Principles of Software Construction: Objects, Design and Concurrency

Object behavioral contracts and exceptions

15-214 toad

Fall 2013

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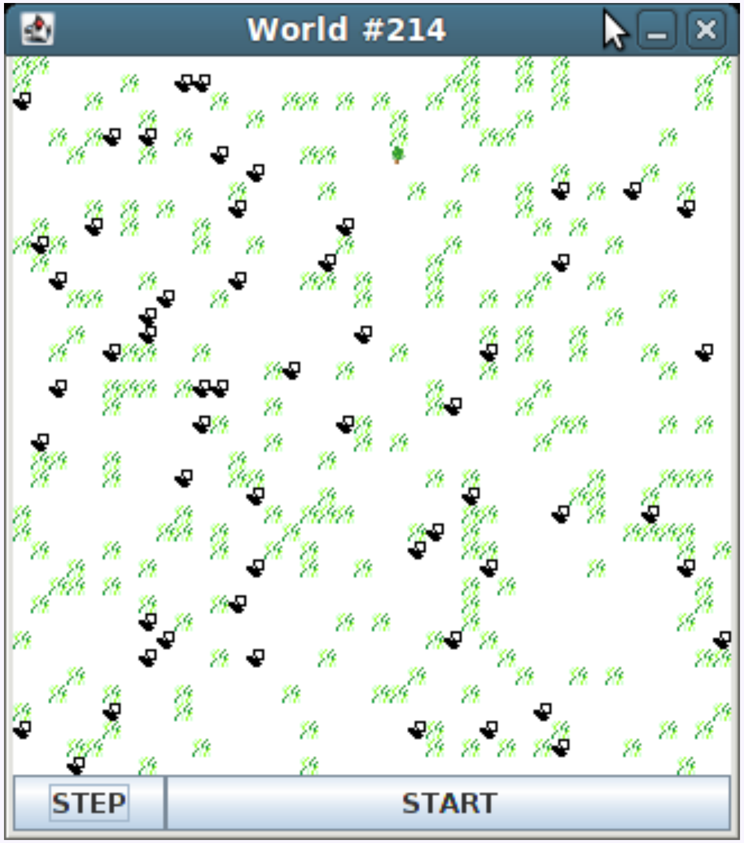
Administrivia

- Homework 1 due tonight
  - We will not evaluate your Javadocs
    - You do not need to generate Javadocs
      - I like deeply nested bullets
- Homework 2 coming soon
  - Due Thursday, 19 September



Key concepts from Thursday

Key concepts from Thursday

- Java-specific inheritance details
  - `this`, `super`, `instanceof`, `final`
  - Type casting
- Type checking
- Method dispatch
  - Overloaded method names
  - Overriding inherited methods

Key concepts for today

- The `java.lang.Object`
  - Behavioral contracts
  - A lesson in equality
- Introduction to Exceptions

The `java.lang.Object`

- All Java objects inherit from `java.lang.Object`
- Commonly-used/overridden public methods:

```
String     toString()
boolean    equals(Object obj)
int        hashCode()
Object     clone()
```

Overriding `java.lang.Object's .equals`

- The default `.equals`:

```
public class Object {
    public boolean equals(Object obj) {
        return this == obj;
    }
}
```

- An aside: Do you like:

```
public class CheckingAccountImpl
        implements CheckingAccount {
    @Override
    public boolean equals(Object obj) {
        return false;
    }
}
```

The `.equals(Object obj)` contract

- An equivalence relation
  - Reflexive: ∀`x` `x.equals(x)`
  - Symmetric: ∀`x,y` `x.equals(y)` if and only if `y.equals(x)`
  - Transitive: ∀`x,y,z` `x.equals(y)` and `y.equals(z)` implies `x.equals(z)`
- Consistent
  - Invoking `x.equals(y)` repeatedly returns the same value unless `x` or `y` is modified
- `x.equals(null)` is always false

