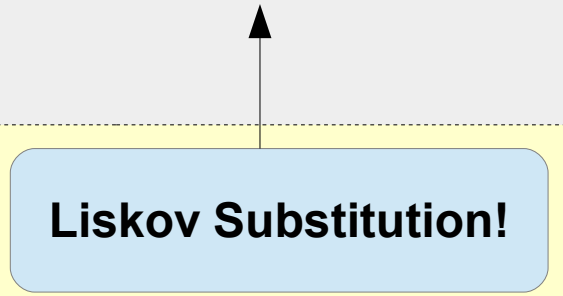
- *Polymorhism:* the ability to have many different forms

```
Employee e = new Employee(...);
System.out.println( e.toString() );

e = new Manager(...); //Correct
System.out.println( e.toString() );
```

Which `toString()` is invoked?

Polymorhic Arguments

```
public String createMessage( Employee e ){
   return "Hello, "+e.getName();
}

//...
Employee e1 = new Employee("Endre",2000,new Date(20,8, 1986));
Manager m1 = new Manager("Johann",3000,
                         new Date(15, 9, 1990),"Sales");

//...
System.out.println( createMessage( e1 ) );
System.out.println( createMessage( m1 ) );
```



Heterogeneous Arrays

```
Employee emps[] = new Employee[ 100 ];
emps[ 0 ] = new Employee();
emps[ 1 ] = new Manager();
emps[ 2 ] = new Employee();
// …

// print employees
for( Employee e: emps ){
   System.out.println( e.toString() );
}

// count managers
int counter = 0;
for( Employee e: emps ){
   if( e instanceof Manager ){
       ++counter;
   }
}
```

Static vs. Dynamic type of a reference

// static (compile time) type is: `Employee`

```
Employee e;
```

// dynamic (run time) type is: `Employee`

```
e = new Employee();
```

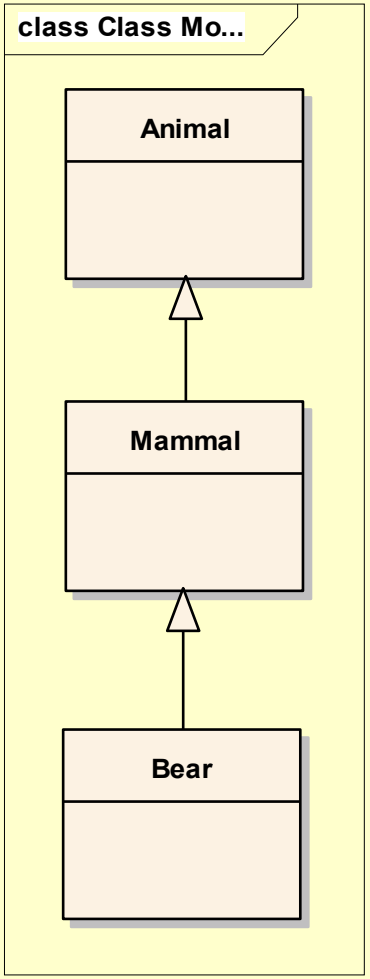
// dynamic (run time) type is: `Manager`

```
e = new Manager();
```

Static vs. Dynamic type of a reference

```
Employee e = new Manager("Johann",3000,
                         new Date(10,9,1980),"sales");
System.out.println( e.getDepartment() );// ERROR

//Solution
System.out.println( ((Manager) e).getDepartment() );// CORRECT

//Better Solution
if( e instanceof Manager ){
     System.out.println( ((Manager) e).getDepartment() );
}
```

The `instanceof` Operator




```
Animal a = new Bear();

//expressions
a instanceof Animal  → true
a instanceof Mammal → true
a instanceof Bear → true
a instanceof Date → false
```

Polymorphism

Overloading Methods

- *Polymorhism:* the ability to have many different forms
- Methods overloading:
  - methods having the **same name**,
  - argument list **must** differ,
  - return types **can be** different.
- Example:

```
public void println(int i)
public void println(float f)
public void println(String s)
```

Polymorphism

Oveloading Constructors

```
public  class Employee{
    protected String name;
    protected double salary;
    protected Date birthDate;
    public Employee( String name, double salary, Date birthDate){
        this.name = name;
        this.salary = salary;
        this.birthDate = birthDate;
    }
    public Employee( String name, double salary){
        this(name, salary, null);
    }
    public Employee( String name, Date birthDate){
        this(name, 1000, birthDate);
    }
    //...
}
```

Remember

- Inheritance
  - Subclass opportunities
- Polymorphism
  - *Overriding* methods
  - *Overloading* methods
  - *Polymorphic* argument
  - *Heterogenous* collections
  - Static vs. dynamic type
  - The `instanceof` operator

Inheritance and Polymorphism

Methods Common to All Objects

- The `equals` method
- The `toString` method
- The `clone` method

Inheritance and Polymorphism

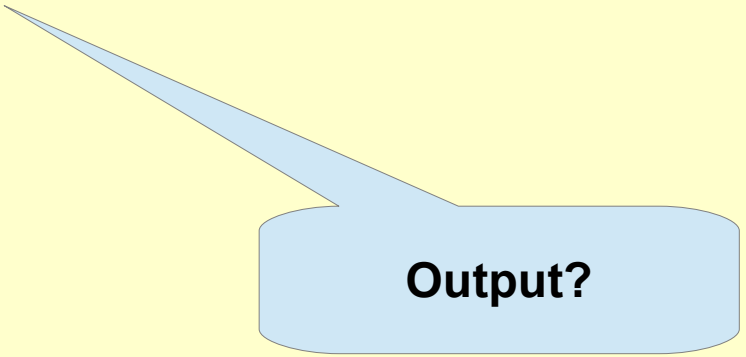
Methods Common to All Objects

- `Object` is a concrete class with (`equals, toString, clone, …`) nonfinal methods
  - **It is designed for extension**
  - Its methods have explicit *general contracts*

The `equals` method

- **In class Object `equals` tests object identity**

```
MyDate s1  = new MyDate(20, 10, 2016);
MyDate s2  = new MyDate(20, 10, 2016);
System.out.println( s1.equals(s2));
s1 = s2;
System.out.println( s1.equals(s2));
```



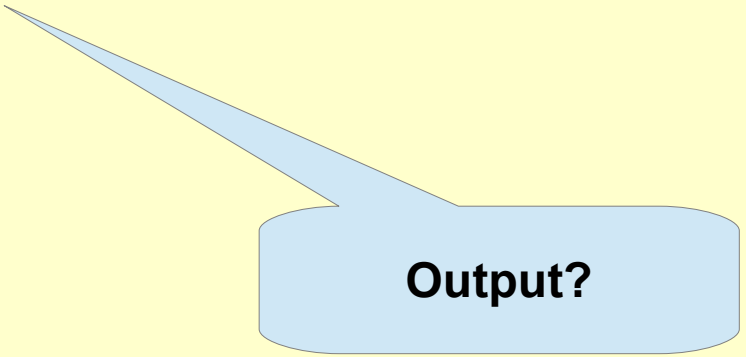
An `equals` example

```
public class MyDate {
    private int day;
    private int month;
    private int year;

    public boolean equals(Object o) {
        boolean result = false;
        if ( (o != null) && (o instanceof MyDate) ) {
            MyDate d = (MyDate) o;
            if ((day == d.day) &&
                (month == d.month) &&
                (year == d.year)) {
                result = true;
            }
        }
        return result;
    }

}
```

The `equals` method

- **In class MyDate `equals` tests object logical equality**

```
MyDate s1  = new MyDate(20, 10, 2016);
MyDate s2  = new MyDate(20, 10, 2016);
System.out.println( s1.equals(s2));
s1 = s2;
System.out.println( s1.equals(s2));
```



The `equals` method implements an equivalence relation

- **Reflexive**
  - `x.equals(x):true`
- **Symmetric**
  - `x.equals(y):true ↔ y.equals(x):true`
- **Transitive**
  - `x.equals(y):true and y.equals(z):true → x.equals(z):true`

The `toString` method

- Characteristics:
  - Converts an object to a `String`
  - Override this method to provide information about a user-defined object in **readable format**

Wrapper Classes

Primitive Type	Wrapper Class
boolean	Boolean
byte	Byte
char	Character
short	Short
int	Integer
long	Long
float	Float
double	Double

Wrapper Classes

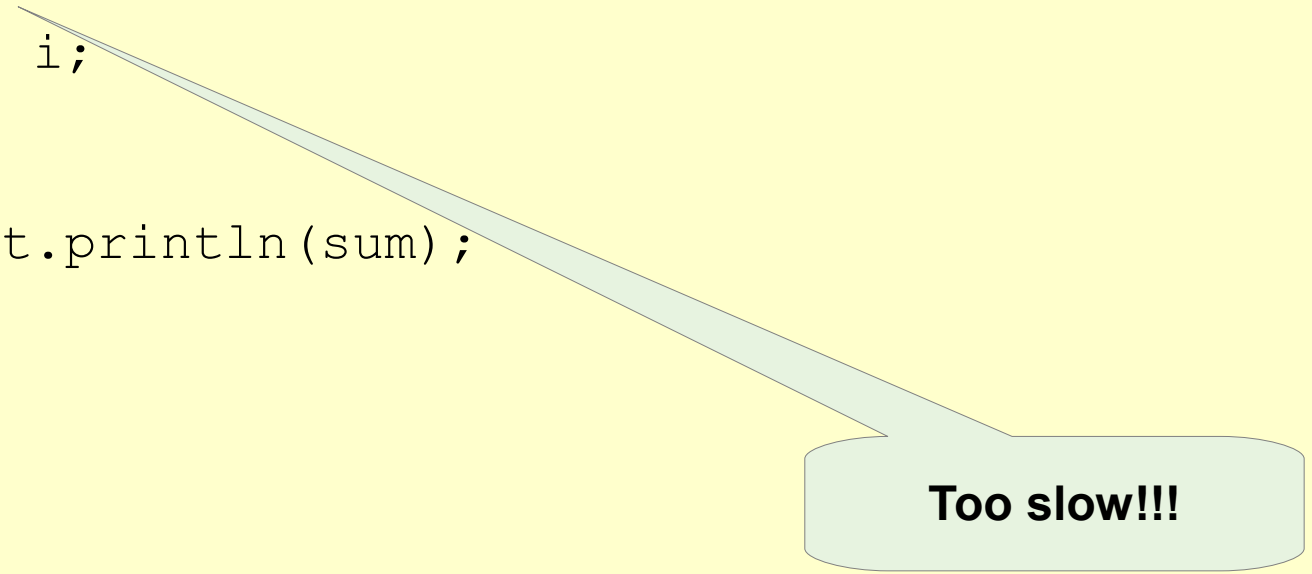
Boxing and Unboxing

```
int i = 420;
Integer anInt = new Integer(i); // boxing
int j = anInt.intValue(); // unboxing
```

Wrapper Classes

Warning! Performance loss!

```
public static void main(String[] args) {
   Long sum = 0L;
   for (long i = 0; i < Integer.MAX_VALUE; i++) {
      sum += i;
   }
   System.out.println(sum);
}
```



Module 4
Static Members

Problems

- How can you create a **constant**?
- How can you declare **data** that is **shared by all instances of a given class**?
- How can you **prevent** a class from being **subclassed**?
- How can you **prevent** a method from being **overridden**?

Problem

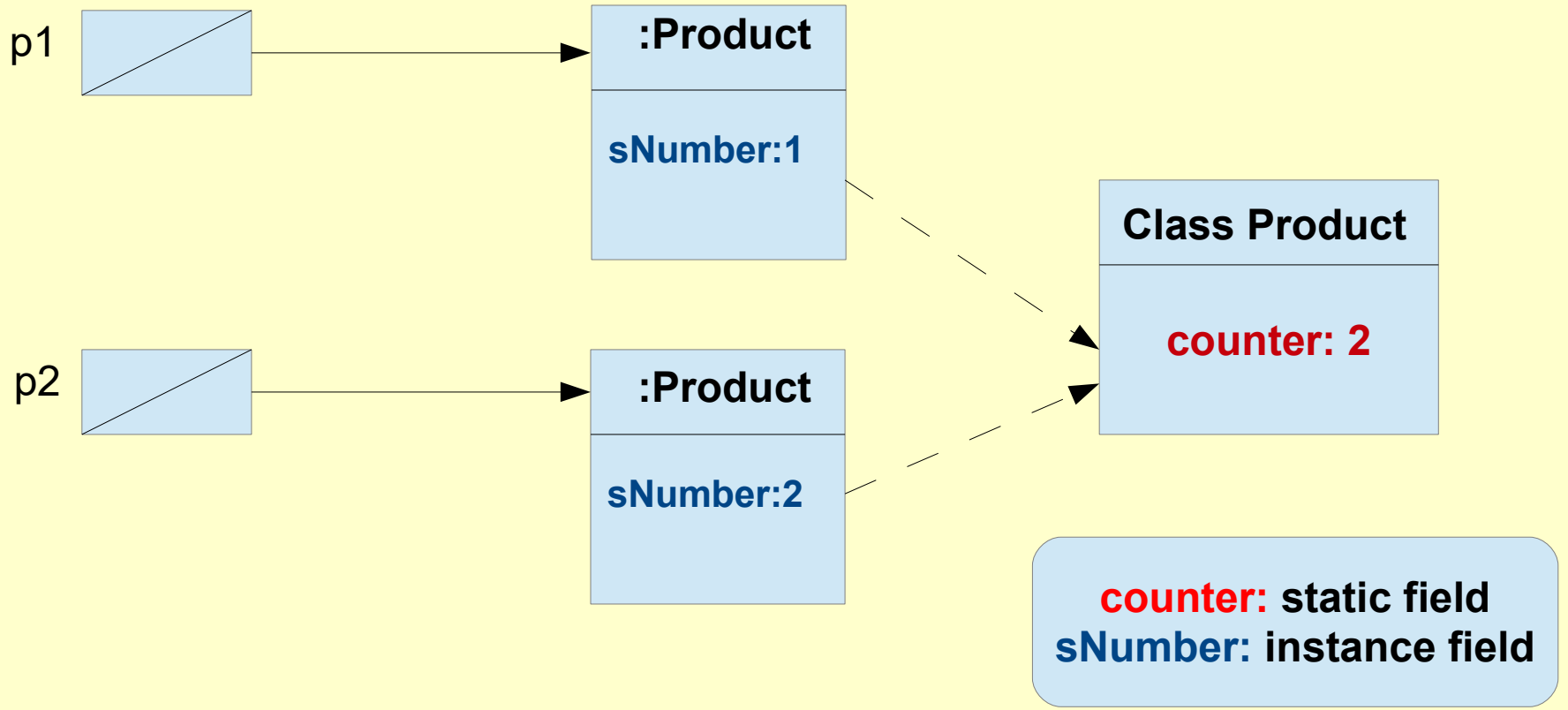
- Create a `Product` class which initializes each new instance with a `serialNumber (1,2, 3,…)`

Solution

```
public class Product{
    private int sNumber;
    public static int counter = 0;
    public Product() {
        counter++;
        sNumber = counter;
    }
 }
```

Solution

```
Product p1 = new Product();
Product p2 = new Product();
```



What's wrong?

```
public class Product{
    private int sNumber;
    public static int counter = 0;
    public Product() {
        counter++;
        sNumber = counter;
    }
}
```

It can be accessed from outside the class!

```
public class AnyClass{
    public void increment() {
        Product.counter++;
    }
}
```

Better solution

```
public class Product{
    private int sNumber;

    private static int counter = 0;

    public static int getCounter(){
        return counter;
    }

    public Product() {
        counter++;
        sNumber = counter;
    }
}
```

Better solution

```
public class Product{
    private int sNumber;

    private static int counter = 0;

    public static int getCounter(){
        return counter;
    }

    public Product() {
        counter++;
        sNumber = counter;
    }
}
```

```
System.out.println(Product.getCounter());
Product p = new Product();
System.out.println(Product.getCounter());
```

Output?

Accessing static members

Recommended:

```
<class name>.<member_name>
```

Not recommended (but working):

```
<instance_reference>.<member_name>
```

```
System.out.println(Product.getCounter());
Product p = new Product();
System.out.println(p.getCounter());
```

Output?

Static Members

- Static data + static methods = static members
- Data are allocated at **class load time** → *can be used without instances*
- Instance methods **may use** static data. **Why?**
- Static methods **cannot use** instance data. **Why?**

The `InstanceCounter` class

```
public class InstanceCounter {
    private static int counter;

    public InstanceCounter(){
        ++counter;
    }

    public static int getCounter(){
        return counter;
    }
}
```

Output?

```
System.out.println( InstanceCounter.getCounter());

InstanceCounter ic = new InstanceCounter();

System.out.println( InstanceCounter.getCounter());
```

Singleton Design Pattern

```
public class Singleton {
    private static Singleton instance;

    private Singleton(){
    }

    public static Singleton getInstance(){
        if( instance == null ){
            instance = new Singleton();
        }
        return instance;
    }
}
```

Static Initializers

```
public class AClass{

  private static int counter;

  static {
     // e.g. read counter from a file
  }
}
```

The `final` Keyword

- **Class**
  - You cannot subclass a `final` class.
- **Method**
  - You cannot override a `final` method.
- **Variable**
  - A `final` variable is a constant.
  - You can set a `final` variable only once.
  - Assignment can occur independently of the declaration (*blank final variable*).

