Java Exceptions

Object Oriented Programming

https://softeng.polito.it/courses/09CBI

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Motivation

- Report anomalies, by delegating error handling to higher levels
  - Methods detecting anomalies might not be able to recover from an error
  - Caller method can handle errors more suitably than the detecting method itself
- Localize error handling code by separating it from operating code
  - Operating code is more readable
  - Error handling code is collected in a single place, instead of being scattered

Anomalies in programs

- Detection
  - Check conditions revealing an anomaly
- Signaling
  - Inform the caller about the anomaly
- Dispatch
  - Receive and redirect the anomaly signal
- Handling
  - Perform operation to address an anomaly

Error signaling techniques

- Program abort (handling)
  - Abrupt termination of the execution
- Special value
  - Return a special value to indicate error
- Global status
  - Global variable contain error reports
- Exceptions
  - Throw an exception

Error signaling/handling: abort

- If a non-remediable error happens, call `System.exit()`
  - Abort program execution, VM does not perform any cleanup or resource release
- A method causing an unconditional program interruption is not very dependable (nor usable)

Error signaling: special value

- If an error happens, return a special value
- Special values are distinct from normal values returned

```
pb.find("non-exist”);        null
"ABCD".indexOf("F");         -1
Math.pow(-1, 0.5);           NaN
```

- What if special values are normal?
  - `"" + null` "null"

Global error variable

- In C many function set the global variable **errno** to signal that an error occurred during an operation
  - See: http://man7.org/linux/man-pages/man3/errno.3.html
- In Java, such error signaling approach is never used used

Error handling code

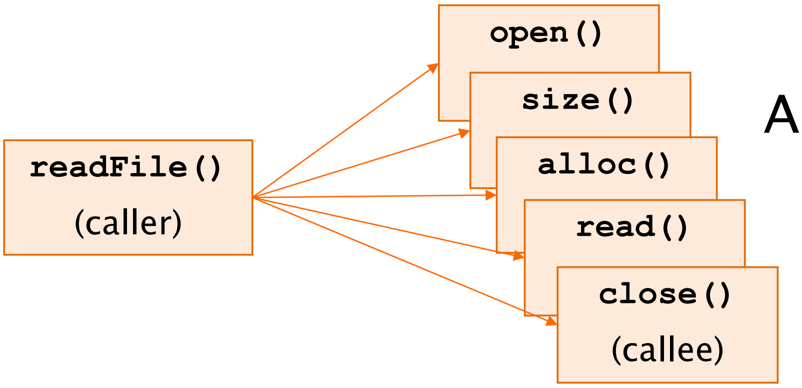
- Code is messy to write and hard to read

```
if( someMethod() == ERROR ) // acknowledge
   //handle the error
else
   //proceed normally
```

- Only the direct caller can intercept errors
  - no simple delegation to any upward method
  - unless further additional code is added
- Developer must remember value/meaning of special values to check for errors

Example – Read file

- open the file
- determine file size
- allocate that much memory
- read the file into memory
- close the file



Any of them can fail

No error handling

```
int readFile() {

   open();
   int n = size;
   alloc(n);
   read();
   close();

   return 0;
}
```

Special return code

```
int readFile() {
   open();
   if (operationFailed)
      return -1;
   int n=size();
   if (operationFailed)
      return -2;
   alloc();
   if (operationFailed) {
      close the file;
      return -3;
   }
   read();
   if (operationFailed) {
      close the file;
      return -4;
   }
   close();
   if (operationFailed)
      return -5;
   return 0;
}
```

Lots of error-detection and error-handling code

To detect errors we must check specs of library calls (no homogeneity)

Using exceptions

```
try {
   open();
   int n = size;
   alloc(n);
   read();
   close();
} catch (fileOpenFailed) {
        doSomething;
} catch (sizeDeterminationFailed) {
        doSomething;
} catch (memoryAllocationFailed) {
        doSomething;
} catch (readFailed) {
        doSomething;
} catch (fileCloseFailed) {
        doSomething;
}
```

