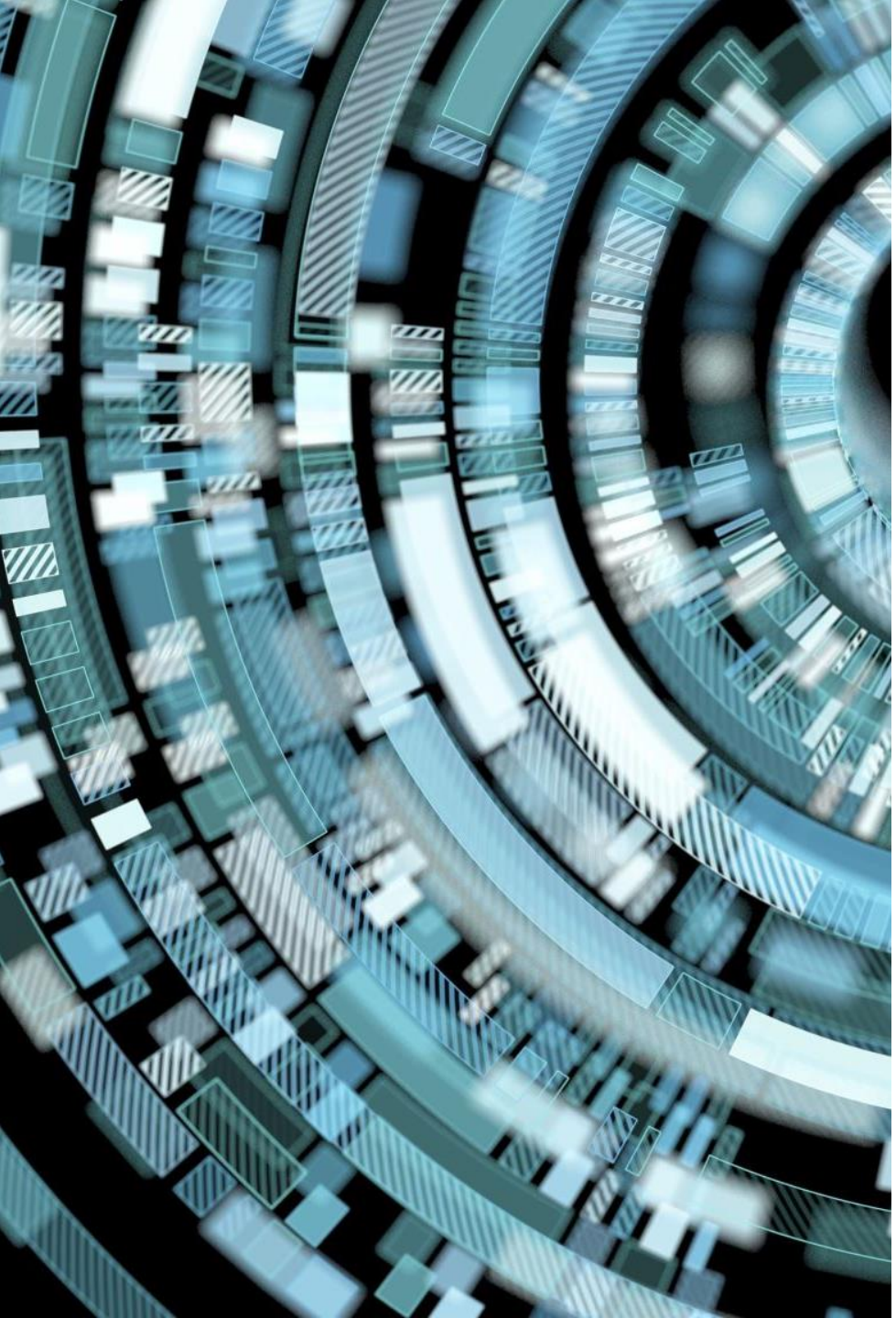
Computer System Design & Application

计算机系统设计与应用A

陶伊达 （TAO Yida）
taoyd@sustech.edu.cn



Lecture 10

- Reflection
- Annotation

What is Reflection (反射)？

- Reflection is a feature in Java, an API in `java.lang.reflect` package
- Reflection is used to examine or modify the behavior of methods, classes, interfaces at runtime
  - Examining all fields and methods of a class
  - Invoking a method of an object
  - Accessing a private field from another class

A Motivating Example

- x might be obtained from users, JSON file, server response, etc.; We do not know its exact type
- Using `instanceof`, we still do not know the exact type of x (it might be a subclass, e.g., `Rectangle`)
- What if we need to perform different actions for different types of x? Should we write a dozen if `instanceof` block?

```
Object x = . . .;
if (x instanceof Shape)
{
   Shape s = (Shape) x;
   g2.draw(s);
}
```

Finding the actual type

```
public final class Class<T>
extends Object
```

- If you have any object reference, you can find the actual type of the object to which it refers with the `getClass()` method
- The `getClass()` method returns an object of type `Class` that describes the object's class.

```
Class c = x.getClass()
```