Blank Final Variables

```
public class Employee{
    private final long ID;

    public Employee(){
      ID = createID();
    }

    private long createID(){
       //return the generated ID
    }
    …
}
```

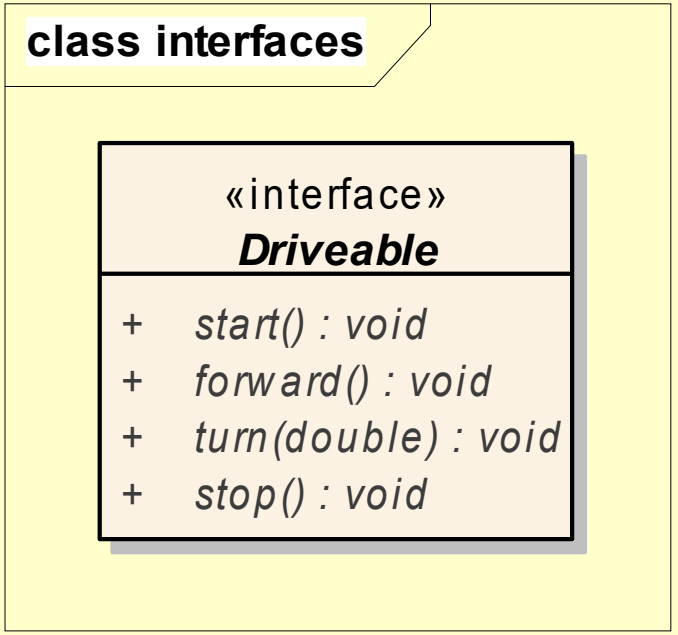
Module 5
Interfaces and Abstract Classes

Interfaces

- Properties
  - Define **types**
  - Declare a **set of methods** (*no implementation!*) – ADT – Abstract Data Type
  - Will be **implemented** by classes

The `Driveable` Interface

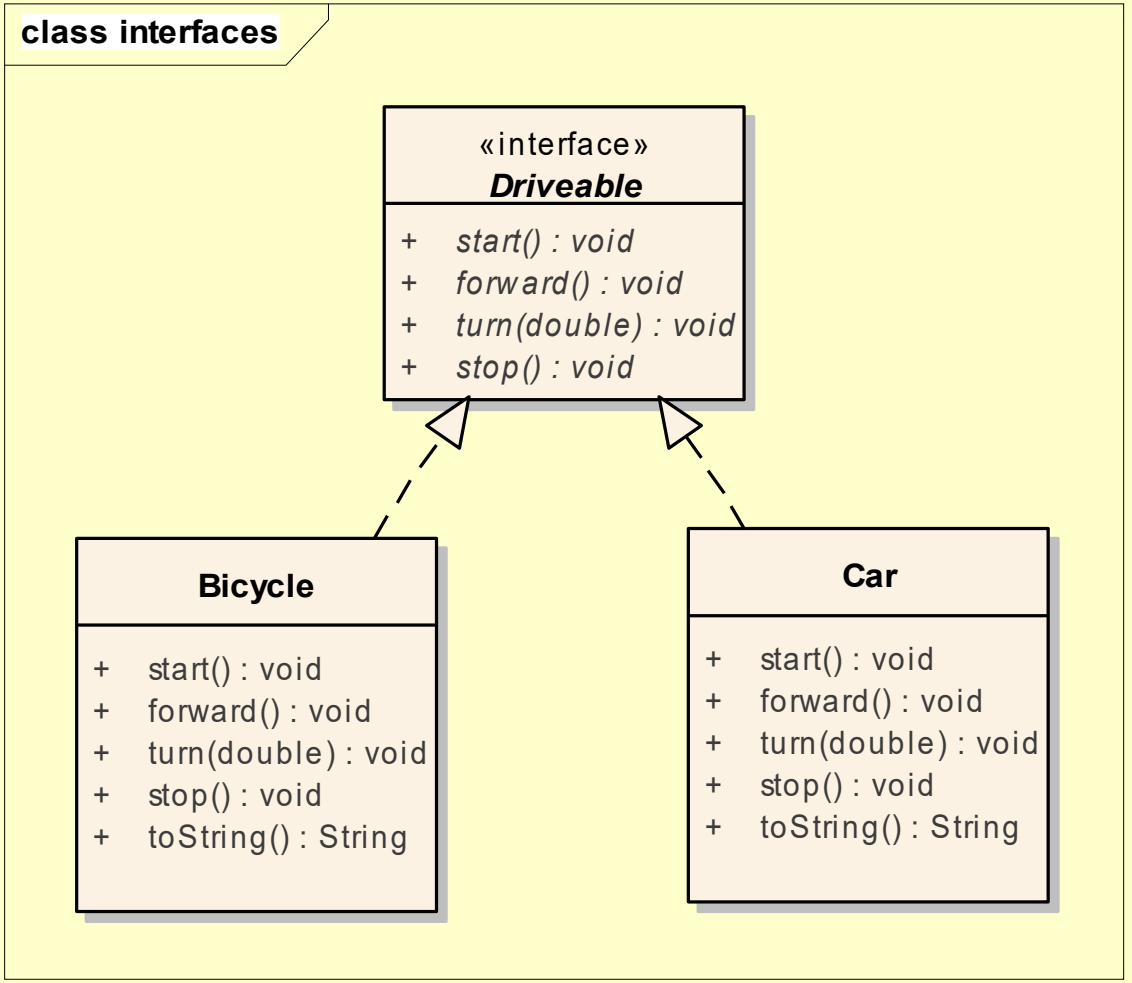
```
public interface Driveable{
        public void start();
        public void forward();
        public void turn( double angle);
        public void stop();
  }
```



Implementing Interfaces

```
public class Bicycle implements Driveable
{
    @Override
    public void start() {
        System.out.println("The bicycle has been started");
    }

    @Override
    public void forward() {
        System.out.println("The bicycle moves forward");
    }

    @Override
    public void turn( double angle) {
        System.out.println("The bicycle turns "+angle+
                                              " clockwise");
    }

    @Override
    public void stop() {
        System.out.println("The bicycle has been stopped");
    }
 }
```

Implementing the `Driveable` Interface



Interfaces

- The interface contains **method declarations** and may contain constants
- All the methods are **public** (even if the modifier is missing)
- Interfaces are **pure abstract classes** → cannot be instantiated
- The implementer classes should **implement all the methods** declared in the interface
- A **class** can **extend a single class** but may **implement any number of interfaces**

Q & A

Select the correct statements!

a) `Driveable a;`

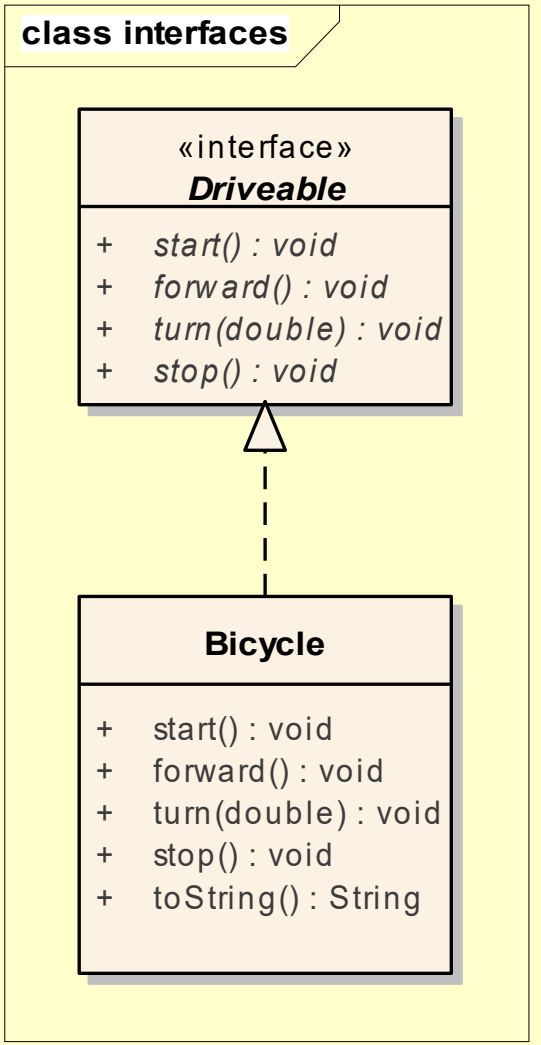
b) `Driveable a = new Driveable();`

c) `Driveable t[] = new Driveable[ 3 ];`

d) `public void drive( Driveable d );`

Interfaces vs. Classes

- **Interface:**
  - User-defined type
  - Set of methods
  - No implementations provided
  - Cannot be instantiated
- **Class:**
  - User-defined type
  - Set of data and methods
  - All the methods are implemented
  - Can be instantiated



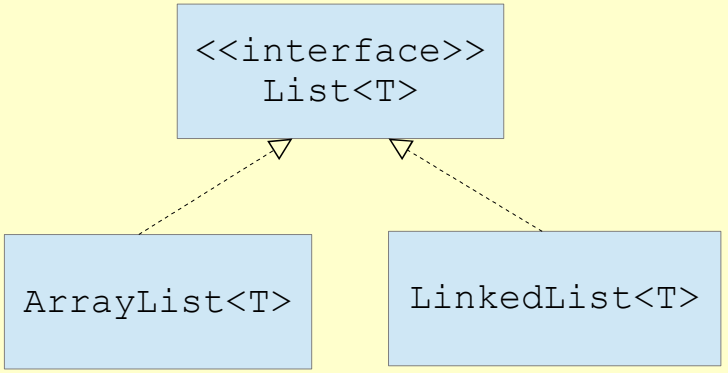
Polymorphic Argument

```
public class Utils{

    public void static void moveMe(Driveable v){
        v.start();
        for( int i=0; i<12; ++i){
          v.turn(15);
        }
        v.stop();
    }
}

Utils.moveMe( new Bicycle() );
Utils.moveMe( new Car() );
```

What am I doing?

Polymorphic Argument

```
public class Utils{
    public static void printIt(List<String> list){
       for( String s: list ){
          System.out.println( s );
       }
    }
}
```

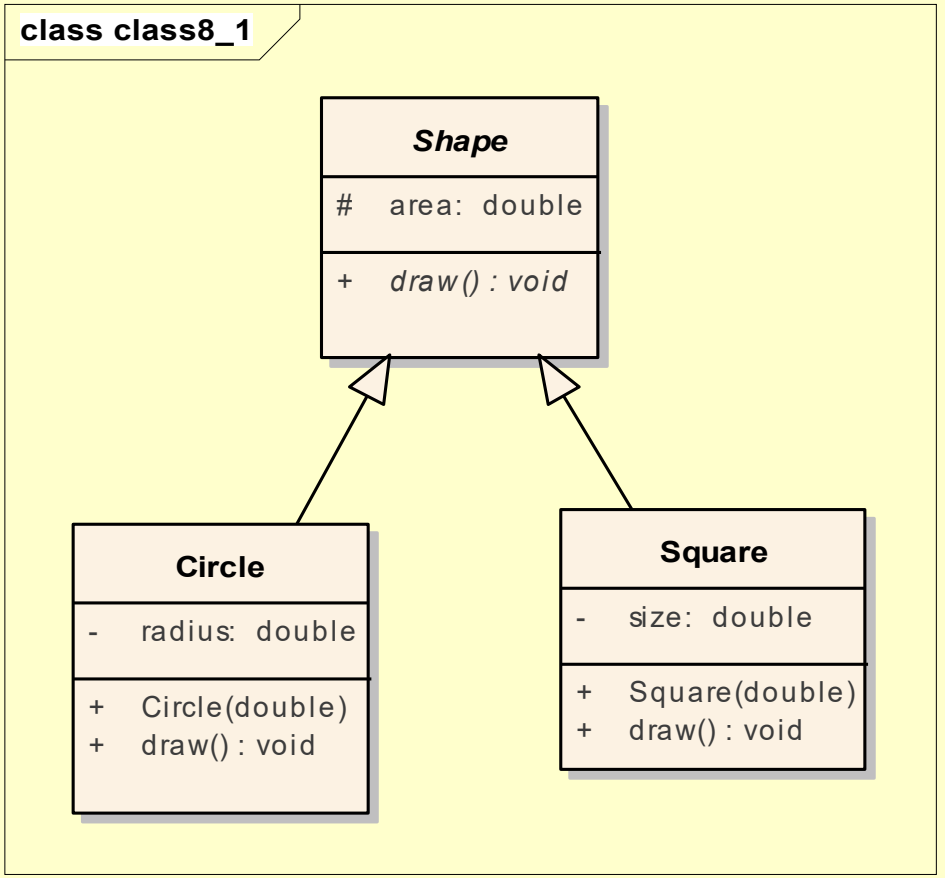



```
ArrayList<String> l1 = new ArrayList<>();
// add elements to l1
Utils.printIt(l1);
LinkedList<String> l2 = new LinkedList<>();
// add elements to l2
Utils.printIt(l2);
```

Abstract Classes

- An abstract class contains **at least one abstract method**
- May contain data and non-abstract methods as well
- **Cannot be instantiated**
- Are designed for subclassing

Abstract Classes



Abstract Classes

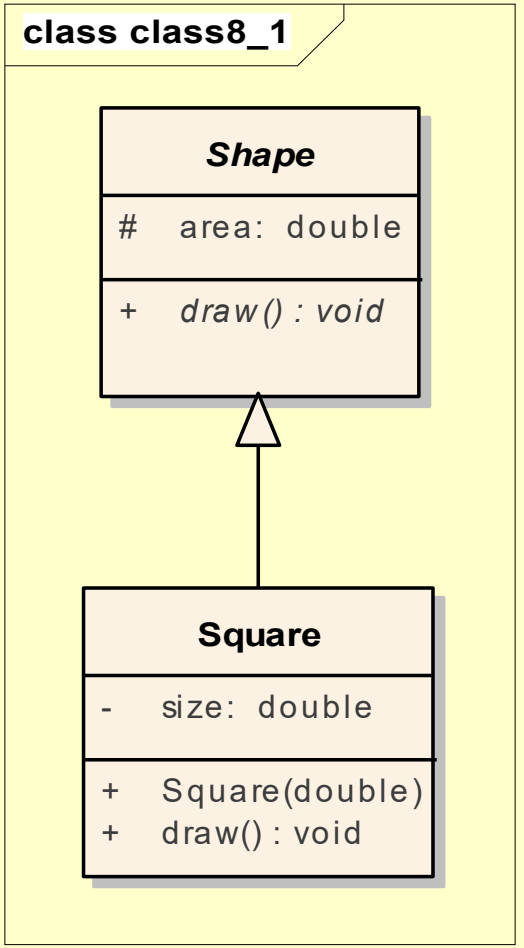
```
public abstract class Shape {
    protected double area;
    public abstract void draw();
}
```

```
public class Square extends Shape{
    private double size;

    public Square( double size ){
        this.size = size;
        this.area = size * size;
    }

    @Override
    public void draw() {
        System.out.println("I am a square");
    }

}
```

Abstract Classes vs. Classes

- **Abstract class:**
  - User-defined type
  - Set of data and methods
  - At least one method is abstract

    (no implementation)
  - Cannot be instantiated
  - Designed to be subclassed
- **Class:**
  - User-defined type
  - Set of data and methods
  - All the methods are implemented
  - Can be instantiated



Sorting and Interfaces

- Sorting Strings, primitives
  - `Arrays.sort()`
  - `Collections.sort()`
- Sort **user-defined** types
  - The `Comparable` interface
  - The `Comparator` interface

Sorting and Interfaces

- https://www.mkyong.com/java/java-object-sorting-example-comparable-and-comparator/

Sorting Collections

- Sorting objects by their natural order
    - The `Comparable` interface
- Sorting object using a Comparator
    - The `Comparator` interface

The `Comparable` interface

```
interface Comparable {
   int compareTo(Object o);
}
```

x.compareTo(y):

- 0: x equal to y
- positive: x > y;
- negative: x< y;

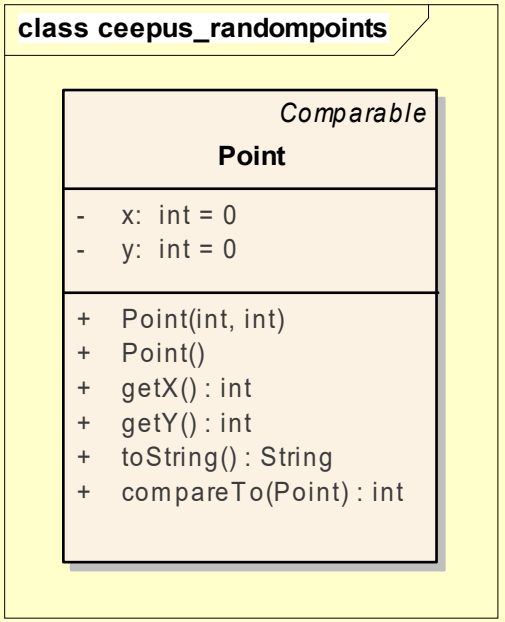
The Comparable<T> interface

```
interface Comparable<T> {
   int compareTo(T o);
}
```

Attempts to use a different type are caught at compile time!!!

The Comparable<T> interface

```
public class Point implements Comparable<Point>

{   ...
    @Override
    public int compareTo(Point o) {
        if( o == null ) throw new NullPointerException();
        if (this.x == o.x && this.y == o.y) {
            return 0;
        } else{
            if( this.x  ==  o.x){
                return this.y - o.y;
            } else{
                return this.x - o.x;
            }
        }
}
```



The `Comparable<T>` interface

Consistency

If a class overrides the `equals` method, then it is

advisable (*but not enforced*) that

```
a.equals(b)
```

exactly when

```
a.compareTo(b) == 0
```

The `Comparator<T>` interface

What if we need multiple sorting criteria?

