哈爾濱工業大學
HARBIN INSTITUTE OF TECHNOLOGY

7 Object-Oriented Programming (OOP)

面向对象的编程

Wang Zhongjie
rainy@hit.edu.cn

March 31, 2024

Objective of this lecture

- **Separating the interface of an abstract data type from its implementation, and using Java interface types to enforce that separation.**
- **Define ADTs with interfaces, and write classes that implement interfaces.**

- **用OOP/接口/类实现ADT**

3-3节学习了ADT理论
本节学习ADT的具体实现技术：OOP

Outline

- **Basic concepts: object, class, attribute, method, interface, and enumerations OOP的基本概念**
- **Distinct features of OOP**

  Encapsulation and information hiding 封装与信息隐藏

  Inheritance and overriding 继承与重写

  Polymorphism, subtyping and overloading 多态、子类型、重载

  *Static and Dynamic dispatch 静态与动态分派
- **Some important `Object` methods in Java**
- **Designing good classes**
- **History of OOP**
- **Summary**

Reading

- **MIT 6.031：12**
- **CMU 17-214：Sep 3、Sep 10、Sep 19、Sep 24**
- **Java编程思想：第7-9章**
- **代码大全：第6章**
- **Effective Java：第3-4、7-9章**

哈爾濱工業大學
HARBIN INSTITUTE OF TECHNOLOGY

1 Basic concepts: object, class, attribute, and method

Object

- **Real-world objects share two characteristics: they all have *states* and *behaviors*.**
- **Identifying the state and behavior for real-world objects is a great way to begin thinking in terms of OOP.**
  - Dogs have state (name, color, breed, hungry) and behavior (barking, fetching, wagging tail).
  - Bicycles have state (current gear, current pedal cadence, current speed) and behavior (changing gear, changing pedal cadence, applying brakes).
- **For each object that you see, ask yourself two questions, and these real-world observations all translate into the world of OOP:**
  - What possible states can this object be in? 状态有哪些？
  - What possible behavior can this object perform? 行为有哪些？

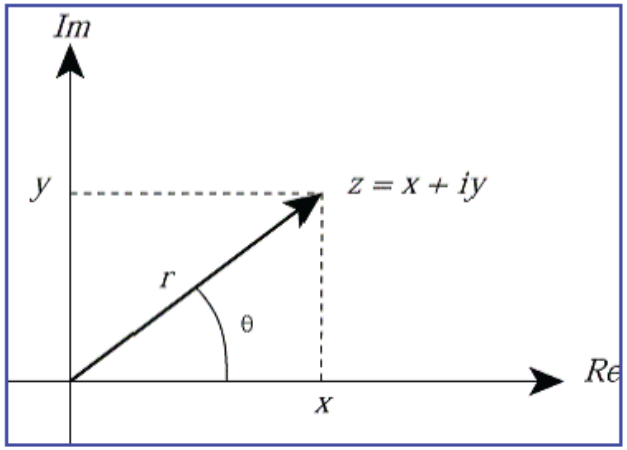
Object

- **An object is a bundle of *state* and *behavior***
- **State – the data contained in the object.**
  - In Java, these are the fields of the object
- **Behavior – the actions supported by the object**
  - In Java, these are called methods
  - Method is just OO-speak for function
  - invoke a method = call a function

Classes

- **Every object has a class**
  - A class defines methods and fields
  - Methods and fields collectively known as members
- **Class defines both type and implementation**
  - type ≈ where the object can be used
  - implementation ≈ how the object does things
- **Loosely speaking, the methods of a class are its Application Programming Interface (API)**
  - Defines how users interact with instances

Class example – complex numbers




```
class Complex {
  private double re;  // Real Part
  private double im;  // Imaginary Part

  public Complex(double re, double im) {
    this.re = re;
    this.im = im;
  }

  public double realPart()      { return re; }
  public double imaginaryPart() { return im; }
  public double r()             { return Math.sqrt(re * re + im * im); }
  public double theta()         { return Math.atan(im / re); }

  public Complex add(Complex c) {
    return new Complex(re + c.re, im + c.im);
  }
  public Complex subtract(Complex c) { ... }
  public Complex multiply(Complex c) { ... }
  public Complex divide(Complex c)   { ... }
}
```

Class usage example

- 客户端代码：

```
public class ComplexUser {
    public static void main(String args[]) {
        Complex c = new Complex(-1, 0);
        Complex d = new Complex(0, 1);

        Complex e = c.plus(d);
        System.out.println(e.realPart() + " + "
                           + e.imaginaryPart() + "i");
        e = c.times(d);
        System.out.println(e.realPart() + " + "
                           + e.imaginaryPart() + "i");
    }
}
```

Static vs. instance variables/methods of a class

- ***Class variable* 类成员变量: a variable associated with the class rather than with an instance of the class. You can also associate methods with a class--*class methods*类方法.**
  - To refer to class variables and methods, you join the class's name and the name of the class method or class variable together with a period ('.').
- **Methods and variables that are not class methods or class variables are known as *instance methods* 实例方法 and *instance variables* 实例成员变量.**
  - To refer to instance methods and variables, you must reference the methods and variables from an instance of the class
- **Summary:**
  - Class variables and class methods are associated with a class and occur once per class. Using them doesn't require object creation.
  - Instance methods and variables occur once per instance of a class.

Static vs. instance variables/methods of a class

```
class DateApp {
    public static void main(String args[]) {
        Date today = new Date();
        System.out.println(today);
    }
}
```

```
class Another {
  public static void main(String[] args) {
    int result;
    result = Math.min(10, 20);
    System.out.println(result);
    System.out.println(Math.max(100, 200));
  }
}
```

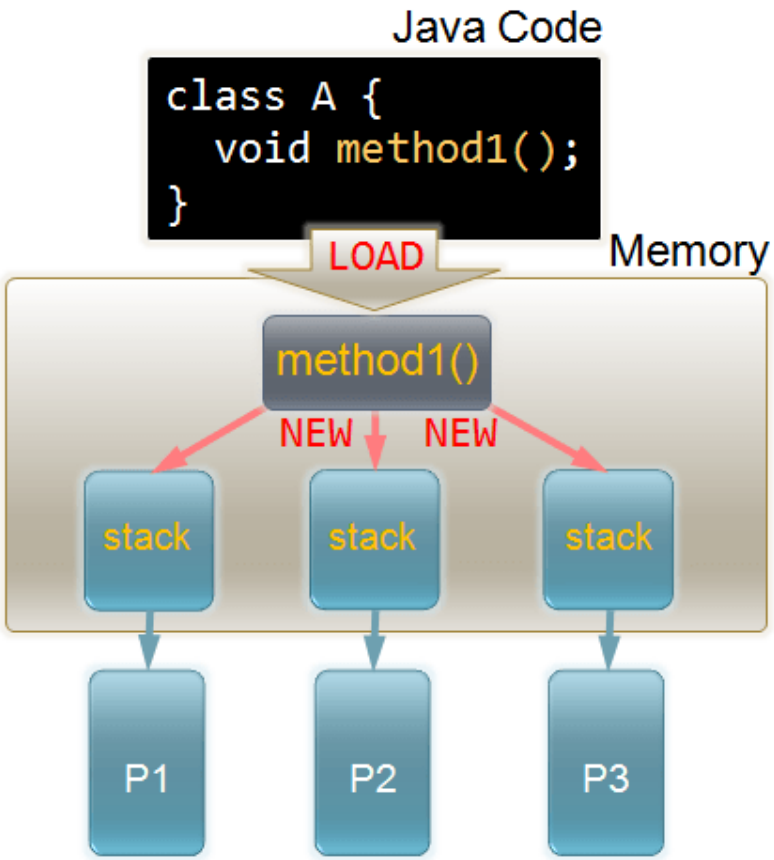
Static vs. instance variables/methods of a class

- **`Static` methods are not associated with any particular instance of a class, while `instance` methods (declared without the static keyword) must be called on a particular object.**

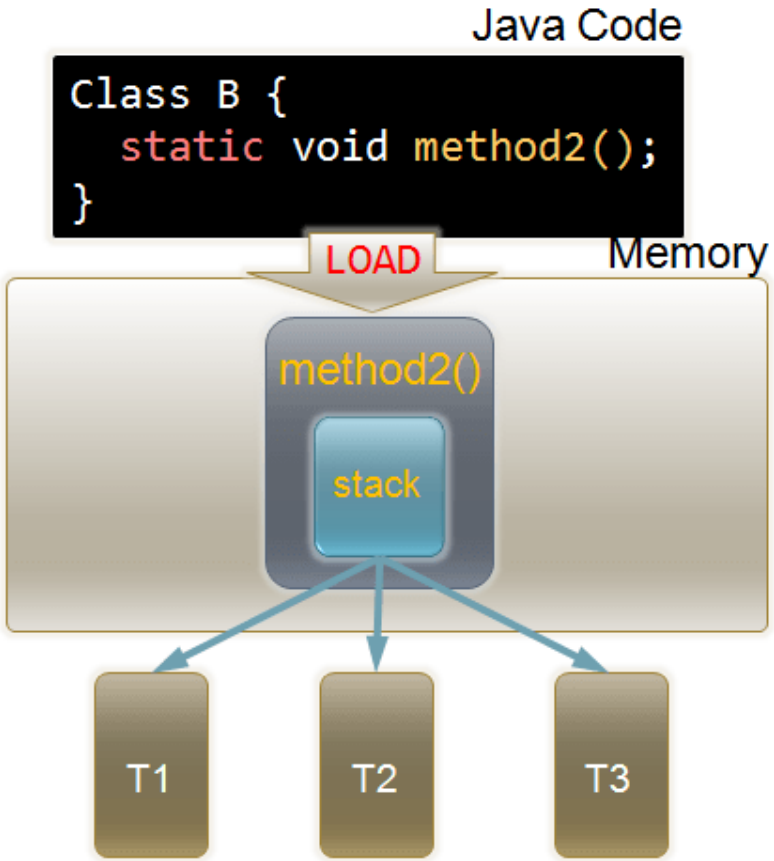
```
class Difference {

  public static void main(String[] args) {
    display();  //calling without object
    Difference t = new Difference();
    t.show();  //calling using object
  }

  static void display() {
    System.out.println("Programming is amazing.");
  }

  void show(){
    System.out.println("Java is awesome.");
  }
}
```

