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Java Programming

9-1
Java Bytecode

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Objectives

- This lesson covers the following topics:
- Understanding Bytecode
  - How to obtain the bytecode listings
  - How to read the bytecode
  - How the language constructs are mirrored by the compiler: calculation, method calls

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Why Understand Bytecode?

- Understanding the Java bytecode is crucial when debugging and doing performance and memory usage tuning
- Knowing the assembler instructions that are generated from source code can help you know how to code differently to achieve your quality goals
- In addition, the knowledge of bytecode can help you to better understand the Java programming language and know the implementation details for your source code

What is the Bytecode?

- It is not usual for programmers to program in Java byte code directly, rather they program in Java and then compile their programs into Java byte code
- Each opcode of the bytecode is represented by a single byte

What is the Bytecode?

- Bytecode is an intermediate representation of a program, halfway between human readable source and machine code
- Bytecode is produced by javac from Java source code files
- Some high-level language features have been removed and do not appear in bytecode
- For example, Java's looping and the if statement are not present, and instead, have become branch instructions in the bytecode

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How to Inspect the Instruction Set

- In order to inspect the output from the Java compiler, we use a program called a disassembler which converts the Java byte code program from a form suitable for efficient interpretation into a textual form suitable for developers to read and study
- Given a compiled Java class in the file SampleClass.class the Java disassembler is invoked with a javap command such as the following:
    - javap -c Sampleclass (The -c option disassembles the code)

JVM Instruction Set

- Java bytecodes are the machine language of the JVM
- In Java source code, the method defines behavior, so after the Classloader loads a class, the stream of bytecodes for each method are stored in the method area of JVM during runtime
- The bytecodes of a method are executed when the method is invoked by the thread during the course of running the application

JVM Instruction Set

- The stream of bytecodes consists of a one-byte opcode followed by zero or more operands
- Instruction Set format:
  - 1 byte opcode
  - 0 or more bytes of operands
- Each opcode has a mnemonic, for example, istore_0.
- JVM instructions are explicitly typed: different codes for instructions for integers, floats, arrays, reference types, etc.

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JVM Instruction Set - Mnemonics

- This is reflected by a naming convention in the first letter of the opcode mnemonics:
    - JVM-Type prefix
        - Byte b
        - Short s
        - Integer i
        - Long l
        - Character c
        - Single float f
        - Double float d
        - References a

        - Example: iload load integer type or fload load float type

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JVM Instruction Set - Mnemonics

- Below is a list of common uses of opcode:
  - Shuffling (pop, swap, dup, ...)
  - Calculating (iadd, isub, imul, idiv, ineg,...)
  - Conversion (d2i, i2b, d2f, i2z,...)
  - Local storage operation (iload, istore,...)
  - Array Operation (arraylength, newarray,...)
  - Object management (get/putfield, invokevirtual, new)
  - Push operation (aconst_null, iconst_m1,....)
  - Control flow (nop, goto, jsr, ret, tableswitch,...)
  - Threading (monitorenter, monitorexit,...)

Loops in Java Source Code

- Consider the following Java Methods :
  - void testFor() {
  -     for (int i = 0 ; i < 100 ; i++){;}
  - }

  - int i = 0;
  - void testWhile() {
  - while (i < 100) {
  -     i++;}
  - }

Both methods initialize the loop variable i to zero and then increment until i reaches the 100 limit.

- We consider these testFor() and testWhile() methods equivalent in that we can use each method to perform the same task without the need to change the code

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Loops in Java Byte Code

- The Java byte code language has neither a for loop nor a while loop
- Unlike the source code where the loops are visible, in Java byte code the two forms of loops are identical:
  - Method void testFor() Method void testWhile()
    - 0: iconst_0 0: iconst_0
    - 1: istore_1 1: istore_1
    - 2: iload_1 2: iload_1
    - 3: bipush 100 3: bipush 100
    - 5: if_icmpge 14 5: if_icmpge 14
    - 8: iinc 1, 1 8: iinc 1, 1
    - 11: goto 2 11: goto 2
    - 14: return 14: return

Loops in Java Byte Code

- Below is the byte code generated from the javac compiler for both methods:
  - 0: iconst_0 The integer constant zero is pushed on top of the stack
  - 1: istore_1 The top of the stack is stored into local variable array one (the variable i)
  - 2: iload_1 Load from the local variable
  - 3: bipush 100 Load the integer 100 on top of the stack
  - 5: if_icmpge 14 Compare the top two items on the stack and jump if (i>=100)
  - 8: iinc 1, 1 Increment local variable on by 1 (i++)
  - 11: goto 2
  - 14: return Return void when the end of the method is reached

