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Java Bytecode

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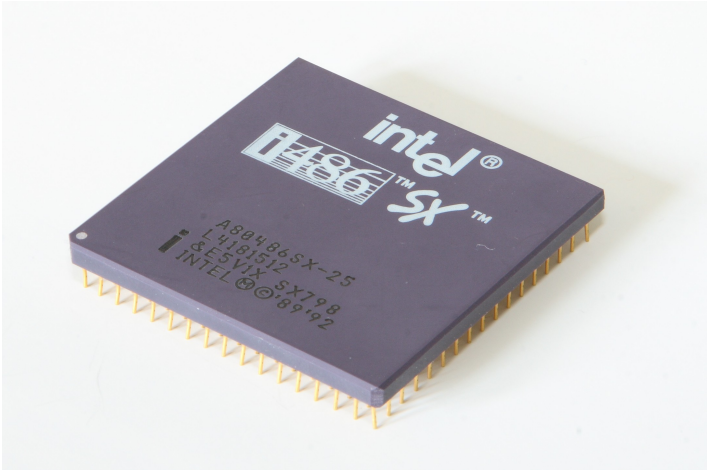
Architektur

- 1 Byte pro Befehl $\rightarrow 2^8 = 256$ Befehle
- 51 davon z.Zt. unbenutzt
- 3 gesperrt
  - `0xCA` $\rightarrow$ Breakpoint-Marker
  - `0xFE`, `0xFF` $\rightarrow$ Reserviert für spezielle Debuggerbefehle
- kompakt
- JVM Stackorientiert $\rightarrow$ kompatibel zu registerarmen Plattformen (z.B. Intel 80486: 9 Register)



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Aufbau

```
<offset> <opcode> [<arg1>, <arg2>]
```

- `offset` → aktuelle Bytezahl, Sprungmarker
- `opcode, args` → Befehl und Argumente

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```
0 iinc 0, 1
```

- Befehl `iinc`: Inkrementieren
- Prefix `i`: → integer
- Argument 1 (0): oberstes Stackelement
- Argument 2 (1): um 1 erhöhen

Aufbau

- Prefixe/Suffixe: Datentypen
  `i` integer, `l` long, `s` short, `b` byte, `c` character
  `f` float, `d` double, `z` boolean, `a` reference

```
0 fcmpl
```

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```
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```

- Suffixe (speziell): `const`, `load`, `store` + `_n`

```
0 iconst_0    // 03                    push int 0 to stack
0 iconst_m1   // 02                   push int -1 to stack
1 sipush 999  // 11 03 E7      push signed int 999 to stack
```

Aufbau

- An Bytegrenzen ausgerichtet
- JVM-Stack Slotgröße: 4 byte
  - `integer, float, byte, short`: 4 byte/1 Slot
  - `long, double`: 8 byte/2 Slots

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Instruktionsgruppen

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- Kontrollübertragung `ifeq, goto`
- Methodenausführung `invokespecial, areturn`

Bytecode-Ausschnitt

```
$ javac Example.java
```

Bytecode-Ausschnitt

```
$ javac Example.java
$ javap -c -s -v -l example.Example
```

Bytecode-Ausschnitt

```
1  Constant pool:
2    #1= Methodref   #5.#15  //java/lang/Object."<init>":()V
3    #2= Fieldref    #16.#17 //java/lang/System.out:Ljava/io/PrintStream;
4    #3= Methodref   #18.#19 //java/io/PrintStream.println:(I)V
5
6  class example.Example {
7    public static void main(java.lang.String[]);
8       0: iconst_0
9       1: istore_1
10      2: iload_1
11      3: iconst_5
12      4: if_icmpge     20
13      7: getstatic     #2
14     10: iload_1
15     11: invokevirtual #3
16     14: iinc          1, 1
17     17: goto          2
18     20: return
19 }
```

Beispielprogramm

```
1  package example;
2
3  class Example {
4
5    public static void main(String[] args) {
6      for(int i = 0; i < 5; i++) {
7        System.out.println(i);
8      }
9    }
10
11 }
```

Classfile Teil 1

