Principles of Software Construction: Objects, Design, and Concurrency

Generics, I/O, and reflection

Josh Bloch Charlie Garrod Darya Melicher

Carnegie Mellon University
School of Computer Science

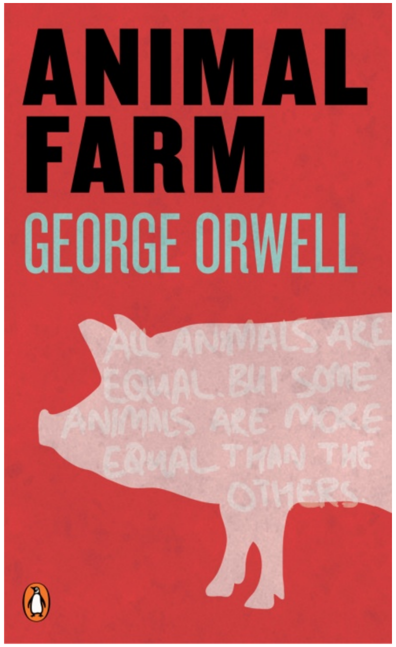
institute for SOFTWARE RESEARCH

Administrivia

- Homework 4b due this Thursday, October 18th

Java puzzlers: "Animal Farm" (2005)

```
public class AnimalFarm {
    public static void main(String[] args) {
        final String pig = "length: 10";
        final String dog = "length: " + pig.length();
        System.out.println("Animals are equal: "
                           + pig == dog);
    }
}
```


ANIMAL FARM
GEORGE ORWELL
ALL ANIMALS ARE EQUAL BUT SOME ANIMALS ARE MORE EQUAL THAN THE OTHERS

What does it print?

```
public class AnimalFarm {
    public static void main(String[] args) {
        final String pig = "length: 10";
        final String dog = "length: " + pig.length();
        System.out.println("Animals are equal: "
                           + pig == dog);
    }
}
```

(a) `Animals are equal: true`

(b) `Animals are equal: false`

(c) It varies

(d) None of the above

What does it print?

(a) `Animals are equal: true`

(b) `Animals are equal: false`

(c) It varies

(d) None of the above: `false`

The + operator binds tighter than ==

Another look

```
public class AnimalFarm {
    public static void main(String[] args) {
        final String pig = "length: 10";
        final String dog = "length: " + pig.length();
        System.out.println("Animals are equal: "
                           + pig == dog);
    }
}
```

You could try to fix it like this...

```
public class AnimalFarm {
    public static void main(String[] args) {
        final String pig = "length: 10";
        final String dog = "length: " + pig.length();
        System.out.println("Animals are equal: "
                                   + (pig == dog));
    }
}
```

Prints `Animals are equal: false`

But this is much better

```
public class AnimalFarm {
    public static void main(String[] args) {
        final String pig = "length: 10";
        final String dog = "length: " + pig.length();
        System.out.println("Animals are equal: "
                                   + pig.equals(dog));
    }
}
```

Prints Animals are equal: true

The moral

- **Use parens, not spacing, to express intent**
- Use parens whenever there is any doubt
- Don't depend on interning of string constants
- **Use `.equals`, not `==` for object references**

Key concepts from Tuesday…

This is actually the conclusion from last lecture, which I forgot to go over

- **It takes a lot of work to make something that appears obvious**
  - Coherent, unified vision
  - Willingness to listen to others
  - Flexibility to accept change
  - Tenacity to resist change
  - Good documentation!
- **It's worth the effort!**
  - A solid foundation can last two+ decades

Outline

I. Generics – better late than never

II. I/O – history, critique, and advice

III. A brief introduction to reflection

Parametric polymorphism (a.k.a. generics)

- *Parametric polymorphism* is the ability to define a type generically, allowing static type-checking without fully specifying the type
  - e.g.:

```
public class Frequency {
  public static void main(String[] args) {
     Map<String, Integer> m = new TreeMap<>();
     for (String word : args) {
         Integer freq = m.get(word);
         m.put(word, (freq == null ? 1 : freq + 1));
     }
     System.out.println(m);
  }
}
```

A generic implementation of pairs

```
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; }
}
```

- Better client code:

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

Some Java Generics details

- Can have multiple type parameters
  - e.g., `Map<String, Integer>`
- Generics are type invariant
  - `ArrayList<String>` is a subtype of `List<String>`
  - `List<String>` is not a subtype of `List<Object>`
- Generic type info is erased (i.e. compile-time only)
  - Cannot use `instanceof` to check generic type
- Cannot create Generic arrays

```
Pair<String>[] foo = new Pair<String>[42]; // won't compile
```