Static and Instance methods

Instance Methods



Class Methods



2 Interface and Enumerations

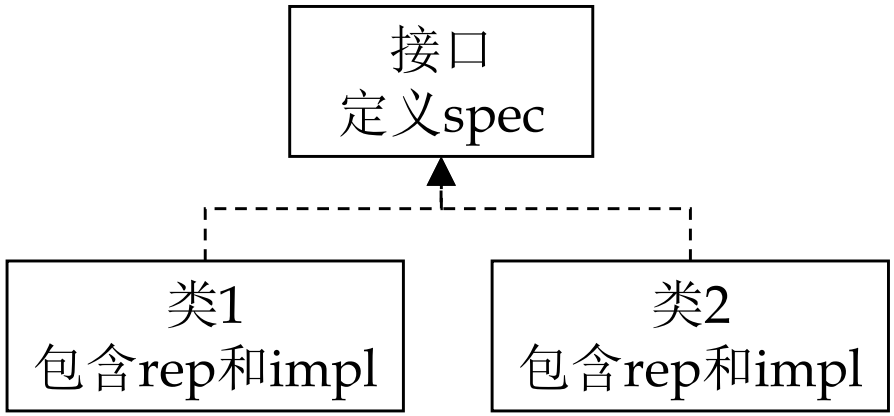
Interface

- **Java's interface is a useful language mechanism for designing and expressing an ADT, with its implementation as a class implementing that interface.**
  - An interface in Java is a list of method signatures, but no method bodies.
  - A class implements an interface if it declares the interface in its implements clause, and provides method bodies for all of the interface's methods.
  - An interface can extend one or more others
  - A class can implement multiple interfaces

  - Interface和Class: 定义和实现ADT
  - 接口之间可以继承与扩展
  - 一个类可以实现多个接口（从而具备了多个接口中的方法）
  - 一个接口可以有多种实现类

An interface to go with the example class

```
public interface Complex {
    // No constructors, fields, or implementations!

    double realPart();
    double imaginaryPart();
    double r();
    double theta();

    Complex plus(Complex c);
    Complex minus(Complex c);
    Complex times(Complex c);
    Complex dividedBy(Complex c);
}
```



Modifying class to use interface

```
class OrdinaryComplex implements Complex {
  double re;  // Real Part
  double im;  // Imaginary Part

  public OrdinaryComplex(double re, double im) {
    this.re = re;
    this.im = im;
  }

  public double realPart()      { return re; }
  public double imaginaryPart() { return im; }
  public double r()             { return Math.sqrt(re * re + im * im); }
  public double theta()         { return Math.atan(im / re); }

  public Complex add(Complex c) {
    return new OrdinaryComplex(re + c.realPart(), im + c.imaginaryPart());
  }
  public Complex subtract(Complex c) { ... }
  public Complex multiply(Complex c) { ... }
  public Complex divide(Complex c)   { ... }
}
```

Modifying client to use interface

```
public class ComplexUser {
    public static void main(String args[]) {
        Complex c = new OrdinaryComplex(-1, 0);
        Complex d = new OrdinaryComplex(0, 1);

        Complex e = c.plus(d);
        System.out.println(e.realPart() + " + "
                           + e.imaginaryPart() + "i");
        e = c.times(d);
        System.out.println(e.realPart() + " + "
                           + e.imaginaryPart() + "i");
    }
}
```

Interface permits multiple implementations

```
class PolarComplex implements Complex {
  double r;
  double theta;

  public PolarComplex(double r, double theta) {
    this.r = r;
    this.theta = theta;
  }

  public double realPart()      { return r * Math.cos(theta) ; }
  public double imaginaryPart() { return r * Math.sin(theta) ; }
  public double r()             { return r; }
  public double theta()         { return theta; }

  public Complex plus(Complex c)      { ... } // Completely different impls
  public Complex minus(Complex c)     { ... }
  public Complex times(Complex c)     { ... }
  public Complex dividedBy(Complex c) { ... }
}
```

Interface decouples client from implementation

```
public class ComplexUser {
    public static void main(String args[]) {
        Complex c = new PolarComplex(Math.PI,   1);  // -1
        Complex d = new PolarComplex(Math.PI/2, 1);  //  i

        Complex e = c.plus(d);
        System.out.println(e.realPart() + " + "
                           + e.imaginaryPart() + "i");
        e = c.times(d);
        System.out.println(e.realPart() + " + "
                           + e.imaginaryPart() + "i");
    }
}
```

Java interfaces and classes

- **Interfaces vs. classes接口：确定ADT规约；类：实现ADT**
  - Interface: specifies expectations
  - Class: delivers on expectations (the implementation)
- **Classes *do* define types 也可以不需要接口直接使用类作为ADT（既有ADT定义也有ADT实现）**
  - Public class methods usable like interface methods
  - Public fields directly accessible from other classes
- **But prefer the use of interfaces 实际中更倾向于使用接口来定义变量**
  - Use interface types for variables and parameters unless you know one implementation will suffice.
  - Supports change of implementation;
  - Prevents dependence on implementation details

```
Set<Criminal> senate = new HashSet<>();          // Do this…
HashSet<Criminal> senate = new HashSet<>();      // Not this
```

An Example

This violates the spec for `Set`, its immutability, so `ArraySet` is not a legal implementation of `Set`.

```
/** Represents an immutable set of elements of type E. */
   public interface Set<E> {
       /** make an empty set */
       public Set();
       /** @return true if this set contains e as a member */
       public boolean contains(E e);
       /** @return a set which is the union of this and that */
       public ArraySet<E> union(Set<E> that);
   }

   /** Implementation of Set<E>. */
   public class ArraySet<E> implements Set<E> {
       /** make an empty set */
       public ArraySet() { ... }
       /** @return a set which is the union of this and that */
       public ArraySet<E> union(Set<E> that) { ... }
       /** add e to this set */
       public void add(E e) { ... }
   }
```

Java interfaces can't have constructors.

It isn't representation-independent.

Java allowes classes to have more methods than the interface

It's missing the `contains()` method.

Using Interface+Class for ADT: `MyString`

```java
/** MyString represents an immutable sequence of characters. */
public interface MyString {

    // We'll skip this creator operation for now
    // /** @param b a boolean value
    //  *  @return string representation of b, either "true" or "false" */
    // public static MyString valueOf(boolean b) { ... }

    /** @return number of characters in this string */
    public int length();

    /** @param i character position (requires 0 <= i < string length)
     *  @return character at position i */
    public char charAt(int i);

    /** Get the substring between start (inclusive) and end (exclusive).
     *  @param start starting index
     *  @param end ending index.  Requires 0 <= start <= end <= string length.
     *  @return string consisting of charAt(start)...charAt(end-1) */
    public MyString substring(int start, int end);
}
```

Implementation 1 of `MyString`

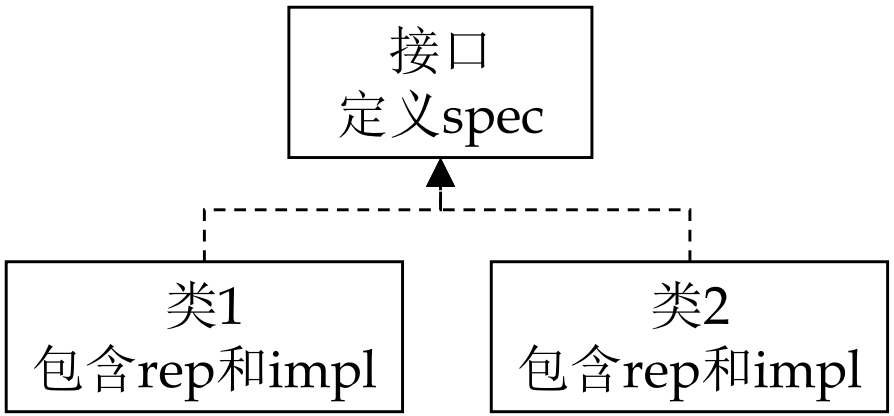
```
public class SimpleMyString implements MyString {

    private char[] a;

    /* Create an uninitialized SimpleMyString. */
    private SimpleMyString() {}

    /** Create a string representation of b, either "true" or "false".
     *  @param b a boolean value */
    public SimpleMyString(boolean b) {
        a = b ? new char[] { 't', 'r', 'u', 'e' }
              : new char[] { 'f', 'a', 'l', 's', 'e' };
    }

    @Override public int length() { return a.length; }

    @Override public char charAt(int i) { return a[i]; }

    @Override public MyString substring(int start, int end) {
        SimpleMyString that = new SimpleMyString();
        that.a = new char[end - start];
        System.arraycopy(this.a, start, that.a, 0, end - start);
        return that;
    }
}
```

Implementation 2 of `MyString`

```
public class FastMyString implements MyString {

    private char[] a;
    private int start;
    private int end;

    /* Create an uninitialized FastMyString. */
    private FastMyString() {}

    /** Create a string representation of b, either "true" or "false".
     *  @param b a boolean value */
    public FastMyString(boolean b) {
        a = b ? new char[] { 't', 'r', 'u', 'e' }
              : new char[] { 'f', 'a', 'l', 's', 'e' };
        start = 0;
        end = a.length;
    }

    @Override public int length() { return end - start; }

    @Override public char charAt(int i) { return a[start + i]; }

    @Override public MyString substring(int start, int end) {
        FastMyString that = new FastMyString();
        that.a = this.a;
        that.start = this.start + start;
        that.end = this.start + end;
        return that;
    }
}
```

Why multiple implementations?

