



Chapter 7: Software Construction for Robustness

7.2 Error and Exception Handling

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Outline


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1 Generic Error and Exception Handling Techniques



Errors in this section

- 
- **The errors described in this section is not exactly equivalent to the “error” in Java.**
 - **It means all abnormal things in program.**

Sorts of errors



■ User input errors

- In addition to the inevitable typos, some users like to blaze their own trail instead of following directions. E.g. a user asks to connect to a URL that is syntactically wrong, the network layer will complain.

■ Device errors

- Hardware does not always do what you want it to. The printer may be turned off. A web page may be temporarily unavailable. Devices will often fail in the middle of a task.

■ Physical limitations

- Disks can fill up; you can run out of available memory

■ Code errors

- A method may not perform correctly. e.g. it could deliver wrong answers or use other methods incorrectly. Computing an invalid array index, trying to find a nonexistent entry in a hash table, or trying to pop an empty stack are all examples of a code error.

Error handling

- Error handling refers to the anticipation, detection, and resolution of programming, application, and communications errors. 错误处理是指编程、应用程序和通信中错误的预测、检测 and 解决。
- Specialized programs, called **error handlers**, are available to deal with errors.
- Possible strategies of error handling:
 - Forestall errors if possible 预先防止
 - Recover from them when they occur without terminating the application, 错误中恢复
 - Gracefully terminate an affected application and save the error information to a log file 优雅地退出

Dealing with Errors

- While encountering errors, or an operation cannot be completed because of an error, **the program ought to either**
 - Notify the user of an error
 - Save all work
 - Return to a safe state and enable the user to execute other commands
 - Allow the user to save all work and terminate the program gracefully
- **This may not be easy to do**, because the code that detects (or even causes) the error condition is usually far removed from the code that can roll back the data to a safe state or the code that can save the user's work and exit cheerfully. 难点在于检测错误的代码通常远离可以回滚数据或保存数据并优雅退出的代码
- **The mission of error handling is to transfer control from where the error occurred to an error handler that can deal with the situation.** 错误处理的任务就是将控制权从发生错误的位置转移到可以处理错误的程序

(1) Return a neutral value

- **Return a neutral value (Robustness) 返回一个中性值**
 - Sometimes the best response to bad data is to continue operating and simply return a value that's known to be harmless.
 - E.g., A numeric computation might return 0. A string operation might return an empty string, or a pointer operation might return an empty pointer. A drawing routine that gets a bad input value for color might use the default background or foreground color. 采用通用值或缺省值，如0、空字符串、空指针等。
- **However, for a drawing program that shows a patient's X-ray film, it is best not to display a neutral value. In this case, it's better to close the program than to show the wrong patient data.**
(Correctness, not robustness) 对安全或生命相关的程序，则需要严格保证正确性。

(2) Substitute the next piece of valid data

- **Substitute the next piece of valid data (Robustness)** 用下一个有效值替代
 - When processing a stream of data, some circumstances call for simply returning the next valid data.
 - E.g., If you're reading records from a database and encounter a corrupted record, you might simply continue reading until you find a valid record. If you're taking readings from a thermometer 100 times per second and you don't get a valid reading one time, you might simply wait another 1/100th of a second and take the next reading.

(3) Return the same answer as the previous time

- **Return the same answer as the previous time (Robustness)**
 - If a thermometer-reading software doesn't get a reading one time, it might simply return the same value as last time. Depending on the application, temperatures might not be very likely to change much in 1/100th of a second. In a video game, if you detect a request to paint part of the screen an invalid color, you might simply return the same color used previously.
- **However, if you are managing a deal on an ATM, you may not want to use this rule, because that is the previous user's bank account. (Correctness)**

(4) Substitute the closest legal value

■ Substitute the closest legal value (**Robustness**)

- In some cases, you might choose to return the closest legal value.
- This is often a reasonable approach when taking readings from a calibrated instrument. The thermometer might be calibrated between 0 and 100 degrees Celsius, for example. If you detect a reading less than 0, you can substitute 0 which is the closest legal value. If you detect a value greater than 100, you can substitute 100.
- For a string operation, if a string length is reported to be less than 0, you could substitute 0.

(5) Log a warning message to a file

- **Log a warning message to a file (Robustness)**
 - When bad data is detected, you might choose to log a warning message to a file and then continue on.
 - This approach can be used in conjunction with other techniques like substituting the closest legal value or substituting the next piece of valid data.
- **See 7.4 logging**

(6) Return an error code

■ Return an error code (**Correctness**)

- You could decide that only certain parts of a system will handle errors; other parts will not handle errors locally; they will simply report that an error has been detected and trust that some other routine higher up in the calling hierarchy will handle the error.
- The specific mechanism for notifying the rest of the system that an error has occurred could be any of the following:
 - Set the value of a status variable 设置状态值
 - Return status as the function's return value 返回状态值
 - Throw an exception using the language's built-in exception mechanism (**See 7.2.3 Exception handling**) 利用异常机制
- In this case, the specific error-reporting mechanism is less important than the decision about which parts of the system will handle errors directly and which will just report that they've occurred. If security is an issue, be sure that calling routines always check return codes.

(7) Call an error processing routine/object

- **Call an error processing routine/object (Correctness)**
 - This is to centralize error handling in a global error handling routine or error handling object. 集中处理错误
 - The advantage is that error processing responsibility can be centralized, which can make debugging easier. 利于调试
 - The tradeoff is that the whole program will know about this central capability and will be coupled to it. If you ever want to reuse any of the code from the system in another system, you'll have to drag the error handling machinery along with the code you reuse. 不利于重用
- **This approach has an important security implication.**
 - If your code has encountered a buffer-overflow, it's possible that an attacker has compromised the address of the handler routine or object.
 - Thus, once a buffer overflow has occurred while an application is running, it is no longer safe to use this approach. 一旦应用程序运行时发生缓冲区溢出，使用此方法就不再安全。

(8) Display an error message

- **Display an error message wherever the error is encountered**
(Correctness)
 - This approach minimizes error-handling overhead, however it does have the potential to spread user interface messages through the entire application, which can create challenges when you need to create a consistent user interface, try to clearly separate the UI from the rest of the system, or try to localize the software into a different language.
 - Also, beware of telling a potential attacker of the system too much. Attackers sometimes use error messages to discover how to attack a system.

(9) Handle the error locally

- **Handle the error in whatever way works best locally (Correctness)**
 - Some designs call for handling all errors locally – the decision of which specific error-handling method to use is left up to the programmer designing and implementing the part of the system that encounters the error.
 - This approach provides individual developers with great flexibility, but it creates a significant risk that the overall performance of the system will not satisfy its requirements for correctness or robustness.
 - Depending on how developers end up handling specific errors, this approach also has the potential to spread user interface code throughout the system, which exposes the program to all the problems associated with displaying error messages.

(10) Shutdown

■ Shutdown (**Correctness**)

- Some systems shut down whenever they detect an error.
- This approach is useful in safety critical applications.
 - For example, if the software that controls radiation equipment for treating cancer patients receives bad input data for the radiation dosage, shutting down is the best option.
 - We'd much prefer to reboot the machine than to run the risk of delivering the wrong dosage.

■ A similar approach can be used to improve security of Microsoft Windows.

- By default, Windows continues to operate even when its security log is full.
- But you can configure Windows to halt the server if the security log becomes full, which can be appropriate in a security-critical environment.
- 当日志写满时，windows允许继续运行，但在严格要求安全的情况的下，应当停机

High-Level Design Implications of Error Processing

- With so many options, you need to **be careful to handle invalid parameters in consistent ways throughout the program.** 整个程序应该采用一致的处理机制
- The way in which errors are handled affects the software's ability to meet requirements related to correctness, robustness, and other non-functional attributes. 错误处理机制同程序的正确性、健壮性和其他非功能指标密切相关
- Deciding on a general approach to bad parameters is an architectural or high-level design decision and should be addressed at one of those levels. 错误处理机制的决策是体系结构级别或者高层的设计决策问题
- Once you decide on the approach, make sure you follow it consistently.