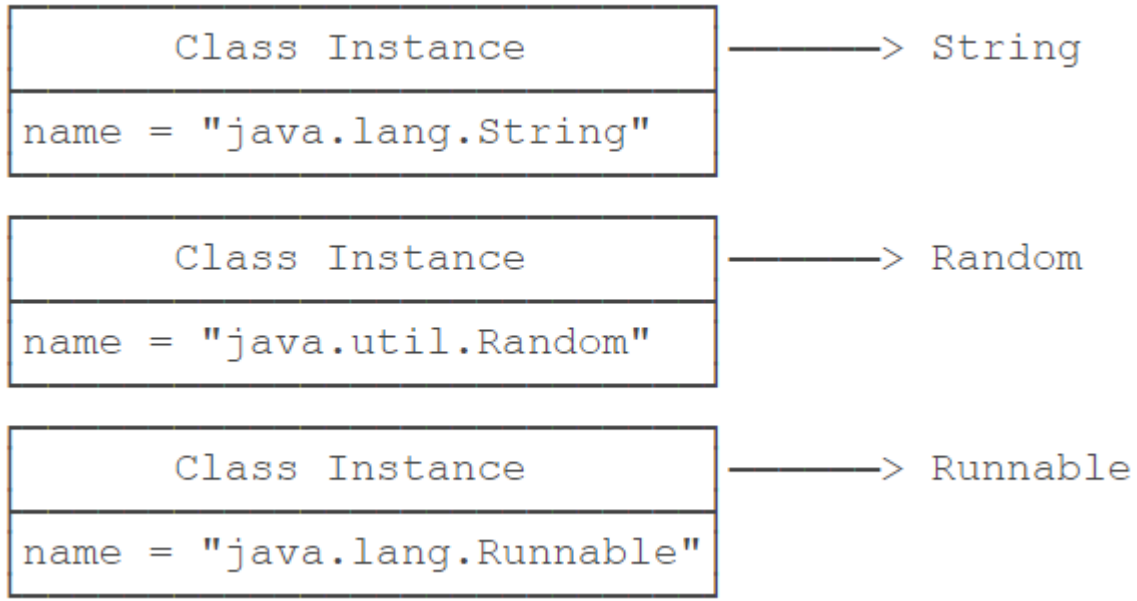
`getClass()`
Returns the runtime class of this `Object`.

After you have a Class instance, you can obtain a large amount of information about the class (e.g., name, fields, constructors, methods)

The `Class` class

Reflection: getting information of a class through its `Class` instance

JVM creates one instance of type `Class` for every data type (including primitive types, classes and interfaces)



A `Class` instance has detailed information for the corresponding class

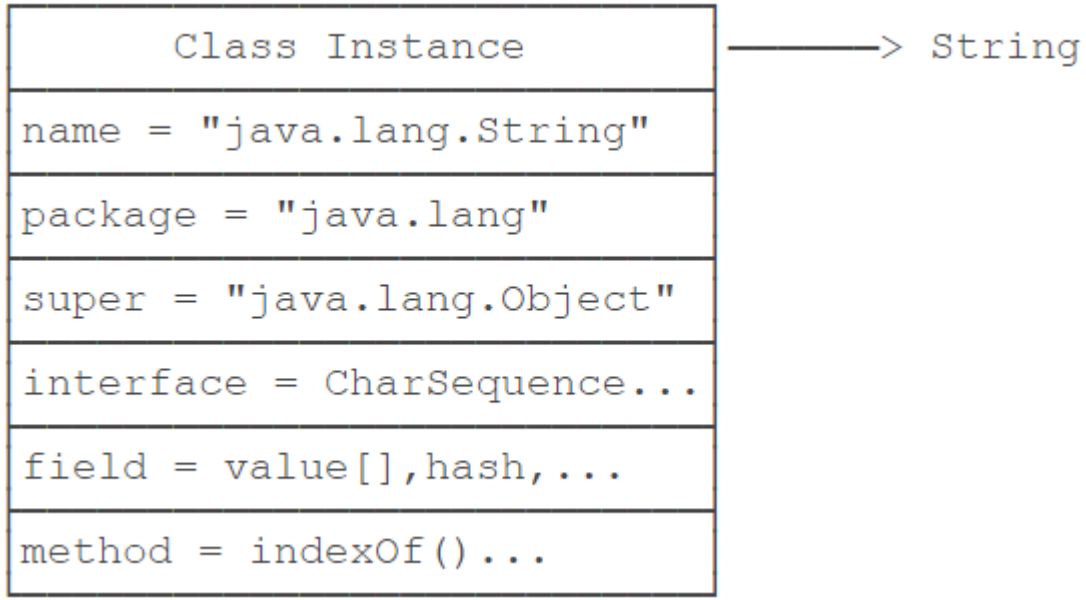


Image source: https://www.liaoxuefeng.com/wiki/1252599548343744/1264799402020448

JVM Loading Process

- `Class` instances are constructed automatically by JVM when it loads classes (`.class` files)
- Whenever JVM loads a class/type (e.g., `String`), it creates an instance of type `Class` for it

```
Class cls = new Class(String);
```

Sort of. Class has no public constructor so we cannot create Class objects, only JVM can.

```
/*
 * Constructor. Only the Java Virtual Machine creates Class
 * objects.
 */
private Class() {}
```

