JVM和字节码基础

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Reference

- http://blog.jamesdbloom.com/JavaCodeToByteCode_PartOne.html
- https://docs.oracle.com/javase/specs/jvms/se7/html/index.html
- http://cs.au.dk/~mis/dOvs/jvmspec/ref-Java.html
- http://blog.csdn.net/luanlouis/article/details/39892027
- http://blog.csdn.net/zq602316498/article/details/38847935
- https://zh.wikipedia.org/wiki/Java%E5%AD%97%E8%8A%82%E7%A0%81

Outline

- JVM与字节码
- class文件结构
- 运行时数据区
- 字节码指令集
- 字节码的执行
- Java指令与字节码

1 JVM与字节码

Java代码

```
outer:
for (int i = 2; i < 1000; i++) {
    for (int j = 2; j < i; j++) {
        if (i % j == 0)
            continue outer;
    }
    System.out.println (i);
}
```

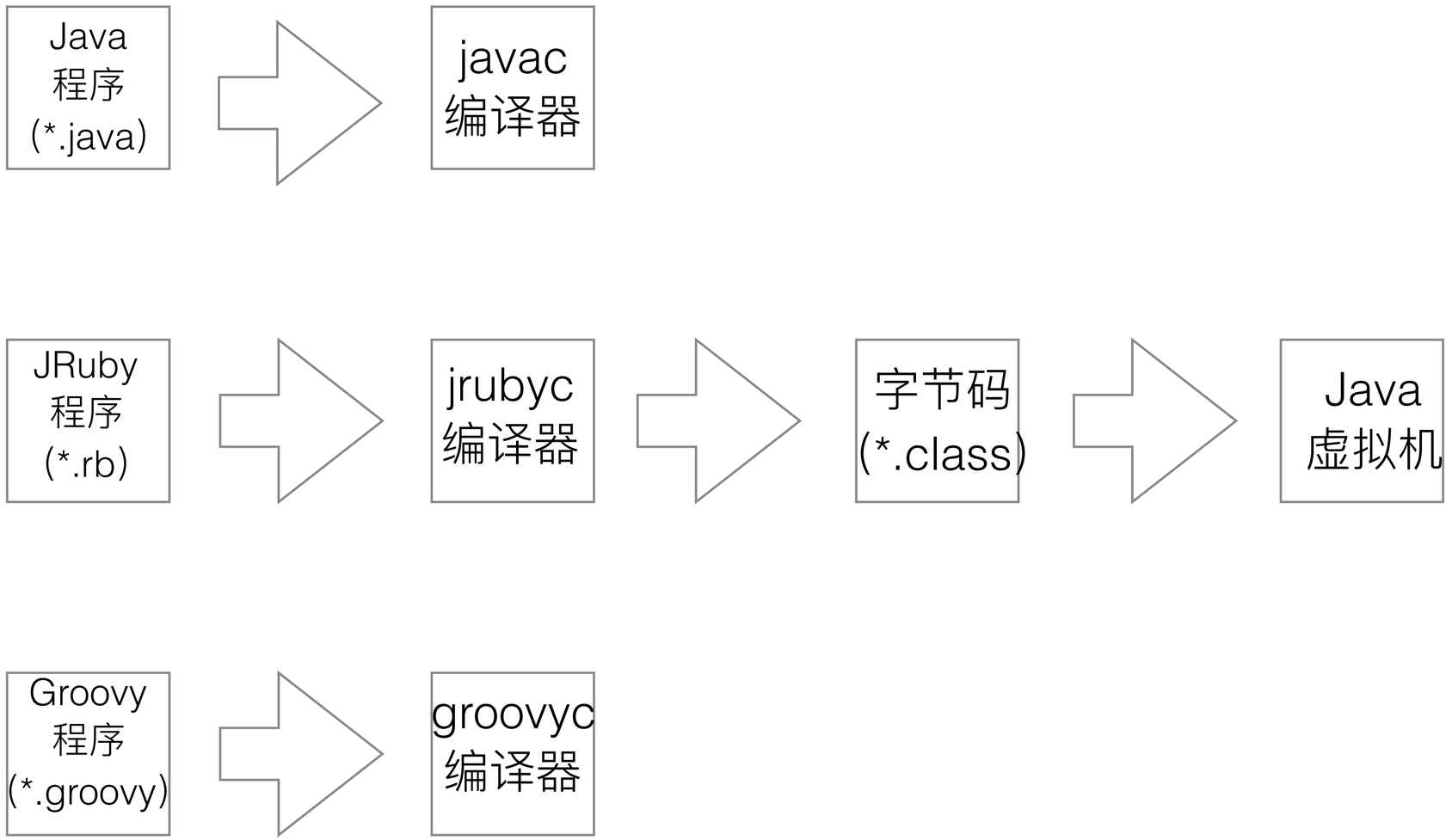
Java代码编译成字节码

字节码

- 0: iconst_2
- 1: istore_1
- 2: iload_1
- 3: sipush 1000
- 6: if_icmpge 44
- 9: iconst_2
- 10: istore_2
- 11: iload_2
- 12: iload_1
- 13: if_icmpge 31
- 16: iload_1
- 17: iload_2
- 18: irem
- 19: ifne 25
- 22: goto 38
- 25: iinc 2, 1
- 28: goto 11
- 31: getstatic #84; // Field java/lang/System.out:Ljava/io/PrintStream;
- 34: iload_1
- 35: invokevirtual #85; // Method java/io/PrintStream.println:(I)V
- 38: iinc 1, 1
- 41: goto 2
- 44: return

字节码
在虚拟机中
执行

语言无关性



Java虚拟机提供的语言无关性

2 class文件结构

实例文件

```
1.  package org.fenixsoft.clazz;


3.  public class TestClass{
4.
5.      private int m;


7.      public int inc(){
8.              return m+1;
9.      }
10.}
```

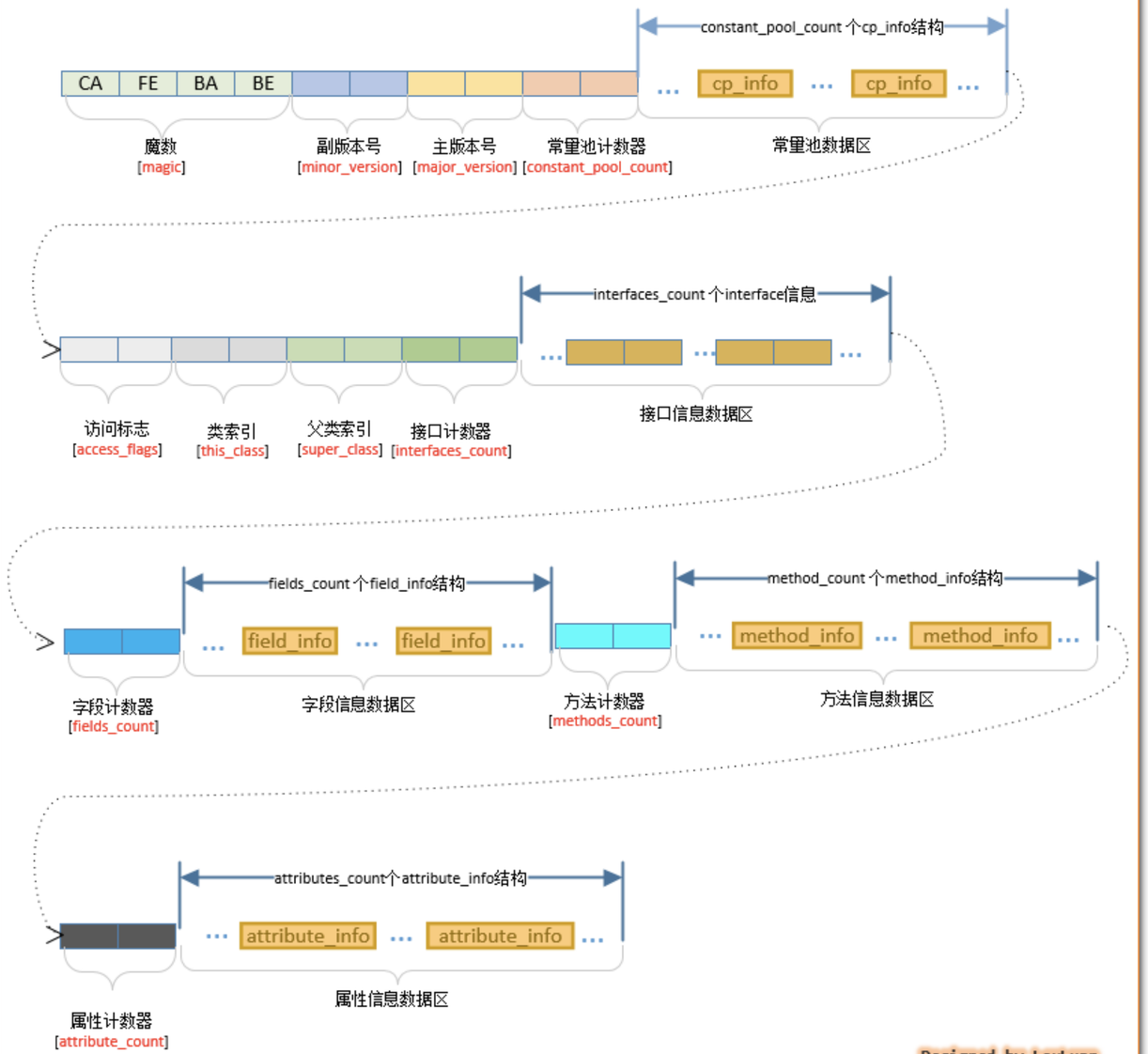
```
promote:~ qinliu$ javac TestClass.java
promote:~ qinliu$ javap -verbose TestClass
警告: 二进制文件TestClass包含org.fenixsoft.clazz.TestClass
Classfile /Users/qinliu/TestClass.class
  Last modified 2015-4-15; size 295 bytes
  MD5 checksum 81f2ab948a7a3068839b61a8f91f634b
  Compiled from "TestClass.java"
public class org.fenixsoft.clazz.TestClass
  minor version: 0
  major version: 52
  flags: ACC_PUBLIC, ACC_SUPER
Constant pool:
   #1 = Methodref          #4.#15         // java/lang/
Object."<init>":()V
   #2 = Fieldref           #3.#16         // org/fenixsoft/clazz/
TestClass.m:I
   #3 = Class              #17            // org/fenixsoft/clazz/
TestClass
   #4 = Class              #18            // java/lang/Object
   #5 = Utf8               m
   #6 = Utf8               I
   #7 = Utf8               <init>
   #8 = Utf8               ()V
   #9 = Utf8               Code
  #10 = Utf8               LineNumberTable
  #11 = Utf8               inc
  #12 = Utf8               ()I
  #13 = Utf8               SourceFile
  #14 = Utf8               TestClass.java
  #15 = NameAndType        #7:#8          // "<init>":()V
  #16 = NameAndType        #5:#6          // m:I
  #17 = Utf8               org/fenixsoft/clazz/TestClass
  #18 = Utf8               java/lang/Object
{
  public org.fenixsoft.clazz.TestClass();
    descriptor: ()V
    flags: ACC_PUBLIC
    Code:
      stack=1, locals=1, args_size=1
         0: aload_0
         1: invokespecial #1                  // Method java/
lang/Object."<init>":()V
         4: return
      LineNumberTable:
        line 3: 0

  public int inc();
    descriptor: ()I
    flags: ACC_PUBLIC
    Code:
      stack=2, locals=1, args_size=1
         0: aload_0
         1: getfield      #2                  // Field m:I
         4: iconst_1
         5: iadd
         6: ireturn
      LineNumberTable:
        line 8: 0
}
SourceFile: "TestClass.java"
```