- **Different performance**
  - Choose implementation that works best for your use
- **Different behavior**
  - Choose implementation that does what you want
  - Behavior *must* comply with interface spec ("contract")
- **Often performance and behavior *both* vary**
  - Provides a functionality – performance tradeoff
  - Example: `HashSet, TreeSet`



To use `MyString` and its implementations

```
MyString s = new FastMyString(true);
System.out.println("The first character is: " + s.charAt(0));
```

- **Problem: breaks the abstraction barrier**
  - Clients must know the name of the concrete representation class.
  - Because interfaces in Java cannot contain constructors, they must directly call one of the concrete class' constructors.
  - The spec of that constructor won't appear anywhere in the interface, so there's no static guarantee that different implementations will even provide the same constructors.
  - 打破了抽象边界，接口定义中没有包含constructor，也无法保证所有实现类中都包含了同样名字的constructor。
  - 故而，客户端需要知道该接口的某个具体实现类的名字

Using static factory instead of constructor

```
public interface MyString {

    /** @param b a boolean value
     *  @return string representation of b, either "true" or "false" */
    public static MyString valueOf(boolean b) {
        return new FastMyString(true);
    }

    // ...
```

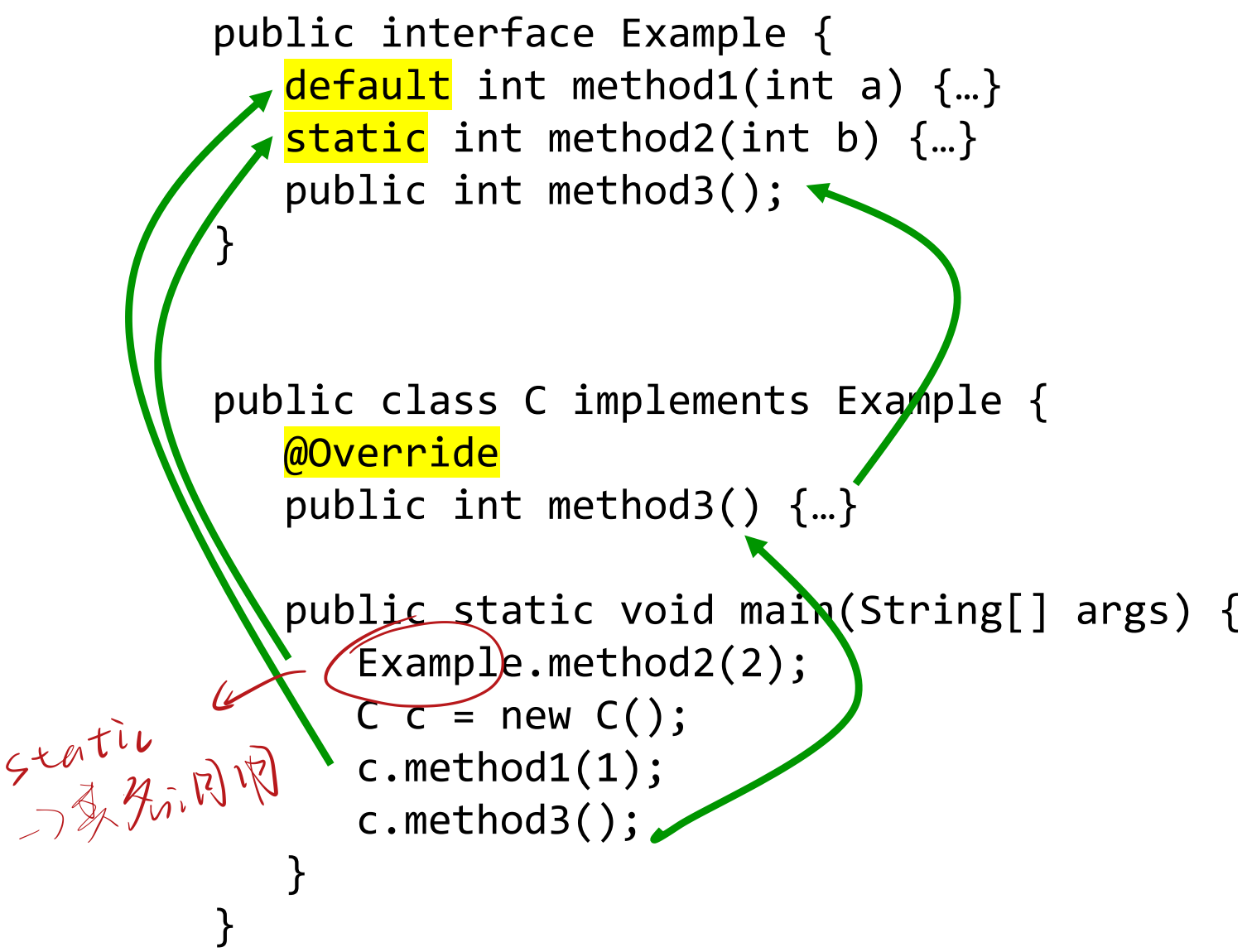
```
MyString s = MyString.valueOf(true);
System.out.println("The first character is: " + s.charAt(0));
```

From Java 8 interfaces are allowed to contain static methods.

Using `default` methods in an interface

- In a typical design based on abstractions, where an interface has one or multiple implementations, if one or more methods are added to the interface, all the implementations will be forced to implement them too. Otherwise, the design will just break down. 接口中的每个方法在所有类中都要实现 (default, private, static)
- `default` interface methods are an efficient way to deal with this issue. They allow us to add new methods to an interface that are automatically available in the implementations. Thus, there's no need to modify the implementing classes. 通过default方法，在接口中统一实现某些功能，无需在各个类中重复实现它。
- The most typical use of default methods in interfaces is to incrementally provide additional functionality to a given type without breaking down the implementing classes. 以增量式的为接口增加额外的功能而不破坏已实现的类

Using `default` methods in an interface



Summary of Interface

- **Safe from bugs**
  - An ADT is defined by its operations, and interfaces do just that.
  - When clients use an interface type, static checking ensures that they only use methods defined by the interface.
  - If the implementation class exposes other methods — or worse, has visible representation — the client can't accidentally see or depend on them.
  - When we have multiple implementations of a data type, interfaces provide static checking of the method signatures.

Summary of Interface

- **Easy to understand.**
  - Clients and maintainers know exactly where to look for the specification of the ADT.
  - Since the interface doesn't contain instance fields or implementations of instance methods, it's easier to keep details of the implementation out of the specifications.

- **Ready for change.**
  - We can easily add new implementations of a type by adding classes that implement interface.
  - If we avoid constructors in favor of static factory methods, clients will only see the interface.
  - That means we can switch which implementation class clients are using without changing their code at all.

Enumerations

- Sometimes a type has a small, finite set of immutable values, such as:
  - Months of the year: `January`, `February`, …, `November`, `December`
  - Days of the week: `Monday`, `Tuesday`, …, `Saturday`, `Sunday`
  - Compass points: `north`, `south`, `east`, `west`
- When the set of values is small and finite, it makes sense to define all the values as named constants, called an **enumeration**. Java has the `enum` construct.

```
public enum Month {
    JANUARY, FEBRUARY, MARCH, ...,
    OCTOBER, NOVEMBER, DECEMBER;
}
public enum PenColor {
    BLACK, GRAY, RED, ..., BLUE;
}
```

```
PenColor drawingColor = PenColor.RED;
Month month = Month.MARCH;

if(month.equals(Month.MARCH)) {...}

for(Month m : Month.values())
   m.name();
   m.ordinal();
   m.comparedTo();
   m.toString();
   ...
```

Add data and behaviors to enumerations

```
public enum Planet {
  MERCURY(3.302e+23, 2.439e6), VENUS (4.869e+24, 6.052e6),
  EARTH(5.975e+24, 6.378e6), MARS(6.419e+23, 3.393e6);

  private final double mass; // In kg.
  private final double radius; // In m.
  private static final double G = 6.67300E-11;

  Planet(double mass, double radius) {
    this.mass = mass;
    this.radius = radius;
  }
  public double mass() { return mass; }
  public double radius() { return radius; }
  public double surfaceGravity() {
    return G * mass / (radius * radius);
  }
}
```

```
for (Planet p : Planet.values())
   System.out.println(p.surfaceGravity());
```

4 Encapsulation and information hiding

Information hiding

- **Single most important factor that distinguishes a well-designed module from a bad one is the degree to which it hides internal data and other implementation details from other modules**
- **Well-designed code hides *all* implementation details**
  - Cleanly separates API from implementation
  - Modules communicate *only* through APIs
  - The are oblivious to each others' inner workings
- **Known as information hiding or encapsulation, a fundamental tenet of software design.**

Benefits of information hiding

- **Decouples** the classes that comprise a system
  - Allows them to be developed, tested, optimized, used, understood, and modified in isolation
- **Speeds up system development**
  - Classes can be developed in parallel
- **Eases burden of maintenance**
  - Classes can be understood more quickly and debugged with little fear of harming other modules
- **Enables effective performance tuning**
  - "Hot" classes can be optimized in isolation
- **Increases software reuse**
  - Loosely-coupled classes often prove useful in other contexts

Information hiding with interfaces

- **Declare variables using interface type** 使用接口类型声明变量
- **Client can use only interface methods** 客户端仅使用接口中定义的方法
- **Fields not accessible from client code** 客户端代码无法直接访问属性

- **But this only takes us so far**
  - Client can access non-interface members directly
  - In essence, it's voluntary information hiding

Visibility modifiers for members

- `private` – Accessible *only* from declaring class
- `protected` – Accessible from subclasses of declaring class (and within package)
- `public` – Accessible from anywhere

```
class OrdinaryComplex implements Complex {
  private double re;  // Real Part
  private double im;  // Imaginary Part

  public OrdinaryComplex(double re, double im) {
    this.re = re;
    this.im = im;
  }

  public double realPart()      { return re; }
  public double imaginaryPart() { return im; }
  public double r()             { return Math.sqrt(re * re + im * im); }
  public double theta()         { return Math.atan(im / re); }

  public Complex add(Complex c) {
    return new OrdinaryComplex(re + c.realPart(), im + c.imaginaryPart());
  }
  public Complex subtract(Complex c) { ... }
  public Complex multiply(Complex c) { ... }
  public Complex divide(Complex c)   { ... }
}
```

Best practices for information hiding

- **Carefully design your API**
- **Provide *only* functionality required by clients, and all other members should be `private`**
- **You can always make a `private` member `public` later without breaking clients**
  - But not vice-versa!