JVM Loading Process

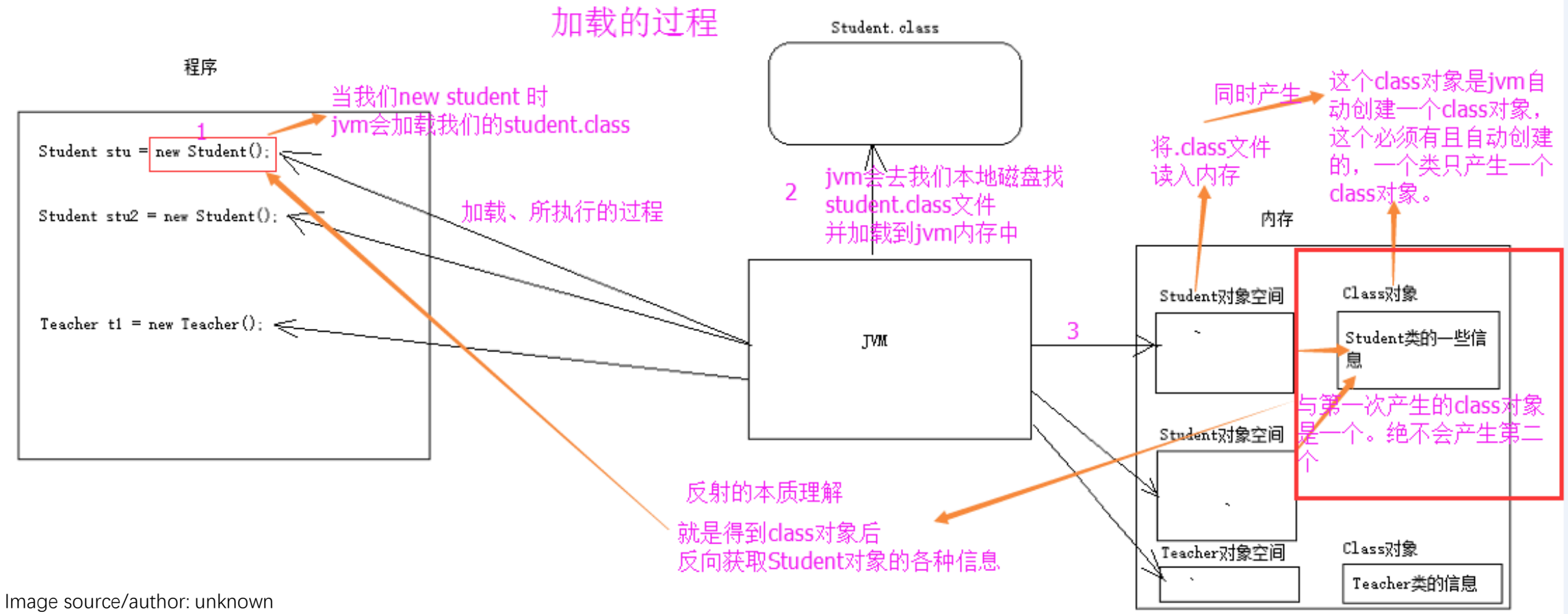


Image source/author: unknown

Getting `Class` Objects

- Approach 1: using `.class` (for known classes)

```
Class cls1 = String.class;
```

- Approach 2: using `Class.forName()` (using full package name)

```
Class cls2 = Class.forName("java.lang.String");
```

- Approach 3: using `getClass()` on class instances

```
String s = "Hello";
Class cls3 = s.getClass();
```

What is the relationship between cls1, cls2, and cls3?

Getting `Class` Objects

- There is only one `Class` object for every type that has been loaded into JVM
- We can use the `==` operator to test whether two `class` instances describe the same type

```
Class cls1 = String.class;
Class cls2 = Class.forName("java.lang.String");
Class cls3 = "hello".getClass();

System.out.println(cls1 == cls2);
System.out.println(cls1 == cls3);
```

Getting Class Names

- To get the exact class name of a Java object, get its `Class` object and invoke `getName()` on it

```
String s = "Hello";
System.out.println(s.getClass().getName());
```

java.lang.String

Getting Class Names

NOTE For historical reasons, the `getName` method produces strange-looking names for array types. For example, `double[].class.getName()` is

```
"[D"
```

and `String[][].class.getName()` is

```
"[[Ljava.lang.String;"
```

In general, an array type name is made up according to the following rules:

[*type*	array type
B	byte
C	char
D	double
F	float
I	int
J	long
L*name*;	class or interface
S	short
Z	boolean

Reference: Object-Oriented Design & Patterns. Cay S. Horstmann. Chapter 7.

Getting Class Fields

`Field getField(name)`	get public field given the name
`Field getDeclaredField(name)`	get field given the name
`Field[] getFields()`	get all public fields
`Field[] getDeclaredFields()`	get all fields (excludes inherited fields)

This includes public, protected, default (package) access, and private fields, but excludes inherited fields.

The `Field` Class

- A `Field` provides information about, and dynamic access to, a single field of a class or an interface

```
Field f = String.class.getDeclaredField( name: "value");
System.out.println(f.getName()); // value
System.out.println(f.getType()); // [B

int m = f.getModifiers();
System.out.println(Modifier.isFinal(m)); // true
System.out.println(Modifier.isPrivate(m)); // true
```

```
public final class String
    implements java.io.Serializable, Comparable<String>, CharSequence,
               Constable, ConstantDesc {

    The value is used for character storage.
    Implementation This field is trusted by the VM, and is a subject to constant folding i
    Note:          is constant. Overwriting this field after construction will cause probl
                   Additionally, it is marked with Stable to trust the contents of the ar
                   facility in JDK provides this functionality (yet). Stable is safe here, b
                   never null.
    @Stable
    private final byte[] value;
```

`getModifiers()` returns the Java language modifiers for the field represented by this `Field` object, as an integer. The `Modifier` class should be used to decode the modifiers.

The Field Class

Using Reflection, we could update a field value (even for private fields)

```
BankAccount bc = new BankAccount();
System.out.println(bc.getBalance()); // 0.0

Class clz = bc.getClass();
// get the private field
Field f = clz.getDeclaredField( name: "balance");
// make the private field accessible
f.setAccessible(true);
// set the balance
f.set(bc, 1000);
System.out.println(bc.getBalance()); // 1000.0
```

Getting Class Methods

An array of `Class` objects that identify the method's formal parameter types, in declared order (e.g., `int.class`)

`Method getMethod(name, Class...)`	get public method
`Method getDeclaredMethod(name, Class...)`	get method
`Method[] getMethods()`	get all public methods
`Method[] getDeclaredMethods()`	get all methods (excludes inherited methods)

This includes public, protected, default access, and even private methods, but excludes inherited ones.

The Method Class

int	**getModifiers**() Returns the Java language **modifiers** for t
String	**getName**() Returns the name of the method represen
Annotation[][]	**getParameterAnnotations**() Returns an array of arrays of Annotations of the Executable represented by this obj
int	**getParameterCount**() Returns the number of formal parameters executable represented by this object.
Class<?>[]	**getParameterTypes**() Returns an array of Class objects that rep represented by this object.
Class<?>	**getReturnType**() Returns a Class object that represents th

- A Method provides information about, and access to, a single method on a class or interface.
- The reflected method may be a class method or an instance method (including an abstract method).

Invoking Methods using Reflection

- Invokes the underlying method represented by this `Method` object, on the specified object with the specified parameters.

```
public Object invoke(Object obj,
                     Object... args)
              throws IllegalAccessException,
                     IllegalArgumentException,
                     InvocationTargetException
```

```
String s = "Hello Java";
Method m = String.class.getMethod("substring", int.class);
System.out.println(m.invoke(s,6));
```

What's the output?

