Chapter 15: Exception Handling

TAO Yida

taoyd@sustech.edu.cn

Objectives

- What exceptions are
- How exception handling works
- Exception class hierarchy
- Checked/unchecked exceptions
- Stack traces and chained exceptions

Exception

- An ***exception*** is an indication of a problem that occurs during a program's execution. It would disrupt the normal flow of instructions.

```
public static void main(String[] args) {
    Scanner scanner = new Scanner(System.in);
    System.out.print("Enter an integer numerator: ");
    int numerator = scanner.nextInt();
    System.out.print("Enter an integer denominator: ");
    int denominator = scanner.nextInt();
    int result = quotient(numerator, denominator);
    System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
    scanner.close();
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

Three executions of the program

```
Enter an integer numerator: 3
Enter an integer denominator: 2
Result: 3 / 2 = 1
```

A normal execution, where the result is calculated correctly.

```
Enter an integer numerator: 3
Enter an integer denominator: 0
Exception in thread "main" java.lang.ArithmeticException: / by zero
at ExceptionExample.quotient(ExceptionExample.java:15)
at ExceptionExample.main(ExceptionExample.java:10)
```

用户不会按开发后期望使用程序

An execution where the "/ by zero" exception is thrown and the program terminates

Three executions of the program

```
Enter an integer numerator: 3
Enter an integer denominator: a
Exception in thread "main" java.util.InputMismatchException
at java.util.Scanner.throwFor(Unknown Source)
at java.util.Scanner.next(Unknown Source)
at java.util.Scanner.nextInt(Unknown Source)
at java.util.Scanner.nextInt(Unknown Source)
at ExceptionExample.main(ExceptionExample.java:9)
```

An execution where the "InputMismatch" exception is thrown and the program terminates

Exception (Cont.)

The name (type) of the exception

Stack Trace

```
Exception in thread "main" java.lang.ArithmeticException: / by zero
at ExceptionExample.quotient(ExceptionExample.java:15)
at ExceptionExample.main(ExceptionExample.java:10)
```

The method call stack when the exception occurs

Stack trace contains the path of execution that led to the exception!!!

一般来说，错误离栈顶近
(但可能错误参数产生与使用离得远)

Exception (Cont.)

```
Exception in thread "main" java.lang.ArithmeticException: / by zero
at ExceptionExample.quotient(ExceptionExample.java:15)
at ExceptionExample.main(ExceptionExample.java:10)
```

```
public static void main(String[] args) {
    Scanner scanner = new Scanner(System.in);
    System.out.print("Enter an integer numerator: ");
    int numerator = scanner.nextInt();
    System.out.print("Enter an integer denominator: ");
    int denominator = scanner.nextInt();
    int result = quotient(numerator, denominator);
    ...
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

Line 10

Line 15

Exception throw point: top row of the call stack

The execution path information in the stack trace helps debugging

Exceptions we've seen so far

- `ArithmeticException (3/0)`
- `ArrayIndexOutOfBoundsException (array[-1])`
- `ClassCastException ((String) obj)`
- `NullPointerException (obj.foo())`
- `FileNotFoundException`
- ……

Objectives

- What exceptions are
- How exception handling works
- Exception class hierarchy
- Checked/unchecked exceptions
- Stack traces and chained exceptions

Exception handling

- An exception would disrupt program execution flows (for example, causing crashes). 会打断
- **Exception handling** is a nice feature of the Java language that can help you write **robust** and **fault-tolerant** programs. → 要允许发生错误，继续执行 强健 容错
- With exception handling, a program can **continue executing (rather than terminating)** after dealing with a problem. It is very useful in **mission-critical** or **business-critical** computing.

try-catch statement syntax

```
try {
    // code that might throw an exception
} catch( ExceptionType1 e1 ) {
    // code that handles type1 exception
} catch( ExceptionType2 e2 ) {
    // code that handles type2 exception
} catch( ExceptionType3 e3 ) {
    // code that handles type3 exception
} ...
```

Exception parameter
e1 is a local variable in the catch block

At least one catch block or a finally block must **immediately** follow the try block ("immediately" means no content in between)

Handling the two exceptions

```
public static void main(String[] args) {
    Scanner scanner = new Scanner(System.in);
    boolean continueLoop = true;
    do {
        try {
            System.out.print("Enter an integer numerator: ");
            int numerator = scanner.nextInt();
            System.out.print("Enter an integer denominator: ");
            int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            System.err.printf("Exception: %s\n", inputMismatchException);
            scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}
```

非数字

除0

Enclose the code that might throw an exception in a try block

Each catch block (exception handler) handles a certain type of exception.

The type is specified in the exception parameter.

Handling the two exceptions

```
public static void main(String[] args) {
    Scanner scanner = new Scanner(System.in);
    boolean continueLoop = true;
    do {
        try {
            System.out.print("Enter an integer numerator: ");
            int numerator = scanner.nextInt();
            System.out.print("Enter an integer denominator: ");
            int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            System.err.printf("Exception: %s\n", inputMismatchException);
            scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}
```

Loop until all inputs are valid

Let's examine the control flow of a typical case


```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
    boolean continueLoop = true;
    do {
        try {
            System.out.print("Enter an integer numerator: ");
            int numerator = scanner.nextInt();
            System.out.print("Enter an integer denominator: ");
            int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            System.err.printf("Exception: %s\n", inputMismatchException);
            scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
            System.out.print("Enter an integer numerator: ");
            int numerator = scanner.nextInt();
            System.out.print("Enter an integer denominator: ");
            int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            System.err.printf("Exception: %s\n", inputMismatchException);
            scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
        3   System.out.print("Enter an integer numerator: ");
            int numerator = scanner.nextInt();
            System.out.print("Enter an integer denominator: ");
            int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            System.err.printf("Exception: %s\n", inputMismatchException);
            scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
Enter an integer numerator:
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
        3   System.out.print("Enter an integer numerator: ");
        4   int numerator = scanner.nextInt();
            System.out.print("Enter an integer denominator: ");
            int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            System.err.printf("Exception: %s\n", inputMismatchException);
            scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
Enter an integer numerator: 3
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
3           System.out.print("Enter an integer numerator: ");
4           int numerator = scanner.nextInt();
5           System.out.print("Enter an integer denominator: ");
            int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            System.err.printf("Exception: %s\n", inputMismatchException);
            scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
Enter an integer denominator:
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
        3   System.out.print("Enter an integer numerator: ");
        4   int numerator = scanner.nextInt();
        5   System.out.print("Enter an integer denominator: ");
        6   int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            System.err.printf("Exception: %s\n", inputMismatchException);
            scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
Enter an integer denominator: a
```

Exception occurs!