Classroom Exercises

```
class Wallet {
  private int amount;

  public void loanTo(Wallet that) {
/*A*/       that.amount += this.amount;
/*B*/       amount = 0;
  }

   public static void main(String[] args) {
/*C*/       Wallet w = new Wallet();
/*D*/       w.amount = 100;
/*E*/       w.loanTo(w);
   }
}
```

Are there any errors for each line of A-G?

```
class Person {
        private Wallet w;

        public int getNetWorth() {
/*F*/       return w.amount;
        }

        public boolean isBroke() {
/*G*/       return Wallet.amount == 0;
        }
}
```

5 Inheritance and Overriding

Variation in the real world

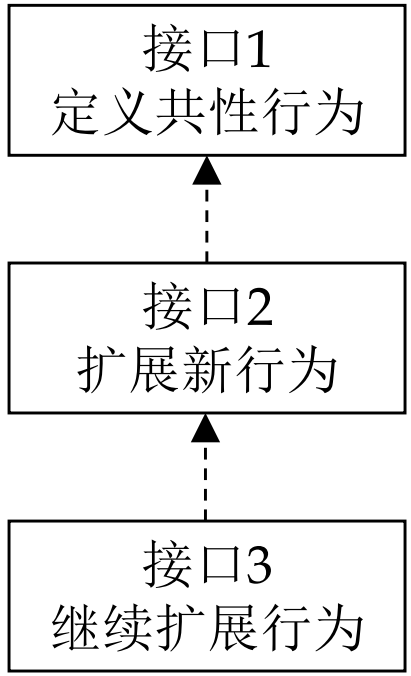
- **Two types of "Bank Account"**

```
public interface CheckingAccount {
    public long getBalance();
    public void  deposit(long amount);
    public boolean withdraw(long amount);
    public boolean transfer(long amount, Account target);
    public long getFee();
}
```

```
public interface SavingsAccount {
    public long getBalance();
    public void  deposit(long amount);
    public boolean withdraw(long amount);
    public boolean transfer(long amount, Account target);
    public double getInterestRate();
}
```

Interface inheritance for an account type hierarchy

```
public interface Account {
    public long getBalance();
    public void  deposit(long amount);
    public boolean withdraw(long amount);
    public boolean transfer(long amount, Account target);
    public void monthlyAdjustment();
}

public interface CheckingAccount extends Account {
    public long getFee();
}

public interface SavingsAccount extends Account {
    public double getInterestRate();
}

public interface InterestCheckingAccount
                        extends CheckingAccount, SavingsAccount {
}
```



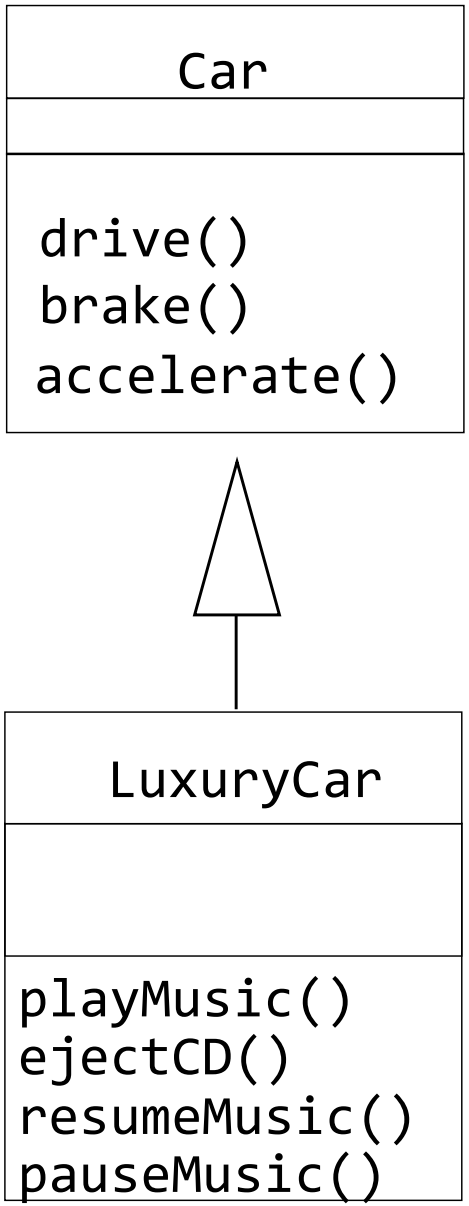
(1) Overriding

Rewriteable Methods and Strict Inheritance

- **Rewriteable Method: A method which allow a re-implementation.**
  - In Java methods are rewriteable by default, i.e. there is no special keyword.

- **Strict inheritance (严格继承：子类只能添加新方法，无法重写超类中的方法)**
  - The subclass can only add new methods to the superclass, it cannot overwrite them
  - If a method cannot be overwritten in a Java program, it must be prefixed with the keyword `final`.

Strict Inheritance



- **Superclass**

不能在子类中重写.

```
public class Car {
    public final void drive() {…}
    public final void brake() {…}
    public final void accelerate() {…}
}
```

- **Subclass**

```
public class LuxuryCar extends Car {
    public void playMusic() {…}
    public void ejectCD() {…}
    public void resumeMusic() {…}
    public void pauseMusic() {…}
}
```

Strict Inheritance and Rewriteable Methods

```
class Device {
      int serialnr;
      public final void help() {….}
      public void setSerialNr(int n) {
         serialnr = n;
      }
}

class Valve extends Device {
      Position s;
      public void setSerialNr(int n) {
         ...
      }
}
```

help() not overwritable

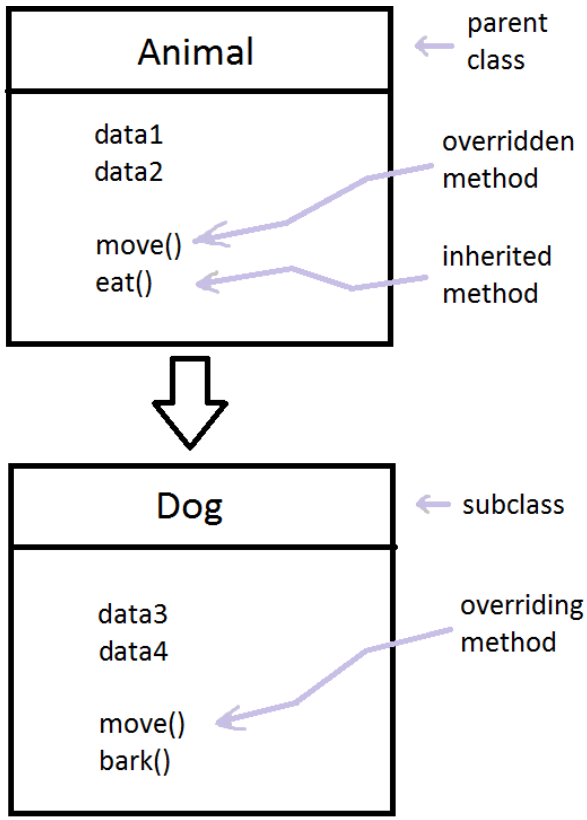
setSerialNr() overwritable

final

- **A `final` field: prevents reassignment to the field after initialization**
- **A `final` method: prevents overriding the method**
- **A `final` class: prevents extending the class**
  - e.g., `public final class CheckingAccountImpl { ... }`

Overriding (覆盖/重写)

- **Method overriding is a language feature that allows a subclass or child class to provide a specific implementation of a method that is already provided by one of its superclasses or parent classes.**
  - The same name, same parameters or signature, and same return type. 重写的函数：完全同样的signature
  - The version of a method that is executed will be determined by the object that is used to invoke it. 实际执行时调用哪个方法，运行时决定。
  - If an object of a parent class is used to invoke the method, then the version in the parent class will be executed;
  - If an object of the subclass is used to invoke the method, then the version in the child class will be executed.



Example: Overwriting a Method

```
class Device {
      int serialnr;
      public final void help() {….}
      public void setSerialNr(int n) {
        serialnr = n;
      }
}
```

父类型中的被重写函数体不为空：意味着对其大多数子类型来说，该方法是可以被直接复用的。

```
class Valve extends Device {
      Position s;
      public void on() {
        …
      }
      public void setSerialNr(int n) {
        serialnr = n + s.serialnr;
      }
}
```

对某些子类型来说，有特殊性，故重写父类型中的函数，实现自己的特殊要求

Rewriteable Methods are set to empty

如果父类型中的某个函数实现体为空，意味着其所有子类型都需要这个功能，但各有差异，没有共性，在每个子类中均需要重写。

```
class Device {
      int serialnr;
      public void setSerialNr(int n) {}
}
class Valve extends Device {
    Position s;
    public void on() {
        …..
    }
    public void setSerialNr(int n) {
        seriennr = n + s.serialnr;
    }
} // class Valve
```

I expect that the method `setSerialNr()` will be overwritten. I only write an empty body

Overwriting of the method `setSerialNr()` of Class `Device`

Overriding (覆盖/重写)

- **When a subclass contains a method that overrides a method of the superclass, it can also invoke the superclass method by using the keyword super.**

重写之后，利用super()复用了父类型中函数的功能，并对其进行了扩展

```
class Thought {
    public void message() {
        System.out.println( “Thought.");
    }
}

public class Advice extends Thought {
    @Override  // @Override annotation in Java 5 is optional but helpful.
    public void message() {
        System.out.println( “Advice.");
        super.message();  // Invoke parent's version of method.
    }
}

Thought parking = new Thought();
parking.message();  // Prints "Thought."

Thought dates = new Advice();
dates.message();  // Prints  “Advice. \n Thought."
```

Extended reuse with super

重写之后，利用super()复用了父类型中函数的功能，并对其进行了扩展

```
public abstract class AbstractAccount implements Account {
   protected long balance = 0;
   public boolean withdraw(long amount) {
       // withdraws money from account (code not shown)
   }
}

public class ExpensiveCheckingAccountImpl
      extends AbstractAccount implements CheckingAccount {
   public boolean withdraw(long amount) {
      balance -= HUGE_ATM_FEE;
      boolean success = super.withdraw(amount)
      if (!success)
         balance += HUGE_ATM_FEE;
      return success;
   }
}
```

Overrides `withdraw` but also uses the superclass `withdraw` method

Constructors with `this` and `super`

```
public class CheckingAccountImpl
      extends AbstractAccount implements CheckingAccount {

   private long fee;

   public CheckingAccountImpl(long initialBalance, long fee) {
      super(initialBalance);
      this.fee = fee;
   }

   public CheckingAccountImpl(long initialBalance) {
      this(initialBalance, 500);
   }
   /* other methods… */ }
```

Constructor call must be the first statement in a constructor

Invokes a constructor of the superclass. Must be the first statement of the constructor.