- Class **Point**
  - Sorting by `x` then by `y`
  - Sorting by `y` then by `x`
  - Sorting by the distance from the origin `(0,0)`

- For each class we can define **only one natural ordering** through the **Comparable** interface
- We can define an **unlimited number of ordering** using the **Comparator** interface

The Comparator<T> interface

```
interface Comparator<T> {
    int compare (T x, T y);
}
```

The Comparator<T> interface

```
class DistanceComparator implements Comparator<Point>{
    private final Point o = new Point(0,0);

    @Override
     public int compare(Point p1, Point p2) {
         Double d1 = p1.distanceTo(o);
         Double d2 = p2.distanceTo(o);
         return d1.compareTo(d2);
     }
}
```

```
ArrayList<Point> points = new ArrayList<Point>();
points.add( new Point(2,2));
points.add( new Point(1,2));
points.add( new Point(2,1));
points.add( new Point(1,1));
Collections.sort( points, new DistanceComparator() );
for( Point p: points ){
  System.out.println(p);
}
```

Module 6
Exceptions
and
nested classes

Exceptions

- Define exceptions
- Exception handling: `try, catch,` and `finally`
- Exception categories
- User-defined exceptions
- Enumerations
- Nested classes

Exception Example

```
public class AddArguments {
   public static void main(String[] args) {
        int sum = 0;
        for( String arg: args ){
            sum += Integer.parseInt( arg );
        }
        System.out.println( "Sum: "+sum );
   }
}
```

```
java AddArguments 1 2 3
Sum: 6
```

```
java AddArguments 1 foo 2 3
Exception in thread "main" java.lang.NumberFormatException: For input string: "foo"
at java.lang.NumberFormatException.forInputString(NumberFormatException.java:65)
at java.lang.Integer.parseInt(Integer.java:580)
at java.lang.Integer.parseInt(Integer.java:615)
at addarguments.AddArguments.main(AddArguments.java:line_number)
Java Result: 1
```

The `try-catch` statement

```
public class AddArguments2 {
   public static void main(String[] args) {
        try{
            int sum = 0;
            for( String arg: args ){
                  sum += Integer.parseInt( arg );
            }
            System.out.println( "Sum: "+sum );
        } catch( NumberFormatException e ){
             System.err.println("Non-numeric argument");
        }
   }
}
```

```
java AddArguments2 1 foo 2 3
Non-numeric argument
```

The `try-catch` statement

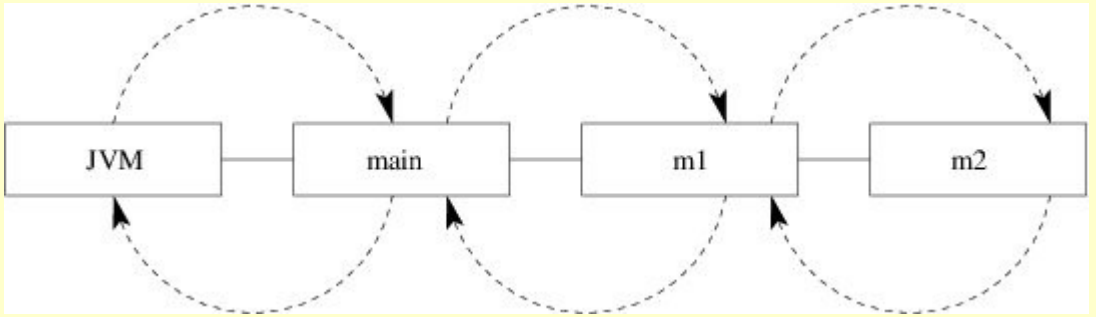
```
public class AddArguments3 {
   public static void main(String[] args) {
        int sum = 0;
        for( String arg: args ){
           try{
              sum += Integer.parseInt( arg );
           } catch( NumberFormatException e ){
              System.err.println(arg+"is not an integer");
           }
        }
        System.out.println( "Sum: "+sum );
   }
}
```

```
java AddArguments3  1 foo 2 3
foo is not an integer
Sum: 6
```

The `try-catch` statement

```
try{
   // critical code block
   // code that might throw exceptions
} catch( MyException1 e1 ){
   // code to execute if a MyException1 is thrown
} catch( MyException2 e2 ){
   // code to execute if a MyException1 is thrown
} catch ( Exception e3 ){
   // code to execute if any other exception is thrown
}
```

Call Stack Mechanism



- If an exception is not handled in a method, it is thrown to the caller of that method
- If the exception gets back to the main method and is not handled there, the program is terminated abnormally.

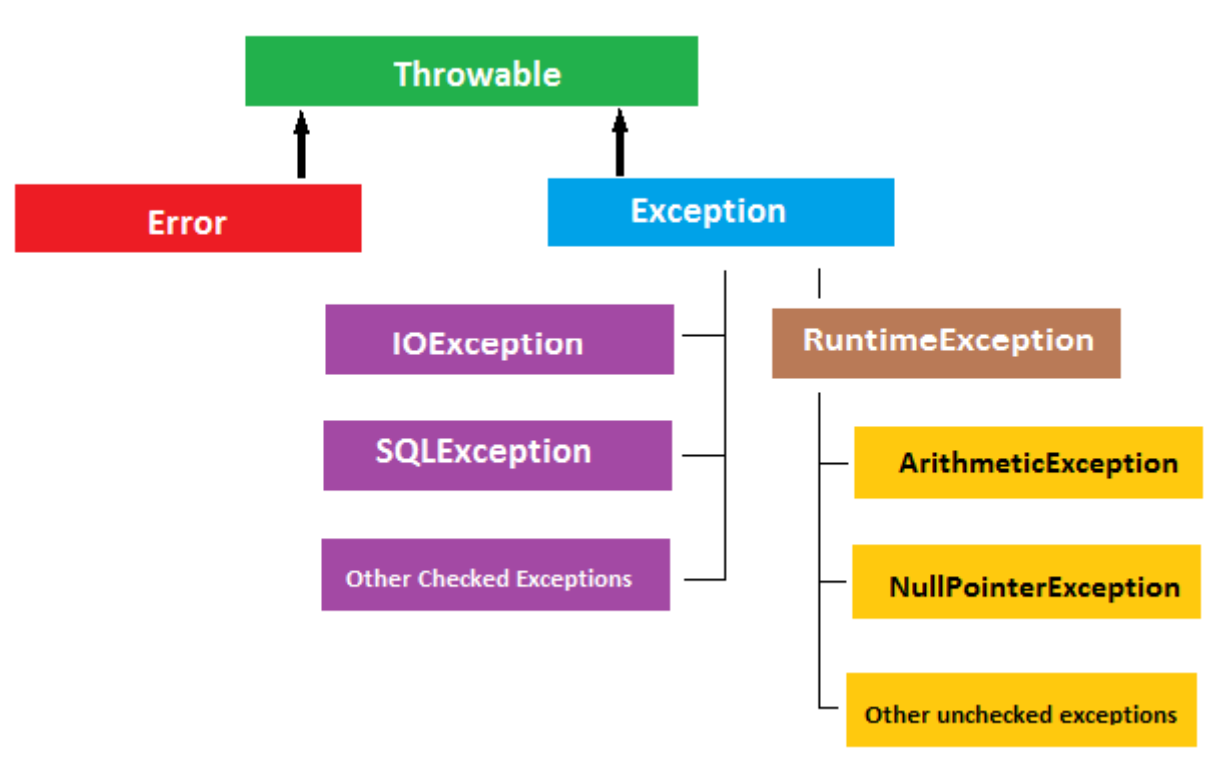
The `finally` clause

```
try{
    connectDB();
    doTheWork();
} catch( AnyException e ){
    logProblem( e );
} finally {
    disconnectDB();
}
```

- The code in the **`finally`** block is always executed (even in case of return statement)

Exception Categories

- **Checked** and **unchecked** exceptions



The Handle or Declare Rule

```
public static int countLines( String filename ){
    int counter = 0;
    Scanner scanner = null;
    try {
        scanner = new Scanner( new File( filename ));
    } catch (FileNotFoundException ex) {
        ex.printStackTrace();
    }
    String line;
    while ( scanner.hasNextLine() ){
        line = scanner.nextLine();
        ++counter;
    }
    return counter;
}
```

HANDLE

Usage:

```
ClassName.countLines("input.txt");
```

The Handle or Declare Rule

```
public static int countLines( String filename )
                                throws FileNotFoundException{
   int counter = 0;
   Scanner scanner = new Scanner(new File( filename ));
   String line;
   while ( scanner.hasNextLine() ){
       line = scanner.nextLine();
       ++counter;
   }
   return counter;
}
```

DECLARE
throws

Usage:

```
try{
    ClassName.countLines("input.txt");
} catch( FileNotFoundException e ){
    e.printStackTrace();
}
```

The `throws` Clause

```
void trouble1 () throws Exception1 {...}
void trouble2 () throws Exception1, Exception2 {...}
```

Principles

- You do not need to declare runtime (unchecked) exceptions
- You can choose to handle runtime exceptions (e.g. **`IndexArrayOutOfBounds`**, **`NullPointerException`**)

Creating Your Own Exceptions

The overriding method can throw:

- No exceptions
- One or more of the exceptions thrown by the overridden method
- One or more subclasses of the exceptions thrown by the overridden method

The overridden method cannot throw:

- Additional exceptions not thrown by the overridden method
- Superclasses of the exceptions thrown by the overridden method

User-Defined Exception

```
public class StackException extends Exception {
    public StackException(String message) {
        super( message );
    }
}
```

User-Defined Exception

```
public class Stack {
    private Object elements[];
    private int capacity;
    private int size;

    public Stack( int capacity ){
        this.capacity = capacity;
        elements = new Object[ capacity ];
    }

    public void push(Object o) throws StackException {
        if (size == capacity) {
            throw new StackException("Stack is full");
        }
        elements[size++] = o;
    }

    public Object top() throws StackException {
        if (size == 0) {
            throw new StackException("stack is empty");
        }
        return elements[size - 1];
    }

}
```

User-Defined Exception

```
Stack s = new Stack(3);
for (int i = 0; i < 3; ++i) {
   try {
       s.push(i);
    } catch (StackException ex) {
          ex.printStackTrace();
    }
}
```

Enumerations

```
public enum GestureType {
    UP (0, "fel"),
    RIGHT (1, "jobb"),
    DOWN (2, "le"),
    LEFT (3, "bal");

    GestureType( int value, String name ){
        this.value = value;
        this.name = name;
    }

    public int getValue(){
        return value;
    }

    public String getName(){
        return name;
    }

    private int value;
    private String name;
}
```

Enumerations

```
for(GestureType type: GestureType.values()){
    System.out.println(type.name()+", "+
                       type.getName()+", "+
                       type.getValue());
}
```

Output

```
UP, fel, 0
RIGHT, jobb, 1
DOWN, le, 2
LEFT, bal, 3
```

Nested Classes

- **When?**
  - If a class is used only inside of another class (encapsulation)
  - Helper classes

Nested Classes

- **The place of nesting**
  - Class
  - Method
  - Instruction
- **Embedding method**
  - Static
  - Non-static

Static Nested Class

```
public class Slist{
  private Element head;

  public void insertFirst( Object value ){
     head = new Element(value, head);
  }

  private static class Element{
     private Object value;
     private Element next;
     public Element( Object value, Element next){
        this.value = value;
        this.next = next;
     }
     public Element( Object value){
        this.value = value;
        this.next = null;
     }
  }
}
```

Used only inside the Slist class

The Iterator interface

Package: `java.util`

```
public interface Iterator{
     public boolean hasNext();
     public Object next();
     //optional
     public void remove();
}
```

Make Slist iterable using the Iterator interface!!!

The Iterator interface

```
Slist list = new Slist();
for( int i=0; i<10; ++i ){
   list.insertFirst( i );
}

Iterator it = list.createIterator();
while( it.hasnext() ){
  System.out.println( it.next() );
}
```

Factory Method Design Pattern

1. Solution – Non-static Nested Class

```
public class Slist{
  private Element head;
  //...

  public Iterator createIterator(){
     return new ListIterator();
  }

  private class ListIterator implements Iterator{
     private Element act = head;
     public boolean hasNext(){
         return act != null;
     }
     public Object next(){
        Object value = act.value;
        act = act.next;
        return value;
     }
  }
}
```

Relation between Slist and ListIterator objects

1. Solution – Non-static Nested Class

```
public class Slist{
  private Element head;
  //...

  public Iterator createIterator(){
     return new ListIterator();
  }

  private class ListIterator implements Iterator{
     private Element act = head;
     public boolean hasNext(){
         return act != null;
     }
     public Object next(){
        Object value = act.value;
        act = act.next;
        return value;
     }
  }
}
```

Class ListIterator is used only once!!!

2. Solution – Anonymous Inner Class

```
public class Slist{
  private Element head;
  //...

  public Iterator createIterator(){
     return new Iterator(){
        private Element act = head;

        public boolean hasNext(){
           return act != null;
        }

        public Object next(){
           Object value = act.value;
           act = act.next;
           return value;
        }
     }
}
```

Module 7
Threads

Outline

- **Definition**
- **Creation:** *Thread* **and** *Runnable*
- **Synchronization**
- **Executors and thread pools**

What are threads?

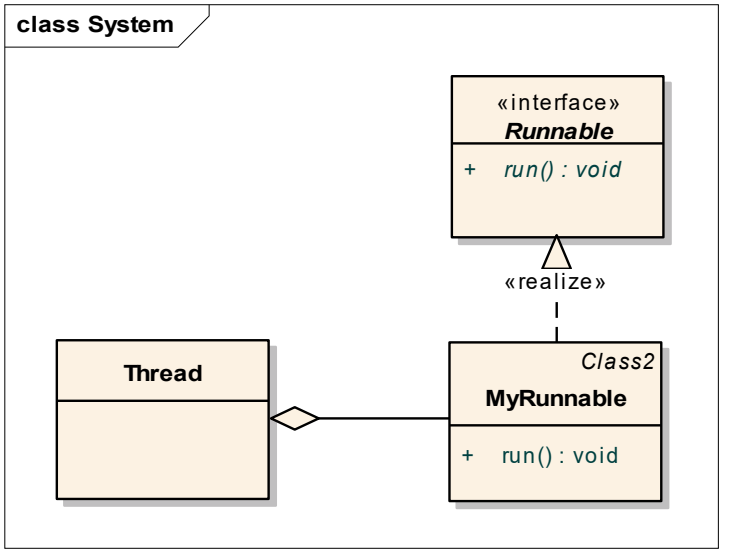
- **Operating Systems**
  - lightweight process
  - runs in the address space of a process
  - has its own program counter (PC)+stack
  - shares code and data with other threads
- **Object-oriented Programming**
  - an object – an instance of the class Thread

Threads

- `java.lang.Thread` = Infrastructure(PC+Stack)
- `java.lang.Runnable` = Code

Thread's creation (1)

```
public class  MyRunnable implements Runnable{
  private int id;

  public MyRunnable(int id ){
    this.id = id;
  }

  public void run(){
    for( int i=0; i<10; ++i){
     System.out.println("Hello"+id+" "+i);
   }
  }
}


…
MyRunnable r = new MyRunnable(1);
Thread t = new Thread( r );
```



Starting the thread

```
Thread t = new Thread( r );
```

Constructor initializes the thread object

```
t.start();
```

Calls the thread object's run method

Thread's creation (1)

```
public class Test{
  public static void main(String args[]){
     Thread t1 = new Thread( new MyRunnable(1));
     Thread t2 = new Thread( new MyRunnable(2));
     t1.start();
     t2.start();
  }
}
```

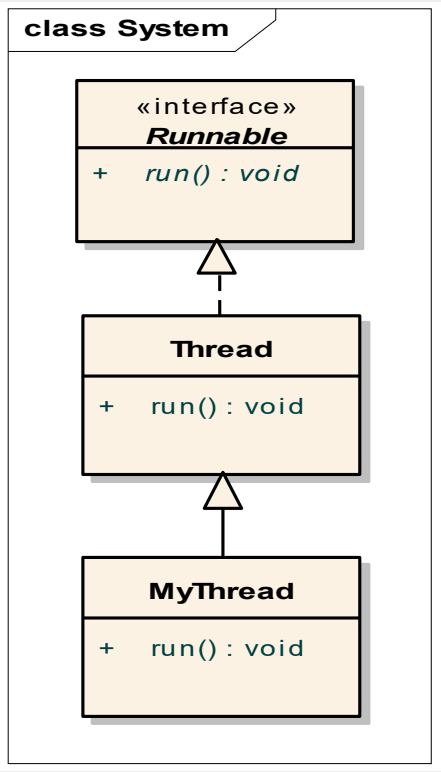
Output?

Thread's creation (2)

```
class MyThread extends Thread {
   private int id;

   public MyThread(int id) {
       this.id = id;
   }
   @Override
   public void run() {
       for (int i = 0; i < 10; ++i) {
           System.out.println("Hello" + id + " " + i);
       }
   }
}

…
Thread t = new MyThread(1);
t.start();
```

Thread's creation (2)

```
public class Test {
    public static void main(String[] args) {
        Thread t1 = new MyThread(1);
        Thread t2 = new MyThread(2);
        t1.start();
        t2.start();
    }
}`
```



Example (1)

```
public class MyFirstRunnable implements Runnable{
    @Override
    public void run() {
        System.out.println("In a thread");
    }
}
```

Usage:

```
Thread thread = new Thread(new MyFirstRunnable());
thread.start();
System.out.println("In the main Thread");
```

Output?

Example (2)

```
public class MyFirstRunnable implements Runnable{
    @Override
    public void run() {
        System.out.println("In a thread");
    }
}
```

Usage:

```
Runnable runnable = new MyFirstRunnable();
for(int i = 0; i<25; i++){
    new Thread(runnable).start();
}
```

How many threads?

Example (3)

```
public class MyFirstRunnable implements Runnable{
    @Override
    public void run() {
        System.out.println("In a thread");
    }
}
Usage:

Thread thread = new Thread(new MyFirstRunnable());
thread.run();
System.out.println("In the main Thread");
```

Output?

