java.lang.reflect.*

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1. Introduction to Reflection

JavaSpecialists

1.1. Welcome

Who Am I?

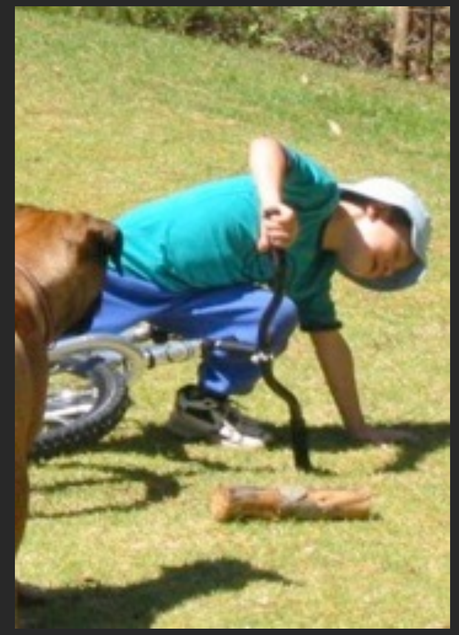
- **Dr Heinz Kabutz**
  - Born in Cape Town, South Africa, now lives on Crete
    - Founder of JCrete - See https://www.jcrete.org
  - Created The Java Specialists' Newsletter
    - https://www.javaspecialists.eu/archive/
  - One of the first Java Champions
    - http://javachampions.org

Questions

- **There are some stupid questions**
  - They are the ones we did not ask
  - Once asked, they are no longer stupid
- **The more you ask, the more we all learn**
  - And the more fun we will have today
- **We can ask questions in the group chat**
  - Let's try it now to make sure that it works for you
    - How warm is it where you are at the moment? In C or F

Exercises

- **We learn cycling by "falling"**
  - Listening to lectures is not enough
- **Exercises help us to try out the ideas ourselves**
  - We have a git repository for this course
    - My work will be in the "kabutz" branch
    - Please don't push to master :-)



JavaSpecialists

1.2. Why learn reflection?

1.2. Why learn reflection?

- **Reflection is like Opium**
  - A bit too strong for every day use
  - But can relieve serious pain
  - Please do not become a Reflection Addict!

Reflection Introduction

- **We can discover what class an object is**
- **Once we know, we can**
  - call methods
  - read and write fields
  - construct new instances

Usefulness of Reflection

- **Frameworks**
  - A lot of the magic behind the scenes happens with reflection
  - Dependency injection, data serialization, dynamic configuration
- **Serialization**
  - ObjectOutputStream.writeObject() uses reflection extensively
- **A little bit of code can do a lot**

Dangers of Reflection

- **Reflection can make code harder to understand**
  - No longer WYSIWYG (what you see is what you get)
- **Static code tools do not work anymore**

Popular interview question:
"*Do you know reflection?*"

"*Yes, I do. You can use it to modify private final fields and call methods dynamically.*"

"*This interview is over. Thanks for applying and good luck for your future.*"

JavaSpecialists

1.3. Class Class

1.3. Class Class

- **Each object in Java knows its class**
  - We can find out what it is with Object.getClass()
    - Note: we call the variable "clazz" because "class" is a keyword
      - Alternative typical names are cls and klass
  - getClass() returns the actual object type, not the declaration

```
Collection<String> list = new ArrayList<>();
var clazz = list.getClass();
System.out.println("clazz = " + clazz);
```

```
clazz = class java.util.ArrayList
```

Who has a Class?

- **Every type in Java has a representative Class**
  - Even primitive types, interfaces, enums, annotations!
  - Instead of getClass(), we can use .class

```
System.out.println(Collection.class);
System.out.println(int.class);
System.out.println(Integer.class);
System.out.println(void.class);
System.out.println(Thread.State.class);
```

```
interface java.util.Collection
int
class java.lang.Integer
void
class java.lang.Thread$State
```

Differentiating between class types

- Class has lots of methods for figuring out the type

```
isAnnotation()      // @Override
isAnonymousClass() // (new Object() {}).getClass()
isArray()           // char[]
isEnum()            // Thread.State
isHidden()          // Hidden classes Java 15+
isInterface()       // Collection.class
isLocalClass()      // Class defined inside a method
isMemberClass()     // Nested or inner class
isPrimitive()       // int.class
isRecord()          // record Person(String name) {}
isSealed()          // Executable.class
isSynthetic()       // lambdas and method references
Proxy.isProxyClass(Class<?> cl) // Dynamic Proxies
```

What is the type of Class?

- **Class is a generic class, defined as Class<T>**
  - Objects' generic type parameters are erased at compile time
    - All ArrayList objects share the same class in Java
  - int.class and Integer.class are both type Class<Integer>
    - But they are not the same object

```
Class<ArrayList> clazz1 = ArrayList.class; // raw type
Class<String> clazz2 = String.class;
Class<Integer> clazz3 = int.class;
Class<Integer> clazz4 = Integer.class;
Class<Void> clazz5 = void.class;
```

Name of Class

- **Class Class can return "name" of class**
  - getName()
    - Oldest method, with strange output for arrays (more later)
  - getSimpleName()
    - Java 5: strips away the package name
  - getCanonicalName()
    - Java 5: Full class name, better array output, null for anon types
  - getTypeName() <-- the one we should probably use
    - Java 8: Full class name, better array output, never null
  - getPackageName()
    - Java 9: package in which class resides; java.lang for primitives

Superclass and interfaces

- **Class gives us direct ancestor and interfaces**
  - Does not return inherited ancestor interfaces

```
interface A {}
interface B extends A {}
class C implements B {}
interface D {}
class E extends C implements D {}
System.out.println(
    Arrays.toString(E.class.getInterfaces())); // [D]
System.out.println(E.class.getSuperclass()); // C
System.out.println(C.class.getSuperclass()); // Object
System.out.println(Object.class.getSuperclass()); // null
System.out.println(A.class.getSuperclass()); // null
System.out.println(B.class.getSuperclass()); // null
```

What about Class.forName()?

- **Class.forName() has three forms:**
  - forName(String className)
    - Most simple, all that is needed is the full class name
  - forName(String name, boolean initialize, ClassLoader loader)
    - Most useful - we can avoid initializing until we need it and specify another class loader
  - forName(Module module, String name)
    - Java 9 support for modules
- **All forName() methods return a Class<?>**
  - Cast to the correct type using asSubClass(Class)

DemoClass

```
public class DemoClass implements Runnable {
    static {
        System.out.println("Initializing class");
    }

    public DemoClass() {
        System.out.println("DemoClass object");
    }

    public void run() {
        System.out.println("Running DemoClass");
    }
}
```

Using DemoClass with forName()

```
public class ClassForNameBasic {
    public static void main(String... args)
            throws ClassNotFoundException,
            InstantiationException,
            IllegalAccessException {
        System.out.println("1");
        Class<?> clazz = Class.forName(args[0]);
        System.out.println("2");
        Runnable demo = (Runnable) clazz.newInstance();
        System.out.println("3");
        demo.run();
    }
}

// java ClassForNameBasic DemoClass
```

```
1
Initializing class
2
DemoClass object
3
Running DemoClass
```

What was wrong with previous code?

