A Third Look At Java

A Little Demo

```
public class Test {
  public static void main(String[] args) {
    int i = Integer.parseInt(args[0]);
    int j = Integer.parseInt(args[1]);
    System.out.println(i/j);
  }
}
```

```
> javac Test.java
> java Test 6 3
2
>
```

Exceptions

```
> java Test
Exception in thread "main"
java.lang.ArrayIndexOutOfBoundsException: 0
        at Test.main(Test.java:3)
> java Test 6 0
Exception in thread "main"
        java.lang.ArithmeticException: / by zero
        at Test.main(Test.java:4)
```

In early languages, that's all that happened: error message, core dump, terminate.

Modern languages like Java support *exception handling*.

Outline

- 17.2 Throwable classes
- 17.3 Catching exceptions
- 17.4 Throwing exceptions
- 17.5 Checked exceptions
- 17.6 Error handling
- 17.7 Finally
- 17.8 Farewell to Java

Some Predefined Exceptions

Java Exception	Code to Cause It
`NullPointerException`	`String s = null;` `s.length();`

`ArithmeticException`	`int a = 3;`
	`int b = 0;`
	`int q = a/b;`

`ArrayIndexOutOfBoundsException`	`int[] a = new int[10];` `a[10];`

`ClassCastException`	`Object x =`
	`  new Integer(1);`
	`String s = (String) x;`

`StringIndexOutOfBoundsException`	`String s = "Hello";` `s.charAt(5);`

An Exception Is An Object

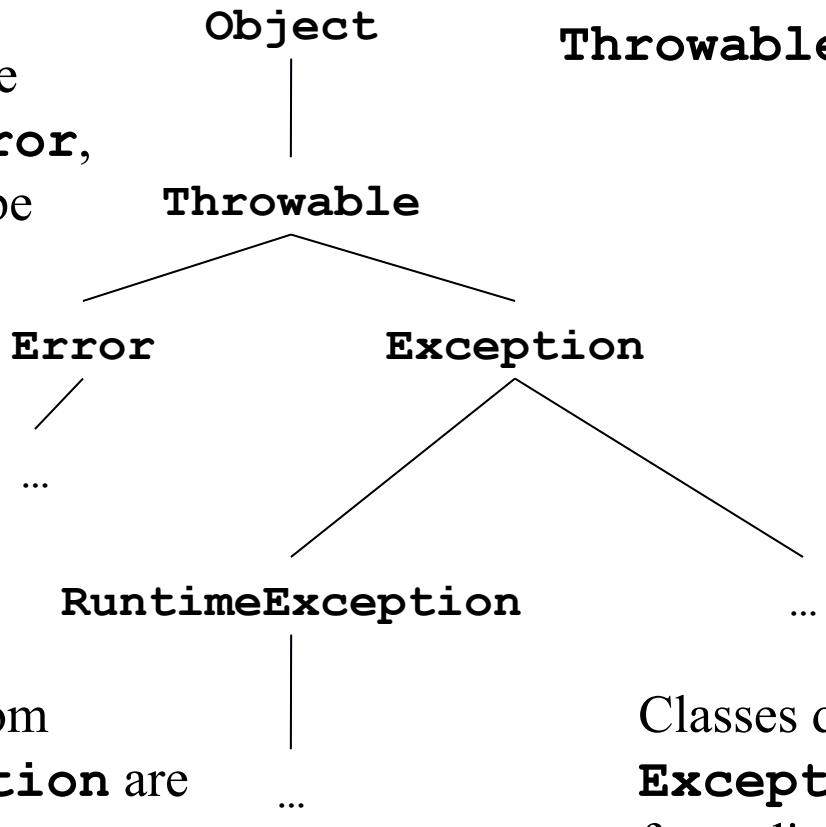
- The names of exceptions are class names, like **`NullPointerException`**
- Exceptions are objects of those classes
- In the previous examples, the Java language system automatically creates an object of an exception class and *throws* it
- If the program does not *catch* it, it terminates with an error message

Throwable Classes

- To be thrown as an exception, an object must be of a class that inherits from the predefined class **`Throwable`**
- There are four important predefined classes in that part of the class hierarchy:
  - **`Throwable`**
  - **`Error`**
  - **`Exception`**
  - **`RuntimeException`**

Classes derived from **`Error`** are used for serious, system-generated errors, like **`OutOfMemoryError`**, that usually cannot be recovered from