Basic concepts

- The code detecting the the error will throw an exception, can be either
  - Developers code
  - Third-party library
- At some point, up in the hierarchy of method invocations, a caller will intercept and handle the exception
- In between, dispatching methods can
  - Relay the exception (complete delegation)
  - Intercept and re-throw (partial delegation)

Syntax

- Java provides three keywords
  - ♦ `throw`
    - – Throws an exception
  - ♦ `throws`
    - – Declare a potential exception
  - ♦ `try`
    - – Introduces code to watch for exceptions
  - ♦ `catch`
    - – Defines the exception handling code
- Java also defines a new type
  - ♦ `Throwable` class

Generating Exceptions

1. Identify/define an exception class
2. Declare the method as potential source of exception
3. Create an exception object
4. Throw the exception

Generation

```
public class EmptyStack extends Exception{}
                                         (1)
```

```
public class Stack{
   public int pop() throws EmptyStack {  (2)

      if(size == 0) {
        EmptyStack e = new EmptyStack(); (3)
        throw e;
      }
      ...          (4)
   }
}
```

Keyword **throw**

- Performs the exception throw
- When an exception is thrown, the execution of the current method is interrupted immediately
  - The code immediately following the **throw** statement is not executed
  - Like a **return** statement
- The catching phase starts

Declaration `throws`

- Every method that might generate an exception must must declare it in its signature
  - All exception type(s) are listed after the `throws` keyword
- Allow checking dispatching by caller
- Must declare exception thrown both
  - directly by the method, or
  - by called methods and relayed

Exception dispatching

- When a fragment of code can possibly generate an exception, the exception must be dispatched
- Dispatching can be:
  - Relay the exception and let it propagate
    - Method has a `throws` declaration,
  - Catch, stop the exception, and handle it
    - Code enclosed in `try{}catch(){}` statement
  - Catch, partially handle, and re-throw

Run-time catching phase

- Once an exception is thrown the normal execution is suspended
- The thrown exception *“walks back”* the call stack until either:
  - It is caught by one of the methods
  - It overtakes **`main()`**
    - In this case the JVM prints the exception (and the full stack trace) and terminates the program

Relay

```
class Dummy {
  Stack st;
  public int foo() throws EmptyStack{
    int v = st.pop();
    return v + 1;
  }
}
```

Not executed in case of an exception

Relay

- Exception not caught can be relayed until the **`main()`** method and the JVM

```
class Dummy {
  Stack st;
  public int foo() throws EmptyStack{
    int v = st.pop();
    return v + 1;
  }
}
```

```
public static void main(String args[])
        throws EmptyStack {
         Dummy d = new Dummy();
         d.foo();
}
```

Catch and handle

```
class Dummy {
  Stack st;
  public int foo(){
    try{
      int v = st.pop();
      return v + 1;
    } catch (StackEmpty se) {
       // do something
    }
    return 0; // default value
} }
```

Not executed in case of an exception

Note: all paths must end with a return

Catch and re-throw

```
class Dummy {
  Stack st;
  public void foo() throws EmptyStack{
    try{
      int v = st.pop();
      return v + 1;
    } catch (StackEmpty se) {
      // intermediate handling
      throw se;
    }
} }
```

