Principles of Software Construction: Objects, Design, and Concurrency

Object-Oriented Programming in Java

Josh Bloch   Charlie Garrod   Darya Melicher
Administrivia

• Homework 1 due Thursday 11:59 p.m.
  – Everyone must read and sign our collaboration policy
• First reading assignment due Tuesday
  – Effective Java Items 15 and 16
Key concepts from Thursday

• Bipartite type system – primitives & object refs
  – Single implementation inheritance
  – Multiple interface inheritance
• Easiest output – println, printf
• Easiest input – Command line args, Scanner
• Collections framework is powerful & easy to use
Outline

I. Object-oriented programming basics
II. Information hiding
III. Exceptions
Objects

• 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 final double re;  // Real Part
    private final 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)   { ...  }
}
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");
    }
}

When you run this program, it prints
-1.0 + 1.0i
-0.0 + -1.0i
Interfaces and implementations

• Multiple implementations of API can coexist
  – Multiple classes can implement the same API
  – They can differ in performance and behavior

• In Java, an API is specified by *interface* or *class*
  – Interface provides only an API
  – Class provides an API and an implementation
  – A class can implement multiple interfaces
An interface to go with our class

```java
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);
}
```

An interface defines but does not implement API
Modifying class to use interface

class OrdinaryComplex implements Complex {
    final double re;  // Real Part
    final 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

```java
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");
    }
}
```

When you run this program, it still prints

```
-1.0 + 1.0i
-0.0 + -1.0i
```
Interface permits multiple implementations

class PolarComplex implements Complex {
    final double r;
    final 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

```java
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");
    }
}
```

When you run this program, it STILL prints

-1.0 + 1.0i
-0.0 + -1.0i
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
Java interfaces and classes

• A type defines a family of objects
  – Each type offers a specific set of operations
  – Objects are otherwise opaque

• Interfaces vs. classes
  – Interface: specifies expectations
  – Class: delivers on expectations (the implementation)
Classes as types

• Classes *do* define types
  – Public class methods usable like interface methods
  – Public fields directly accessible from other classes

• But generally prefer the use of interfaces
  – Use interface types for variables and parameters unless you know a single implementation will suffice
    • Supports change of implementation
    • Prevents dependence on implementation details

```java
Set<Criminal> senate = new HashSet<>();          // Do this...
HashSet<Criminal> senate = new HashSet<>();      // Not this
```
interface Animal {
    void vocalize();
}

class Dog implements Animal {
    public void vocalize() {
        System.out.println("Woof!"不容许);
    }
}

class Cow implements Animal {
    public void vocalize() {
        moo();
    }
    public void moo() {
        System.out.println("Moo!"不容许);
    }
}

What Happens?
1. Animal a = new Animal();
   a. vocalize();
2. Dog d = new Dog();
   d.vocalize();
3. Animal b = new Cow();
   b.vocalize();
4. b.moo();
Historical note: simulation and the origins of OO programming

• Simula 67 was the first object-oriented language

• Developed by Kristin Nygaard and Ole-Johan Dahl at the Norwegian Computing Center

• Developed to support *discrete-event simulation*
  — Application: operations research, e.g. traffic analysis
  — Extensibility was a key quality attribute for them
  — Code reuse was another
Outline

I. Object-oriented programming basics
II. Information hiding
III. Exceptions
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
  – They are oblivious to each others’ inner workings

• Known as *information hiding* or *encapsulation*

• Fundamental tenet of software design [Parnas, ‘72]
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 types
• Client can use only interface methods
• Fields not accessible from client code
• But this only takes us so far
  – Client can access non-interface members directly
  – In essence, it’s voluntary information hiding
Mandatory Information hiding

visibility modifiers for members

• private – Accessible only from declaring class

• package-private – Accessible from any class in the package where it is declared
  – Technically known as default access
  – You get this if no access modifier is specified

• 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) { ... }
}
Discussion

• You know the benefits of private fields
• What are the benefits of private methods?
Best practices for information hiding

