Exception Handling and First-class Functions

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Errors and Exceptions in Java

- In Java, a common supertype, Throwable, is used to encompass all error values and exception values.

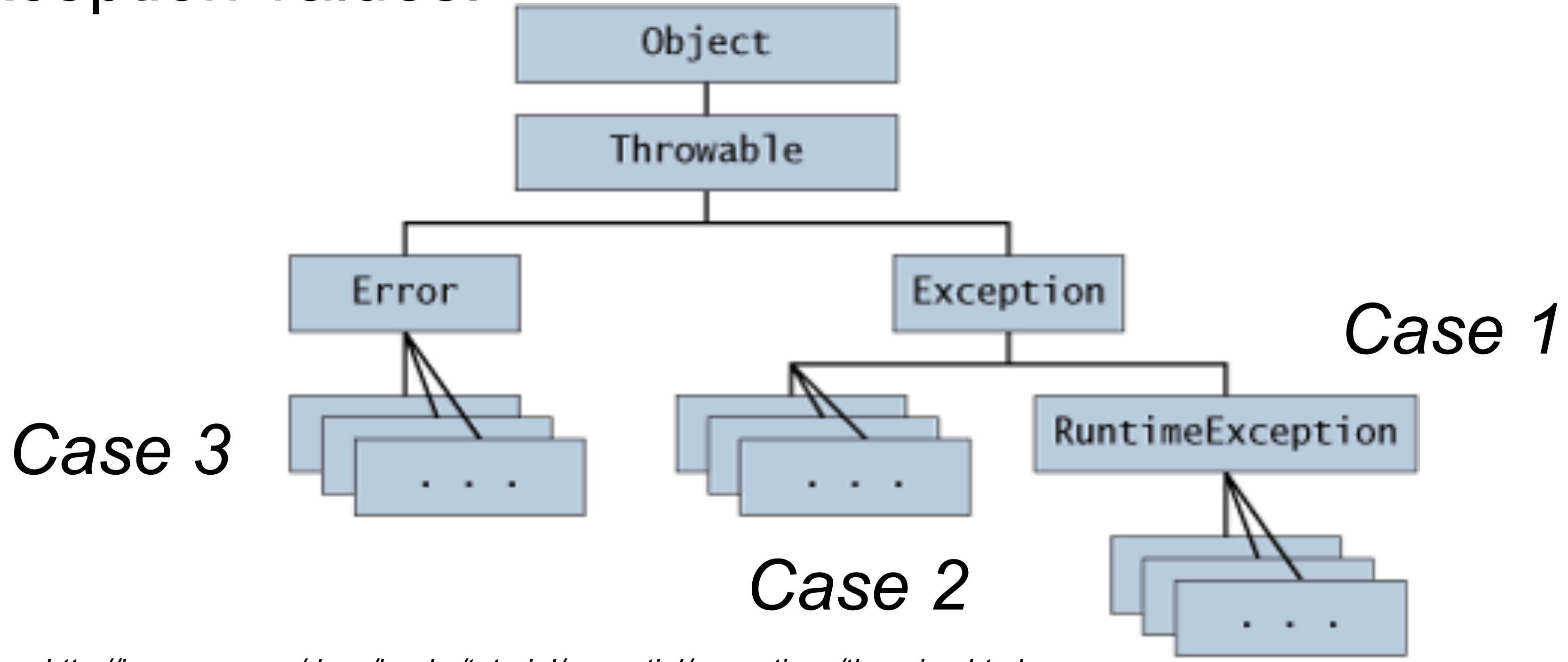


Figure source: http://java.sun.com/docs/books/tutorial/essential/exceptions/throwing.html

Case 1: RuntimeException

- Used for error conditions that a program may want to handle, but are not explicitly part of a method's contract e.g.,
  - `NullPointerException`
  - `IndexOutOfBoundsException`
  - `ArithmeticException (e.g., divide by zero)`
  - `NegativeArraySizeException`
  - `ArrayStoreException`
  - `ClassCastException`
  - `IllegalArgumentException`
- We will primarily use RuntimeException (Case 1) in this course except when the use of a library dictates the use of Case 2 or Case 3

Example

Execution of method foo() in class T1 throws an `ArithmeticException` when x = 0

```
class T1 {
  int x;
  . . .
  int foo() {
    return 100 / x;
  }
}
```

Unhandled Exceptions

- An Unhandled Exception results in program exit with a stack trace e.g.,

```
Exception in thread "main"
java.lang.ArithmeticException: / by zero
at T1.foo(T1.java:50)
```

. . .