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
        3   System.out.print("Enter an integer numerator: ");
        4   int numerator = scanner.nextInt();
        5   System.out.print("Enter an integer denominator: ");
        6   int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
            scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

Skip the remaining statements in the try block (termination model)

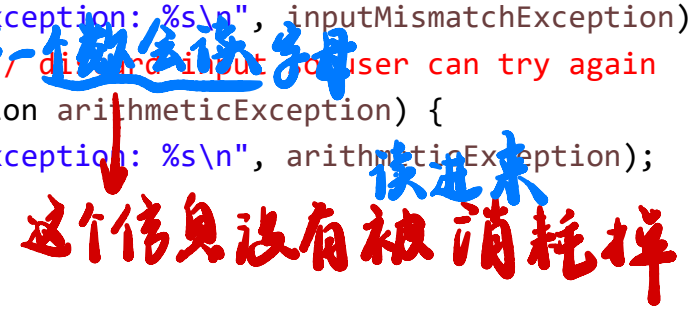
The first catch block whose exception type matches the thrown one gets executed

跳到符合的 catch

```
Exception: java.util.InputMismatchException
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
3       System.out.print("Enter an integer numerator: ");
4       int numerator = scanner.nextInt();
5       System.out.print("Enter an integer denominator: ");
6       int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
7       System.err.printf("Exception: %s\n", inputMismatchException);
8       scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```



What happens if we delete this line?

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
        3   System.out.print("Enter an integer numerator: ");
        4   int numerator = scanner.nextInt();
        5   System.out.print("Enter an integer denominator: ");
        6   int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

Exit the try-catch statement and continue with the loop condition test

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
10  3   System.out.print("Enter an integer numerator: ");
    4   int numerator = scanner.nextInt();
    5   System.out.print("Enter an integer denominator: ");
    6   int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
    7   System.err.printf("Exception: %s\n", inputMismatchException);
    8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
Enter an integer numerator:
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
10  3   System.out.print("Enter an integer numerator: ");
11  4   int numerator = scanner.nextInt();
    5   System.out.print("Enter an integer denominator: ");
    6   int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
    7   System.err.printf("Exception: %s\n", inputMismatchException);
    8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
Enter an integer numerator: 3
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
10  3   System.out.print("Enter an integer numerator: ");
11  4   int numerator = scanner.nextInt();
12  5   System.out.print("Enter an integer denominator: ");
    6   int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
Enter an integer denominator:
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
10  3       System.out.print("Enter an integer numerator: ");
11  4       int numerator = scanner.nextInt();
12  5       System.out.print("Enter an integer denominator: ");
13  6       int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

0是被读入的数字

```
Enter an integer denominator: 0
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
10  3       System.out.print("Enter an integer numerator: ");
11  4       int numerator = scanner.nextInt();
12  5       System.out.print("Enter an integer denominator: ");
13  6       int denominator = scanner.nextInt();
14          int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
10  3   System.out.print("Enter an integer numerator: ");
11  4   int numerator = scanner.nextInt();
12  5   System.out.print("Enter an integer denominator: ");
13  6   int denominator = scanner.nextInt();
14      int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9
}

public static int quotient(int numerator, int denominator) {
15  return numerator / denominator;
}
```

quotient 的异常传给调用者

Exception occurs!

main

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
10  3       System.out.print("Enter an integer numerator: ");
11  4       int numerator = scanner.nextInt();
12  5       System.out.print("Enter an integer denominator: ");
13  6       int denominator = scanner.nextInt();
14          int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
16          System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9
}

public static int quotient(int numerator, int denominator) {
15  return numerator / denominator;
}
```

Skip the remaining statements in the try block

The first catch block whose exception type matches the thrown one gets executed

```
Exception: java.lang.ArithmeticException: / by zero
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
10  3       System.out.print("Enter an integer numerator: ");
11  4       int numerator = scanner.nextInt();
12  5       System.out.print("Enter an integer denominator: ");
13  6       int denominator = scanner.nextInt();
14          int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
16          System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9   17
}

public static int quotient(int numerator, int denominator) {
15  return numerator / denominator;
}
```

Exit the try-catch statement and continue with the loop condition test

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
18  10  3   System.out.print("Enter an integer numerator: ");
    11  4   int numerator = scanner.nextInt();
    12  5   System.out.print("Enter an integer denominator: ");
    13  6   int denominator = scanner.nextInt();
    14      int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
    16      System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9   17
}

public static int quotient(int numerator, int denominator) {
15  return numerator / denominator;
}
```

```
Enter an integer numerator:
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
18  10  3   System.out.print("Enter an integer numerator: ");
19  11  4   int numerator = scanner.nextInt();
    12  5   System.out.print("Enter an integer denominator: ");
    13  6   int denominator = scanner.nextInt();
    14      int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            7   System.err.printf("Exception: %s\n", inputMismatchException);
            8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
    16      System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9   17
}

public static int quotient(int numerator, int denominator) {
15  return numerator / denominator;
}
```

```
Enter an integer numerator: 3
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
18  10  3   System.out.print("Enter an integer numerator: ");
19  11  4   int numerator = scanner.nextInt();
20  12  5   System.out.print("Enter an integer denominator: ");
    13  6   int denominator = scanner.nextInt();
    14      int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
    16      System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9   17
}

public static int quotient(int numerator, int denominator) {
15  return numerator / denominator;
}
```

```
Enter an integer denominator:
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
18  10  3   System.out.print("Enter an integer numerator: ");
19  11  4   int numerator = scanner.nextInt();
20  12  5   System.out.print("Enter an integer denominator: ");
21  13  6   int denominator = scanner.nextInt();
    14      int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
    16      System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9  17
}

public static int quotient(int numerator, int denominator) {
15  return numerator / denominator;
}
```

```
Enter an integer denominator: 2
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
18  10  3   System.out.print("Enter an integer numerator: ");
19  11  4   int numerator = scanner.nextInt();
20  12  5   System.out.print("Enter an integer denominator: ");
21  13  6   int denominator = scanner.nextInt();
22  14      int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
    16      System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9   17
}

public static int quotient(int numerator, int denominator) {
15  return numerator / denominator;
}
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
18  10  3   System.out.print("Enter an integer numerator: ");
19  11  4   int numerator = scanner.nextInt();
20  12  5   System.out.print("Enter an integer denominator: ");
21  13  6   int denominator = scanner.nextInt();
22  14      int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
    16      System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9   17
}

public static int quotient(int numerator, int denominator) {
23  15  return numerator / denominator;
}
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
18  10  3   System.out.print("Enter an integer numerator: ");
19  11  4   int numerator = scanner.nextInt();
20  12  5   System.out.print("Enter an integer denominator: ");
21  13  6   int denominator = scanner.nextInt();
22  14      int result = quotient(numerator, denominator);
24          System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
        7   System.err.printf("Exception: %s\n", inputMismatchException);
        8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
    16      System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9   17
}

public static int quotient(int numerator, int denominator) {
23  15  return numerator / denominator;
}
```