The `.hashCode()` contract

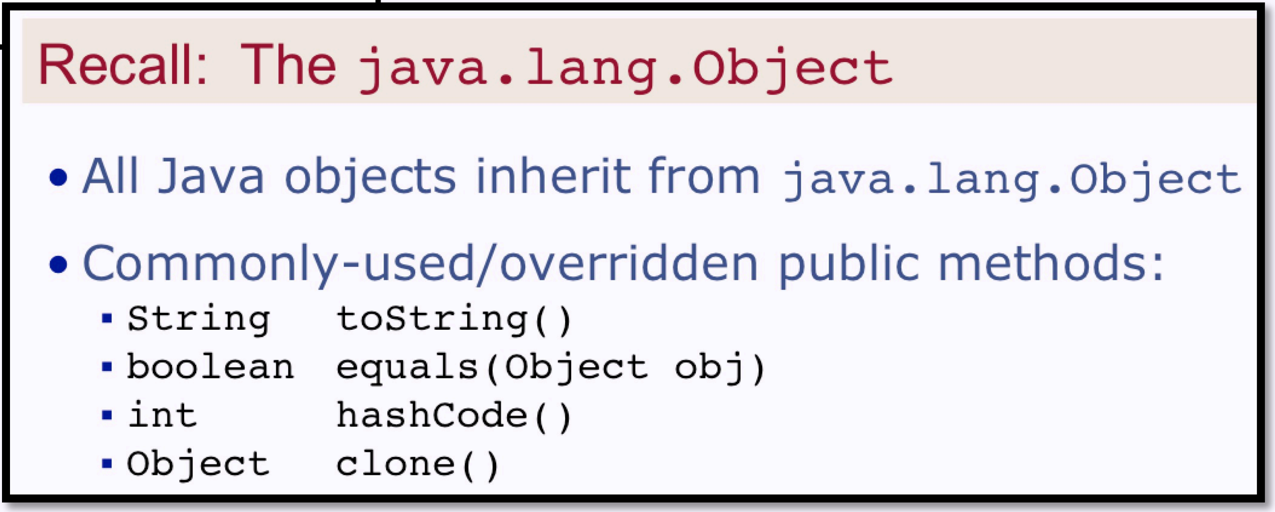
- Consistent
  - Invoking `x.hashCode()` repeatedly returns same value unless x is modified
- `x.equals(y)` implies `x.hashCode() == y.hashCode()`
  - The reverse implication is not necessarily true:
    - `x.hashCode() == y.hashCode()` does not imply `x.equals(y)`
- Advice: You should override `.equals()` if and only if you override `.hashCode()`

The `.clone()` contract

- Returns a *deep copy* of an object
- Generally (but not required!):
  - `x.clone() != x`
  - `x.clone().equals(x)`