Invokes another constructor in this same class

Bad Use of Overwriting Methods

- **One can overwrite the operations of a superclass with completely new meanings.** 重写的时候，不要改变原方法的本意
- **Example:**

```
Public class SuperClass {
  public int add (int a, int b) { return a+b; }
  public int subtract (int a, int b) { return a-b; }
}
Public class SubClass extends SuperClass {
  public int add (int a, int b) { return a-b; }
  public int subtract (int a, int b) { return a+b; }
}
```

- **We have redefined addition as subtraction and subtraction as addition!!**

(2) Abstract Class

Abstract Methods and Abstract Classes

- **Abstract method:**
  - A method with a signature but without an implementation (also called abstract operation)
  - Defined by the keyword `abstract`
- **Abstract class:** 含有抽象方法
  - A class which contains at least one abstract method is called abstract class
- **Interface: An abstract class which has only abstract methods**
  - An interface is primarily used for the specification of a system or subsystem. The implementation is provided by a subclass or by other mechanisms.
- **Concrete class → Abstract Class → Interface**

An example of abstract class

```
abstract class GraphicObject {
    int x, y;
    ...
    void moveTo(int newX, int newY) {
        ...
    }
    abstract void draw();
    abstract void resize();
}
```

如果某些操作是所有子类型都共有，但彼此有差别，可以在父类型中设计抽象方法，在各子类型中重写

```
class Circle extends GraphicObject {
    void draw() {
        ...
    }
    void resize() {
        ...
    }
}
class Rectangle extends GraphicObject {
    void draw() {
        ...
    }
    void resize() {
        ...
    }
}
```

所有子类型完全相同的操作，放在父类型中实现，子类型中无需重写。

有些子类型有而其他子类型无的操作，不要在父类型中定义和实现，而应在特定子类型中实现。

Implementation inheritance for code reuse

```
public abstract class AbstractAccount
        implements Account {
   protected long balance = 0;
   public long getBalance() {
        return balance;
   }
   abstract public void monthlyAdjustment();
   // other methods…
}

public class CheckingAccountImpl
        extends AbstractAccount
        implements CheckingAccount {
   public void monthlyAdjustment() {
        balance -= getFee();
   }
   public long getFee() { … }
}
```

An `abstract` class is missing the implementation of one or more methods

`Protected` elements are visible in subclasses

An `abstract` method is left to be implemented in a subclass

No need to define `getBalance()`, and the code is inherited from `AbstractAccount`

哈爾濱工業大學
HARBIN INSTITUTE OF TECHNOLOGY

6 Polymorphism, subtyping and overloading
多态、子类型、重载

(1) Three Types of Polymorphism

Three Types of Polymorphism (多态)

- **Ad hoc polymorphism (特殊多态):** when a function denotes different and potentially heterogeneous implementations depending on a limited range of individually specified types and combinations. Ad hoc polymorphism is supported in many languages using **function overloading (功能重载)**.
- **Parametric polymorphism (参数化多态):** when code is written without mention of any specific type and thus can be used transparently with any number of new types. In the object-oriented programming community, this is often known as **generics** or **generic programming**.
- **Subtyping (also called subtype polymorphism or inclusion polymorphism 子类型多态、包含多态):** when a name denotes instances of many different classes related by some common superclass.

(2) Ad hoc polymorphism and Overloading

Ad hoc polymorphism

- **Ad-hoc polymorphism** is obtained when a function works on several different types (which may not exhibit a common structure) and may behave in unrelated ways for each type.

```
public class OverloadExample {
        public static void main(String args[]) {
                System.out.println(add("C","D"));
                System.out.println(add("C","D","E"));
                System.out.println(add(2,3));
        }
        public static String add(String c, String d) {
                return c.concat(d);
        }
        public static String add(String c, String d, String e){
                return c.concat(d).concat(e);
        }
        public static int add(int a, int b) {
                return a+b;
        }
}
```

Overloading

- **Overloaded methods let you reuse the same method name in a class, but with different arguments (and optionally, a different return type).**

- **Overloading a method often means you're being a little nicer to those who call your methods, because your code takes on the burden of coping with different argument types rather than forcing the caller to do conversions prior to invoking your method.**

- **重载：多个方法具有同样的名字，但有不同的参数列表或返回值类型**
- **价值：方便client调用，client可用不同的参数列表，调用同样的函数**

Overloading (重载)

- **`doTask()` and `doTask(Object O)` are overloaded methods.**
  - To call the latter, an object must be passed as a parameter, whereas the former does not require a parameter, and is called with an empty parameter field.
  - A common error would be to assign a default value to the object in the second method, which would result in an ambiguous call error, as the compiler wouldn't know which of the two methods to use.
- **A method `print(Object O)`: one might like the method to be different when printing, for example, text or pictures.**
  - Two different methods may be overloaded as `print(text_object T)`; `print(image_object P)`.
  - If we write the overloaded `print` methods for all objects our program will "print", we never have to worry about the type of the object, and the correct function call again, the call is always: `print(something)`.

Overloading (重载)

- **Function overloading** is the ability to create multiple methods of the same name with different implementations.
  - Calls to an overloaded function will run a specific implementation of that function appropriate to the context of the call, allowing one function call to perform different tasks depending on context.

- **Overloading is a static polymorphism 静态多态**
  - A function call is resolved using the 'best match technique', i.e. the function is resolved depending upon the argument list. 根据参数列表进行最佳匹配
  - Static type checking in function calls 静态类型检查
  - The determination of which of these methods are used is resolved at compile time. 在编译阶段时决定要具体执行哪个方法 (static type checking)
  - 与之相反，overridden methods则是在run-time进行dynamic checking！

Overloading rules

- **Rules in function overloading: the overloaded function must differ either by the arity or data types**
  - MUST change the argument list. 不同的参数列表
  - CAN change the return type. 相同/不同的返回值类型
  - CAN change the access modifier. 相同/不同的public/private/protected
  - CAN declare new or broader checked exceptions. 异常
  - A method can be overloaded in the same class or in a subclass. 可以在同一个类内重载，也可在子类中重载

Legal Overloads

```
public void changeSize(int size,
                       String name, float pattern) { }
```

- **The following methods are legal overloads of the `changeSize()` method:**
  - `public void changeSize(int size, String name) { }`
  - `public int changeSize(int size, float pattern) { }`
  - `public void changeSize(float pattern, String name){ }`
  - `public void changeSize(int length, String pattern, float size){ }` The same signature!
  - `public boolean changeSize(int size, String name, float pattern) { }` No changes on parameters

Invoking overloaded methods

```
public class Adder {
  public int addThem(int x, int y) {
    return x + y;
  }
  public double addThem(double x, double y) {
    return x + y;
  }
}
```

```
public class TestAdder {
  public static void main (String [] args) {
    Adder a = new Adder();
    int b = 27;
    int c = 3;

    // Which addThem is invoked?
    int result = a.addThem(b,c);
    double doubleResult = a.addThem(22.5,9.3);

    System.out.println (result);
    System.out.println (doubleResult);
  }
}
```

Invoking overloaded methods

Overload也可以发生在父类和子类之间

```
class Animal {
   public void eat() {}
}


class Horse extends Animal {
   public void eat(String food) {}
}


public class UseAnimals {
   public void doStuff(Animal a) {
      System.out.println("Animal");
   }
   public void doStuff(Horse h) {
      System.out.println("Horse");
   }
}
```

```
public class TestUseAnimals {


   public static void main (String [] args) {
      UseAnimals ua = new UseAnimals();


      Animal animalobj = new Animal();
      Horse horseobj = new Horse();
      Animal animalRefToHorse = new Horse();


      ua.doStuff(animalobj);
      ua.doStuff(horseobj);
      ua.doStuff(animalRefToHorse);
   }
}
```

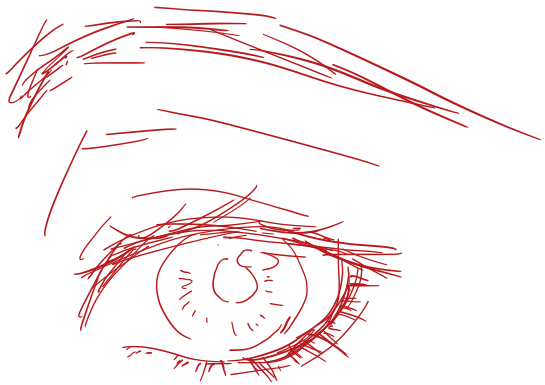
"Animal"

Which overridden version of the method to call is decided at runtime based on object type, but which overloaded version of the method to call is based on the reference type of the argument passed at compile time.

Invoking overloaded methods

```
class Animal {
   public void eat() {}
}

class Horse extends Animal {
   public void eat(String food) {}
}
```

Method Invocation Code	Result
`Animal a = new Animal();` `a.eat();`	
`Horse h = new Horse();` `h.eat();`	
`Animal ah = new Horse();` `ah.eat();`	
`Horse he = new Horse();` `he.eat("Apples");`	
`Animal a2 = new Animal();` `a2.eat("treats");`	
`Animal ah2 = new Horse();` `ah2.eat("Carrots");`	



Check your understanding

```
interface Animal {
    void vocalize();
}
class Dog implements Animal {
    public void vocalize() { System.out.println("Woof!"); }
}
class Cow implements Animal {
    public void vocalize() { moo(); }
    public void moo() {System.out.println("Moo!"); }
}
```

- **What will happen?**

```
1. Animal a = new Animal();
   a. vocalize();
2. Dog d = new Dog();
   d.vocalize();
3. Animal b = new Cow();
   b.vocalize();
4. b.moo();
```

Compile: Cannot Instantiate the type Animal

"Woof!"

"Moo!"

Compile: The method moo() is undefined for the type Animal

Overriding vs. Overloading

```
public class Test {
  public static void main(String[] args) {
    A a = new A();
    a.p(10);
  }
}

class B {
  public void p(int i) {
  }
}

class A extends B {
  // This method overrides the method in B
  public void p(int i) {
    System.out.println(i);
  }
}
```

The method p(int i) in class A overrides the same method defines in class B.

```
public class Test {
  public static void main(String[] args) {
    A a = new A();
    a.p(10);
  }
}

class B {
  public void p(int i) {
  }
}

class A extends B {
  // This method overloads the method in B
  public void p(double i) {
    System.out.println(i);
  }
}
```

The method p(int i) in class A overloads the same method defines in class B.