- **A few things stand out:**
  - Too many checked exceptions hurt our eyes
  - Compiler warning when we cast to Runnable
  - Class initialized before we check it is the correct type
    - And we are perhaps using the wrong class loader
  - Class.newInstance() is deprecated

ReflectiveOperationException

- **ReflectiveOperationException has 7 subclasses**
  - ClassNotFoundException - Class.forName() did not resolve
  - IllegalAccessException - trying to access a private member
  - InstantiationException - trying to instantiate an abstract type
  - NoSuchFieldException - field by that name not found
  - NoSuchMethodException - method / constructor not found
  - InvocationTargetException - wrapper for another exception
- **Often better to throw ReflectiveOperationException**

Using ReflectiveOperationException

```
public class ClassForNameBetterException {
    public static void main(String... args)
            throws ReflectiveOperationException {
        System.out.println("1");
        Class<?> clazz = Class.forName(args[0]);
        System.out.println("2");
        Runnable demo = (Runnable) clazz.newInstance();
        System.out.println("3");
        demo.run();
    }
}
```

Getting rid of the unchecked cast

- **We usually know the super-type of Class.forName()**
  - Instead of casting directly, let's use asSubclass()
    - We pass in Class<U> and it returns Class<? extends U>
    - Type is checked in the asSubClass() call

```
Class<? extends Runnable> clazz =
        Class.forName(args[0])
                .asSubclass(Runnable.class);
Runnable demo = clazz.newInstance();
```

Class initialized before cast

- **Class.forName(String) calls all the static initializers**
  - This happens before asSubclass can check the type
  - Better is to load the class uninitialized
    - It will be initialized before we use it for the first time
- **By default loaded into the current class' class loader**
  - Better to use Thread.currentThread().getContextClassLoader()
    - Allows frameworks to inject different class loaders

Better way of loading unknown class

```
public class ClassForNameBetter {
  public static void main(String... args)
        throws ReflectiveOperationException {
    System.out.println("1");
    Class<?> clazz = Class.forName(args[0], false,
      Thread.currentThread().getContextClassLoader());
    Class<? extends Runnable> runnableClazz =
      clazz.asSubclass(Runnable.class);
    System.out.println("2");
    Runnable demo = runnableClazz.newInstance();
    System.out.println("3");
    demo.run();
  }
}
```

```
1
2
Initializing class
DemoClass object
3
Running DemoClass
```

Deprecation warning on newInstance()

- We will explain that in a bit

Exercise 1A:

- **Find all distinct interfaces implemented by an object**

```
public class LinkedList<E>
    extends AbstractSequentialList<E>
    implements List<E>, Deque<E>, Cloneable, Serializable
```

  - But recursively, LinkedList implements

```
Iterable<E>, Collection<E>, List<E>, Queue<E>,
Deque<E>, Cloneable, Serializable
```

JavaSpecialists

1.3.1. Method

1.3.1. Method

- **Class returns Method objects**
  - Class.getMethod(String name, Class<?>... parameterTypes)

```
public class MethodFromClass {
    public static void main(String... args)
            throws ReflectiveOperationException{
        Class<String> clazz = String.class;
        // Might throw NoSuchMethodException
        Method method = clazz.getMethod("toUpperCase");
        // Might throw exception
        String result =
            (String) method.invoke("Hello World!");
        System.out.println("result = " + result);
    }
}
```

```
result = HELLO WORLD!
```

Exceptions from getMethod() & invoke()

- **We face several ReflectionOperationExceptions:**
  - NoSuchMethodException: A method with that name and parameters was not found
  - InvocationTargetException: An exception (checked or unchecked) occurred when calling method. This wraps it.
  - IllegalAccessException: The method is not public we can't call it
    - Strange though - getMethod() only returns public methods!

NoSuchMethodException

- **ArrayDeque does not have method get(int)**

```
var clazz = ArrayDeque.class;
try {
    clazz.getMethod("get", int.class); // from List
} catch (NoSuchMethodException e) {
    System.out.println("Could not find method get(int)");
}
```

```
Could not find method get(int)
```

InvocationTargetException

- pop() might throw NoSuchElementException

```
var clazz = ArrayDeque.class;
Deque<Integer> deque = new ArrayDeque<>();
try {
    Method pop = clazz.getMethod("pop");
    pop.invoke(deque);
} catch (InvocationTargetException e) {
    System.out.println("pop() caused a " + e.getCause());
}
```

```
pop() caused a java.util.NoSuchElementException
```

IllegalAccessException

- **Why would this throw an IllegalAccessException?**
  - hasNext() is a public interface method

```
Deque<Integer> deque = new ArrayDeque<>();
Iterator<Integer> iterator = deque.iterator();
var hasNext = iterator.getClass().getMethod("hasNext");
try {
    System.out.println(hasNext.invoke(iterator));
} catch (IllegalAccessException e) {
    System.out.println("hasNext() is not accessible!");
}
```

```
hasNext() is not accessible!
```

Private nested classes

- **Methods in private nested classes aren't accessible**
  - getMethod() sometimes gives us these inaccessible methods
    - Solution in www.javaspecialists.eu/archive/Issue273.html
- **Better to call getMethod() on Iterator interface:**

```
Deque<Integer> deque = new ArrayDeque<>();
Iterator<Integer> iterator = deque.iterator();
var hasNext = Iterator.class.getMethod("hasNext");
try {
    System.out.println(hasNext.invoke(iterator));
} catch (IllegalAccessException e) {
    System.out.println("hasNext() is not public!");
}
```

```
false
```

Modifiers

- **Modifiers such as public / static / final are in a bitset**
  - e.g. public is 0b0001, private is 0b0010, protected 0b0100
- **Best to use them with java.lang.reflect.Modifier**
  - e.g. Modifier.isPublic(method.getModifiers())

isPublic	isPrivate	isProtected
isAbstract	isFinal	isStatic
isSynchronized	isVolatile	isTransient
isNative	isStrict	isInterface

Mystery of non-accessible hasNext()

- **Whilst hasNext() is public, the class is not**

```
Deque<Integer> deque = new ArrayDeque<>();
Iterator<Integer> iterator = deque.iterator();
var clazz = iterator.getClass();
var hasNext = clazz.getMethod("hasNext");
System.out.println("hasNext() public? " +
        Modifier.isPublic(hasNext.getModifiers())
);
System.out.println("Iterator class public? " +
        Modifier.isPublic(clazz.getModifiers())
);
```

```
hasNext() public? true
Iterator class public? false
```

Finding all methods

- **We can also get all methods with getMethods()**
  - It also shows inherited public methods
  - Methods are not ordered in any particular way

OutputStream.class.getMethods()

```
public void OutputStream.flush() throws IOException
public void OutputStream.write(byte[]) throws IOException
public void OutputStream.write(byte[],int,int) throws IOException
public abstract void OutputStream.write(int) throws IOException
public void OutputStream.close() throws IOException
public static OutputStream OutputStream.nullOutputStream()
public final void Object.wait(long,int) throws InterruptedException
public final void Object.wait() throws InterruptedException
public final native void Object.wait(long) throws InterruptedException
public boolean Object.equals(Object)
public String Object.toString()
public native int Object.hashCode()
public final native Class Object.getClass()
public final native void Object.notify()
public final native void Object.notifyAll()
```

Co-variant return types

- **Methods are distinguished by name and parameters**
  - A class can have identical methods with different return types
  - e.g. ArrayDeque.clone:

```
public java.util.ArrayDeque java.util.ArrayDeque.clone()
public java.lang.Object java.util.ArrayDeque.clone()
    throws java.lang.CloneNotSupportedException
```

