JAVA

Classes and classloader

Overview

- classes are loaded to VM dynamically
  - it can be changed
    - from where they are loaded
    - how they are loaded
- java.lang.ClassLoader
  - VM uses classloaders to load classes
- each class is loaded by a classloader
  - Class.getClassLoader()
- exception
  - classes for arrays
    - created automatically when they are necessary
    - Class.getClassLoader() returns the same class as for elements of the array

Steps in class loading into VM

1. class loading
   - classloader
   - can cause exceptions (extending LinkageError)
     - ClassCircularityError
     - ClassFormatError
     - NoClassDefFoundError
   - can cause also OutOfMemoryError
2. "linking"

Steps in class loading into VM

2. "linking"
   - verification
     - a test, whether the class corresponds with the Java Virtual Machine Specification
     - exceptions (extending LinkageError)
       - VerifyError
   - preparation
     - creation of static fields
       - no initialization yet
     - OutOfMemoryError
   - resolution
     - symbolic references to other classes
     - exceptions – IncompatibleClassChangeError a potomci
       - IllegalAccessError, InstantiationError, NoSuchFieldError, NoSuchMethodError, UnsatisfiedLinkError

Steps in class loading into VM

3. initialization
4. creation of a new instance

Class and classloader

- a class in VM is identified by its name AND by its classloader
  - the same class loaded by different classloaders => two different classes from the view of VM
- each classloader has a parent (not in the sense of inheritance)
  - exception
    - bootstrap classloader
      - has no parent
  - if not specified => the system classloader
- during loading, the classloader first delegates class loading to its parent and only if the parent have not loaded the class, then it loads the class

Class and classloader

- other classes, necessary during a class loading, are loaded by the **same** classloader

Own classloader

- extends java.lang.ClassLoader
  - overrides the method findClass()

```
class MyClassLoader extends ClassLoader {
   public Class<?> findClass(String name) {
     byte[] b = loadClassData(name);
     return defineClass(name, b, 0, b.length);
   }

   private byte[] loadClassData(String name) {
     . . .
   }
}
```

- usage

```
Class.forName("clazz", true, new MyClassLoader());
```

or

```
new MyClassLoader().loadClass("clazz");
```

Own classloader

- it is possible to override loadClass()
  - not recommended
  - method does
    - findLoadedClass()
      - test, whether the class has been already loaded
    - delegates loading to the parent classloader
    - findClass()
    - resolveClass()