Invoking Methods using Reflection

- Invokes the underlying method represented by this `Method` object, on the specified object with the specified parameters.

```
public Object invoke(Object obj,
                     Object... args)
              throws IllegalAccessException,
                     IllegalArgumentException,
                     InvocationTargetException
```

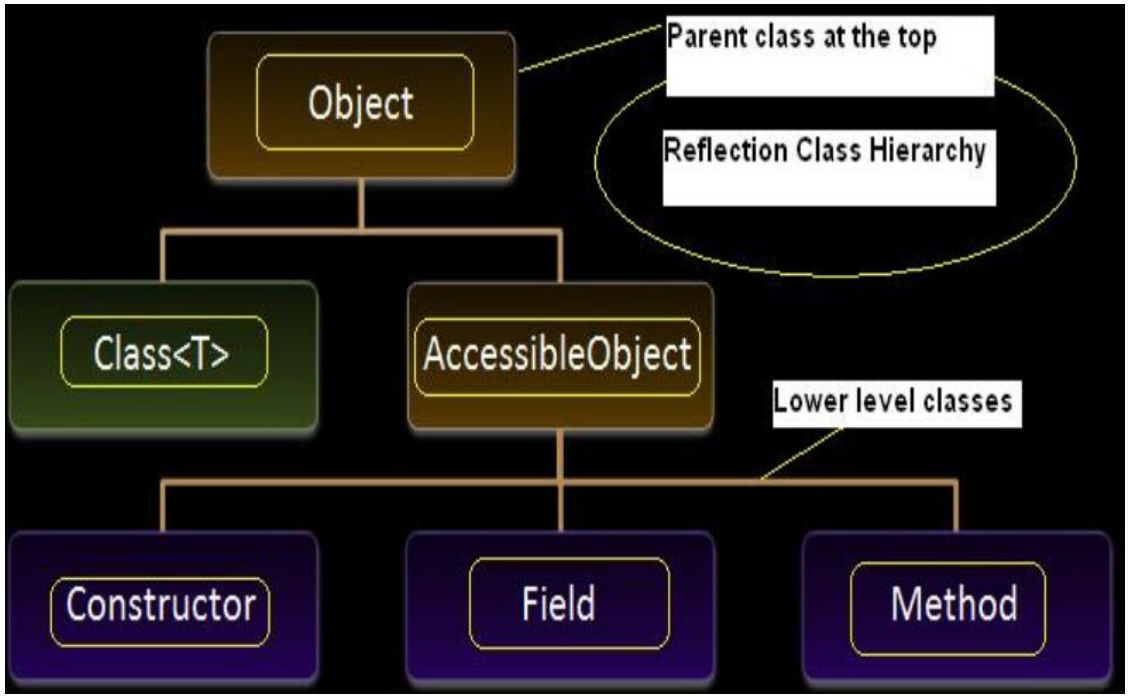
```
Method m2 = Integer.class.getMethod("parseInt", String.class);
System.out.println(m2.invoke(null, "12345").getClass().getName());
```

Why null?

Method Accessibility

- By default, not all reflected methods are accessible. This means that the JVM enforces access control checks when invoking them.
- For instance, if we try to call a `private` method outside its defining class or a `protected` method from outside a subclass or its class's package, we'll get an `IllegalAccessException`
- By calling `setAccesible(true)` on a reflected method object, the JVM suppresses the access control checks and allows us to invoke the method without throwing an exception

AccessibleObject



- The `AccessibleObject` class is the base class for `Field`, `Method`, and `Constructor` objects (known as reflected objects)
- It provides features to check access and suppress access checks

boolean	**canAccess**(**Object** obj)
void	**setAccessible**(boolean flag)
static void	**setAccessible** (**AccessibleObject**[] array, boolean flag)
boolean	**trySetAccessible**()

https://docs.oracle.com/javase/9/docs/api/java/lang/reflect/AccessibleObject.html

Object Instantiation using Reflection

- Using `newInstance()`
  - Creates a new instance of the class represented by this Class object.
  - The class is instantiated as if by a `new` expression with an empty argument list.

```
public T newInstance()
                throws InstantiationException,
                       IllegalAccessException
```

```
Class cls = Student.class;
Student s = (Student) cls.newInstance();
```

Deprecated

Object Instantiation using Reflection

- Use `getConstructor(Class<?>...)`
  - Returns a Constructor object that reflects the specified public constructor of the class represented by this Class object
  - Could specify formal parameters of constructors

```
Class clz = Student.class;
Constructor constructor = clz.getConstructor(String.class, int.class);
Student std = (Student) constructor.newInstance("Alice", 15);
```

Inspecting Class Inheritance with Reflection

```
Class ac = ArrayList.class;
Class sc = ac.getSuperclass();
System.out.println(sc);
System.out.println("-----");
Class[] ai = ac.getInterfaces();
for (Class i : ai) {
    System.out.println(i);
}
```

```
class java.util.AbstractList
-----
interface java.util.List
interface java.util.RandomAccess
interface java.lang.Cloneable
interface java.io.Serializable
```

Real Usages of Reflection

- **JUnit testing**:
  - Previous Junit processor was using reflection to iterate over all methods in test classes, and find-out methods starting with *test* and run them as testcases.
  - We may need to set private fields or invoke private methods for testing purpose

- **Spring framework:**
  - Dependency injection (DI) heavily uses reflection
  - Identify dependencies (e.g., parameter types for constructors)
  - Create instances of classes at runtime and inject the instances to other objects

Problems of Reflection

- **Risky:** you could set private final fields and invoke private methods
- **You lose compile-time type safety** - it's helpful to have the compiler verify that a method is available at compile time. If you are using reflection, you'll get an error at runtime which might affect end users if you don't test well enough. Even if you do catch the error, it will be more difficult to debug.
- **It causes bugs when refactoring** - if you are accessing a member based on its name (e.g. using a hard-coded string) then this won't get changed by most code refactoring tools and you'll instantly have a bug, which might be quite hard to track down.
- **Performance is slower** - reflection at runtime is going to be slower than statically compiled method calls/variable lookups. If you're only doing reflection occasionally then it won't matter, but this can become a performance bottleneck in cases where you are making calls via reflection thousands or millions of times per second.