Local Storage Operation

- The load and store instructions transfer values between the local variables and the operand stack of a Java Virtual Machine frame
  - iload, iload_0,fload_0, ..
  - Istore, Istore, istore_0..
  - ldc, sipush

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Arithmetic Instructions Mnemonics

- For a Complete list of the Arithmetic instructions, refer to the JVM Specifiction
- Below is a small subset :
  - Add: iadd, ladd, fadd, dadd
  - Subtract: isub, lsub, fsub, dsub
  - Multiply: imul, lmul, fmul, dmul
  - Divide: idiv, ldiv, fdiv, ddiv

Java Bytecode Example

- Java Souce Code:

```
public class SampleClass {
   public static int test(){
      int x=99999;
      int y=1;
      int z = x + y;
      return z;
   }//end method test
}//end class SampleClass
```

- # javap –c SampleClass
- Java ByteCode:
- public static int test();
- Code:
- 0: ldc #2 // int 99999
- 2: istore_0
- 3: iconst_1
- 4: istore_1
- 5: iload_0
- 6: iload_1
- 7: iadd
- 8: istore_2
- 9: iload_2
- 10: ireturn

Object Management

- Although both class instances and arrays are objects, the Java Virtual Machine creates and manipulates class instances and arrays using distinct sets of instructions:
  - Create a new class instance: new
  - Create a new array: newarray, anewarray, multianewarray
- Access fields of classes (static fields, known as class variables) and fields of class instances (non-static fields, known as instance variables):
  - getstatic, putstatic, getfield, putfield

Instruction-Set: Memory Access

- In the JVM, the contents of different "kinds" of memory can be accessed by different kinds of instructions
  - accessing locals and arguments: load and store instructions
  - accessing fields in objects: getfield, putfield
  - accessing static fields: getstatic, putstatic

Instruction-Set: Memory Access

- Note:
  - Static fields are like global variables
  - They are allocated in the “method area” where code for methods and representations for classes (including method tables) are also stored
  - getfield and putfield access memory in the heap

The new Operator Example

- Java Souce Code:

```
public class SampleClass {
    public static int testID=100;
    public static void test()
    {
        SampleClass sc=new SampleClass();
        testID=200;
    }//end method test

}//end class SampleClass
```

- In the SampleClass java class, we declare a static variable testID.
- And the the test() method, a new Sampleclass object is instantiated

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The new Operator Example

- Java ByteCode:
- 0: new #2 // class SampleClass
- 3: dup
- 4: invokespecial #3 // Method "<init>":()V
- 7: astore_0
- 8: sipush 200
- 11: putstatic #4 // Field testID:I
- 14: return

- In the SampleClass test() method bytecode:
  - Line 0: create a new object
  - Line 3: duplicate the top operand stack value
  - Line 4: invoke the SampleClass constructor
  - Line 7: store the newly created object reference into the local variable

The new Operator Example

- Java ByteCode:
- 0: new #2 // class SampleClass
- 3: dup
- 4: invokespecial #3 // Method "<init>":()V
- 7: astore_0
- 8: sipush 200
- 11: putstatic #4 // Field testID:I
- 14: return

- In the SampleClass test() method bytecode:
  - Line 8: push the short 200 into the top of the stack
  - Line 11: set the static field testID to 200
  - Line 14: return the method call

Instruction-Set

- Method invocation:
  - invokevirtual: the usual instruction for calling a method on an object. invokeinterface: same as invokevirtual, but used when the called method is declared in an interface (requires a different kind of method lookup)
  - invokespecial: for calling things such as constructors, which are not dynamically dispatched (this instruction is also known as invokenonvirtual)
  - invokestatic: for calling methods that have the “static” modifier (these methods are sent to a class, not to an object)
- Returning from methods:
  - return, ireturn, lreturn, areturn, freturn, …

Analyze the Bytecode : invokespecial

- Java Source Code:
  - SampleClass sc=new SampleClass();
    - The new operator will be translated into 4 instructions by javac compiler
- Java ByteCode:
  - 0: new #2 // class SampleClass
    - 3: dup
    - Duplicate the top operand stack value
    - 4: invokespecial #3 // Method "<init>":()V
    - Call the constructor of the SampleClass
  - Memory for a new instance of SampleClass class is allocated from the garbage-collected heap, and the instance variables of the new object are initialized to their default initial values