  - ArrayDeque.class.getMethod("clone") returns correct method:

```
public java.util.ArrayDeque java.util.ArrayDeque.clone()
```

Methods with parameters

- **Adding items to a collection:**

```
List<String> names = new ArrayList<>();
Method add = List.class.getMethod("add", Object.class);
add.invoke(names, "John");
add.invoke(names, "Anton");
add.invoke(names, "Heinz");
System.out.println("names = " + names);
```

```
names = [John, Anton, Heinz]
```

Careful with varargs

- **This throws an IllegalStateException**
  - Assumed to be a null Object[] of parameters, thus no parameters

```
add.invoke(names, null);
```

  - Instead, we can cast null to Object, then it's a null parameter

```
add.invoke(names, (Object)null);
```

  - Or we can add the explicit Object[] creation

```
add.invoke(names, new Object[]{null});
```

Static methods

- We pass in "null" instead of the instance

```
List<String> strings = new ArrayList<>();
Collections.addAll(strings, args);
System.out.println(strings);
for (Method m : Collections.class.getMethods()) {
    if (m.getParameterCount() == 1
            && m.getReturnType() == void.class
            && m.getParameterTypes()[0] == List.class
    ) {
        System.out.println(m.getName());
        m.invoke(null, strings);
        System.out.println(strings);
    }
}
```

```
[3, 1, 4, 1, 5, 9]
reverse
[9, 5, 1, 4, 1, 3]
sort
[1, 1, 3, 4, 5, 9]
shuffle
[1, 1, 4, 3, 9, 5]
```

Parameter names

- **Java does not consider parameter names important**
  - Traditionally they were not stored in the class files
  - Only the parameter type and their order matter
  - This makes it tricky to introduce named and default parameters
- **Include names by compiling with -parameters flag**

Parameter names

```
public class ParameterNames {
    public void names(String hello, boolean world) {}
    public static void main(String... args)
            throws ReflectiveOperationException {
        Method names = ParameterNames.class.getMethod(
                "names", String.class, boolean.class);
        Arrays.stream(names.getParameters())
                .map(Parameter::getName)
                .forEach(System.out::println);
    }
}
```

```
// without -parameters javac flag:
arg0
arg1
// with -parameters javac flag:
hello
world
```

Exercise 1B:

- **Write a ListMangler for Collections methods sort(List), reverse(List), shuffle(List)**
  - Should return a new immutable list and not change input list
  - Find the method and call it on our copy of the input list
  - More instructions in the comments of the class

```
public class ListMangler {
    public static List<String> reorder(
            List<String> list, String methodName) {
        // TODO
    }
}
```

JavaSpecialists

1.3.2. Constructor

1.3.2. Constructor

- **Constructor is a special case of a method**
  - We do not specify a name, but do specify the parameter types
  - Even the exceptions are the same - NoSuchMethodException
- **Instead of calling invoke(), we call newInstance()**

```
private static final Collection<Integer> PI =
        List.of(3, 1, 4, 1, 5, 9, 265, 358);

public static void createCollection(String name)
        throws ReflectiveOperationException {
    Class<? extends Collection> clazz =
            Class.forName(name)
                    .asSubclass(Collection.class);
    System.out.println(clazz.getSimpleName());

    Constructor<? extends Collection> noArgs =
            clazz.getConstructor();
    System.out.println(noArgs.newInstance());

    Constructor<? extends Collection> copy =
            clazz.getConstructor(Collection.class);
    System.out.println(copy.newInstance(PI));
}
```

```
ArrayDeque
[]
[3, 1, 4, 1, 5, 9, 265, 358]
```

What about getConstructors()

- **Similar to getMethods()**
  - Constructors are differentiated only by parameter types
    - If we know the type we are looking for, just use getConstructor()
- **Unlike getMethods(), does not include superclasses**
- **Returns all the public constructors**

Defensive copies in reflection API

- **Mutable objects in reflection are returned as copies**
  - For example, Method.getParameterTypes() is an array
  - We can change these without affecting safety in other code

Class.newInstance()?

- Inside the bowels of this method we see

```
try {
    Class<?> caller = Reflection.getCallerClass();
    return getReflectionFactory().newInstance(
        tmpConstructor, null, caller);
} catch (InvocationTargetException e) {
    Unsafe.getUnsafe().throwException(e.getTargetException());
    // Not reached
    return null;
}
```

Class.newInstance() abuse

```
public class UncheckedThrower {
    private static final ThreadLocal<Throwable> throwable =
            new ThreadLocal<>();
    public UncheckedThrower() throws Throwable {
        Throwable t = throwable.get();
        throwable.remove();
        throw t;
    }
    @SuppressWarnings("deprecation")
    public static void uncheckedThrow(Throwable t) {
        throwable.set(t);
        try {
            UncheckedThrower.class.newInstance();
        } catch (ReflectiveOperationException ignored) {}
    }
}
```

Do not use deprecated newInstance()

- Instead, get the constructor, then call newInstance()

Exercise 1C: MagicClassInstantiator

- **Taking the following command line parameters:**
  - ClassName [Parameter1 ... ParameterN] MethodName
    - java.lang.String "Hello World" toUpperCase → HELLO WORLD
    - java.util.ArrayDeque poll → null
- **Write a MagicClassInstantiator that:**
  - Loads the class specified in ClassName
  - Finds the constructor taking correct number of String parameters
  - Constructs the object
  - Calls the method (with no parameters)
    - If the return type is not void, prints the result to the console

JavaSpecialists

1.3.3. Generics

1.3.3. Generics

- **Java strives to be backwards compatibility**
  - We can run most classes from Java 1.0 with Java 19
    - Do not even need to recompile the code
- **Generics were added in Java 5 with type erasure**
  - The generics are only a compile time construct
  - ArrayList<String> is exactly the same class as ArrayList<Integer>

```
ArrayList<String> strings = new ArrayList<>();
ArrayList<Integer> numbers = new ArrayList<>();
assertSame(strings.getClass(), numbers.getClass());
```

TypeVariable

- We can get generic type variables for elements

```
public class GenericsFieldDemo {
    public final List<String> strings = new ArrayList<>();
    public static void main(String... args)
            throws NoSuchFieldException {
        Field STRINGS = GenericsFieldDemo.class
                .getField("strings");
        Type type = STRINGS.getGenericType();
        System.out.println("Field type: " + type);
        var ptype = (ParameterizedType) type;
        for (Type arg : ptype.getActualTypeArguments()) {
            System.out.println("Actual argument: " + arg);
        }
    }
}
```

```
Field type: java.util.List<java.lang.String>
Actual argument: class java.lang.String
```

JavaSpecialists

1.4. Nested classes

1.4. Nested classes

- **We can discover nested classes Class.getClasses()**
  - But not local or anonymous classes
  - As before, only public classes are returned with getClasses()

```
public class SuperNestedClassDemo {
    public static class SuperNestedClass {}
}
public class NestedClassDemo extends SuperNestedClassDemo {
    public static class PublicStaticNestedClass {}
    public class PublicInnerClass {}
    class PackageAccessInnerClass {}
    private class PrivateInnerClass {}
    protected class ProtectedInnerClass {}
    public final Object anonInner = new Object() {};
    public static final Object anonNested = new Object() {};
    public static void main(String... args) {
        Object anonLocal = new Object() {};
        class Local {}
        Arrays.stream(NestedClassDemo.class.getClasses())
                .map(Class::getSimpleName)
                .forEach(System.out::println);
    }
}
```

```
PublicInnerClass
PublicStaticNestedClass
SuperNestedClass
```