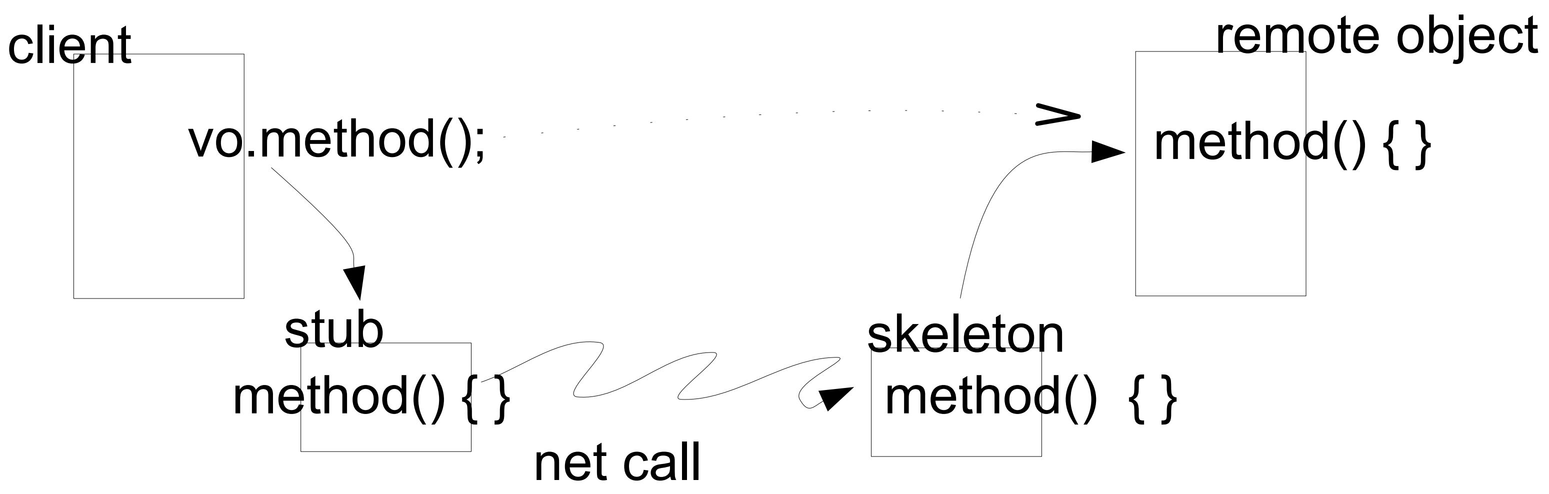
Examples of usage

- class loading from different sources – e.g. net

```
private byte[] loadClassData(String name) throws
  ClassNotFoundException {
  URL url = new URL("........");
  URLConnection con = defURL.openConnection();
  InputStream is = con.getInputStream();
  ByteArrayOutputStream bo = new ByteArrayOutputStream();
  int a = is.read();
  while (a != -1) {
    bo.write(a);
    a = is.read();
  }
  is.close();
  byte[] ar = bo.toByteArray();
  bo.close();
  return ar;
}
```

Examples of usage

- RMI
  - automatic loading of stubs over net



Examples of usage

- separation of name spaces
  - *(since Java 9 – better solution to use modules)*
  - e.g. application server
    - a single VM
    - "applications" are loaded by own classloaders
      - can use different version of libraries
        - (different classes with the same names)
  - problems if the “applications” want to communicate directly
    - solution – for communication, interfaces and classes loaded by a common parent classloader are used
    - non-ideal solution – via the reflection API

Loading other resources

- a classloader can load “anything”
- the same rules as for loading classes

- methods

```
URL getResource(String name)

InputStream getResourceAsStream(String name)

Enumeration<URL> getResources(String name)
```

Java

Service loader & provides

Overview

- let us have an interface for a “service”
  - e.g. javax.xml.parsers.DocumentBuilderFactory
- different “providers” of the service implementations
  - if we would like to use a particular implementation in a program, it would be necessary to use its name directly in source code
    - change of the implementation => change of code
  - better => use ServiceLoader<?>

Usage

- pack the implementation to JAR
  - add a file META-INF/services/service.interface.name e.g: `META-INF/services/javax.xml.parsers.DocumentBuilderFactory`
  - in the file, the name of a class implementing the interface per line
- in code
  - sl = ServiceLoader.load(interface.class, classloader);
  - sl.iterator()

- ServiceLoader is available since JDK 6
  - META-INF/services is used since JDK 1.3
    - it was necessary to create own ServiceLoader

- explicitly supported by modules (since Java 9)
  - definition in module-info.java

Bytecode

Bytecode

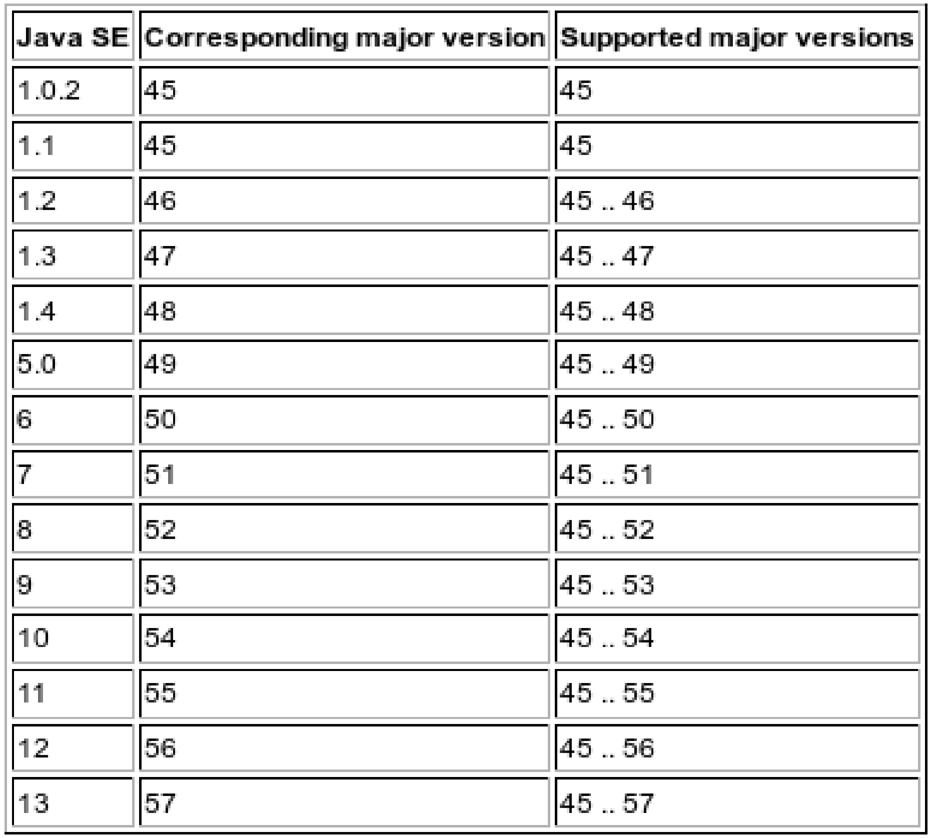
- The Java Virtual Machine Specification
- https://docs.oracle.com/javase/specs/

