Programming Software Systems

Introduction to Programming for the Computer Engineering Track

Lecture 5 + Tutorial 5
An Introduction to Java

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Innopolis University

The Overall Structure of the Course

Three main parts of the course

- **The C language**

  Small, system-level (but still general-purpose) language

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  Powerful application language

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  Fast and powerful general-purpose language **with deep semantics**

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- Some basic principles behind them often are very much similar!

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If so, you will be able to learn a new language in one week.

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  => You shouldn't learn just a language – learn principles!
  If so, you will be able to learn a new language in one week.
- However, **the more languages you know the better** ☺.
  A software professional **must** know several programming languages.

How Many Languages to Learn?

There are many texts saying something like:

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```

C++? – yes
Java? – yes
C#? – yes!

The same syntax & semantics in all languages

C++?
=========
Java?
C#?

Different semantics for C++ and for Java/C#

How Many Languages to Learn?

- This part of the course is based on the **Java language**.
  This doesn't mean it is *the best PL* over the world of programming…
- Later at Innopolis (and in your further professional career!) you will have to learn **many other PLs**. Be prepared and don't be afraid of it.

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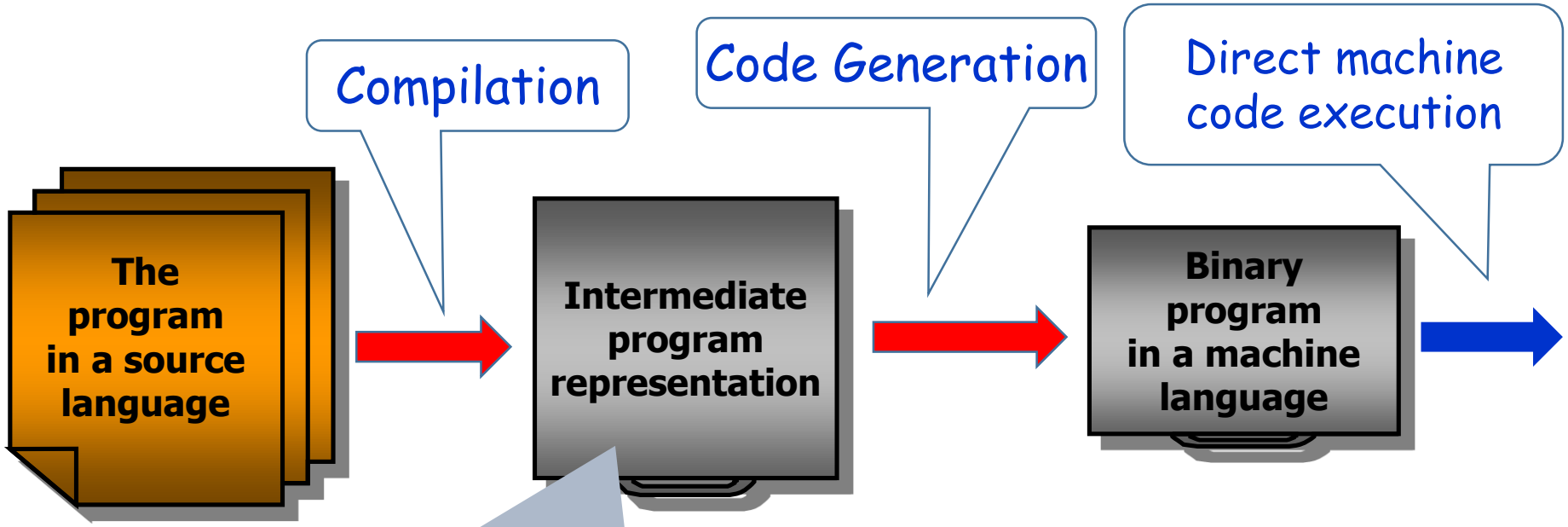
  - ***C#*** very similar to Java but is evolving much faster
  - ***C++*** the most powerful and complicated language ever
  - ***C*** middle-level language; "the (god)father" of many current PLs
  - **Javascript** for Web programming (is not similar to Java!!)
  - **Swift** Apple's alternative to Java/C#/C++/Objective C
  - **Go** Google's product for server-side programming
  - **Scala** Powerful extension of Java with functional programming
  - **Python** Dynamic language for scripting and application programming
  - **Eiffel** Systematically designed "contract based" OOP language
  - … *Many-many-many other languages*

The Plan for Today

- Program compilation & execution:
  - Conventional model
  - The Java model
- Memory model: code, stack & heap
- The structure of Java programs
- A gentle introduction to OOP
- The notion of class (without OOP ☺)

Compilation & Execution: Conventional Model

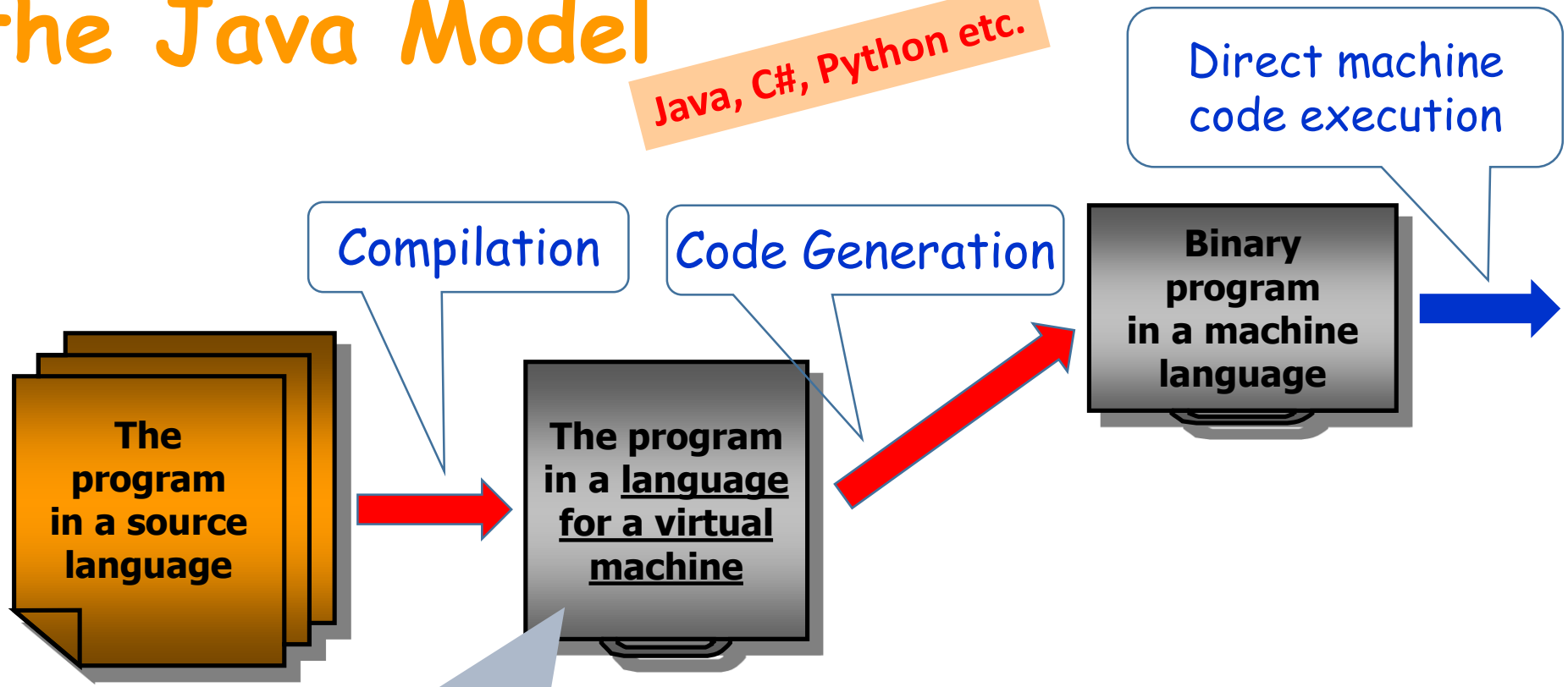
Pascal, C/C++, Eiffel, Go etc.