High-Level Design Implications of Error Processing

- E.g., if you decide to have high-level code handle errors and low-level code merely report errors, make sure the high level code actually handles the errors!
- Don't ignore error information! Test the function return value. If you don't expect the function ever to produce an error, check it anyway.
- Unless you've set an architectural guideline of not checking system calls for errors, check for error codes after each call.
- If you detect an error, include the error number and the description of the error.
- 确定错误处理机制后，要严格执行。
- The whole point of defensive programming is guarding against errors you don't expect. 防御性编程的重点在于防范不期望的错误。

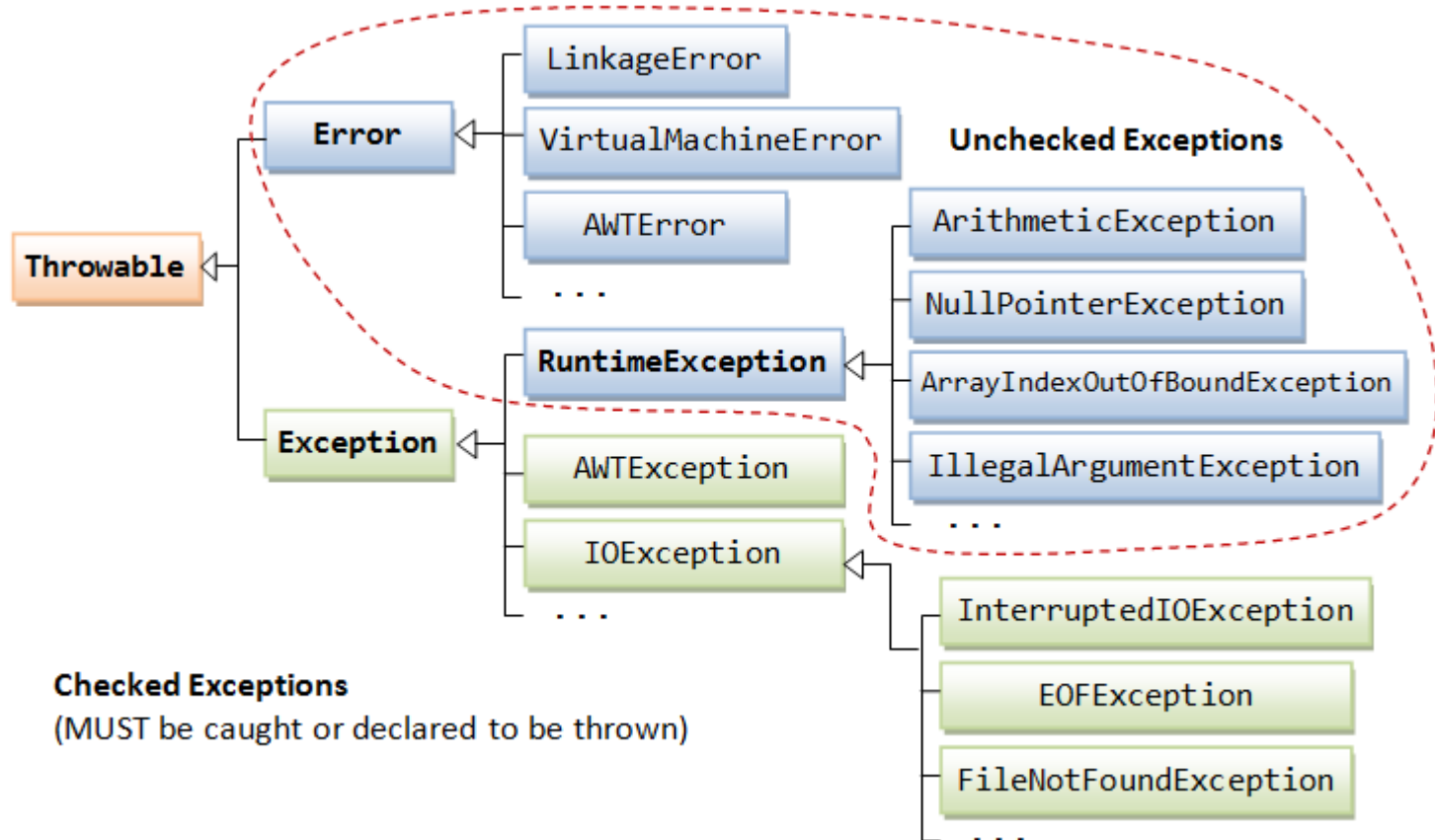


2 Error and Exception Handling in Java



“Abnormals” in Java

- The base class for all Exception objects is `java.lang.Throwable`, together with its two subclasses `java.lang.Exception` and `java.lang.Error`.



Error and Exception

- The **Error** class describes internal system errors and resource exhaustion situations inside the Java runtime system (e.g., `VirtualMachineError`, `LinkageError`) that rarely occur. **Error**类描述Java虚拟机内部错误(资源耗尽和系统错误等), 多数情况下无需处理, 也无法处理
 - You should not throw an object of this type.
 - There is little you can do if such an internal error occurs, beyond notifying the user and trying to terminate the program gracefully.
- The **Exception** class describes the error caused by your program (e.g. `FileNotFoundException`, `IOException`). **Exception**类描述程序导致的错误, 需要处理
 - These errors could be caught and handled by your program (e.g., perform an alternate action or do a graceful exit by closing all the files, network and database connections).

An Example

```
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");
    }
}
```



(1) What is Exception?



Exceptions

- An exception is an *abnormal event* that arises during the execution of the program and disrupts the normal flow of the program.
- Exceptions mechanism are a specific means by which code can pass along errors or exceptional events to the code that called it. 异常处理机制将允许代码将错误或者异常事件传递给调用它的代码。
- Java allows every method an alternative exit path if it is unable to complete its task in the normal way. 当方法不能正常完成时，提供了另外一个退出路径
 - In this situation, the method *throws* an object that encapsulates the error information. The method exits immediately and does not return any value. Moreover, execution does not resume at the code that called the method; 方法抛出异常，停止执行，不返回任何值，不执行后续代码。
 - Instead, the *exception-handling* mechanism begins its search for an exception handler that can deal with this particular error condition. 异常处理机制捕获异常，寻找到可以处理此异常的代码进行处理。

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**
 - Separate normal code path from exceptional
 - Ease task of recovering from failure
- **Ease task of writing robust, maintainable code**

Benefits of exceptions

```
FileInputStream fIn = new FileInputStream(fileName);
if (fIn == null) {
    switch (errno) {
        case _ENOFIL:
            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;
}
return i;
```

缺点：业务逻辑代码
与错误处理代码
交织在一起

Benefits of exceptions

```
FileInputStream fileInput = null;

try {
    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();
}
```