Overriding vs. Overloading

- **Do not confuse overriding a method in a derived class with overloading a method name**
  - When a method is overridden, the new method definition given in the derived class has the exact same number and types of parameters as in the base class
  - When a method in a derived class has a different signature from the method in the base class, that is overloading
  - Note that when the derived class overloads the original method, it still inherits the original method from the base class as well

Overriding vs. Overloading

	Overloading	Overriding
Argument list	Must change	Must not change
Return type	Can Change	Must not change
Exceptions	Can Change	Can reduce or eliminate Must not throw new or broader checked exception
Access	Can Change	Must not make more restrictive (can be less restrictive)
Invocation	Reference type determines which overloaded version (based on declared argument types) is selected. Happens at compile time. The actual method that's invoked is still a virtual method invocation that happens at runtime, but the compiler will always know the signature of the method that is to be invoked. So at runtime, the argument match will have already been nailed down, just not the actual class in which the method lives	Object type (in other words, the type of the actual instance on the heap) determines which method is selected. Happens at runtime.

(3) Parametric polymorphism and Generic programming

Parametric polymorphism

- **Parametric polymorphism** is obtained when a function works uniformly on a range of types; these types normally exhibit some common structure.
  - It the ability to define functions and types in a generic way so that it works based on the parameter passed at runtime, i.e., allowing static type-checking without fully specifying the type.
  - This is what is called "Generics (泛型)" in Java.
- **Generic programming** is a style of programming in which data types and functions are written in terms of types to-be-specified-later that are then instantiated when needed for specific types provided as parameters.

Generic programming centers around the idea of ***abstracting from concrete***, efficient algorithms to obtain generic algorithms that can be combined with different data representations ***to produce a wide variety of useful software.***

Template in C++

```
template<typename T>
class List {
   /* class contents */
};

List<Animal> list_of_animals;
List<Car> list_of_cars;
```

C++ Standard Library includes the Standard Template Library (STL) that provides a framework of templates for common data structures and algorithms.

```
template<typename T>
void Swap(T & a, T & b) {
   T temp = b;
   b = a;
   a = temp;
}

string hello = “world!”
string world = “Hello,”;
Swap( world, hello );
cout << hello << world << endl;
```

Generics in Java

- A **type variable** is an unqualified identifier 类型变量.
  - They are introduced by generic class declarations, generic interface declarations, generic method declarations, and by generic constructor declarations.

- A **class** is generic if it declares one or more type variables. 泛型类：其定义中包含了类型变量
  - These type variables are known as the type parameters of the class.
  - It defines one or more type variables that act as parameters.
  - A generic class declaration defines a set of parameterized types, one for each possible invocation of the type parameter section.
  - All of these parameterized types share the same class at runtime.

Generics in Java

- An **interface** is generic if it declares type variables 泛型接口
  - These type variables are known as the type parameters of the interface.
  - It defines one or more type variables that act as parameters.
  - A generic interface declaration defines a set of types, one for each possible invocation of the type parameter section.
  - All parameterized types share the same interface at runtime.

- A **method** is generic if it declares type variables.泛型方法
  - These type variables are known as the formal type parameters of the method.
  - The form of the formal type parameter list is identical to a type parameter list of a class or interface.

Type variables

- **Using <>, the diamond operator, to help declare type variables.**
- **For example:**
  - `List<Integer> ints = new ArrayList<Integer>();`
  - `public interface List<E>`
  - `public class Entry<KeyType, ValueType>`

```
public class PapersJar<T> {

        private List<T> itemList = new ArrayList<>();

        public void add(T item) {
                itemList.add(item);
        }

        public T get(int index) {
                return (T) itemList.get(index);
        }

        public static void main(String args[]) {
                PapersJar<String> papersStr = new PapersJar<>();
                papersStr.add("Lion");
                String str = (String) papersStr.get(0);
                System.out.println(str);

                PapersJar papersInt = new PapersJar();
                papersInt.add(new Integer(100));
                Integer integerObj = (Integer) papersInt.get(0);
                System.out.println(integerObj);
        }
}
```

Example

```
public class Pair<E> {
   private final E first, second;
   public Pair(E first, E second) {
      this.first = first;
      this.second = second;
   }
   public E first() { return first; }
   public E second() { return second; }
}
```

Client:

```
Pair<String> p = new Pair<>("Hello", "world");
String result = p.first();
```

Another example: Java Set

- `Set` is the ADT of finite sets of elements of some other type `E` .

```
/** A mutable set.
 *  @param <E> type of elements in the set */
public interface Set<E> {
```

- `Set` is an example of a generic type : a type whose specification is in terms of a placeholder type to be filled in later.
- Instead of writing separate specifications and implementations for `Set<String>` , `Set<Integer>` , and so on, we design and implement one `Set<E>` .

Another example: Java Set

- **Creator**

```
// example creator operation
/** Make an empty set.
 *  @param <E> type of elements in the set
 *  @return a new set instance, initially empty */
public static <E> Set<E> make() { ... }
```

- **Observer**

```
// example observer operations

/** Get size of the set.
 *  @return the number of elements in this set */
public int size();

/** Test for membership.
 *  @param e an element
 *  @return true iff this set contains e */
public boolean contains(E e);
```

- **Mutator**

```
// example mutator operations

/** Modifies this set by adding e to the set.
 *  @param e element to add */
public void add(E e);

/** Modifies this set by removing e, if found.
 *  If e is not found in the set, has no effect.
 *  @param e element to remove */
public void remove(E e);
```

Generic Interfaces

- **Suppose we want to implement the generic `Set<E>` interface.**
  - Way 1: Generic interface, non-generic implementation: to implement `Set<E>` for a particular type `E`. 泛型接口，非泛型的实现类

```
public interface Set<E> {

    // ...

    /**
     * Test for membership.
     * @param e an element
     * @return true iff this set contains e
     */
    public boolean contains(E e);

    /**
     * Modifies this set by adding e to the set.
     * @param e element to add
     */
    public void add(E e);

    // ...
}
```

```
public class CharSet1 implements Set<Character> {

    private String s = "";


    // ...


    @Override
    public boolean contains(Character e) {
        checkRep();
        return s.indexOf(e) != -1;
    }

    @Override
    public void add(Character e) {
        if (!contains(e)) s += e;
        checkRep();
    }
    // ...
}
```

Generic Interfaces

- **Way 2: Generic interface, generic implementation.** 泛型接口，泛型的实现类
  - We can also implement the generic `Set<E>` interface without picking a type for `E` .
  - In that case, we write our code blind to the actual type that clients will choose for `E` .
  - Java's `HashSet` does that for `Set`.

```
public interface Set<E> {

    // ...
```

```
public class HashSet<E> implements Set<E> {

    // ...
```

Some Java Generics details

- **Can have multiple type parameters**
  - e.g., `Map<E, F>, Map<String, Integer>`
- **Wildcards 通配符，只在使用泛型的时候出现，不能在定义中出现**
  - `List<?> list = new ArrayList<String>();`
  - `List<? extends Animal>`
  - `List<? super Animal>`
- **Generic type info is erased (i.e. compile-time only)**
  - Cannot use `instanceof()` to check generic type 运行时泛型消失了！
- **Cannot create Generic arrays**
  - `Pair<String>[] foo = new Pair<String>[42]; // won't compile`

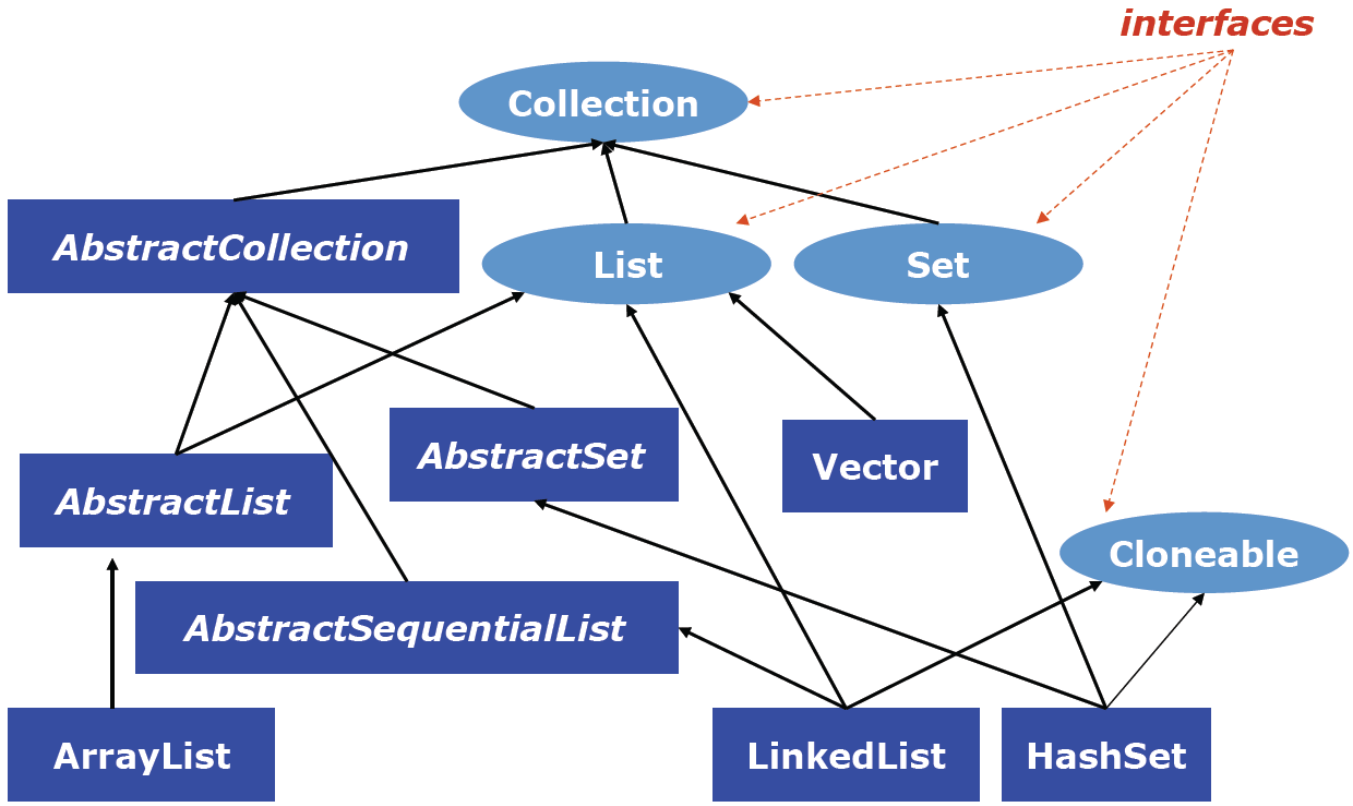
(4) Subtyping Polymorphism

Subtypes

- **A type is a set of values.**
  - The Java `List` type is defined by an interface.
  - If we think about all possible `List` values, none of them are `List` objects: we cannot create instances of an interface.
  - Instead, those values are all `ArrayList` objects, or `LinkedList` objects, or objects of another class that implements `List` .
- **A subtype is simply a subset of the supertype**
  - `ArrayList` and `LinkedList` are subtypes of `List`.