- Regular representation; only for internal purposes
- Low-level and semantically poor representation
- Targeted mainly to generate machine code for real hardware

Compilation & Execution: the Java Model

Java, C#, Python etc.



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- Portable & compact code transferring over network
- Similar to code for real hardware: kind of «generic assembler language»

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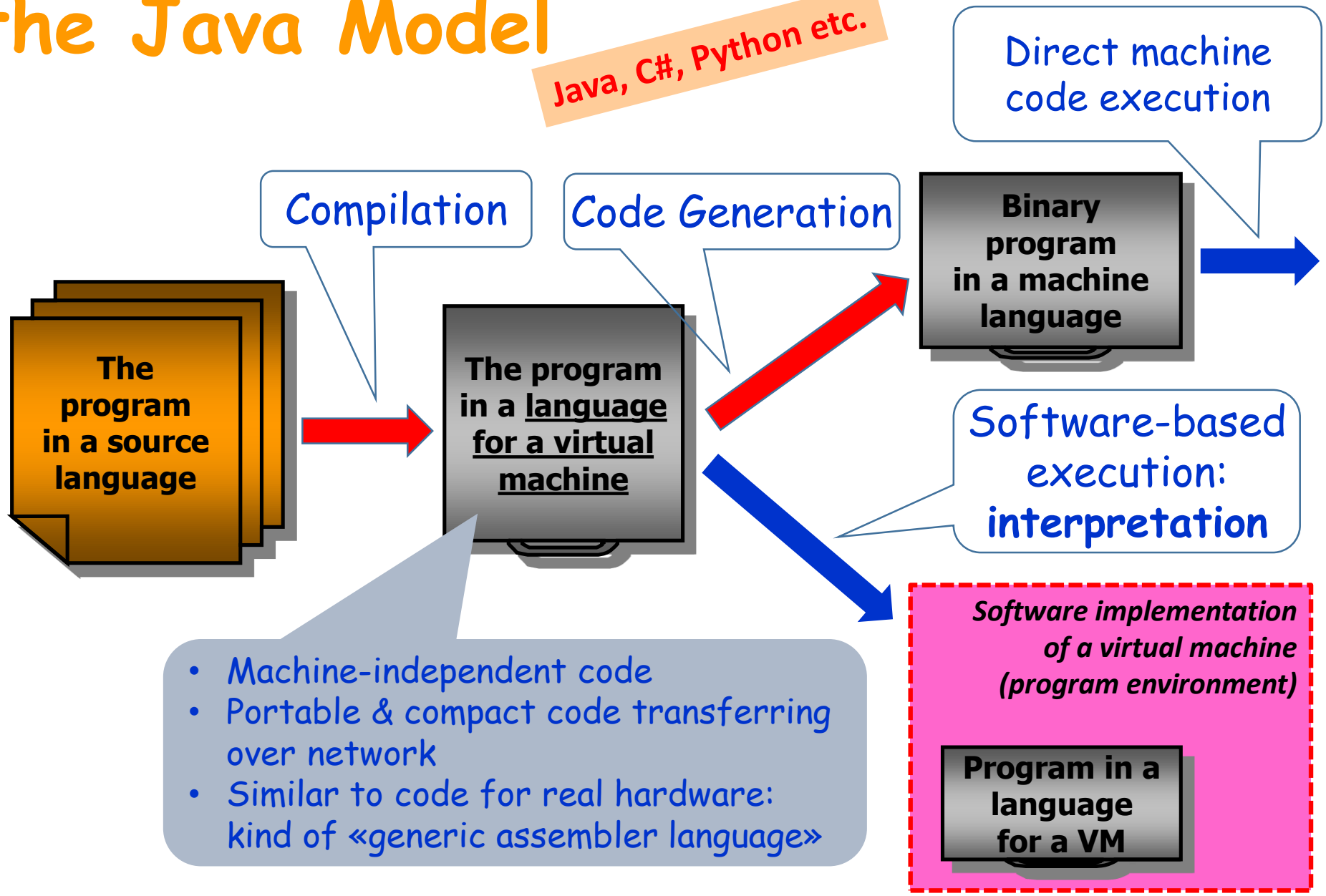

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- Interpretation
- Just-in-time compilation (JIT)
- Ahead-of-time compilation (AOT)

Java Virtual Machine (JVM)

- Java programs get compiled not to machine code for a particular hardware architecture, but to code for some **hypothetical** (**abstract**, **virtual**) computer.
- This "computer" (actually, system software) has all architectural features of a real computer: a "CPU" with instruction set, with memory, registers etc.
- Such a "computer" is called **virtual machine**. Instructions being executed by this virtual machine are called **bytecode**.

Java Slogan:

Write once – run everywhere

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Java Slogan:

Java Virtual Machine: Major Features

- Hardware independence
  - however, rather "close" to real machines
- **Stack-based execution model**
  - not only function calls, but expression calculations as well
- Rather high level of the instruction set
  - high-level function call mechanism; exception mechanism is supported; rather compact code
- Advanced code structure;
  - constants, metadata (!), debug information
- Open format:
  - complete & detailed documentation

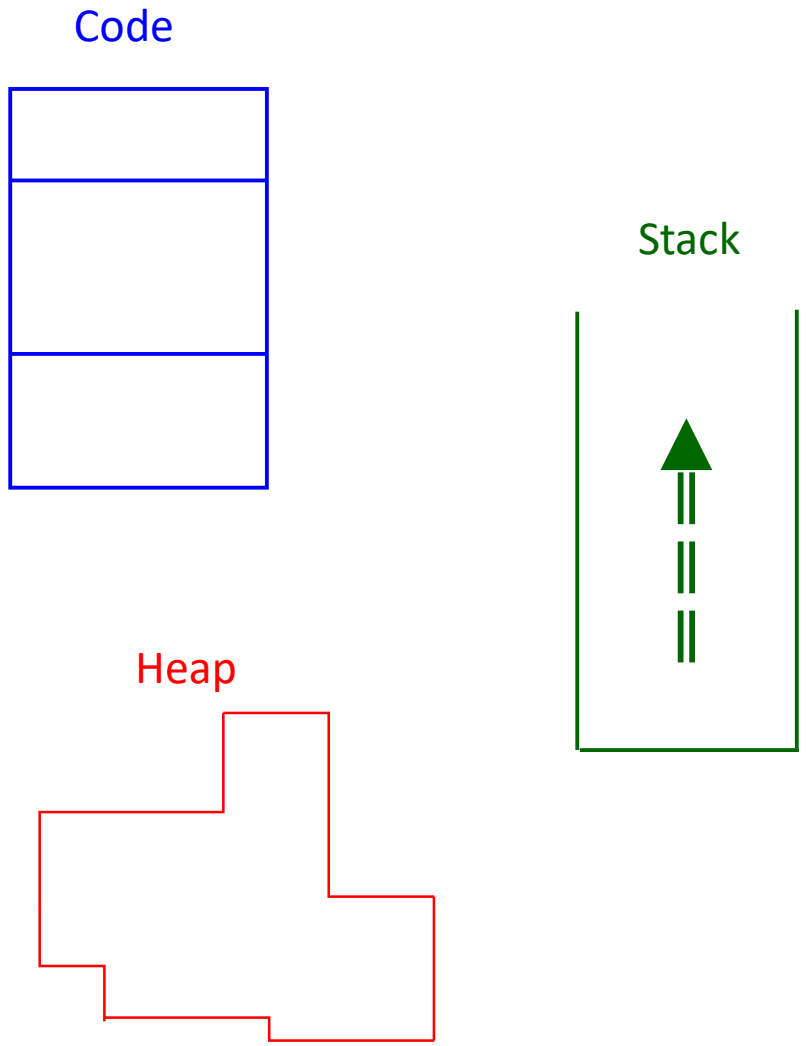
Memory Model

There are different models of the program execution. In the model we use, when started, program is assigned **three separate and independent portions of memory** (referred to as address space of a running program - aka process). These are:

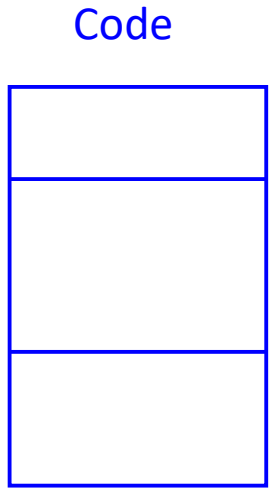
- **Code** area
  - where code to be executed is loaded & stored
- **Stack** (or **execution stack**)
  - used to perform computation,
  - store local variables and
  - perform function call management
- **Heap**, or dynamic memory area
  - used to store variables and objects allocated dynamically

Memory Model

- The code and the heap area can be accessed with no special restrictions
- The stack area is accessed using a **LIFO (Last In – First Out)** policy
- The most languages are "stack-based"

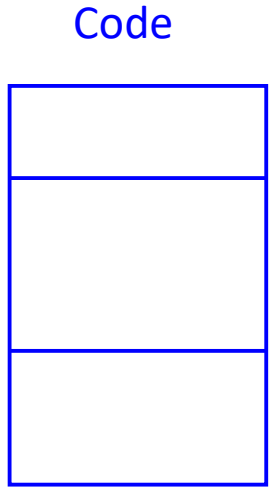


Memory Model & Management: Code



- ***C, C++***
  - We can assume that the **entire code** is loaded in the code area (neglecting issues like dynamic linking…)
  - **stack** is managed by the hardware (if possible)
  - **heap** is managed by run-time support software (OS)

Memory Model & Management: Code



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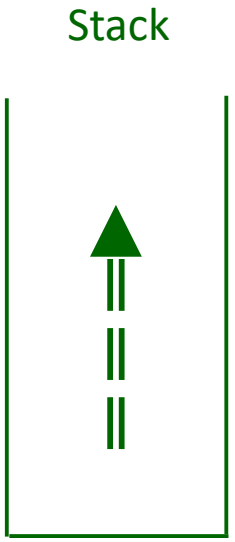
- **Java**
  - code is loaded on the **class-by-class** basis: the execution (actually, the JVM) proceeds loading and running new classes when the need arises, according to the flow of the computation

    The first class to be loaded is a special class containing the static "main" method (will consider it later)
  - **stack** & **heap** are managed by the JVM

Memory Model: Stack



- In most modern languages (including Java) the execution is centered around the **execution stack**.
- All algorithms are organized into functions (sometimes called procedures, methods, routines etc.)
- The order of execution of functions is LIFO, i.e. the last function called is the first to terminate (this behavior is obtained using the stack)

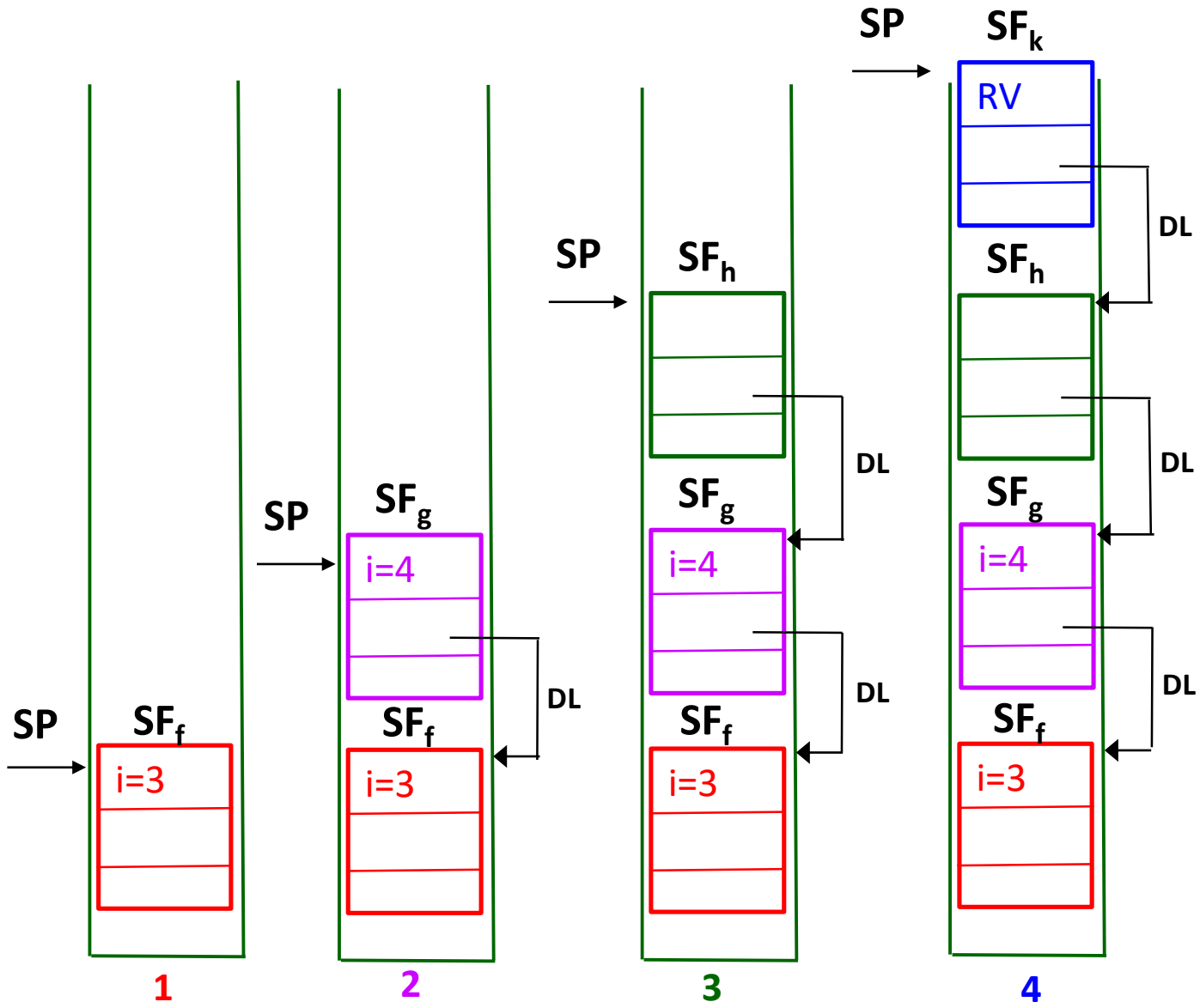
Typical operations on stack:
push, pop, empty

Memory Model: Stack for Function Calls

Call chain

```
void f() {
    int i = 3;
    g();
}
void g() {
    int i = 4;
    i = i + h();
}
int h() {
    return 1 + k(5);
}
int k(int z) {
    return z+1;
}
```

Return chain



Memory Model: Stack for Function Calls

- Each time a function is called, **all the information specifically needed for the function** execution are put on the stack (function call arguments, local variables, reference to the information about the previously called function etc.).
- That information is collectively called the **stackframe** of the function call.
- This allows recursion, since for each call there will be a separate activation record on the stack.
- When the call is completed (the function "returns") the corresponding AR is destroyed ("popped out" of the stack).
- Activation records are organized from bottom to top in memory diagram (see the prev. slide).

The Structure of Java Programs

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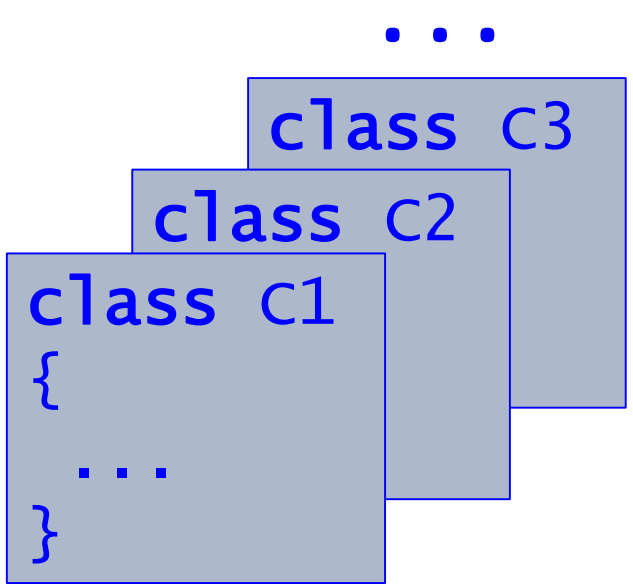
- **Class** is the main program building block, and the key notion of **object-oriented programming**
- In general, class has many important features (*later we will consider them all carefully*), but all you have to know *for today* is:

Class is a language construct comprising **algorithms** (in form of **functions**) and **data** the algorithms work on

Simplified!

