CS 228: Introduction to Data Structures
Lecture 7
Wednesday, January 28, 2015

Lifetimes of Variables

- A local variable — i.e., one declared within a method — is gone forever as soon as the method in which it is declared finishes executing. (If it references an object, the object might continue to exist, though.)

- An instance variable — i.e., a non-static field — lasts as long as the object exists. An object lasts as long as there's a reference to it.

- A class variable — i.e., a static field — lasts as long as the program runs.

Exceptions

An ***exception*** is any special condition that alters the normal flow of program execution. For example, you might try to divide by zero or open a file that does not exist or that you aren't allowed to read. These errors can cause your program to terminate immediately.

Your perspective on exceptions depends on whether you are API ***developer*** or an API ***client***.

- As a developer, your main concern is to ***throw*** the right exception at the right time. This is often just a matter of putting in a `throw` statement and creating the right `Exception` object.

- As a client, you may have to ***handle*** the exceptions thrown by methods you call. This is done with a `try/catch` block. This prevents an error message from printing and the program from terminating.

Exceptions are a way to escape a “sinking ship”. By letting the system throw an exception, or by throwing your own, you can move program execution out of a method whose purpose has been defeated. Throwing an exception is different from a `return` statement because

- You don't have to return anything.

- An exception can fly several stack frames down the stack, not just one.

Catching Exceptions

To handle an exception, you have to ***catch*** it. As an example, here is a program that tries to open a file named by the first command-line argument.

```
public static void main(String[] args)
{
   InputStream istream;
   File        inputFile;

   try {
      inputFile = new File(args[0]);
      istream = new InputStream(inputFile);
      // may throw FileNotFoundException
    }
    catch (FileNotFoundException ex) {
        System.out.println("file " + args[0]
           + " not found");
    }
}
```

If the user runs the program with a bad file name `foo`, the program will print the message

```
file foo not found
```

and then halt. Note that the `try/catch` for the `FileNotFoundException` is needed for the program to compile because the program does not list that exception as one that might be thrown.

Comments

- The program should probably take the additional precaution of checking that there *is* a command-line argument before attempting to use `args[0]`.
- It probably makes more sense to put the `try` block in a loop, so that if the file is not found the user can be asked to enter a new file name, and a new attempt to open the file can be made.

In general, we catch exceptions using `try/catch` blocks:

```
try {
   // statements that might cause exceptions
   // possibly including function calls
}
catch ( exception-1 id-1 ) {
   // statements to handle this exception
}
catch ( exception-2 id-2 ) {
   // statements to handle this exception
```

```
    .
    .
    .
}
finally {
    // statements to execute every time this
    // try block executes
}
```

This code does the following:

1. It executes the code inside the `try` braces.

2. If the `try` code executes normally, it skips over the `catch` clauses.

3. If the `try` code throws an exception, it jumps directly (without finishing the `try` code) to the first `catch` clause that ***matches*** the exception, and executes that `catch` clause. There is a ***match*** if the actual exception object thrown is the same class as, or a subclass of, the exception type listed in the `catch` clause.

4. When the `catch` clause finishes executing, the `finally` clause, if there is one (it is optional), is executed, ***whether or not there was an exception***. A `finally` clause is typically used to ensure that some clean-up (e.g., closing opened files) is done. If there

is no `finally` clause, we go to the next step.

5. Java jumps to the next line of code immediately after the `try/catch` block.

The code within a `catch` clause is called an ***exception handler***. Note that you don't need a `catch` clause for every exception that can occur. You can catch some exceptions and let others propagate. If an exception propagates all the way out of `main()` without being caught, the Java Virtual Machine prints an error message and halts.

In general, there can be one or more catch clauses. If there is a `finally` clause, there can be zero `catch` clauses.

Further details (not covered in class). An exception may occur in a `catch` or `finally` clause. An exception thrown in a `catch` clause will terminate the `catch` clause, but the `finally` clause will still get executed before the exception goes on. An exception thrown in a `finally` clause replaces the old exception, and terminates the `finally` clause and the method immediately. However, you can nest a `try` clause inside a `catch` or `finally` clause, thereby catching those exceptions as well.

If a `finally` clause includes a transfer of control statement — i.e., a `return`, `break`, `continue`, or `throw` — then that statement overrides any transfer of control initiated in the `try` or in a `catch` clause.