Class文件结构

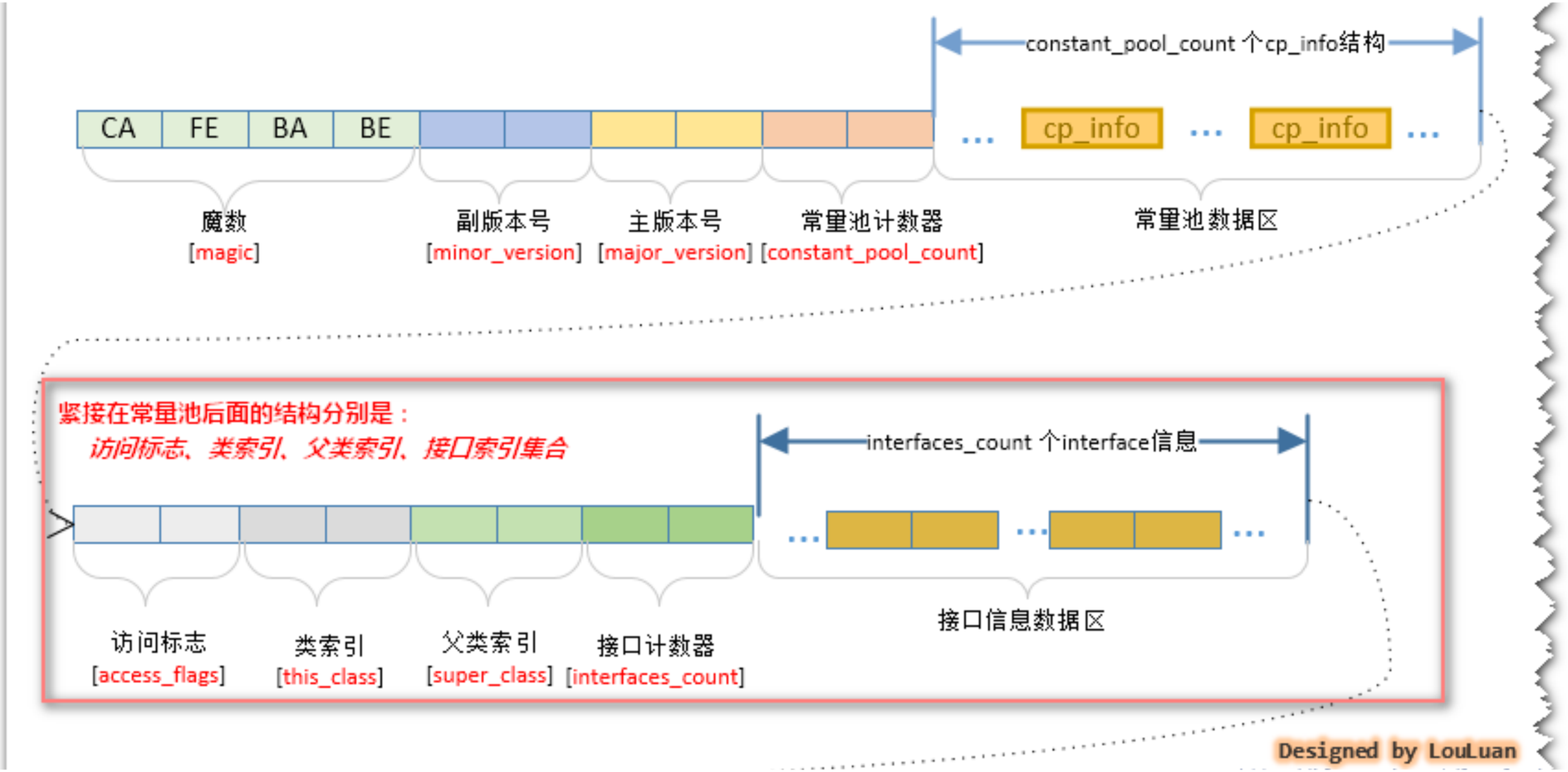
- 一组以8位字节为基础单位的二进制流
- 魔数
    - 0xCAFEBABE
- 版本号
- 常量池
    - 字面量
    - 符号引用
- 访问标志
- 类索引、父类索引与接口索引集合
- 字段表集合
- 方法表集合
- 属性表集合　（代码的实现作为一个属性值）

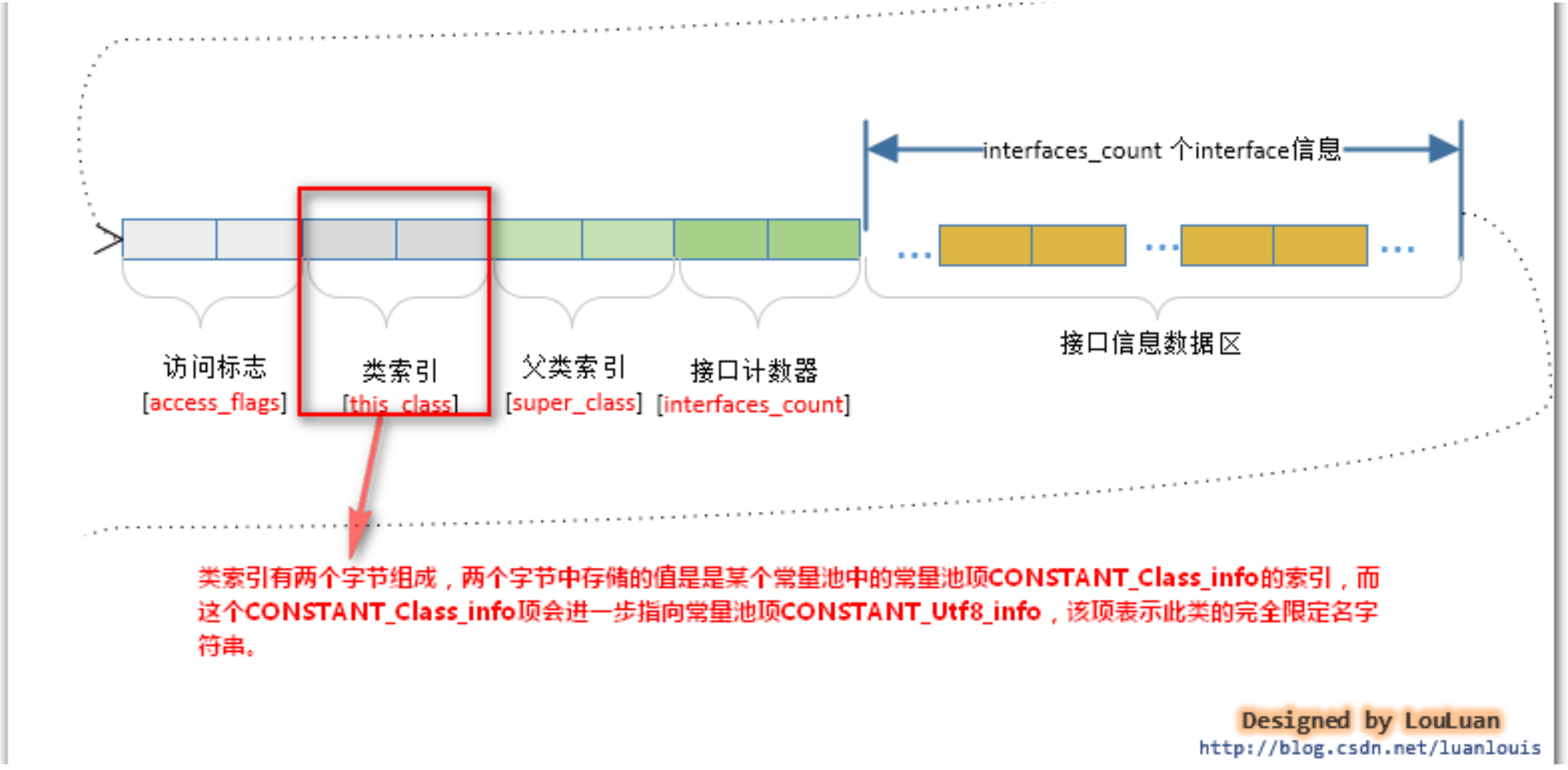
Class文件字节码结构组织示意图

注：被编译器编译成的.class字节码文件的字节流以及其组织结构如下如所示：



Designed by LouLuan


constant_pool_count 个cp_info结构
CA
FE
BA
BE
cp_info
cp_info
魔数
[magic]
副版本号
[minor_version]
主版本号
[major_version]
常量池计数器
[constant_pool_count]
常量池数据区
紧接在常量池后面的结构分别是：
访问标志、类索引、父类索引、接口索引集合
interfaces_count 个interface信息
访问标志
[access_flags]
类索引
[this_class]
父类索引
[super_class]
接口计数器
[interfaces_count]
接口信息数据区
Designed by LouLuan