Not executed in case of an exception

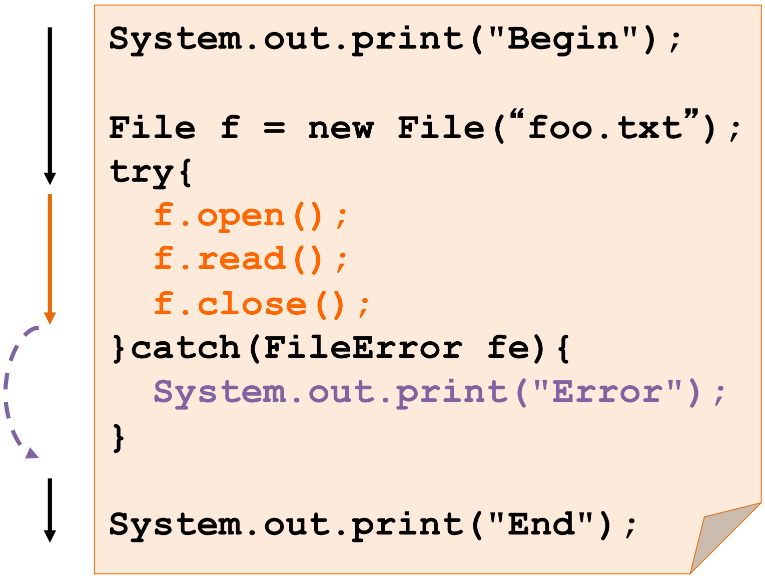
Execution flow

- **open** and **close** can generate a **FileError**
- Suppose `read` does not generate exceptions

```
System.out.print("Begin");

File f = new File("foo.txt");
try{
  f.open();
  f.read();
  f.close();
}catch(FileError fe){
  System.out.print("Error");
}

System.out.print("End");
```

Execution flow – no exception

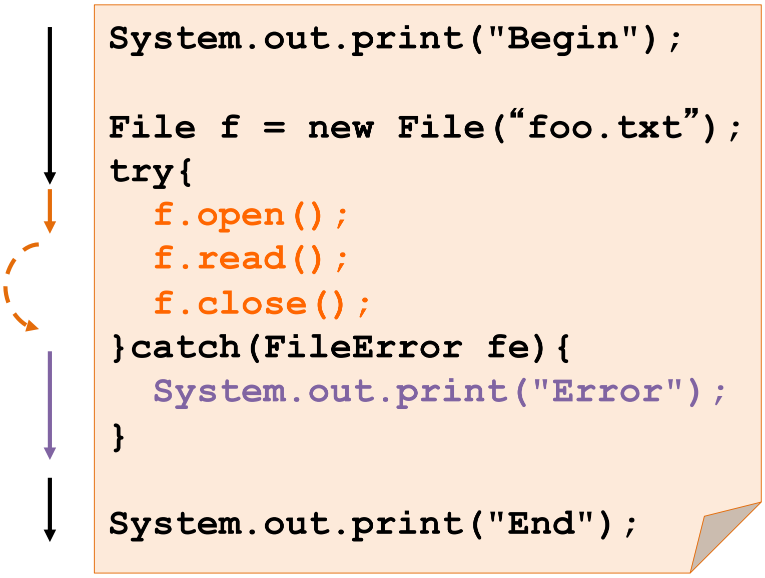
If no exception is generated then the **`catch`** block is skipped



```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
  f.open();
  f.read();
  f.close();
}catch(FileError fe){
  System.out.print("Error");
}

System.out.print("End");
```

Execution flow – exception

If **`open()`** generates an exception then **`read()`** and **`close()`** are skipped