Operations on threads

- make the current Thread **sleep**
- wait for another thread to complete (**join**)
- manage the **priorities** of threads
- **interrupt** a thread

sleep()

```
try {
    Thread.sleep(1000);
} catch (InterruptedException e){
    e.printStackTrace();
}
```

sleep()

```
try {
    Thread.sleep(1000);
} catch (InterruptedException e){
    e.printStackTrace();
}
```

join()

```
Thread t2 = new Thread(new R());
t2.start();
try {
    t2.join();
} catch (InterruptedException e){
    e.printStackTrace();
}
```

setPriority()/getPriority()

```
public class ThreadPriorityRange {
    public static void main(String[] args) {
        System.out.println("Minimal priority : " +
                           Thread.MIN_PRIORITY);
        System.out.println("Maximal priority : " +
                           Thread.MAX_PRIORITY);
        System.out.println("Norm priority : " +
                           Thread.NORM_PRIORITY);
         }
}
```

interrupt()

A thread can be interrupted:

- if the thread is sleeping
- if the thread is waiting for another thread to join

interrupt()

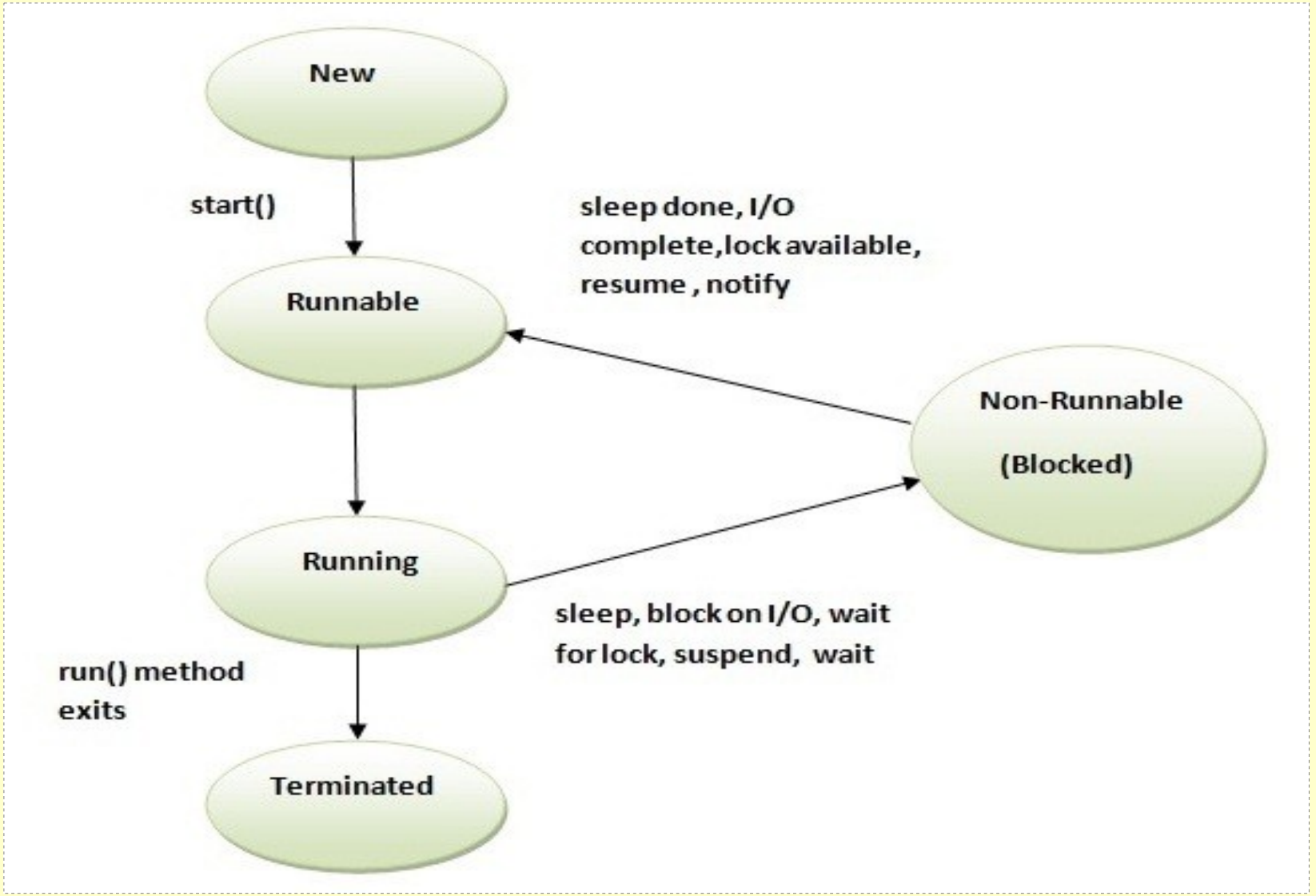
```
private static class ForeverRunnable implements Runnable {
  public void run() {
    while (true) {
       System.out.println(Thread.currentThread().getName() +
                          ": " + System.currentTimeMillis());
       try {
         Thread.sleep(5000);
       } catch (InterruptedException e) {
         System.out.println(
            Thread.currentThread().getName() +
                                  "has been interrupted");
       }
    }
  }
}
```

interrupt()

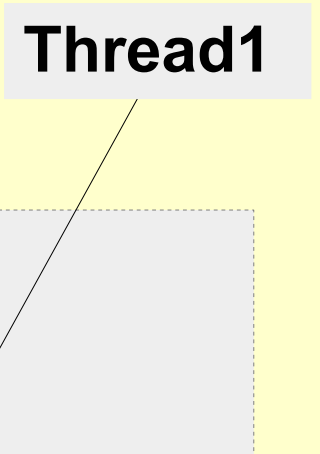
```
private static class ForeverRunnable implements Runnable {
  public void run() {
    while (true) {
       System.out.println(Thread.currentThread().getName() +
                          ": " + System.currentTimeMillis());
       try {
         Thread.sleep(5000);
       } catch (InterruptedException e) {
         System.out.println(
            Thread.currentThread().getName() +
                                  "has been interrupted");
       }
    }
```

```
public static void main(String[] args) {
  Thread t2 = new Thread(new ForeverRunnable());
  System.out.println("Current time millis : " +
                                 System.currentTimeMillis());
  t2.start();
  t2.interrupt();
}
```

Thread's states

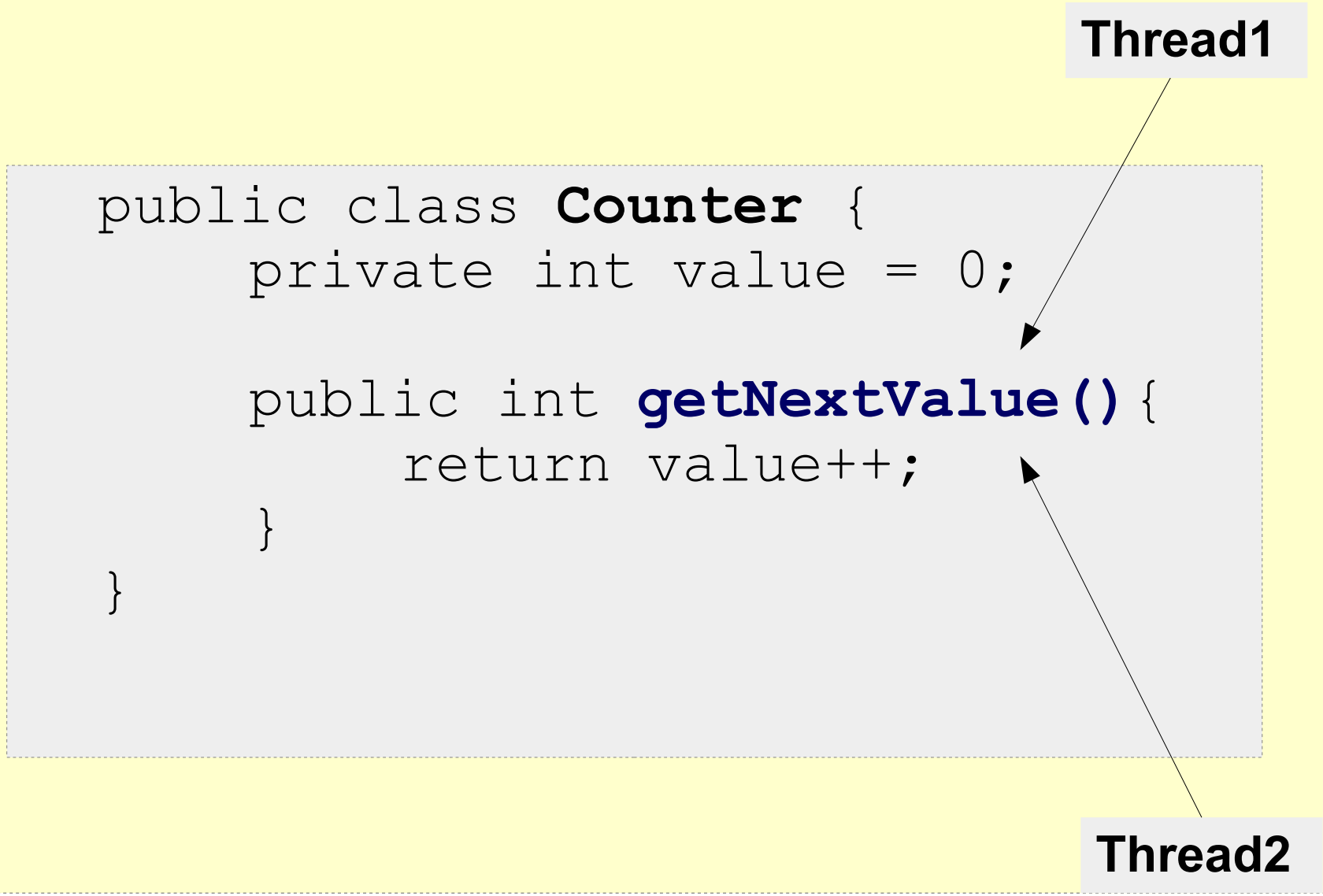


Need for synchronization




```
public class Counter {
    private int value = 0;

    public int getNextValue(){
        return value++;
    }
}
```

Need for synchronization



Need for synchronization

```
class Counter {
    private int value;

    public int getNextValue() {
        return ++value;
    }
    public int getValue(){
        return value;
    }
}
```

Need for synchronization

```
class Thread3 extends Thread {
    private Counter counter;

    public Thread3(Counter counter) {
        this.counter = counter;
    }

    public void run() {
        for (int i = 0; i < 10000; ++i){
            counter.getNextValue();
        }
    }
}
```

Need for synchronization

```
Counter counter = new Counter();
Thread t1 = new Thread3(counter);
Thread t2 = new Thread3(counter);
t1.start();
t2.start();
try{
   t1.join();
   t2.join();
} catch( InterruptedException e ){
}
System.out.println("COUNTER: "
                   +counter.getValue());
```

Output?

Need for synchronization

`value++`

1. Read the current value of "value"
2. Add one to the current value
3. Write that new value to "value"

Solution (1)

```
public class Counter {
  private int value = 0;

  public synchronized int getNextValue(){
              return value++;
  }
 }
```

Solution (2)

```
public class Counter {
      private int value = 0;

      public int getNextValue(){
            synchronized(this){
               value++;
            }
            return value;
      }
}
```

Synchronized Blocks

- every object contains a single **lock**
- the **lock** is taken when synchronized section is entered
- if the **lock** is not available, thread enters a waiting queue
- if the **lock** is returned, thread is resumed

Thread Safe

- A class is **thread safe** if it behaves always in the same manner when accessed from multiple threads.

- Stateless objects (**immutable classes**) are always thread safe:
    - String
    - Long
    - Double

Executors and thread pools

http://www.vogella.com/tutorials/JavaConcurrency/article.html#threadpools

ExecutorService

Callable

Future

Module 8
GUI Programming
Swing

Java GUIs

- **AWT (Abstract Windowing Toolkit) –** since JDK 1.0
  - Uses native control
    - Appearance/behavior depends on platform
- **Swing –** since JDK 1.2
  - Implemented completely in Java (light weight)
- **JavaFX –** since JDK 8
  - Written as a native library
  - Provided on a wide variety of devices
- **SWT (Standard Widget Toolkit)**
  - Eclipse

Outline

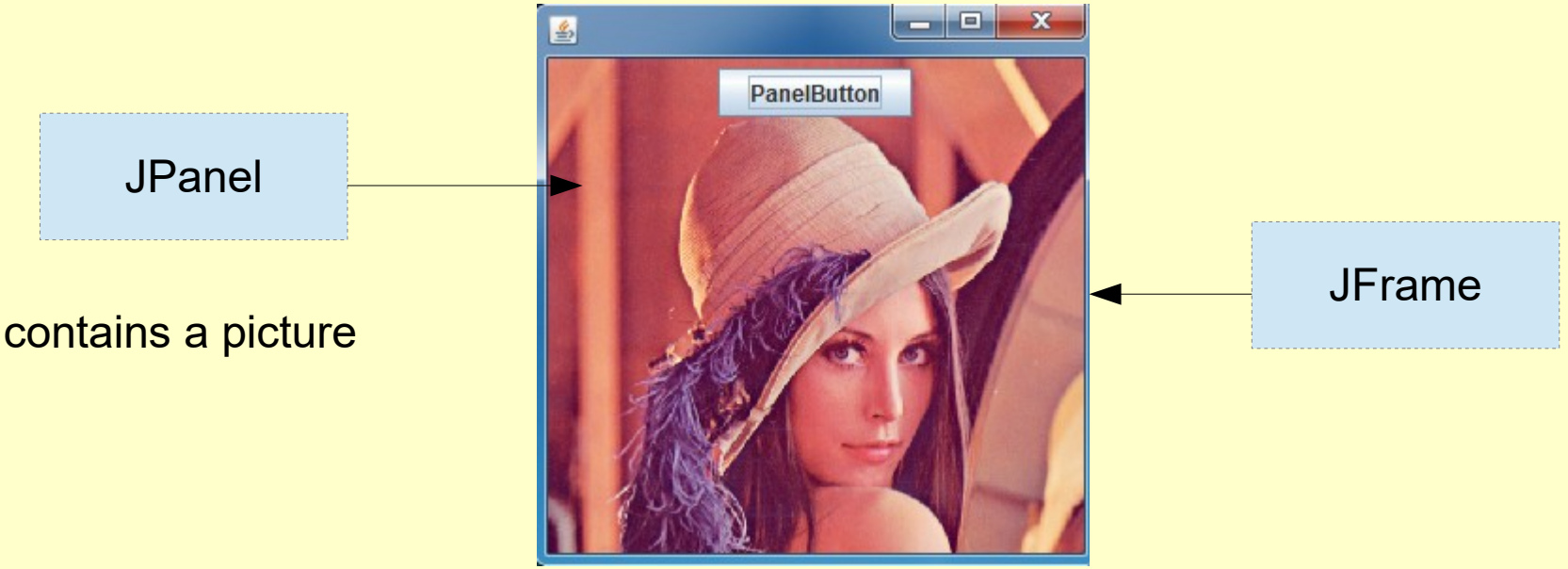
- ***Containers, components* and *layout managers***
- `FlowLayout`, `BorderLayout`, and `GridLayout`
- Add components to a container
- Events and event handling
- Delegation model
- Adapter classes

Component

- Represents an object with *visual* representation
- Other names for components: widgets, controls

Container

- A special component that holds other components
- Used for grouping other components



The first GUI program

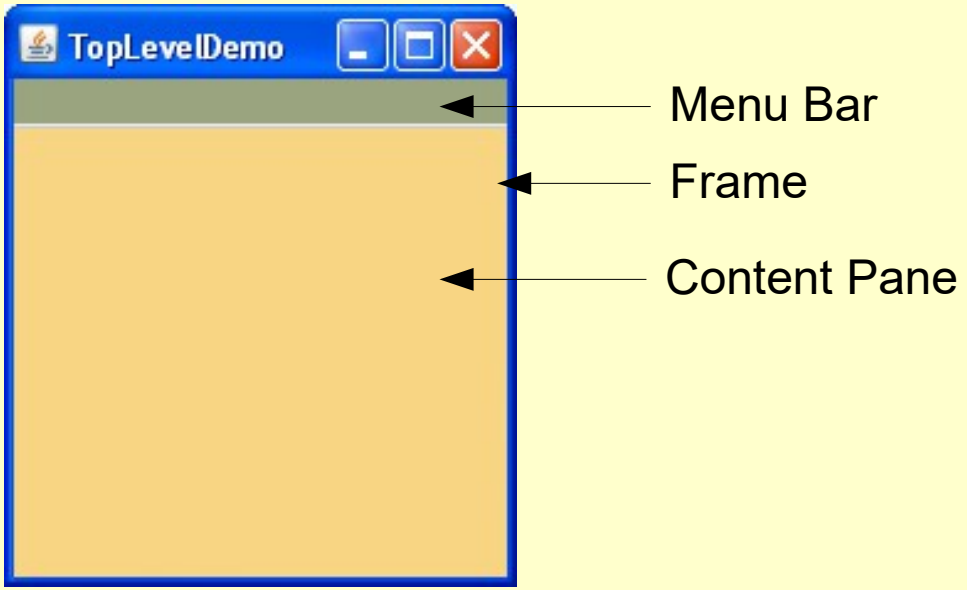
```
public static void main(String[] args) {
      JFrame f = new JFrame("The First Swing
                                    Application");
      f.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      f.setBounds( 100,100, 300, 300);
      f.setVisible(true);
}
```

Frames

JFrame

- Top level container
  - can have menu bars
- Contains a JRootPane
- Have title and resizing corners
- Have BorderLayout as

  the default layout manager



Positioning Components

- Responsibility of the layout manager
  - **size** (dimension: width and height in pixels)
  - **position** (location of the top left corner)
- You can disable the layout manager: setLayout(null),

  then use
  - `setSize() + setLocation()`
  - `setBounds()`

Organizing Components (1)