1.5. Sealed classes

1.5. Sealed classes

- **Java 15 introduced sealed classes**
  - Limits who can subclass
  - Also allows us to discover all subclasses of a class via reflection

All permitted subclasses

- Returns only the most direct descendants

```
public class SealedClassExplorer {
    public static void showSubclasses(Class<?> clazz) {
        System.out.println("Subclasses of " + clazz);
        Arrays.stream(clazz.getPermittedSubclasses())
                .map(Class::getName)
                .forEach(System.out::println);
    }
}
```

Subclasses of Executable

- Returns only the most direct descendants

```
SealedClassExplorer.showSubclasses(Executable.class);
```

```
Subclasses of class java.lang.reflect.Executable
java.lang.reflect.Constructor
java.lang.reflect.Method
```

Subclasses of ConstantDesc

- Missing quite a few subclasses this time

```
SealedClassExplorer.showSubclasses(ConstantDesc.class);
```

```
Subclasses of interface java.lang.constant.ConstantDesc
java.lang.constant.ClassDesc
java.lang.constant.MethodHandleDesc
java.lang.constant.MethodTypeDesc
java.lang.Double
java.lang.constant.DynamicConstantDesc
java.lang.Float
java.lang.Integer
java.lang.Long
java.lang.String
```

Exercise 1D: Find *all* permitted classes

- **Implement the following class**
  - Needs to find *all* permitted subclasses

```
public class PermittedSubclassExplorer {
    /**
     * Return all permitted subclasses underneath a root
     * class or interface. The root must be a sealed type.
     *
     * @param root class to find permitted subtypes under
     * @return a set of all permitted subclasses
     * @throws IllegalArgumentException if root isn't sealed
     */
    public static Set<Class<?>> find(Class<?> root) {
        throw new UnsupportedOperationException("TODO");
    }
}
```

JavaSpecialists

1.6. Records

1.6. Records

- Java 16 records provide simplified data object
- e.g. Class PersonBean has fields and a constructor

```
public class PersonBean {
    private final String firstName;
    private final String lastName;
    private final int age;

    public PersonBean(String firstName, String lastName,
                      int age) {
        this.firstName = firstName;
        this.lastName = lastName;
        this.age = age;
    }
```

More plumbing

- An equals() and hashCode() methods

```
    public boolean equals(Object o) {
        return o instanceof PersonBean p
                && age == p.age
                && Objects.equals(firstName, p.firstName)
                && Objects.equals(lastName, p.lastName);
    }

    public int hashCode() {
        return Objects.hash(firstName, lastName, age);
    }
```

Standard methods ...

- Don't forget the toString() method

```
    public String toString() {
        return "PersonBean{" +
                "firstName='" + firstName + '\'' +
                ", lastName='" + lastName + '\'' +
                ", age=" + age +
                '}';
    }
```

And more ...

- Getters for all the fields

```
    public String getFirstName() {
        return firstName;
    }

    public String getLastName() {
        return lastName;
    }

    public int getAge() {
        return age;
    }
}
```

Plus more ...

- **And maybe the class also has to be Serializable**
  - With a SerialVersionUID

Records simplify this to

```
public record Person(String firstName,
                     String lastName,
                     int age) {}
```

RecordComponents

- We can also get all the record components

```
public static <T extends Record> void showRecordDetails(
        Class<T> clazz) throws NoSuchMethodException {
    System.out.println("record " + clazz.getSimpleName());
    Arrays.stream(clazz.getRecordComponents())
            .map(Object::toString)
            .map(s -> "\t" + s)
            .forEach(System.out::println);
}
```

```
record Person
      java.lang.String firstName
      java.lang.String lastName
      int age
```

We can find "canonical" constructor

- The RecordComponents are in the correct order

```
static <T extends Record>
Constructor<T> getCanonicalConstructor(Class<T> clazz)
        throws NoSuchMethodException {
    Class<?>[] paramTypes =
            Arrays.stream(clazz.getRecordComponents())
                    .map(RecordComponent::getType)
                    .toArray(Class<?>[]::new);
    return clazz.getDeclaredConstructor(paramTypes);
}
```

JavaBean convention

- **The JavaBean convention used getters and setters**
  - getFirstName(), getLastName(), getAge()
- **Booleans are prepended with "is"**
  - isMarried()
- **What if we have a property called "iPhone"?**
  - getIPhone()
    - But what if the actual property is called IMEI?
      - getIMEI()?
- **For records they moved away from this convention**

JavaBean Introspector

- **Old legacy approach to reading JavaBean properties**
  - Converts getXyz() and setXyz() to property xyz
    - Provides getter and setter methods that match property

```
BeanInfo bi = Introspector.getBeanInfo(PersonBean.class);
var beanClass = bi.getBeanDescriptor().getBeanClass();
System.out.println(beanClass.getSimpleName());
for (var propertyDesc : bi.getPropertyDescriptors()) {
    System.out.printf("%s -> %s()%n",
            propertyDesc.getName(),
            propertyDesc.getReadMethod().getName());
}
```

```
PersonBean
age -> getAge()
class -> getClass()
firstName -> getFirstName()
lastName -> getLastName()
```

Exercise 1E: Convert beans to records

- We need to convert between JavaBean and records

```
/**
 * Given the input bean, create a record instance of type
 * recordType with all properties set in the constructor.
 */
public static <T, R extends Record>
R convertBeanToRecord(T bean, Class<R> recordType) {}
/**
 * Given the input record, create a bean instance of type
 * beanType with all properties set using setters.
 */
public static <T extends Record, R>
R convertRecordToBean(T record, Class<R> beanType) {}
```

JavaSpecialists

2. Deep Reflection

2. Deep Reflection

- **Up to now, we have only used "shallow reflection"**
  - Shallow reflective access is access at runtime via the Core Reflection API (java.lang.reflect) without using setAccessible. Only public elements in exported packages can be accessed.
  - Deep reflective access is access at run time via the Core Reflection API, using the setAccessible method to break into non-public elements. Any element, whether public or not, in any package, whether exported or not, can be accessed. Deep reflective access implies shallow reflective access.
  - [Mark Reinhold on JSR 376 Expert Group mailing list]

In layman's terms

- **Shallow reflective access**
  - Only use public members, never violating encapsulation
- **Deep reflective access**
  - Use setAccessible(true) to also access non-public members

Use cases for "deep reflection"

- **Broken encapsulation mainly for accessing fields**
  - Fields are almost always private
- **Get hold of sun.misc.Unsafe**
- **Serialization and similar mechanisms**
- **Careful: concurrency semantics no longer apply**

JavaSpecialists

2.1. Making private members accessible

2.1. Making private members accessible

- Let's try create an object without calling constructor

```
public class Chatty {
    public Chatty() {
        System.out.println("Creating chatty object");
        System.out.println("Hi there!");
        System.out.println("You look great!");
        System.out.println("Have you been working out?");
    }

    public void run() {
        System.out.println("Chatty running");
    }
}
```