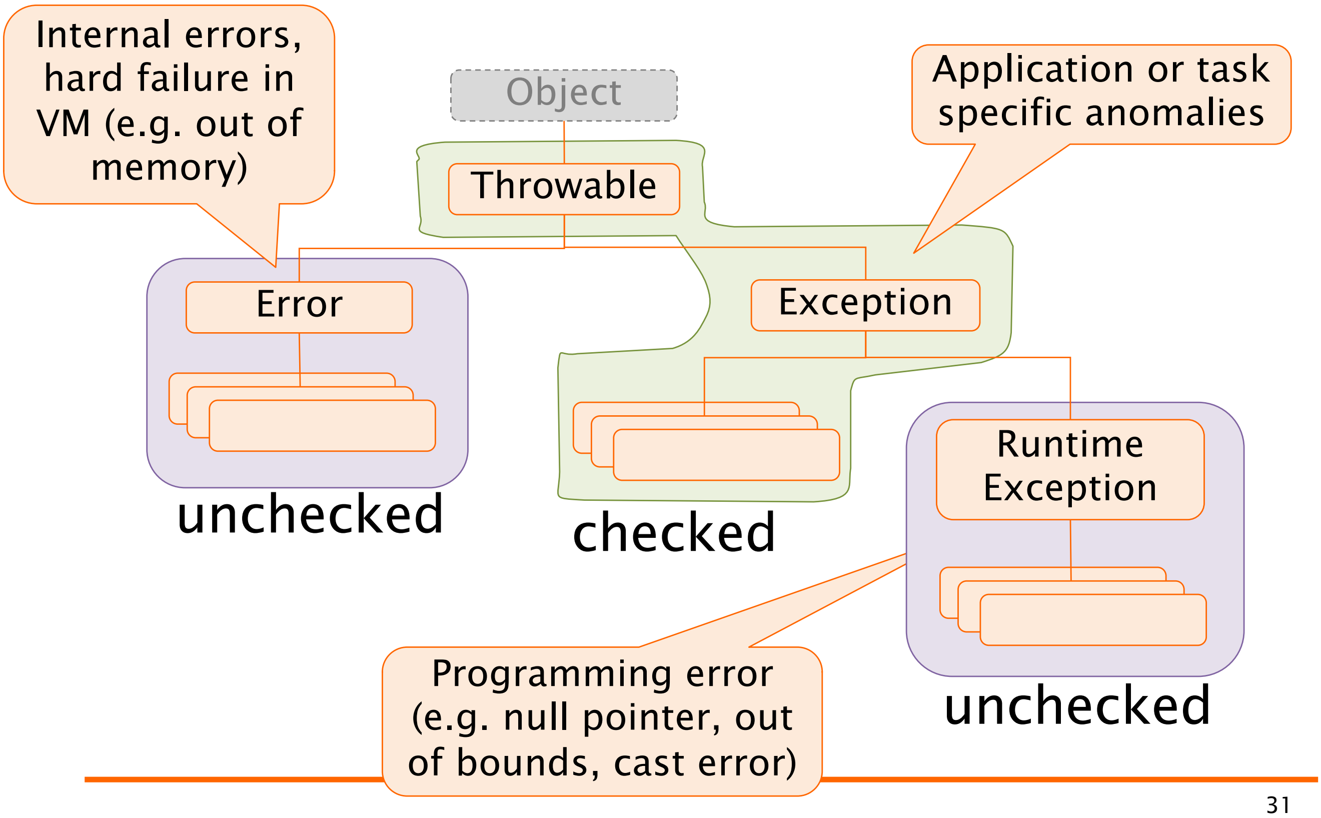
```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
  f.open();
  f.read();
  f.close();
}catch(FileError fe){
  System.out.print("Error");
}

System.out.print("End");
```

EXCEPTION CLASSES

Class **Throwable**

- Exception classes must extend class **`Throwable`**
- Contains a snapshot of the call stack
- May contain a message string
  - provides information about the anomaly
- May also contain a cause
  - another exception that caused this one to be thrown

Exceptions hierarchy


Internal errors, hard failure in VM (e.g. out of memory)
Object
Throwable
Application or task specific anomalies
Error
Exception
unchecked
checked
Runtime Exception
Programming error (e.g. null pointer, out of bounds, cast error)
unchecked

Checked and unchecked

- Unchecked exceptions
  - Their generation is not foreseen (can happen everywhere)
  - Need not to be declared
    - not checked by the compiler
  - Typically generated by JVM
- Checked exceptions
  - Exceptions must be declared
    - checked by the compiler
  - Generated with `throw`

Exception classes examples

- **`Error`**
  - **`OutOfMemoryError`**
- **`Exception`**
  - **`ClassNotFoundException`**
  - **`InstantiationException`**
  - **`IOException`**
  - **`InterruptedException`**
- **`RuntimeException`**
  - **`NullPointerException`**
  - **`ClassCastException`**

Application specific exceptions

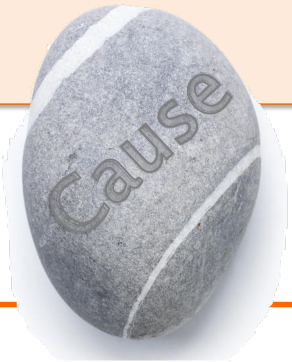
- Represent anomalies specific for the application
- Usually extend **`Exception`**
- Can be caught separately from the predefined ones
  - Allow more fine-grained control than using just **`Exception`**

Application specific exceptions

- Exceptions are like stones
  - When they hit you, they first matters because they exists and are thrown, then for their message

```
class Stone
extends Throwable
{}
```

```
class MsgStone
extends Exception {
public MsgStone(String m){
   super(m); }
}
```