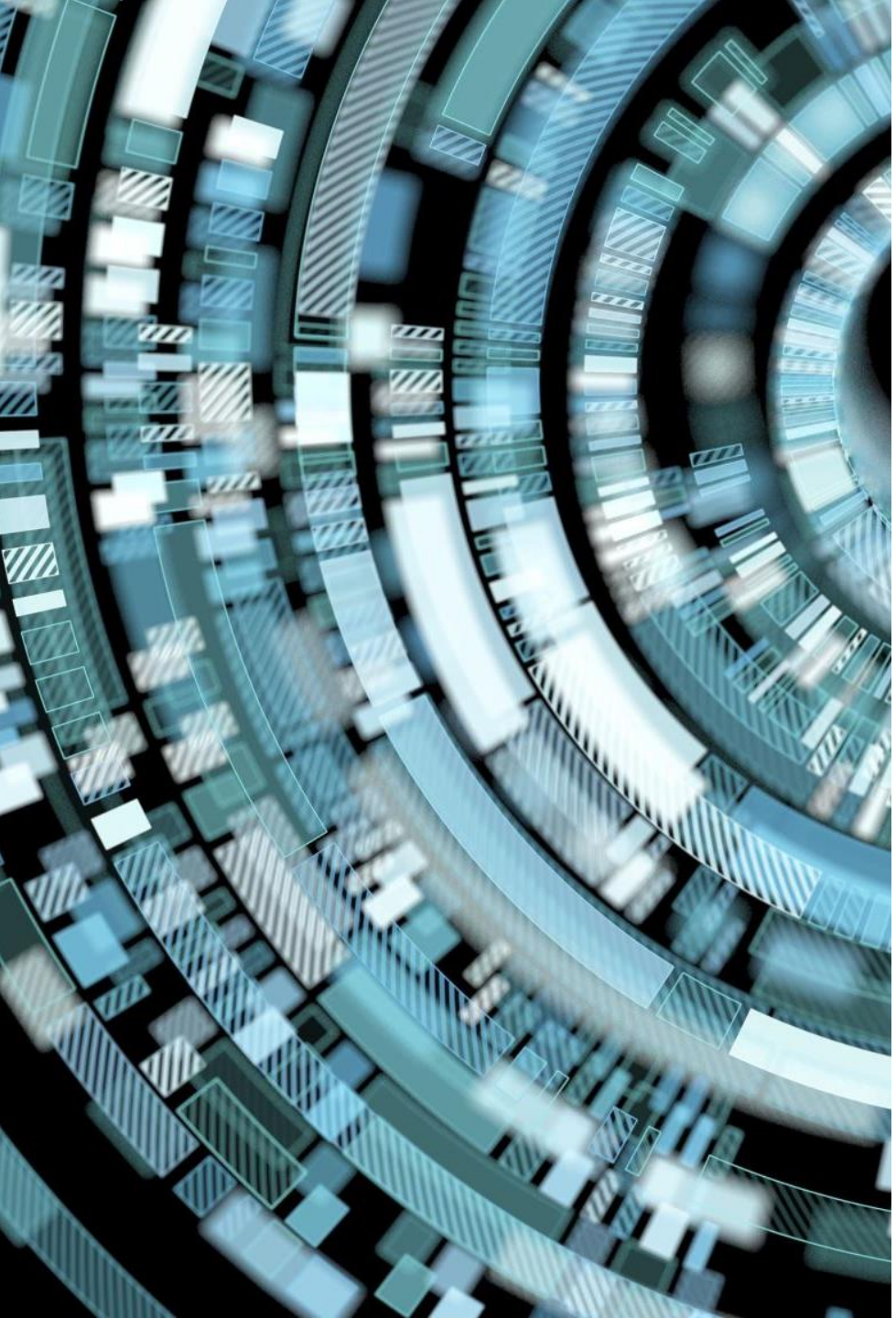
https://softwareengineering.stackexchange.com/a/101217/21021

Using Reflection?

If you could do something without reflection, stick to that.

Normal code is simpler, cleaner, and more readable, with compiler type safety and optimization

WITH
GREAT POWER
COMES
GREAT
RESPONSIBILITY



Lecture 10

- Reflection
- Annotation

Java Annotation Overview

- Java annotations start with '@'
- Java annotations are metadata (data about data) attached to program entities such as classes, interfaces, fields and methods
- Java annotations leave the semantics of a program unchanged (i.e., annotations do not change the action or execution of a compiled program)
- We cannot consider annotations (注解) as pure comments (注释) as they can change the way a compiler or runtime treats a program

Java Annotation Overview

- Java annotations are typically used for providing the following extra information:
  - **Compiler instructions**: The compiler can use annotations to catch errors or suppress warnings.
  - **Build-time instructions**: Build tools may scan Java code for specific annotations and generate source code or other files (e.g., XML) based on these annotations
  - **Runtime instructions**: Some annotations are available to be examined (by reflection) at runtime.

Compiling vs Building

The "Build" is a process that covers all the steps required to create a "deliverable" of your software. In the Java world, this typically includes:

1. Generating sources (sometimes).
2. Compiling sources.
3. Compiling test sources.
4. Executing tests (unit tests, integration tests, etc).
5. Packaging (into jar, war, ejb-jar, ear).
6. Running health checks (static analyzers like Checkstyle, Findbugs, PMD, test coverage, etc).
7. Generating reports.