interfaces_count 个interface信息
访问标志
[access_flags]
类索引
[this_class]
父类索引
[super_class]
接口计数器
[interfaces_count]
接口信息数据区
类索引有两个字节组成，两个字节中存储的值是是某个常量池中的常量池项CONSTANT_Class_info的索引，而这个CONSTANT_Class_info项会进一步指向常量池项CONSTANT_Utf8_info，该项表示此类的完全限定名字符串。
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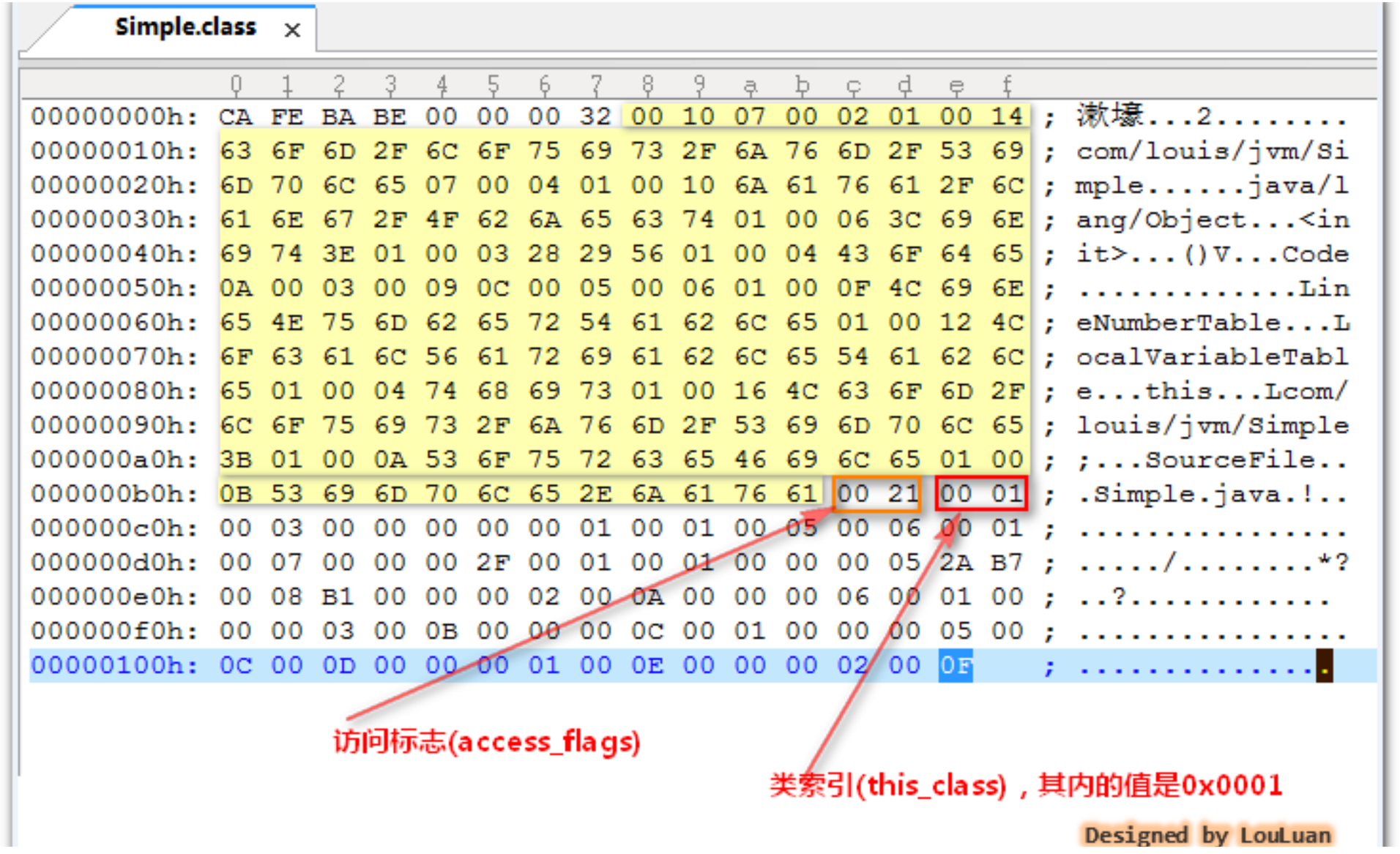
Simple.class
0 1 2 3 4 5 6 7 8 9 a b c d e f
00000000h: CA FE BA BE 00 00 00 32 00 10 07 00 02 01 00 14 ; 潵壕...2........
00000010h: 63 6F 6D 2F 6C 6F 75 69 73 2F 6A 76 6D 2F 53 69 ; com/louis/jvm/Si
00000020h: 6D 70 6C 65 07 00 04 01 00 10 6A 61 76 61 2F 6C ; mple......java/l
00000030h: 61 6E 67 2F 4F 62 6A 65 63 74 01 00 06 3C 69 6E ; ang/Object...<in
00000040h: 69 74 3E 01 00 03 28 29 56 01 00 04 43 6F 64 65 ; it>...()V...Code
00000050h: 0A 00 03 00 09 0C 00 05 00 06 01 00 0F 4C 69 6E ; ....Lin
00000060h: 65 4E 75 6D 62 65 72 54 61 62 6C 65 01 00 12 4C ; eNumberTable...L
00000070h: 6F 63 61 6C 56 61 72 69 61 62 6C 65 54 61 62 6C ; ocalVariableTabl
00000080h: 65 01 00 04 74 68 69 73 01 00 16 4C 63 6F 6D 2F ; e...this...Lcom/
00000090h: 6C 6F 75 69 73 2F 6A 76 6D 2F 53 69 6D 70 6C 65 ; louis/jvm/Simple
000000a0h: 3B 01 00 0A 53 6F 75 72 63 65 46 69 6C 65 01 00 ; ;...SourceFile..
000000b0h: 0B 53 69 6D 70 6C 65 2E 6A 61 76 61 00 21 00 01 ; .Simple.java.!..
000000c0h: 00 03 00 00 00 00 00 01 00 01 00 05 00 06 00 01 ; ....
000000d0h: 00 07 00 00 00 2F 00 01 00 01 00 00 00 05 2A B7 ; ...../........*?
000000e0h: 00 08 B1 00 00 00 02 00 0A 00 00 00 06 00 01 00 ; ..?.............
000000f0h: 00 00 03 00 0B 00 00 00 0C 00 01 00 00 00 05 00 ; ....
00000100h: 0C 00 0D 00 00 00 01 00 0E 00 00 00 02 00 0F ; ....
访问标志(access_flags)
类索引(this_class)，其内的值是0x0001
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```
Constant pool:
   #1 = Class              #2             //  com/louis/jvm/Simple
   #2 = Utf8               com/louis/jvm/Simple
   #3 = Class              #4             //  java/lang/Object
   #4 = Utf8               java/lang/Object
   #5 = Utf8               <init>
   #6 = Utf8               ()V
```

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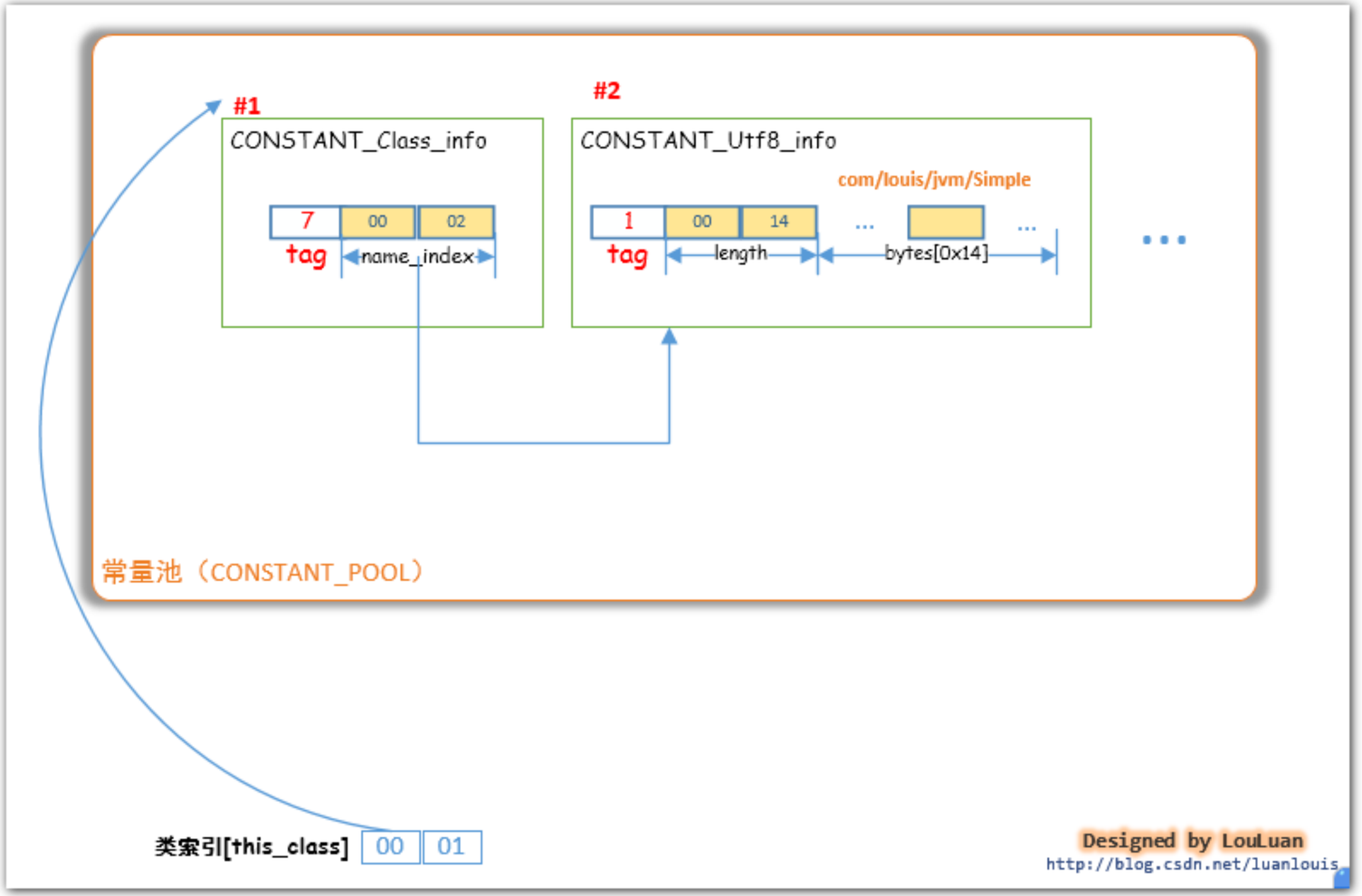

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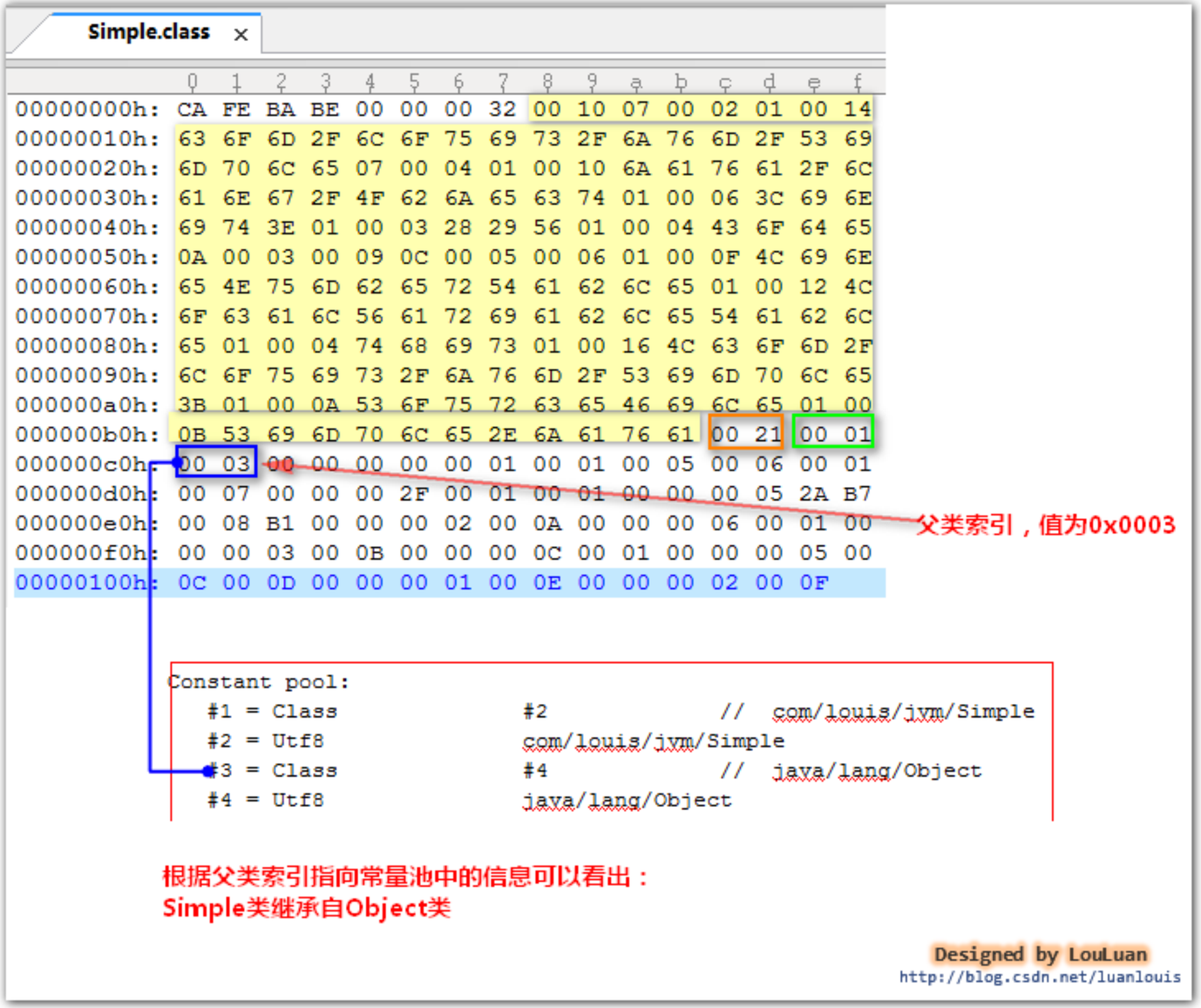
Simple.class
0 1 2 3 4 5 6 7 8 9 a b c d e f
00000000h: CA FE BA BE 00 00 00 32 00 10 07 00 02 01 00 14
00000010h: 63 6F 6D 2F 6C 6F 75 69 73 2F 6A 76 6D 2F 53 69
00000020h: 6D 70 6C 65 07 00 04 01 00 10 6A 61 76 61 2F 6C
00000030h: 61 6E 67 2F 4F 62 6A 65 63 74 01 00 06 3C 69 6E
00000040h: 69 74 3E 01 00 03 28 29 56 01 00 04 43 6F 64 65
00000050h: 0A 00 03 00 09 0C 00 05 00 06 01 00 0F 4C 69 6E
00000060h: 65 4E 75 6D 62 65 72 54 61 62 6C 65 01 00 12 4C
00000070h: 6F 63 61 6C 56 61 72 69 61 62 6C 65 54 61 62 6C
00000080h: 65 01 00 04 74 68 69 73 01 00 16 4C 63 6F 6D 2F
00000090h: 6C 6F 75 69 73 2F 6A 76 6D 2F 53 69 6D 70 6C 65
000000a0h: 3B 01 00 0A 53 6F 75 72 63 65 46 69 6C 65 01 00
000000b0h: 0B 53 69 6D 70 6C 65 2E 6A 61 76 61 00 21 00 01
000000c0h: 00 03 00 00 00 00 00 01 00 01 00 05 00 06 00 01
000000d0h: 00 07 00 00 00 2F 00 01 00 01 00 00 00 05 2A B7
000000e0h: 00 08 B1 00 00 00 02 00 0A 00 00 00 06 00 01 00
000000f0h: 00 00 03 00 0B 00 00 00 0C 00 01 00 00 00 05 00
00000100h: 0C 00 0D 00 00 00 01 00 0E 00 00 00 02 00 0F
父类索引，值为0x0003
Constant pool:
#1 = Class #2 // com/louis/jvm/Simple
#2 = Utf8 com/louis/jvm/Simple
#3 = Class #4 // java/lang/Object
#4 = Utf8 java/lang/Object
根据父类索引指向常量池中的信息可以看出：
Simple类继承自Object类
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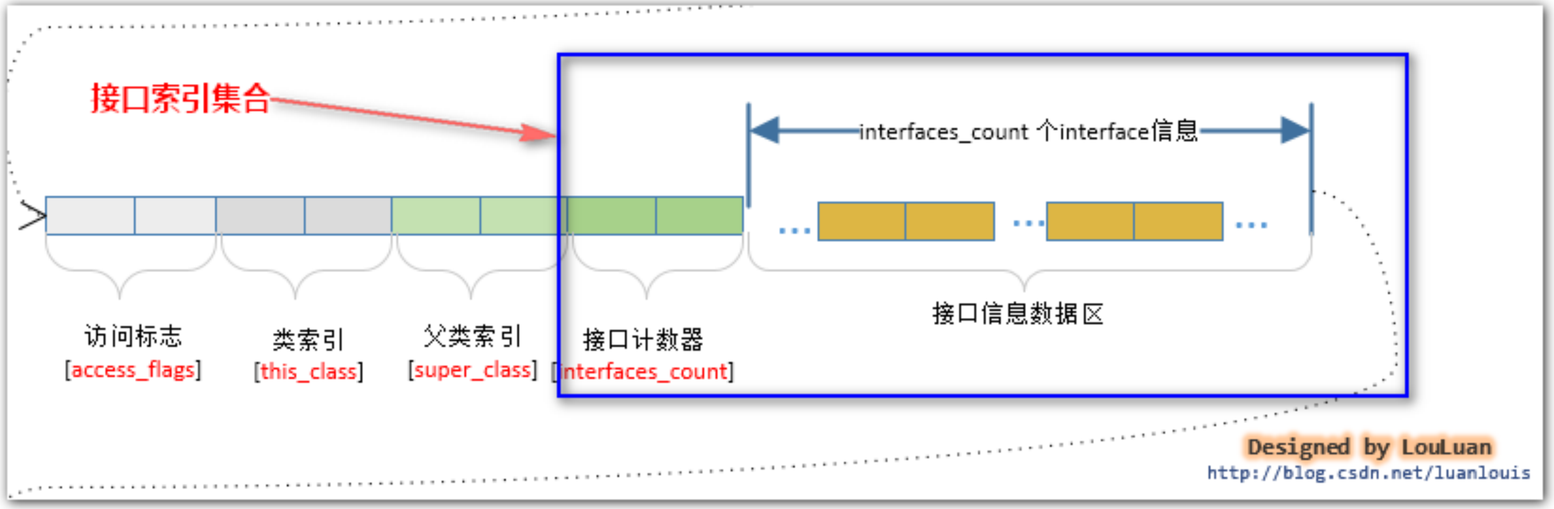
接口索引集合
interfaces_count 个interface信息
访问标志
[access_flags]
类索引
[this_class]
父类索引
[super_class]
接口计数器
[interfaces_count]
接口信息数据区
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[java] view plain copy print ?