The Structure of Java Programs



Program:
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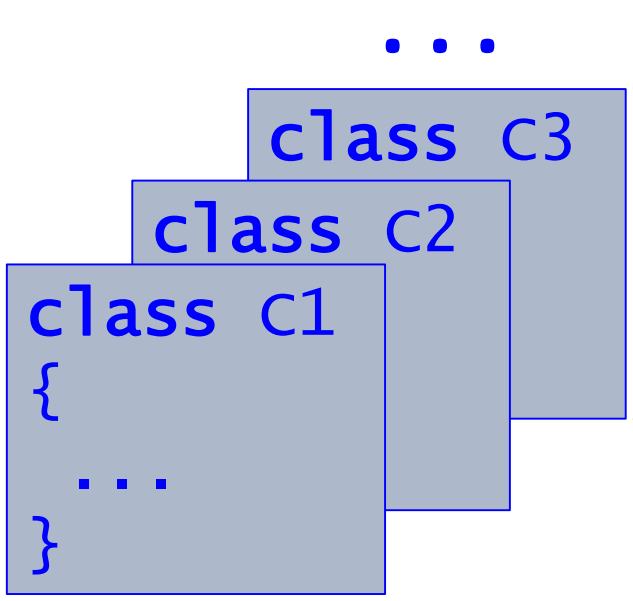

Program:
collection of classes

```
class C3
{
  int a, b, c;
  ...

  void f1()
  { working with a }

  int f2()
  { working with b, c }
    ...
}
```

Class:
collection of data & functions

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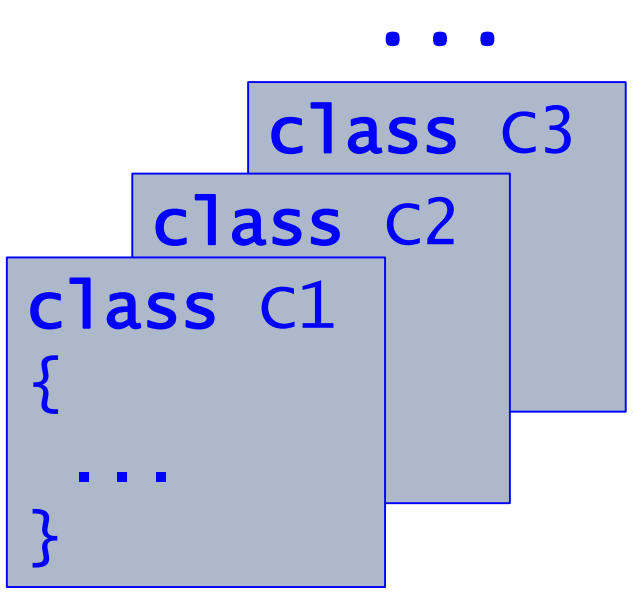

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For comparison:
How it is in *C*

```
struct C3
{
   int a, b, c;
};
 ...

void f1(C3* c)
{ ... }

int f2(C3* c)
{ ... }
```

OOP: Origins & Present

Simula-67 (based on Algol-60):

The concept of **class**

Smalltalk: "Pure" OOP: its features are centered around the notions of class and object

Classes & **message passing**

C++: "Hybrid" language: it mixes typical OO features with those typical to classic imperative, stack-based languages (like C, Ada, Pascal)

OOP as industry-level technique

Java: "Pure" OOP: its features are centered around the notions of class and object

OOP worldwide

Object-Oriented Approach

Basic idea

- A computer program is a **model** (reflection, representation) of a (part of the) **real world**, or of an application domain.

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- The real world consists of a set of related and communicating **objects**.
- Therefore, to create an adequate model of the real world we need a means that would reflect/represent objects of the world, and their relationships.
- There are a lot of various and different **kinds of objects** in the real world; the set of objects is (potentially) **infinite**.
- Therefore, we need a mechanism that could **uniformly** represent the structure and behavior of the all objects.

What is Class?

Bjarne Straustrup:

Класс непосредственно выражает некое понятие в программе. Класс – это тип, определённый пользователем. Он определяет, как представляются объекты этого класса, как они создаются, используются и уничтожается.

Если вы размышляете о чём-то как об отдельной сущности, то вполне возможно, должны определить класс, представляющий эту «вещь» в программе.

Примерами [*классов*] служат вектор, матрица, поток ввода, строка, быстрое преобразование Фурье, **клапанный регулятор**, **рука робота**, драйвер устройства, рисунок на экране, диалоговое окно, график, окно, **термометр**, **часы**.

Programming Principles and Practice Using C++

Classes & Objects

Class declaration

Compile time
entity

Class specifies a pattern (a template, an example) for creating real entities of the class: they are called instances, or objects of the class.

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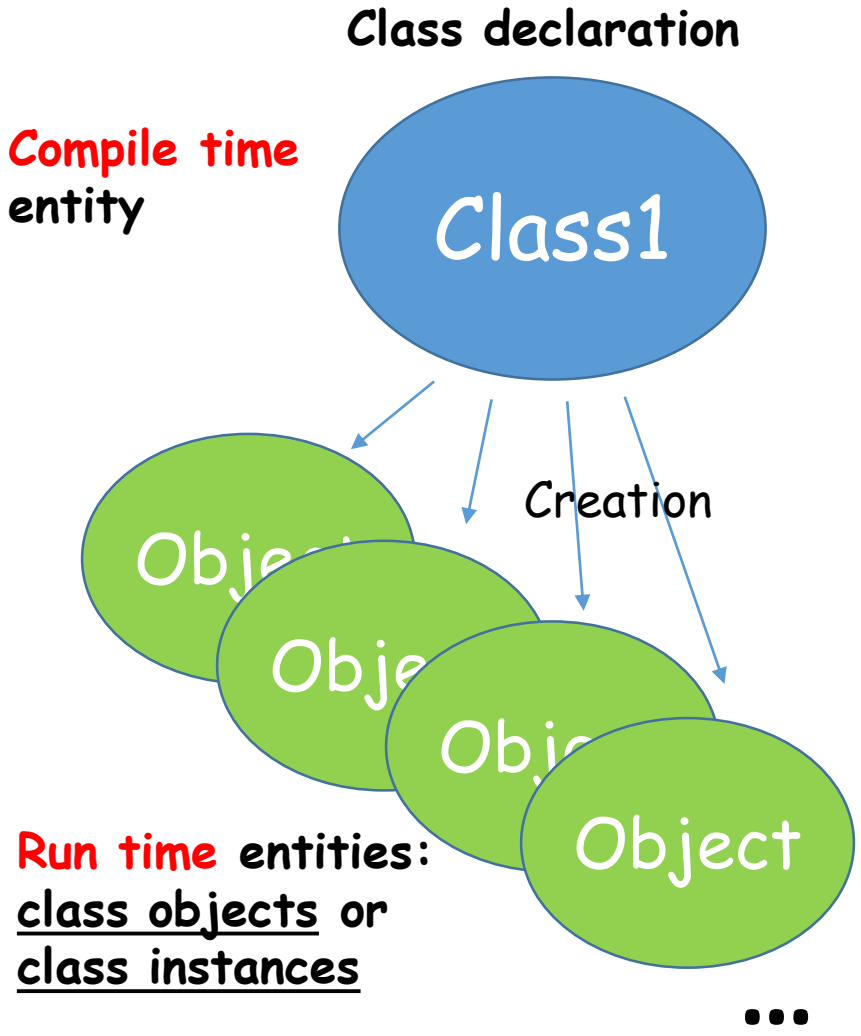