Format of the class file

```
ClassFile {
    u4 magic;
    u2 minor_version;
    u2 major_version;
    u2 constant_pool_count;
    cp_info constant_pool[constant_pool_count-1];
    u2 access_flags;
    u2 this_class;
    u2 super_class;
    u2 interfaces_count;
    u2 interfaces[interfaces_count];
    u2 fields_count;
    field_info fields[fields_count];
    u2 methods_count;
    method_info methods[methods_count];
    u2 attributes_count;
    attribute_info attributes[attributes_count];
}
```

Format of the class file

- magic
  - 0xCAFEBABE
- version



Java SE	Corresponding major version	Supported major versions
1.0.2	45	45
1.1	45	45
1.2	46	45 .. 46
1.3	47	45 .. 47
1.4	48	45 .. 48
5.0	49	45 .. 49
6	50	45 .. 50
7	51	45 .. 51
8	52	45 .. 52
9	53	45 .. 53
10	54	45 .. 54
11	55	45 .. 55
12	56	45 .. 56
13	57	45 .. 57

Code

- a stack-oriented assembler

```
void spin() {
    int i;
    for (i = 0; i < 100; i++) { ; }
}


Method void spin()
 0    iconst_0      // Push int constant 0
 1    istore_1      // Store into local variable 1 (i=0)
 2    goto 8        // First time through don't increment
 5    iinc 1 1      // Increment local variable 1 by 1 (i++)
 8    iload_1       // Push local variable 1 (i)
 9    bipush 100    // Push int constant 100
11    if_icmplt 5   // Compare and loop if less than (i<100)
14    return        // Return void when done
```

Instructions

- opcodes
- size 1 byte
  - max 256 possible instructions
    - not all of them are used
- instruction categories
  - load and store (aload_0, istore,...)
  - arithmetic and logic (ladd, fcmpl,...)
  - type conversion (i2b, d2i,...)
  - object creation and manipulation (new, putfield)
  - operand stack management (swap, dup2,...)
  - control transfer (ifeq, goto,...)
  - method invocation and return (invokespecial, areturn,...)

Instructions

- invokedynamic
  - since Java 7
  - support for compiling dynamic languages into Java bytecode

  - since Java 8 used also for compiling lambda expressions

Bytecode

- tools for bytecode manipulation
  - ASM, BCEL, SERP, ...
- ASM
  - http://asm.ow2.org/
    - bytecode manipulation
    - new classes creation
    - updating existing ones

    - used in OpenJDK, Kotlin and Groovy compilers,...

JAVA

JNI
(Java Native Interface)

Overview

- integration of native code (in C, C++,...) to Java
- integration of Java code to native code

- common usage
  - platform-specific operations

Example

```
class HelloWorld {
    public native void displayHelloWorld();

    static {
        System.loadLibrary("hello");
    }

    public static void main(String[] args) {
        new HelloWorld().displayHelloWorld();
    }
}
```

Example

- javac -h <output_dir> HelloWorld.java
    - (old way – javah -jni HelloWorld)
  - > HelloWorld.h

```
/* DO NOT EDIT THIS FILE - it is machine generated */
#include <jni.h>
/* Header for class HelloWorld */
#ifndef _Included_HelloWorld
#define _Included_HelloWorld
#ifdef __cplusplus
extern "C" {
#endif
/*
 * Class:     HelloWorld
 * Method:    displayHelloWorld
 * Signature: ()V
 */
JNIEXPORT void JNICALL Java_HelloWorld_displayHelloWorld
  (JNIEnv *, jobject);
#ifdef __cplusplus
}
#endif
#endif
```

Example

- implementation of the native method

```
#include <jni.h>
#include "HelloWorld.h"
#include <stdio.h>

JNIEXPORT void JNICALL
Java_HelloWorld_displayHelloWorld(JNIEnv *env,
                                       jobject obj) {
    printf("Hello world!\n");
}
```

Example

- compilation of native code (HelloWorld.c)
  - result – shared library (.so, .dll)
  - UNIX

    -
      ```
      gcc -shared -Wall -fPIC -o libhello.so
      -I/java/include -I/java/include/linux HelloWorld.c
      ```
  - Windows

    -
      ```
      cl -Ic:\java\include -Ic:\java\include\win32
                      -LD HelloWorldImp.c -Fehello.dll
      ```
- run the program
  - java HelloWorld