• Carefully design your API
• Provide *only* functionality required by clients
  – *All* other members should be private
• You can always make a private member public later without breaking clients
  – But not vice-versa!
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What does this code do?

```java
FileInputStream fIn = new FileInputStream(fileName);
if (fIn == null) {
    switch (errno) {
    case _ENOFILE:
        System.err.println("File not found: " + ...);
        return -1;
    default:
        System.err.println("Something else bad happened: " + ...);
        return -1;
    }
}
DataInputStream dataInput = new DataInputStream(fIn);
if (dataInput == null) {
    System.err.println("Unknown internal error.");
    return -1;  // errno > 0 set by new DataInputStream
}
int i = dataInput.readInt();
if (errno > 0) {
    System.err.println("Error reading binary data from file");
    return -1;
}
// The Slide lacks space to close the file. Oh well.
return i;
```
What does this code do?

```java
FileInputStream fIn = new FileInputStream(fileName);
if (fIn == null) {
    switch (errno) {
    case _ENOFILE:
        System.err.println("File not found: " + …);
        return -1;
    default:
        System.err.println("Something else bad happened: " + …);
        return -1;
    }
}
DataInputStream dataInput = new DataInputStream(fIn);
if (dataInput == null) {
    System.err.println("Unknown internal error.");
    return -1;  // errno > 0 set by new DataInputStream
}
int i = dataInput.readInt();
if (errno > 0) {
    System.err.println("Error reading binary data from file");
    return -1;
}  // The Slide lacks space to close the file. Oh well.
return i;
```
Compare to:

```java
FileStream fileInput = null;
try {
    fileInput = new FileInputStream(fileName);
    DataInput dataInput = new DataInputStream(fileInput);
    return dataInput.readInt();
} catch (FileNotFoundException e) {
    System.out.println("Could not open file " + fileName);
} catch (IOException e) {
    System.out.println("Couldn’t read file: " + e);
} finally {
    if (fileInput != null)
        fileInput.close();
}
```
Exceptions

• Notify the caller of an exceptional condition by automatic transfer of control

• Semantics:
  – Propagates up stack until main method is reached (terminates program), or exception is caught

• Sources:
  – Program – e.g., IllegalArgumentException
  – JVM – e.g., StackOverflowError
public static void main(String[] args) {
    try {
        test();
    } catch (IndexOutOfBoundsException e) {
        System.out.println("Caught index out of bounds");
    }
}

public static void test() {
    try {
        System.out.println("Top");
        int[] a = new int[10];
        a[42] = 42;
        System.out.println("Bottom");
    } catch (NegativeArraySizeException e) {
        System.out.println("Caught negative array size");
    }
}
Checked vs. unchecked exceptions

• Checked exception
  – Must be caught or propagated, or program won’t compile

• Unchecked exception
  – No action is required for program to compile
  – But uncaught exception will cause program to fail!
The exception hierarchy in Java

- Exception
  - RuntimeException
  - IOException
  - EOFException
  - ClassNotFoundException
  - ...
Design choice: checked and unchecked exceptions and return values

• Unchecked exception
  – Programming error, other unrecoverable failure
• Checked exception
  – An error that every caller should be aware of and handle
• Special return value (e.g., null from Map.get)
  – Common but atypical result
• Do NOT use return codes
• NEVER return null to indicate a zero-length result
  – Use a zero-length list or array instead
One more alternative – return Optional<T>