Chatty is annoying

- **Creepy friendly**

```
public class ChattyObjectDemo1 {
    public static void main(String... args) {
        Chatty chatty = new Chatty();
        chatty.run();
    }
}
```

```
Creating chatty object
Hi there!
You look great!
Have you been working out?
Chatty running
```

Reflection does not help

- We still hear the overly friendly dialogue

```
public class ChattyObjectDemo2 {
    public static void main(String... args)
            throws ReflectiveOperationException {
        var constructor = Chatty.class.getConstructor();
        Chatty chatty = constructor.newInstance();
        chatty.run();
    }
}
```

```
Creating chatty object
Hi there!
You look great!
Have you been working out?
Chatty running
```

Easiest to create object with Unsafe

- Let's try with Unsafe.allocateInstance(Class<?>)

```
import sun.misc.Unsafe;

public class ChattyObjectDemo3 {
    public static void main(String... args)
            throws InstantiationException {
        Chatty chatty = (Chatty) Unsafe.getUnsafe()
                .allocateInstance(Chatty.class);
        chatty.run();
    }
}
```

```
Exception in thread "main" java.lang.SecurityException: Unsafe
        at jdk.unsupported/sun.misc.Unsafe.getUnsafe(Unsafe.java:99)
        at reflection.ch2.ChattyObjectDemo3.main(ChattyObjectDemo3.java:8)
```

sun.misc.Unsafe only for trusted use

```
private static final Unsafe theUnsafe = new Unsafe();
/**
 * Provides the caller with the capability of performing
 * unsafe operations.
 *
 * @throws  SecurityException if the class loader of the
 *          caller class is not in the system domain in
 *          which all permissions are granted.
 */
@CallerSensitive
public static Unsafe getUnsafe() {
    Class<?> caller = Reflection.getCallerClass();
    if (!VM.isSystemDomainLoader(caller.getClassLoader()))
        throw new SecurityException("Unsafe");
    return theUnsafe;
}
```

How can we get theUnsafe instance?

- Let's first find the field with getDeclaredField(name)

```
Field field = Unsafe.class.getDeclaredField("theUnsafe");
```

- Next we make it accessible

```
field.setAccessible(true);
```

- Then we read the value

```
ourUnsafe = (Unsafe) field.get(null);
```

Let's create our own UnsafeProvider

```
public class UnsafeProvider {
    private static final Unsafe ourUnsafe;
    static {
        try {
            Field field = Unsafe.class.
                    getDeclaredField("theUnsafe");
            field.setAccessible(true);
            ourUnsafe = (Unsafe) field.get(null);
        } catch (ReflectiveOperationException e) {
            throw new ExceptionInInitializerError(e);
        }
    }
    public static Unsafe getUnsafe() {
        return ourUnsafe;
    }
}
```

Finally, blissful silence!

- **Can allocate instances without calling constructor**
  - No fields would be initialized either

```
public class ChattyObjectDemo4 {
    private static final Unsafe ourUnsafe =
            UnsafeProvider.getUnsafe();

    public static void main(String... args)
            throws InstantiationException {
        Chatty chatty = (Chatty) ourUnsafe
                .allocateInstance(Chatty.class);
        chatty.run();
    }
}
```

```
Chatty running
```

Fields, fields, fields, fields, fields, ...

- **Most common use case for deep reflection**
  - Even for our UnsafeProvider, we read the private theUnsafe field
- **Fields are usually private, and preferably final**
  - The purpose of private fields is for encapsulation
    - Makes it easier to reason about *who* is reading / writing them
  - The purpose of final fields is safety
    - Cannot be changed accidentally
    - State is exactly what we wanted when we constructed the object
    - Concurrency is way easier

Danger of reading / writing fields

- With encapsulated fields we can protect invariants

```
public class Person {
    private final String name;
    private final int age;

    public Person(String name, int age) {
        this.name = name;
        if (age < 0) throw new IllegalArgumentException();
        this.age = age;
    }

    public String toString() {
        return name +" is " + age + " years old";
    }
}
```

Constructor protects field

- **Cannot create a Person with negative age**

```
Person wally = new Person("Wally", -42);
System.out.println("wally = " + wally);
```

```
java.lang.IllegalArgumentException
        at reflection.ch2.Person.<init>(Person.java:11)
        at reflection.ch2.PersonDemo.main(PersonDemo.java:9)
```

But we can with reflection

- We change age, even though it is private and final

```
Person heinz = new Person("Heinz", 50);
System.out.println("heinz = " + heinz);
Field ageField = Person.class.getDeclaredField("age");
ageField.setAccessible(true);
ageField.set(heinz, -57);
System.out.println("heinz = " + heinz);
```

```
heinz = Heinz is 50 years old
heinz = Heinz is -57 years old
```

But isn't that dangerous?

- **Yes, it is very dangerous**
  - Final fields are assumed to be final, and can be inlined
    - Either at compile time or during execution
  - We should never change a final field after it is published
  - With setAccessible(true), we get rid of private **and** final
- **We cannot change static final fields**
  - A static field is assumed published when the class is loaded
    - It would thus always be unsafe to allow this to be changed
  - We *can* change a static final field with sun.misc.Unsafe
    - But it is highly recommended that we do not

Use case of writing private final fields

- **Serialization writes objects to a stream**
  - It reads the private fields, bypassing the security manager
- **When it reads them back from a stream**
  - It first creates the object, without calling the constructor
    - But calling its superclass constructor
      - sun.reflect.ReflectionFactory.newConstructorForSerialization()
  - It then writes the fields, whether they are private/final or not
- **The object is not published until all fields are written**

Imagine a badly written Animal class

- "legs" should definitely have been configurable

```
public class Animal {
    private final int legs = 4;
    private final String genus, species;

    public Animal(String genus, String species) {
        this.genus = genus;
        this.species = species;
    }
    public String toString() {
        return "Animal %s %s with %d legs".formatted(
                genus, species, legs);
    }
}
```

Trying to change legs with reflection

- **No exception, but it also seems to have no effect!**

```
public class AnimalDemo {
    public static void main(String... args)
            throws ReflectiveOperationException {
        Animal human = new Animal("homo", "sapiens");
        Field legs =
            Animal.class.getDeclaredField("legs");
        legs.setAccessible(true);
        legs.set(human, 2);
        System.out.println(human);
        System.out.println("legs = " + legs.get(human));
    }
}
```

```
Animal homo sapiens with 4 legs
legs = 2
```

Did the field value change or not?