Generic array creation is illegal

```
                             // won't compile
List<String>[] stringLists = new List<String>[1];
List<Integer> intList = Arrays.asList(42);
Object[] objects = stringLists;
objects[0] = intList;
String s = stringLists[0].get(0); // Would be type-safe
```

Generic design advice: Prefer lists to arrays

```
// Fails at runtime
Object[] oArray = new Long[42];
oArray[0] = "I don't fit in"; // Throws ArrayStoreException

// Won't compile
List<Object> ol = new ArrayList<Long>(); // Incompatible type
ol.add("I don't fit in");
```

Wildcard types provide API flexibility

- `List<String>` is *not* a subtype of `List<Object>`
  - i.e., generic types are invariant
  - But **wildcard types provide inheritance on generics**
- How wildcard types are read
  - `List<?>` is a "list of some type"
  - `List<? extends Animal>` is "list of some subtype of animal"
  - `List<? Super Animal>` is "list of some supertype of animal"
- Subtyping relations
  - `List<String>` is a subtype of `List<? extends Object>`
  - `List<Object>` is a subtype of `List<? super String>`
  - `List<Anything>` is a subtype of `List<?>`
- Wildcards are technically know as *variance annotations*

Wildcards in the java.util.Collection API

```
public interface Collection<E> … {
  boolean     add(E e);
  boolean     addAll(Collection<? extends E> c);
  boolean     remove(Object e);
  boolean     removeAll(Collection<?> c);
  boolean     retainAll(Collection<?> c);
  boolean     contains(Object e);
  boolean     containsAll(Collection<?> c);
  void        clear();
  int         size();
  boolean     isEmpty();
  Iterator<E> iterator();
  Object[]    toArray()
  <T> T[]     toArray(T[] a);
  …
}
```

An inflexible API without wildcards

- Suppose you want to add bulk methods to `Stack<E>`:

```
void pushAll(Collection<E> src);

void popAllInto(Collection<E> dst);
```

- Problem:
  - It should be fine to push a `Long` onto a `Stack<Number>`:

```
Collection<Long> numbers = …;
Stack<Number> numberStack = …;
for (Long n : numbers) {
    numberStack.push(n);
}
```

  - This API prevents `pushAll(Collection<Long>)` onto a `Stack<Number>`

Generic design advice: Use your PECS

- PECS: Producer extends, Consumer super
  - For a T producer, use `Foo<? extends T>`
  - For a T consumer, use `Foo<? super T>`
  - Mnemonic only works for input parameters

Use your PECS

- Suppose you want to add bulk methods to `Stack<E>`:

```
void pushAll(Collection<E> src);

void popAllInto(Collection<E> dst);
```

Use your PECS

- Suppose you want to add bulk methods to `Stack<E>`:

```
void pushAll(Collection<? extends E> src);
```

  - `src` is an E producer

```
void popAllInto(Collection<? super E> dst);
```

  - `dst` is an E consumer

Outline

I. Generics – better late than never

II. I/O – history, critique, and advice

III. A brief introduction to reflection

A brief, sad history of I/O in Java

Release, Year	Changes
JDK 1.0, 1996	`java.io.InputStream/OutputStream` – byte-based
JDK 1.1, 1997	`java.io.Reader/Writer` – char-based wrappers
J2SE 1.4, 2002	`java.nio.Channel/Buffer` – “Flexible” + select/poll, mmap
J2SE 5.0, 2004	`java.util.Scanner`, `String.printf/format` – Formatted
Java 7, 2011	`java.nio.file  Path/Files` – file systems `java.nio.AsynchronousFileChannel` - *Real* async I/O
Java 8, 2014	`Files.lines` – lambda/stream integration
3d party, 2014	`com.squareup.okio.Buffer` – “Modern”

