Principles of Software Construction

Designing classes for reuse

Principles, patterns, and parametric polymorphism

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Administrivia

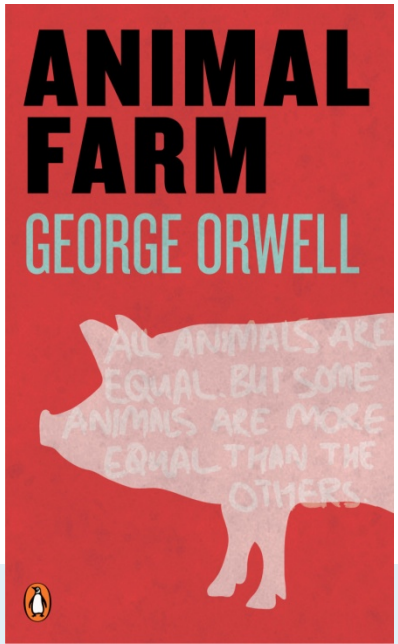
- Homework 3 due Sunday, February 7th

```
   SEND
 + MORE
 -------
  MONEY
```

- Midterm exam next Thursday, February 12th
  - Review session Wednesday, Feb 11th, 7-9 p.m. DH 1212
  - Practice exam will be released this weekend

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);
    }
}
```



From An Evening Of Puzzlers by Josh Bloch

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
  - The compiler ignores whitespace
  - Spacing can be deceptive; parentheses never lie
- Use parens whenever there is any doubt
  - They clarify your intent and cost nothing
  - They make your code easier to read and maintain
  - They may save your bacon
- Don't depend on interning of string constants
- Use `.equals`, not `==` for object references

Key concepts from Thursday…

Behavioral subtyping

> Let q(x) be a property provable about objects x of type T. Then q(y) should be provable for objects y of type S where S is a subtype of T.
>
> Barbara Liskov

- e.g., Compiler-enforced rules in Java:
  - Subtypes can add, but not remove methods
  - Concrete class must implement all undefined methods
  - Overriding method must return same type or subtype
  - Overriding method must accept the same parameter types
  - Overriding method may not throw additional exceptions
- Also applies to specified behavior:
  - Same or stronger invariants
  - Same or stronger postconditions for all methods
  - Same or weaker preconditions for all methods

This is called the *Liskov Substitution Principle*.

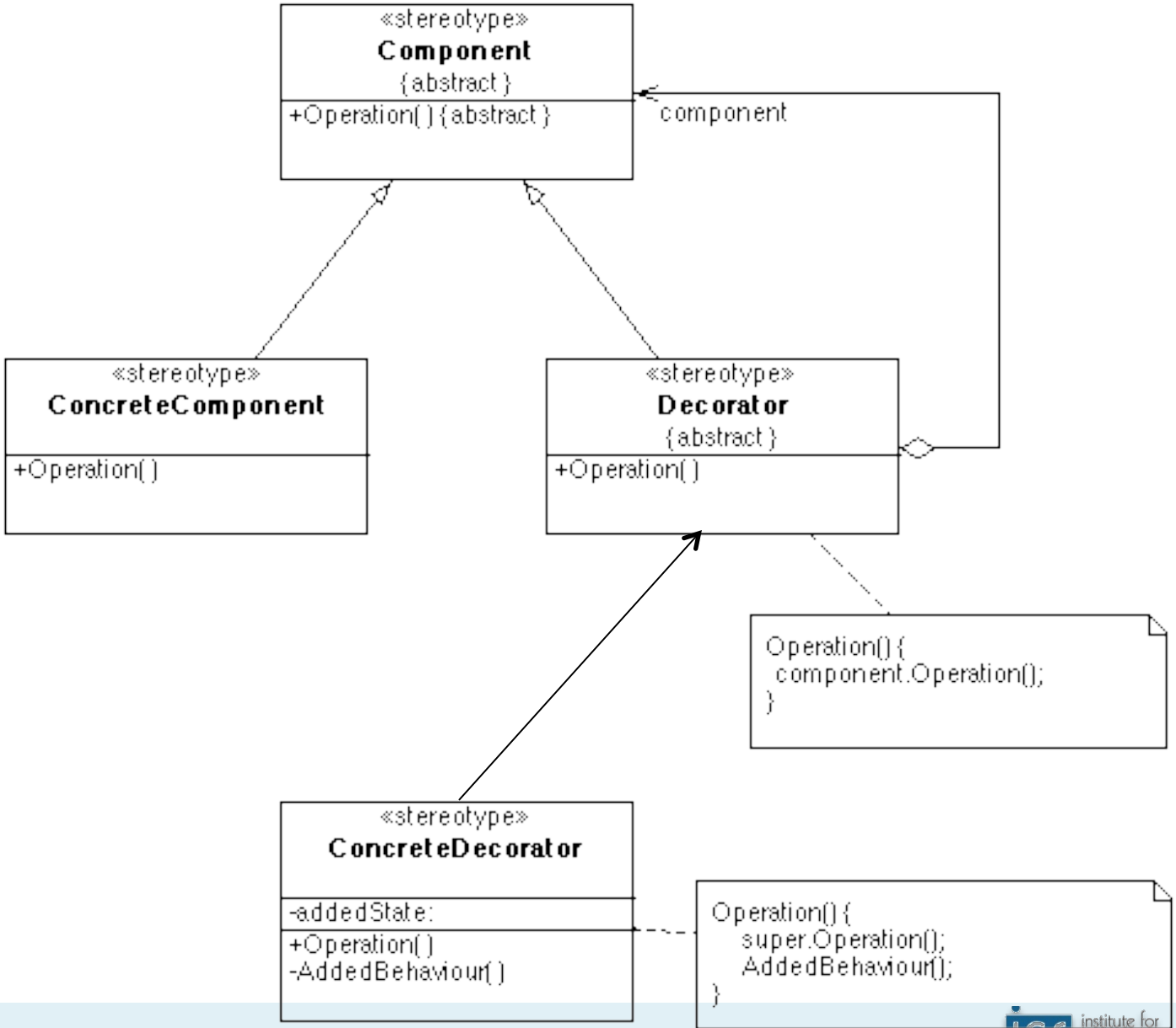
Avoiding `instanceof` with the template method pattern