业务逻辑代码与错误处理代码分离

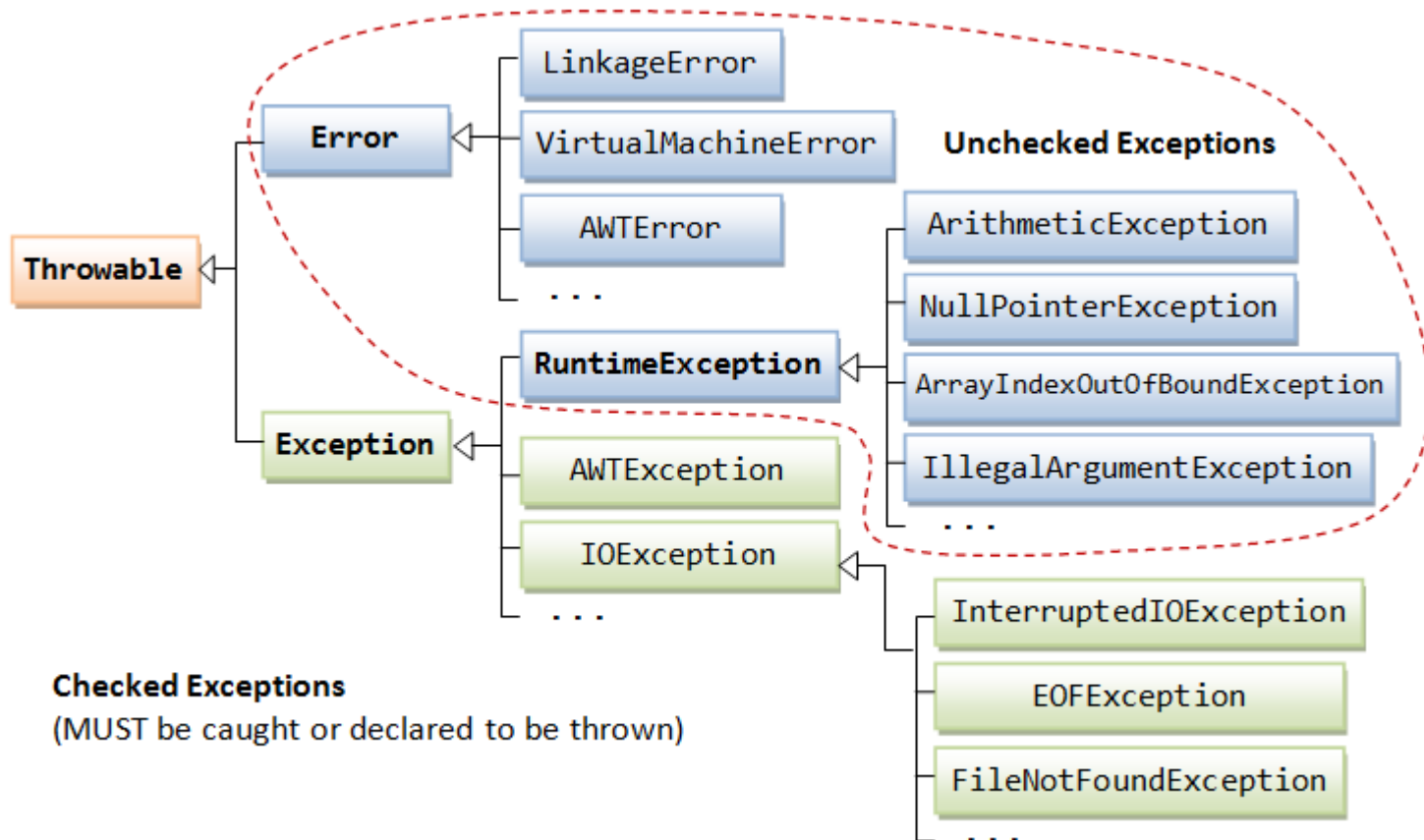


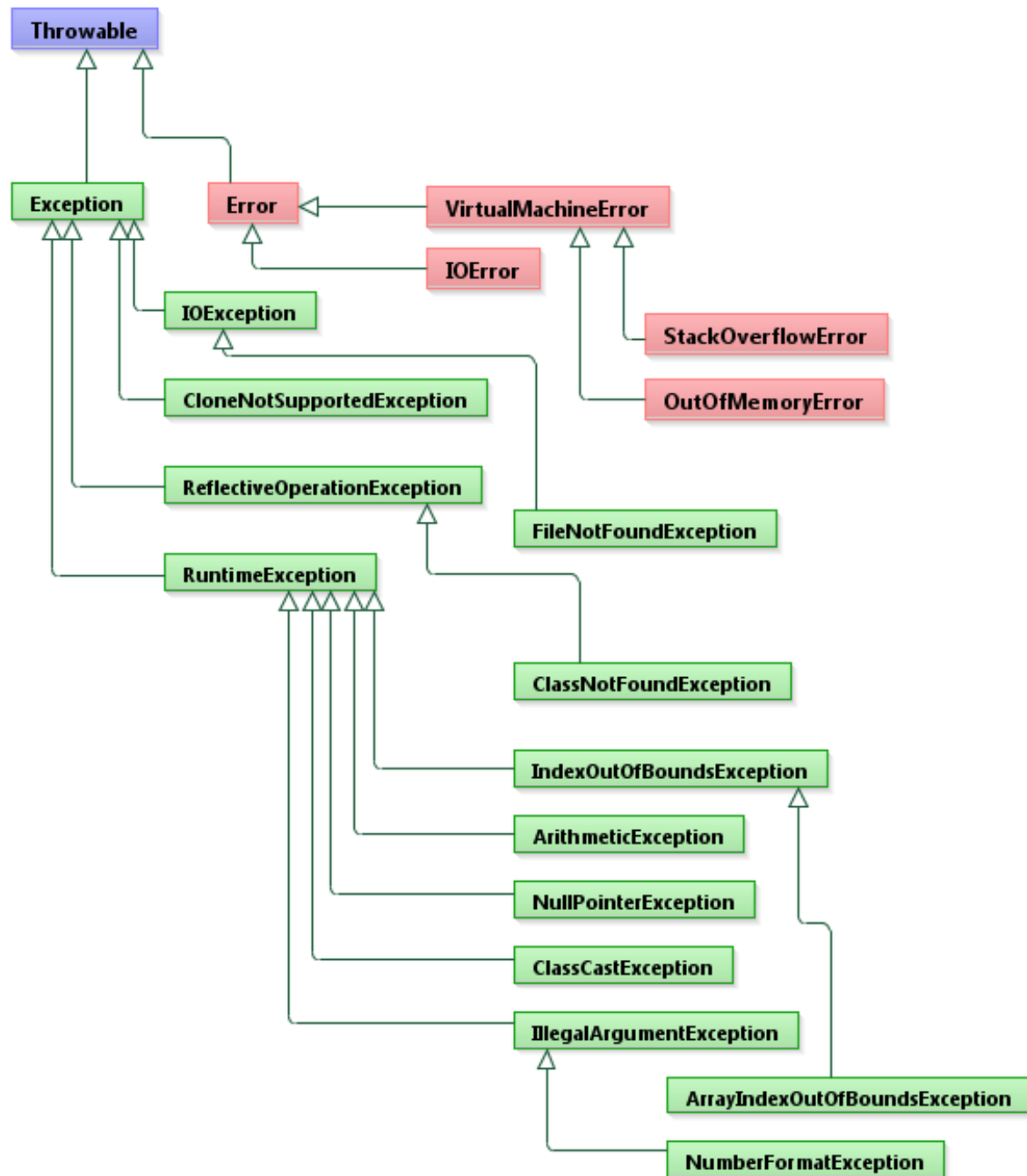
(2) Classification of exceptions



Exceptions are derived from Throwable

- In Java programming language, an exception object is always an instance of a class derived from **Throwable**.





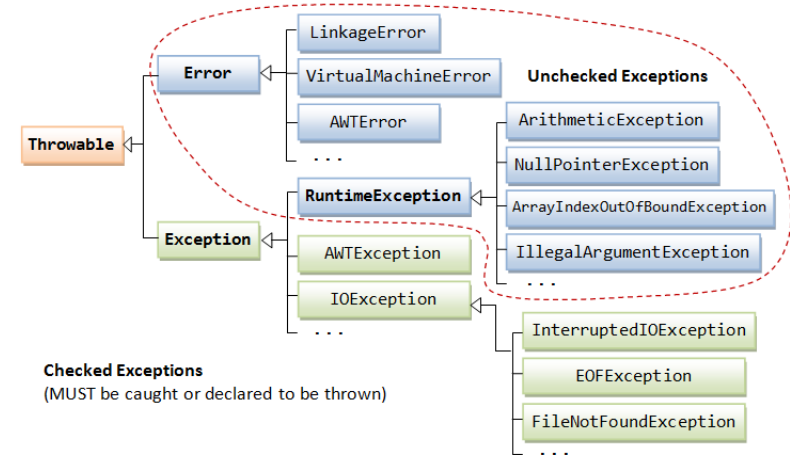
RuntimeException and Other Exceptions

- When doing Java programming, focus on the *Exception* hierarchy.
- The *Exception* hierarchy also splits into **two branches**: **Exceptions that derive from RuntimeException** and **those that do not**.
- **General rule:**
 - A RuntimeException happens because you made a programming error.
 - Any other exception occurs because a bad thing, such as an I/O error, happened to your otherwise good program.

Runtime Exception and Other Exceptions

■ Exceptions that inherit from RuntimeException include such problems as:

- A bad cast(类型转换)
- An out-of-bounds array access
- A null pointer access
-



■ Exceptions that do not inherit from RuntimeException include

- Trying to read past the end of a file
- Trying to open a file that doesn't exist
- Trying to find a Class object for a string that does not denote an existing class
-

RuntimeException

- **If it is a RuntimeException, it was your fault**

- You could have avoided `ArrayIndexOutOfBoundsException` by testing the array index against the array bounds.
- The `NullPointerException` would not have happened had you checked whether the variable was null before using it.