So as you can see, compiling is only a (small) part of the build (and the best practice is to fully automate all the steps with tools like Maven or Ant and to run the build continuously which is known as Continuous Integration).

https://stackoverflow.com/a/2650423/636398

Annotation Categories

- **Predefined annotations**

①
  - Built-in annotation: annotation types used by the Java language
  - Meta-annotation: annotations that apply to other annotations

③

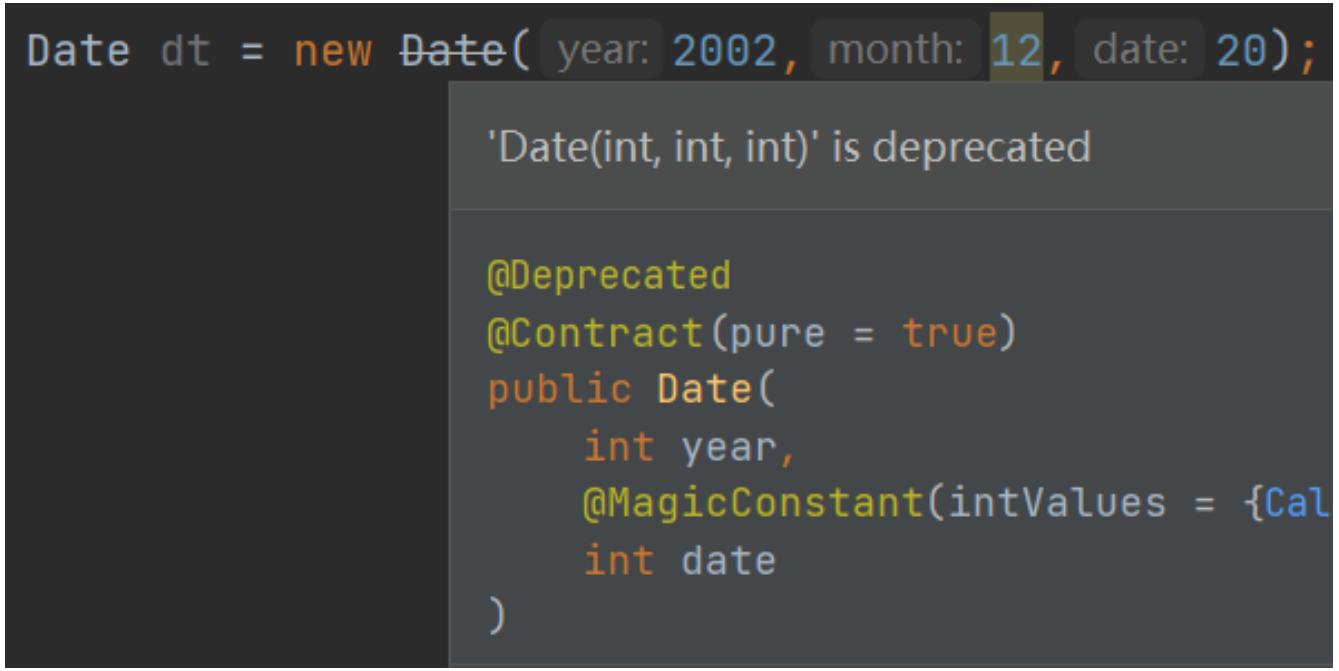
② - **Custom annotations**

Built-in Annotations

Annotation types defined in `java.lang`

- `@Deprecated`
- `@Override`
- `@SuppressWarnings`
- `@FunctionalInterface`
- `@SafeVarargs`

@Deprecated



- This annotation indicates the element (class, method, field, etc.) is deprecated and should no longer be used
- The compiler generates a warning whenever a program uses a method, class, or field with the `@Deprecated` annotation

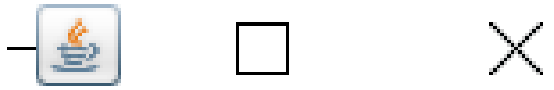
@Override

- This annotation informs the compiler that a method is meant to override a method declared in a superclass
- While it is not mandatory to use this annotation when overriding a method, it helps to prevent errors.
- If a method marked with @Override fails to correctly override a method of its superclass (e.g., wrong parameter type), the compiler generates an error.

Example of using @Override

- The code compiles and runs, but the close button won't work

```
import java.awt.*;
import java.awt.event.*;
public class AnnotationOverrideDemo extends Frame {
   public AnnotationOverrideDemo() {
      this.addWindowListener(new WindowAdapter() {
         public void windowclosing(WindowEvent e) {
            System.exit(0);
         }
      });
      setSize(200, 100);
      setTitle("Annotation Override Demo");
      setVisible(true);
   }
   public static void main(String[] args) { new AnnotationOverrideDemo(); }
}
```

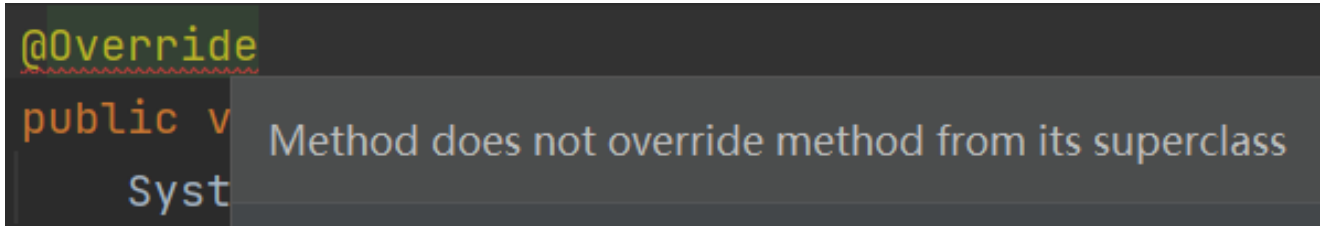


Example: https://www3.ntu.edu.sg/home/ehchua/programming/java/Annotation.html

Example of using @Override

- Add annotation @Override to the `windowClosing()`, which signals your intention, serves as documentation, and allows the compiler to catch this error.

```
@Override
public void windowclosing(WindowEvent e) {
   System.exit(0);
}
```