• Optional<T> is a single T instance or nothing
  – A value is said to present, or the optional is empty
  – Can think of it as a subsingleton collection
• Similar in spirit to checked exceptions
  – Force caller to confront possibility of no value
• But optionals demand less boilerplate in client
• Can be tricky to decide which alternative to use
• See Effective Java Item 55 for more information
A sample use of `Optional<T>`

```java
// Returns maximum value in collection as an Optional<E>
public static <E extends Comparable<E>> Optional<E> max(Collection<E> c) {
    if (c.isEmpty())
        return Optional.empty();

    E result = null;
    for (E e : c)
        if (result == null || e.compareTo(result) > 0)
            result = Objects.requireNonNull(e);

    return Optional.of(result);
}
```
Creating and throwing your own exceptions

```java
public class SpanishInquisitionException extends RuntimeException {
    public SpanishInquisitionException() {
    }
}

public class HolyGrail {
    public void seek() {
        ...
        if (heresyByWord() || heresyByDeed())
            throw new SpanishInquisitionException();
        ...
    }
}
```
Benefits of exceptions

• You can’t forget to handle common failure modes
  – Compare: using a flag or special return value
• Provide high-level summary of error, and stack trace
  – Compare: core dump in C
• Improve code structure
  – Separate normal code path from exceptional
  – Ease task of recovering from failure
• Ease task of writing robust, maintainable code
Guidelines for using exceptions (1)

• Avoid unnecessary checked exceptions (EJ Item 71)
• Favor standard exceptions (EJ Item 72)
  – IllegalArgumentException – invalid parameter value
  – IllegalStateException – invalid object state
  – NullPointerException – null param where prohibited
  – IndexOutOfBoundsException – invalid index param
• Throw exceptions appropriate to abstraction (EJ Item 73)
Guidelines for using exceptions (2)

• Document all exceptions thrown by each method
  – Checked and unchecked (EJ Item 74)
  – But don’t declare unchecked exceptions!

• Include failure-capture info in detail message (Item 75)
  – throw new IllegalArgumentException(
    "Modulus must be prime: " + modulus);

• Don’t ignore exceptions (EJ Item 77)
  // Empty catch block IGNORES exception – Bad smell in code!
  try {
      ...
  } catch (SomeException e) { }
FileInputStream fileInput = null;
try {
    FileInputStream fileInput = new FileInputStream(fileName);
    DataInput dataInput = new DataInputStream(fileInput);
    return dataInput.readInt();
} catch (FileNotFoundException e) {
    System.out.println("Could not open file " + fileName);
} catch (IOException e) {
    System.out.println("Couldn’t read file: " + e);
} finally {
    if (fileInput != null) fileInput.close();
}
Manual resource termination is ugly and error prone

• Even good programmers usually get it wrong
  – Sun’s Guide to Persistent Connections got it wrong in code that claimed to be exemplary
  – Solution on page 88 of Bloch and Gafter’s *Java Puzzlers* is badly broken; no one noticed for years

• 70% of the uses of the close method in the JDK itself were wrong in 2008(!)

• Even “correct” idioms for manual resource management are deficient
The solution: try-with-resources (TWR)

Automatically closes resources

```java
try (DataInput dataInput =
     new DataInputStream(new FileInputStream(fileName))) {
    return dataInput.readInt();
}
catch (FileNotFoundException e) {
    System.out.println("Could not open file " + fileName);
}
catch (IOException e) {
    System.out.println("Couldn’t read file: " + e);
}
```
File copy without TWR

static void copy(String src, String dest) throws IOException {
    InputStream in = new FileInputStream(src);
    try {
        OutputStream out = new FileOutputStream(dest);
        try {
            byte[] buf = new byte[8 * 1024];
            int n;
            while ((n = in.read(buf)) >= 0)
                out.write(buf, 0, n);
        } finally {
            out.close();
        }
    } finally {
        in.close();
    }
}

File copy with TWR

static void copy(String src, String dest) throws IOException {
    try (InputStream in = new FileInputStream(src);
        OutputStream out = new FileOutputStream(dest)) {
        byte[] buf = new byte[8 * 1024];
        int n;
        while ((n = in.read(buf)) >= 0)
            out.write(buf, 0, n);
    }
}
Summary

• Interface-based designs handle change well
• Information hiding is crucial to good design
• Exceptions are far better than error codes
• The need for checked exceptions is rare
• try-with-resources (TWR) is a big win