- **How about a file that doesn't exist?**

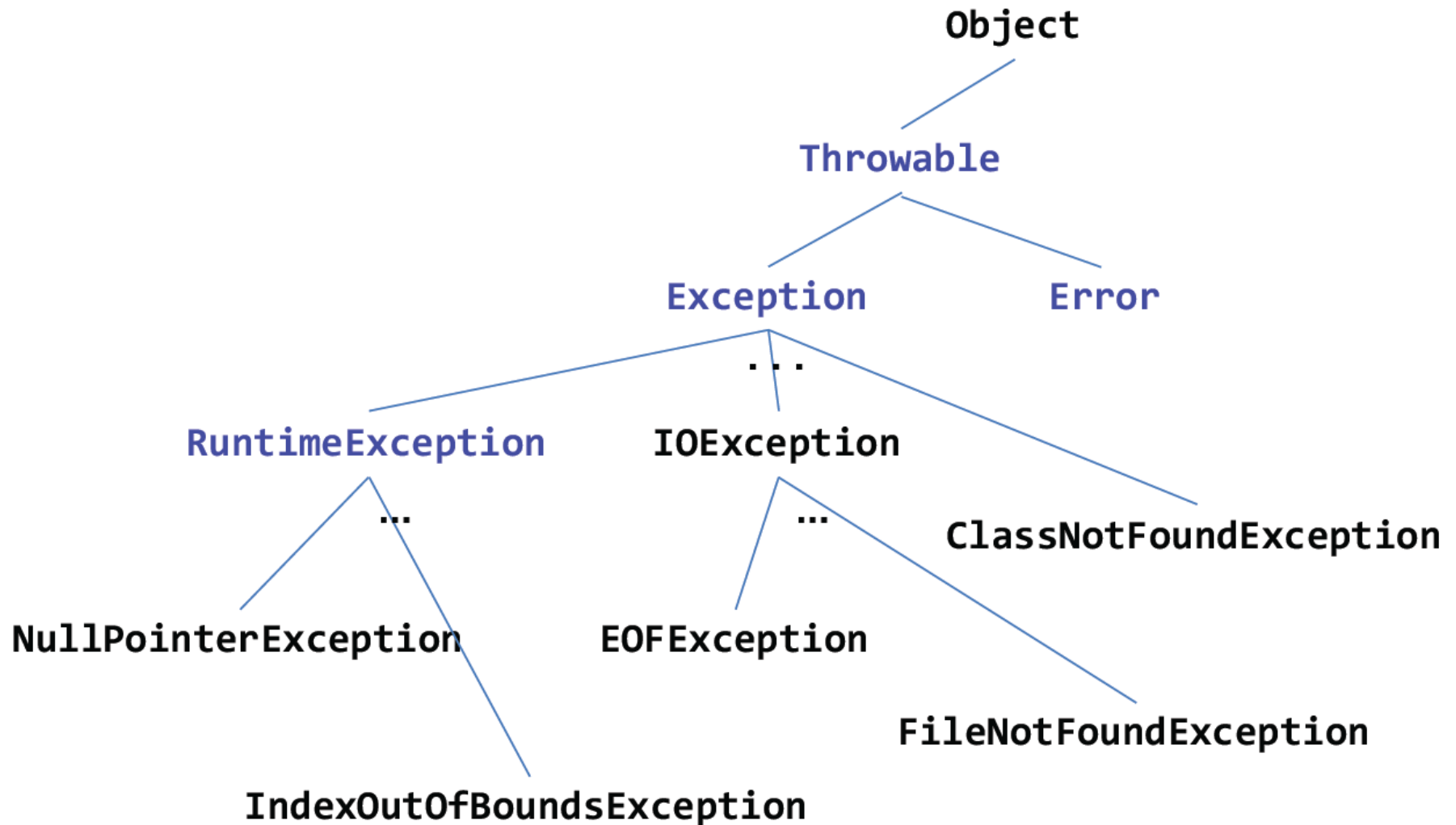
- Can't you first check whether the file exists, and then open it?
- Actually, the file might be deleted right after you checked for its existence. Thus, the notion of “existence” depends on the environment, not just on your code.



(3) *Checked* and *unchecked* exceptions

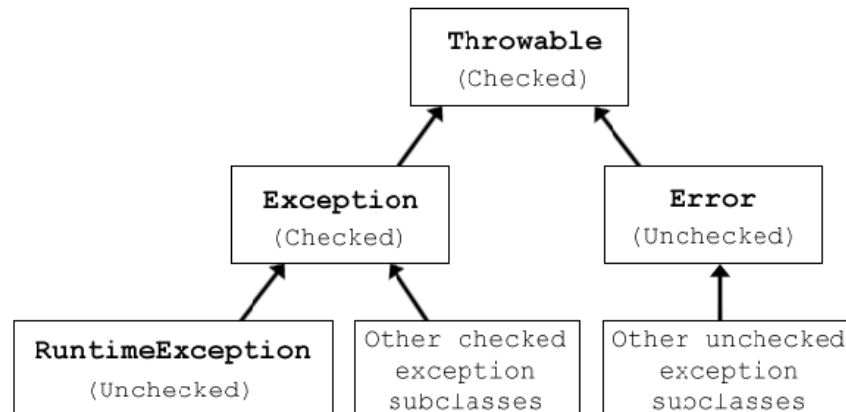


Again, the exception hierarchy in Java



Checked/unchecked exceptions

- **Unchecked exception:** Programming error, other unrecoverable failure (**Error + RuntimeException**)
 - No action is required for program to compile, but uncaught exception will cause program to fail 不要求必须捕获处理
- **Checked exception:** An error that every caller should be aware of and handle
 - Must be caught or propagated, or program won't compile (The compiler checks that you provide exception handlers for all checked exceptions) 要求必须捕获处理, **compiler**会进行检查



Common **Unchecked** Exception Classes

- **ArrayIndexOutOfBoundsException: thrown by JVM when your code uses an array index, which is outside the array's bounds.**

```
int[] anArray = new int[3];  
System.out.println(anArray[3]);
```

Exception in thread "main" **java.lang.ArrayIndexOutOfBoundsException: 3**

- **NullPointerException: thrown by the JVM when your code attempts to use a null reference where an object reference is required.**

```
String[] strs = new String[3];  
System.out.println(strs[0].length());
```

Exception in thread "main" **java.lang.NullPointerException**

Common **Unchecked** Exception Classes

- **NumberFormatException: Thrown programmatically (e.g., by `Integer.parseInt()`) when an attempt is made to convert a string to a numeric type, but the string does not have the appropriate format.**

```
Integer.parseInt("abc");
```

Exception in thread "main" java.lang.NumberFormatException:
For input string: "abc"

- **ClassCastException: thrown by JVM when an attempt is made to cast an object reference fails.**

```
Object o = new Object();
```

```
Integer i = (Integer)o;
```

Exception in thread "main" java.lang.ClassCastException:
java.lang.Object cannot be cast to java.lang.Integer

Common **Unchecked** Exception Classes

- **IllegalArgumentException**: thrown programmatically to indicate that a method has been passed an illegal or inappropriate argument. You could re-use this exception for your own methods.
- **IllegalStateException**: thrown programmatically when a method is invoked and the program is not in an appropriate state for that method to perform its task. This typically happens when a method is invoked out of sequence, or perhaps a method is only allowed to be invoked once and an attempt is made to invoke it again.
- **NoClassDefFoundError**: thrown by the JVM or class loader when the definition of a class cannot be found.

Checked Exception Handling Operations

- Five keywords are used in exception handling: **try**, **catch**, **finally**, **throws** and **throw**.