Should be windowClosing

Example: https://www3.ntu.edu.sg/home/ehchua/programming/java/Annotation.html

@SuppressWarnings

- This annotation tells the compiler to suppress specific warnings that it would otherwise generate
- Every compiler warning belongs to a category. The Java Language Specification lists two categories: `deprecation` and `unchecked`. The `unchecked` warning can occur when interfacing with legacy code written before the advent of generics.
- To suppress multiple categories of warnings, use:

```
@SuppressWarnings({"unchecked", "deprecation"})
```

@SuppressWarnings

```
public class SuppressWarningsTest {

    public static void addSth(List list){
        list.add("Test");

    }
    public stat
        List li
    }
}
```

Unchecked call to 'add(E)' as a member of raw type 'java.util.List'

Try to generify 'SuppressWarningsTest.java' Alt+Shift+Enter

```
@Contract(value = "_->true", mutates = "this")
public abstract boolean add(
    E e
```

```
public class SuppressWarningsTest {

    @SuppressWarnings("unchecked")
    public static void addSth(List list){
        list.add("Test");

    }
    public static void main(String[] args) {
        List list = new ArrayList<>();
    }
}
```

@SafeVarargs

- varargs: a method has parameter(s) of variable length
- Compiler gives the warning about unsafe usage
- If we are sure that our actions are safe, we could use the `@SafeVarargs` annotation to suppress this warning

```
public class SafeVarargsDemo {
    public static void main(String[] args) {
        display( ...array: "10", 20, 30.00);
    }

    public static <T> void display(T... array){
        for(T arg: array){
            System.out.print
        }
    }
}
```

Possible heap pollution from parameterized

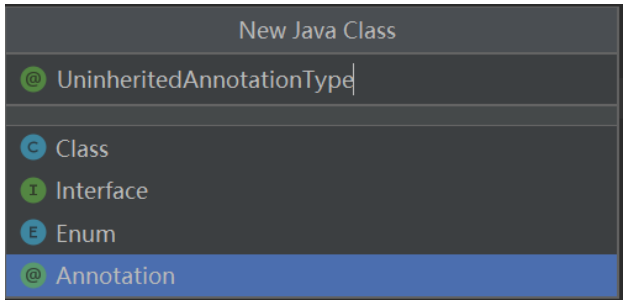
Annotate as '@SafeVarargs' Alt+Shift+Enter

```
public static <T> void display(
    @NotNull T... array
```

```
public class SafeVarargsDemo {
    public static void main(String[] args) {
        display( ...array: "10", 20, 30.00);
    }

    @SafeVarargs
    public static <T> void display(T... array){
        for(T arg: array){
            System.out.println(arg.getClass().getName());
        }
    }
}
```

Custom Annotations



- It is also possible to create your own custom annotations.
- An annotation type class implicitly extends the marker interface `java.lang.annotation.Annotation`
- The `@interface` keyword is used to declare a new annotation type
- Annotation type declarations are similar to normal interface declarations

Custom Annotations

Meta-annotations go here

```
[Access Specifier] @interface<AnnotationName> {
  DataType <Method Name>() [default value];
}
```

- Annotations can be created by using **@interface** followed by the annotation name.
- The annotation can have elements that look like methods but they do not have an implementation.
- The default value is optional. The parameters cannot have a null value.
- The return type (DataType) of the method can be primitive, enum, string, class name or array of these types.

https://www.programiz.com/java-programming/annotation-types

Example

https://docs.oracle.com/javase/tutorial/java/annotations/declaring.html

Many annotations replace comments in code.

Suppose that a software group traditionally starts the body of every class with comments providing important information:

```
public class Generation3List extends Generation2List {

   // Author: John Doe
   // Date: 3/17/2002
   // Current revision: 6
   // Last modified: 4/12/2004
   // By: Jane Doe
   // Reviewers: Alice, Bill, Cindy

   // class code goes here

}
```

Example

https://docs.oracle.com/javase/tutorial/java/annotations/declaring.html

To add this same metadata with an annotation, you must first define the *annotation type*. The syntax for doing this is:

```
@interface ClassPreamble {
   String author();
   String date();
   int currentRevision() default 1;
   String lastModified() default "N/A";
   String lastModifiedBy() default "N/A";
   // Note use of array
   String[] reviewers();
}
```

```
[Access Specifier] @interface<AnnotationName> {
  DataType <Method Name>() [default value];
}
```

The annotation type definition looks similar to an interface definition where the keyword `interface` is preceded by the at sign (`@`) (@ = AT, as in annotation type). Annotation types are a form of *interface*, which will be covered in a later lesson. For the moment, you do not need to understand interfaces.

Example

https://docs.oracle.com/javase/tutorial/java/annotations/declaring.html

After defining the **`ClassPreamble`** annotation, you can use it with the values filled in, which is:

- More organized and a fixed, consistent format
- Easy to be included in automatically generated Javadoc

```
public class Generation3List extends Generation2List {

   // Author: John Doe
   // Date: 3/17/2002
   // Current revision: 6
   // Last modified: 4/12/2004
   // By: Jane Doe
   // Reviewers: Alice, Bill, Cindy

   // class code goes here

}
```

```
@ClassPreamble (
   author = "John Doe",
   date = "3/17/2002",
   currentRevision = 6,
   lastModified = "4/12/2004",
   lastModifiedBy = "Jane Doe",
   // Note array notation
   reviewers = {"Alice", "Bob", "Cindy"}
)
public class Generation3List extends Generation2List {

// class code goes here

}
```

Meta-annotations

- Annotations that apply to other annotations are called meta-annotations.
- There are several meta-annotation types defined in `java.lang.annotation`.
  - `@Target`
  - `@Retention`
  - `@Documented`
  - `@Inherited`
  - `@Repeatable`

@Target

- This annotation marks another annotation to restrict what kind of Java elements the annotation can be applied to.
  - ElementType.ANNOTATION_TYPE can be applied to an annotation type.
  - ElementType.CONSTRUCTOR can be applied to a constructor.
  - ElementType.FIELD can be applied to a field or property.
  - ElementType.LOCAL_VARIABLE can be applied to a local variable.
  - ElementType.METHOD can be applied to a method-level annotation.
  - ElementType.PACKAGE can be applied to a package declaration.
  - ElementType.PARAMETER can be applied to the parameters of a method.
  - ElementType.TYPE can be applied to any element of a class.