Inheritance and Subtype: a glimpse at the hierarchy

- **Java Collections API**



- **Benefits of inheritance/subtype:** Reuse of code, Modeling flexibility
- **In Java:** Each class can directly extend only one parent class; A class can implement multiple interfaces.

Subtypes

- **"B is a subtype of A" means "every B is an A."**
- **In terms of specifications: "every B satisfies the specification for A."**
  - B is only a subtype of A if B's specification is at least as strong as A's specification.
  - When we declare a class that implements an interface, the Java compiler enforces part of this requirement automatically: it ensures that every method in A appears in B, with a compatible type signature.
  - Class B cannot implement interface A without implementing all of the methods declared in A.

Static checking on subtypes

- **But the compiler cannot check that we haven't weakened the specification in other ways:**
  - Strengthening the precondition on some inputs to a method
  - Weakening a postcondition
  - Weakening a guarantee that the interface abstract type advertises to clients.
- **If you declare a subtype in Java (e.g., implementing an interface), then you must ensure that the subtype's spec is at least as strong as the supertype's.**
- 子类型的规约不能弱化超类型的规约。

Subtype polymorphism

- **Subtype polymorphism: Different kinds of objects can be treated uniformly by client code**

  子类型多态：不同类型的对象可以统一的处理而无需区分

- **Each object behaves according to its type (e.g., if you add new kind of account, client code does not change)** 从而隔离了“变化”

```
If today is the last day of the month:
   For each acct in allAccounts:
      acct.monthlyAdjustment();
```

- **Liskov Substitution Principle (LSP):**
  - If S is a subtype of T, then objects of type T may be replaced with objects of type S (i.e. an object of type T may be substituted with any object of a subtype S) without altering any of the desirable properties of T.

➔ **Section 5-2 Reusability**

An example

```java
/** A mutable rectangle. */
public interface MutableRectangle {
    // ... same methods as above ...
    /** Set this rectangle's dimensions to width x height. */
    public void setSize(int width, int height);
}
```

```java
/** A mutable square. */
public class MutableSquare {
    private int side;
    // ... same constructor and methods as above ...
    // TODO implement setSize(..)
}
```

```java
/** Set this square's dimensions to width x height.
 *  Requires width = height. */
public void setSize(int width, int height) { ... }
```

The stronger requirement `width = height` violates the contract of the interface ➔ Stronger precondition

```java
/** Set this square's dimensions to width x height.
 *  @throws BadSizeException if width != height */
public void setSize(int width, int height) throws BadSizeException { ... }
```

This postcondition requires different behavior, incompatible with the original spec.

An example

```java
/** A mutable rectangle. */
public interface MutableRectangle {
    // ... same methods as above ...
    /** Set this rectangle's dimensions to width x height. */
    public void setSize(int width, int height);
}
```

```java
/** A mutable square. */
public class MutableSquare {
    private int side;
    // ... same constructor and methods as above ...
    // TODO implement setSize(..)
}
```

A weaker postcondition

```java
/** If width = height, set this square's dimensions to width x height.
 *  Otherwise, new dimensions are unspecified. */
public void setSize(int width, int height) { ... }
```

Overload !

```java
/** Set this square's dimensions to side x side. */
public void setSize(int side) { ... }
```

instanceof

- **Operator that tests whether an object is of a given class**

```
public void doSomething(Account acct) {
    long adj = 0;
    if (acct instanceof CheckingAccount) {
        checkingAcct = (CheckingAccount) acct;
         adj = checkingAcct.getFee();
    } else if (acct instanceof SavingsAccount) {
        savingsAcct = (SavingsAccount) acct;
         adj = savingsAcct.getInterest();
    }
    …
}
```

- **Advice: avoid `instanceof()` if possible, and never(?) use `instanceof()` in a superclass to check type against subclass.**

Type casting

- **Sometimes you want a different type than you have**

```
double pi = 3.14;
int indianaPi = (int) pi;
```

- **Useful if you know you have a more specific subtype:**

```
Account acct = …;
CheckingAccount checkingAcct = (CheckingAccount) acct;
long fee = checkingAcct.getFee();
```

- **But it will get a `ClassCastException` if types are incompatible**
- **Advice:**
  - Avoid downcasting types WHY?
  - Never(?) downcast within superclass to a subclass WHY?

哈爾濱工業大學
HARBIN INSTITUTE OF TECHNOLOGY

9 *Dynamic dispatch

Dynamic dispatch

- **Dynamic dispatch is the process of selecting which implementation of a polymorphic operation to call at run time.**
  - Object-oriented systems model a problem as a set of interacting objects that enact operations referred to by name.
  - Polymorphism is the phenomenon wherein somewhat interchangeable objects each expose an operation of the same name but possibly differing in behavior.

Determining which method to call at runtime, i.e., a call to an overridden or polymorphic method is resolved at runtime

Dynamic dispatch

- **As an example, a `File` object and a `Database` object both have a `StoreRecord` method that can be used to write a personnel record to storage. Their implementations differ.**
- **A program holds a reference to an object which may be either a `File` object or a `Database` object. Which it is may have been determined by a run-time setting, and at this stage, the program may not know or care which.**
- **When the program calls `StoreRecord` on the object, something needs to decide which behavior gets enacted.**
- **The program sends a `StoreRecord` message to an object of unknown type, leaving it to the run-time support system to dispatch the message to the right object. The object enacts whichever behavior it implements.**

Dynamic dispatch

```
dividend.divide(divisor)  # dividend / divisor
```

- **This is thought of as sending a message named `divide` with parameter `divisor` to `dividend`.**
- **An implementation will be chosen based only on `dividend`'s type (perhaps rational, floating point, matrix), disregarding the type or value of `divisor`.**

Dynamic dispatch

- **Dynamic dispatch contrasts with static dispatch, in which the implementation of a polymorphic operation is selected at compile-time.**

- **The purpose of dynamic dispatch is to support cases where the appropriate implementation of a polymorphic operation cannot be determined at compile time because it depends on the runtime type of one or more actual parameters to the operation.**

- **静态分派：编译阶段即可确定要执行哪个具体操作。**

Overloaded methods are bonded using static binding while overridden methods are bonded using dynamic binding at runtime.

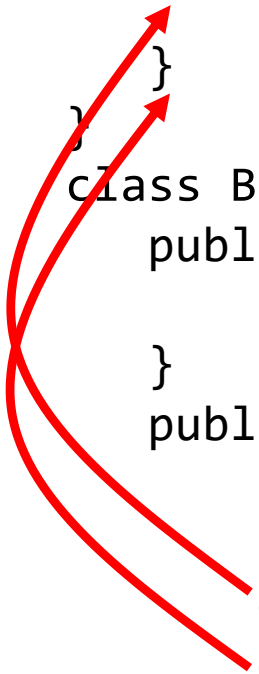
Dynamic dispatch

- **Dynamic dispatch is different from late binding (also known as dynamic binding 推迟绑定).**
  - When selecting an operation, binding associates a name to an operation.
  - Dispatching chooses an implementation for the operation after you have decided which operation a name refers to.
  - 绑定：将调用的名字与实际的方法名字联系起来（可能很多个）；分派：具体执行哪个方法（early binding → static dispatch）
  - With dynamic dispatch, the name may be bound to a polymorphic operation at compile time, but the implementation not be chosen until run time. 动态分派：编译阶段可能绑定到多态操作，运行阶段决定具体执行哪个（override和overload均是如此）；
  - While dynamic dispatch does not imply late binding, late binding does imply dynamic dispatching since the binding is what determines the set of available dispatches. 推迟绑定：编译阶段不知道类型，一定是动态分派（override是推迟绑定，overload是early binding）

Early/static binding

- **Whenever a binding of static, private and final methods happen, type of the class is determined by the compiler at compile time and the binding happens then and there.**

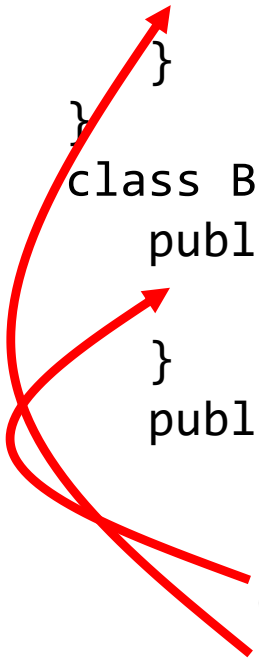
```
class Human{
    public static void walk() {
        System.out.println("Human walks");
    }
}
class Boy extends Human{
    public static void walk(){
        System.out.println("Boy walks");
    }
    public static void main( String args[]) {
        Human obj = new Boy();
        Human obj2 = new Human();
        obj.walk();
        obj2.walk();
    }
}
```



Late/dynamic binding

- **In overriding both parent and child classes have same method and in this case the type of the object determines which method is to be executed. The type of object is determined at the run.**

```
class Human{
    public void walk() {
        System.out.println("Human walks");
    }
}
class Boy extends Human{
    public void walk(){
        System.out.println("Boy walks");
    }
    public static void main( String args[]) {
        Human obj = new Boy();
        Human obj2 = new Human();
        obj.walk();
        obj2.walk();
    }
}
```



Dynamic method dispatch

1. **(Compile time) Determine which class to look in**
2. **(Compile time) Determine method signature to be executed**
   - Find all accessible, applicable methods
   - Select most specific matching method
3. **(Run time) Determine dynamic class of the receiver**
4. **(Run time) From dynamic class, locate method to invoke**
   - Look for method with the same signature found in step 2
   - Otherwise search in superclass and etc.