First, let's assume that the finally clause does not include any transfer of control. Here are the situations that can arise:

1. No exception occurs during execution of the `try`, and the `try` does no transfer of control.

   ⇒ The `finally` clause executes, then the statement following the `try` block.

2. No exception occurs during execution of the `try`, but it does execute a transfer of control.

   ⇒ The `finally` clause executes, then the transfer of control takes place.

3. An exception occurs during execution of the `try`, and there is no `catch` clause for that exception.

   ⇒ The `finally` clause executes, then the uncaught exception is passed up to the next enclosing `try` block, possibly in a calling method.

4. An exception occurs during execution of the `try`, and there is a `catch` clause for that exception. The `catch` clause does not execute a transfer of control.

   ⇒ The `catch` clause executes, then the `finally`

clause, then the statement following the try block.

5. An exception occurs during execution of the `try`, there is a `catch` clause for that exception, and the `catch` clause does execute a transfer of control.

   ⇒ The `catch` clause executes, then the `finally` clause, then the transfer of control takes place.

If the `finally` block ***does*** include a transfer of control, then that takes precedence over any transfer of control executed in the `try` or in an executed catch clause. So for all of the cases listed above, the finally clause would execute, then its transfer of control would take place. Here's one example:

```
try {
    return 0;
}
finally {
    return 2;
}
```

The result of executing this code is that 2 is returned. Note that this is rather confusing! The moral is that you probably do not want to include transfer-of-control statements in both the try statements and the `finally` clause, or in both a catch clause and the `finally` clause.

Checked and Unchecked Exceptions

Every exception is either a ***checked*** exception or an ***unchecked*** exception. If a method has instructions that could cause a ***checked*** exception to be thrown, then the method must acknowledge the possibility that such a checked exception may be thrown. This is done by either

- putting a `throws` clause in the method header to declare that the exception could be thrown, or

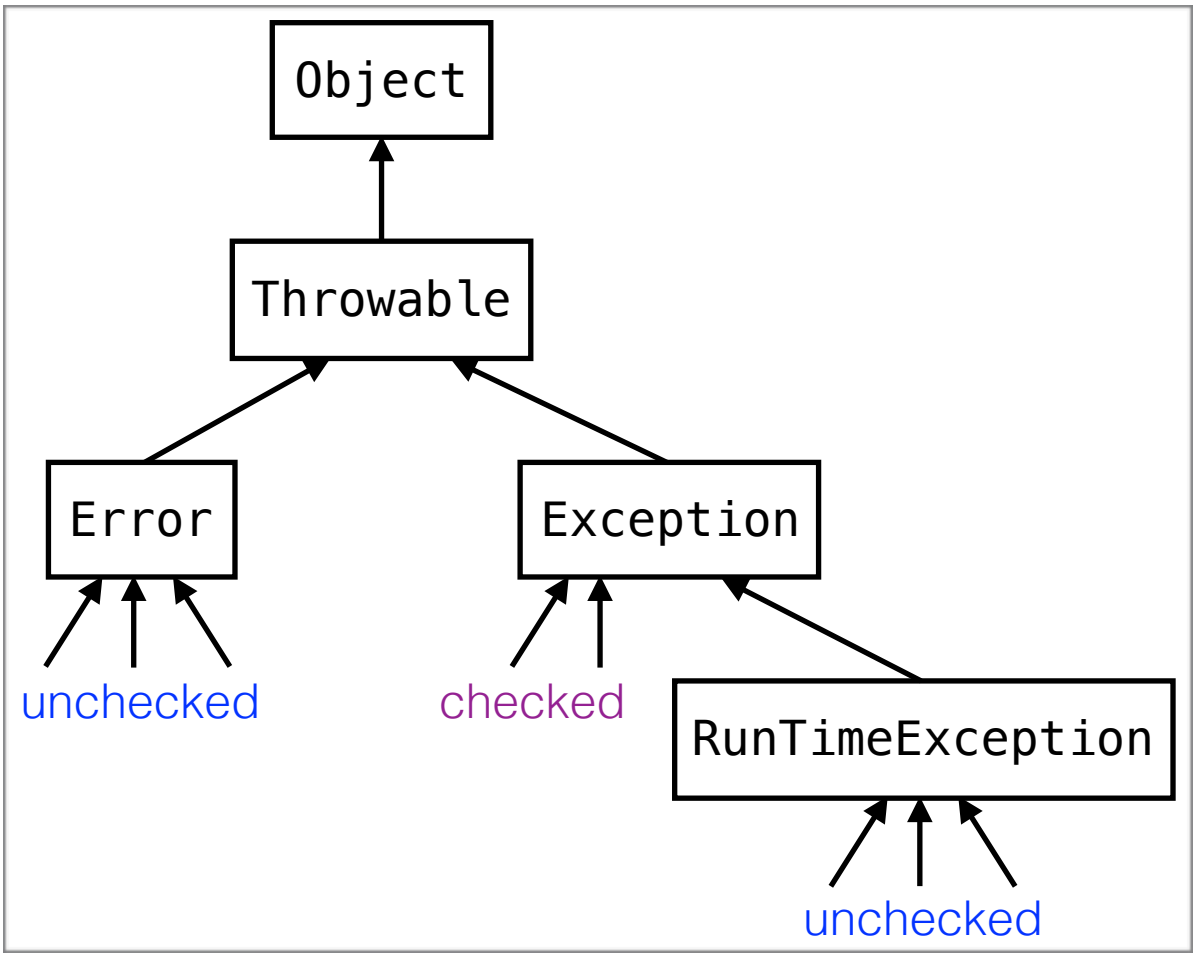
- enclosing the code that might cause the exception within a `try` block with a `catch` clause for that exception.