- The line numbers in the stack trace can help you locate the source of the error

Handled Exceptions

- The programmer has the option of handling exceptions in Java with a try-catch statement e.g.,

```
class T1 {
  int x;
  . . .
  int foo() {
    int n;
    try { n = 100 / x; } // scope of exception handler
    catch (ArithmeticException e)
      {n = Integer.MAX_VALUE;} // handler for arith exceptions
    return n;
  } }
```

Exception Propagation

- Exceptions are propagated up the call chain until a handler is found; if none an error message is printed on the console

```
class T2 {
  int x;
  int baz() { return 100 / x; }
  int foo() {
    int n;
    try { baz(); } // scope of exception handler
    catch (ArithmeticException e)
      {n = Integer.MAX_VALUE;} // handler for arith exceptions
    return n;
  } }
```

Food for Thought

- What would you have to do to propagate errors up a call chain in a language that did not have support for exception handling?
- It is possible to convert any Java program into one that never prints an exception on the console. How?

Throwing Exceptions Explicitly

- The programmer also has the option of throwing instances of RuntimeException for user-defined errors e.g.,

Argument of throw statement must be of type Throwable

```
class T3 {
  int x;
  . . .
  float bar(float y) {
    // throw ArithmeticException if y < 0
    if (y < 0) throw new ArithmeticException(“Negative arg”);
    return Math.sqrt(y);
  }
}
```

Exception Objects

- In Java, exceptions are conventional objects, and can be created by expressions of the form

  `new <exception-class>(<arg`$_1$`>, ..., <arg`$_n$`>)`

- Examples

```
throw new IllegalArgumentException
    ("max applied to an empty list")

throw new java.util.NoSuchElementException
    ("no more elements")
```

Type Casts and ClassCastException

- Java supports type casts (coercions) for cases when the declared or inferred type of an expression is weaker than what is required for a particular computation

- `(<type>) <expr>` simply converts the type of `<expr>` to `<type>` for type-checking purposes. If the value of `<expr>` does not have type `<type>`, the computation throws a `ClassCastException`.

- If the cast needs to be performed repeatedly, it is also possible to assign `<expr>` to a new variable declared to be of `<type>`

- **Example**: consider the **`merge`** method on **`IntList`** for today's homework (HW7) written using the conventional Scheme solution.

merge Example

```
abstract class IntList {
  IntList cons(Comparable n) { return new ConsIntList(n, this); }
  abstract IntList merge(IntList other);
}

class EmptyIntList extends IntList {
  static EmptyIntList ONLY = new EmptyIntList();
  private EmptyIntList() { }
  IntList merge(IntList other) { return other;}
}

class ConsIntList extends IntList {
  int first;
  IntList rest;
  IntList merge(IntList other) {
    if (other == EmptyIntList.ONLY) return this;
    ConsIntList o = (ConsIntList) other; // cast operation
    if (first < o.first()) return rest.merge(o).cons(first);
    else return merge(o.rest()).cons(o.first());
  }
}
```

Cast needed because first() can only be invoked on ConsIntList

Casting vs. Compiler Type-Checking

- The type-checking in the Java compiler disallows casts
  `(<type>) <expr>`
  where `<type>` is an object type and the static type of `<expr>` and `<type>` do not overlap (other than `null`)

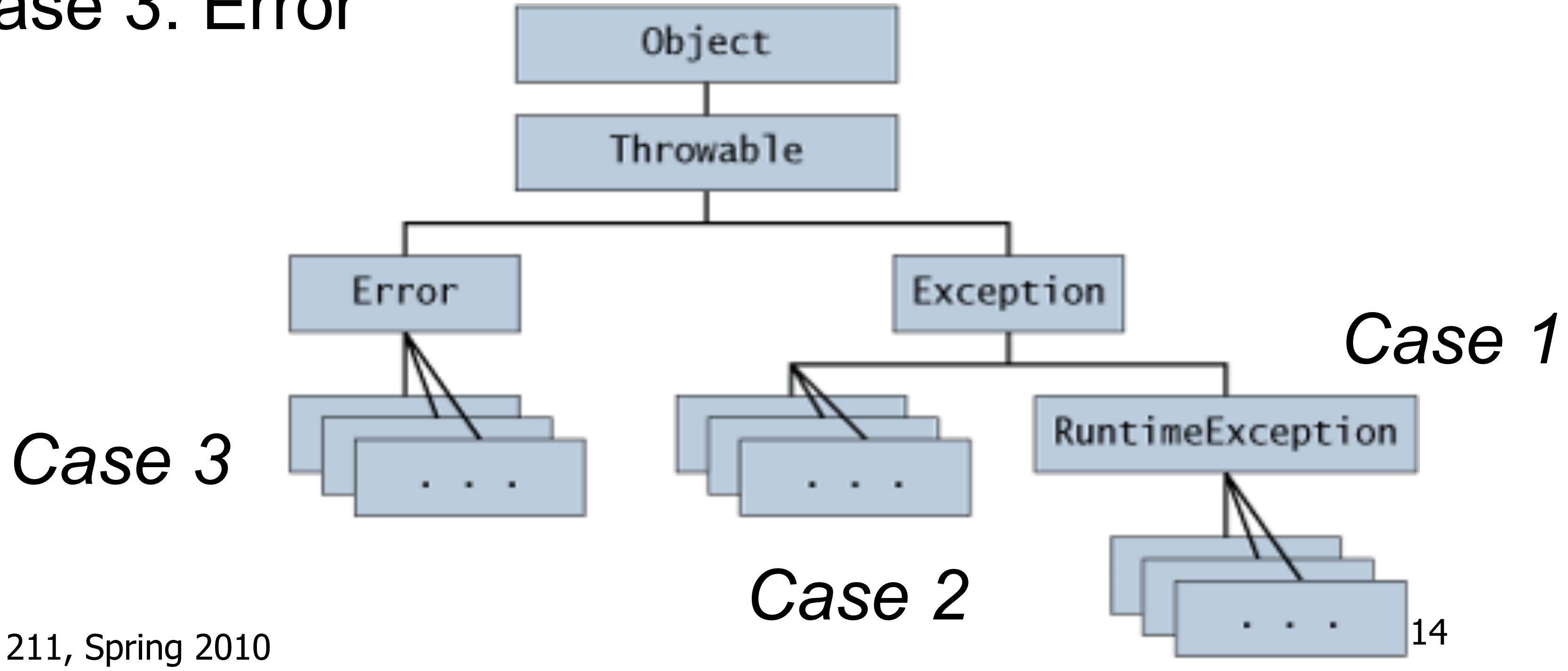
- For example

  ```
  EmptyIntList e = new EmptyIntList();
  ConsIntList o = (ConsIntList) e;
  ```