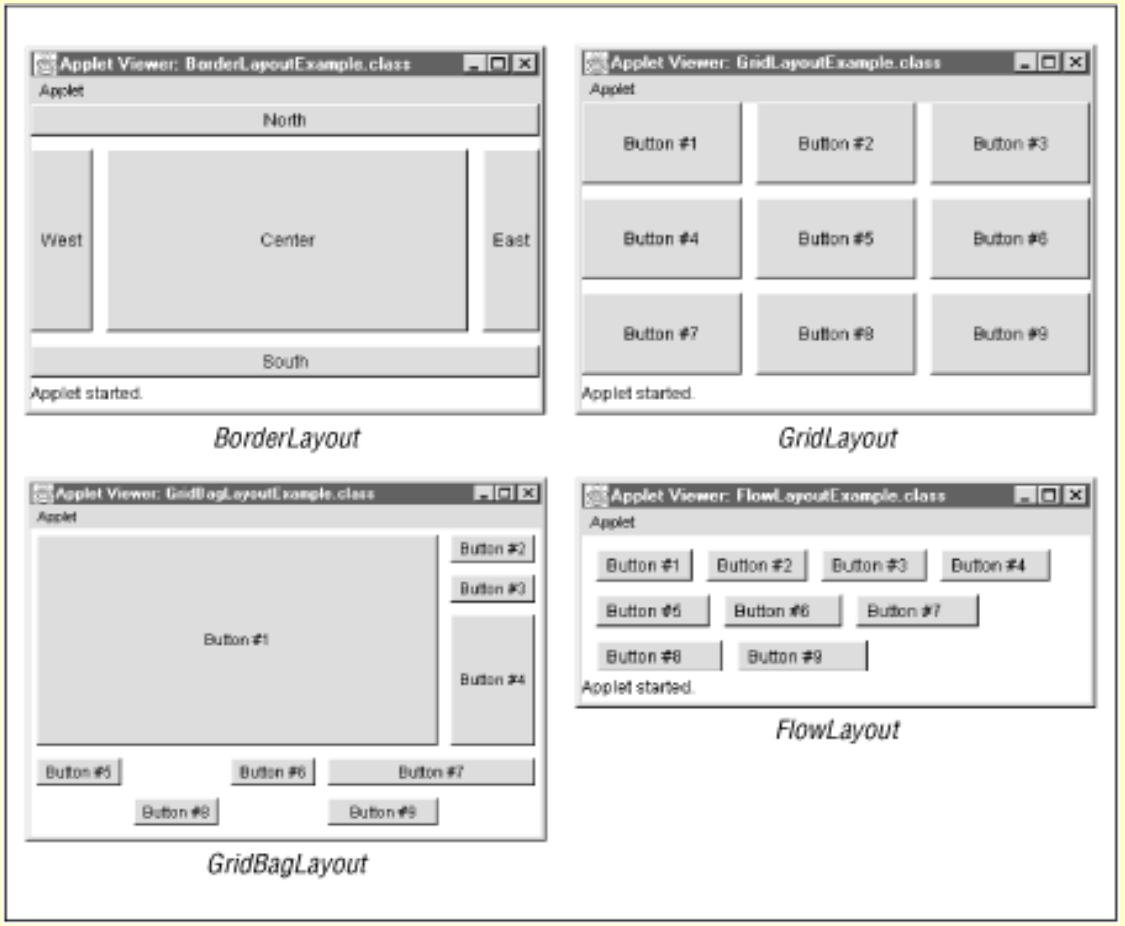
```
JFrame f = new JFrame("The First Swing Application");
f.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

JPanel p = new JPanel();
p.setBackground(Color.blue);
JButton b = new JButton("Yes");
p.add(b);
f.setContentPane(p);

f.setBounds( 100,100, 300, 300);
f.setVisible(true);
```

Organizing Components (2)

```
JFrame f = new JFrame("The First Swing Application");
f.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

JPanel p = new JPanel();
p.setBackground(Color.blue);
p.setLayout( null );
JButton b = new Jbutton("Yes");
b.setSize(100,60);
b.setLocation(200, 200);
p.add(b);
f.setContentPane(p);

f.setBounds( 100,100, 300, 300);
f.setVisible(true);
```

Layout Managers

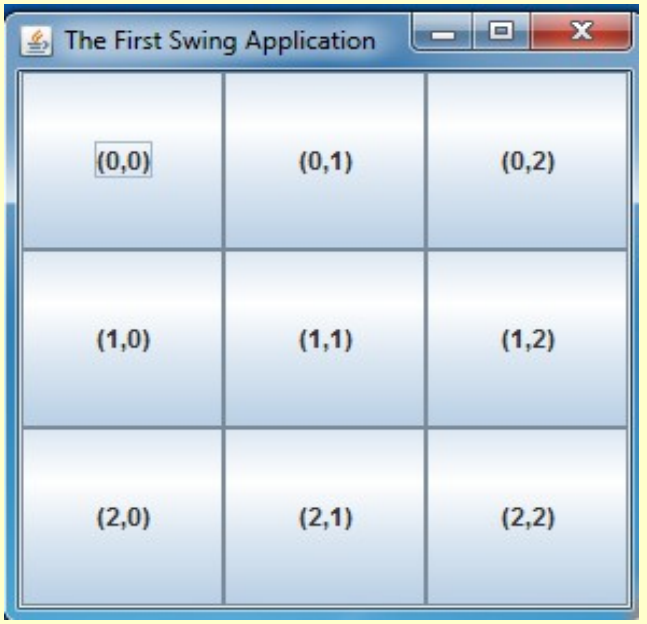
- FlowLayout
- BorderLayout
- GridLayout
- GridBagLayout



Layout Managers

GridLayout

```
public static JPanel createPanel( int n){
    JPanel panel = new JPanel();
    panel.setLayout(new GridLayout( n, n));
    for( int i=0; i<n; ++i){
        for( int j=0; j<n; ++j){
            panel.add( new JButton
                    ("("+i+","+j+")"));
        }
    }
    return panel;
}
```



Creating UI

- Aggregation
  - FrameAggregation
- Inheritance
  - FrameInheritance

Creating UI

Aggregation

```
public class FrameAggregation {

    private static void initFrame() {
      JFrame frame = new JFrame("FrameAggregation");
      frame.add(new JButton("Ok"), "Center");

frame.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
      frame.setBounds(100, 100, 200, 200);
      frame.setVisible(true);
    }

    public static void main(String[] args) {
        initFrame();
    }
}
```

Creating UI

Inheritance

```
public class FrameInheritance extends JFrame {
    private JButton button;
    public FrameInheritance(){
        initComponents();
    }
    private void initComponents() {
      this.setTitle("FrameInheritance");
        this.add(new JButton("Ok"), "Center");
        this.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        this.setBounds(100, 100, 200, 200);
        this.setVisible(true);
    }
    public static void main(String[] args) {
       new FrameInheritance();
    }
}
```

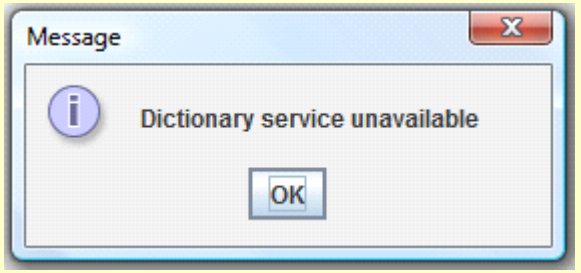
Menus

```
private static JMenuBar createMenu() {
    //Menubar
    MenuBar menuBar; JMenu filemenu, helpmenu;
    JMenuItem  menuItem;
    menuBar = new JMenuBar();
  // Build File menu.
  filemenu = new JMenu("File"); menuBar.add(filemenu);
  menuItem = new JMenuItem("New"); filemenu.add(menuItem);
  menuItem = new JMenuItem("Exit"); filemenu.add(menuItem);
  // Build Help menu.
  helpmenu = new JMenu("Help");
  menuBar.add(helpmenu);
  menuItem = new JMenuItem("About");
  helpmenu.add(menuItem);
  return menuBar;
}

frame.setJMenuBar(createMenu());
```

Dialogs

JOptionPane (1)

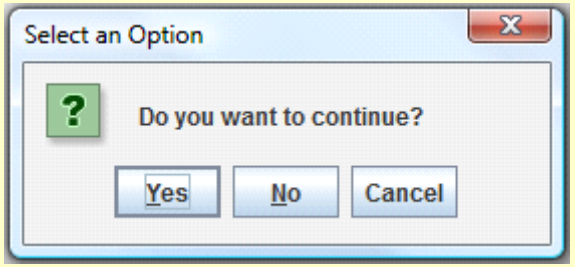
```
JOptionPane.showMessageDialog(
      Component parent, String message);
```



Dialogs

JOptionPane (2)

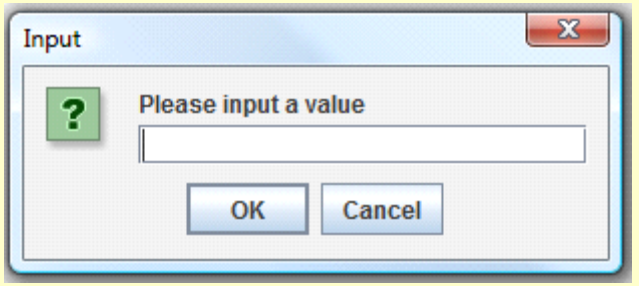
```
int result =
JOptionPane.showConfirmDialog(
            Component parent, String message);
Result:
      YES_OPTION (0), NO_OPTION (1), CANCEL_OPTION (2)
```



Dialogs

JOptionPane (3)

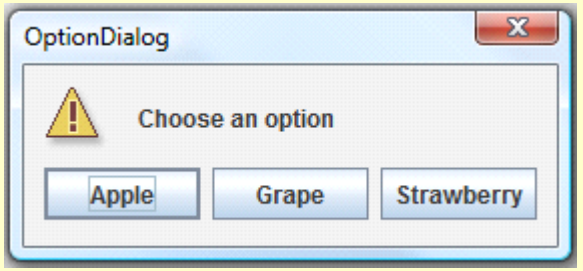
```
String value=
      JOptionPane.showInputDialog("Please input a value");
```



Dialogs

JOptionPane (4)

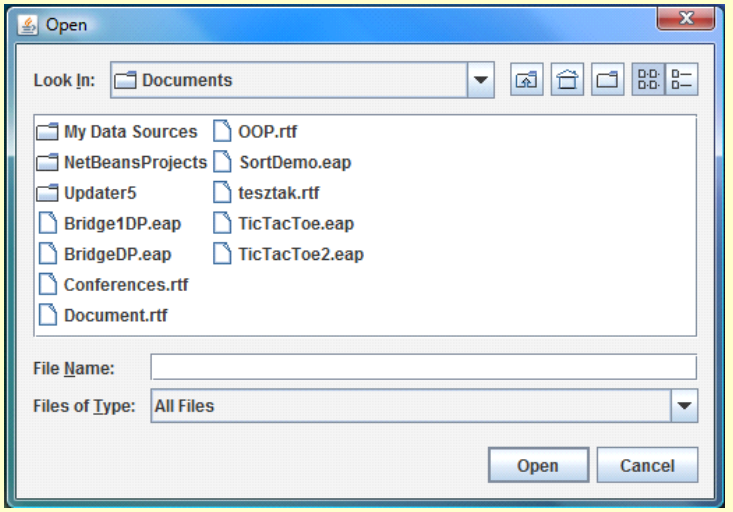
```
String options[]={"Apple", "Grape", "Strawberry"};

int res = JOptionPane.showOptionDialog(form, "Choose an
   option", "OptionDialog",JOptionPane.DEFAULT_OPTION,
   JOptionPane.WARNING_MESSAGE,null, options,
   options[0]);
```



Dialogs

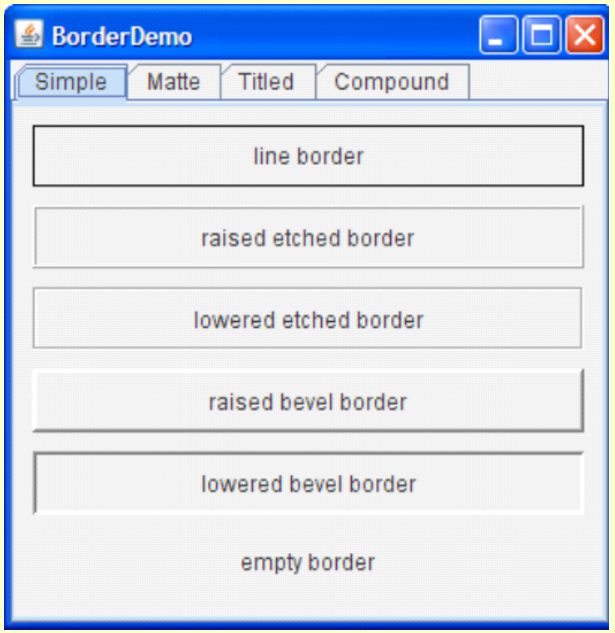
Chooser

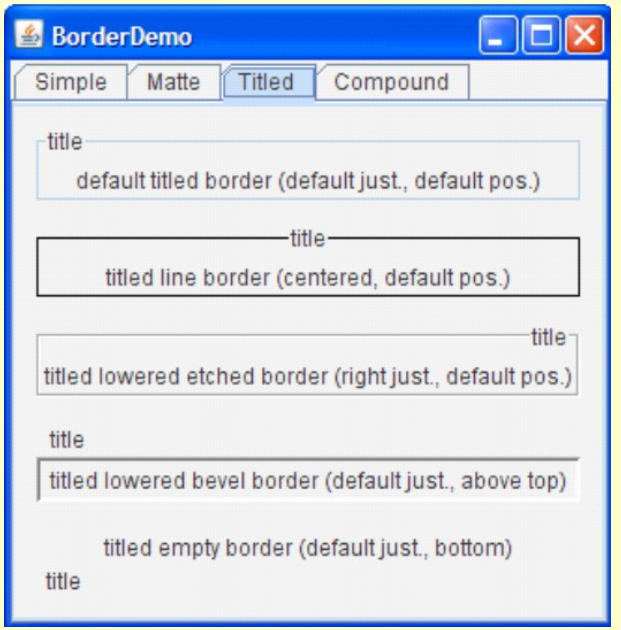
```
JFileChooser chooser = new JFileChooser();
int returnVal = chooser.showOpenDialog(parent);
if(returnVal == JFileChooser.APPROVE_OPTION) {
       System.out.println(
   "You chose to open this file: " +
            chooser.getSelectedFile().getName());
}
```



Borders

```
JPanel pane = new JPanel();
pane.setBorder(BorderFactory.createLineBorder(Color.black));
```





http://docs.oracle.com/javase/tutorial/uiswing/components/border.html

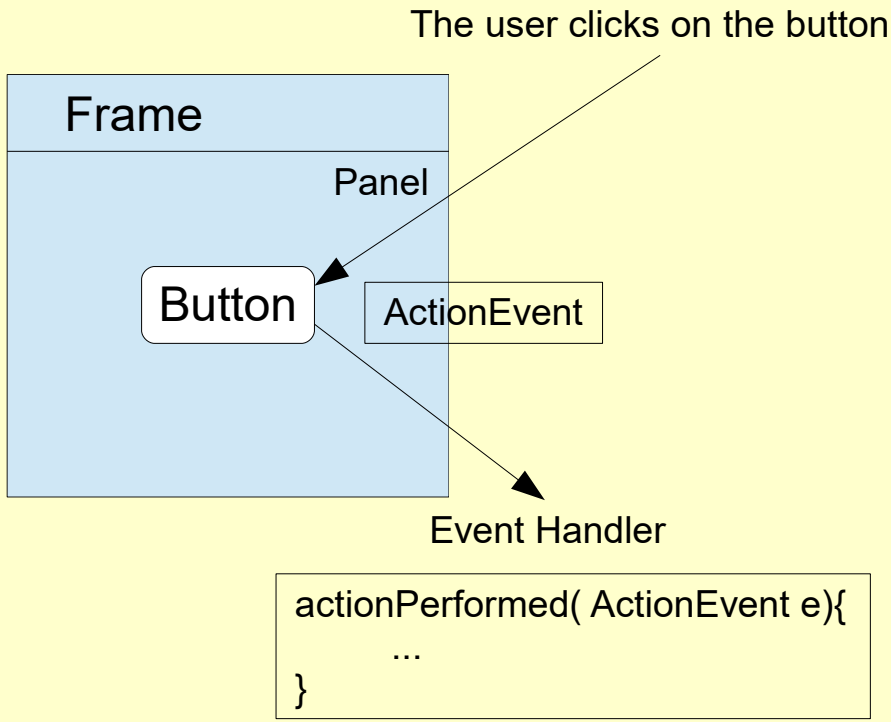
Custom properties

- (key, value) pairs associated to **`JComponent`** type objects
  - Key: **`Object`**
  - Value: **`Object`**

```
JButton button = new JButton("Press Me");
button.putClientProperty("order","10");
//...
button.getClientProperty("order");
```

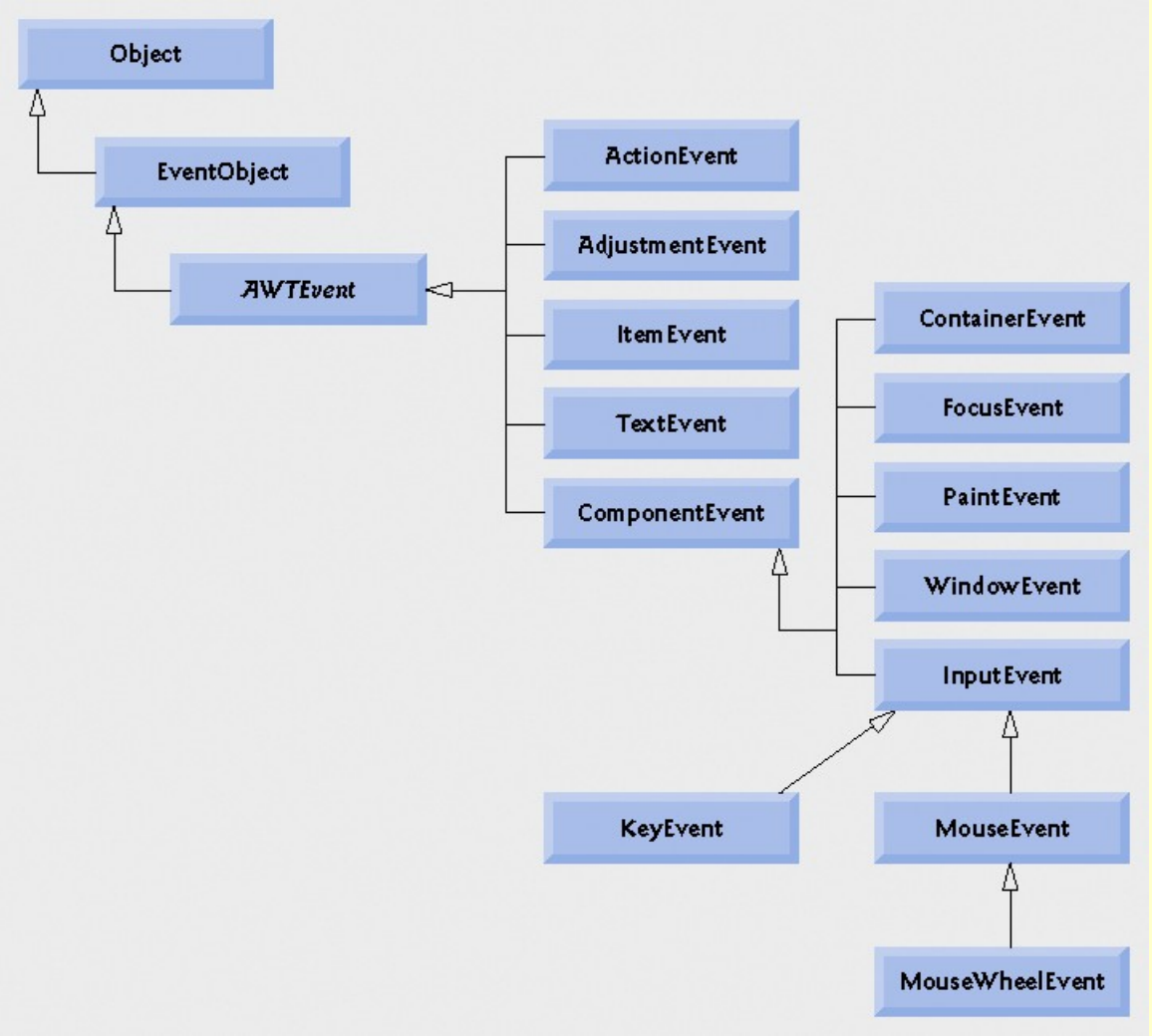
Event Handling

- **Event** – objects that describe what happened
- **Event source** – the generator of an event
- **Event handler** – a method that
  - receives an event object,
  - deciphers it,
  - and processes the user's interaction