A lesson in equality

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }
}
```



Recall: The `java.lang.Object`

- All Java objects inherit from `java.lang.Object`
- Commonly-used/overridden public methods:
  - `String   toString()`
  - `boolean  equals(Object obj)`
  - `int      hashCode()`
  - `Object   clone()`

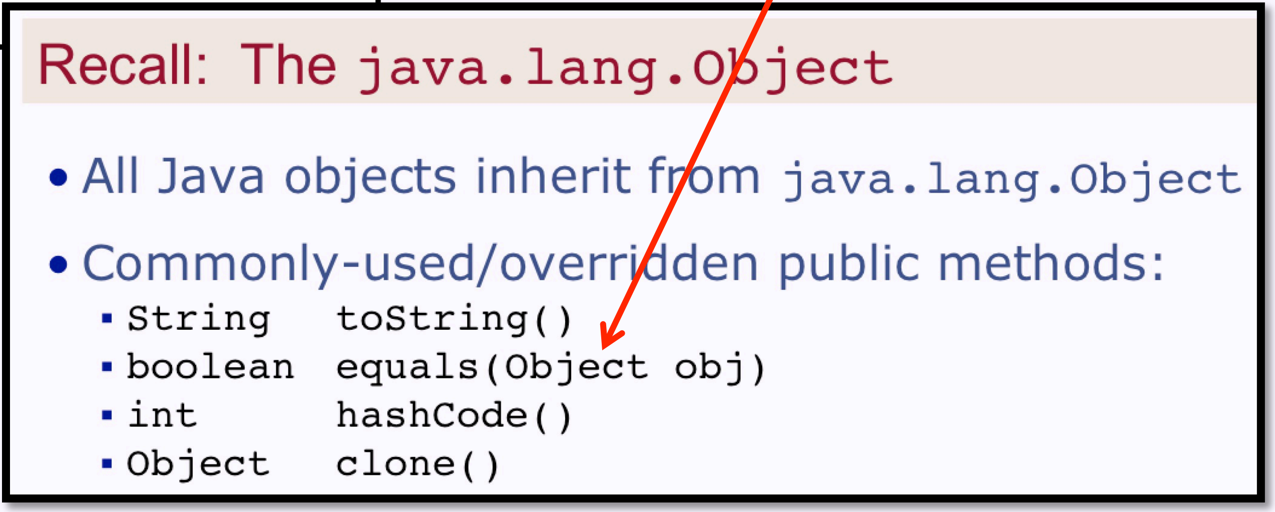
Implement the `.equals` method for the `Point` class.

A tempting but incorrect solution

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }
}
```

```
public boolean equals(Point p) {
  return x == p.x && y == p.y;
}
```

Types must match



Recall: The `java.lang.Object`

- All Java objects inherit from `java.lang.Object`
- Commonly-used/overridden public methods:
  - `String    toString()`
  - `boolean   equals(Object obj)`
  - `int       hashCode()`
  - `Object    clone()`

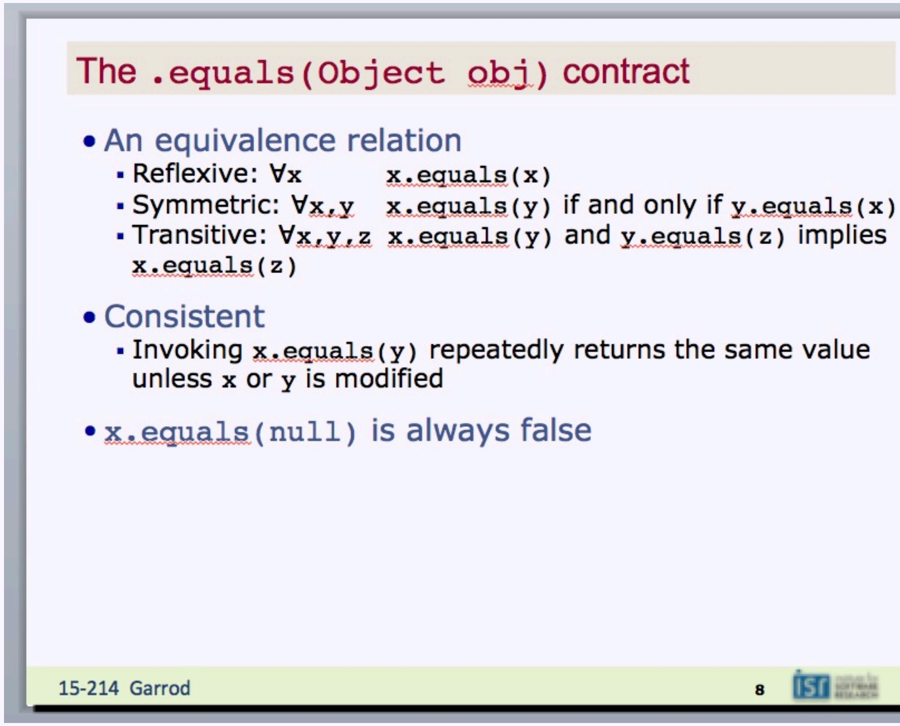
`boolean equals(Point p)` does not override `boolean equals(Object obj)`