A Rogue's Gallery of cats

Thanks to Tim Bloch for cat-herding

cat 1: StreamCat

```
/**
 * Reads all lines from a text file and prints them.
 * Uses Java 1.0-era (circa 1996) Streams to read the file.
 */
public class StreamCat {
    public static void main(String[] args) throws IOException {
        DataInputStream dis = new DataInputStream(
                new FileInputStream(args[0]));

        // Don't do this! DataInputStream.readLine is DEPRECATED!
        String line;
        while ((line = dis.readLine()) != null)
            System.out.println(line);
    }
}
```

cat 2: ReaderCat

```
/**
 * Reads all lines from a text file and prints them.
 * Uses Java 1.1-era (circa 1997) Streams to read the file.
 */
public class ReaderCat {
    public static void main(String[] args) throws IOException {
        try (BufferedReader rd = new BufferedReader(
                new FileReader(args[0]))) {
            String line;
            while ((line = rd.readLine()) != null) {
                System.out.println(line);
                // you could also wrap System.out in a PrintWriter
            }
        }
    }
}
```

cat 3: NioCat

```
/**
 * Reads all lines from a text file and prints them.
 * Uses nio FileChannel and ByteBuffer.
 */
public class NioCat {
    public static void main(String[] args) throws IOException {
        ByteBuffer buf = ByteBuffer.allocate(512);
        try (FileChannel ch = FileChannel.open(Paths.get(args[0]),
                StandardOpenOption.READ)) {
            int n;
            while ((n = ch.read(buf)) > -1) {
                System.out.print(new String(buf.array(), 0, n));
                buf.clear();
            }
        }
    }
}
```

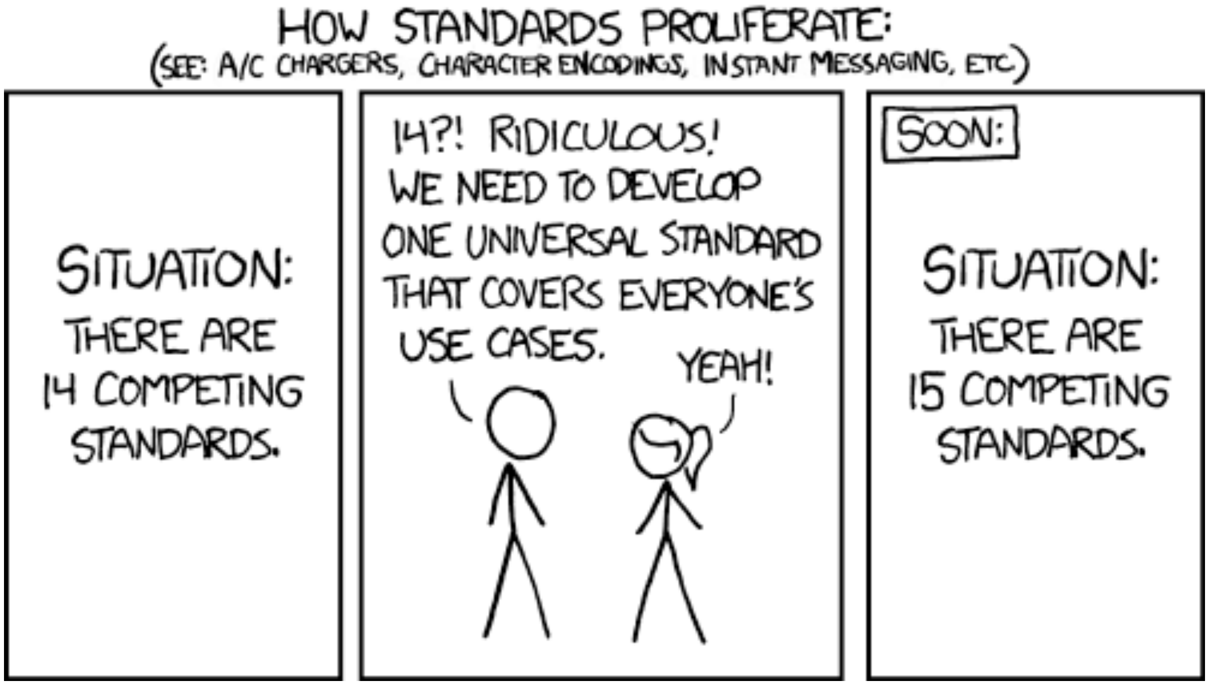
cat 4: ScannerCat

```
/**
 * Reads all lines from a text file and prints them
 * Uses Java 5 scanner.
 */
public class ScannerCat {
    public static void main(String[] args) throws IOException {
        try (Scanner s = new Scanner(new File(args[0]))) {
            while (s.hasNextLine())
                System.out.println(s.nextLine());
        }
    }
}
```

cat 5: LinesCat

```
/**
 * Reads all lines from a text file and prints them.  Uses Files,
 * Java 8-era Stream API (not IO Streams!) and method references.
 */
public class LinesCat {
  public static void main(String[] args) throws IOException {
    Files.lines(Paths.get(args[0])).forEach(System.out::println);
  }
}
```