```java
/**
 * Worker 接口类
 * @author luan louis
 */
public interface Worker{

    public void work();

}
```

[java] view plain copy print ?

```java
package com.louis.jvm;

public class Programmer implements Worker {

    @Override
    public void work() {
        System.out.println("I'm Programmer,Just coding....");
    }
}
```

Programmer.class

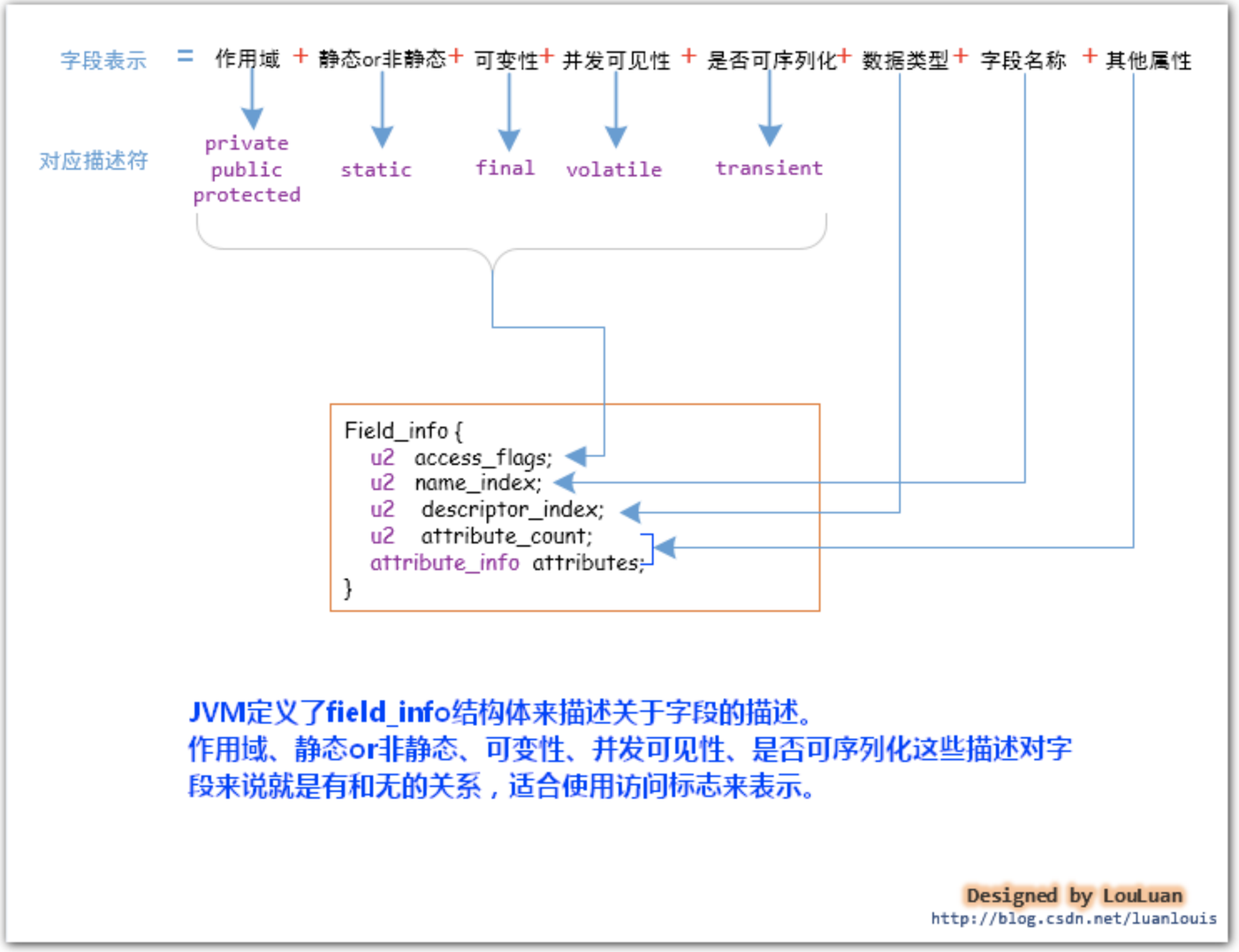
```
          0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00000000h: CA FE BA BE 00 00 00 32 00 21 07 00 02 01 00 18
00000010h: 63 6F 6D 2F 6C 6F 75 69 73 2F 6A 76 6D 2F 50 72
00000020h: 6F 67 72 61 6D 6D 65 72 07 00 04 01 00 10 6A 61
00000030h: 76 61 2F 6C 61 6E 67 2F 4F 62 6A 65 63 74 07 00
00000040h: 06 01 00 14 63 6F 6D 2F 6C 6F 75 69 73 2F 6A 76
00000050h: 6D 2F 57 6F 72 6B 65 72 01 00 06 3C 69 6E 69 74
00000060h: 3E 01 00 03 28 29 56 01 00 04 43 6F 64 65 0A 00
00000070h: 03 00 0B 0C 00 07 00 08 01 00 0F 4C 69 6E 65 4E
00000080h: 75 6D 62 65 72 54 61 62 6C 65 01 00 12 4C 6F 63
00000090h: 61 6C 56 61 72 69 61 62 6C 65 54 61 62 6C 65 01
000000a0h: 00 04 74 68 69 73 01 00 1A 4C 63 6F 6D 2F 6C 6F
000000b0h: 75 69 73 2F 6A 76 6D 2F 50 72 6F 67 72 61 6D 6D
000000c0h: 65 72 3B 01 00 04 77 6F 72 6B 09 00 12 00 14 07
000000d0h: 00 13 01 00 10 6A 61 76 61 2F 6C 61 6E 67 2F 53
000000e0h: 79 73 74 65 6D 0C 00 15 00 16 01 00 03 6F 75 74
000000f0h: 01 00 15 4C 6A 61 76 61 2F 69 6F 2F 50 72 69 6E
00000100h: 74 53 74 72 65 61 6D 3B 08 00 18 01 00 1E 49 27
00000110h: 6D 20 50 72 6F 67 72 61 6D 6D 65 72 2C 4A 75 73
00000120h: 74 20 63 6F 64 69 6E 67 2E 2E 2E 2E 0A 00 1A 00
00000130h: 1C 07 00 1B 01 00 13 6A 61 76 61 2F 69 6F 2F 50
00000140h: 72 69 6E 74 53 74 72 65 61 6D 0C 00 1D 00 1E 01
00000150h: 00 07 70 72 69 6E 74 6C 6E 01 00 15 28 4C 6A 61
00000160h: 76 61 2F 6C 61 6E 67 2F 53 74 72 69 6E 67 3B 29
00000170h: 56 01 00 0A 53 6F 75 72 63 65 46 69 6C 65 01 00
00000180h: 0F 50 72 6F 67 72 61 6D 6D 65 72 2E 6A 61 76 61
00000190h: 00 21 00 01 00 03 00 01 00 05 00 00 00 02 00 01
000001a0h: 00 07 00 08 00 01 00 09 00 00 00 2F 00 01 00 01
000001b0h: 00 00 00 05 2A B7 00 0A B1 00 00 00 02 00 0C 00
000001c0h: 00 00 06 00 01 00 00 00 03 00 0D 00 00 00 0C 00
000001d0h: 01 00 00 00 05 00 0E 00 0F 00 00 00 01 00 10 00
000001e0h: 08 00 01 00 09 00 00 00 37 00 02 00 01 00 00 00
000001f0h: 09 B2 00 11 12 17 B6 00 19 B1 00 00 00 02 00 0C
00000200h: 00 00 00 0A 00 02 00 00 00 07 00 08 00 08 00 0D
00000210h: 00 00 00 0C 00 01 00 00 00 09 00 0E 00 0F 00 00
00000220h: 00 01 00 1F 00 00 00 02 00 20
```

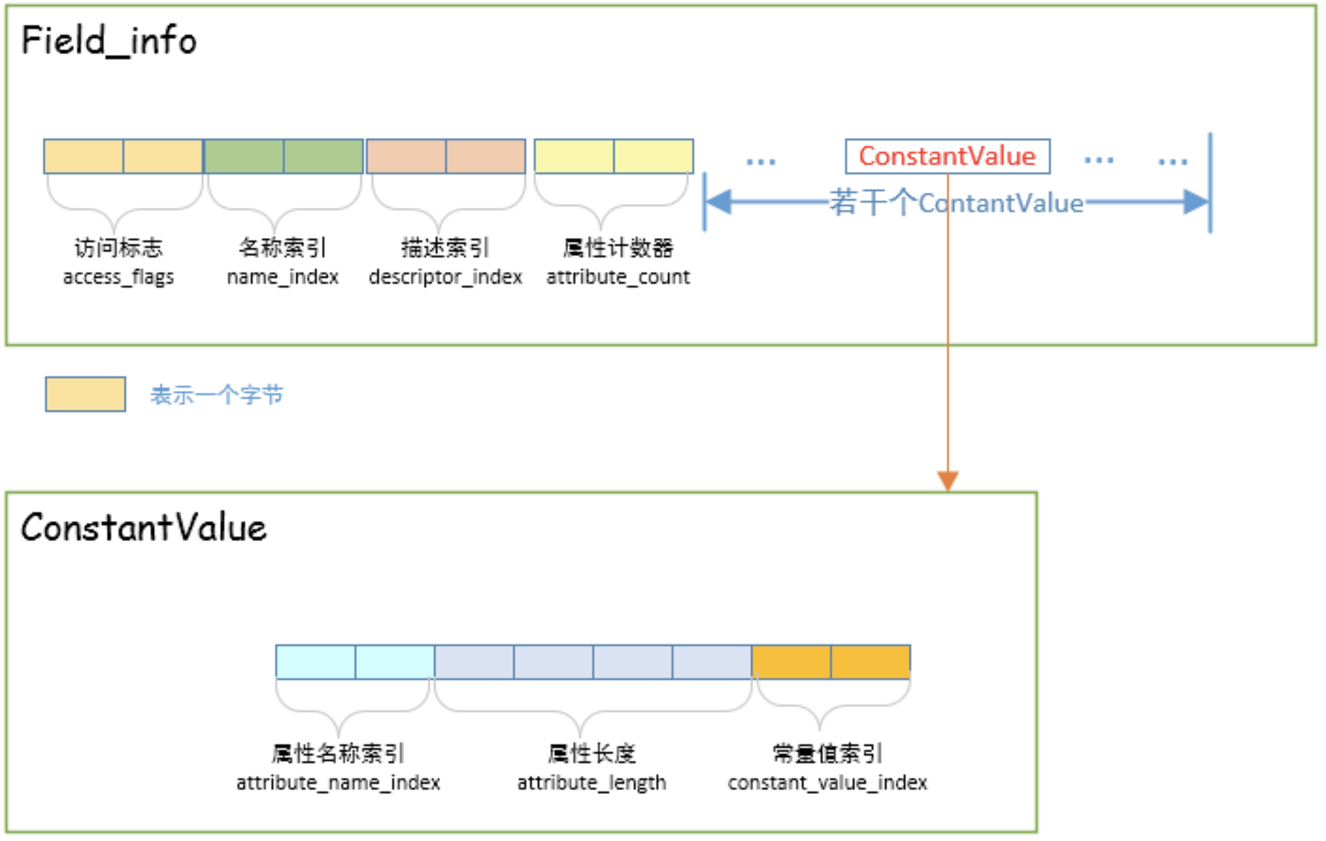
常量池

访问标志　类索引　父类索引　接口索引集合

接口索引集合区域，接口计数器为**01**，表示就实现了一个接口，
该接口引用指向常量池的第5个常量池项

