Java and C# in depth
Carlo A. Furia, Marco Piccioni, Bertrand Meyer

Java: exceptions
and genericity
Java and C# in depth
Carlo A. Furia, Marco Piccioni, Bertrand Meyer

Exceptions
Exceptions are objects

- **Raise with a** `throw ExceptionObject instruction`
  
  ```java
  throw new AnExceptionClass("ErrorInfo");
  ```

- **Checked exceptions**
  
  Declared in method signature:
  ```java
  public void foo() throws SomeCheckedException
  ```
  
  Must be handled explicitly
  
  - provide an exception handler (with a `try/catch/finally` block)
  - propagate the exception to the caller (with a `throws` declaration)

- **Unchecked exceptions**
  
  May be handled, if desired
  
  Unhandled exceptions terminate the current execution thread
Exception class hierarchy

- Throwable
  - Exception
    - RuntimeException
      - unchecked
    - ...
    - unchecked
  - Error
    - unchecked
    - checked
Exception handlers

The scope of an exception handler is denoted by a `try` block

Every `try` block is immediately followed by zero or more `catch` blocks, zero or one `finally` block, or both. At least one of `catch` blocks and `finally` block is required (otherwise, what’s the `try` for?)

```java
public int foo(int b) {
    try {
        if (b > 3) {
            throw new Exception();
        }
    }
    catch (Exception e) { b++; }
    finally { b++; }
    return b;
}
```
Exception handlers: catch blocks

**catch** blocks can be exception-specific:

```java
catch (ExceptionType name) { /* handler */ }
```

- Targets exceptions whose type conforms to `ExceptionType`
- `ExceptionType` must be a descendant of `Throwable`
- `name` behaves as a local variable inside the handler block
- A `catch` block of type `T` cannot follow a `catch` block of type `S` if `T ≤ S` (otherwise the `T`-type block would be shadowed)

Multi `catch` blocks (introduced in Java 7):

```java
catch (ET1 | ET2 | ET3 name) { /* handler */ }
```

- Targets exceptions whose type conforms to `ET1`, `ET2`, or `ET3`
- `ET1`, `ET2`, and `ET3` cannot be related by subclassing
- `name` behaves as a constant (`final`) inside the handler block
Exception handlers: catch/finally blocks

When an exception of type $T$ is thrown within a `try` block:
- control is transferred to the first (in textual order) `catch` block whose type $T$ conforms to, if one exists
- then, the control is then transferred to the `finally` block (if it exists)
- finally, execution continues after the `try` block

When no conforming `catch` exists or an exception is re-thrown inside the handler:
- After executing the `finally` block, the exception propagates to the next available enclosing handler

When a `try` block terminates without exceptions:
- the control is transferred to the `finally` block (if it exists)
- then, execution continues after the `try` block
Exception handlers: catch/finally blocks

A **finally** block is always executed after the **try** block even if no exceptions are thrown

- Typically used to free resources

```java
// foo() returns 2 (!)
public int foo() {
    try { return 1; } finally { return 2; }
}
```

A control-flow breaking instruction (**return**, **break**, **continue**) inside a **finally** block terminates the propagation of exceptions.

```java
// foo() returns 2 and propagates no exception
public int foo() {
    try { throw new Exception(); } finally { return 2; }
}
```
Exception handlers

A `catch` block may contain other `try` blocks

From within a `catch` block an exception can be re-thrown:
```
catch (Exception e) { if (...) {throw e;} ...}
```

Exceptions that propagate to the `main` method without being handled force termination of the program (typically, showing a trace of the call stack).
A method

```java
int readNum(String fn, int n)
```

tries to read an \( n \)-digit integer from file with name \( fn \).

Exceptions handle things that may go wrong:

- a file with name \( s \) doesn’t exist
- the file cannot be opened
- the file doesn’t encode an integer
- the integer has fewer than \( n \) digits
public int readNum(String fn, int n) throws TooFewDigitsException, FileNotFoundException, IOException {
    int res;  BufferedReader br = null;
    try {
        br = new BufferedReader(new FileReader(fn));
        String str = br.readLine();
        if (str.length() < n)
            throw new TooFewDigitsException(str.length());
        res = Integer.parseInt(str);
    } catch (FileNotFoundException e) { throw e; } catch (IOException e) { throw e; } catch (NumberFormatException e) { res = 0; } finally { if (br != null) br.close(); }
    return res;   }
Here’s how a client may use `readNum`:

```java
int readInt;
String aFileName;
try {
    readInt = n.readNum(aFileName, 5);
}

catch (TooFewDigitsException e) {
    try {
        readInt = n.readNum(FileName, e.numRead);
    } catch (Exception e) {System.out.println("Give up!");}
}

catch (Exception e) { System.out.println("IO error"); }
```
Try with resources

Starting with Java 7, a `try` may also list some resources that are automatically closed after the block terminates (as with a `finally` block).

```java
try {
    FileOutputStream out = new FileOutputStream("o.txt");
    FileInputStream in = new FileInputStream("i.txt");
} {
    // use out and in
} catch (IOException e) { /* Couldn’t open files */ }
```

`catch` and `finally` are completely optional in try-with-resources blocks (but checked exceptions must still be caught or propagated).