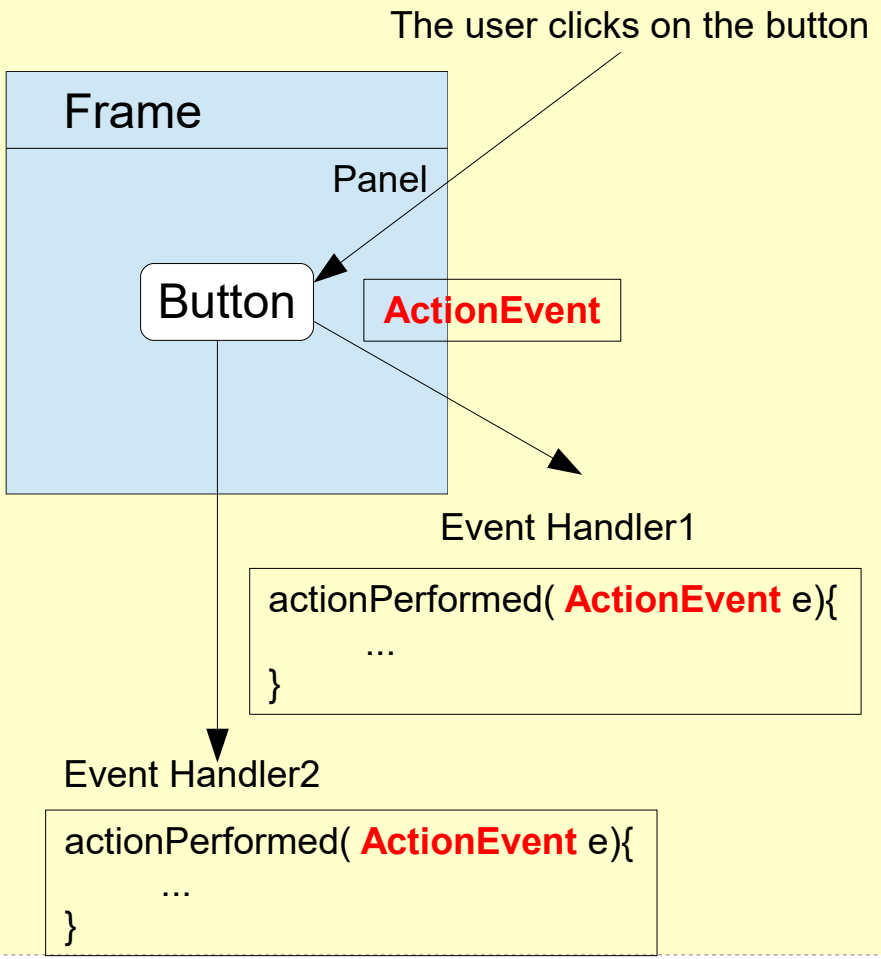
Event Types

- Low level
  - Window
  - Keyboard
  - Mouse
- High level
  - ActionEvent
  - ItemEvent



Event Handling

- *One event* – many *handlers*
- Event handlers are registered by event source components



Delegation Model

- Client objects (handlers) register with a GUI component that they want to observe
- GUI components trigger the handlers for the type of event that has occurred
- Components can trigger more than one type of events

Delegation Model

Event handler

```
JButton b = new JButton("Yes");
f.add( b );
b.addActionListener( new ActionListener(){
   @Override
   public void actionPerformed(ActionEvent e) {
      if( b.getText().equals("Yes")){
         b.setText("No");
      }else{
         b.setText("Yes");
      }
   }
});
```

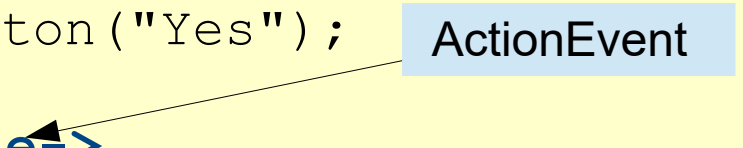
Event source

(I) Definition of an **anonymous inner class** which implements ActionListener interface
(II) Creation of an instance from that anonymous inner class
(III) This instance is responsible for event handling

Delegation Model

Java 8 - Lambdas

```
JButton b = new JButton("Yes");
f.add( b );
b.addActionListener(e->
 {
   b.setText( b.getText().equals("No") ? "Yes": "No");
 }
);
```



Many sources – One listener

```
public class MyFrame implements ActionListener{
    // ...
    public void initComponents(){
      for( int i=0; i<n; ++i){
          for( int j=0; j<n; ++j){
              JButton b = new JButton("");
              panel.add( b);
              b.addActionListener( this );
          }
      }
    }
    @Override
    public void actionPerformed(ActionEvent e) {
      JButton source = (JButton) e.getSource();
      source.setBackground(Color.red);
   }
}
```

Example
Custom Component

```
public class DrawComponent extends JComponent{
   private ArrayList<Point> points= new ArrayList<Point>();
   private Color color = Color.red;

   public DrawComponent(){
     this.addMouseListener(new MouseAdapter(){
        @Override
        public void mousePressed(MouseEvent e) {
           points.clear();
           points.add( new Point( e.getX(), e.getY()));
        }
     });
     this.addMouseMotionListener(new MouseMotionAdapter(){
        @Override
        public void mouseDragged(MouseEvent e) {
           points.add( new Point( e.getX(), e.getY()));
           DrawComponent.this.repaint();
        }
     });
   }
   …
}
```

Example
Custom Component

```
public class DrawComponent extends JComponent{
    //...
    @Override
    public void paint(Graphics g) {
       g.setColor(color);
       if( points != null && points.size()>0){
          Point startPoint = points.get(0);
          for( int i=1; i<points.size(); ++i ){
             Point endPoint = points.get(i);
              g.drawLine(startPoint.x, startPoint.y,
                         endPoint.x, endPoint.y);
              startPoint = endPoint;
          }
       }
    }

    public void clear(){
        points.clear();
        repaint();
    }
}
```

Event listeners

- **General listeners**
  - `ComponentListener`
  - `FocusListener`
  - `MouseListener`
- **Special listeners**
  - `WindowListener`
  - `ActionListener`
  - `ItemListener`

Event adapter classes

- **Problem:**
  - Sometimes you need only one event handler method, but the listener interface contains several ones
  - You have to implement all methods, most of them with empty ones
- **Solution:**
  - An Event Adapter is a convenience class
  - Implements all methods of a listener interface with empty methods
  - You extend the adapter class and override that specific method

Event Adapter Classes

Example

```
public class MyClass extends JFrame {
    ...
    someObject.addMouseListener(
        new MouseAdapter() {
            public void mouseClicked(MouseEvent e) {
           //Event listener implementation
       }
        });

}
```

Module 9
Collections and Generics

Outline

- Data Structures
- Interfaces: `Collection, List, Set, Map, ...`
- Implementations: `ArrayList, HashSet, TreeMap, ...`
- Traversing collections
- Overriding **`equals`** and **`hashCode`**
- Sorting
- Problems

The Collections API

- What is?
  - Unified architecture
    - Interfaces – implementation-independence
    - Implementations – resusable data structures
    - Algorithms – reusable functionality
  - Best-known examples
    - C++ Standard Template Library (STL)
    - Smalltalk collections

The Collections API

- Benefits:
  - Reduces programming effort
  - Increases performance
    - High performance implementations of data structures
  - Fosters software reuse

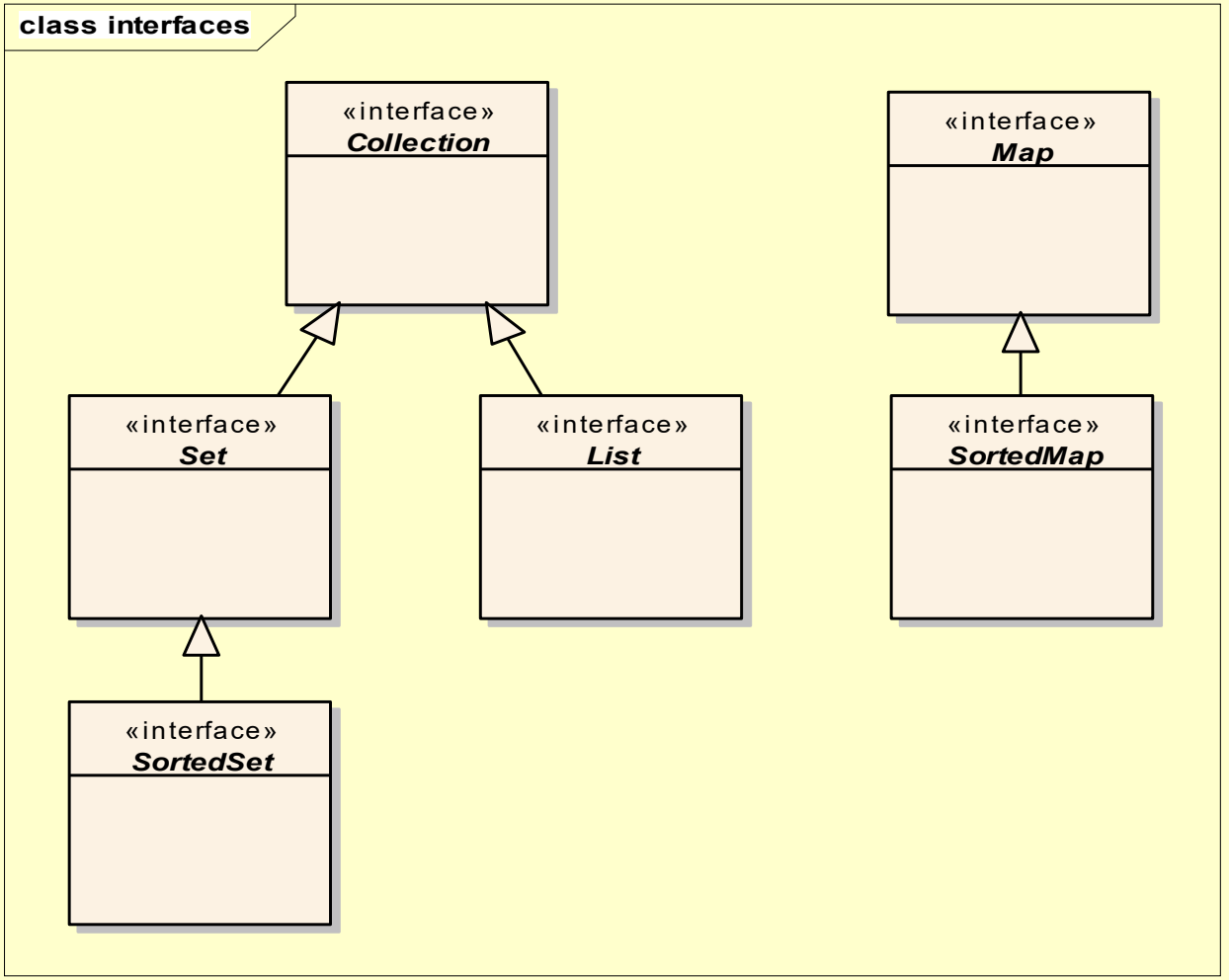
The Collections API

Design Goals

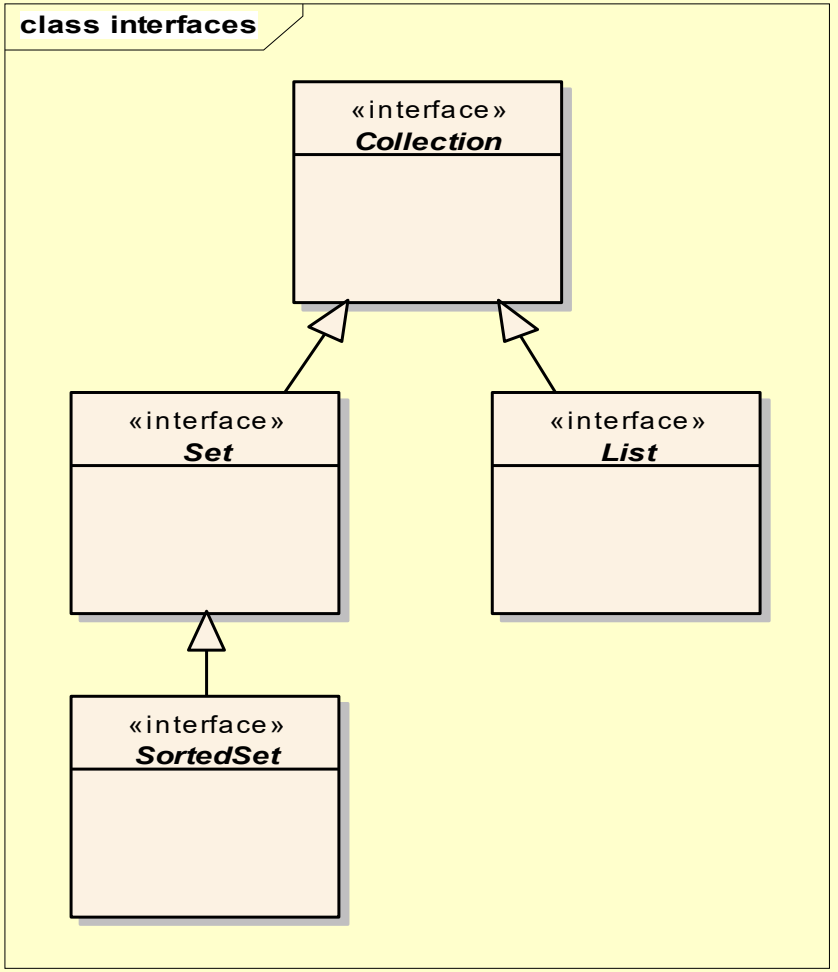
- Small and simple
- Powerful
- Easily extensible
- Compatible with preexisting collections
- Easy to use