- Java's exception handling consists of three operations:
 - Declaring exceptions (**throws**)
 - Throwing an exception (**throw**)
 - Catching an exception (**try**, **catch**, **finally**)

Declaring Checked Exceptions by throws

- A Java method can throw an exception if it encounters a situation it cannot handle.
 - A method will not only tell the Java compiler what values it can return, it is also going to tell the compiler what can go wrong. 方法不仅可以告诉编译器返回值是什么，也可以声明会出现什么样的错误
 - E.g. code that attempts to read from a file knows that the file might not exist or that it might be empty. The code that tries to process the information in a file therefore will need to notify the compiler that it can throw some sort of IOException.
- **The place in which you advertise that your method can throw an exception is the header of the method;** the header changes to reflect the checked exceptions the method can throw.

```
public FileInputStream(String name)  
    throws FileNotFoundException
```

Declaring Checked Exceptions by throws

- When you write your own methods, you don't have to advertise every possible throwable object that your method might actually throw. 不需要为方法声明出所有可能的异常
- To understand when (and what) you have to advertise in the *throws clause* of the methods you write, keep in mind that an exception is thrown in any of the following four situations: 会抛出异常的四种情况
 - You call a method that throws a checked exception—for example, the `FileInputStream` constructor. 调用的方法抛出了异常
 - You detect an error and throw a checked exception with the `throw` statement. 自己的方法抛出了异常
 - You make a programming error, such as `a[-1] = 0` that gives rise to an unchecked exception (`ArrayIndexOutOfBoundsException`). 程序存在错误
 - An internal error occurs in the virtual machine or runtime library. 虚拟机或者运行时类库错误

Declaring Checked Exceptions by throws

- **If either of the first two scenarios occurs, you must tell the programmers who will use your method about the possibility of an exception.** 前两种情况需要声明
 - Any method that throws an exception is a potential death trap.
 - If no handler catches the exception, the current thread of execution terminates.
- **As with Java methods that are part of the supplied classes, you declare that your method may **throw an exception** with an *exception specification* in the method header.**

```
class MyAnimation {  
    . . .  
    public Image loadImage(String s) throws IOException  
    { . . . }  
}
```

Declare more than one Checked Exceptions

- If a method might **throw more than one checked exception type**, you must list all exception classes in the header. Separate them by commas, as in the following example

```
class MyAnimation {  
    . . .  
    public Image loadImage(String s)  
        throws FileNotFoundException, EOFException  
    {  
        . . .  
    }  
}
```

Don't throw Error and unchecked exceptions

- **Do not need to advertise internal Java errors – that is, exceptions inheriting from Error.** 不需要声明Error类型的异常
 - Any code could potentially throw those exceptions, and they are entirely beyond your control.
- **Similarly, you should not advertise unchecked exceptions inheriting from RuntimeException.** 不需要声明RuntimeException类型的异常
 - These runtime errors are completely under your control.
 - If you are so concerned about array index errors, you should spend your time fixing them instead of advertising the possibility that they can happen.

```
void drawImage(int i) throws ArrayIndexOutOfBoundsException  
// bad style
```

Summary

■ Summary:

- A method must declare all the *checked* exceptions that it might throw. 一个方法必须声明它可能抛出的所有**checked**异常。
- If your method fails to faithfully declare all checked exceptions, the compiler will issue an error message. **Compiler**会检查是否所有**checked**异常都被正确声明了
- Unchecked exceptions are either beyond your control (Error) or result from conditions that you should not have allowed in the first place (RuntimeException). **Unchecked**异常不需要处理(要么无法处理, 要么不应该发生)

Summary

■ Caution:

- If you override a method from a superclass, the checked exceptions that the subclass method declares cannot be more general than those of the superclass method. 如果子类中重写超类的方法，则子类方法声明的受检查异常不能比超类方法更普遍。
- It is OK to throw more specific exceptions, or not to throw any exceptions in the subclass method. 可以抛出更特定的异常(子类型)，或者不要在子类方法中抛出任何异常。
- In particular, if the superclass method throws no checked exception at all, neither can the subclass. 如果超类方法根本不抛出checked异常，那么子类中方法(重写)也不应抛出。



(4) How to Throw an Exception



How to Throw an Exception

- Suppose you have a method, `readData`, that is reading in a file. Something terrible has happened in your code.
- You may decide this situation is so abnormal that you want to **throw an exception** `EOFException` with the description “Signals that an EOF has been reached unexpectedly during input.”

```
throw new EOFException();
```

or

```
EOFException e = new EOFException();  
throw e;
```

How to Throw an Exception

```
String readData(Scanner in) throws EOFException
{
    . . .
    while (. . .)
    {
        if (!in.hasNext()) // EOF encountered
        {
            if (n < len)
                throw new EOFException();
        }
        . . .
    }
    return s;
}
```

How to Throw an Exception

- The `EOFException` has a second constructor that takes a **string** argument.
- You can put this to good use by describing the exceptional condition more carefully.

```
String gripe = "Content-length: " + len + ", Received: " + n;  
throw new EOFException(gripe);
```

How to Throw an Exception

- Throwing an exception is easy if one of the existing exception classes works for you:
 - Find an appropriate exception class. 找到或者设计合适的异常类
 - Make an object of that class. 创建异常类的对象
 - Throw it. 抛出
- Once a method throws an exception, it does not return to its caller. This means you do not have to worry about cooking up a default return value or an error code. 一旦方法抛出一个异常，它就不会返回到调用者，这意味着不需要担心会产生默认返回值或错误编码。



(5) Creating Exception Classes



Creating Exception Classes

- Your code may run into a problem which is not adequately described by any of the standard exception classes.
- In this case, it is easy enough to create your own exception class.
- Just **derive it from `Exception`, or from a child class of `Exception` such as `IOException`.**
- It is customary to **give both a default constructor and a constructor that contains a detailed message.**习惯上同时给出一个默认构造函数和一个包含详细消息的构造函数。
 - The `toString` method of the `Throwable` superclass returns a string containing that detailed message, which is handy for debugging.

Creating Exception Classes

```
class FileFormatException extends IOException
```

```
{  
    public FileFormatException() {}  
    public FileFormatException(String gripe)  
    {  
        super(gripe);  
    }  
}
```

```
String readData(BufferedReader in) throws FileFormatException {  
    . . .  
    while (. . .){  
        if (ch == -1) { // EOF encountered  
            if (n < len)  
                throw new FileFormatException();  
        }  
        . . .  
    }  
    return s;  
}
```




(6) Catching Exceptions



Catching Exceptions

- If an exception occurs that is not caught anywhere, the program will terminate and print a message to the console, giving the type of the exception and a stack trace.
- GUI programs catch exceptions, print stack trace messages, and then go back to the user interface processing loop.
- To catch an exception, set up a **try/catch** block :

```
try {  
    code  
    more code  
    more code  
}  
catch (ExceptionType e) {  
    handler for this type  
}
```

Catching Exceptions

- If any code inside the `try` block throws an exception of the class specified in the catch clause, then

- The program skips the remainder of the code in the *try block*.
- The program executes the handler code inside the *catch clause*.

当try块中出现异常时，将忽略出现异常位置之后的代码，由catch子句进行异常处理。

- If none of the code inside the `try` block throws an exception, then the program skips *the catch clause*. 无异常时，catch子句不执行
- If any of the code in a method throws an exception of a type other than the one named in the *catch clause*, this method exits immediately. (Hopefully, one of its callers has already provided a catch clause for that type.) 如果catch语句中没有匹配的异常处理，则被访问的程序退出。

Catching Exceptions

```
public void read(String filename) {  
    try {  
        InputStream in = new FileInputStream(filename);  
        int b;  
        while ((b = in.read()) != -1) {  
            process input...  
        }  
    }  
    catch (IOException exception) {  
        exception.printStackTrace();  
    }  
}
```

Pass the exception on to the caller

- Another choice to handle the exceptions: **do nothing at all and simply pass the exception on to the caller**. 另一种处理异常的策略：将异常处理交给调用者，某些情况下，调用者更清楚如何处理。
 - Let the caller of the read method worry about it!
 - Might be the best choice (prefer more correctness to robustness).
- If we take that approach, then we have to advertise the fact that the method may throw an IOException. 此时，需要在方法声明中声明异常

```
public void read(String filename) throws IOException {  
    InputStream in = new FileInputStream(filename);  
    int b;  
    while ((b = in.read()) != -1) {  
        process input  
    }  
}
```

- The compiler strictly enforces the throws specifiers. If you call a method that throws a checked exception, you must either handle it or pass it on. 调用声明了checked异常的方法，则必须处理异常或继续传递。

Try/catch and throw an exception?

- As a general rule, **you should catch those exceptions that you know how to handle** and **propagate those that you do not know how to handle**. 准则：处理知道如何处理的异常，传播不知道如何处理的异常。
- When you propagate an exception, you must add a **throws** specifier to alert the caller that an exception may be thrown. 传播异常时，通过 **throws** 通知调用者处理。
- Notice:
 - If you are writing a method that overrides a superclass method which throws no exceptions, then you must catch each checked exception in the method's code. 如果子类方法重写了父类方法，父类方法没有抛出异常，则子类方法中需要 **catch** 所有的 **checked** 异常(不能继续传播)
 - You are not allowed to add more **throws** specifiers to a subclass method that are present in the superclass method. 子类继承自父类的方法，在子类中不能增加异常

Get detailed information from an Exception

- **The exception object may contain information about the nature of the exception.**
 - To find out more about the object, try `e.getMessage()` to get the detailed error message (if there is one)
 - Use `e.getClass().getName()` to get the actual type of the exception object.