If you fail to do this, you will get a compiler error.

The `Exception` Hierarchy

Exceptions in Java are objects belonging to the `Exception` class, which is itself a subclass of `Throwable`, the class of things that you can `throw` and `catch` (see the figure). The other subclass of Throwable is `Error`. An `Error` generally represents a fatal error, like running out of memory or stack space. Although you can throw or catch any kind of `Throwable`, catching an `Error` is rarely appropriate.

Most `Exceptions`, unlike `Errors`, signify problems you could conceivably recover from. The subclass `RunTimeException` is made up of exceptions that might be thrown by the Java Virtual Machine, such as `NullPointerException`, `ArrayIndexOutOfBoundsException`, and `ClassCastException`.



Exception Constructors

Java exceptions are objects; they are defined by defining a class, for example:

```
public class EmptyStackException
extends Exception { }
```

New exceptions are usually subclasses of `Exception`, so that they are checked. The exceptions you define do not have to be public classes; however, remember that if you do not make them public, then they can only be used in the package in which they are defined.

By convention, most `Throwables` (including `Exceptions`) have two constructors. One takes no parameters, and one takes an error message in the form of a `String`.

```
class MyException extends Exception {
  public MyException() { super(); }
  public MyException(String s)
  { super(s); }
}
```

The error message will be printed if it propagates out of `main()`. The constructors usually call the superclass constructors, which are defined in `Throwable`.

Throwing Exceptions

To throw an exception, we use a `throw` statement:

```
public class Stack {
   ...
   public Object pop() throws
   EmptyStackException
   {
      if (Empty())
         throw new EmptyStackException();
      ...
   }
}
```

Observe that

- since exceptions are objects, you must use `new` to create an `Exception` object, and
- since the `pop` method might throw the (checked) exception `EmptyStackException`, that must be indicated in `pop`'s `throws` clause.

Introduction to the Analysis of Algorithms

An ***algorithm*** is a step-by-step method for solving a problem. A well-specified algorithm can be directly translated into working code; however, an algorithm is independent of the programming language used to code it. For example, consider the following problem.

ARRAY EQUALITY

Input: Two arrays A and B, of the same length and without duplicates.
Question: Do A and B contain the same elements?

Here are two possible algorithms, described informally.

Algorithm 1

```
for each position i in array A
    if element A[i] does not appear in array B
        return false
return true
```

Algorithm 2

make a copy of both arrays and sort them
for each position `i`
    if `A[i]` is different from `B[i]`
        return `false`
return `true`

Which strategy is better? What does "better" mean for an algorithm? We will focus on comparing relative speeds. In the next few lectures, we will see how to analyze an algorithm to determine its ***time complexity***, a measure of how the algorithm's running time *scales* as a function of the size of its input.