```
Result: 3 / 2 = 1
```

```
public static void main(String[] args) {
    Scanner scanner = new Scanner(System.in);
    boolean continueLoop = true;
    do {
        try {
            System.out.print("Enter an integer numerator: ");
            int numerator = scanner.nextInt();
            System.out.print("Enter an integer denominator: ");
            int denominator = scanner.nextInt();
            int result = quotient(numerator, denominator);
            System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
            scanner.close();
            continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            System.err.printf("Exception: %s\n", inputMismatchException);
            scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
            System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop);
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator;
}
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
18  10  3   System.out.print("Enter an integer numerator: ");
19  11  4   int numerator = scanner.nextInt();
20  12  5   System.out.print("Enter an integer denominator: ");
21  13  6   int denominator = scanner.nextInt();
22  14      int result = quotient(numerator, denominator);
24          System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
25          scanner.close();
26          continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            7   System.err.printf("Exception: %s\n", inputMismatchException);
            8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
    16      System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9   17

}

public static int quotient(int numerator, int denominator) {
23  15  return numerator / denominator;
}
```

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
18  10  3   System.out.print("Enter an integer numerator: ");
19  11  4   int numerator = scanner.nextInt();
20  12  5   System.out.print("Enter an integer denominator: ");
21  13  6   int denominator = scanner.nextInt();
22  14      int result = quotient(numerator, denominator);
24          System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
25          scanner.close();
26          continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            7   System.err.printf("Exception: %s\n", inputMismatchException);
            8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
    16      System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9   17   27
}

public static int quotient(int numerator, int denominator) {
23  15  return numerator / denominator;
}
```

No exception occurs, continue with the loop condition test

```
public static void main(String[] args) {
1   Scanner scanner = new Scanner(System.in);
2   boolean continueLoop = true;
    do {
        try {
18  10  3   System.out.print("Enter an integer numerator: ");
19  11  4   int numerator = scanner.nextInt();
20  12  5   System.out.print("Enter an integer denominator: ");
21  13  6   int denominator = scanner.nextInt();
22  14      int result = quotient(numerator, denominator);
24          System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
25          scanner.close();
26          continueLoop = false;
        } catch(InputMismatchException inputMismatchException) {
            7   System.err.printf("Exception: %s\n", inputMismatchException);
            8   scanner.nextLine(); // discard input so user can try again
        } catch(ArithmeticException arithmeticException) {
    16      System.err.printf("Exception: %s\n", arithmeticException);
        }
    } while(continueLoop); 9   17   27
}

public static int quotient(int numerator, int denominator) {
23  15  return numerator / denominator;
}
```

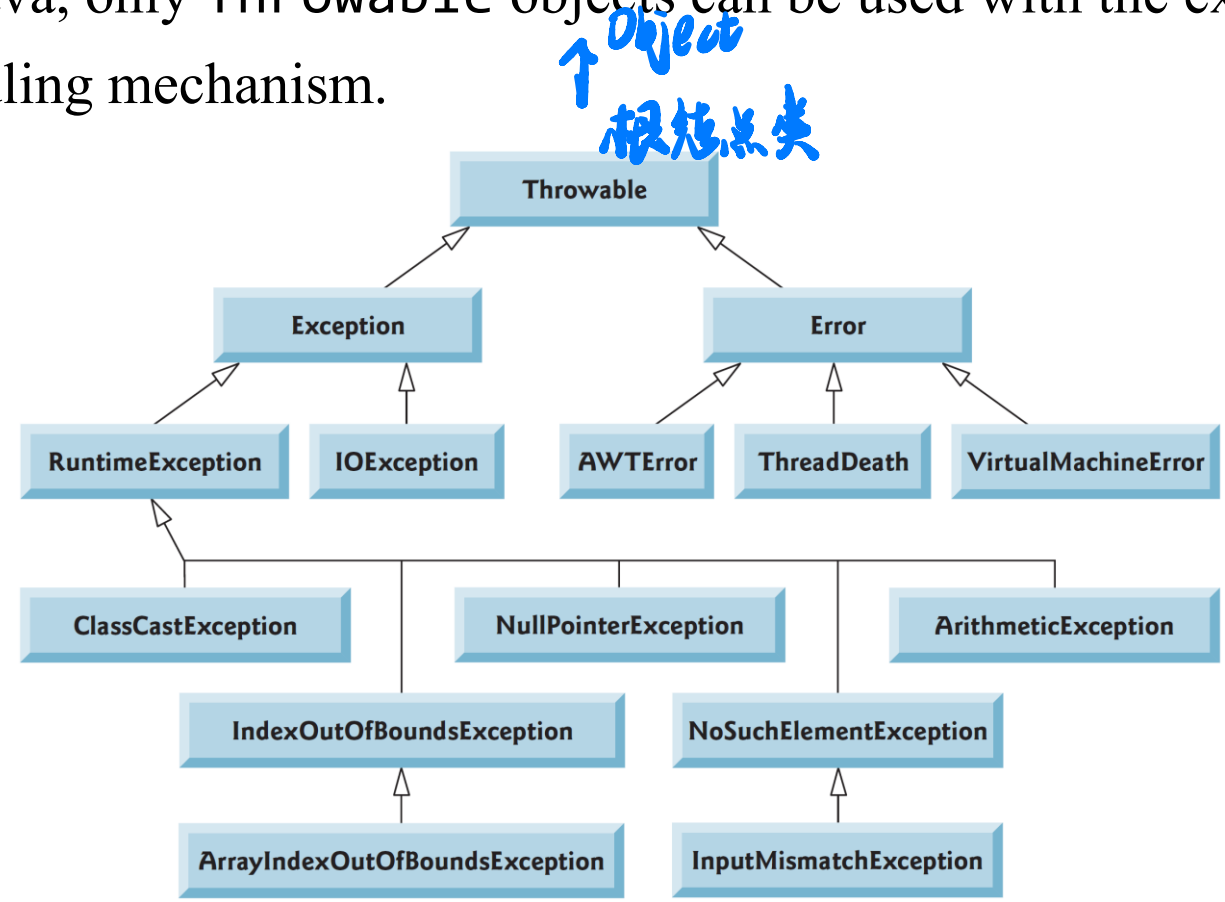
Exit loop and main method terminates normally

Objectives

- What exceptions are
- How exception handling works
- Exception class hierarchy
- Checked/unchecked exceptions
- Stack traces and chained exceptions