```
1  Classfile /data/Repositories/FUBerlin/Semester/ss13/ss13-com/Vortrag/example/Example.class
2    Last modified 17.04.2013; size 446 bytes
3    MD5 checksum 1f4fd95d93cfdb73b348333b97ca87d2
4    Compiled from "Example.java"
5  class example.Example
6    SourceFile: "Example.java"
7    minor version: 0
8    major version: 51
9    flags: ACC_SUPER
10 Constant pool:
11    #1 = Methodref          #5.#15         //  java/lang/Object."<init>":()V
12    #2 = Fieldref           #16.#17        //  java/lang/System.out:Ljava/io/PrintStream;
13    #3 = Methodref          #18.#19        //  java/io/PrintStream.println:(I)V
14    #4 = Class              #20            //  example/Example
15    #5 = Class              #21            //  java/lang/Object
16    #6 = Utf8               <init>
17    #7 = Utf8               ()V
18    #8 = Utf8               Code
19    #9 = Utf8               LineNumberTable
20   #10 = Utf8               main
21   #11 = Utf8               ([Ljava/lang/String;)V
22   #12 = Utf8               StackMapTable
23   #13 = Utf8               SourceFile
24   #14 = Utf8               Example.java
25   #15 = NameAndType        #6:#7          //  "<init>":()V
26   #16 = Class              #22            //  java/lang/System
27   #17 = NameAndType        #23:#24        //  out:Ljava/io/PrintStream;
28   #18 = Class              #25            //  java/io/PrintStream
29   #19 = NameAndType        #26:#27        //  println:(I)V
30   #20 = Utf8               example/Example
31   #21 = Utf8               java/lang/Object
32   #22 = Utf8               java/lang/System
33   #23 = Utf8               out
34   #24 = Utf8               Ljava/io/PrintStream;
35   #25 = Utf8               java/io/PrintStream
```

Classfile Teil 2

```
36    #26 = Utf8               println
37    #27 = Utf8               (I)V
38  {
39    example.Example();
40      Signature: ()V
41      flags:
42      LineNumberTable:
43        line 3: 0
44      Code:
45        stack=1, locals=1, args_size=1
46           0: aload_0
47           1: invokespecial #1                  // Method java/lang/Object."<init>":()V
48           4: return
49        LineNumberTable:
50          line 3: 0
51
52    public static void main(java.lang.String[]);
53      Signature: ([Ljava/lang/String;)V
54      flags: ACC_PUBLIC, ACC_STATIC
55      LineNumberTable:
56        line 6: 0
57        line 7: 7
58        line 6: 14
59        line 9: 20
60      Code:
61        stack=2, locals=2, args_size=1
62           0: iconst_0
63           1: istore_1
64           2: iload_1
65           3: iconst_5
66           4: if_icmpge     20
67           7: getstatic     #2                  // Field java/lang/System.out:Ljava/io/PrintStream;
68          10: iload_1
69          11: invokevirtual #3                  // Method java/io/PrintStream.println:(I)V
70          14: iinc          1, 1
71          17: goto          2
```

Classfile Teil 3

```
72          20: return
73        LineNumberTable:
74          line 6: 0
75          line 7: 7
76          line 6: 14
77          line 9: 20
78        StackMapTable: number_of_entries = 2
79             frame_type = 252 /* append */
80               offset_delta = 2
81          locals = [ int ]
82             frame_type = 250 /* chop */
83            offset_delta = 17
84
85    }
```

Quellen

- The Java Virtual Machine Specification, Java SE 7 Edition
  `http://docs.oracle.com/javase/specs/jvms/se7/html/`
  insbesondere Kapitel 6: Java Virtual Machine Instruction Set
- Java Class File Disassembler Documentation
  `http://docs.oracle.com/javase/7/docs/technotes/tools/windows/javap.html`
- `http://en.wikipedia.org/wiki/Java_bytecode`
- `http://www.javaworld.com/jw-09-1996/jw-09-bytecodes.html`