```
public void doSomething(Account acct) {
  float adj = 0.0;
  if (acct instanceof CheckingAccount) {
    checkingAcct = (CheckingAccount) acct;
    adj = checkingAcct.getFee();
  } else if (acct instanceof SavingsAccount) {
    savingsAcct = (SavingsAccount) acct;
    adj = savingsAcct.getInterest();
  }
  …
}
```

Instead:

```
public void doSomething(Account acct) {
  long adj = acct.getMonthlyAdjustment();
  …
}
```

The decorator design pattern



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- Also applies to specified behavior:
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This is called the *Liskov Substitution Principle*.

Learning goals for today

- Be able to write reusable data structures using Java Generics.
- Be able to use and write `Iterators`.
- Be able to use and write `Exceptions`, including client code depending on `try`, `catch`, and `finally`.

Today: More class-level reuse

- Puzzlers…
- Parametric polymorphism (a.k.a. generics)
- The Iterator design pattern
- An important aside: Exceptions

An implementation of pairs, a la 2003

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

An implementation of pairs, a la 2003

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

- Some possible client code?

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

An implementation of pairs, a la 2003

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

- Some possible client code?

```
Pair p = new Pair("Hello", "world");
String result = p.first(); // Won't compile--type error
```

An implementation of pairs, a la 2003

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

- Some possible client code:

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

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>`
- Wildcards
  - e.g. `List<?>` or `List<? extends Animal>` or `List<? super Animal>`
- 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>`
- `List<String>` is a subtype of `List<? extends Object>`
- `List<Object>` is a subtype of `List<? super String>`

An inflexible API without wildcards

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

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

void popAll(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>`

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);
  …
}
```

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 popAll(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 popAll(Collection<? super E> dst);
```

  - `dst` is an E consumer

Today: More class-level reuse

- Puzzlers…
- Parametric polymorphism (a.k.a. generics)
- The Iterator design pattern
- An important aside: Exceptions

Traversing a collection

- Old-school Java for loop for ordered types

```
List<String> arguments = …;
for (int i = 0; i < arguments.size(); i++) {
  System.out.println(arguments.get(i));
}
```

- Modern standard Java for-each loop

```
List<String> arguments = …;
for (String s : arguments) {
  System.out.println(s);
}
```

Traversing a collection

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List<String> arguments = …;
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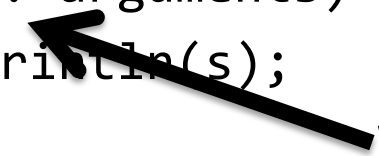
```