- **Yes it did!**
  - However, javac inlined the value of "legs" to where it was used
  - Thus we do not see the change, except via reflection
- **Here is the decompiled Animal.class file:**

```
public String toString() {
    return "Animal %s %s with %d legs".formatted(
        this.genus, this.species, 4);
}
```

Reading and writing record properties

- We do not need deep reflection for reading records

```
PersonRecord heinz = new PersonRecord("Heinz", 50);

System.out.println("From accessors:");
for (RecordComponent component :
        PersonRecord.class.getRecordComponents()) {
    System.out.println(component.getName() + ": " +
            component.getAccessor().invoke(heinz));
}

System.out.println("From fields:");
for (Field field : PersonRecord.class.getDeclaredFields()) {
    field.setAccessible(true);
    System.out.println(field.getName() + ": " +
            field.get(heinz));
}
```

```
From accessors:
name: Heinz
age: 50
From fields:
name: Heinz
age: 50
```

"Final" is enforced for record

- We cannot write to fields, even with deep reflection

```
try {
    PersonRecord heinz = new PersonRecord("Heinz", 50);
    System.out.println("heinz = " + heinz);
    var age = PersonRecord.class.getDeclaredField("age");
    age.setAccessible(true);
    age.set(heinz, -57); // does not work for records
    System.out.println("heinz = " + heinz);
} catch (ReflectiveOperationException e) {
    System.out.println(e);
}
```

```
heinz = Heinz is 50 years old
java.lang.IllegalAccessException: Can not set final
    int field PersonRecord.age to java.lang.Integer
```

Private members in other modules

- Let's change the Integer cache

```
public class IntegerHack {
    public static void main(String... args)
            throws ReflectiveOperationException {
        Field value = Integer.class
                .getDeclaredField("value");
        value.setAccessible(true);
        value.set(42, 43);
        for (int i = 1; i <= 10; i++) {
            System.out.printf("%d x 7 = %d%n",
                    i, i * 7);
        }
    }
}
```

Java 8 result

- Works exactly as expected

```
Java 8:
1 x 7 = 7
2 x 7 = 14
3 x 7 = 21
4 x 7 = 28
5 x 7 = 35
6 x 7 = 43
7 x 7 = 49
8 x 7 = 56
9 x 7 = 63
10 x 7 = 70
```

Java 11 result

- Warns us that we should fix the code

```
Java 11:
WARNING: An illegal reflective access operation has occurred
WARNING: Illegal reflective access by IntegerHack
WARNING: Please consider reporting this to the maintainers of
         IntegerHack
1 x 7 = 7
2 x 7 = 14
3 x 7 = 21
4 x 7 = 28
5 x 7 = 35
6 x 7 = 43
7 x 7 = 49
8 x 7 = 56
9 x 7 = 63
10 x 7 = 70
```

Java 17 result

- **Crashes with an InaccessibleObjectException**

```
Java 17:
Exception in thread "main" InaccessibleObjectException: Unable
     to make field private final int java.lang.Integer.value
     accessible: module java.base does not "opens java.lang"
     to unnamed module @4dca0ecd
```

- **We can run the code with the JVM parameter**

```
--add-opens java.base/java.lang=ALL-UNNAMED
```

  - (Instead of ALL-UNNAMED, use module name if using JPMS)

getDeclaredXyz() vs getXyz()

- **Classes can have several members**
  - Annotations, nested classes, constructors, fields and methods
  - The get() methods would only return public members
    - Includes all public members of similar type from superclasses
    - Note that "public" does not meant that method is accessible
      - We saw before that a class itself can be inaccessible
  - The getDeclared() methods return all members of that class only
    - Includes private, protected, package access and public members
    - But only from the current class, not from superclasses

Exercise 2A:

- **Make System.out.println("Hello World") print out "Goodbye, cruel world" by using deep reflection on java.lang.String**
  - Run with JVM option

```
--add-opens java.base/java.lang=ALL-UNNAMED
```

Exercise 2B:

- **Return all the methods of a class, including private, protected, package private methods:**

```
/**
 * Returns a set of all the methods defined on clazz and
 * its superclasses, including private, protected,
 * public, and package private methods.
 *
 * @param includeObjectMethods true if the Set should
 *                             include Object's methods
 */
public static Set<Method> findAllMethods(
        Class<?> clazz, boolean includeObjectMethods) { }
```

JavaSpecialists

2.2. Performance considerations

2.2. Performance considerations

- **Reflection used to be quite slow**
  - But nowadays, with escape analysis and inlining, it is not too bad
  - There might be a small method call overhead from allocation
    - Boxing of parameters
    - Vararg array and boxed return values with dynamic proxies
      - See our Dynamic Proxies in Java Course
    - Extra wrapping of exceptions
  - Additional costs from security checks
    - May happen every time we call the method
    - Can turn off by calling setAccessible(true), even on public methods
  - Actual method invocation speed is the same as calling it directly

Counter class

```
public class Counter {
    private long total;
    public void reset() {
        total = 0;
    }
    public void add(int value) {
        total += value;
    }
    public long get() {
        return total;
    }
    public void thrower() {
        throw new IllegalStateException();
    }
}
```

Boxing of parameters

- **Primitive wrappers for long/int/short/byte cached**
  - At least values -128 to 127 have to be cached
  - Outside of that range, wrapper objects might be created
- **Return types cast to primitives do not allocate bytes**

Extra InvocationTargetExcepton cost

- **Every exception has a stack trace**
  - And then is wrapped again in an InvocationTargetException
    - Which also has a stack trace

Experiment

- **Calling add(int), get(), throwing() for 10 seconds**
  - Times in nanoseconds

	Direct	Method	Method Fast	MethodHandle
add(0..100)	5.5	8.4 16 bytes	7.9 16 bytes	5.6
add(200..1000)	5.7	8.1 16 bytes	7.6 16 bytes	5.7
get():42	3.7	4.4	3.7	3.7
get():142	3.7	5.7	3.6	3.6
thrower()	730 728 bytes	1500 1456 bytes	1500 1456 bytes	760 728 bytes

Methods as fields

- Reflection optimized if Methods are static final fields

```
private static final Method ADD, GET, THROWER;
static {
    try {
        ADD = Counter.class.getMethod("add", int.class);
        ADD.setAccessible(true);
        GET = Counter.class.getMethod("get");
        GET.setAccessible(true);
        THROWER = Counter.class.getMethod("thrower");
        THROWER.setAccessible(true);
    } catch (Throwable e) {
        throw new ExceptionInInitializerError(e);
    }
}
```

JavaSpecialists

3. Arrays

3. Arrays

- **Arrays are special types of classes**
  - Dynamic class – created at runtime
  - Can contain primitives and classes
- **Only common superclass of *all* arrays is Object**
  - No other relation between `int[]` and `long[]` and `short[]`
    - Primitive arrays are not subclasses of `Object[]`
  - However, multi-dimensional primitive arrays are `Object[]`
    - Thus `new int[0][] instanceof Object[] == true`

Showing component types

- **Arrays contain either primitives or objects**
  - Find the type with getComponentType()

```
public class ArrayElements {
    public static void main(String... args) {
        showComponent(char[].class);
        showComponent(Integer[][][].class);
        showComponent(int[][][].class);
    }
    private static void showComponent(Class<?> c) {
        Class<?> comp = c.getComponentType();
        System.out.println(comp);
        System.out.println(comp.getTypeName());
    }
}
```

```
char
char
class [[Ljava.lang.Integer;
java.lang.Integer[][]
class [[I
int[][]
```

Element Types

- **These are the standard encodings with getName()**
  - e.g. `char[].class.getName() = [C`
  - e.g. `int[][][].class.getName() = [[[I`

Element Type	Encoding
boolean	`Z`
byte	`B`
char	`C`
class or interface with binary name N	`LN;`
double	`D`
float	`F`
int	`I`
long	`L`
short	`S`

Finding array component type

- **Class has several methods for arrays:**
  - Class.isArray()
    - Returns true if the class is for a primitive or object array
  - Class.getComponentType()
    - Returns the component types of the array
      - e.g. int[].class.getComponentType() -> int.class
  - Class.arrayType
    - The opposite of getComponentType()
      - e.g. int.class.arrayType() -> int[ ].class