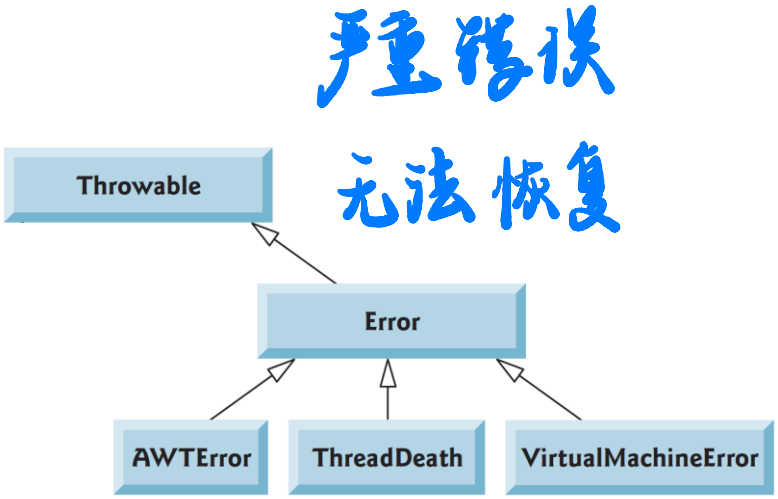
Java Exception Hierarchy

- In Java, only `Throwable` objects can be used with the exception-handling mechanism.



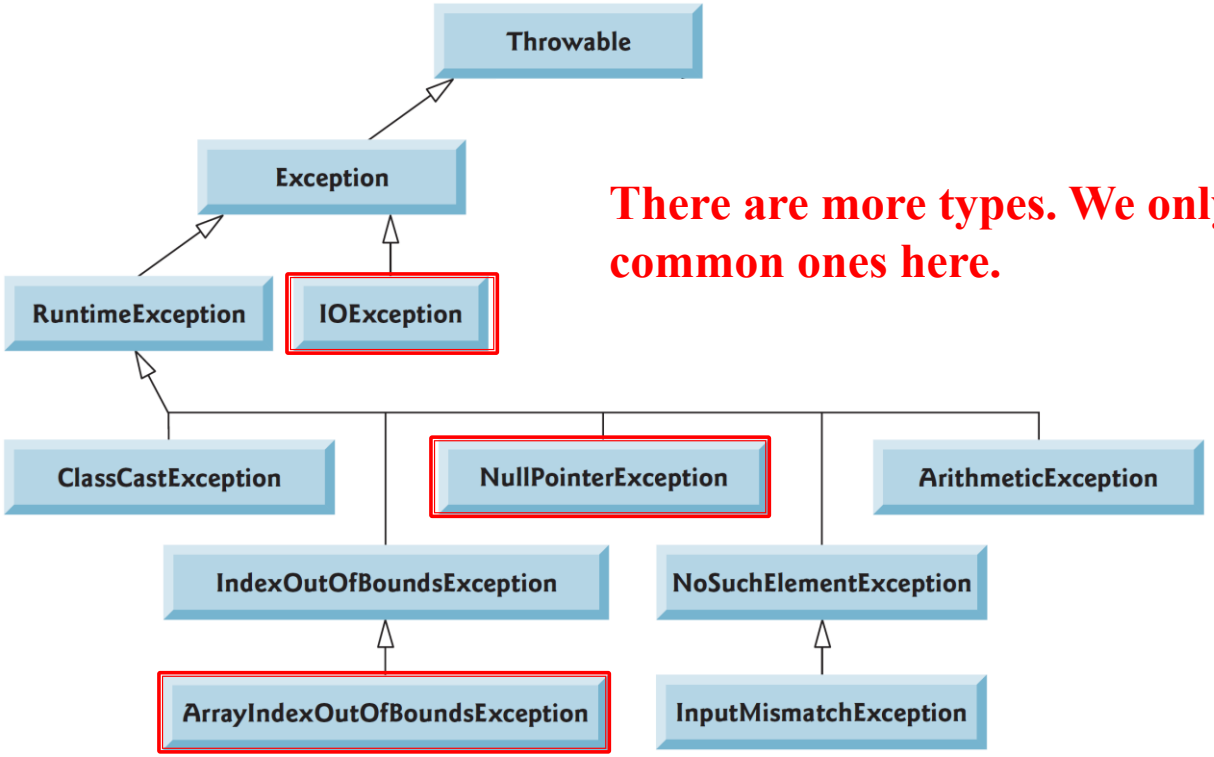
Java Exception Hierarchy

- `Error` and its subclasses represent abnormal situations that happen in the JVM (e.g., JVM out of memory) and should not be caught by applications. It's usually impossible for applications to recover from `Errors`.



Java Exception Hierarchy

- `Exception` (in `java.lang`) and its subclasses represent exceptional situations that can occur in a Java program and should be caught by applications



There are more types. We only list some common ones here.