The Collections API

Interfaces



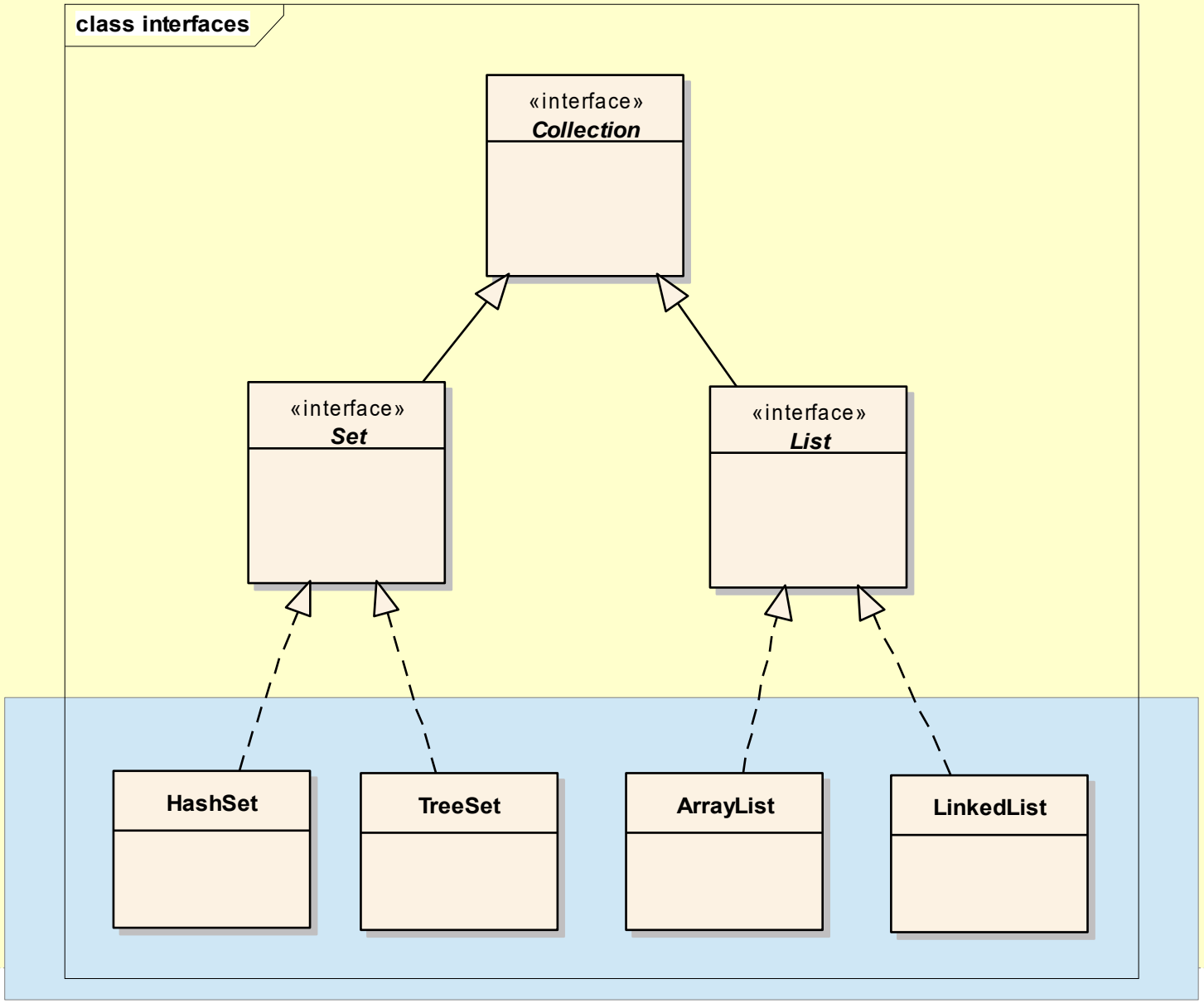
The `Collection` interface



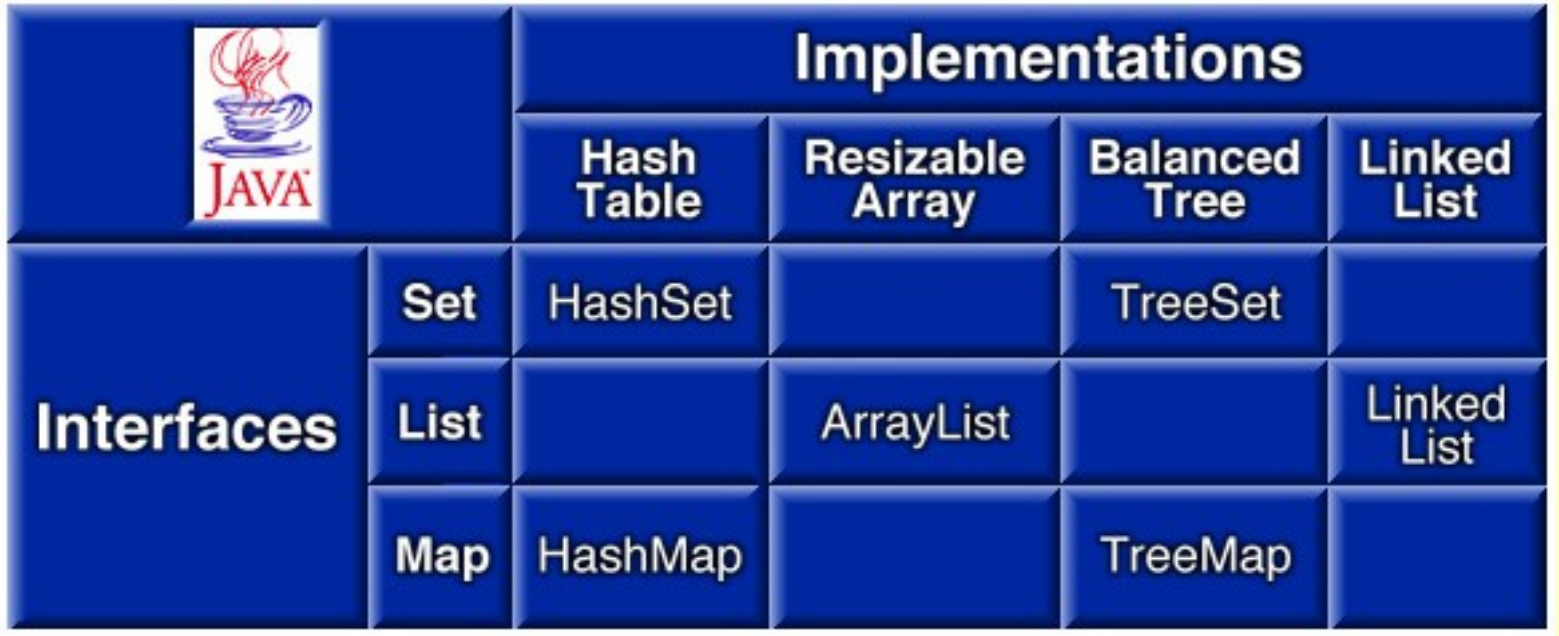
Methods:

- `add(T what): boolean`
- `remove(T what): boolean`
- `size(): int`
- `contains(T what): boolean`
- `containsAll(Collection c): boolean`
- `equals(T what): boolean`
- `iterator(): Iterator`

Implementations

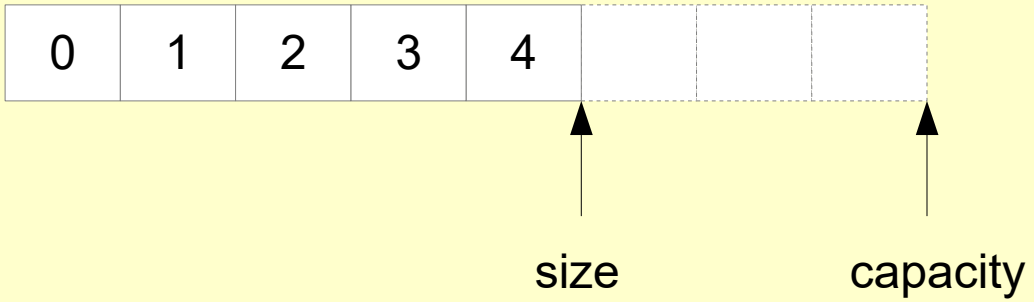


Implementations

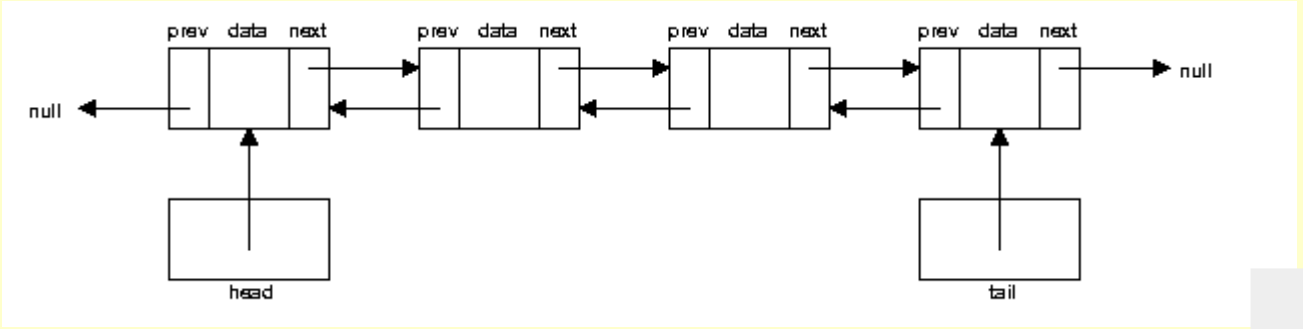


`List` implementations

ArrayList



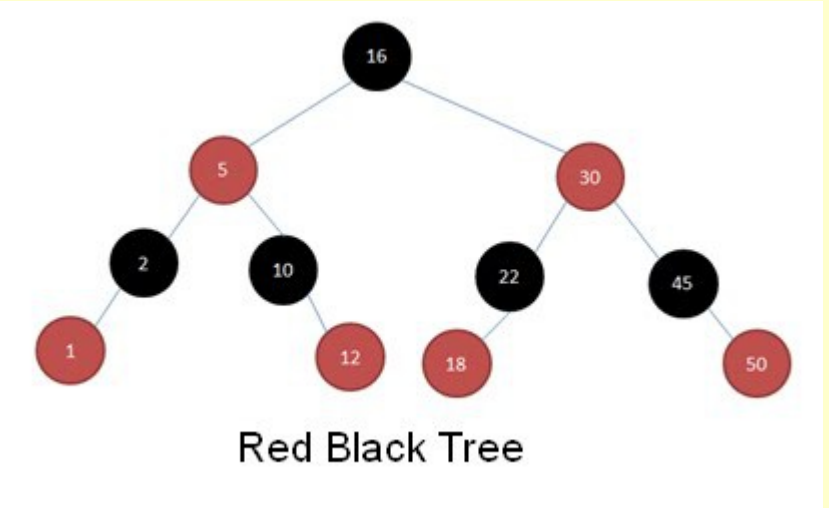
LinkedList



Source

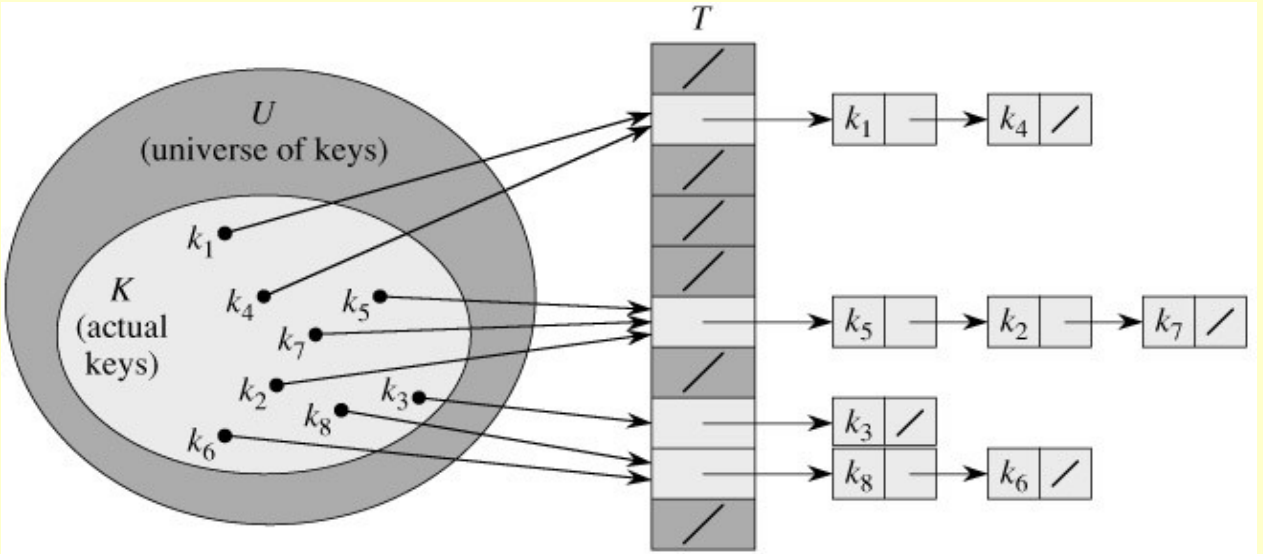
`Set` implementations

TreeSet



Source

HashSet



Source

Ordered vs. sorted collections

- **Ordered**
  - You can iterate through the collection in a specific (not random) order.
  - Each element has a previous and a next element (except the first and the last ones).
- **Sorted**
  - The order is determined according to some rule or rules (**sort order**).
  - Is a specific type of ordering
- **Collections**
  - `HashSet:` unordered and unsorted
  - `List:` ordered but unsorted
  - `TreeSet:` ordered and sorted

Complexities

	add (append)	get (position)	remove	contains
ArrayList	O(1)	O(1)	O(n)	O(n)
LinkedList	O(1)	O(n)	O(1)	O(n)
HashSet	O(1)*	-	O(1)*	O(1)*
TreeSet	O(log n)	-	O(log n)	O(log n)

* in the case of a proper hash function

Traversing Collections

- **There are 3 ways:**

  (1) for-each

  (2) Iterator

  (3) Using aggregate operations (**Java 8**)

Traversing Collections

(1) for-each

```
ArrayList list1 = new ArrayList();
…
for(Object o: list1){
     System.out.println(o);
}
-----------------------------------------
ArrayList<Person> list2 = new ArrayList<>();
…
for(Person p: list2){
 System.out.println(p);
}
```

Traversing Collections

(2) Iterator

```
package java.util;

   public interface Iterator{
      boolean hasNext();
      Object next();
      void remove(); //optional
   }
-----------------------------------------
   public interface Iterator<E>{
      boolean hasNext();
      E next();
      void remove(); //optional
   }
```

Traversing Collections

(2) Iterator

```
ArrayList list1 = new ArrayList();
…
Iterator it1 = list1.iterator();
while(it1.hasNext()){
     System.out.println(it1.next());
}
-----------------------------------------
ArrayList<Person> list2 = new ArrayList<>();
…
Iterator<Person> it2 = list2.iterator();
while(it2.hasNext()){
   System.out.println(it2.next());
}
```

Traversing Collections

(2) Iterator

```
ArrayList list1 = new A
…
Iterator it1 = list1.it
while(it1.hasNext()){
     System.out.println(it1.next());
}
-----------------------------------------
ArrayList<Person> list2 = new ArrayList<>();
…
Iterator<Person> it2 = list2.iterator();
while(it2.hasNext()){
   System.out.println(it2.next());
}
```

An Iterator is an object

- **State:** represents a position in a collection
- **Behavior:** permits to step through the collection

Traversing Collections

(3) Using aggregate operations

Java 8

```
TreeSet<String> dict = new TreeSet<>();
Scanner scanner = new Scanner( new File("dict.txt"));
while( scanner.hasNext()){
    dict.add( scanner.next());
}
System.out.println("SIZE: "+dict.size());
long counter = dict.stream()
                   .filter( e ->
                           e.startsWith("the"))
                   .count();
System.out.println("#words: "+counter);
```

Problems

Which data structure to use?

Problem:

Split a text file into words and print the words in

(1) Increasing order (alphabetically)

(2) Decreasing order

Problems

Which data structure to use?

Problem:

Split a text file into words and print the **distinct** words in

(1) Increasing order (alphabetically)

(2) Decreasing order

Solutions:

(1) `TreeSet<String>`

(2) `TreeSet<String> (Comparator<String>)`

Problems

Decreasing Order

```
TreeSet<String> set = new TreeSet<>();
//...
TreeSet<String> rev = new TreeSet<>(
                      new Comparator<String>(){
   @Override
   public int compare(String o1, String o2) {
      return o2.compareTo(o1);
   }
});
rev.addAll( set );
```

Problem

Which data structure to use?

Problem:

Generate 2D Points having integer coordinates and print them in increasing order. Points are ordered according to their distance to the origin.

Problem

2D Points

```
public class Point implements Comparable<Point>{
    public static final Point origin = new Point(0,0);

    private final int x, y;
    // constructor + getters
    public String toString(){ //...}
    public boolean equals(Object obj){ //...}
    public double distanceTo( Point point ){ //...}

    @Override
    public int compareTo(Point o) {
       double d = this.distanceTo(origin)-o.distanceTo(origin);
       if( d < 0 ) return -1;
       else
          if( d>0 ) return 1;
          else return 0;
    }
}
```

Problem

2D Points

Discussion!

```
public class Point implements Comparable<Point>{
    public static final Point origin = new Point(0,0);

  TreeSet<Point> points1 = new TreeSet<>();
  // OR
  ArrayList<Point> points2 = new ArrayList<>();
  Collections.sort(points2);

    @Override
    public int compareTo(Point o) {
       double d = this.distanceTo(origin)-o.distanceTo(origin);
       if( d < 0 ) return -1;
       else
          if( d>0 ) return 1;
          else return 0;
    }
}
```

Problem

Generate randomly **N = 1.000.000** (one million) **distinct** bidimensional points (x, y) having positive integer coordinates (**0 ≤ x ≤M, 0 ≤ y ≤ M, M ≤ 1.000.000**).

Requirements:

- Optimal solution is required.
- Print the number of duplicates generated.

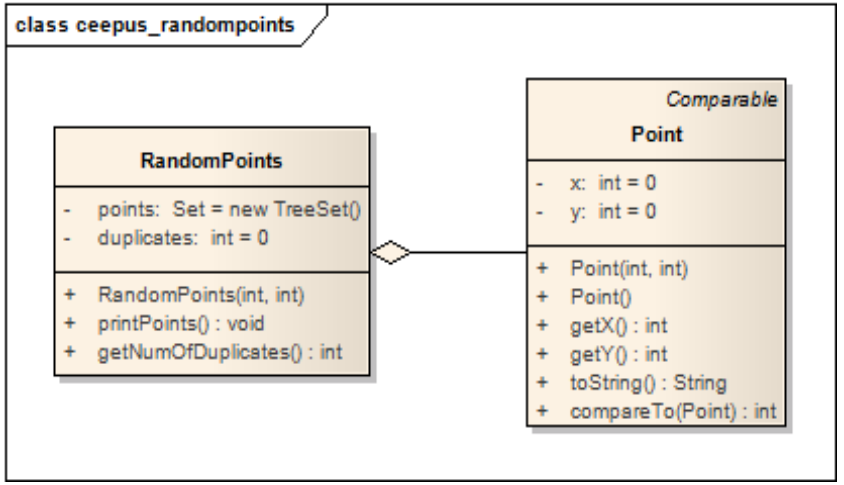
Which collection to use?

Hint: Finding an existing element must be fast.