Example

```
class Game {
 public void type(){
    System.out.println("Indoor & outdoor");
}

class Cricket extends Game {
 public void type() {
    System.out.pri                    me"); }

 public static void                  (String[] args) {
   Game gm = new G                  ();
   Cricket ck = new Cricket();
   gm.type();
   ck.type();
   gm=ck;        //gm refers to Cricket object
   gm.type();  //calls Cricket's version of type
 }
}
```

Override方法
Late biding
Dynamic dispatch

Early binding
Static dispatch

Upcasting: a
Parent class
variable refers to
Child class object

Late binding
Dynamic dispatch

Late binding
Dynamic dispatch

10 Some important `Object` methods in Java

Overriding `Object` methods

- `equals()` – **true if the two objects are "equal"**
- `hashCode()` – **a hash code for use in hash maps**
- `toString()` – **a** `printable` **string representation**

- `toString()` – **ugly and uninformative**
  - You know what your object is so you can do better
  - Always override unless you know in won't be called
- `equals` **&** `hashCode` – ***identity semantics***
  - You *must* override if you want *value* semantics
  - Otherwise don't

Overriding `toString()`

```
final class PhoneNumber {
    private final short areaCode;
    private final short prefix;
    private final short lineNumber;
      ...
    @Override public String toString() {
        return String.format("(%03d) %03d-%04d",
            areaCode, prefix, lineNumber);
    }
}

Number jenny = ...;
System.out.println(jenny);
```

Prints: `(707) 867-5309`

`equals` Override Example

```
public final class PhoneNumber {
    private final short areaCode;
    private final short prefix;
    private final short lineNumber;

    @Override public boolean equals(Object o) {
        if (!(o instanceof PhoneNumber))  // Does null check
            return false;
        PhoneNumber pn = (PhoneNumber) o;
        return pn.lineNumber == lineNumber
                && pn.prefix == prefix
                && pn.areaCode == areaCode;
    }

    ...
}
```

hashCode override example

```
public final class PhoneNumber {
    private final short areaCode;
    private final short prefix;
    private final short lineNumber;

    @Override public int hashCode() {
        int result = 17;  // Nonzero is good
        result = 31 * result + areaCode;   // Constant must be odd
        result = 31 * result + prefix;     //      "     "   "   "
        result = 31 * result + lineNumber; //      "     "   "   "
        return result;
    }

    ...
}
```

Alternative `hashCode` override

- **Less efficient, but otherwise equally good!**

```
public final class PhoneNumber {
    private final short areaCode;
    private final short prefix;
    private final short lineNumber;

    @Override public int hashCode() {
        return arrays.hashCode(areaCode, prefix, lineNumber);
    }

    ...
}
```

What does this print?

```
public class Name {
    private final String first, last;
    public Name(String first, String last) {
        if (first == null || last == null)
            throw new NullPointerException();
        this.first = first; this.last = last;
    }
    public boolean equals(Name o) {
        return first.equals(o.first) && last.equals(o.last);
    }
    public int hashCode() {
        return 31 * first.hashCode() + last.hashCode();
    }
    public static void main(String[] args) {
        Set<Name> s = new HashSet<>();
        s.add(new Name("Mickey", "Mouse"));
        System.out.println(
            s.contains(new Name("Mickey", "Mouse")));
    }
}
```

(a) true
(b) false
(c) It varies
(d) None of the above

- `Name` overrides `hashCode` but not `equals`! The two `Name` instances are thus unequal.

How do you fix it?

- Replace the overloaded equals method with an overriding equals method.

```
@Override public boolean equals(Object o) {
    if (!(o instanceof Name))
        return false;
    Name n = (Name) o;
    return n.first.equals(first) && n.last.equals(last);
}
```

哈爾濱工業大學
HARBIN INSTITUTE OF TECHNOLOGY

11 Designing good classes

Advantages of immutable classes

- **Simplicity**
- **Inherently Thread-Safe**
- **Can be shared freely**
- **No need for defensive copies**
- **Excellent building blocks**

How to write an immutable class

- Don't provide any mutators
- Ensure that no methods may be overridden
- Make all fields `final`
- Make all fields `private`
- Ensure security of any mutable components (avoid rep exposure)
- **Implement** `toString()`, `hashCode()`, `clone()`, `equals()`, **etc.**

Immutable class example

```
public final class Complex {
    private final double re, im;

    public Complex(double re, double im) {
        this.re = re;
        this.im = im;
    }

    // Getters without corresponding setters
    public double realPart()      { return re; }
    public double imaginaryPart() { return im; }

    // subtract, multiply, divide similar to add
    public Complex add(Complex c) {
        return new Complex(re + c.re, im + c.im);
    }
```

Immutable class example

```
    @Override public boolean equals(Object o) {
        if (!(o instanceof Complex)) return false;
        Complex c = (Complex)o;
        return Double.compare(re, c.re) == 0 &&
               Double.compare(im, c.im) == 0;
    }

    @Override public int hashCode() {
       return 31*Double.hashCode(re) + Double.hashCode(im);
    }

    @Override public String toString() {
        return String.format("%d + %di”, re, im)";
    }
}
```

When to make classes immutable

- **Always, unless there's a good reason not to**
- Always make small "value classes" immutable!
  - Examples: `Color`, `PhoneNumber`, `Unit`
  - `Date` and `Point` were mistakes!
  - Experts often use `long` instead of `Date`

When to make classes mutable

- **Class represents entity whose state changes**
  - Real-world - `BankAccount`, `TrafficLight`
  - Abstract - `Iterator`, `Matcher`, `Collection`
  - Process classes - `Thread`, `Timer`
- **If class must be mutable, *minimize mutability***
  - Constructors should fully initialize instance
  - Avoid reinitialize methods

哈爾濱工業大學
HARBIN INSTITUTE OF TECHNOLOGY

12 History of OOP

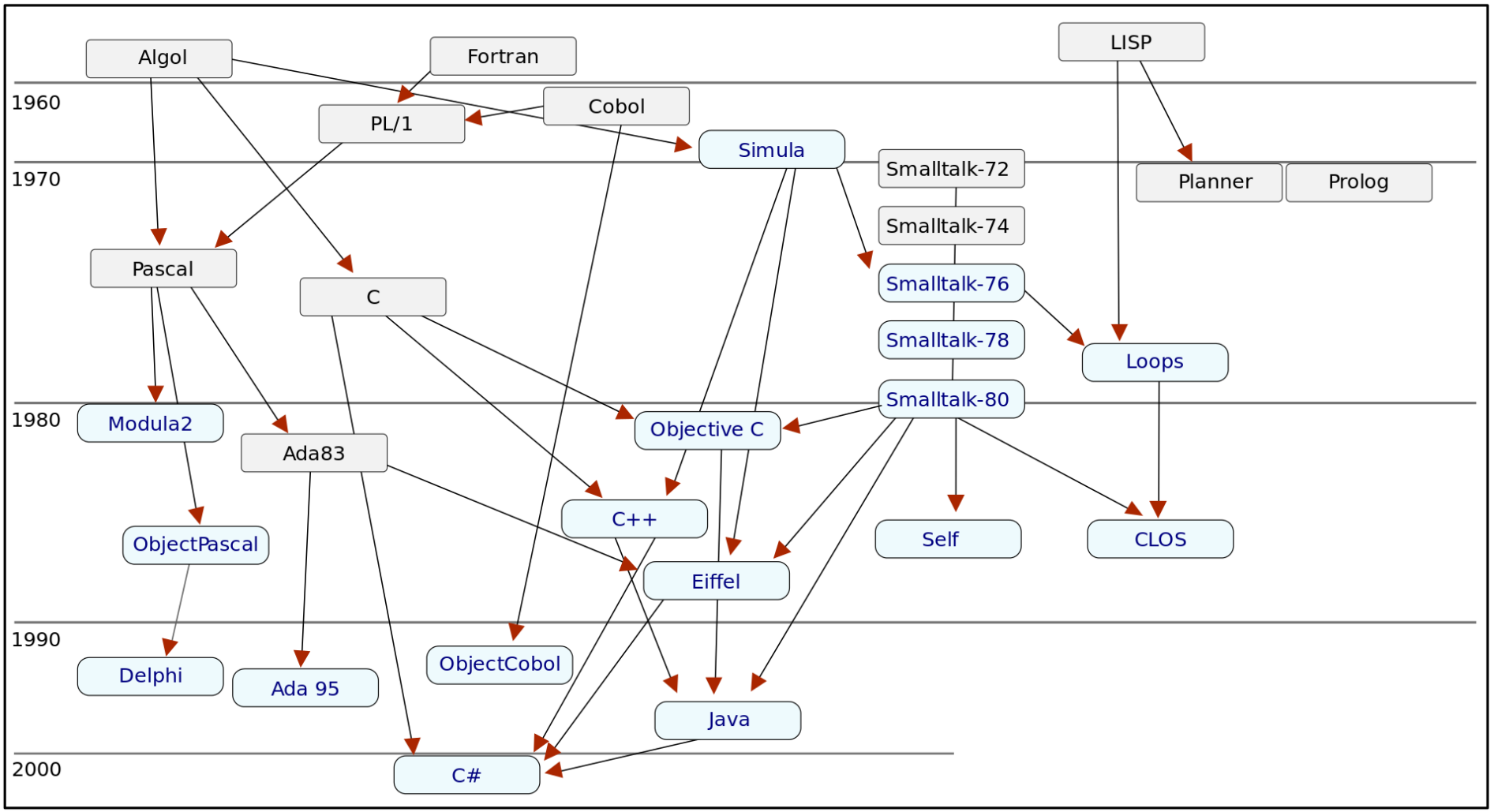
Simulation and the origins of OO programming

- **1960s: Simula 67** was the first object-oriented language developed by **Kristin Nygaard and Ole-Johan Dahl** at the Norwegian Computing Center, to support *discrete-event simulation*. (Class, object, inheritance, etc)

- The term "object oriented programming (OOP) " was first used by Xerox PARC in their Smalltalk language.

- 1980s: OOP had become prominent, and the primary factor in this is C++.
- Niklaus Wirth for modular programming and data abstraction, with Oberon and Modula-2;
- Eiffel and Java

History of OOP languanges



Summary

Summary

- **Criteria of Object-Orientation**
- **Basic concepts: object, class, attribute, method, and interface**
- **Distinct features of OOP**
  - Encapsulation and information hiding
  - Inheritance and overriding
  - Polymorphism, subtyping and overloading
  - Static and Dynamic dispatch
- **Some important `Object` methods in Java**
- **To write an immutable class**
- **History of OOP**
- **Summary**

哈爾濱工業大學
HARBIN INSTITUTE OF TECHNOLOGY

The end

March 31, 2024