Type mapping

Java Type	Native Type	Size in bits
boolean	jboolean	8, unsigned
byte	jbyte	8
char	jchar	16, unsigned
short	jshort	16
int	jint	32
long	jlong	64
float	jfloat	32
double	jdouble	64
void	void	n/a

Type mapping

- "non-primitive" types
  - jobject
  - jstring
  - jclass
  - jthrowable
  - jarray
  - jobjectArray
  - jbooleanArray
  - jintArray
  - .....Array

Accessing Strings

- **jstring** cannot be used directly
  - convert ot char*

```
Java_.....(JNIEnv *env, jobject obj, jstring prompt) {
  char *str = (*env)->GetStringUTFChars(env, prompt, 0);
  printf("%s", str);
  (*env)->ReleaseStringUTFChars(env, prompt, str);
  ...
```

  - new string

```
char buf[128];
...
jstring jstr = (*env)->NewStringUTF(env, buf);
```

Accessing arrays

```
Java_..._sumArray(JNIEnv *env, jobject obj,
                                       jintArray arr) {
  int i, sum = 0;
  jsize len = (*env)->GetArrayLength(env, arr);
  ...
  jint *body = (*env)->GetIntArrayElements(env,arr,0);
  for (i=0; i<len; i++) {
    sum += body[i];
  }
  ...
  (*env)->ReleaseIntArrayElements(env, arr, body, 0);
  return sum;
}
```

Accessing methods

```
JNIEXPORT void JNICALL
Java_..._nativeMethod(JNIEnv *env, jobject obj, jint i) {
  jclass cls = (*env)->GetObjectClass(env, obj);
  jmethodID mid = (*env)->GetMethodID(env, cls, "method", "(I)V");
  (*env)->CallVoidMethod(env, obj, mid, i);
}
```

- method signature
  - the **javap** tool
    - javap -s class

Signature	Java type
Z	boolean
B	byte
C	char
S	short
I	int
J	long
F	float
D	double
L*class;*	class
[*type*	type []
(*parameters*)*return-type*	method

Accessing methods

- GetMethodID()
- GetStaticMethodID()

- CallVoidMethod()
- CallIntMethod()
- ....
- CallStaticVoidMethod()
- CallStaticIntMethod()
- ....

Accessing fields

- similar as methods

- fid = (*env)->GetStaticFieldID(env, cls, "si", "I");
- fid = (*env)->GetFieldID(env, cls, "s", "Ljava/lang/String;");

- si = (*env)->GetStaticIntField(env, cls, fid);
- jstr = (*env)->GetObjectField(env, obj, fid);

- SetObjectField
- SetStaticIntField
- ...

Exception handling

```
jmethodID mid = ....
...
(*env)->CallVoidMethod(env, obj, mid);
jthroable exc = (*env)->ExceptionOccurred(env);
if (exc) {
  (*env)->ExceptionDescribe(env);
  (*env)->ExceptionClear(env);
  ....
}
```

Supporting synchronization

```
...
(*env)->MonitorEnter(env, obj);
     synchronized block
(*env)->MonitorExit(env, obj);
...
```

- wait() and notify() are not directly supported
  - but can be called as any other method

C++

- C

  -
    ```
    jstring jstr = (*env)->GetObjectArrayElement
                                            (env, arr, i);
    ```
- C++

  -
    ```
    jstring jstr = (jstring) env->GetObjectArrayElement
                                                  (arr, i);
    ```

JNA
(Java Native Access)

Overview

- not a part of JDK
- https://github.com/java-native-access/jna

- automatic mapping between Java and native libraries
  - support for “all” platforms

- no need to manually create native code
  - JNI is used internally

JNA „Hello world“

```
import com.sun.jna.Library;
import com.sun.jna.Native;


public interface JNAApiInterface extends Library {
  JNAApiInterface INSTANCE = (JNAApiInterface)
Native.loadLibrary((Platform.isWindows() ? "msvcrt" :
"c"), JNAApiInterface.class);

  void printf(String format, Object... args);
}



public static void main(String args[]) {
  JNAApiInterface jnaLib = JNAApiInterface.INSTANCE;
  jnaLib.printf("Hello World");
}
```

Type mapping

Native Type	Size	Java Type
char	8-bit integer	byte
short	16-bit integer	short
w char_t	16/32-bit character	char
int	32-bit integer	int
int	boolean value	boolean
long	32/64-bit integer	NativeLong
long long	64-bit integer	long
float	32-bit FP	float
double	64-bit FP	double
char*	C string	String
void*	pointer	Pointer

Type mapping

- array (pointer) → array
- struct → … extends Structure
- by-reference arguments
  - char **bufp → PointerByReference bufp
  - int* lenp → IntByReference lenp
- …
- JNAerator
  - https://github.com/nativelibs4java/JNAerator
  - generates headers of Java methods