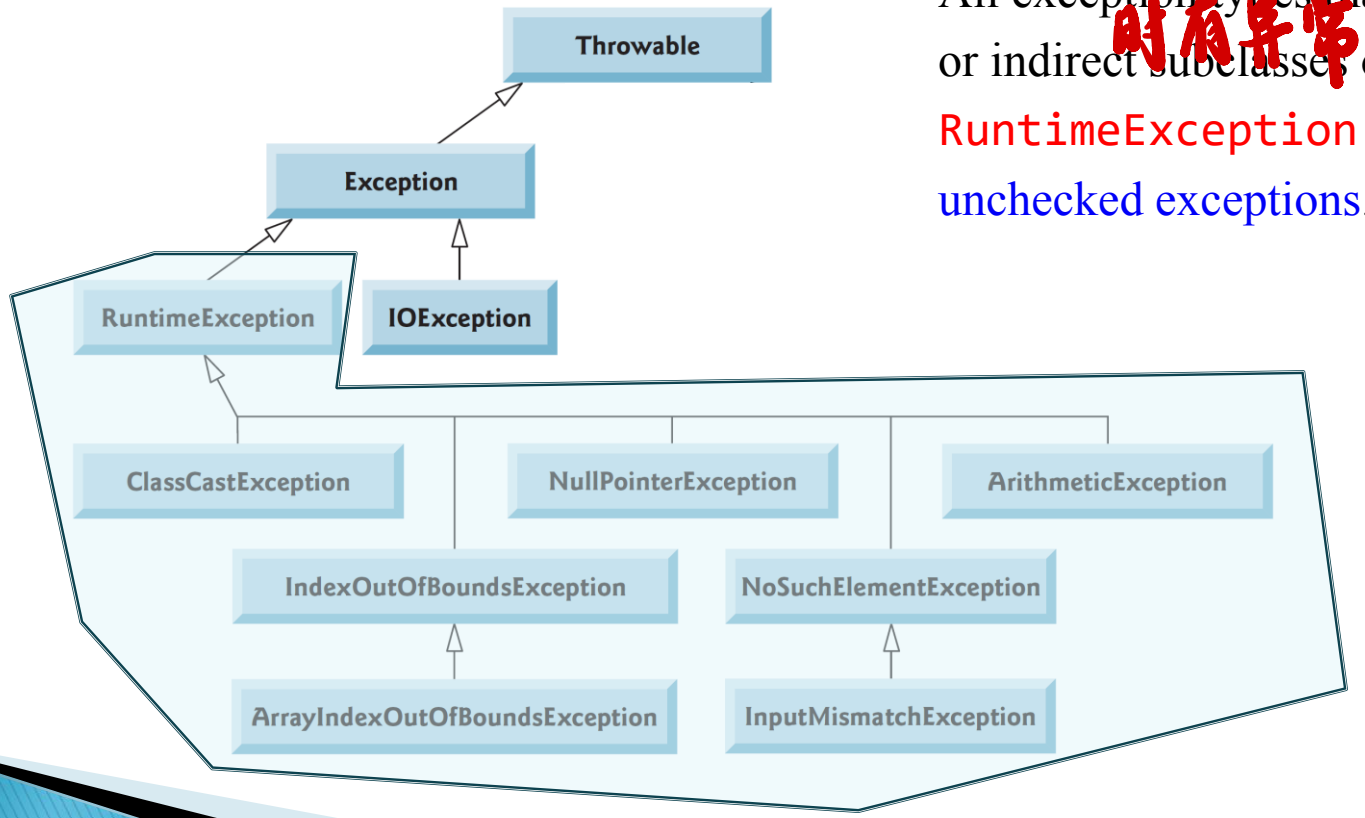
Java Exception Hierarchy

所有RuntimeException及子类都是

- Java distinguishes between **checked exceptions** and **unchecked exceptions**.

编译不报错，运行时有异常

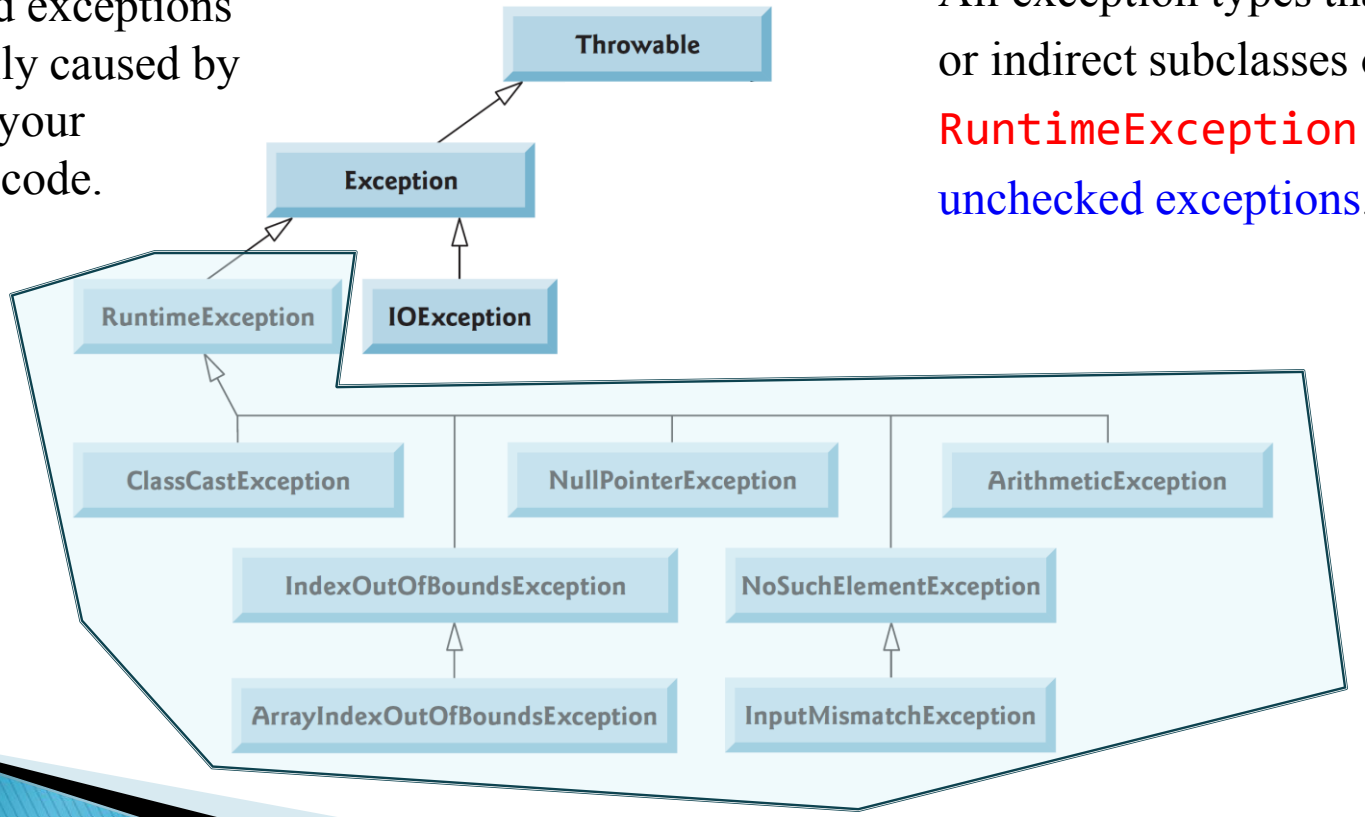
All exception types that are direct or indirect subclasses of the class `RuntimeException` are unchecked exceptions.



Java Exception Hierarchy

- Java distinguishes between **checked exceptions** and **unchecked exceptions**.