```
Constant pool:
   #1 = Class              #2             //  com/louis/jvm/Programmer
   #2 = Utf8               com/louis/jvm/Programmer
   #3 = Class              #4             //  java/lang/Object
   #4 = Utf8               java/lang/Object
   #5 = Class              #6             //  com/louis/jvm/Worker
   #6 = Utf8               com/louis/jvm/Worker
```


字段表示
=
作用域
+
静态or非静态
+
可变性
+
并发可见性
+
是否可序列化
+
数据类型
+
字段名称
+
其他属性
对应描述符
private
public
protected
static
final
volatile
transient
Field_info {
u2 access_flags;
u2 name_index;
u2 descriptor_index;
u2 attribute_count;
attribute_info attributes;
}
JVM定义了field_info结构体来描述关于字段的描述。
作用域、静态or非静态、可变性、并发可见性、是否可序列化这些描述对字段来说就是有和无的关系，适合使用访问标志来表示。
Designed by LouLuan
http://blog.csdn.net/luanlouis



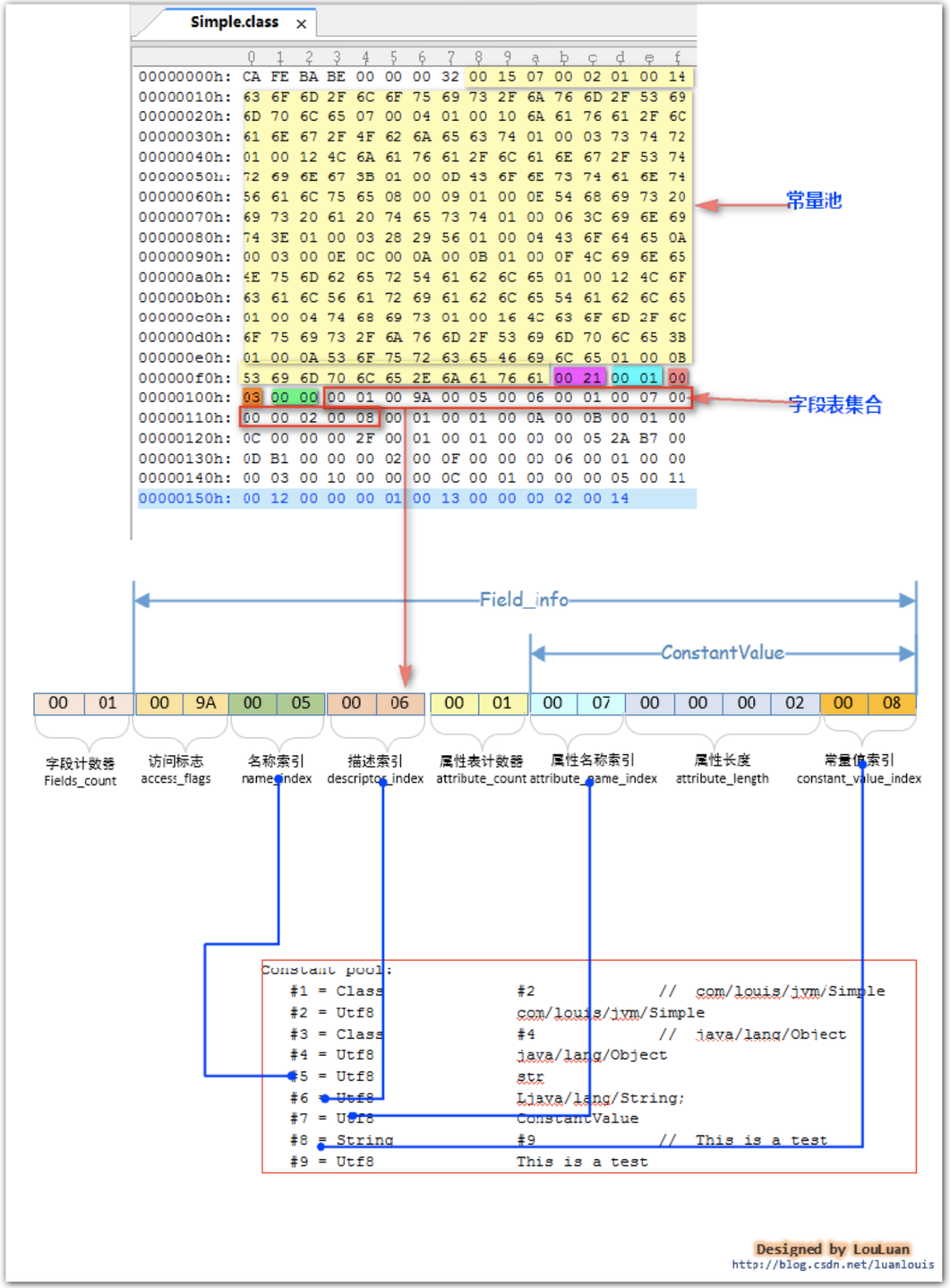
属性名称索引的值是指向常量池中某个常量池项的索引，该常量池项表示的字符串为“ConstantValue”
属性长度中的值固定为2
常量池索引的值是指向常量池中某个常量池项的索引，表示要复制给field字段的值

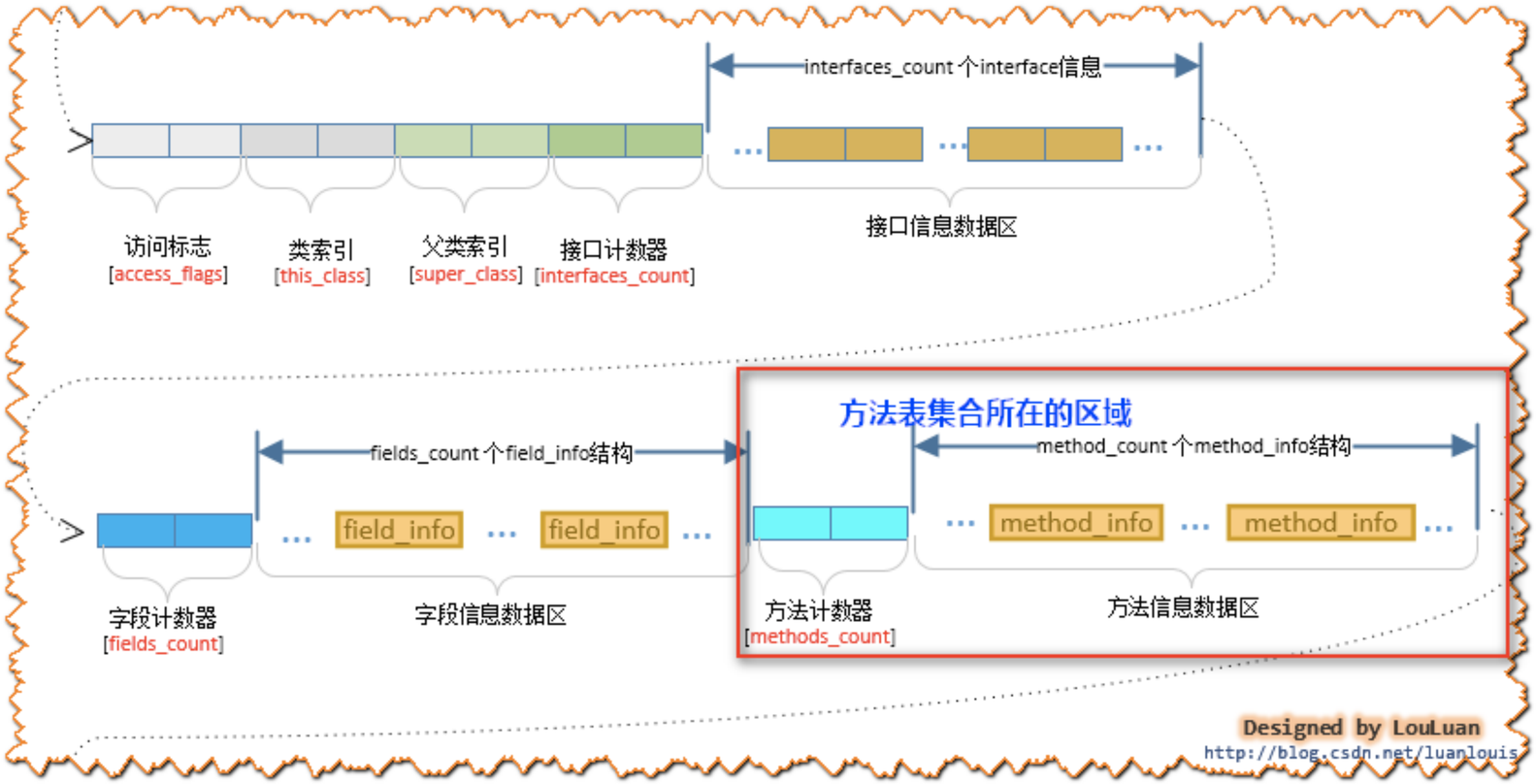
Sample Code

```
1. package com.louis.jvm;