JavaSpecialists

3.1. Accessing elements

3.1. Accessing elements

- **We can get() and set() array elements with**
  - java.lang.reflect.Array - for working with arrays reflectively
  - java.util.Arrays - facade with convenience methods for arrays

```
import java.lang.reflect.Array;
import java.util.Arrays;

public class ModifyArrayContentsTest {
    public static void main(String... args) {
        String[] values = {"a", "b", "c"};
        Array.set(values, 2, "hello");
        System.out.println(Arrays.toString(values));
        System.out.println(Array.get(values, 1));
    }
}
```

Exercise 3A

- Convert an array to a stream

```
public class CollectionConverter {
    /**
     * Converts an array to a stream, either with the
     * elements being the wrapper class of the primitive
     * array elements, or if it is an Object[] then the
     * containing objects.
     *
     * @throws IllegalArgumentException if parameter is
     *                                  not an array
     */
    public static Stream<?> asStream(Object array) { }
}
```

JavaSpecialists

3.2. Creating new

3.2. Creating new

- We can create a new Array from any class type

```
import java.lang.reflect.Array;
public class ArrayCreateTest {
    public static void main(String... args) {
        int[] m = (int[]) Array.newInstance(int.class, 5);
        m[0] = 35;
        m[1] = 36;
        m[2] = 9;
        m[3] = 6;
        m[4] = 1;
        for (int i : m) {
            System.out.println(i);
        }
    }
}
```

Exercise 3B

- **Returns a deep clone of the array source**
  - If source is an array, clone it; otherwise return it
  - For each element, call deepClone() recursively

```
public class ArraysWithReflectionMagic {
    /**
     * Returns a deep clone of the array source, but
     * does not clone the actual elements of the array
     * (unless they are also arrays). If the source
     * is not an array, simply return it.
     */
    public static <A> A deepClone(A source) {
        return source;
    }
}
```

JavaSpecialists

4. java.lang.invoke

4. java.lang.invoke

- **Reflection suffers from amnesia**
  - Checks permission every time you invoke method
- **Reflection wraps all exceptions**
  - Needs to generate an additional stack trace every time

MethodHandles and VarHandles

- **MethodHandles are used to call**
  - Methods and constructors
- **VarHandles are used to read and modify fields**
  - Can do so in a thread-safe way with compare-and-swap

JavaSpecialists

4.1. MethodHandles .Lookup

4.1. MethodHandles.Lookup

- **We say up front who we are**
  - This means we can have finer-grained access control

```
public class LookupDemo {
    public static void main(String... args) {
        MethodHandles.Lookup lookup =
                MethodHandles.lookup();
        // Usually we cannot know our class in a static
        // context, since getClass() is not available
        Class<?> whoami = lookup.lookupClass();
        System.out.println("whoami = " + whoami);
    }
}
```

```
whoami = class reflection.ch4.LookupDemo
```

MethodHandles.Lookup

- **Lookup is used to find any class member**
  - findClass() - nested classes
  - findConstructor() - constructors
  - find[Static]Getter() - reading fields
  - find[Static]Setter() - writing fields, not for final fields
  - find[Static]VarHandle() - VarHandle for accessing fields
  - findSpecial() - call to super()
  - findStatic() - static method call
  - findVirtual() - non-static method call
- **Can also define hidden classes**

JavaSpecialists

4.1.1. privateLookupIn()

4.1.1. privateLookupIn()

- We can also find private members in other classes

```
// --add-opens java.base/java.lang=ALL-UNNAMED
public class Spyglass {
    public static void main(String... args)
            throws IllegalAccessException {
        // normal lookup
        System.out.println(MethodHandles.lookup());
        // private lookup inside java.lang.String
        MethodHandles.Lookup privateLookup =
            MethodHandles.privateLookupIn(
                String.class, MethodHandles.lookup());
        System.out.println(privateLookup);
    }
}
```

```
reflection.ch4.Spyglass
java.lang.String/reflection.ch4.Spyglass
```

JavaSpecialists

4.2. MethodHandle

4.2. java.lang.invoke.MethodHandle

- **Similar to java.lang.reflect.Method**
  - Avoids boxing parameters with @PolymorphicSignature
- **Throws method exceptions directly, not wrapping**
  - All invoke() methods throw Throwable
- **Does not check security access**
  - That has already been done when we created the Lookup
- **Matches return type**
  - Additional safety measure in case we call the wrong method

MethodType

- **To find a MethodHandle, we need a MethodType**
  - Contains the return type, followed by the parameter types
    - Constructor return type is void.class

```
public class FooBar {
    // MethodType.methodType(void.class)
    public FooBar() {}
    // MethodType.methodType(void.class, String.class)
    public FooBar(String id) {}
    // MethodType.methodType(void.class)
    public void foo() {}
    // MethodType.methodType(void.class, String.class,
    //     int.class)
    public void bar(String name, int age) {}
}
```

Finding Constructors

- **Constructors have only a MethodType, no name**

```
MethodHandles.Lookup lookup = MethodHandles.lookup();
MethodHandle constructor1 = lookup.findConstructor(
        FooBar.class,
        MethodType.methodType(void.class));
MethodHandle constructor2 = lookup.findConstructor(
        FooBar.class,
        MethodType.methodType(void.class,
                String.class));
```

Finding Methods

- **Methods need a name and a MethodType**

```
MethodHandles.Lookup lookup = MethodHandles.lookup();
MethodHandle foo = lookup.findVirtual(
        FooBar.class,
        "foo",
        MethodType.methodType(void.class));
MethodHandle bar = lookup.findVirtual(
        FooBar.class,
        "foo",
        MethodType.methodType(void.class,
                String.class, int.class));
```

Invoking MethodHandle

- **We can call methods with**
  - invoke(Object...args)
    - Return type does not have to be exactly correct
  - invokeExact(Object...args)
    - Return type has to be exactly the same, not upcast to Object
  - invokeWithArguments(Object...args)
  - invokeWithArguments(List<?> args)

ConstructDemo

- **Constructing an Integer(String) with invoke()**

```
public class ConstructDemo {
    public static void main(String... args)
            throws Throwable {
        var lookup = MethodHandles.lookup();
        MethodHandle constr = lookup.findConstructor(
                Integer.class,
                MethodType.methodType(void.class,
                        String.class));
        Integer value = (Integer) constr.invoke("42");
        System.out.println("value = " + value);
    }
}
```

```
value = 42
```

InvokeDemo

- Calling toUpperCase() using a MethodHandle

```
public class InvokeDemo {
    public static void main(String... args)
            throws Throwable {
        var lookup = MethodHandles.lookup();
        MethodHandle toUpper = lookup.findVirtual(
                String.class, "toUpperCase",
                MethodType.methodType(String.class));
        System.out.println(toUpper.invoke("Java123"));
    }
}
```

```
JAVA123
```

Lookup figures out security context

```
public class PrivateMethodCalls {
    private void foo() {
        System.out.println("PrivateMethodCalls.foo()");
    }
    public static void main(String... args)
            throws Throwable {
        var obj = new PrivateMethodCalls();
        MethodHandles.lookup().findVirtual(
                PrivateMethodCalls.class, "foo",
                MethodType.methodType(void.class))
                .invoke(obj); // OK
        PrivateMethodCalls.class.getMethod("foo")
                .invoke(obj); // NoSuchMethodException
    }
}
```

```
PrivateMethodCalls.foo()
NoSuchMethodException: reflection.ch4.
    PrivateMethodCalls.foo()
```