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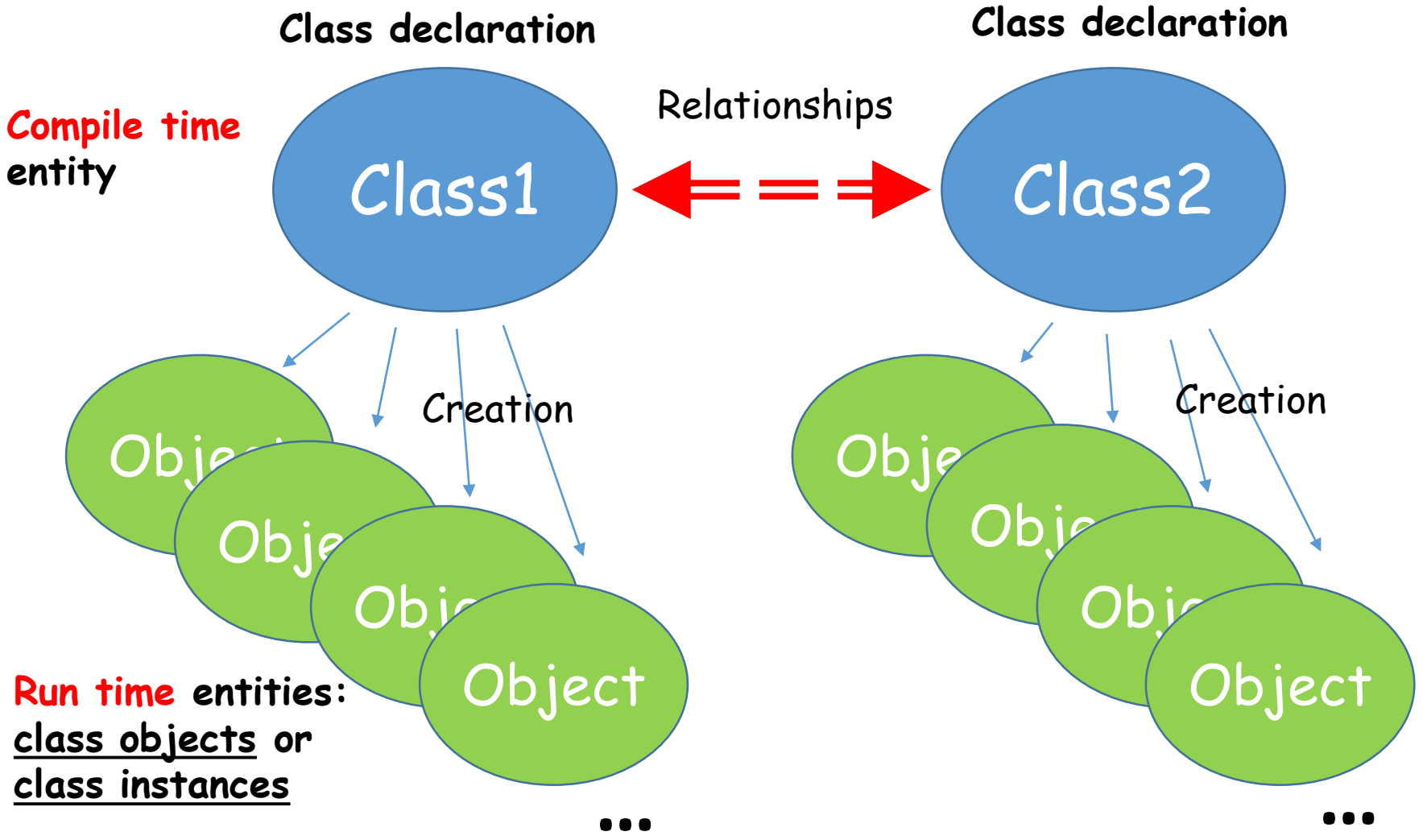

Classes & Objects

- A class represents the general properties as well as the structure shared by a group of entities: the **instances** (or **objects**) of that class.
- An object is **an instance of a class**, a class *in action*.
- Object is a particular entity, which shares the general structure and behavior with all the other instances of the class it belongs to.
- Conceptual relationship between classes and objects is similar to that which exists between an **abstract idea** and a **concrete example of it**.
  - e.g. the idea of dog and a particular dog Rex
  - e.g. the idea of a point and real points composing a picture
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Role of Classes in Software Development

- Classes are **units of data abstraction**
  - Each class should, ideally, define a unique and cohesive behavior, with limited coupling to other classes
- Classes are **units of interaction**
  - In "pure" object oriented languages, the task of a program is accomplished by objects (instances of classes) interacting among themselves
- Classes are **units of development**
  - Classes are assigned to programmers for development and to testers to test
- Classes and objects may also be used as **units of requirement and planning**
  - Agile methods develop user stories with interacting objects to negotiate with the customers the work to do
  - new planning techniques use objects counts to estimate effort

The First Class Example

- So.. I want to create a program drawing figures on the screen.
- I know that figures are to be composed from lines/curves – and the latter consist of points.
- Therefore, the notion of **point** will be the basic notion in my program.

```
class Point
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- Each point is characterized, first of all, by its coordinates, say, x and y. These coordinates are primary **features** or **properties**, or **attributes** of each point.
- Also, I would like to perform some **operations** on points: for example, to move it to a new position.
- …

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

    void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

Class Example

Class is a (user-defined) **type**

In general, class should **completely specify all aspects** of objects that are created by this class:

- The **state** of class objects
- The **behavior** of class objects
- The way of **creating** objects
- The way of **destroying** objects (when/if they are not needed anymore)
- **Relationships** between this object and other objects of the same class or of some other class(es)

Class declaration specifies *pattern*. Objects will be created using this pattern.

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```

Objects

To conclude:

- Objects are created (occur) & destroyed (disappear) **dynamically** while program execution.
- Objects have a **state**, i.e., have data stored in memory. The state "structure" is the same but values can be different.
- Objects have a "**behavior**", i.e., they are "machines" offering operations (features, methods). Different objects always have **the same** set of operations.
- Objects are in some **relations** with other objects of the same class or with objects of some other class(es).

For example, objects can compose **arrays**, or can be parts of other objects – will see later

Objects: How to Create

- Creation (instantiating) an object means creating an object of a given class.
- There is a special operator in Java for creating objects: **new**.

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new Point()
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What's **semantics** of the **new** operator?

- **Memory is allocated** to keep the current state of the new object (for x and y in our example).
- The memory is allocated **in the heap**.
- State of the object **is initialized** by some default values.
- The result of the operator is the **reference** to the object.

Objects and References

```
class Point
{
    int x, y;
    void move(int dx, int dy)
    {
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}
...
class OtherClass
{
    void f()
    {
        Point p = new Point();
        ...
    }
}
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- The object just created by **new** **doesn't have a name**.
- In order to use it we have to **assign** the result of **new** to an object of type `Point`.
- Now we can work with the new object **by using the reference to it**.