A class must implement interface `java.lang.AutoCloseable` to be usable in a try-with-resources block.

- Basically, it needs a `close()` method
Checked vs. unchecked exceptions

Checked exceptions are quite unique to Java
  - C++ and C#, in particular, have only the equivalent of unchecked exceptions

Which type of exception should you use in your Java programs?

Java orthodoxy: checked exceptions should be the norm

Rationale for preferring checked exceptions:
  - exceptions usually carry information the client of a class should be informed about
  - a method throwing unchecked exceptions is similar to a method with undocumented behavior
  - clients may run into all sorts of troubles if they receive unexpected exceptions
Disadvantages of using checked exceptions extensively:

- lots of exception handling code to write
  - lazy programmer’s shortcut: empty `catch` blocks
- many `catch` blocks pollute code and decrease readability
- complex unwinding of the call stack to decide which exceptions to propagate and which to handle
- new exceptions change the interface of methods
Checked vs. unchecked exceptions

How to strike a balance:

- As a norm, checked exceptions should replace error codes when the client should check the return code.
- Use a checked exception if the caller can do something sensible with the exception.
  - useless with fatal errors whose causes are outside of the client’s influence.
- Document the usage of unchecked exceptions.
- Don’t use exceptions (checked or unchecked) when you should use assertions (contracts).
  - see examples in C# slides of this class.
Java and C# in depth
Carlo A. Furia, Marco Piccioni, Bertrand Meyer

Genericity in Java
Generics

Java’s genericity mechanism, available since Java 5.0

Most common use:
- Use (and implement) generic type-safe containers
  ```java
  ArrayList<String> safeBox = new ArrayList<String>();
  ```
- Compile-time type-checking is enforced

More sophisticated uses:
- Custom generic classes and methods
- Bounded genericity (also called constrained genericity)
  ```java
  public <T extends Interface1 & Interface2> T test(T x)
  ```
A **generic class** is a class parameterized w.r.t. one or more generic types.

```java
public class Cell<T> {
    private T val;
    public T getVal() { return val; }
    public void setVal(T v) { val = v; }
}
```

To instantiate a generic class we must provide an actual type for the generic parameters.

```java
Cell<String> c = new Cell<String>();
```
Generic classes

The generic parameters of a generic class may constrain the valid actual types.

```java
public class Cell<T extends S> { ... }
```

This is valid only if `X` is a subtype of `S`:

```java
Cell<X> c = new Cell<X>();
```

The constrains may involve multiple types.

```java
public class C<T extends String & Iterable> { ... }
```

This is valid only if `Y` is a subtype of both `String` and `Iterable`:

```java
C<Y> c = new C<Y>();
```
Before generics were available, using class `Object` was the way to achieve generic implementations.

```java
public class OldCell {
    private Object val;
    public Object getVal() { return val; }
    public void setVal(Object v) { val = v; }
}
```

Requires explicit castings, with major problems:

- verbose code
- no compile-time checks

```java
OldCell c = new OldCell();
c.setVal(“A string”); // upcasting
String s = (String) c.getVal(); // downcasting
Car c = (Car) c.getVal(); // runtime error
```
Diamond operators and raw types

When creating an instance of a generic class, the compiler is often able to infer the generic type from the context. In such cases, we can use the diamond operator.

```java
Cell<String> c = new Cell<>();
```

is equivalent to:

```java
Cell<String> c = new Cell<String>();
```

Generic classes can be instantiated as raw types, without providing any generic parameter. Raw types correspond to the old type-unsafe generic classes:

```java
Cell c = new Cell();
c.setVal(12); // warning of unsafe behavior
Cell<String> c = new Cell();
// not equivalent to new Cell<>()!
```
Generics: features and limitations

Generic classes are translated into ordinary classes by the compiler:

- Process called “type erasure”
- The generic type is replaced by Object
- Casts are added as needed, after checking that they are type-safe

Limitations of type erasure:

- Can’t instantiate generic parameter with primitive types
  - but can use wrapper classes
- At runtime you cannot tell the difference between ArrayList<Integer> and ArrayList<String>
- Exception classes cannot be generic classes
- Can’t create objects of the generic type
  - but can assign the value null to a variable of generic type
- Arrays with elements of a generic type parameter cannot be created
- A static member cannot reference a generic type parameter
Generics and inheritance

Let S be a subtype of T (i.e. S ≤ T)

There is no inheritance relation between:

SomeGenericClass<S> and SomeGenericClass<T>

In particular: the former is not a subtype of the latter

However, let AClass be a non-generic type:

- T<AClass> is a subtype of T
  - T denotes the raw type derived from the generic class T
- S<AClass> is a subtype of T<AClass>
Why subtyping with generics is tricky

Consider a method of class F:

```java
public static void foo(LinkedList<Vehicle> x){
    // add a Truck to the end of list 'x'
    x.add(new Truck());
}
```

If `LinkedList<Car>` were a subtype of `LinkedList<Vehicle>`, this would be valid code:

```java
LinkedList<Vehicle> cars = new LinkedList<Car>();
cars.add(new Car());
F.foo(cars);
```

But now a `LinkedList<Car>` would contain a Truck, which is not a Car!
Wildcards

Give some polymorphic features to generics

Unbounded wildcards: `Collection<?>`

- “`Collection` of unknowm(s)”
- It is a super-type of `Collection<T>`, for any class `T`
  - A method can read elements from a wildcard collection argument
  - Can assign elements of the collection to references of type `Object`
  - Cannot add new elements to the collection (see previous example)
  - But it can add new `null` entries
    - because `null` is a subtype of every other type
Bounded wildcards

Bounded wildcards with upper bound: 
`Collection<? extends X>`

- It is a super-type of `Collection<T>`, for any subclass `T` of `X`
  - A method can read elements from the wildcard collection argument
  - Can assign elements of the collection to references of type `X`
  - Cannot add new elements to the collection
  - But it can add new null entries
    - because `null` is a subtype of every other type
Upper-bounded wildcards: example

Consider the following hierarchy of classes:

```
Shape
 - Circle
 - Rectangle
```

What should be the signature of a method `drawShapes` that takes a list of `Shape` objects and draws all of them?

- `drawShapes(List<Shape> shapes)`
  - this doesn’t work on a `List<Circle>`, which is not a subtype of `List<Shape>`

- `drawShapes(List<? extends Shape> shapes)`
  - this works on `List<Shape>`, `List<Circle>`, and `List<Rectangle>`, but doesn’t work on `List<Object>` (correctly, as drawing is not defined for something that may not be a `Shape`
Bounded wildcards

Bounded wildcards with lower bound:
\textit{Collection}\textless{}? super \textit{X}\textgreater{}

- It is a super-type of \textit{Collection}\textless{}\textit{T}\textgreater{}, for any superclass \textit{T} of \textit{X}
  - A method can add elements to the collection (i.e., through the wildcard collection argument)
  - Cannot assign elements of the collection to references of type \textit{X}
  - But it can read elements and assign them to reference of type \textit{Object}
    - because \textit{Object} is a supertype of every other type

Lower bounds are often used for write-only resources such as log streams.
Consider a class for a list, including a sort method:

```java
class MySortedList<T> implements List
{
    ...
    void sort(Comparator<T> cmp) {
        ...
    }
}
```

- `MySortedList<String> sl = new MySortedList<>();`
- `Comparator<String> mc = ... ;`
- `Comparator<Object> oc = ... ;`
- Valid call: `sl.sort(mc);`
- Invalid call: `sl.sort(oc);`
  - `Comparator<Object>` is incompatible with `Comparator<String>`
- Solution: use a lower-bounded wildcard in `sort`'s signature
  ```java
  void sort(Comparator <? super T> cmp)
  ```
Generic methods

They are useful where wildcards fall short: adding elements to a generic collection

Example: a method that assigns the elements in an array to a generic collection

```java
static void a2c(Object[] a, Collection<?> c) {
    for (Object o : a) { c.add(o); /* Error */ }
}
```

- We will know whether the type of o’s elements is compatible with the type of c’s elements only at runtime
Generic methods

Example: a method that assigns the elements in an array to a generic collection

Generic methods come to the rescue (notice the position of the generic parameter):

```java
static <G> void a2c(G[] a, Collection<G> c) {
    for (G o : a) { c.add(o); /* OK */ }
}
```

This is how client use the generic method.

```java
String[] arr = {"Hello", "world", "!"};
ArrayList<Object> lst = new ArrayList<>();
a2c(arr, lst);
```

The actual generic parameter is inferred from context.
Collections

A classic example of separating interface from implementation

Some useful library interfaces from `java.util`:

- `Collection<E>`
  - `boolean add(E el)`
    - returns whether the collection actually changed
  - `void clear()`
    - remove all elements in the collection
  - `Iterator<E> iterator()`
    - returns an iterator over the collection

- `Iterator<E>`
  - `E next()`
  - `void remove()`
    - removes the last element returned by the iterator
Collections: some implementations

- **ArrayList**: indexed, dynamically growing
- **LinkedList**: ordered, efficient insertion and removal
- **HashSet**: unordered, rejects duplicates
- **TreeSet**: ordered, rejects duplicates
- **HashMap**: key/value associations
- **TreeMap**: key/value associations, sorted keys
Java collections framework

Figure 1  Collections Framework major interfaces
Java collections framework
Java collections framework

Figure 4  Map category
Java collections framework

Figure 2 Set category