Catching Multiple Exceptions

- You can catch multiple exception types in a try block and handle each type differently.
- Use a separate catch clause for each type as in the following example:

```
try {  
    code that might throw exceptions  
}  
catch (FileNotFoundException e) {  
    emergency action for missing files  
}  
catch (UnknownHostException e) {  
    emergency action for unknown hosts  
}  
catch (IOException e) {  
    emergency action for all other I/O problems  
}
```




(7) Rethrowing and Chaining Exceptions



Rethrowing and Chaining Exceptions

- **You can throw an exception in a catch clause.**
- Typically, you do this when you want to change the exception type. If you build a subsystem that other programmers use, it makes a lot of sense to use an exception type that indicates a failure of the subsystem. 用于改变异常的类型，对异常信息进行重新封装。
 - E.g., `ServletException`, the code that executes a servlet may not want to know in minute detail what went wrong in the servlet, but it definitely wants to know that the servlet was at fault.
- Here is how you can catch an exception and rethrow it:

```
try {  
    access the database  
}  
catch (SQLException e) {  
    throw new ServletException("database error: " + e.getMessage());  
}
```
- Here, the `ServletException` is constructed with the message text of the exception.

Rethrowing and Chaining Exceptions

- However, it is a better idea to set the original exception as the “cause” of the new exception: 将原始异常信息传递出去

```
try {  
    access the database  
}  
catch (SQLException e) {  
    Throwable se = new ServletException("database error");  
    se.initCause(e);  
    throw se;  
}
```

- When the exception is caught, the original exception can be retrieved

```
Throwable e = se.getCause();
```

- This wrapping technique is highly recommended. It allows you to throw high level exceptions in subsystems without losing the details of the original failure. 这种包装技术允许在子系统中抛出高级异常，而不会丢失原始失败的细节。



(8) finally Clause



finally Clause

- When your code throws an exception, it stops processing the remaining code in your method and exits the method.
- **This is a problem if the method has acquired some resource** (files, database connections,...), **which only this method knows about, and that resource must be cleaned up.** 问题:出现异常时, 需要清理已经占用的资源
- One solution is to catch and re-throw all exceptions.
- But this solution is tedious because you need to clean up the resource allocation in two places — in the normal code and in the exception code.
- **Java has a better solution: *the finally clause*.**

Try-Catch-Finally

- The code in the finally clause executes whether or not an exception was caught. **Finally**部分的代码，是否捕获异常都会被执行。
- In the following example, the program will close the file *under all circumstances*:

```
InputStream in = new FileInputStream(. . .);
try {
    // 1
    code that might throw exceptions
    // 2
}
catch (IOException e) {
    // 3
    show error message
    // 4
}
Finally {
    // 5
    in.close();
}
// 6
```

Try-Catch-Finally: case 1

- Look at the three possible situations in which the program will execute the finally clause.
- **Case 1: The code throws no exceptions.** 没有抛出异常
 - In this case, the program first executes all the code in the try block.
 - Then, it executes the code in the finally clause.
 - Afterwards, execution continues with the first statement after the finally clause.
 - In other words, execution passes through points **1, 2, 5, and 6.**

```
InputStream in = new FileInputStream(. . .);
try {
    // 1
    code that might throw exceptions
    // 2
}
catch (IOException e) {
    // 3
    show error message
    // 4
}
Finally {
    // 5
    in.close();
}
// 6
```

Try-Catch-Finally: case 2

- **Case 2: The code throws an exception that is caught in a catch clause and the catch clause does not throw an exception.** 抛出一个被捕获的异常，catch没有继续抛出异常
 - The program executes all code in the try block, up to the point at which the exception was thrown. The remaining code in the try block is skipped. The program then executes the code in the matching catch clause, and then the code in the finally clause.
 - If the catch clause does not throw an exception, the program executes the first line after the finally clause.
 - Execution passes through points **1, 3, 4, 5, and 6.**

```
InputStream in = new FileInputStream(. . .);
try {
    // 1
    code that might throw exceptions
    // 2
}
catch (IOException e) {
    // 3
    show error message
    // 4
}
Finally {
    // 5
    in.close();
}
// 6
```


Try-Catch-Finally: case 3

- **Case 3: The code throws an exception that is caught in a catch clause and the catch clause throws an exception. 抛出一个被捕获的异常，catch继续抛出异常**
 - The program executes all code in the try block, up to the point at which the exception was thrown. The remaining code in the try block is skipped. The program then executes the code in the matching catch clause, and then the code in the finally clause.
 - If the catch clause throws an exception, then the exception is thrown back to the caller of this method, and execution passes through points **1, 3, and 5** only.

```
InputStream in = new FileInputStream(. .
.);
try {
    // 1
    code that might throw exceptions
    // 2
}
catch (IOException e) {
    // 3
    show error message
    // 4
}
Finally {
    // 5
    in.close();
}
// 6
```

Try-Catch-Finally: case 4

- **Case4: The code throws an exception that is not caught in any catch clause. 抛出一个未被捕获的异常**
 - Here, the program executes all code in the try block until the exception is thrown.
 - The remaining code in the try block is skipped.
 - Then, the code in the finally clause is executed, and the exception is thrown back to the caller of this method.
 - **Execution passes through points 1 and 5 only.**

```
InputStream in = new FileInputStream(. . .);
try {
    // 1
    code that might throw exceptions
    // 2
}
catch (IOException e) {
    // 3
    show error message
    // 4
}
Finally {
    // 5
    in.close();
}
// 6
```

Using finally without a Catch

- You can use the **finally** clause without a **catch** clause.
- For example, consider the following **try** statement:

```
InputStream in = . . .;
try {
    code that might throw exceptions
}
finally {
    in.close();
}
```

- The `in.close()` statement in the **finally** clause is executed whether or not an exception is encountered in the **try** block.
- If an exception is encountered, it is rethrown and must be caught in another **catch** clause.



(9) The Try-with-Resources Statement



The Try-with-Resources Statement

- **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 Try-with-Resources Statement

- Java SE 7 provides a useful shortcut to the code pattern provided the resource belongs to a class that implements the `AutoCloseable` interface. 对于实现了 `AutoCloseable` 接口的资源，Java 提供自动 close 资源的方法
- That interface has a single method

`void close() throws Exception`

- In its simplest variant, the try-with-resources statement has the form

```
try (Resource res = . . .) {  
    work with res  
}
```

=

```
open a resource  
try {  
    work with the resource  
}  
finally {  
    close the resource  
}
```

The Try-with-Resources Statement

- When try block exits, then `res.close()` is called automatically.
- Here is a typical example — reading all words of a file

```
try (Scanner in = new Scanner(new FileInputStream("/dict/words"), "UTF-8"))  
{  
    while (in.hasNext())  
        System.out.println(in.next());  
}
```

- When the block exits normally, or when there was an exception, the `in.close()` method is called, exactly as if you had used a `finally` block.

The Try-with-Resources Statement

- **Specify multiple resources:**

```
try (Scanner in = new Scanner(new
    FileInputStream("/usr/share/dict/words"), "UTF-8");
    PrintWriter out = new PrintWriter("out.txt"))
{
    while (in.hasNext())
        out.println(in.next().toUpperCase());
}
```

- **No matter how the block exits, both `in` and `out` are closed.**
- **If you programmed this by hand, you would need two nested `try/finally` statements.**