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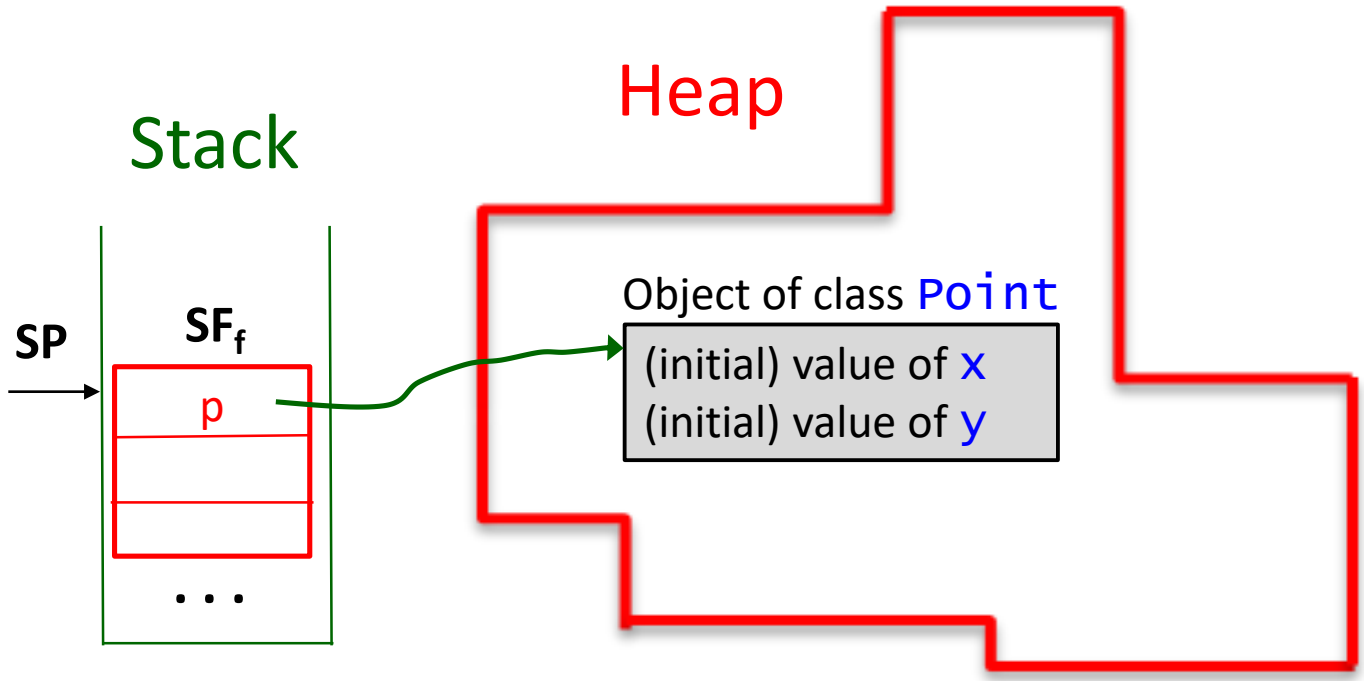

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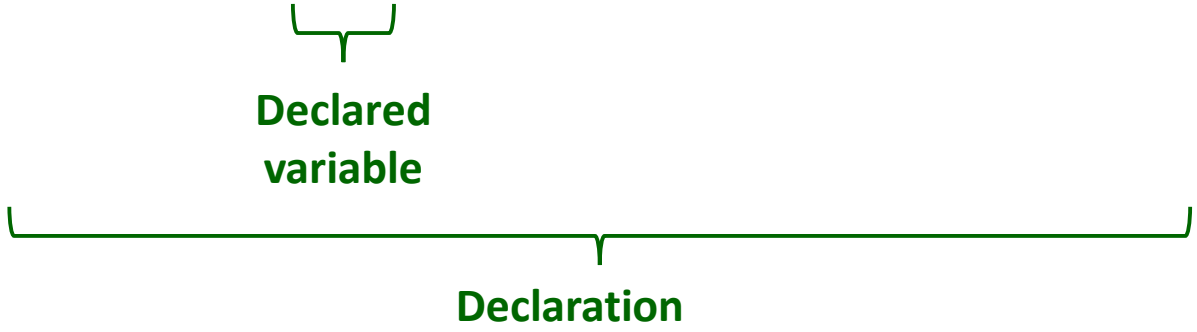

- This is the **declaration**. The variable p is declared.

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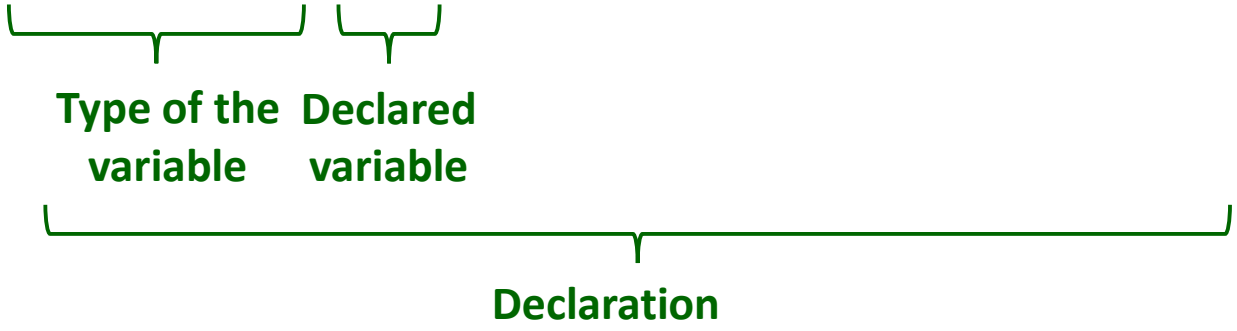
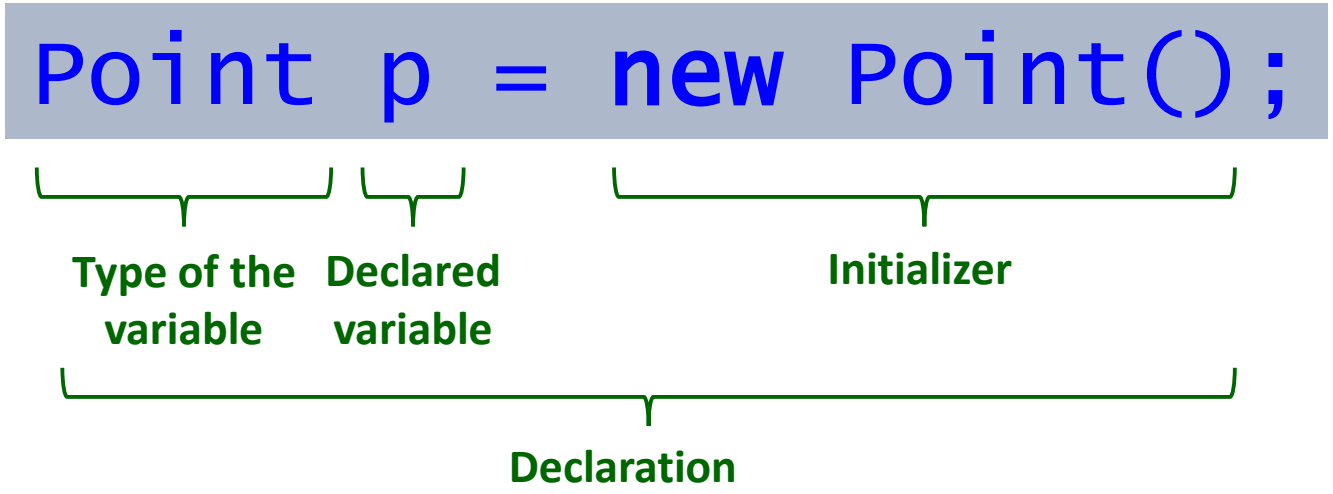
Point p = new Point();
```



- This is the **declaration**. The variable `p` is declared.
- The type of `p` is class type `Point`. This means that `p` can refer to an object of type `Point`.

Objects and References



- This is the **declaration**. The variable `p` is declared.
- The type of `p` is class type `Point`. This means that `p` can refer to an object of type `Point`.
- The declaration contains **initialization**. This means that the initial value of `p` is the value of the expression after `=`. The value of the expression is the result of the unary **`new`** operator, i.e., the reference to the object of class `Point` just created.

Value and Reference Types

- There are two categories of types in Java: **value types** and **reference types**.

  Examples of value types: integers, floating, doubles. Values of these types are represented directly:

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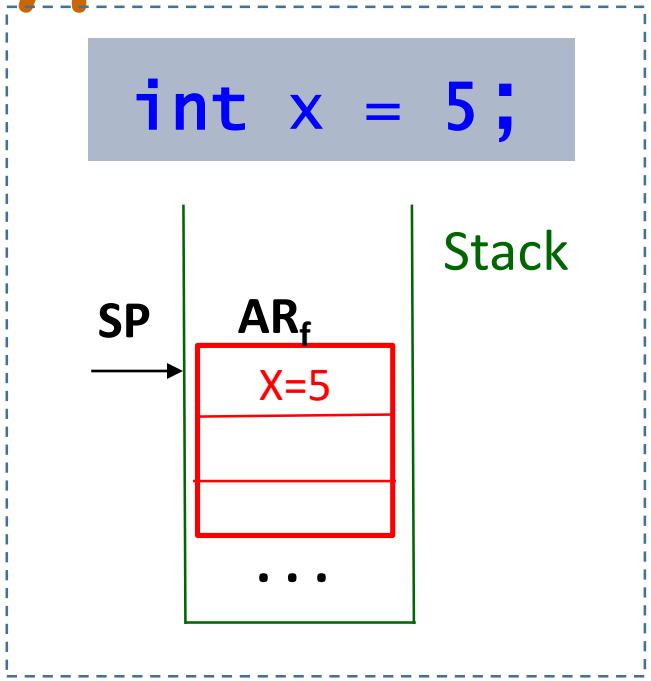
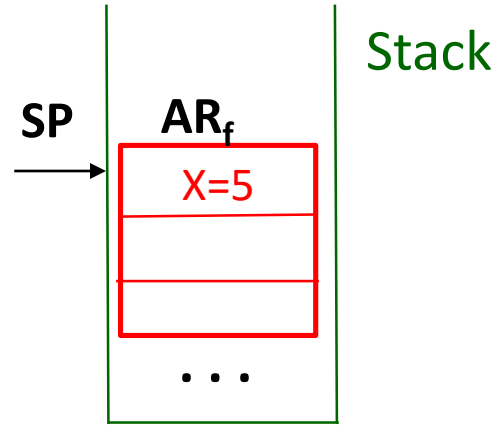


Value and Reference Types

- There are two categories of types in Java: **value types** and **reference types**.

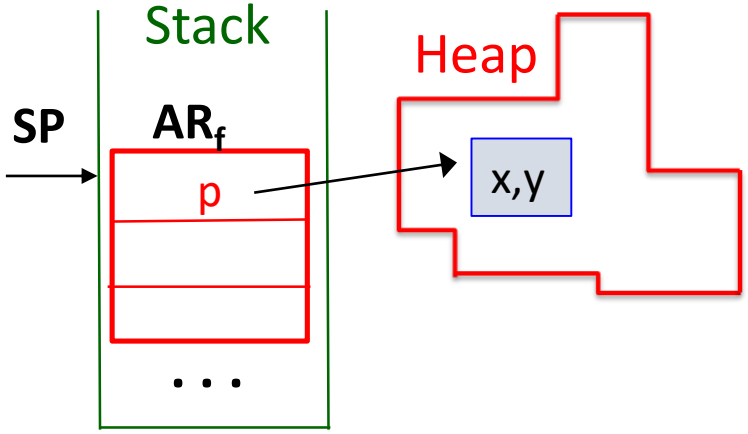
  Examples of value types: integers, floating, doubles. Values of these types are represented directly:

```
int x = 5;
```



- **Classes** are **reference types**. This means instances of classes always exist **as pairs**: the instance itself **and** the representative of the instance – the **reference**:

```
Point p = new Point();
```

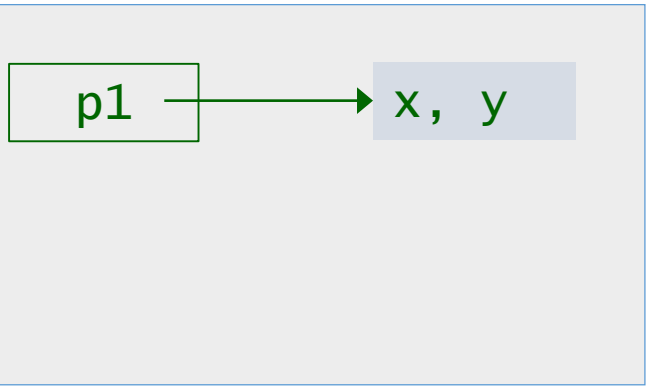


Internally, p is just an **address (pointer)** of the instance in the heap…

Objects and References

```
class Point
{
    int x, y;
    void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}

class OtherClass
{
    void f() {
        Point p1 = new Point;
        Point p2 = p1;
        {
            Point p3 = new Point;
        }
        ...
    }
}
```



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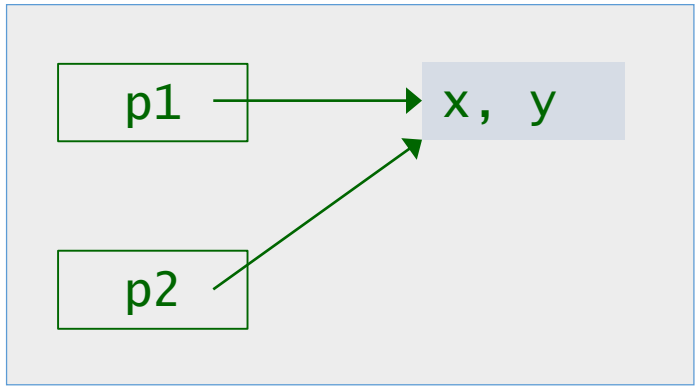

Two references refer to (share) the same instance

Objects and References

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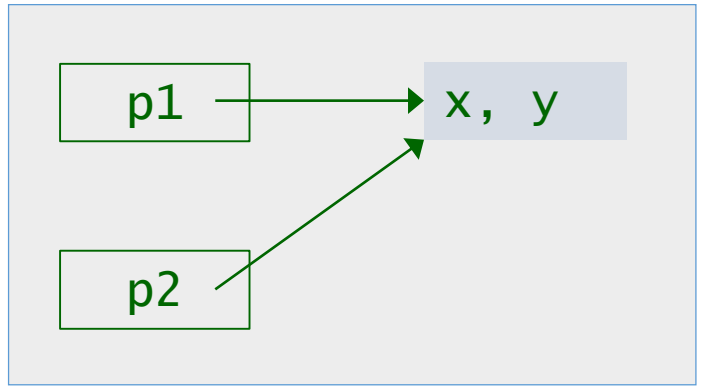

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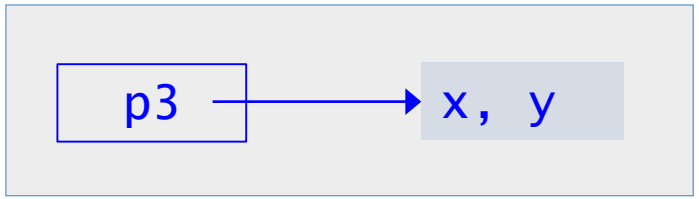

Objects and References

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    int x, y;
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    {
        x += dx;
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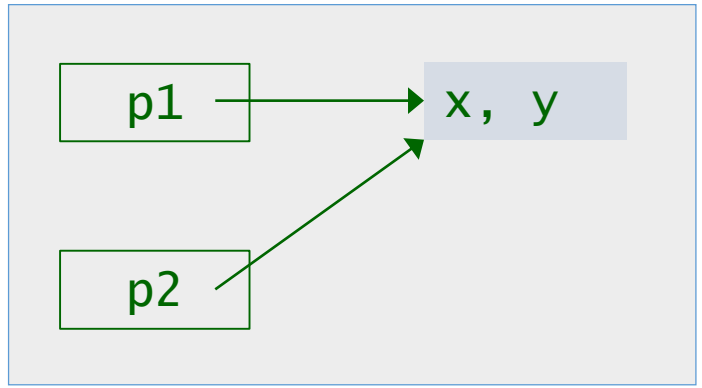
}
```



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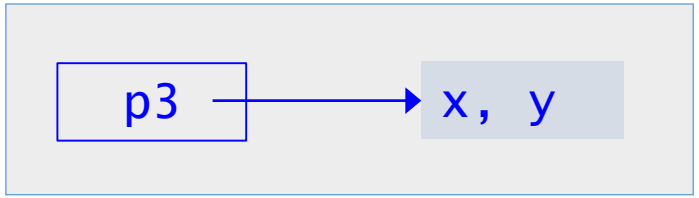

The instance still exists but there is no way to access it: The instance is lost!

Access to Class Instances

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

    void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

So… we have declared the class, we know how to create instances of the class…

But what can we **do with instances** after creating them? ☺

Access to Class Instances

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

    void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

```
Point p = new Point();
...
p.move(1,3);
```

So… we have declared the class, we know how to create instances of the class…

But what can we **do with instances** after creating them? ☺

The common rule is that that **the only way** to access instance's features (members) is to use a reference to the instance. The whole construct is called **dot notation**.