3. public class Simple {


5. private  transient static final String str ="This is a test";
6. }
7.
```


Simple.class
常量池
字段表集合
Field_info
ConstantValue
00 01 00 9A 00 05 00 06 00 01 00 07 00 00 00 02 00 08
字段计数器 Fields_count
访问标志 access_flags
名称索引 name_index
描述索引 descriptor_index
属性表计数器 attribute_count
属性名称索引 attribute_name_index
属性长度 attribute_length
常量值索引 constant_value_index
Constant pool:
#1 = Class #2 // com/louis/jvm/Simple
#2 = Utf8 com/louis/jvm/Simple
#3 = Class #4 // java/lang/Object
#4 = Utf8 java/lang/Object
#5 = Utf8 str
#6 = Utf8 Ljava/lang/String;
#7 = Utf8 ConstantValue
#8 = String #9 // This is a test
#9 = Utf8 This is a test
Designed by LouLuan
http://blog.csdn.net/luanlouis


interfaces_count 个interface信息
访问标志
[access_flags]
类索引
[this_class]
父类索引
[super_class]
接口计数器
[interfaces_count]
接口信息数据区
方法表集合所在的区域
fields_count 个field_info结构
method_count 个method_info结构
field_info
field_info
method_info
method_info
字段计数器
[fields_count]
字段信息数据区
方法计数器
[methods_count]
方法信息数据区
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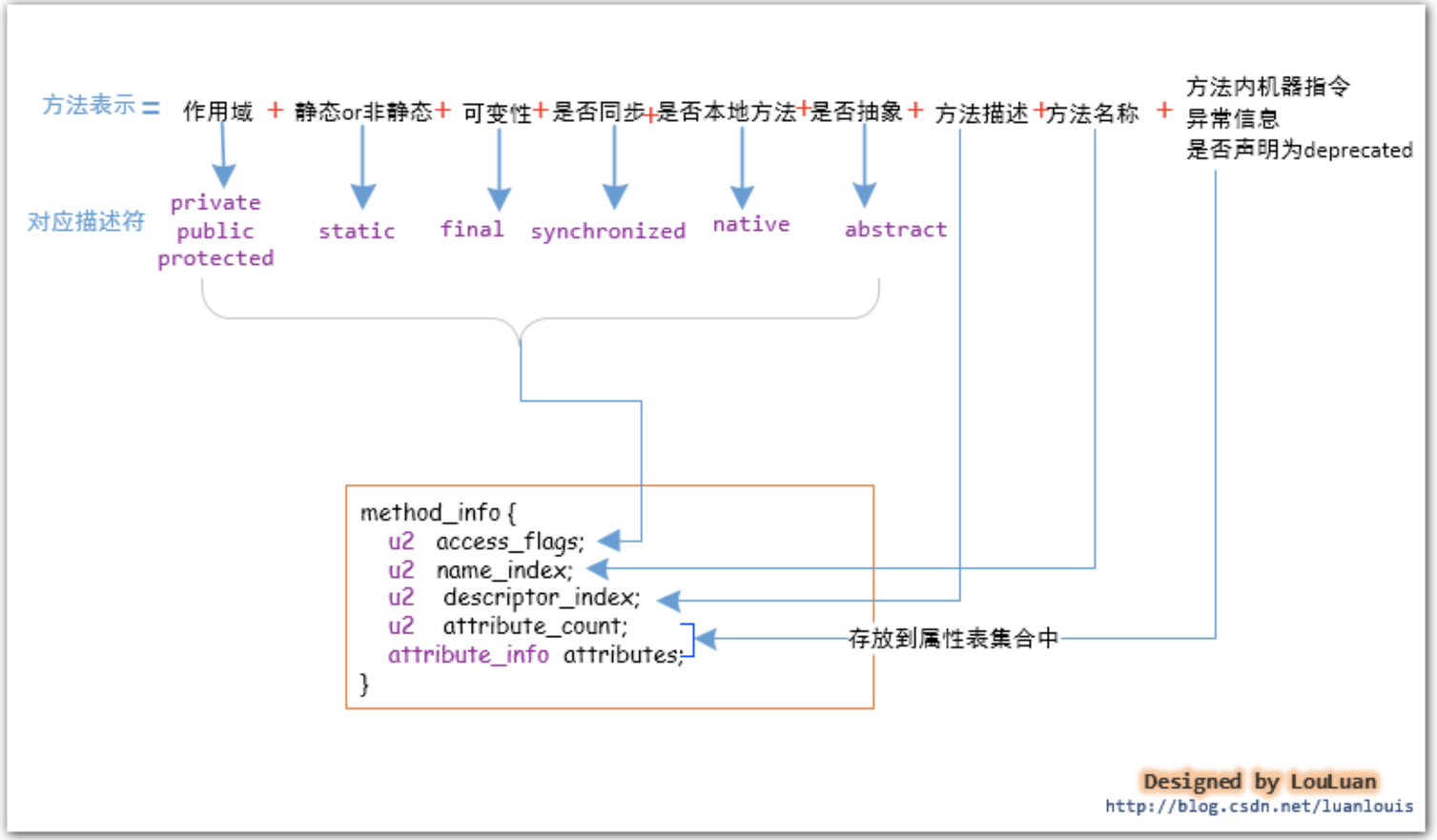
方法表示 =
作用域
+
静态or非静态
+
可变性
+
是否同步
+
是否本地方法
+
是否抽象
+
方法描述
+
方法名称
+
方法内机器指令
异常信息
是否声明为deprecated
对应描述符
private
public
protected
static
final
synchronized
native
abstract
method_info {
u2 access_flags;
u2 name_index;
u2 descriptor_index;
u2 attribute_count;
attribute_info attributes;
}
存放到属性表集合中
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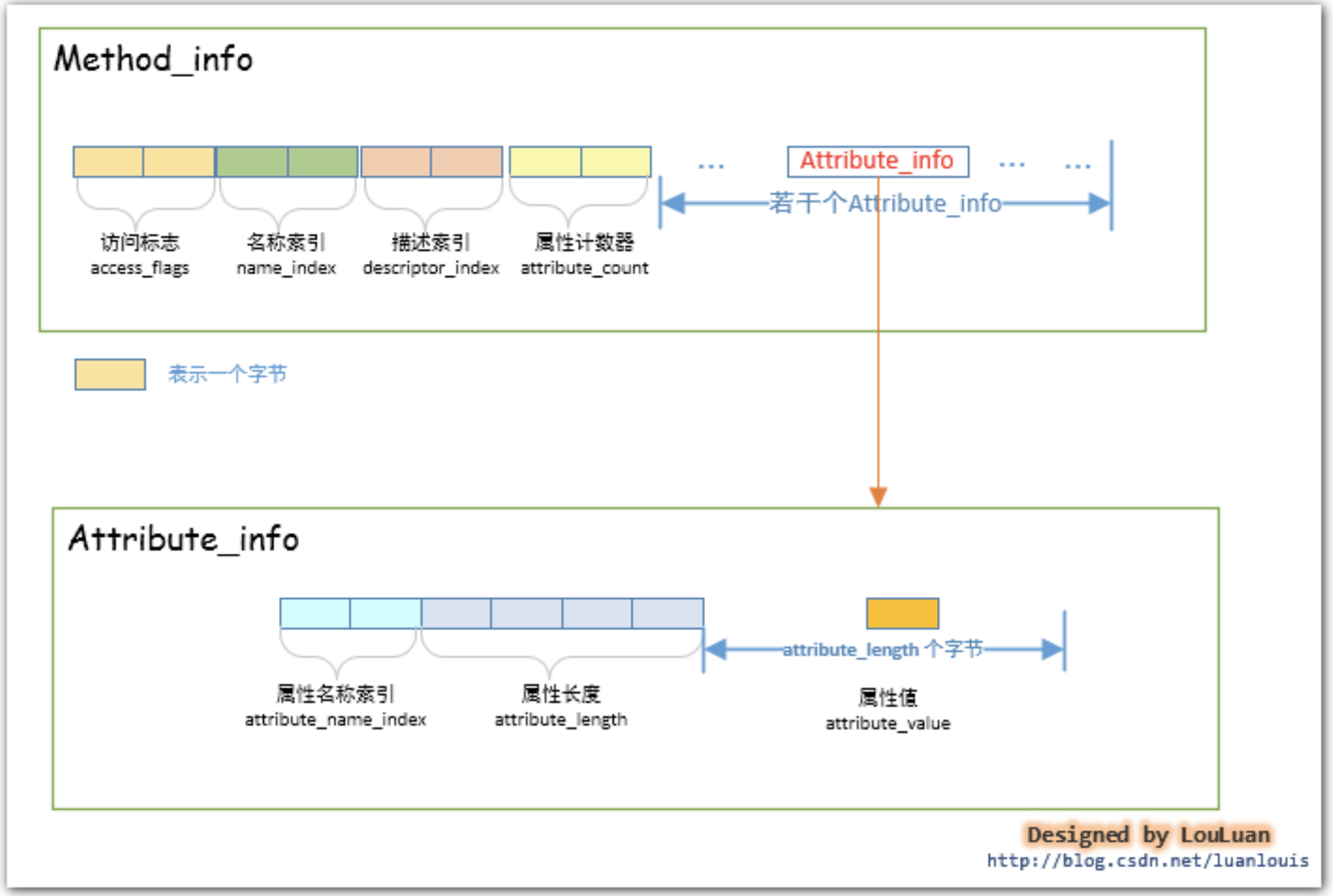
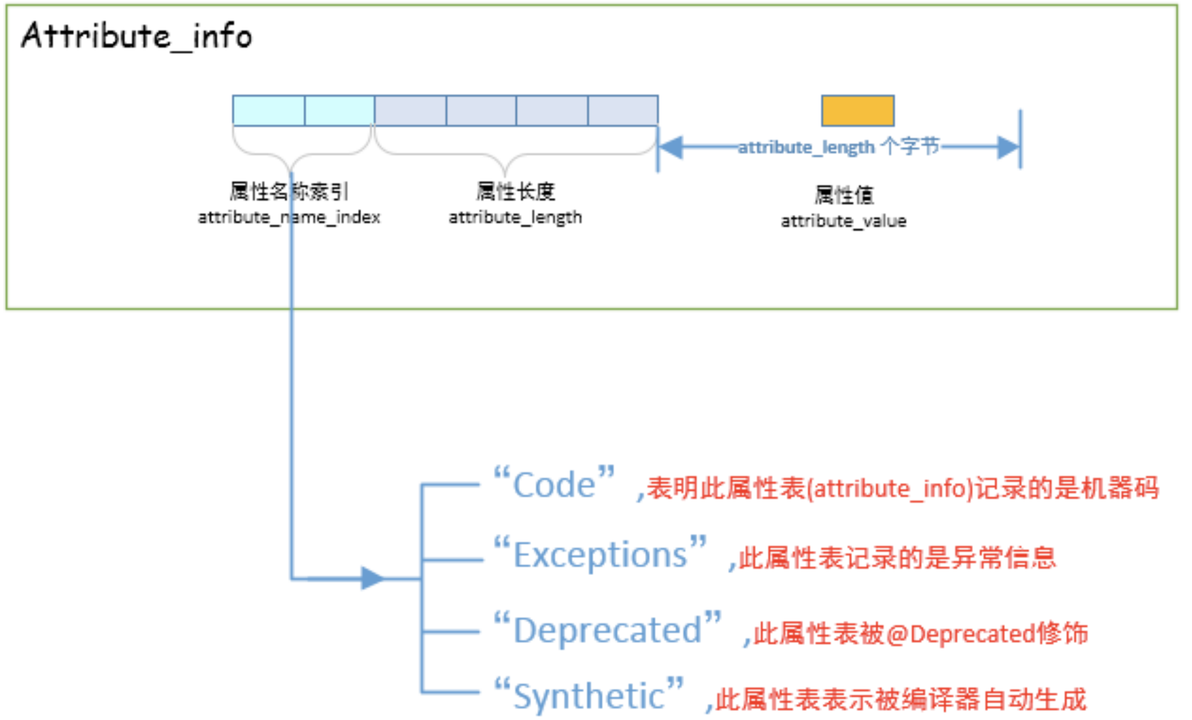

Method_info
Attribute_info
若干个Attribute_info
访问标志
access_flags
名称索引
name_index
描述索引
descriptor_index
属性计数器
attribute_count
表示一个字节
Attribute_info
attribute_length 个字节
属性名称索引
attribute_name_index
属性长度
attribute_length
属性值
attribute_value
Designed by LouLuan
http://blog.csdn.net/luanlouis

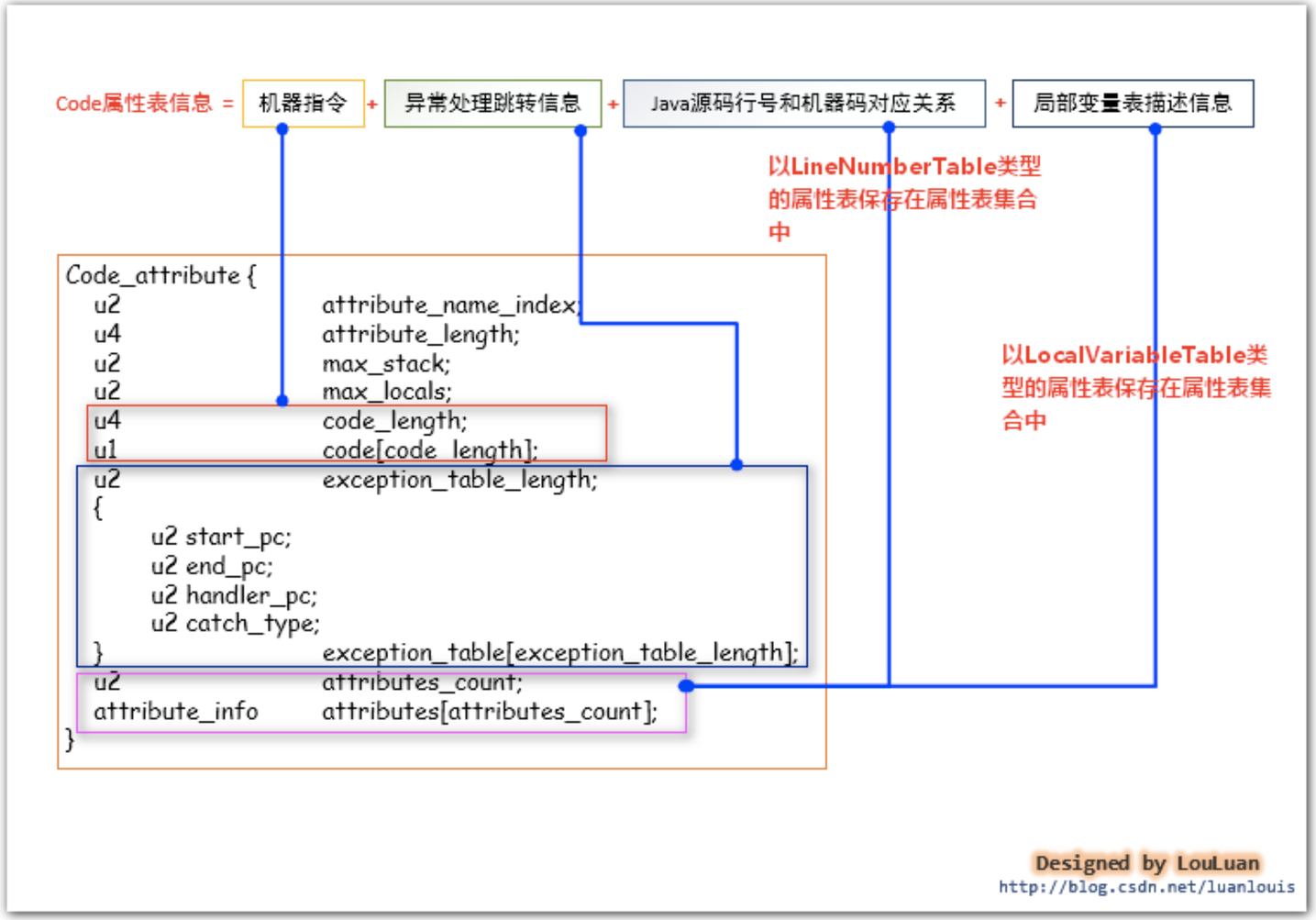


属性名称索引（attribute_name_index）占有**两个**字节，其中的值是指向了常量池中的某一项，该项表示的字符串表明该attribute_info表示的是什么类型的属性表。如：如上所示，如果指向的常量池项表示“Code”，则表明该属性表(attribute_info)表示的是代码实现，即可执行的机器码；

对于不同类型的属性表，它们的**属性长度和组织形式**会有所不同。

属性长度(attribute_length)占有两个字节，它的值表示紧跟其后的多少个字节是拿来表示这个属性信息的。即如果属性长度中的值为N，则表示它后面的N个字节是用来表示属性信息的。

属性值(attribute_value)是由若干个字节构成的，字节的个数由属性长度中的值决定。


Code属性表信息 =
机器指令
+
异常处理跳转信息
+
Java源码行号和机器码对应关系
+
局部变量表描述信息
以LineNumberTable类型的属性表保存在属性表集合中
以LocalVariableTable类型的属性表保存在属性表集合中
Code_attribute {
u2 attribute_name_index;
u4 attribute_length;
u2 max_stack;
u2 max_locals;
u4 code_length;
u1 code[code_length];
u2 exception_table_length;
{
u2 start_pc;
u2 end_pc;
u2 handler_pc;
u2 catch_type;
} exception_table[exception_table_length];
u2 attributes_count;
attribute_info attributes[attributes_count];
}
Designed by LouLuan
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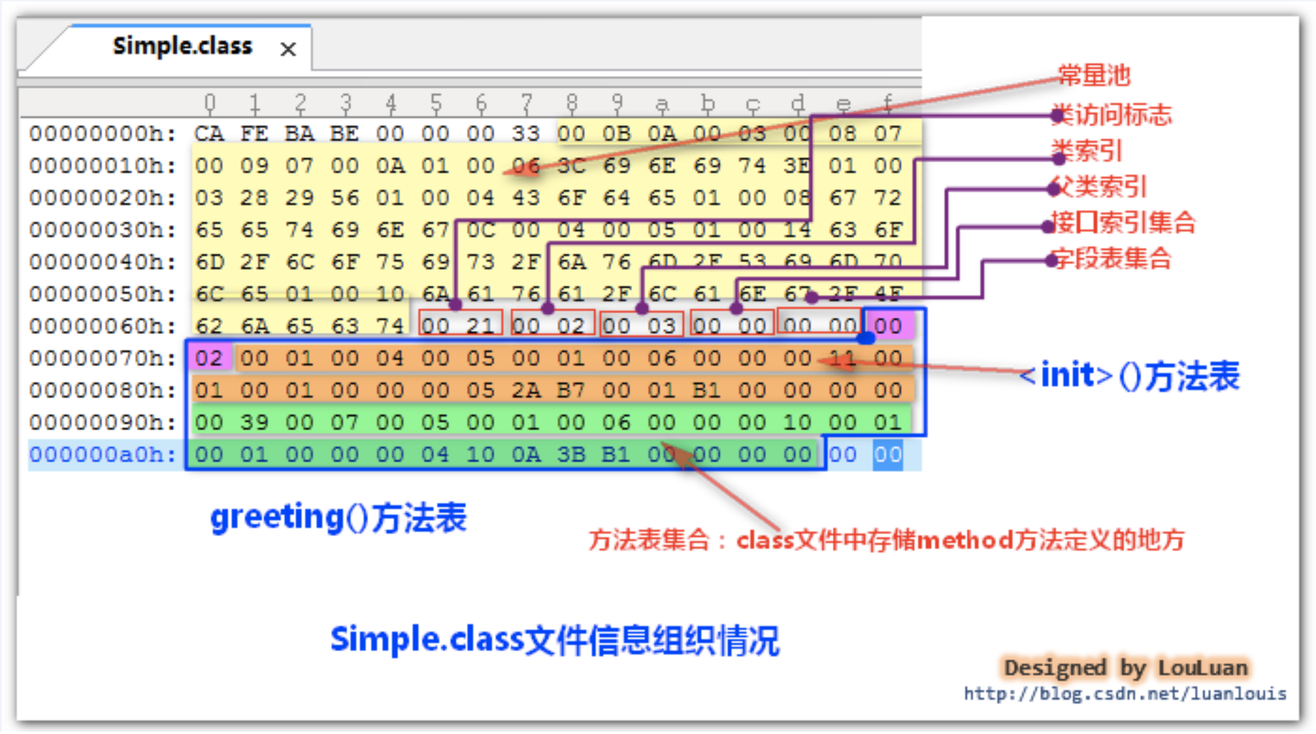
Sample Code - 方法

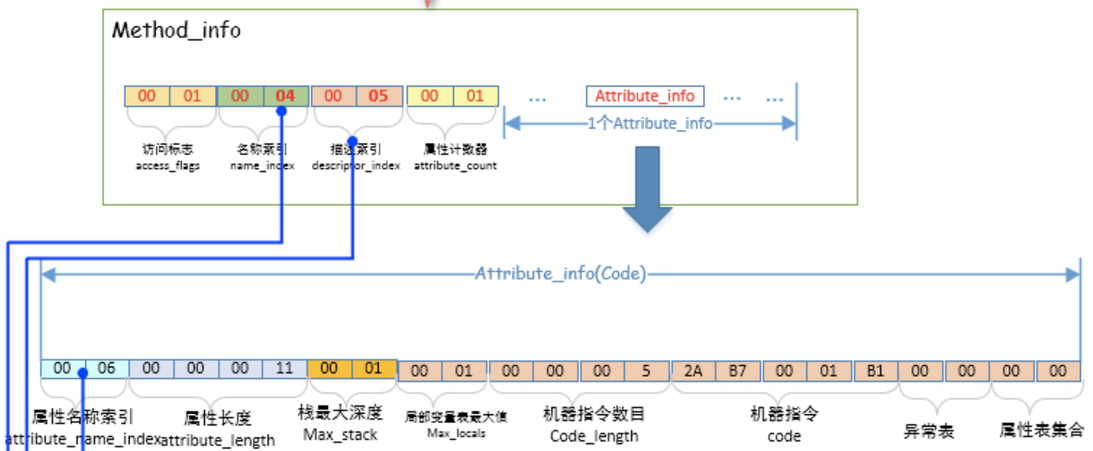
```
1. package com.louis.jvm;
2.
3. public class Simple {
4.
5.     public static synchronized final void greeting(){
6.         int a = 10;
7.     }
8. }
```


Simple.class
常量池
类访问标志
类索引
父类索引
接口索引集合
字段表集合
<init>()方法表
greeting()方法表
方法表集合：class文件中存储method方法定义的地方
Simple.class文件信息组织情况
Designed by LouLuan
http://blog.csdn.net/luanlouis

Simple.class × Simple.class ×