(10) Analyzing Stack Trace Elements



Method Call Stack

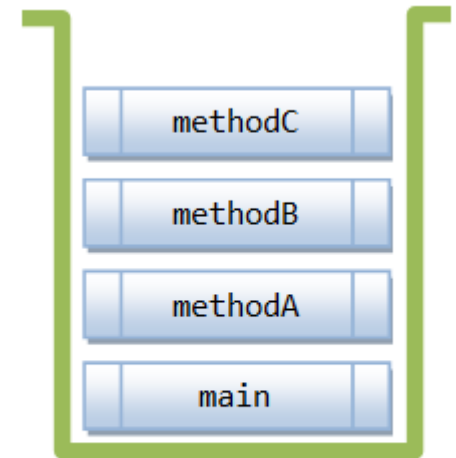
- A typical application involves many levels of method calls, which is managed by a so-called method **call stack**.
- A **stack** is a **last-in-first-out queue**.
- What's the result?
 - Enter main()
 - Enter methodA()
 - Enter methodB()
 - Enter methodC()
 - Exit methodC()
 - Exit methodB()
 - Exit methodA()
 - Exit main()

```
public class MethodCallStackDemo {  
    public static void main(String[] args) {  
        System.out.println("Enter main()");  
        methodA();  
        System.out.println("Exit main()");  
    }  
  
    public static void methodA() {  
        System.out.println("Enter methodA()");  
        methodB();  
        System.out.println("Exit methodA()");  
    }  
  
    public static void methodB() {  
        System.out.println("Enter methodB()");  
        methodC();  
        System.out.println("Exit methodB()");  
    }  
  
    public static void methodC() {  
        System.out.println("Enter methodC()");  
        System.out.println("Exit methodC()");  
    }  
}
```

Method Call Stack

■ The sequence of events:

- JVM invoke the `main()`.
- `main()` pushed onto call stack, before invoking `methodA()`.
- `methodA()` pushed onto call stack, before invoking `methodB()`.
- `methodB()` pushed onto call stack, before invoking `methodC()`.
- `methodC()` completes.
- `methodB()` popped out from call stack and completes.
- `methodA()` popped out from the call stack and completes.
- `main()` popped out from the call stack and completes. Program exits.



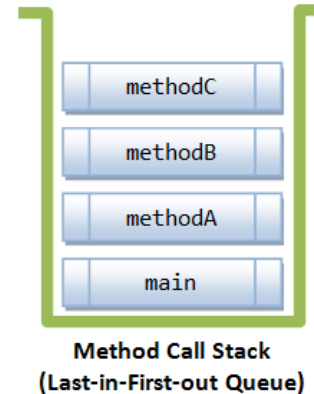
Method Call Stack
(Last-in-First-out Queue)

Call Stack Trace

- Suppose `methodC()` carries out a "divide-by-0" operation, which triggers an `ArithmeticException`.
- The exception message clearly shows the *method call stack trace* with the relevant statement line numbers:

```
Enter main()  
Enter methodA()  
Enter methodB()  
Enter methodC()
```

```
Exception in thread "main" java.lang.ArithmeticException: / by zero  
    at MethodCallStackDemo.methodC(MethodCallStackDemo.java:22)  
    at MethodCallStackDemo.methodB(MethodCallStackDemo.java:16)  
    at MethodCallStackDemo.methodA(MethodCallStackDemo.java:10)  
    at MethodCallStackDemo.main(MethodCallStackDemo.java:4)
```



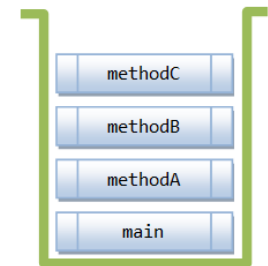
Call Stack Trace

■ Process:

- MethodC() triggers an ArithmeticException. As it does not handle this exception, it popped off from the call stack immediately.
- MethodB() also does not handle this exception and popped off the call stack. So does methodA() and main() method.
- The main() method passes back to JVM, which abruptly terminates the program and print the call stack trace.

```
Enter main()  
Enter methodA()  
Enter methodB()  
Enter methodC()
```

```
Exception in thread "main" java.lang.ArithmeticException: / by zero  
    at MethodCallStackDemo.methodC(MethodCallStackDemo.java:22)  
    at MethodCallStackDemo.methodB(MethodCallStackDemo.java:16)  
    at MethodCallStackDemo.methodA(MethodCallStackDemo.java:10)  
    at MethodCallStackDemo.main(MethodCallStackDemo.java:4)
```



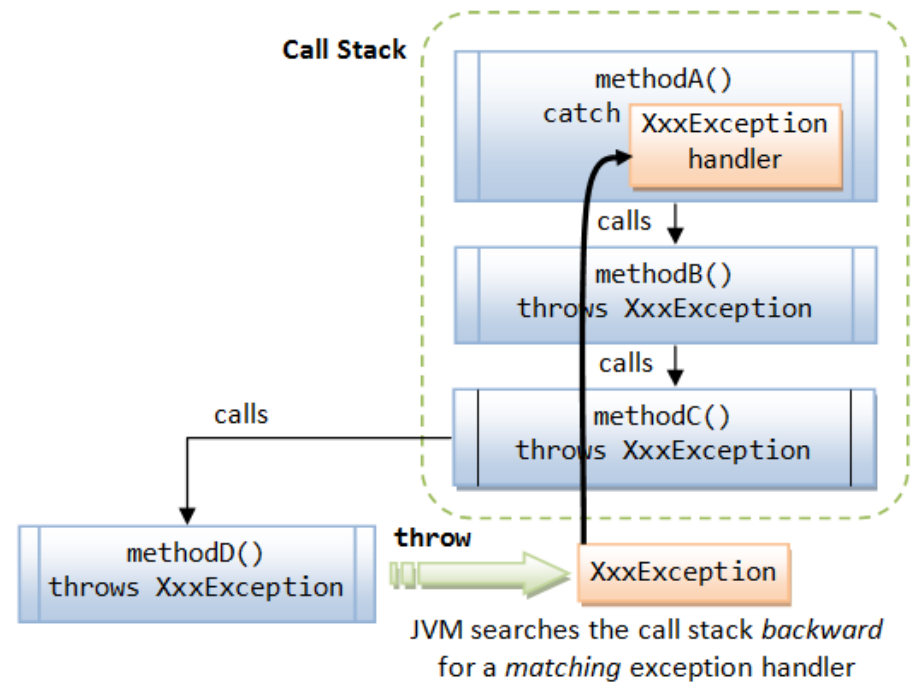
Method Call Stack
(Last-in-First-out Queue)

Exception & Call Stack

- When an exception occurs inside a Java method, the method creates an `Exception` object and passes the `Exception` object to the JVM (i.e., the method "throw" an `Exception`).
- The `Exception` object contains the type of the exception, and the state of the program when the exception occurs.
- The JVM is responsible for finding an exception handler to process the `Exception` object.
 - It searches backward through the call stack until it finds a matching exception handler for that particular class of `Exception` object (in Java term, it is called "catch" the `Exception`).
 - If the JVM cannot find a matching exception handler in all the methods in the call stack, it terminates the program.
 - 异常处理机制：异常被抛出时，JVM根据异常中的信息查找处理异常的代码，通过调用栈进行反向查找，直到找到为止，如果找不到则终止程序。

Exception & Call Stack

- Suppose that `methodD()` encounters an abnormal condition and throws a `XxxException` to the JVM.
- The JVM searches backward through the call stack for a matching exception handler.
- It finds `methodA()` having a `XxxException` handler and passes the exception object to the handler.
 - Notice that `methodC()` and `methodB()` are required to declare “throws `XxxException`” in their method signatures in order to compile the program.
 - 方法B和C需要声明抛出此异常(进行传播), 以通过编译



Analyzing Stack Trace Elements

- A *stack trace* is a listing of all pending method calls at a particular point in the execution of a program.
- You have almost certainly seen stack trace listings – they are displayed whenever a Java program terminates with an uncaught exception.
- You can access the text description of a stack trace by calling the `printStackTrace` method of the `Throwable` class.

```
Throwable t = new Throwable();  
StringWriter out = new StringWriter();  
t.printStackTrace(new PrintWriter(out));  
String description = out.toString();
```