Java will only throw objects of a class descended from **`Throwable`**



Classes derived from **`RuntimeException`** are used for ordinary system-generated errors, like **`ArithmeticException`**

Classes derived from **`Exception`** are used for ordinary errors that a program might want to catch and recover from

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The **`try`** Statement

<try-statement> **`::=`** *<try-part>* *<catch-part>*
<try-part> **`::=`** **`try`** *<compound-statement>*
<catch-part> **`::=`** **`catch (`***<type>* *<variable-name>***`)`**
<compound-statement>

- Simplified… full syntax later
- The *<type>* is a throwable class name
- Does the **`try`** part
- Does the **`catch`** part only if the **`try`** part throws an exception of the given *<type>*

Example

```
public class Test {
  public static void main(String[] args) {
    try {
      int i = Integer.parseInt(args[0]);
      int j = Integer.parseInt(args[1]);
      System.out.println(i/j);
    }
    catch (ArithmeticException a) {
      System.out.println("You're dividing by zero!");
    }
  }
}
```

This will catch and handle any **`ArithmeticException`**. Other exceptions will still get the language system's default behavior.

Example

```
> java Test 6 3
2
> java Test 6 0
You're dividing by zero!
> java Test
Exception in thread "main"
java.lang.ArrayIndexOutOfBoundsException: 0
        at Test.main(Test.java:3)
```

- Catch type chooses exceptions to catch:
  - **`ArithmeticException`** got zero division
  - **`RuntimeException`** would get both examples above
  - **`Throwable`** would get all possible exceptions

After The `try` Statement

- A `try` statement can be just another in a sequence of statements
- If no exception occurs in the `try` part, the `catch` part is not executed
- If no exception occurs in the `try` part, or if there is an exception which is caught in the `catch` part, execution continues with the statement following the `try` statement

Exception Handled

```
System.out.print("1, ");
try {
  String s = null;
  s.length();
}
catch (NullPointerException e) {
  System.out.print("2, ");
}
System.out.println("3");
```

This just prints the line

```
1, 2, 3
```

Throw From Called Method

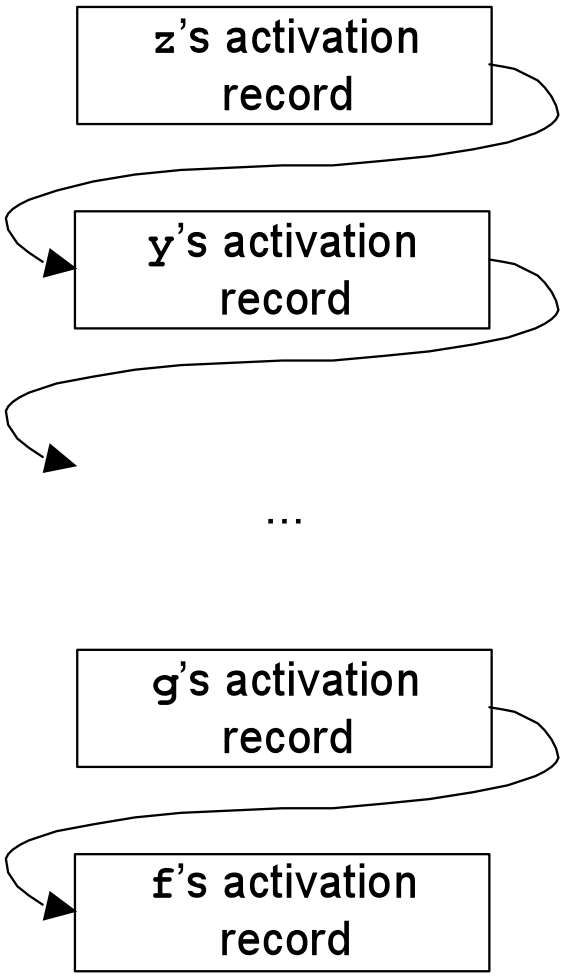
- The **`try`** statement gets a chance to catch exceptions thrown while the **`try`** part runs
- That includes exceptions thrown by methods called from the **`try`** part

Example

```
void f() {
  try {
    g();
  }
  catch (ArithmeticException a) {
    …
  }
}
```

- If **`g`** throws an **`ArithmeticException`**, that it does not catch, **`f`** will get it
- In general, the throw and the catch can be separated by any number of method invocations

- If **`z`** throws an exception it does not catch, **`z`**'s activation stops…
- …then **`y`** gets a chance to catch it; if it doesn't, **`y`**'s activation stops…
- …and so on all the way back to **`f`**