```
          0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00000000h: CA FE BA BE 00 00 00 33 00 0B 0A 00 03 00 08 07
00000010h: 00 09 07 00 0A 01 00 06 3C 69 6E 69 74 3E 01 00
00000020h: 03 28 29 56 01 00 04 43 6F 64 65 01 00 08 67 72
00000030h: 65 65 74 69 6E 67 0C 00 04 00 05 01 00 14 63 6F
00000040h: 6D 2F 6C 6F 75 69 73 2F 6A 76 6D 2F 53 69 6D 70
00000050h: 6C 65 01 00 10 6A 61 76 61 2F 6C 61 6E 67 2F 4F
00000060h: 62 6A 65 63 74 00 21 00 02 00 03 00 00 00 00 00
00000070h: 02 00 01 00 04 00 05 00 01 00 06 00 00 00 11 00
00000080h: 01 00 01 00 00 00 05 2A B7 00 01 B1 00 00 00 00
00000090h: 00 39 00 07 00 05 00 01 00 06 00 00 00 10 00 01
000000a0h: 00 01 00 00 00 04 10 0A 3B B1 00 00 00 00 00 00
```

<init>()方法表信息



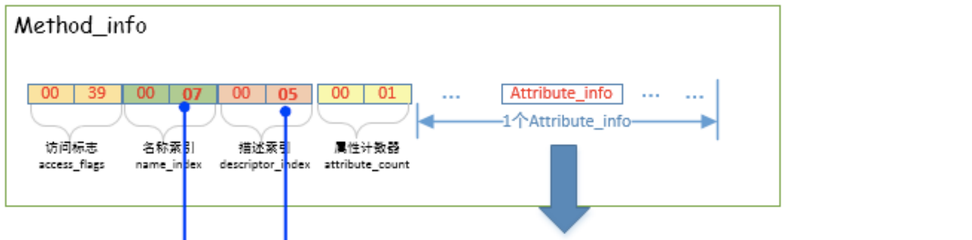

```
Constant pool:
   #1 = Methodref          #3.#8          //  java/lang/Object."<init>":()V
   #2 = Class              #9             //  com/louis/jvm/Simple
   #3 = Class              #10            //  java/lang/Object
   #4 = Utf8               <init>
   #5 = Utf8               ()V
   #6 = Utf8               Code
   #7 = Utf8               greeting
   #8 = NameAndType        #4:#5          //  "<init>":()V
   #9 = Utf8               com/louis/jvm/Simple
  #10 = Utf8               java/lang/Object
```

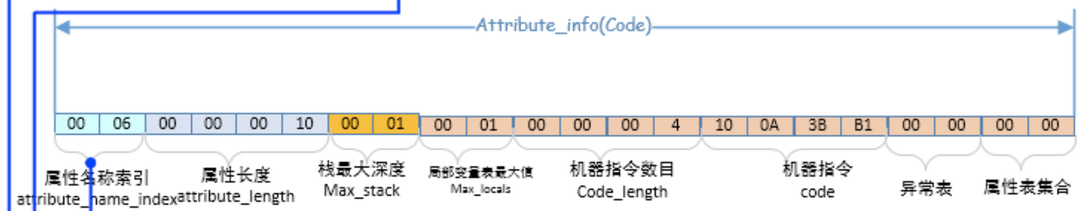
Designed by LouLuan
http://blog.csdn.net/luanlouis

```
public com.louis.jvm.Simple();
  flags: ACC_PUBLIC

  Code:
    stack=1, locals=1, args_size=1
       0: aload_0      2A
       1: invokespecial #1   B7 00 01       // Method java/lang/Object."<init>":()V
       4: return     B1
```

Simple.class × Simple.class ×

```
          0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00000000h: CA FE BA BE 00 00 00 33 00 0B 0A 00 03 00 08 07 ,
00000010h: 00 09 07 00 0A 01 00 06 3C 69 6E 69 74 3E 01 00 ,
00000020h: 03 28 29 56 01 00 04 43 6F 64 65 01 00 08 67 72 ,
00000030h: 65 65 74 69 6E 67 0C 00 04 00 05 01 00 14 63 6F ,
00000040h: 6D 2F 6C 6F 75 69 73 2F 6A 76 6D 2F 53 69 6D 70 ,
00000050h: 6C 65 01 00 10 6A 61 76 61 2F 6C 61 6E 67 2F 4F ,
00000060h: 62 6A 65 63 74 00 21 00 02 00 03 00 00 00 00 00 ,
00000070h: 02 00 01 00 04 00 05 00 01 00 06 00 00 00 11 00 ,
00000080h: 01 00 01 00 00 00 05 2A B7 00 01 B1 00 00 00 00 ,
00000090h: 00 39 00 07 00 05 00 01 00 06 00 00 00 10 00 01 ,
000000a0h: 00 01 00 00 00 04 10 0A 3B B1 00 00 00 00 00 00 ,
```






```
Constant pool:
   #1 = Methodref          #3.#8          //  java/lang/Object."<init>":()V
   #2 = Class              #9             //  com/louis/jvm/Simple
   #3 = Class              #10            //  java/lang/Object
   #4 = Utf8               <init>
   #5 = Utf8               ()V
   #6 = Utf8               Code
   #7 = Utf8               greeting
   #8 = NameAndType        #4:#5          //  "<init>":()V
   #9 = Utf8               com/louis/jvm/Simple
  #10 = Utf8               java/lang/Object
```

Designed by LouLuan
http://blog.csdn.net/luanlouis

```
public static final synchronized void greeting();
  flags: ACC_PUBLIC, ACC_STATIC, ACC_FINAL, ACC_SYNCHRONIZED