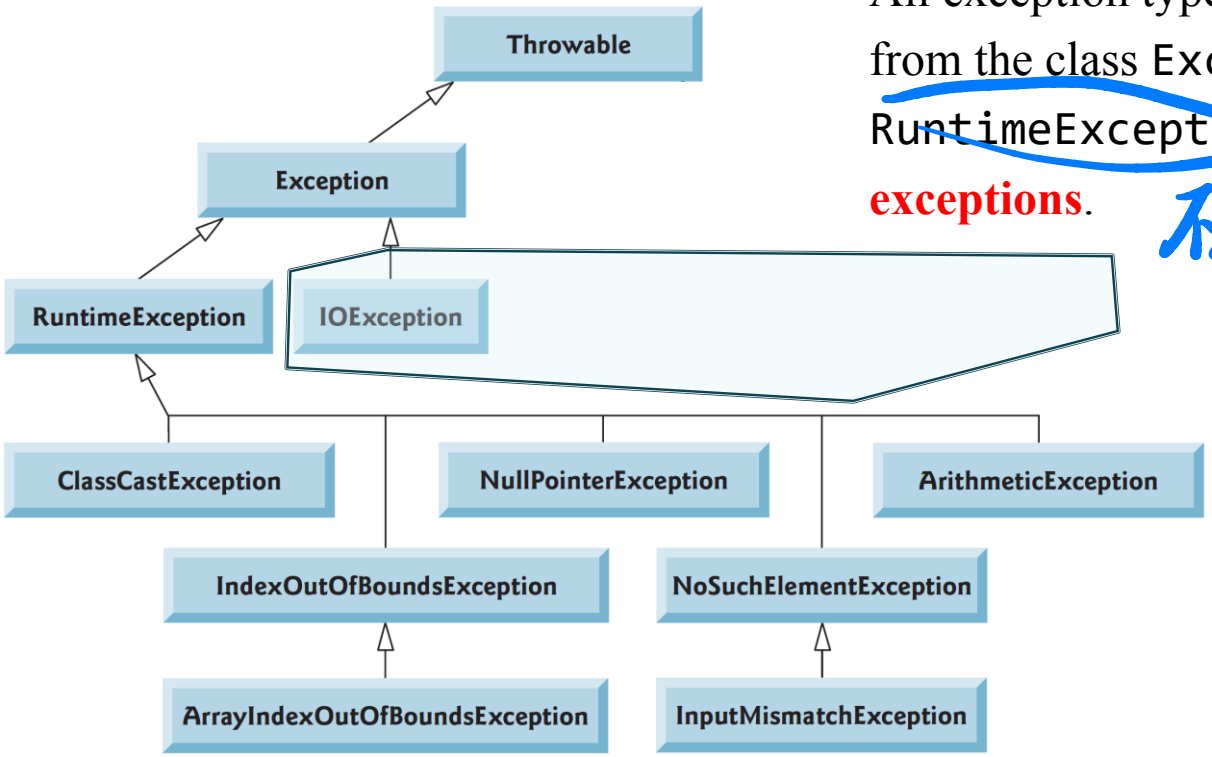
Unchecked exceptions are typically caused by defects in your program's code.



All exception types that are direct or indirect subclasses of the class `RuntimeException` are unchecked exceptions.

Java Exception Hierarchy

- Java distinguishes between **checked exceptions** and **unchecked exceptions**.



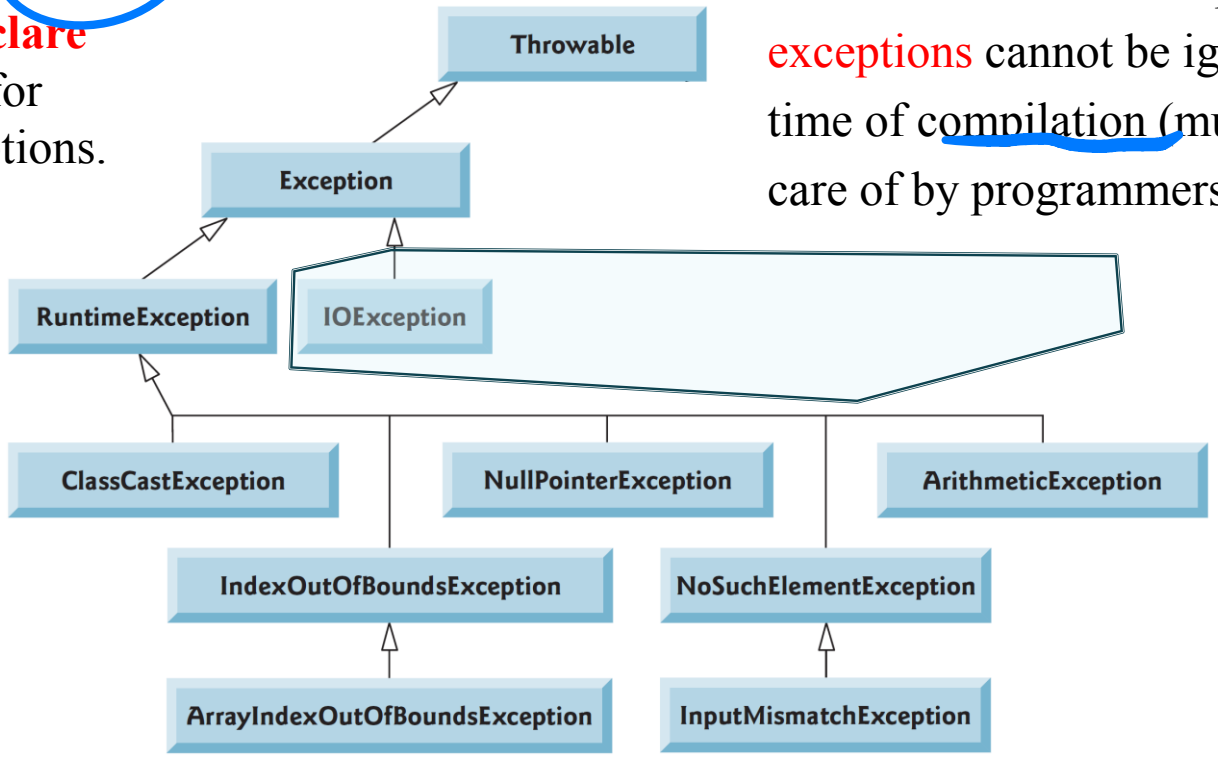
All exception types that inherit from the class `Exception` but not `RuntimeException` are **checked exceptions**.

不是 RE

Java Exception Hierarchy

- Java distinguishes between **checked exceptions** and **unchecked exceptions**.

Java compiler enforces a **catch-or-declare requirement** for checked exceptions.



Unlike unchecked exceptions, checked exceptions cannot be ignored at the time of compilation (must be taken care of by programmers).

Example: Unchecked Exceptions

```
public static void main(String[] args) {
    Scanner scanner = new Scanner(System.in);
    System.out.print("Enter an integer numerator: ");
    int numerator = scanner.nextInt(); // potential runtime exception
    System.out.print("Enter an integer denominator: ");
    int denominator = scanner.nextInt(); // potential runtime exception
    int result = quotient(numerator, denominator);
    System.out.printf("Result: %d / %d = %d\n", numerator, denominator, result);
    scanner.close();
}

public static int quotient(int numerator, int denominator) {
    return numerator / denominator; // potential runtime exception
}
```

It's fine if programmers do not take care of unchecked exceptions in the code, which can still compile.