Long-Distance Throws

- That kind of long-distance throw is one of the big advantages of exception handling
- All intermediate activations between the throw and the catch are stopped and popped
- If not throwing or catching, they need not know anything about it

Multiple **`catch`** Parts

<*try-statement*> **`::=`** <*try-part*> <*catch-parts*>
<*try-part*> **`::=`** **`try`** <*compound-statement*>
<*catch-parts*> **`::=`** <*catch-part*> <*catch-parts*>
| <*catch-part*>
<*catch-part*> **`::=`** **`catch (`**<*type*> <*variable-name*>**`)`**
<*compound-statement*>

- To catch more than one kind of exception, a **`catch`** part can specify some general superclass like **`RuntimeException`**
- But usually, to handle different kinds of exceptions differently, you use multiple **`catch`** parts

Example

```
public static void main(String[] args) {
  try {
    int i = Integer.parseInt(args[0]);
    int j = Integer.parseInt(args[1]);
    System.out.println(i/j);
  }
  catch (ArithmeticException a) {
    System.out.println("You're dividing by zero!");
  }
  catch (ArrayIndexOutOfBoundsException a) {
    System.out.println("Requires two parameters.");
  }
}
```

This will catch and handle both **`ArithmeticException`** and **`ArrayIndexOutOfBoundsException`**

Example

```
public static void main(String[] args) {
  try {
    int i = Integer.parseInt(args[0]);
    int j = Integer.parseInt(args[1]);
    System.out.println(i/j);
  }
  catch (ArithmeticException a) {
    System.out.println("You're dividing by zero!");
  }
  catch (ArrayIndexOutOfBoundsException a) {
    System.out.println("Requires two parameters.");
  }
  catch (RuntimeException a) {
    System.out.println("Runtime exception.");
  }
}
```

Overlapping Catch Parts

- If an exception from the **`try`** part matches more than one of the **`catch`** parts, only the first matching **`catch`** part is executed
- A common pattern: **`catch`** parts for specific cases first, and a more general one at the end
- Note that Java does not allow unreachable **`catch`** parts, or unreachable code in general

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The **`throw`** Statement

<throw-statement> **`::=`** **`throw`** *<expression>* **`;`**

- Most exceptions are thrown automatically by the language system
- Sometimes you want to throw your own
- The *<expression>* is a reference to a throwable object—usually, a new one:

```
throw new NullPointerException();
```

Custom Throwable Classes

```
public class OutOfGas extends Exception {
}
```

```
System.out.print("1, ");
try {
  throw new OutOfGas();
}
catch (OutOfGas e) {
  System.out.print("2, ");
}
System.out.println("3");
```

Using The Exception Object

- The exception that was thrown is available in the catch block—as that parameter
- It can be used to communicate information from the thrower to the catcher
- All classes derived from **`Throwable`** inherit a method **`printStackTrace`**
- They also inherit a **`String`** field with a detailed error message, and a **`getMessage`** method to access it

Example

```
public class OutOfGas extends Exception {
  public OutOfGas(String details) {
    super(details);
  }
}
```

This calls a base-class constructor to initialize the field returned by **`getMessage()`**.

```
try {
  throw new OutOfGas("You have run out of gas.");
}
catch (OutOfGas e) {
  System.out.println(e.getMessage());
}
```

About `super` In Constructors

- The first statement in a constructor can be a call to **`super`** (with parameters, if needed)
- That calls a base class constructor
- Used to initialize inherited fields
- All constructors (except in **`Object`**) start with a call to another constructor—if you don't include one, Java calls **`super()`** implicitly

More About Constructors

- Also, all classes have at least one constructor—if you don't include one, Java provides a no-arg constructor implicitly

```
public class OutOfGas extends Exception {
}
```

```
public class OutOfGas extends Exception {
  public OutOfGas() {
    super();
  }
}
```

These are equivalent!

```
public class OutOfGas extends Exception {
  private int miles;
  public OutOfGas(String details, int m) {
    super(details);
    miles = m;
  }
  public int getMiles() {
    return miles;
  }
}

try {
  throw new OutOfGas("You have run out of gas.",19);
}
catch (OutOfGas e) {
  System.out.println(e.getMessage());
  System.out.println("Odometer: " + e.getMiles());
}
```