  will result in a compile-time error

Cases 2 and 3

- Case 2: subtype of Exception, but not a subtype of RuntimeException (also called “checked exceptions”)
- Case 3: Error



Case 2: Checked Exceptions

- Used for error conditions that a program may want to handle, and that are also explicitly part of a method's contract in the throws clausee.g.,
  - `void foo() throws MyException { . . . }`

- The Java compiler enforces the following rules on checked exceptions
  - Every method that throws a checked exception must advertise it in the throws clause in its method definition (contract)
  - Every method that calls a method that advertises a checked exception must either handle that exception (with try and catch) or must in turn advertise that exception in its own throws clause.

Case 3: Errors

- Subtypes of Error are used to identify error conditions that normal programs (including all your programs!) are not expected to handle
- One direct subtype of Error is VirtualMachineError, which in turn includes the following direct subtypes
  - InternalError
  - OutOfMemoryError
  - StackOverflowError
  - UnknownError
- A VirtualMachineError is “thrown to indicate that the Java Virtual Machine is broken or has run out of resources necessary for it to continue operating”

Encoding First-class Functions in Java

- Java methods are *not* data values; *they cannot be used as values.*
- But java classes include methods so we can pass methods (functions) by passing an appropriate class implementing an interface type that is designed exclusively to represent Java functions.
- Example: Scheme `map`

Interfaces for Representing Functions

- For accurate typing, we need different interfaces for different arities. With generics, we can define parameterized interfaces for each arity. For now, we will have to define separate interfaces for each desired typing.

`map` example:

```
interface UnaryFun {
  Object apply(Object arg);  // Object -> Object
}

abstract class ObjectList {
  ObjectList cons(Object n) { return new ConsObjectList(n, this); }
  abstract ObjectList map(UnaryFun f);
}
...
```

Representing Specific Funcions

- For each function that we want to use a value, we must define a class, preferably a singleton. Since the class has no fields, all instances are effectively identical.
- Java provides a lightweight notation for singleton classes called *anonymous classes*. Moreover these classes can refer to fields and `final` method variables that are in scope.
- Anonymous class notation:

```
new <type>() {
   <member_1>
   ...
   <member_n>
}
```

Anonymous Class Example

```
new UnaryFun() {
 Object apply(Object arg) {
    // Return a list containing arg
    return EmptyObjectList.ONLY.cons(arg);
  }
}
```

There are pending proposals to provide better notation for lambda abstractions.

Free Variables in Anonymous Classes

- What do free variables mean inside anonymous classes? What do they mean in λ-expressions?
- In Java, the free variables can be either:
  - fields, or
  - local (method) variables.
- Use them in doing the `filter` problem in HW8.

Another Anonymous Class Example

```
. . .
final Integer negativeOne = new Integer(-1);
ObjectList ol1 = . . .;
ObjectList ol2 = ol1.map(
    new UnaryFun() {
       Object apply(Object arg) {
          if (arg.predicate())
            return EmptyObjectList.ONLY.cons(arg);
          else
            return negativeOne; // Free variable
        }
    }
);
```