Works for every implementation of `Iterable`:

```
public interface Iterable<E> {
    public Iterator<E> iterator();
}
```

The Iterator interface

```
public interface java.util.Iterator<E> {
  boolean hasNext();
  E next();
  void remove();  // removes previous returned item
}                 // from the underlying collection
```

- To use explicitly, e.g.:

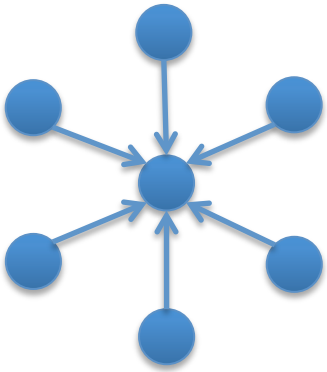
```
List<String> arguments = …;
for (Iterator<String> it = arguments.iterator();
     it.hasNext();  ) {
  String s = it.next();
  System.out.println(s);
}
```

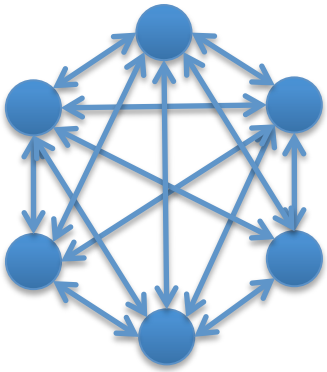
The Iterator design pattern

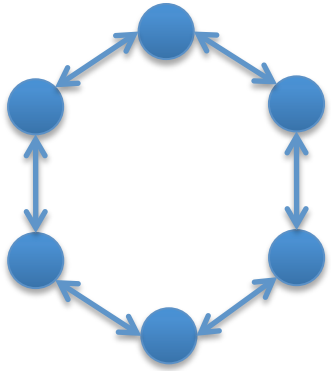
- Strategy to uniformly access all elements in a sequence
  - Independent of the container implementation
  - Ordering is unspecified, but every element visited once
- Design for change, information hiding
  - Hides internal implementation of underlying container
- Design for reuse, division of labor
  - Hides complex data structure behind simple interface
  - Facilitates communication between parts of the program

A design principle for reuse: *low coupling*

- Each component should depend on as few other components as possible







Getting an Iterator

```
public interface Collection<E> extends Iterable<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);
  …
}
```

Defines an interface for creating an Iterator, but allows Collection implementation to decide which Iterator to create.

An Iterator implementation for Pairs

```
public class Pair<E> {
  private final E first, second;
  public Pair(E f, E s) { first = f; second = s; }
```

```
}
```

```
Pair<String> pair = new Pair<String>("foo", "bar");
for (String s : pair) { … }
```

An Iterator implementation for Pairs

```
public class Pair<E> implements Iterable<E> {
  private final E first, second;
  public Pair(E f, E s) { first = f; second = s; }
  public Iterator<E> iterator() {
    return new PairIterator();
  }
  private class PairIterator implements Iterator<E> {
    private boolean seenFirst = false, seenSecond = false;
    public  boolean hasNext() { return !seenSecond; }
    public  E next() {
      if (!seenFirst)  { seenFirst  = true; return first;  }
      if (!seenSecond) { seenSecond = true; return second; }
      throw new NoSuchElementException();
    }
    public void remove() {
      throw new UnsupportedOperationException();
    }
  }
}
```

```
Pair<String> pair = new Pair<String>("foo", "bar");
for (String s : pair) { … }
```

Using a `java.util.Iterator<E>`: A warning

- The default Collections implementations are mutable…
- …but their `Iterator` implementations assume the collection does not change while the `Iterator` is being used
  - You will get a `ConcurrentModificationException`

Using a `java.util.Iterator<E>`: A warning

- The default Collections implementations are mutable…
- …but their `Iterator` implementations assume the collection does not change while the `Iterator` is being used
  - You will get a `ConcurrentModificationException`
  - If you simply want to remove an item:

```
List<String> arguments = …;
for (Iterator<String> it = arguments.iterator();
     it.hasNext();  ) {
  String s = it.next();
  if (s.equals("Charlie"))
    arguments.remove("Charlie"); // runtime error
}
```

Using a `java.util.Iterator<E>`: A warning

- The default Collections implementations are mutable…
- …but their `Iterator` implementations assume the collection does not change while the `Iterator` is being used
  - You will get a `ConcurrentModificationException`
  - If you simply want to remove an item:

```
List<String> arguments = …;
for (Iterator<String> it = arguments.iterator();
     it.hasNext();  ) {
  String s = it.next();
  if (s.equals("Charlie"))
    it.remove();
}
```

Today: More class-level reuse

- Puzzlers…
- Parametric polymorphism (a.k.a. generics)
- The Iterator design pattern
- An important aside: Exceptions

What does this code do?

```
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;
  }
}
DataInput 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?