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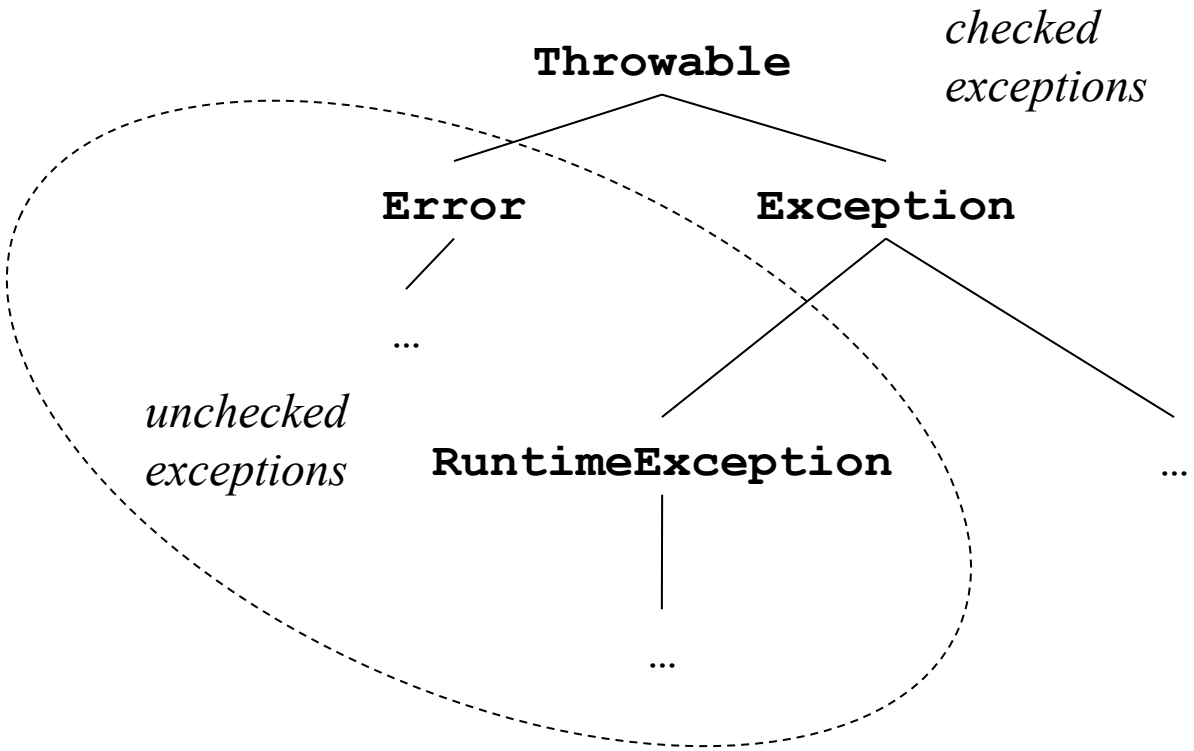
Checked Exceptions

```
void z() {
  throw new OutOfGas("You have run out of gas.", 19");
}
```

- This method will not compile: “The exception **`OutOfGas`** is not handled”
- Java has not complained about this in our previous examples—why now?
- Java distinguishes between two kinds of exceptions: checked and unchecked



The unchecked exceptions classes are **`Error`** and **`RuntimeException`** and their descendants. All others are checked.

What Gets Checked?

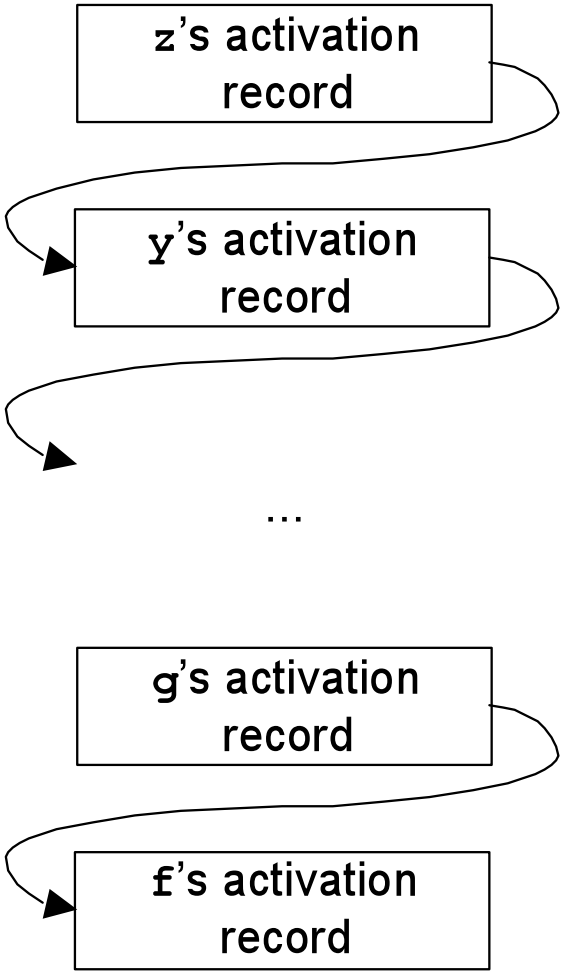
- A method that can get a checked exception is not permitted to ignore it
- It can catch it
  - That is, the code that generates the exception can be inside a **`try`** statement with a **`catch`** part for that checked exception
- Or, it can declare that it does *not* catch it
  - Using a **`throws`** clause