A correct solution

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
  }

  public int hashCode() {
    return 31*x + y;
  }
}
```



The .equals(Object obj) contract

- An equivalence relation
  - Reflexive: ∀x x.equals(x)
  - Symmetric: ∀x,y x.equals(y) if and only if y.equals(x)
  - Transitive: ∀x,y,z x.equals(y) and y.equals(z) implies x.equals(z)
- Consistent
  - Invoking x.equals(y) repeatedly returns the same value unless x or y is modified
- x.equals(null) is always false

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A new challenge

```java
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof Point))
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
}
```

```java
public class ColorPoint
      extends Point {
  private final Color color;

  public ColorPoint(int x,
                    int y,
                    Color color) {
    super(x, y);
    this.color = color;
  }
}
```

Implement `.equals` for the `ColorPoint` class.
You may assume `Color` correctly implements `.equals`

A tempting solution

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
}
```

```
public class ColorPoint
      extends Point {
  private final Color color;

  public ColorPoint(int x,
                    int y,
                    Color color) {
    super(x, y);
    this.color = color;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof ColorPoint))
       return false;
    ColorPoint cp = (ColorPoint) obj;
    return super.equals(cp) &&
           color.equals(cp.color);
}
```

A tempting solution

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
}
```

```
public class ColorPoint
      extends Point {
  private final Color color;

  public ColorPoint(int x,
                    int y,
                    Color color) {
    super(x, y);
    this.color = color;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof ColorPoint))
       return false;
    ColorPoint cp = (ColorPoint) obj;
    return super.equals(cp) &&
           color.equals(cp.color);
}
```

A problem: p.equals(cp)
but !cp.equals(p):

```
Point p = new Point(2, 42);
ColorPoint cp = new ColorPoint(2, 42, Color.BLUE);
```

More problems

```
public class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
}
```

```
public class ColorPoint
      extends Point {
  private final Color color;

  public ColorPoint(int x,
                    int y,
                    Color color) {
    super(x, y);
    this.color = color;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof Point))
       return false;
    if (!(obj instanceof ColorPoint))
       return super.equals(obj);
    ColorPoint cp = (ColorPoint) obj;
    return super.equals(cp) &&
           color.equals(cp.color);
}
```

Consider:

```
Point p = new Point(2, 42);
ColorPoint cp1 = new ColorPoint(2, 42, Color.BLUE);
ColorPoint cp2 = new ColorPoint(2, 42, Color.MAUVE);
```

An abstract solution

```
public abstract class Point {
  private final int x;
  private final int y;
  public Point(int x, int y) {
    this.x = x;
    this.y = y;
  }

  public boolean equals(Object obj
    if (!(obj instanceof Point)
      return false;
    Point p = (Point) obj;
    return x == p.x && y == p.y;
}
```

```
public class ColorPoint
      extends Point {
  private final Color color;

  public ColorPoint(int x,
                    int y,
                    Color color) {
    super(x, y);
    this.color = color;
  }

  public boolean equals(Object obj) {
    if (!(obj instanceof ColorPoint))
      return false;
    ColorPoint cp = (ColorPoint) obj;
    return super.equals(cp) &&
           color.equals(cp.color);
}
```

```
public class PointImpl extends Point {
  public PointImpl(int x, int y) { super(x,y); }
  public boolean equals(Object obj) {
    if (!(obj instanceof PointImpl))
      return false;
    return super.equals(obj);
  }
```

The lesson

- Conforming to behavioral contracts can be difficult
- Advice:
  - Don't allow equality between distinct types
  - Be careful when inheriting from a concrete class

"Overriding the `equals` *method seems simple, but there are many ways to get it wrong and the consequences can be dire."* -- Josh Bloch

The lesson

- Conforming to behavioral contracts can be difficult

- Advice:
  - Don't allow equality between distinct types
  - Be careful when inheriting from a concrete class

- Symmetry kills:

```
public class EvilButTrue {
  public boolean equals(Object obj) {
      return obj != null;
  }
  public int hashCode() {
      return 0;
  }
}
```

"Overriding the `equals` *method seems simple, but there are many ways to get it wrong and the consequences can be dire."* -- Josh Bloch

Key concepts for today

- The `java.lang.Object`
  - Behavioral contracts
  - A lesson in equality
- Introduction to 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;
```

Exceptions

- Exceptions notify the caller of an exceptional circumstance (usually operation failure)
- Semantics
  - An exception propagates *up the function-call stack* until `main()` is reached or until the exception is caught
- Sources of exceptions:
  - Programmatically throwing an exception
  - Exceptions thrown by the Java runtime

Compare to:

```
try {
    FileInputStream fileInput = new FileInputStream(filename);
    DataInput dataInput = new DataInputStream(fileInput);
    int i = dataInput.readInt();
    fileInput.close();
    return i;
} catch (FileNotFoundException e) {
    System.out.println("Could not open file " + filename);
    return -1;
} catch (IOException e) {
    System.out.println("Error reading binary data from file "
                                     + filename);
    return -1;
}
```

Exceptional control-flow

```
try {
    System.out.println("Top");
    int[] a = new int[10];
    a[42] = 42;
    System.out.println("Bottom");
} catch (IndexOutOfBoundsException e) {
    System.out.println("Caught index out of bounds");
}
```

- Prints:

  Top
  Caught index out of bounds

Exceptional control-flow, part 2

```
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");
    }
}
```

- Prints:

```
Top
Caught index out of bounds
```

Exceptional examples

- `ReadFromFileV*.java`

The `finally` keyword

- The finally block always runs after try/catch:

```
try {
    System.out.println("Top");
    int[] a = new int[10];
    a[42] = 42;
    System.out.println("Bottom");
} catch (IndexOutOfBoundsException e) {
    System.out.println("Caught index out of bounds");
} finally {
    System.out.println("Finally got here");
}
```