@Target

- This annotation marks another annotation to restrict what kind of Java elements the annotation can be applied to.

```java
@Target(ElementType.METHOD)
@Retention(RetentionPolicy.SOURCE)
public @interface Override {
}
```

```java
@Documented
@Retention(RetentionPolicy.RUNTIME)
@Target(ElementType.TYPE)
public @interface FunctionalInterface {}
```

```java
@Documented
@Retention(RetentionPolicy.RUNTIME)
@Target({ElementType.CONSTRUCTOR, ElementType.METHOD})
public @interface SafeVarargs {}
```

@Retention

- This annotation specifies how an annotation is stored (at which level it is available)
- Syntax: `@Retention(RetentionPolicy)`
- 3 types of RententionPolicy
  - `RetentionPolicy.SOURCE` – The marked annotation is retained only in the source level and is ignored by the compiler (do not exist in .class files).
  - `RetentionPolicy.CLASS` – The marked annotation is retained by the compiler at compile time, but is ignored by JVM (recorded in the .class file but are discarded during runtime)
  - `RetentionPolicy.RUNTIME` – The marked annotation is retained by the JVM so it can be accessed by the runtime environment.

RetentionPolicy.SOURCE

The marked annotation is retained only in the source level and is ignored by the compiler (do not exist in .class files).

```java
@Target(ElementType.METHOD)
@Retention(RetentionPolicy.SOURCE)
public @interface Override {
}
```

```java
@Target({TYPE, FIELD, METHOD, PARAMETER,
@Retention(RetentionPolicy.SOURCE)
public @interface SuppressWarnings {
```

RetentionPolicy.CLASS

- The marked annotation is retained by the compiler at compile time, but is ignored by JVM
- The compiler keeps the annotations in the .class files, however they are not loaded by the ClassLoader when running a program.
- Useful for bytecode manipulation/processing tools (without interfering with runtime behaviors)

RetentionPolicy.RUNTIME

```java
@Target(ElementType.FIELD)
@Retention(RetentionPolicy.RUNTIME)
public @interface Range {
    int min() default 0;
    int max() default 255;
}
```

RUNTIME policy signals to the Java compiler and JVM that the annotation should be available via reflection at runtime.

```java
public class Person {
    @Range(min=3, max=20)
    public String name;

    @Range(max=10)
    public String city;

    @Range(min=1, max=100)
    public int age;

    public Person(String name, String city, int age) {
        this.name = name;
        this.city = city;
        this.age = age;
    }
}
```

Example adapted from
https://www.liaoxuefeng.com/wiki/1252599548343744/1265102026065728

RetentionPolicy.RUNTIME

```java
public static void check(Person person) throws IllegalAccessException {
    // go through each field
    for(Field field: person.getClass().getFields()){
        // get the @Range annotation of the field
        Range range = field.getAnnotation(Range.class);
        // if there is a @Range annotation
        if (range != null){
            // get the value of the field
            Object value = field.get(person);
            if (value instanceof String){
                String s = (String) value;
                if (s.length() < range.min() || s.length() > range.max()){
                    throw new IllegalArgumentException("Invalid range " +
                            "of string field: " + field.getName());
                }
            }
            else{
                int i = (int) value;
                if (i < range.min() || i > range.max()){
                    throw new IllegalArgumentException("Invalid range of " +
                            "int field: " + field.getName());
                }
            }
        }
    }
}
```

RetentionPolicy.RUNTIME

```
Person p1 = new Person( name: "Alice",  city: "Beijing",  age: 20);
Person p2 = new Person( name: "a",  city: "Beijing",  age: 20);
Person p3 = new Person( name: "Alice",  city: "The city name is Beijing",  age: 20);
Person p4 = new Person( name: "Alice",  city: "Shenzhen",  age: 200);

check(p1);  OK
check(p2);  java.lang.IllegalArgumentException: Invalid range of string field: name
check(p3);  java.lang.IllegalArgumentException: Invalid range of string field: city
check(p4);  java.lang.IllegalArgumentException: Invalid range of int field: age
```

What if we use SOURCE or CLASS retention policy for @Range?

@Inherited

- `@Inherited` annotation indicates that the annotation type can be inherited from the super class
- Subclasses of annotated classes are considered having the same annotation as their superclass.

```java
@Inherited
@Target(ElementType.TYPE)
@Retention(RetentionPolicy.RUNTIME)
@interface InheritAnnotation{

}
```

```java
@Target(ElementType.TYPE)
@Retention(RetentionPolicy.RUNTIME)
@interface UninheritAnnotation{

}
```

```java
@UninheritAnnotation
class A{

}

@InheritAnnotation
class B extends A{

}

class C extends B{

}
```

```java
System.out.println(new A().getClass().isAnnotationPresent(InheritAnnotation.class));
System.out.println(new B().getClass().isAnnotationPresent(InheritAnnotation.class));
System.out.println(new C().getClass().isAnnotationPresent(InheritAnnotation.class));

System.out.println(new A().getClass().isAnnotationPresent(UninheritAnnotation.class));
System.out.println(new B().getClass().isAnnotationPresent(UninheritAnnotation.class));
System.out.println(new C().getClass().isAnnotationPresent(UninheritAnnotation.class));
```

```
false
true
true

true
false
false
```

Other meta-annotations

- `@Documented` indicates that annotations with a type are to be documented by javadoc and similar tools by default.

- `@Repeatable` indicates that the marked annotation can be applied more than once to the same declaration or type use. See https://docs.oracle.com/javase/tutorial/java/annotations/repeating.html for more info.

Next Lecture

- Java EE