The Throws Clause

```
void z() throws OutOfGas {
  throw new OutOfGas("You have run out of gas.", 19);
}
```

- A **`throws`** clause lists one or more throwable classes separated by commas
- This one always throws, but in general, the throws clause means *might* throw
- So any caller of **`z`** must catch **`OutOfGas`**, or place it in its own **`throws`** clause

- If **`z`** declares that it **`throws OutOfGas`**…
- …then **`y`** must catch it, or declare it **`throws`** it too…
- …and so on all the way back to **`f`**



Why Use Checked Exceptions

- The **`throws`** clause is like documentation: it tells the reader that this exception can result from a call of this method
- But it is *verified* documentation; if any checked exception can result from a method call, the compiler will insist it be declared
- This can make programs easier to read and more likely to be correct

How To Avoid Checked Exceptions

- You can always define your own exceptions using a different base class, such as **`Error`** or **`Throwable`**
- Then they will be unchecked
- Weigh the advantages carefully

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Handling Errors

- Example: popping an empty stack
- Techniques:
  - Preconditions only
  - Total definition
  - Fatal errors
  - Error flagging
  - Using exceptions

Preconditions Only

- Document preconditions necessary to avoid errors
- Caller must ensure these are met, or explicitly check if not sure

```
/**
  * Pop the top int from this stack and return it.
  * This should be called only if the stack is
  * not empty.
  * @return the popped int
  */
 public int pop() {
   Node n = top;
   top = n.getLink();
   return n.getData();
 }
```

```
if (s.hasMore()) x = s.pop();
else …
```

Drawbacks

- If the caller makes a mistake, and pops an empty stack: **`NullPointerException`**
  - If that is uncaught, program crashes with an unhelpful error message
  - If caught, program relies on undocumented internals; an implementation using an array would cause a different exception

Total Definition

- We can change the definition of **`pop`** so that it always works
- Define some standard behavior for popping an empty stack
- Like character-by-character file I/O in C: an EOF character at the end of the file
- Like IEEE floating-point: NaN and signed infinity results

```
/**
 * Pop the top int from this stack and return it.
 * If the stack is empty we return 0 and leave the
 * stack empty.
 * @return the popped int, or 0 if the stack is empty
 */
public int pop() {
  Node n = top;
  if (n==null) return 0;
  top = n.getLink();
  return n.getData();
}
```

Drawbacks

- Can mask important problems
- If a client pops more than it pushes, this is probably a serious bug that should be detected and fixed, not concealed

Fatal Errors

- The old-fashioned approach: just crash!
- Preconditions, plus decisive action
- At least this does not conceal the problem…

```
 /**
 * Pop the top int from this stack and return it.
 * This should be called only if the stack is
 * not empty.  If called when the stack is empty,
 * we print an error message and exit the program.
 * @return the popped int
 */
public int pop() {
  Node n = top;
  if (n==null) {
    System.out.println("Popping an empty stack!");
    System.exit(-1);
  }
  top = n.getLink();
  return n.getData();
}
```

Drawbacks

- Not an object-oriented style: an object should do things to itself, not to the rest of the program
- Inflexible: different clients may want to handle the error differently
  - Terminate
  - Clean up and terminate
  - Repair the error and continue
  - Ignore the error
  - Etc.