Exceptions and loops (I)

- For errors affecting a single iteration, the **try-catch** blocks is nested in the loop.
- In case of exception the execution goes to the **catch** block and then proceed with the next iteration.

```
while(true){
   try{
     // potential exceptions
   }catch(AnException e){
     // handle the anomaly
   } // and continue with next iteration
}
```

Exceptions and loops (II)

- For serious errors compromising the whole loop, the loop is nested within the try block.
- In case of exception, the execution goes to the catch block, thus exiting the loop.

```
try{
    while(true){
        // potential exceptions
    }
}catch(AnException e){ // exit the loop and …
    // handle the anomaly
}
```

Unchecked and loop

```
String[] strings =
{"1","2","III","4","V","6"};
int sum = 0;
for(String s : strings) {
  sum += Integer.parseInt(s);
}
System.out.println("Sum: " + sum);
```

```
NumberFormatException: For input string: "III"
```

Unchecked and loop

```
try{
  int sum = 0;
  for(String s : strings) {
    sum += Integer.parseInt(s);
  }
  System.out.println("Sum: " + sum);
}catch(Exception e){
  System.err.println("Error!");
}
```

```
Error!
```
No sum computed

Unchecked and loop

```
int sum = 0;
for(String s : strings) {
  try{
    sum += Integer.parseInt(s);
  }catch(NumberFormatException e){
    System.err.println("Wrong: "+s);
  }
}
System.out.println("Sum: " + sum);
```

```
Wrong III
Wrong V
```

```
Sum: 13
```

Nesting

- Try/catch blocks can be nested
  - E.g. because error handlers may generate new exceptions

```
try{
    /* Do something */
}catch(…){
  try      { /* Log on file */ }
  catch(…){ /* Ignore */ }
}
```

Unchecked and loop

```
sum = 0;
for(String s : strings) {
  try {
    sum += Integer.parseInt(s);
  }catch(NumberFormatException nfe) {
    try {
      sum += parseRoman(s);
    }catch(NumberFormatException re) {
      System.err.println("Wrong " + s);
} } }
System.out.println("Sum: " + sum);
```

```
Sum: 21
```

Multiple catch

- Capturing different types of exception is possible with different catch blocks

```
try {
 ...
}
catch(StackEmpty se) {
  // here stack errors are handled
}
catch(IOException ioe) {
  // here all other IO problems are handled
}
```

Matching rules

- Only one handler is executed
  - The first one matching the thrown exception
  - A a **catch** matches if the thrown exception is **instanceof** the **catch**’s exception class
- Catch blocks must be ordered by their “generality”
  - From the most specific (derived classes) to the most general (base classes)
  - Placing the more general first would obscure the more specific, making them unreachable

Execution flow

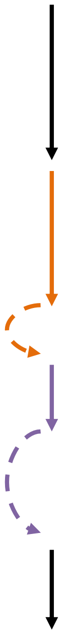
- `open` and `close` can generate a `FileError`
- `read` can generate a `IOError`

```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
  f.open();
  f.read();
  f.close();
}catch(FileError fe){
  System.out.print(“File err”);
}catch(IOError ioe){
  System.out.print(“I/O err”);
}

System.out.print("End");
```

Execution flow

If `close` fails

- “*File error*” is printed
- Eventually program terminates with “*End*”

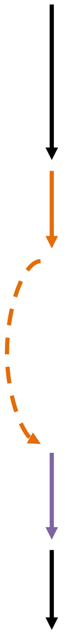


```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
  f.open();
  f.read();
  f.close();
}catch(FileError fe){
  System.out.print(“File err”);
}catch(IOError ioe){
  System.out.print(“I/O err”);
}

System.out.print("End");
```