Example: Checked Exceptions

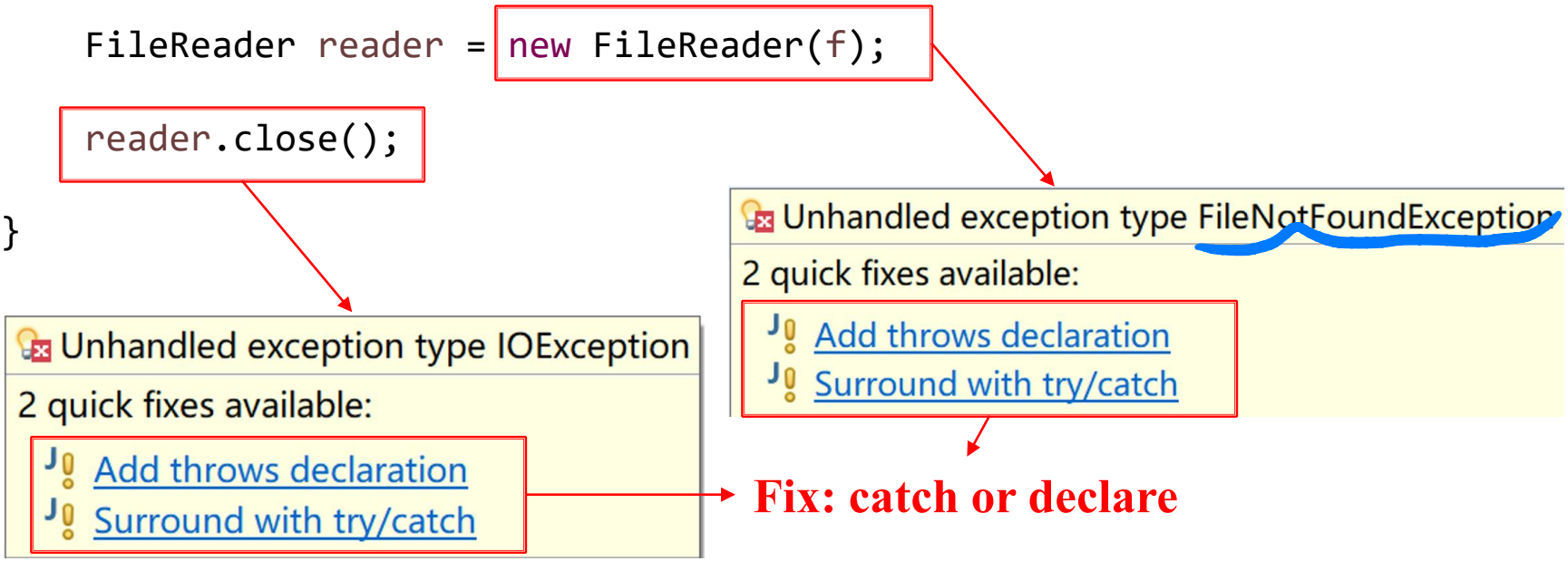
```
public static void main(String[] args) {

    File f = new File("test.txt");

    FileReader reader = new FileReader(f);

    reader.close();

}
```



The catch solution

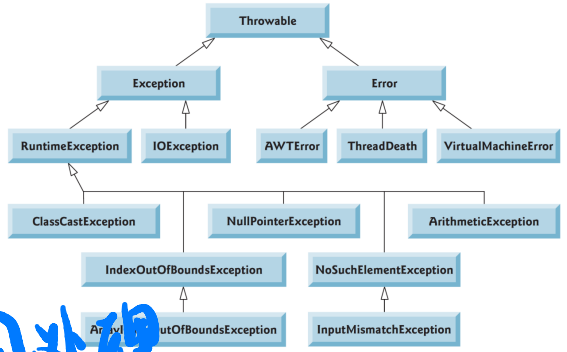
```
public static void main(String[] args) {
    try {
        File f = new File("test.txt");
        FileReader reader = new FileReader(f);
        reader.close();
    } catch(FileNotFoundException e) {
        // handle file not found exception
    } catch(IOException e) {
        // handle IO exception
    }
}
```

Catching subclass exceptions

- If a `catch` handler is written to catch superclass-type exceptions, it can also catch subclass-type exceptions.
  - Good: This makes the exception handling code concise (when the handling behavior is the same for all types) and allows for polymorphic processing of exception objects.
  - Bad: Exception info is too general to be useful

(多态)

```
public static void main(String[] args) {
    try {
        File f = new File("test.txt");
        FileReader reader = new FileReader(f);
        reader.close();
    } catch(Exception e) {
        // catch and handle multiple types of exceptions
    }
}
```



可以用父类捕获
不同种类异常不同处理
但若有未知异常也捕获但没有处理掉
不好的 debug

The declare/throw solution

```
public static void main(String[] args)
                    throws FileNotFoundException, IOException {
    File f = new File("test.txt");
    FileReader reader = new FileReader(f);
    reader.close();
}
```

直接允许异常发生

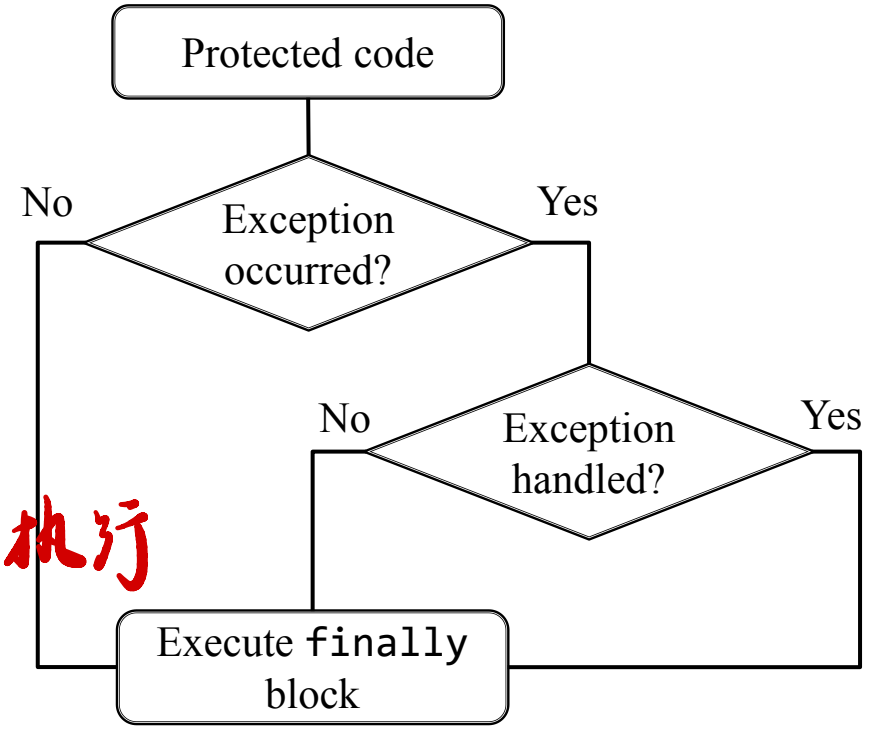
main抛异常会给JVM

The `throws` clause declares the exceptions that might be thrown when the method is executed and let the callers handle the exceptions.