Error Flagging

- The method that detects the error can flag it somehow
  - By returning a special value (like C **`malloc`**)
  - By setting a global variable (like C **`errno`**)
  - By setting an instance variable to be checked by a method call (like C **`ferror(f)`**)
- Caller must explicitly test for error

```
/**
 * Pop the top int from this stack and return it.
 * This should be called only if the stack is
 * not empty.  If called when the stack is empty,
 * we set the error flag and return an undefined
 * value.
 * @return the popped int if stack not empty
 */
public int pop() {
  Node n = top;
  if (n==null) {
    error = true;
    return 0;
  }
  top = n.getLink();
  return n.getData();
}
```

```
/**
 * Return the error flag for this stack.  The error
 * flag is set true if an empty stack is ever popped.
 * It can be reset to false by calling resetError().
 * @return the error flag
 */
public boolean getError() {
  return error;
}

/**
 * Reset the error flag.  We set it to false.
 */
public void resetError() {
  error = false;
}
```

```
/**
 * Pop the two top integers from the stack, divide
 * them, and push their integer quotient.  There
 * should be at least two integers on the stack
 * when we are called.  If not, we leave the stack
 * empty and set the error flag.
 */
public void divide() {
  int i = pop();
  int j = pop();
  if (getError()) return;
  push(i/j);
}
```

The kind of explicit error check required by an error flagging technique.

Note that **`divide`**'s caller may also have to check it, and its caller, and so on…

Using Exceptions

- The method that first finds the error throws an exception
- May be checked or unchecked
- Part of the documented behavior of the method

```
/**
 * Pop the top int from this stack and return it.
 * @return the popped int
 * @exception EmptyStack if stack is empty
 */
public int pop() throws EmptyStack {
  Node n = top;
  if (n==null) throw new EmptyStack();
  top = n.getLink();
  return n.getData();
}
```

```
/**
 * Pop the two top integers from the stack, divide
 * them, and push their integer quotient.
 * @exception EmptyStack if stack runs out
 */
public void divide() throws EmptyStack {
  int i = pop();
  int j = pop();
  push(i/j);
}
```

Caller makes no error check—just passes the exception along if one occurs

Advantages

- Good error message even if uncaught
- Documented part of the interface
- Error caught right away, not masked
- Caller need not explicitly check for error
- Error can be ignored or handled flexibly

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The Full **`try`** Syntax

<try-statement> **`::=`** *<try-part>* *<catch-parts>*
| *<try-part>* *<catch-parts>* *<finally-part>*
| *<try-part>* *<finally-part>*

<try-part> **`::=`** **`try`** *<compound-statement>*

<catch-parts> **`::=`** *<catch-part>* *<catch-parts>* | *<catch-part>*

<catch-part> **`::=`** **`catch (`***<type>* *<variable-name>***`)`**
<compound-statement>

<finally-part> **`::=`** **`finally`** *<compound-statement>*

- There is an optional **`finally`** part
- No matter what happens, the **`finally`** part is always executed at the end of the **`try`** statement

Using **`finally`**

```
file.open();
try {
  workWith(file);
}
finally {
  file.close();
}
```

- The **`finally`** part is usually used for cleanup operations
- Whether or not there is an exception, the file is closed

Example

```
System.out.print("1");
try {
  System.out.print("2");
  if (true) throw new Exception();
  System.out.print("3");
}
catch (Exception e) {
  System.out.print("4");
}
finally {
  System.out.print("5");
}
System.out.println("6");
```

What does this print?

What if we change **`new Exception()`** to **`new Throwable()`**?

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Parts We Skipped

- Fundamentals
  - Primitive types: **`byte`**, **`short`**, **`long`**, **`float`**
  - The **`enum`** type constructor for enumerations
  - Various statements: **`do`**, **`for`**, **`break`**, **`continue`**, **`switch`**, **`assert`**
- Refinements
  - Inner classes: define classes in any scope: inside other classes, in blocks, in expressions
  - Generics: we saw only a quick peek

More Parts We Skipped

- Packages
  - Classes are grouped into packages
  - In many Java systems, the source files in a directory correspond to a package
  - Default access (without **`public`**, **`private`** or **`protected`**) is package-wide
- Concurrency
  - Synchronization constructs for multiple threads
  - Parts of the API for creating threads

More Parts We Skipped

- The vast API
  - containers (stacks, queues, hash tables, etc.)
  - graphical user interfaces
  - 2D and 3D graphics
  - math
  - pattern matching with regular expressions
  - file IO
  - network IO and XML
  - encryption and security
  - remote method invocation
  - interfacing to databases and other tools