- Prints:

```
Top
Caught index out of bounds
Finally got here
```

The `finally` keyword, part 2

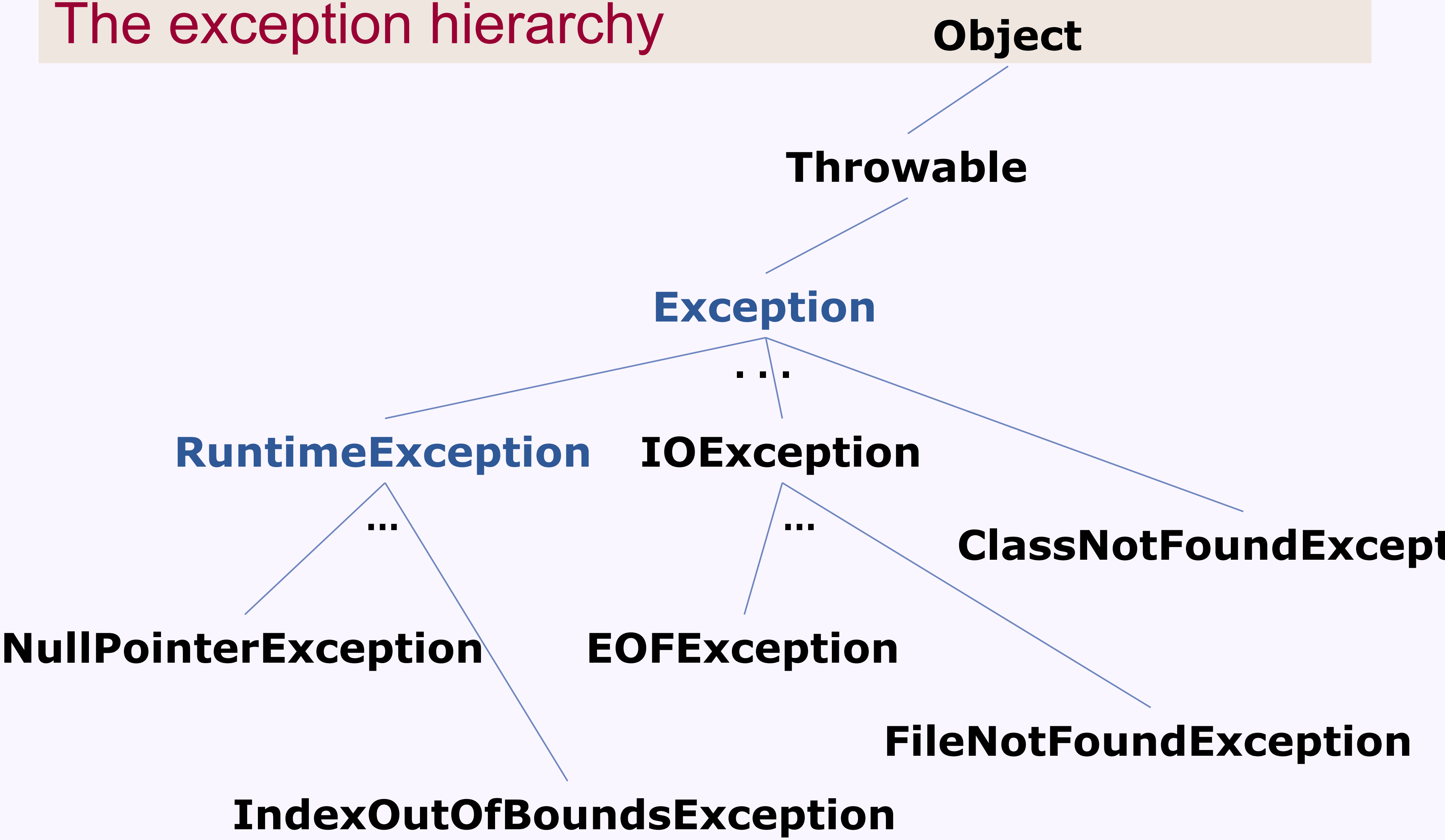
- The finally block always runs after try/catch:

```
try {
    System.out.println("Top");
    int[] a = new int[10];
    a[2] = 2;
    System.out.println("Bottom");
} catch (IndexOutOfBoundsException e) {
    System.out.println("Caught index out of bounds");
} finally {
    System.out.println("Finally got here");
}
```

- Prints:

```
Top
Bottom
Finally got here
```

The exception hierarchy



Object

Throwable

Exception

. . .

RuntimeException

IOException

ClassNotFoundExcept

…

…

NullPointerException

EOFException

FileNotFoundException

IndexOutOfBoundsException

Checked and unchecked exceptions

- Unchecked exception: any subclass of `RuntimeException`
  - Indicates an error which is highly unlikely and/or typically unrecoverable

- Checked exception: any subclass of `Exception` that is not a subclass of `RuntimeException`
  - Indicates an error that every caller should be aware of and explicitly decide to handle or pass on

Creating and throwing your own exceptions

- Methods must declare any checked exceptions they might throw
- If your class extends `java.lang.Exception` you can throw it:

```
if (someErrorBlahBlahBlah) {
   throw new MyCustomException(“Blah blah blah”);
}
```

- See `ReadFromFile` examples and `IllegalBowlingScoreException` and `ReadBowlingScore` example

Benefits of exceptions

Benefits of exceptions

- Provide high-level summary of error and stack trace
  - Compare: core dumped in C
- Can’t forget to handle common failure modes
  - Compare: using a flag or special return value
- Can optionally recover from failure
  - Compare: calling `System.exit()`
- Improve code structure
  - Separate routine operations from error-handling
- Allow consistent clean-up in both normal and exceptional operation

Guidelines for using exceptions

- Catch and handle all checked exceptions
  - Unless there is no good way to do so…
- Use runtime exceptions for programming errors
- Other good practices
  - Do not catch an exception without (at least somewhat) handling the error
  - When you throw an exception, describe the error
  - If you re-throw an exception, always include the original exception as the cause