Execution flow

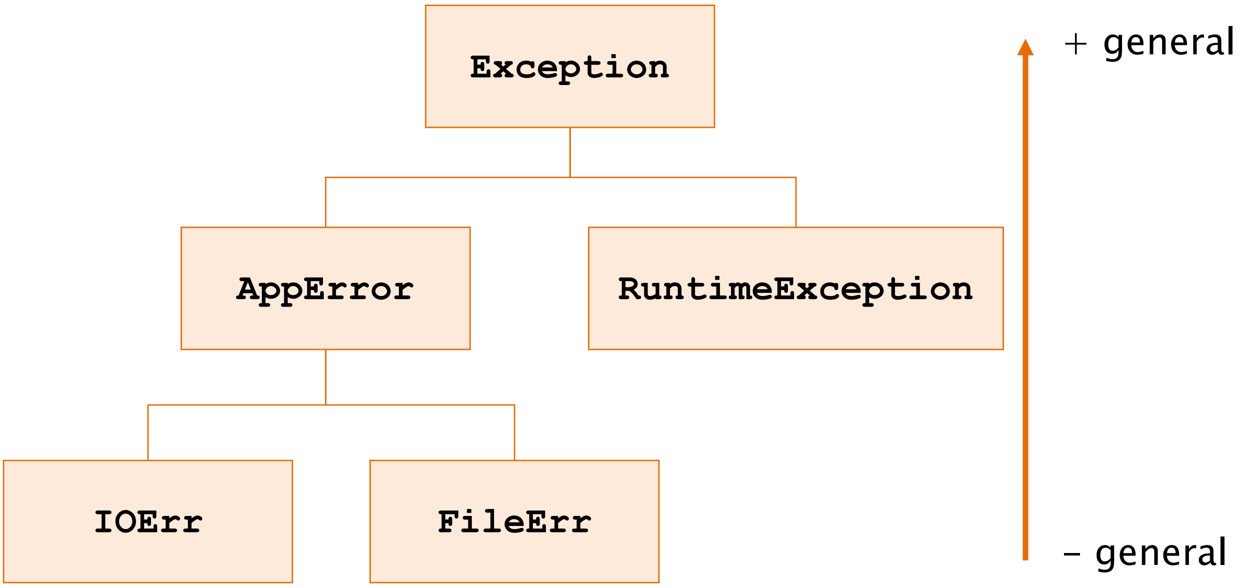
If **read** fails:

- “*I/O error*” is printed
- Eventually program terminates with “*End*”



```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
   f.open();
   f.read();
   f.close();
}catch(FileError fe){
   System.out.print(“File err”);
}catch(IOError ioe){
   System.out.print(“I/O err”);
}

System.out.print("End");
```

Matching rules example



Exception

AppError

RuntimeException

IOErr

FileErr

+ general

– general

Matching rules example

```
class MyError extends Exception{}
class IOErr   extends Error{}
class FileErr extends Error{}
class FatalEx extends Exception{}
```

```
try{ /*…*/ }
catch(IOErr ioe){ /*…*/ }
catch(MyError er){ /*…*/ }
catch(Exception ex){ /*…*/ }
```

– general

↓

+ general

Keyword `finally`

- The keyword **`finally`** introduces a code block that is executed in any case
  - No exception
  - Caught exception
  - Uncaught exception
    - Both checked and unchecked
  - Does not work in case of **`System.exit()`**
- Can be used to
  - Dispose of resources
  - Close a file

Keyword `finally`

```
MyFile f = new MyFile();
if (f.open(“myfile.txt")) {
   try {
      exceptionalMethod();
   }catch(IOException e){
     //…
   } finally {
      f.close();
   }
}
```

After all catch branches (if any)

Summary

- Exceptions provide a mechanism to manage anomalies and errors
- Allow separating “nominal case” code from exceptional case code
- Decouple anomaly detection from anomaly handling
- They are used pervasively throughout the standard Java library

Summary

- Exceptions are classes extending the **`Throwable`** base class
- Inheritance is used to classify exceptions
  - **`Error`** represent internal JVM errors
  - **`RuntimeException`** represent programming error detected by JVM
  - **`Exception`** represent the usual application-level error

Summary

- Exception must be dispatched by
  - Catching them with **`try{ }catch{ }`**
  - Relaying with **`throws`**
  - Catching and re-throwing
- Unchecked exception can avoid mandatory dispatching
  - All exceptions extending **`Error`** and **`RuntimeException`**