Passing in an argument list

◉ **java ConstructWithArgumentListDemo "1023"**

```
public class ConstructWithArgumentListDemo {
    public static void main(String... args)
            throws Throwable {
        var lookup = MethodHandles.lookup();
        MethodHandle constr = lookup.findConstructor(
                Integer.class,
                MethodType.methodType(void.class,
                        String.class));
        Integer value = (Integer) constr
                .invokeWithArguments(args);
        System.out.println("value = " + value);
    }
}
```

```
value = 1023
```

Creating a Spreader for argument lists

◉ **java ConstructWithSpreaderDemo "21342"**

```
public class ConstructWithSpreaderDemo {
    public static void main(String... args)
            throws Throwable {
        var lookup = MethodHandles.lookup();
        MethodHandle constr = lookup.findConstructor(
                Integer.class,
                MethodType.methodType(void.class,
                        String.class))
                .asSpreader(String[].class, 1);
        Integer value = (Integer) constr
                .invoke(args);
        System.out.println("value = " + value);
    }
}
```

```
value = 21342
```

Experiment

- Calling new Integer(String) with parameter list

	new Integer(args[0])	invoke(args[0])	invokeWith Arguments(args)	invoke(args) Spreader
Nanos	120	140	1300	150
Bytes	16	16	224	16

invoke() vs invokeExact()

- **We can check return type with invokeExact()**
  - More strict
  - Will discover more mistakes in reflection code

InvokeExactDemo

```
public class InvokeExactDemo {
    public static void main(String... args)
            throws Throwable {
        var lookup = MethodHandles.lookup();
        MethodHandle mh = lookup.findVirtual(
                String.class, "toUpperCase",
                MethodType.methodType(String.class));
        try {
            System.out.println(mh.invokeExact("Java"));
        } catch (WrongMethodTypeException e) {
            System.out.println(e.getMessage());
        }
        System.out.println((String)mh.invokeExact("Java"));
    }
}
```

```
expected (String)String but found (String)Object
JAVA
```

JavaSpecialists

4.3. VarHandle

4.3. VarHandle

- **Access fields in a thread-safe way**
  - Replaces AtomicReferenceFieldUpdater
    - Had the same issue as reflection with amnesia
  - VarHandle is checked once when we create it with a Lookup
- **We have different modes of reading/writing**
  - set()/get() - plain access
  - setOpaque()/getOpaque()
  - setRelease()/getAcquire() - ok for single writer, many readers
  - setVolatile()/getVolatile() - strongest concurrent semantics
  - getAndAdd(), getAndBitwiseAnd/Or/Xor(), getAndSet()

Compare And Swap

- **Non-blocking algorithms use CAS CPU instructions**
  - Keep trying to write, given expected value, until we succeed
- **Let's start with a simple Point class**

```
public class Point {
    private int x, y;
    public Point(int x, int y) {this.x = x; this.y = y;}
    public synchronized double distanceFromOrigin() {
        return Math.hypot(x, y);
    }
    public synchronized void moveBy(int dX, int dY) {
        x += dX;
        y += dY;
    }
}
```

Point using compareAndSet

```
public class Point2 {
    private volatile int[] xy;

    public Point2(int x, int y) {xy = new int[] {x, y};}

    public double distanceFromOrigin() {
        int[] xy = this.xy;
        return Math.hypot(xy[0], xy[1]);
    }

    public void moveBy(int dX, int dY) {
        int[] current, next;
        do {
            current = xy;
            next = new int[] {xy[0] + dX, xy[1] + dY};
        } while(!XY.compareAndSet(current, next));
    }
```

VarHandle XY inside Point2

```
    private static final VarHandle XY;
    static {
        try {
            var l = MethodHandles.lookup();
            XY = l.findVarHandle(Point2.class,
                    "xy", int[].class);
        } catch (ReflectiveOperationException e) {
            throw new ExceptionInInitializerError(e);
        }
    }
}
```

ConcurrentLinkedQueue

- Using compareAndSet to update the item in Node

```
public class ConcurrentLinkedQueue<E> {
    static final class Node<E> {
        volatile E item;
        boolean casItem(E cmp, E val) {
            return ITEM.compareAndSet(this, cmp, val);
        }
    }
    static final VarHandle ITEM;
    static {
        try {
            MethodHandles.Lookup l = MethodHandles.lookup();
            ITEM = l.findVarHandle(Node.class, "item", Object.class);
        } catch (ReflectiveOperationException e) {
            throw new Error(e);
        }
    }
}
```

JavaSpecialists

4.4. Converting from Method to MethodHandle

4.4. Converting from Method to MethodHandle

- **MethodHandles cannot be used to reflect classes**
  - We have to know exactly what we are looking for
    - Including return types for methods and types for fields
- **Use reflection to discover the available methods**

Unreflecting elements

- **We can "unreflect" the following elements:**
  - unreflect(Method)
  - unreflectConstructor(Constructor)
  - unreflectGetter(Field) and unreflectSetter(Field)
  - unreflectSpecial(Method, Class)
  - unreflectVarHandle()

UnreflectingDemo

- Here we are "unreflecting" a method from String

```
public class UnreflectingDemo {
    public static void main(String... args)
            throws Throwable {
        var lookup = MethodHandles.lookup();
        Method method = String.class
                .getMethod("toUpperCase");
        MethodHandle mh = lookup.unreflect(method);
        System.out.println(mh.invoke("unreflective"));
    }
}
```

Unreflecting a setter for a private field

```
// --add-opens java.base/java.lang=ALL-UNNAMED
public class IntegerHackUnreflected {
    public static void main(String... args)
            throws Throwable {
        Field value = Integer.class
                .getDeclaredField("value");
        value.setAccessible(true);
        MethodHandle VALUE_SETTER = MethodHandles.lookup()
                        .unreflectSetter(value);
        VALUE_SETTER.invoke(42, 43);
        for (int i = 1; i <= 10; i++) {
            System.out.printf("%d x 7 = %d%n",
                    i, i * 7);
        }
    }
}
```

```
...
5 x 7 = 35
6 x 7 = 43
7 x 7 = 49
...
```

Writing final fields with MethodHandle

- **Remember MethodHandles.privateLookupIn(...)**
  - Added in Java 9 to give access to private fields with VarHandles
  - Will only find getters and not setters for final fields
  - Similarly, VarHandles cannot write, only read
    - Even if we unreflect
  - Unreflected setters can write non-static final fields
    - Backwards compatibility

IMPL_LOOKUP

- **Superuser power on all elements**
  - Can write to final fields with VarHandles, call private methods
- **Hidden away inside MethodHandles.Lookup class**

JavaSpecialists

4.6. Exercise

4.6. Exercise 4A

- **Redo the MagicClassInstantiator from exercise 1C**
  - This time using MethodHandles for the constructor and method
  - Use privateLookupIn() in case the constructor is private
    - Either use invokeWithArguments() or make a Spreader
  - Unreflect the method into a MethodHandle

5. Conclusion

Conclusion

- **Java reflection allows flexible frameworks**
  - Configured using annotations and other configuration
- **The child that gets a hammer for Christmas ...**
  - sees everything as a nail!
- **Do not overuse**

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