Stack trace

```

java.lang.RuntimeException
    at sun.reflect.NativeConstructorAccessorImpl.newInstance0(Native Method)
    at sun.reflect.NativeConstructorAccessorImpl.newInstance(NativeConstructorAccessorImpl.java:39)
    at sun.reflect.DelegatingConstructorAccessorImpl.newInstance(DelegatingConstructorAccessorImpl.java:27)
    at java.lang.reflect.Constructor.newInstance(Constructor.java:513)
    at org.codehaus.groovy.reflection.CachedConstructor.invoke(CachedConstructor.java:77)
    at org.codehaus.groovy.runtime.callsite.ConstructorSite$ConstructorSiteNoUnwrapNoCoerce.callConstructor(ConstructorSite.java:133)
    at org.codehaus.groovy.runtime.callsite.CallSiteArray.defaultCallConstructor(CallSiteArray.java:52)
    at org.codehaus.groovy.runtime.callsite.AbstractCallSite.callConstructor(AbstractCallSite.java:192)
    at org.codehaus.groovy.runtime.callsite.AbstractCallSite.callConstructor(AbstractCallSite.java:196)
    at newifyTransform$_run_closure1.doCall(newifyTransform.gdsl:21)
    at sun.reflect.NativeMethodAccessorImpl.invoke0(Native Method)
    at sun.reflect.NativeMethodAccessorImpl.invoke(NativeMethodAccessorImpl.java:39)
    at sun.reflect.DelegatingMethodAccessorImpl.invoke(DelegatingMethodAccessorImpl.java:25)
    at java.lang.reflect.Method.invoke(Method.java:597)
    at org.codehaus.groovy.reflection.CachedMethod.invoke(CachedMethod.java:86)
    at groovy.lang.MetaMethod.doMethodInvoke(MetaMethod.java:234)
    at org.codehaus.groovy.runtime.metaclass.ClosureMetaClass.invokeMethod(ClosureMetaClass.java:272)
    at groovy.lang.MetaClassImpl.invokeMethod(MetaClassImpl.java:893)
    at org.codehaus.groovy.runtime.callsite.PogoMetaClassSite.callCurrent(PogoMetaClassSite.java:66)
    at org.codehaus.groovy.runtime.callsite.AbstractCallSite.callCurrent(AbstractCallSite.java:151)
    at newifyTransform$_run_closure1.doCall(newifyTransform.gdsl)
    at sun.reflect.NativeMethodAccessorImpl.invoke0(Native Method)
    at sun.reflect.NativeMethodAccessorImpl.invoke(NativeMethodAccessorImpl.java:39)
    at sun.reflect.DelegatingMethodAccessorImpl.invoke(DelegatingMethodAccessorImpl.java:25)
    at java.lang.reflect.Method.invoke(Method.java:597)
    at org.codehaus.groovy.reflection.CachedMethod.invoke(CachedMethod.java:86)
    at groovy.lang.MetaMethod.doMethodInvoke(MetaMethod.java:234)
    at org.codehaus.groovy.runtime.metaclass.ClosureMetaClass.invokeMethod(ClosureMetaClass.java:272)
    at groovy.lang.MetaClassImpl.invokeMethod(MetaClassImpl.java:893)
    at org.codehaus.groovy.runtime.callsite.PogoMetaClassSite.call(PogoMetaClassSite.java:39)
    at org.codehaus.groovy.runtime.callsite.AbstractCallSite.call(AbstractCallSite.java:121)
    at org.jetbrains.plugins.groovy.dsl.GroovyDslExecutor$_processVariants_closure1.doCall(GroovyDslExecutor.groovy:54)
    at sun.reflect.GeneratedMethodAccessor61.invoke(Unknown Source)
    at sun.reflect.DelegatingMethodAccessorImpl.invoke(DelegatingMethodAccessorImpl.java:25)
    at java.lang.reflect.Method.invoke(Method.java:597)
    at org.codehaus.groovy.reflection.CachedMethod.invoke(CachedMethod.java:86)
    at groovy.lang.MetaMethod.doMethodInvoke(MetaMethod.java:234)
    at org.codehaus.groovy.runtime.metaclass.ClosureMetaClass.invokeMethod(ClosureMetaClass.java:272)

```

Analyzing Stack Trace Elements

- A more flexible approach is the `getStackTrace` method that yields an array of `StackTraceElement` objects, which you can analyze in your program.

```
Throwable t = new Throwable();  
StackTraceElement[] frames = t.getStackTrace();  
for (StackTraceElement frame : frames)  
    analyze frame
```

- The `StackTraceElement` class has methods to obtain the file name and line number, as well as the class and method name, of the executing line of code.
- The `toString` method yields a formatted string containing all of this information.



(11) Tips for Using Exceptions



Exception handling cannot replace test

- *Exception handling is not supposed to replace a simple test.* 异常处理不能代替简单的测试

- As an example, we wrote some code that tries 10,000,000 times to pop an empty stack. It first does this by finding out whether the stack is empty.

```
if (!s.empty()) s.pop();
```

- Next, we force it to pop the stack no matter what and then catch the `EmptyStackException` that tells us we should not have done that.

```
try {  
    s.pop();  
}  
catch (EmptyStackException e) { }
```

- The version that calls `isEmpty` ran in 646 milliseconds. The version that catches the `EmptyStackException` ran in 21,739 milliseconds --- it took far longer to catch an exception than to perform a simple test.
- The moral is: **Use exceptions for exceptional circumstances only.**

Do not micromanage exceptions

- ***Do not micromanage exceptions.*** 不要过分地细化异常

- Many programmers wrap every statement in a separate *try block*.
- Next, we force it to pop the stack no matter what and then catch the `EmptyStackException` that tells us we should not have done that.
- 将正常处理与异常处理分开

```
PrintStream out;
Stack s;
for (i = 0; i < 100; i++) {
    try {
        n = s.pop();
    }
    catch (EmptyStackException e) {
        // stack was empty
    }
    try {
        out.writeInt(n);
    }
    catch (IOException e) {
        // problem writing to file
    }
}
```



```
try {
    for (i = 0; i < 100; i++) {
        n = s.pop();
        out.writeInt(n);
    }
}
catch (IOException e) {
    // problem writing to file
}
catch (EmptyStackException e) {
    // stack was empty
}
```

Make good use of the exception hierarchy

- *Make good use of the exception hierarchy.* 利用好异常层次结构
 - Don't just throw an Exception. Find an appropriate subclass or create your own. 不要只抛出Exception
 - Don't just catch Throwable. It makes your code hard to read and maintain. 不要只捕获Throwable异常
 - Respect the difference between checked and unchecked exceptions. Checked exceptions are inherently burdensome — don't throw them for logic errors. 考虑已检查异常与未检查异常的区别
 - Do not hesitate to turn an exception into another exception that is more appropriate. For example, when you parse an integer in a file, catch the NumberFormatException and turn it into a subclass of IOException or MySubsystemException. 将一种异常转换成另一种更加适合的异常时不要犹豫

“Tough love” works better than indulgence

- *When you detect an error, “tough love” works better than indulgence.* 在检测错误时，“苛刻”要比放任好
 - Some programmers worry about throwing exceptions when they detect errors.
 - Maybe it would be better to return a dummy value rather than throw an exception when a method is called with invalid parameters? For example, should `Stack.pop` return null, or throw an exception when a stack is empty? `Stack.pop` 返回空值还是抛出异常?
 - We think it is better to throw a `EmptyStackException` at the point of failure than to have a `NullPointerException` occur at later time. 此时，抛出异常比稍后出现空指针访问更好

Propagating exceptions is not a sign of shame

- *Propagating exceptions is not a sign of shame.* 不要羞于传递异常
 - Many programmers feel compelled to catch all exceptions that are thrown.
 - If they call a method that throws an exception, such as the `FileInputStream` constructor or the `readLine` method, they instinctively catch the exception that may be generated.
 - Often, it is actually better to propagate the exception instead of catching it:

```
public void readStuff(String filename) throws IOException
                                     // not a sign of shame!
{
    InputStream in = new FileInputStream(filename);
    . . .
}
```
 - Higher-level methods are often better equipped to inform the user of errors or to abandon unsuccessful commands. 让高层方法通知用户发生了错误，或者放弃不成功的命令更加适宜
- **NOTE:** “throw early, catch late.”

Other Tips for Using Exceptions

- **Avoid unnecessary checked exceptions**
- **Favor standard exceptions**
 - Absolutely it makes sense to reuse Exception classes when they reasonably describe the scenario that caused the exception to be thrown. **Java预定义的一些异常，如果能够很好的说明情况，则建议复用**
 - `IllegalArgumentException` – invalid parameter value
 - `IllegalStateException` – invalid object state
 - `NullPointerException` – null param where prohibited
 - `IndexOutOfBoundsException` – invalid index param
- **Throw exceptions appropriate to abstraction** **根据抽象级别抛出合适的异常，高层应该捕获低层的异常，并抛出在高层抽象可以理解的异常**
- **Document all exceptions thrown by each method**
 - Checked and unchecked
 - But don't *declare* unchecked exceptions!

Other Tips for Using Exceptions

- **Include failure-capture info in detail message**

```
throw new IllegalArgumentException("Modulus must be prime: " + modulus);
```

- **Don't ignore exceptions**

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



The end

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