Access to Class Instances

Dot notation, the common form:

Do you remember about the similar construct in C?

```
ref_to_instance . member_name
```

But this is not enough to know about access… ☺

Access to Class Instances

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

    void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

By default, all class members are **not accessible** (i.e., **private**).

Access to Class Instances

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class Point
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    int x;
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    void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

By default, all class members are **not accessible** (i.e., **private**).

To make them accessible (**public**) you should mark them public **explicitly**.

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

    public void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

Private (inaccessible) by default

Public (accessible) by explicit specification

Access to Class Instances

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

    void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

By default, all class members are **not accessible** (i.e., **private**).

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

    public void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

Private (inaccessible) by default

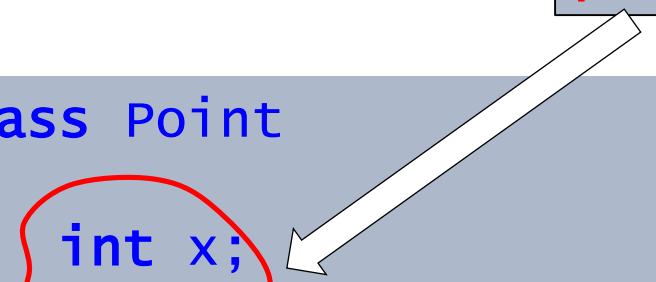
Public (accessible) by explicit specification

```
Point p = new Point();
...
p.move(1,3); // OK
p.x = 7; // Error
```

Interface & Implementation

Can be specified explicitly:

```
private int x;
private int y;
```



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

    public void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

Interface & Implementation

Class **implementation**:

How class instances are organized internally. This is **hidden** from clients of the class.

Can be specified explicitly:

```
private int x;
private int y;
```

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

    public void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

Interface & Implementation

Class **implementation**:

How class instances are organized internally. This is **hidden** from clients of the class.

Class **interface**:

How class communicates with its clients, OR:

How clients accept (understand, work with) class instances.

This is **accessible** for clients of the class.

Can be specified explicitly:

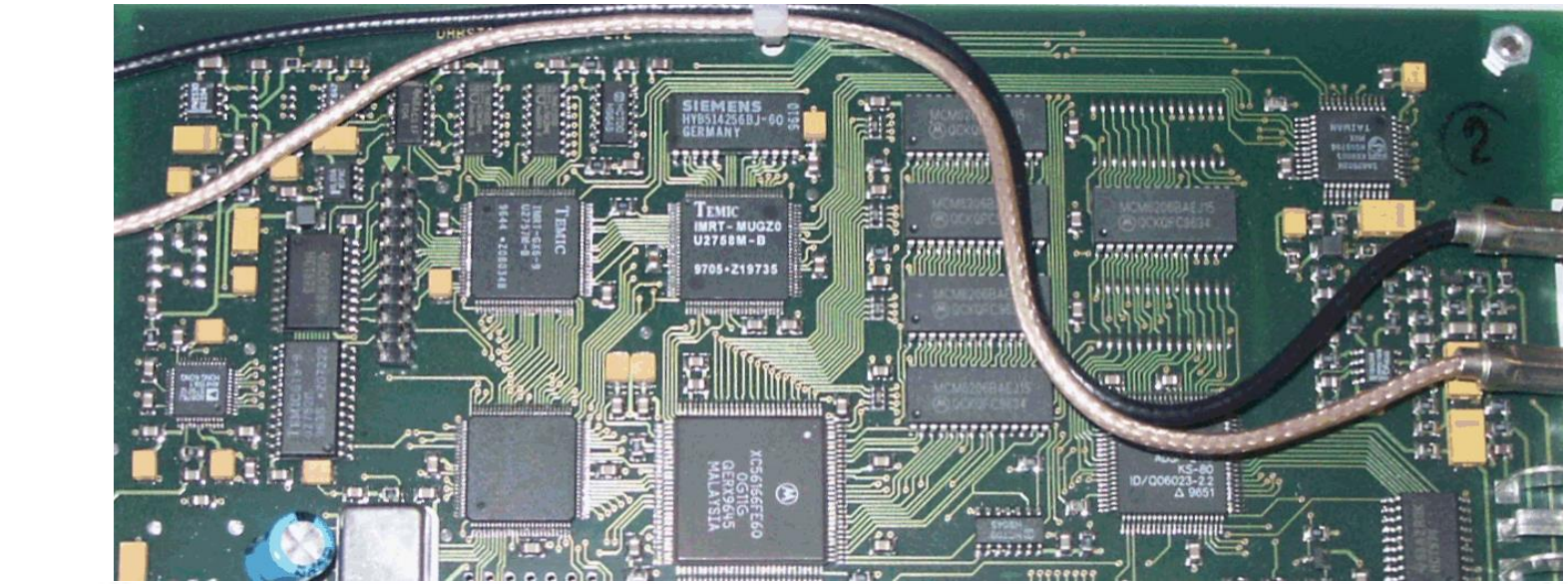
```
private int x;
private int y;
```

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

    public void move(int dx, int dy)
    {
        x += dx;
        y += dy;
    }
}
```

Interface & Implementation

Interface & Implementation



Interface & Implementation

Interface:
what a client sees

Interface & Implementation

Interface:
what a client sees

Implementation:
what's under the hood

Constructors

OR: How to initialize class instances

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

    public void move(int dx, int dy) {
        x += dx;
        y += dy;
    }
}
```

```
class SomeOtherClass
{
    Point p = new Point();
    ...
}
```

The problem: what are (initial) values of x & y?

Constructors

OR: How to initialize class instances

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

    public void move(int dx, int dy) {
        x += dx;
        y += dy;
    }
}
```

```
class SomeOtherClass
{
    Point p = new Point();
    ...
}
```

The problem: what are (initial) values of x & y?

The solution: **constructor**

Constructors

OR: How to initialize class instances

Constructor:
The special method whose name is the same as the class name.
It's automatically called by the **new** operator.

```
class Point
{
  int x, y;

  public Point()
  {
     x = 0; y = 0;
  }



  public void move(int dx, int dy)
  {
    x += dx;
    y += dy;
  }
}
```

```
class SomeOtherClass
{
  Point p1 = new Point();

}
```

Constructors

OR: How to initialize class instances

Constructor:
The special method whose name is the same as the class name.
It's automatically called by the **new** operator.

There can be several constructors defined for a class. The idea is that a class developer can provide several ways for creating instances.

```
class Point
{
  int x, y;

  public Point()
  {
     x = 0; y = 0;
  }
  public Point(int a1, int a2)
  {
    x = a1; y = a2;
  }
  public void move(int dx, int dy)
  {
    x += dx;
    y += dy;
  }
}
```

Constructors here are made **public**: they are treated as a part of class interface

```
class SomeOtherClass
{
  Point p1 = new Point();
  Point p2 = new Point(3,4);
}
```

Destroying Class Instances

What to do when you don’t need an instance anymore?
Or: how to deal with instances with lost references?

- .

Destroying Class Instances

What to do when you don't need an instance anymore?
Or: how to deal with instances with lost references?

- The answer is: **nothing** to do.

Java uses **automatic garbage collection**; the programmer does not have to deal with memory management.

- Objects with no references pointing to them are considered eligible for automatic garbage collection by the system
- The garbage collector runs periodically and performs the real destruction of these objects.
- Thus explicit object destruction is (almost) never an issue in Java (except in JNI and connection to database).
- Garbage collection is not directly under control of the programmer, hence problems could arise if strictly predictable timing behavior is needed (as in real-time systems).

Conclusion

What we have learnt today:

- **Object-oriented approach** to programming: basic idea (to be discussed in more details later these days)
- **Classes**: what's this and how to declare them
- Class **instances** (objects): how to create them
- **Value types** and **reference types**
- Class instances as pairs of the instance itself and the reference to it
- Access to instances: dot notation
- **Access control**: public and private members
- Destroying instances: automatic **garbage collection**
- **Constructors**