Problem

1. solution - TreeSet

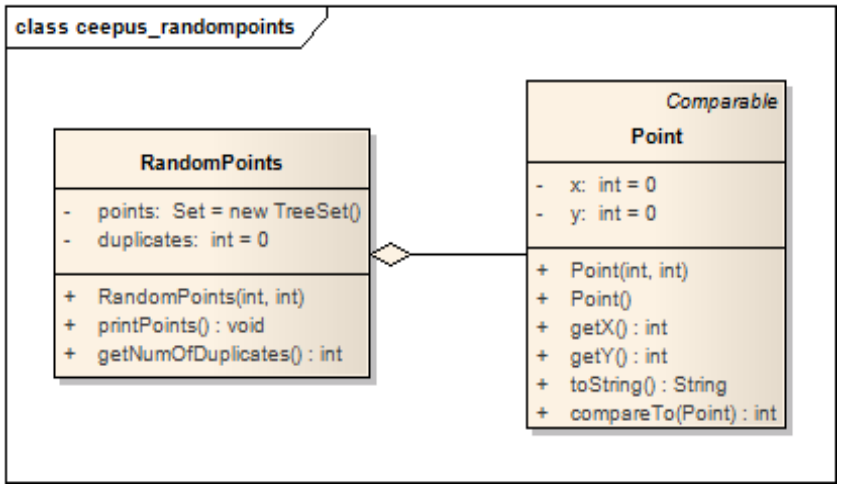
```
public class Point implements
                    Comparable<Point> {
   ...
    @Override
    public int compareTo(Point o) {
        if( o == null ) throw
           new NullPointerException();
        if (this.x == o.x &&
            this.y == o.y){
            return 0;
        } else
            if( this.x  ==  o.x){
                return this.y - o.y;
            } else{
                return this.x - o.x;
            }
   }
}
```



Problem

1. solution - TreeSet

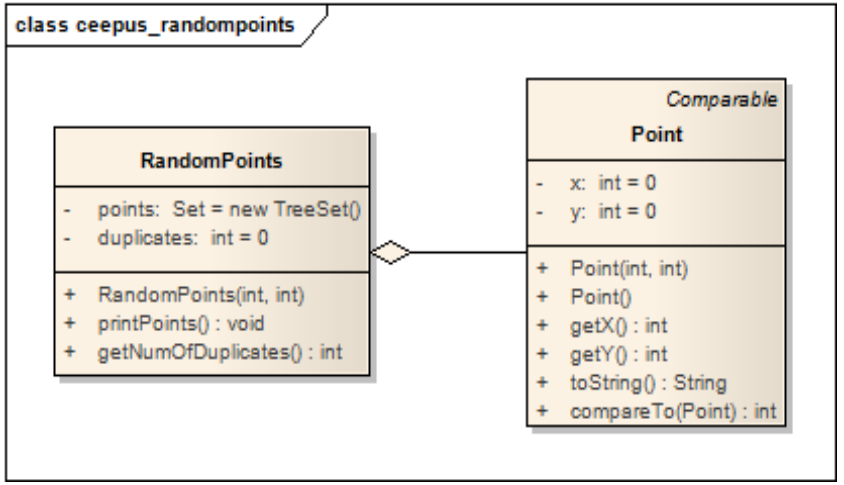
```
public class RandomPoints {
    private TreeSet<Point> points =
                    new TreeSet<Point>();
    private int duplicates = 0;

    public RandomPoints( int size,
                         int interval){
        int counter = 0;
        Random rand = new Random(0);
        while( counter < size ){
            int x =
Math.abs(rand.nextInt() % interval);
            int y =
Math.abs(rand.nextInt() % interval);
            Point p = new Point(x,y);
            if( points.contains( p )){
               ++duplicates;
               continue;
            }
            ++counter;
            points.add(p);
        }
    }
    …
}
```



Problem

1. solution - TreeSet

```
public class RandomPoints {
    private TreeSet<Point> points =
                    new TreeSet<Point>();
    private int duplicates = 0;

    public RandomPoints( int size,
                         int interval){
        int counter = 0;
        Random rand = new Random(0);
        while( counter < size ){
            int x =
Math.abs(rand.nextInt() % interval);
            int y =
Math.abs(rand.nextInt() % interval);
            Point p = new Point(x,y);
            if( points.contains( p )){
               ++duplicates;
               continue;
            }
            ++counter;
            points.add(p);
        }
    }
    …
}
```



TreeSet

- Finding an element: O(log n)

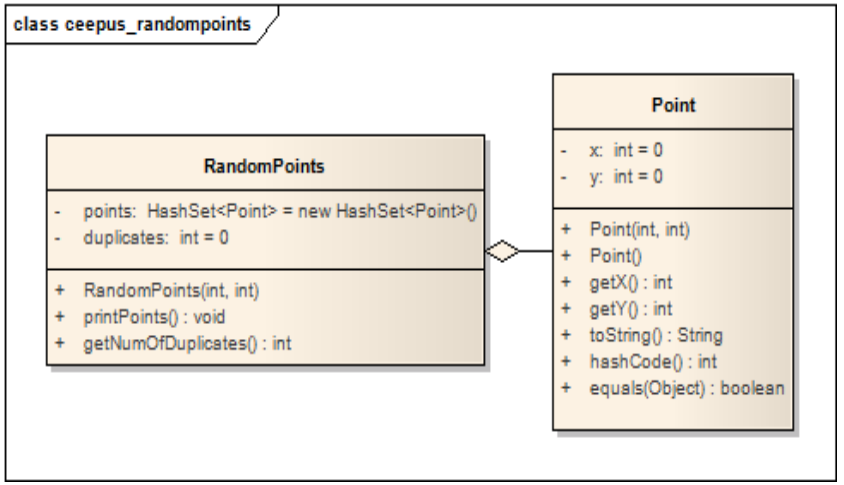
Implementation

Random number generator: seed = 0
N = 1.000.000
M = 10.000
Duplicates: 4976
Time: **approx. 3s**

Problem

2. solution - HashSet

```
@Override
public int hashCode() {
   int hash = (x *31)^ y;
   return hash;
}

@Override
public boolean equals(Object obj) {
   if (obj == null) {
     return false;
   }
   if (getClass() != obj.getClass()) {
           return false;
   }
   final Point other = (Point) obj;
   if (this.x != other.x) {
           return false;
   }
   if (this.y != other.y) {
           return false;
   }
   return true;
}
```



HashSet

- Finding an element: O(1)

Implementation

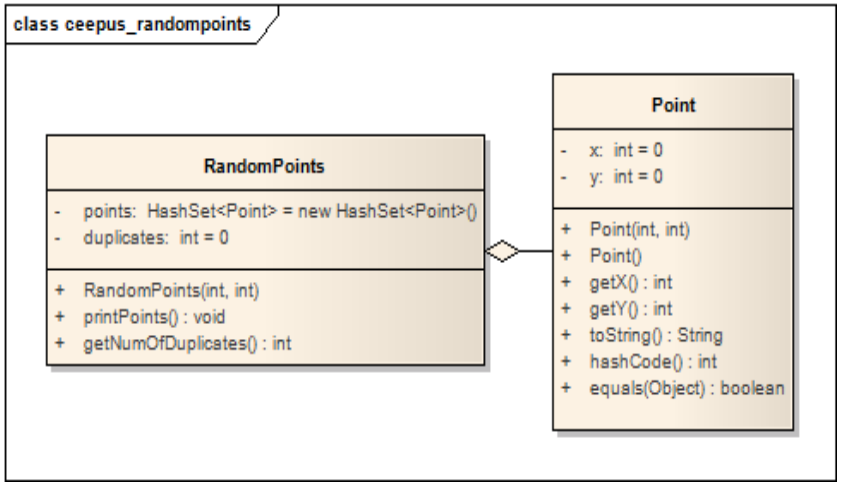
Random number generator: seed = 0
N = 1.000.000
M = 10.000
Duplicates: 4976
Time: **approx. 1 s**

Problem

2. solution - HashSet

```
@Override
public int hashCode() {
   int hash = (x *31)^ y;
   return hash;
}

@Override
public boolean equals(Object obj) {
   if (obj == nu ll) {
     return fals e;
   }
   if (getClass    != obj.getClass()) {
           retu  false;
   }
   final Point o    r = (Point) obj;
   if (this.x !=    er.x) {
           retur    lse;
   }
   if (this.y !
           r
   }
   return tr
}
```

What happens if we don't override equals?
How many duplicates?



HashSet

- Finding an element: O(1)

Implementation

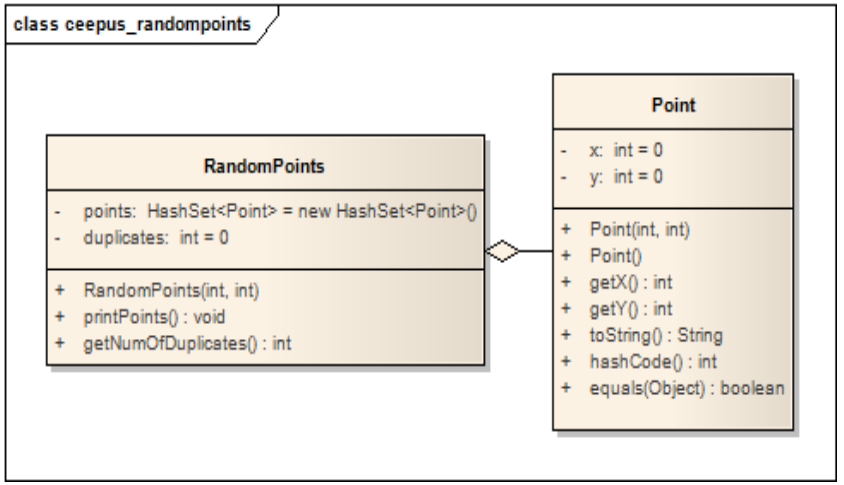
Random number generator: seed = 0
N = 1.000.000
M = 10.000
Duplicates: 4976
Time: **approx. 1s**

Problem

2. solution - HashSet

```
@Override
public int hashCode() {
   int hash = 1;
   return hash;
}

@Override
public boolean equals(Object obj) {
   if (obj == null) {
      return false;
   }
   if (getClass() != obj.getClass()) {
         return false;
   }
   final Point other = (Point) obj;
   if (this.x != other.x) {
         return false;
   }
   if (this.y != other.y) {
         return false;
   }
   return true;
}
```

What happens?



Problem

2. solution - HashSet

The **`hashCode()`** contract:

- each time invoked on the same object must return the same value (consistent, can't be random)
- if **`x.equals(y) == true`**, then
  `x.hashCode() == y.hashCode()` must be true
- It is legal to have the same hashcode for two distinct objects (collision)

Problem

3. solution

Which collection to use if $M \leq 2000$

Hint: Which is the fastest access time of an element in a collection?

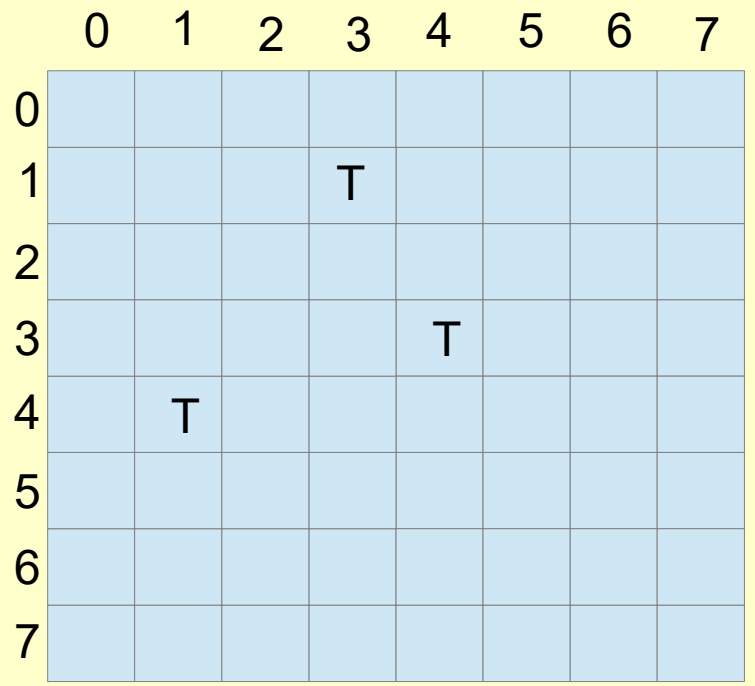
Problem

3. solution

Which collection to use if **M ≤ 2000**

Hint: Which is the fastest access time of an element in a collection?

```
private boolean exists[ ][ ] = new boolean[ M ][ M ];

public RandomPoints( int size, int interval){
  int counter = 0;
  Random rand = new Random(0);
  while( counter < size ){
    int x = Math.abs(rand.nextInt() % interval);
    int y = Math.abs(rand.nextInt() % interval);
    Point p = new Point(x,y);
    if( exists[ x ][y ]){
      ++duplicates;
      continue;
    }
    ++counter;
    exists[ x ][ y ] = true;
  }
}
```



Problem

3. solution

Which collection to use if $M \leq 2000$

Hint: Which is the fastest access time of an element in a collection?

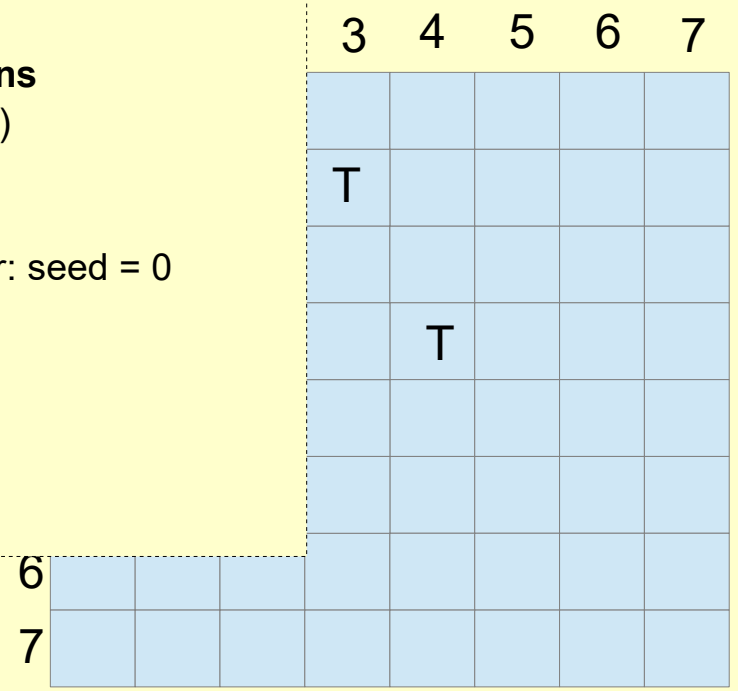
```
private boolean exists[ ][ ] = new boolean[ M ][ M ];

public RandomPoints(
  int counter = 0;
  Random rand = new
  while( counter < s
    int x = Math.abs
    int y = Math.abs
    Point p = new Po
    if( exists[ x ][
      ++duplicates;
      continue;
    }
    ++counter;
    exists[ x ][ y ] = true;
  }
}
```

Bidimensional array of booleans

- Finding an element: O(1)

Implementation

Random number generator: seed = 0
N = 1.000.000
M = **2000**
Duplicates: 150002
Time: **approx. 0.2 s**



Map

Interface

```
interface Map<K, V>
```

- **K** – Key type
- **V** – Value type

interface **Map.Entry<K,V>**
(Key, Value) pair

Maps keys to values.

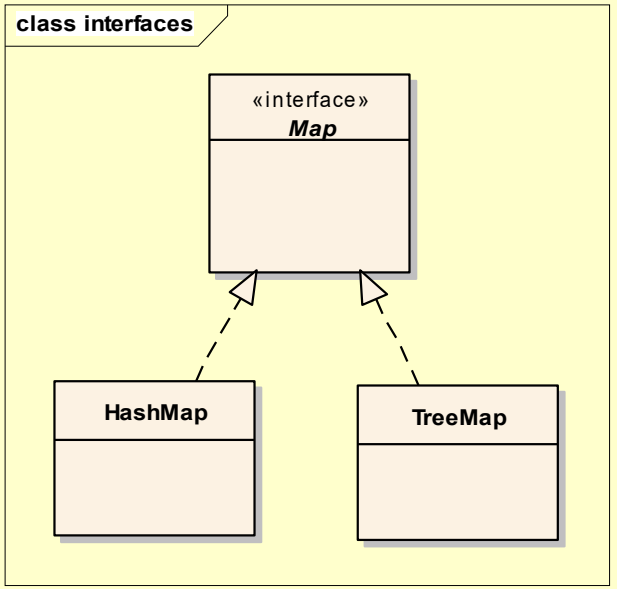
Examples:

Key: country, **Value**: capital city

- Slovenia → Ljubljana
- Austria → Vienna
- Hungary → Budapest
- Romania → Bucharest

Map

Implementations



HashMap: unordered, no duplicates

TreeMap: ordered by key, no duplicates

	get	put	remove
TreeMap	O(log n)	O(log n)	O(log n)
HashMap	O(1)*	O(1)*	O(1)*
* in the case of a proper hash function			

Problem

Which data structure to use?

Problem:

Compute the word frequencies in a text. Print the words and their frequencies:

(1) alphabetically,

(2) in decreasing frequency order.

Problem

Solution (1) alphabetically

```
class MyLong {
    private long value;
    public MyLong(int value) { this.value = value;}
    public long getValue() { return value;}
    public void setValue(long value) { this.value = value;}
    public void increment() { ++value;}
}

//...
TreeMap<String, MyLong> frequency = new TreeMap<>();
```

Problem

Solution (2) decreasing frequency order

```
class Pair {
    private String word;
    private long fr;
    // constructor + get and set methods
}


ArrayList<Pair> list = new ArrayList<Pair>();
for (String key : frequency.keySet()) {
   long value = frequency.get(key).getValue();
   list.add(new Pair(key, value));
}
Collections.sort(list, new Comparator<Pair>() {
   @Override
   public int compare(Pair o1, Pair o2) {
      return (int) (o2.getFr() - o1.getFr());
   }
});
```

Problem

Which data structure to use?

Problem:

Find the anagrams in a text file!

Problem

Which data structure to use?

Problem:

Find the anagrams in a text file!

Solution:

- Split the text into words
- Alphabetize the word
  - sent → ens
  - nest → ens
  - tens → ens
- `Map<String, List<String> >` vs. `Map<String, Set<String> >`
  - Key: alphabetized word → String
  - Value: words → `List<String>` or `Set<String>`

Problem

Anagrams

```
Map<String, Set<String> > groups = new HashMap<>();
//...

String word = cleanWord(word);
String key = alphabetize(word);
// Find the key
Set<String> group = groups.get(key);
if (group == null) {
    Set<String> newGroup = new HashSet<String>();
    newGroup.add(word);
    groups.put(key, newGroup);
} else{
    group.add(word);
}
```

Problem

Anagrams

```
Map<String, Set<String> > groups = new HashMap<>();
//...

private void printGroups(int size) {
    for (String key : groups.keySet()) {
        Collection<String> group = groups.get(key);
        if (group.size() == size) {
            System.out.print("Key: " + key + " --> ");
            for (String word : group) {
                System.out.print(word + " ");
            }
            System.out.println();
        }
    }
}
```