Analyze the Bytecode - Push Short

- Java Souce Code:
  - testID=200;
  - The statement will be translated into two instructions
- Java ByteCode:
  - 8: sipush 200
  - Push short value 200 into stack.
  - 11: putstatic #4 // Field testID:I
  - Set static field in class

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Instructions and the “Constant Pool”

- Many JVM instructions have operands which are indexes pointing to an entry in the so-called constant pool
- The constant pool contains all kinds of entries that represent “symbolic” references for “linking”
- This is the way that instructions refer to things such as classes, interfaces, fields, methods, and constants such as string literals and numbers

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Instructions and the "Constant Pool"

- Examples of constant pool entries that exist :
  - Class_info
  - Fieldref_info
  - Methodref_info
  - InterfaceMethodref_info
  - String
  - Integer
  - Float
  - Long
  - Double
  - Name_and_Type_info
  - Utf8_info   (Unicode characters)

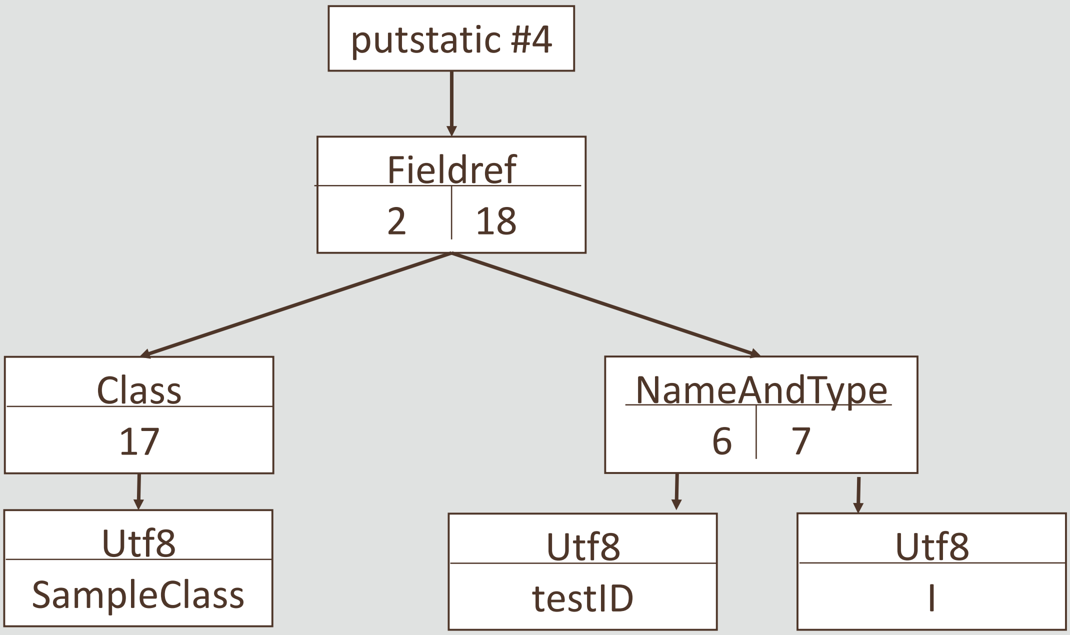
Analyze the Bytecode

- #javap –verbose SampleClass // display the constant pool
- Java ByteCode: 11: putstatic #4 // Field t
- #1 = Methodref #5.#16 // java/lang/Object."<init>":()V
- #2 = Class #17 // SampleClass
- #3 = Methodref #2.#16 // SampleClass."<init>":()V
- #4 = Fieldref #2.#18 // SampleClass.testID:I
- #5 = Class #19 // java/lang/Object
- #6 = Utf8 testID
- #7 = Utf8 I
- #8 = Utf8 <init>
- #9 = Utf8 ()V
- #10 = Utf8 Code
- estID:I

Analyze the Bytecode – Cont.

- #javap –verbose SampleClass // display the constant pool
- Java ByteCode: 11: putstatic #4 // Field testID:I
- #11 = Utf8 LineNumberTable
- #12 = Utf8 test
- #13 = Utf8 <clinit>
- #14 = Utf8 SourceFile
- #15 = Utf8 SampleClass.java
- #16 = NameAndType #8:#9 // "<init>":()V
- #17 = Utf8 SampleClass
- #18 = NameAndType #6:#7 // testID:I
- #19 = Utf8 java/lang/Object

Analyze the Bytecode - Cont



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Summary

- In this lesson, you should have learned:
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  - How to obtain the bytecode listings
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