```
FileInputStream fIn = new FileInputStream(filename);
if (fIN == null) {
  switch (errno) {
  case _ENOFILE:
     System.err.println("File not found: " + …);
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     return -1;
  }
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if (dataInput == null) {
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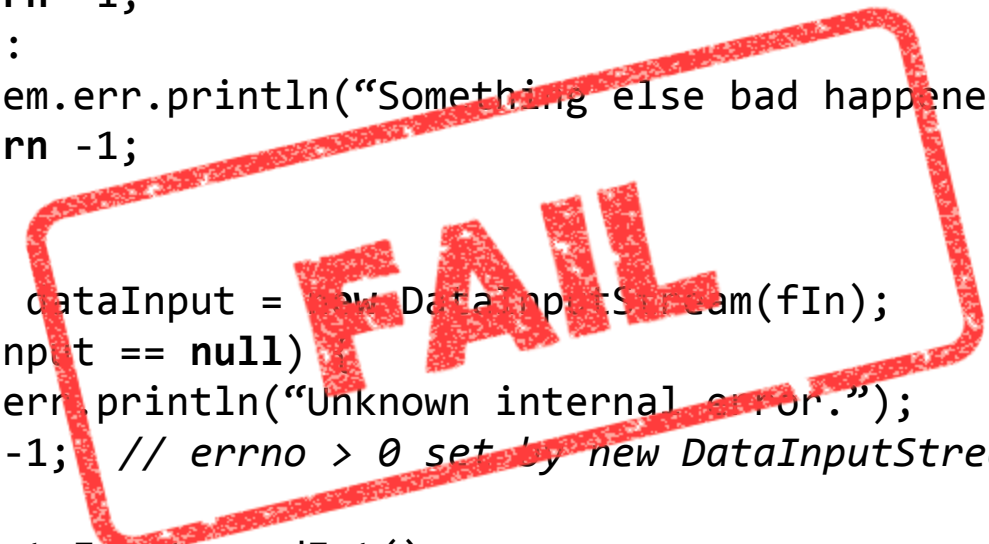
}  // The slide lacks space to close the file.  Oh well.
return i;
```



Compare to:

```
FileInputStream fileInput;
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();
}
```

Exceptions

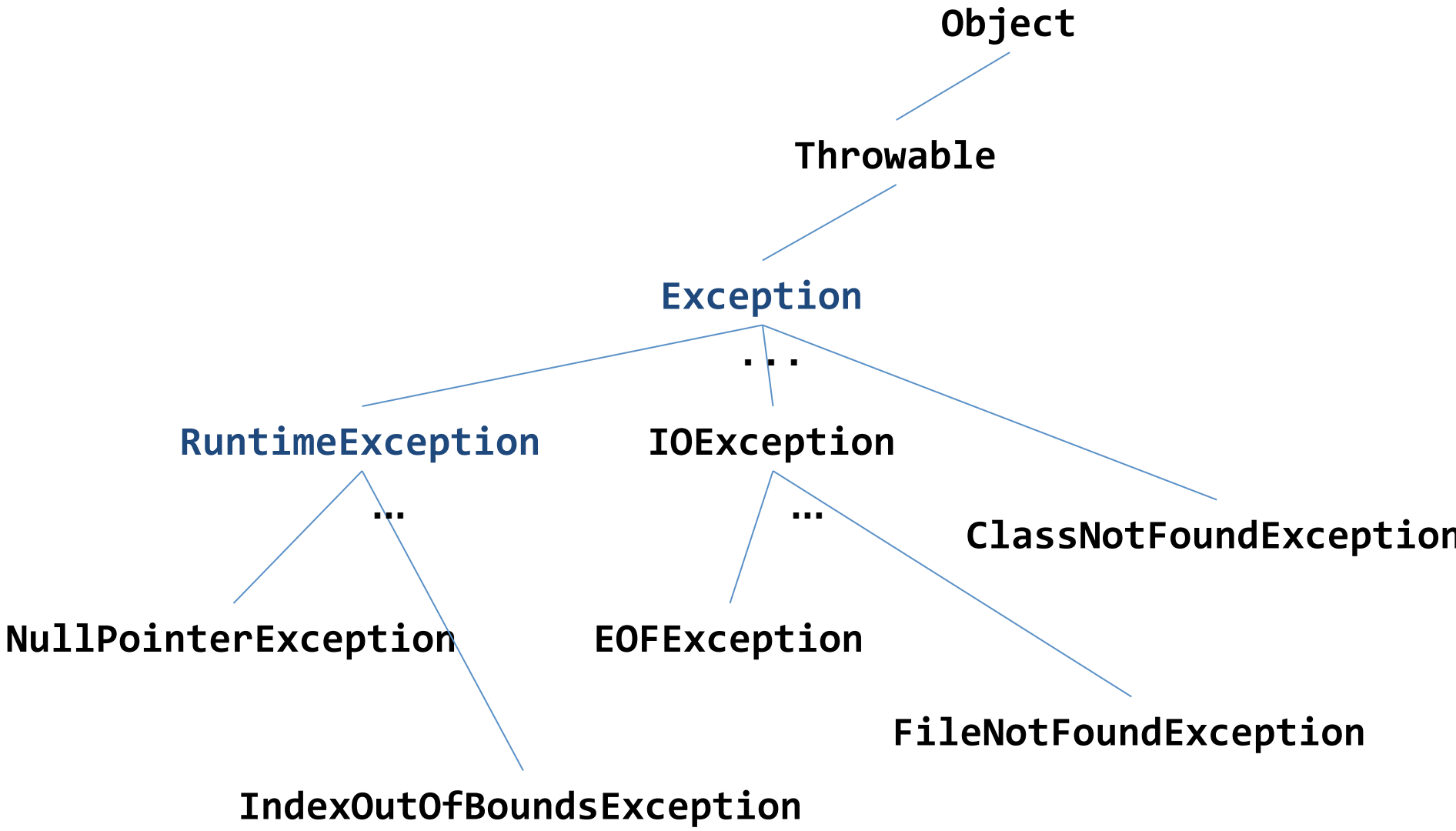
- Notify caller of an exceptional condition by automatic transfer of control
- Semantics:
  - Propagates up stack until `main` method is reached (terminates program), or exception is caught
- Sources:
  - Program – e.g., `IllegalArgumentException`
  - JVM – e.g., `NullPointerException`

Exceptional control-flow in Java

```
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");
    }
}

public static void main(String[] args) {
    try {
        test();
    } catch (IndexOutOfBoundsException e) {
        System.out.println"("Caught index out of bounds");
    }
}
```

The exception hierarchy in Java



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!

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
- Do NOT return `null` to indicate a zero-length result
  - Use a zero-length list or array

Creating and throwing your own exceptions

```
public class SpanishInquisitionException extends RuntimeException {
    ...
}

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
  - Separates normal code path from excptional
  - Eases task of recovering from failure
- In sum: ease task of writing robust, maintainable code

Guidelines for using exceptions (1)

- Avoid unnecessary checked exceptions (EJ Item 59)
- Favor standard exceptions (EJ Item 60)
  - `IllegalArgumentException` – invalid parameter value
  - `IllegalStateException` – invalid object state
  - `NullPointerException` – null param where prohibited
  - `IndexOutOfBoundsException` – invalid index param
- Throw exceptions appropriate to abstraction (EJ Item 61)

Guidelines for using exceptions (2)

- Document all exceptions thrown by each method
  - Checked and unchecked (EJ Item 62)
- Include failure-capture info in detail message (EJ Item 63)
  -
```
throw new IlegalArgumentException(
      "Modulus must be prime: " + modulus);
```
- Don't ignore exceptions (EJ Item 65)

```
// Empty catch block ignores exception – Bad smell in code!
try {
...
} catch (SomeException e) {
}
```

Testing for presence of an exception

```
import org.junit.*;
import static org.junit.Assert.fail;

public class Tests {

        @Test
        public void testSanityTest(){
                try {
                        openNonexistingFile();
                        fail("Expected exception");
                } catch(IOException e) { }
        }

        @Test(expected = IOException.class)
        public void testSanityTestAlternative() {
                openNonexistingFile();
        }
}
```

Remember this slide?

You can do much better!

```
FileInputStream fileInput;
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

Automatically closes resources

```
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 ARM

```
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 ARM

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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);
    }
}
```