finally block

```
try {
    // protected code
}
// catch blocks (optional)
finally {
    // always execute
    //when try block exits
}
```

有无异常都会执行



`finally` is useful for more than just exception handling. It prevents cleanup code from being accidentally bypassed by statements like `return`. Putting cleanup code in a `finally` block is a good practice, even when no exceptions are anticipated.

finally block

In the example below, the `finally` block ensures that the used resource is closed regardless of whether the `try` statement completes normally or abruptly

```
public String readFirstLineFromFile(String path) throws IOException {
    BufferedReader br;
    try {
        br = new BufferedReader(new FileReader(path));
        return br.readLine();
    } finally {
        if (br != null)
        br.close();
    }
}
```

IO包中读字符的类

Common methods of exceptions

- `printStackTrace`: output the stack trace to the standard error stream.

- Standard output stream (`System.out`) and standard error stream (`System.err`) are sequences of bytes. The former displays a program's output in the command prompt and the latter displays errors.

- Using two streams helps separate error messages from other output.

```
public class CheckedExceptionExample {
    public static void main(String[] args) {
        try {
            File f = new File("not-exist.txt");
            FileReader reader = new FileReader(f);
            reader.close();
        } catch (Exception e) {
            e.printStackTrace();
        }
    }
}
```

```
java.io.FileNotFoundException: not-exist.txt (系统找不到指定的文件。)
    at java.io.FileInputStream.open0(Native Method)
    at java.io.FileInputStream.open(Unknown Source)
    at java.io.FileInputStream.<init>(Unknown Source)
    at java.io.FileReader.<init>(Unknown Source)
    at CheckedExceptionExample.main(CheckedExceptionExample.java:11)
```

Common methods of exceptions

```
public class CheckedExceptionExample {
    public static void main(String[] args) {
        try {
            method1();
        } catch (Exception e) {
            StackTraceElement[] traceElements = e.getStackTrace();
            for(StackTraceElement element : traceElements) {
                System.out.printf("%s\t", element.getFileName());
                System.out.printf("%s\t", element.getLineNumber());
                System.out.printf("%s\n", element.getMethodName());
            }
        }
    }
    public static void method1() throws Exception {
        throw new Exception("Exception thrown in method1");
    }
}
```

getStackTrace: retrieves the stack trace for customized processing

The throw keyword can be used to throw an exception object

```
CheckedExceptionExample.java  15  method1
CheckedExceptionExample.java  4   main
```

Common methods of exceptions

```
public class CheckedExceptionExample {
    public static void main(String[] args) {
        try {
            method1();
        } catch (Exception e) {
            System.err.println(e.getMessage());
        }
    }
    public static void method1() throws Exception {
        throw new Exception("Exception thrown in method1");
    }
}
```

`getMessage`: returns the detailed message of the exception

```
Exception thrown in method1
```

Chained exceptions

```
public class CheckedExceptionExample {
    public static void main(String[] args) throws Exception {
        try {
            method1();
        } catch (Exception e) {
            throw new Exception("Exception thrown in main");
        }
    }
    public static void method1() throws Exception {
        throw new Exception("Exception thrown in method1");
    }
}
```

Sometimes we need to throw an exception in the `catch` block

The information of the original exception in `method1` will be lost in such cases

```
Exception in thread "main" java.lang.Exception: Exception thrown in main
    at CheckedExceptionExample.main(CheckedExceptionExample.java:6)
```

Chained exceptions

```
public class CheckedExceptionExample {
    public static void main(String[] args) throws Exception {
        try {
            method1();
        } catch (Exception e) {
            throw new Exception("Exception thrown in main", e);
        }
    }
    public static void method1() throws Exception {
        throw new Exception("Exception thrown in method1");
    }
}
```

由什么引发

Chained exceptions enable an exception object to maintain complete stack-trace information from the original exception

```
Exception in thread "main" java.lang.Exception: Exception thrown in main
    at CheckedExceptionExample.main(CheckedExceptionExample.java:6)
Caused by: java.lang.Exception: Exception thrown in method1
    at CheckedExceptionExample.method1(CheckedExceptionExample.java:10)
    at CheckedExceptionExample.main(CheckedExceptionExample.java:4)
```

User-defined exceptions (Checked)

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

public class UserDefinedExceptionDemo {
    public static void main(String args[]) {
        try {
            throw new MyException("User-defined exception");
        } catch (MyException e) {
            System.err.println(e.getMessage());
        }
    }
}
```

New exception types can be defined by extending an existing exception class

定义自己的异常

Running result: `User-defined exception`

User-defined exceptions (Unchecked)

```
public class MyException2 extends RuntimeException {
    public MyException2(String s) {
        super(s);
    }
}

public class UserDefinedExceptionDemo2 {
    public static void main(String args[]) {
        throw new MyException2("User-defined exception");
    }
}
```

不强制 要处理

Extending `RuntimeException` makes this new exception unchecked (compiler will ignore unchecked exceptions)

Running result:

```
Exception in thread "main" MyException2: User-defined exception
    at UserDefinedExceptionDemo2.main(UserDefinedExceptionDemo2.java:9)
```

Assertions (断言)

- When implementing and debugging a class, it's sometimes useful to state conditions that should be true at a particular point in a method.

表达式真 → 继续执行 / 假 → 抛出异常

- These conditions, called **assertions**, help ensure a program's correctness by catching potential bugs (such as logic errors) during development.

- Java has two versions of `assert` statements
  - `assert expression;` // throws an `AssertionError` if `expression` is `false`
  - `assert expression1 : expression2;` // throws an `AssertionError` with `expression2` as the error message if `expression1` is `false`

Assertions

```
public class AssertionExample {
    public static void main(String[] args) {
        Scanner input = new Scanner(System.in);
        System.out.print("Enter a number between 0 and 10: ");
        int number = input.nextInt();
        assert (number >=0 && number <= 10) : "bad number: " + number;
    }
}
```

判断 错误信息 运行环境中要 enable 其功能

You must explicitly enable assertions: `java -ea AssertionExample`

```
Enter a number between 0 and 10: 12
Exception in thread "main" java.lang.AssertionError: bad number: 12
at AssertionExample.main(AssertionExample.java:8)
```