Randall Munroe understands


HOW STANDARDS PROLIFERATE:
(SEE: A/C CHARGERS, CHARACTER ENCODINGS, INSTANT MESSAGING, ETC.)
SITUATION: THERE ARE 14 COMPETING STANDARDS.
14?! RIDICULOUS! WE NEED TO DEVELOP ONE UNIVERSAL STANDARD THAT COVERS EVERYONE'S USE CASES.
YEAH!
SOON:
SITUATION: THERE ARE 15 COMPETING STANDARDS.

A useful example – curl in Java

prints the contents of a URL

```java
public class Curl {
    public static void main(String[] args) throws IOException {
        URL url = new URL(args[0]);
        try (BufferedReader r = new BufferedReader(
                new InputStreamReader(url.openStream(),
                StandardCharsets.UTF_8))) {
            String line;
            while ((line = r.readLine()) != null)
                System.out.println(line);
        }
    }
}
```

Java I/O Recommendations

- Everyday use – `Buffered{Reader, Writer}`
- Casual use - `Scanner`
  - Easy but not general and swallows exceptions
- Stream integration – `Files.lines`
  - Support for parallelism in Java 9
- Async – `java.nio.AsynchronousFileChannel`
- Many niche APIs, e.g. memory mapped files, line numbering
  - Search them out as needed
- Consider Okio if third party API allowed
  - Very powerful, very fast, high-quality API

Outline

I. Generics – better late than never

II. I/O – history, critique, and advice

III. A brief introduction to reflection

What is reflection?

- Operating programmatically on objects that represent linguistic entities (e.g., classes, methods)
- Allows program to work with classes that were not know (or didn't exist!) at compile time
- Quite complex – involves many APIs
- But there's a simple form
  - Involves **`Class.forName`** and **`newInstance`**

Benchmark interface

```
/** Implementations can be timed by RunBenchmark. */
public interface Benchmark {
    /**
     * Initialize the benchmark.  Passed all command line
     * arguments beyond first three.  Used to parameterize a
     * a benchmark This method will be invoked once by
     * RunBenchmark, prior to timings.
     */
    void init(String[] args);

    /**
     * Performs the test being timed.
     * @param numReps the number of repetitions comprising test
     */
    void run(int numReps);
}
```

RunBenchmark program (1)

```
public class RunBenchmark {
    public static void main(String[] args) throws Exception {
        if (args.length < 3) {
            System.out.println(
"Usage: java RunBenchmark <# tests> <# reps/test> <class name> [<arg>...]");
            System.exit(1);
        }

        int numTests = Integer.parseInt(args[0]);
        int numReps = Integer.parseInt(args[1]);
        Benchmark b =
               (Benchmark) Class.forName(args[2]).newInstance();
        String[] initArgs = new String[args.length - 3];
        System.arraycopy(args, 3, initArgs, 0, initArgs.length);
```

RunBenchmark program (2)

```
        if (initArgs.length != 0)
            System.out.println("Args: " + Arrays.toString(initArgs));
        b.init(initArgs);

        for (int i = 0; i < numTests; i++) {
            long startTime = System.nanoTime();
            b.run(numReps);
            long endTime = System.nanoTime();
            System.out.printf("Run %d: %d ms.%n", i,
                Math.round((endTime - startTime) / 1_000_000.));
        }
    }
}
```

Sample Benchmark

```
public class SortBenchmark implements Benchmark {
    private int[] a;

    @Override public void init(String[] args) {
        int arrayLen = Integer.parseInt(args[0]);
        a = new int[arrayLen];
        Random rnd = new Random(666);
        for (int i = 0; i < arrayLen; i++)
            a[i] = rnd.nextInt(arrayLen);
    }

    @Override public void run(int numReps) {
        for (int i = 0; i < numReps; i++) {
            int[] tmp = a.clone();
            Arrays.sort(tmp);
        }
    }
}
```

Demo – RunBenchmark

Conclusion

- Generics provide API flexibility with type safety
- Java I/O is a bit of a mess
  - There are many ways to do things
  - Use readers most of the time
- Reflection is tricky
  - but `Class.forName` and `newInstance` go a long way
  - A more powerful option that hides the reflection: `ServiceLoader`