  Code:
    stack=1, locals=1, args_size=0
       0: bipush        10
       2: istore_0
       3: return
}
```

10 0A ：将单字节10 推送到栈上

3B ：取栈顶的int类型的值赋给局部变量表的第一个变量

B1： 无结果返回

Designed by LouLuan

http://blog.csdn.net/luanlouis

实例文件

- package org.fenixsoft.clazz;

- public class TestClass{
-
- private int m;

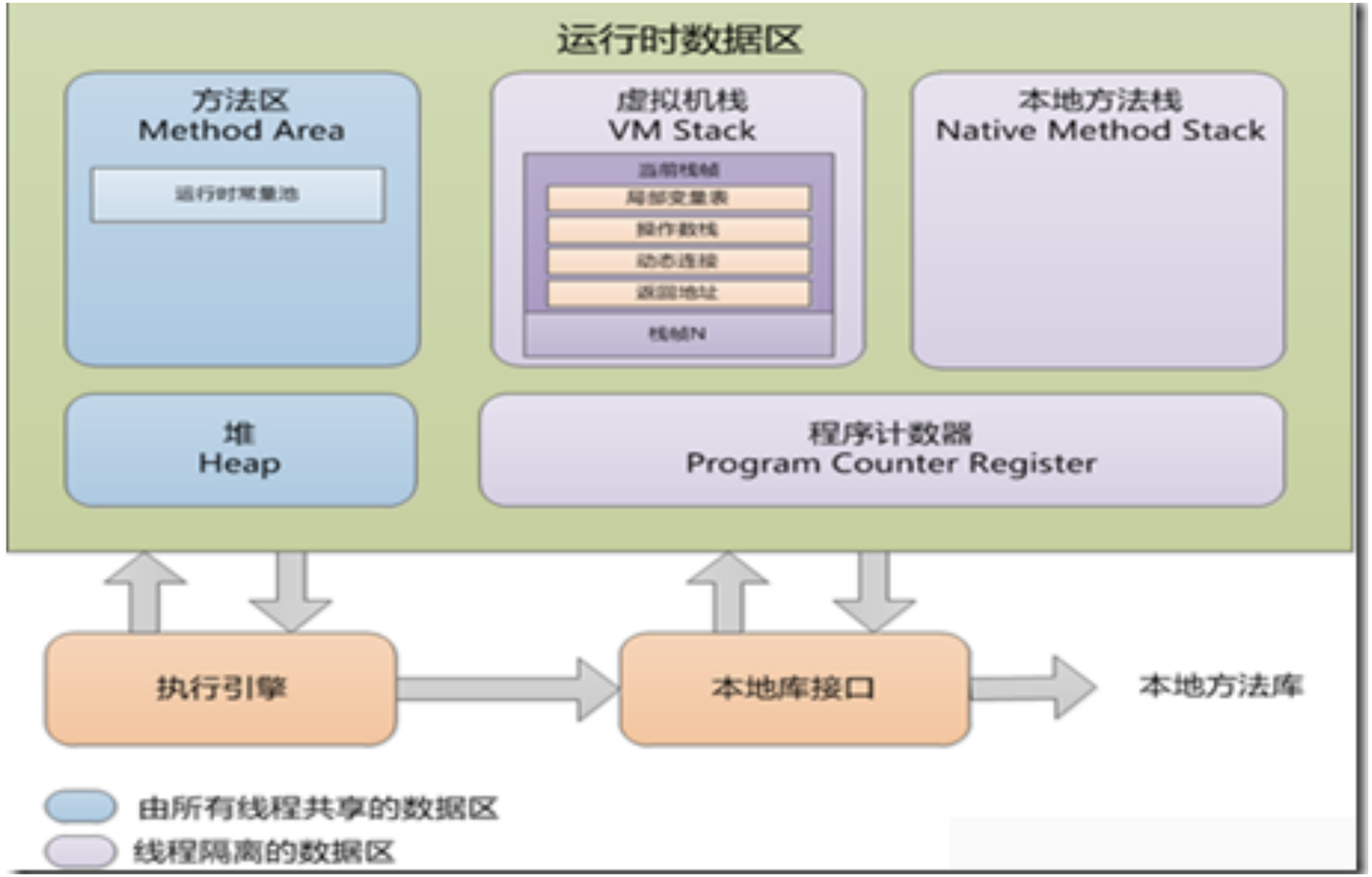
- public int inc(){
- return m+1;
- }
- }

```
promote:~ qinliu$ javac TestClass.java
promote:~ qinliu$ javap -verbose TestClass
警告: 二进制文件TestClass包含org.fenixsoft.clazz.TestClass
Classfile /Users/qinliu/TestClass.class
  Last modified 2015-4-15; size 295 bytes
  MD5 checksum 81f2ab948a7a3068839b61a8f91f634b
  Compiled from "TestClass.java"
public class org.fenixsoft.clazz.TestClass
  minor version: 0
  major version: 52
  flags: ACC_PUBLIC, ACC_SUPER
Constant pool:
   #1 = Methodref          #4.#15         // java/lang/Object."<init>":()V
   #2 = Fieldref           #3.#16         // org/fenixsoft/clazz/TestClass.m:I
   #3 = Class              #17            // org/fenixsoft/clazz/TestClass
   #4 = Class              #18            // java/lang/Object
   #5 = Utf8               m
   #6 = Utf8               I
   #7 = Utf8               <init>
   #8 = Utf8               ()V
   #9 = Utf8               Code
  #10 = Utf8               LineNumberTable
  #11 = Utf8               inc
  #12 = Utf8               ()I
  #13 = Utf8               SourceFile
  #14 = Utf8               TestClass.java
  #15 = NameAndType        #7:#8          // "<init>":()V
  #16 = NameAndType        #5:#6          // m:I
  #17 = Utf8               org/fenixsoft/clazz/TestClass
  #18 = Utf8               java/lang/Object
{
  public org.fenixsoft.clazz.TestClass();
    descriptor: ()V
    flags: ACC_PUBLIC
    Code:
      stack=1, locals=1, args_size=1
         0: aload_0
         1: invokespecial #1                  // Method j
         4: return
      LineNumberTable:
        line 3: 0

  public int inc();
    descriptor: ()I
    flags: ACC_PUBLIC
    Code:
      stack=2, locals=1, args_size=1
         0: aload_0
         1: getfield      #2                  // Field m:
         4: iconst_1
         5: iadd
         6: ireturn
      LineNumberTable:
        line 8: 0
}
SourceFile: "TestClass.java"
```

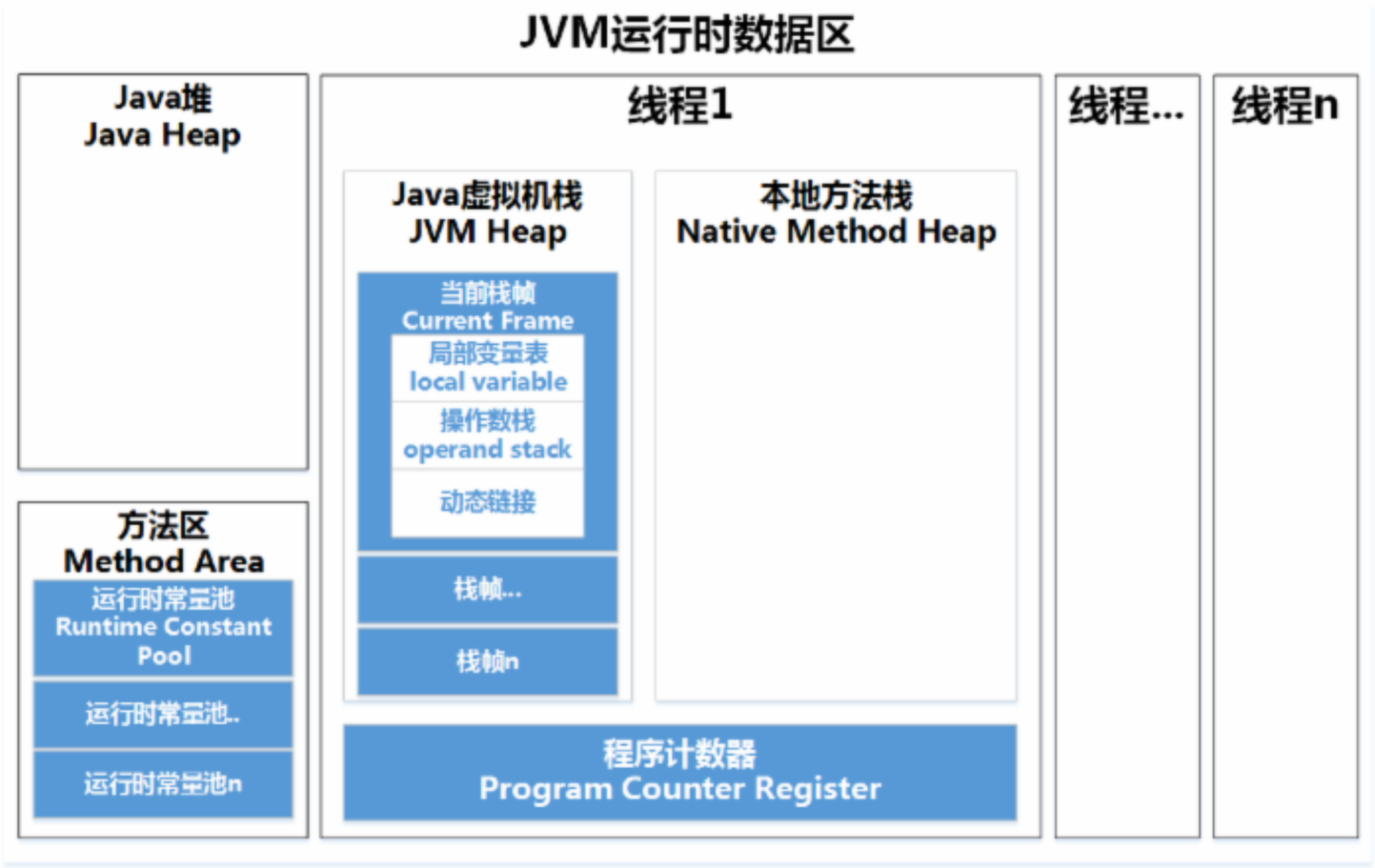
3 运行时数据区

JVM Run-Time Data Areas

- The pc Register
- Java Virtual Machine Stacks
- Heap
- Method Area
- Run-Time Constant Pool
- Native Method Stacks

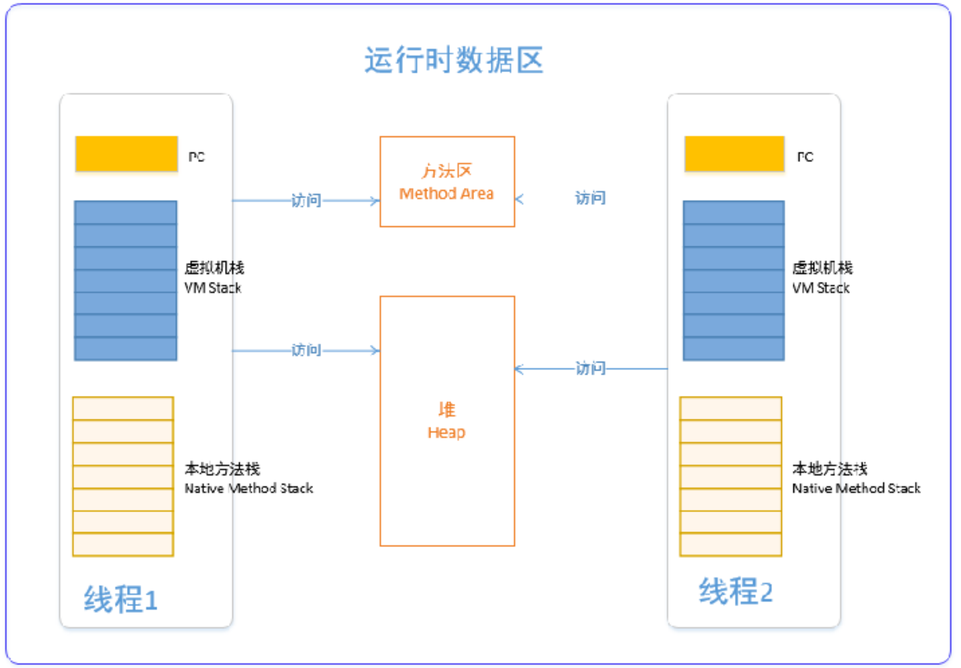


Java虚拟机运行时数据区


JVM运行时数据区
Java堆
Java Heap
线程1
线程...
线程n
Java虚拟机栈
JVM Heap
本地方法栈
Native Method Heap
当前栈帧
Current Frame
局部变量表
local variable
操作数栈
operand stack
动态链接
栈帧...
栈帧n
方法区
Method Area
运行时常量池
Runtime Constant Pool
运行时常量池..
运行时常量池n
程序计数器
Program Counter Register

多线程

Topic 1.JVM运行时数据区里有什么？



PC：即程序计数器（Program Counter Register，一块很小的内存空间，存储了下一条需要执行的（JVM 汇编）字节码指令的地址。JVM多线程是通过线程轮换并分配执行时间的方式实现的。在任何一个确定的时间内，JVM只会执行其中 条指令。每个线程的PC记录了当前线程要执行的指令，每个线程都有自己的PC，这样他们之间不会相互影响。如果当前线程执行的是Java方法，其PC记录的是正在执行的虚拟机字节码指令的地址；如果执行的是本地方法（Native Method），则PC为空。

虚拟机栈（VM stack）：此栈中的元素叫做栈帧（Stack Frame），线程在调用Java方法时，会为每一个方法创建一个栈帧，来存储局部变量表、操作栈、动态链接、方法出口等信息。每个方法被调用和完成的过程，都对应一个栈帧从虚拟机栈上入栈和出栈的过程。虚拟机栈的生命周期和线程相同。

本地方法栈（Native Method Stack）：为线程私有，功能和虚拟机栈非常相似。来存储线程调用本地方法时，本地方法的局部变量表，操作栈等等信息。

堆（Heap）：Heap区被所有的线程共享，在虚拟机启动时创建。此区的功能就是存放对象实例，几乎所有的对象实例都是在这里分配内容。**Heap区垃圾回收器管理的主要区域。**

方法区（Method Area）：该区为各个线程共享，用于存储已经被虚拟机加载的类信息、常量、静态变量、即时编译器编译出来的代码等数据。

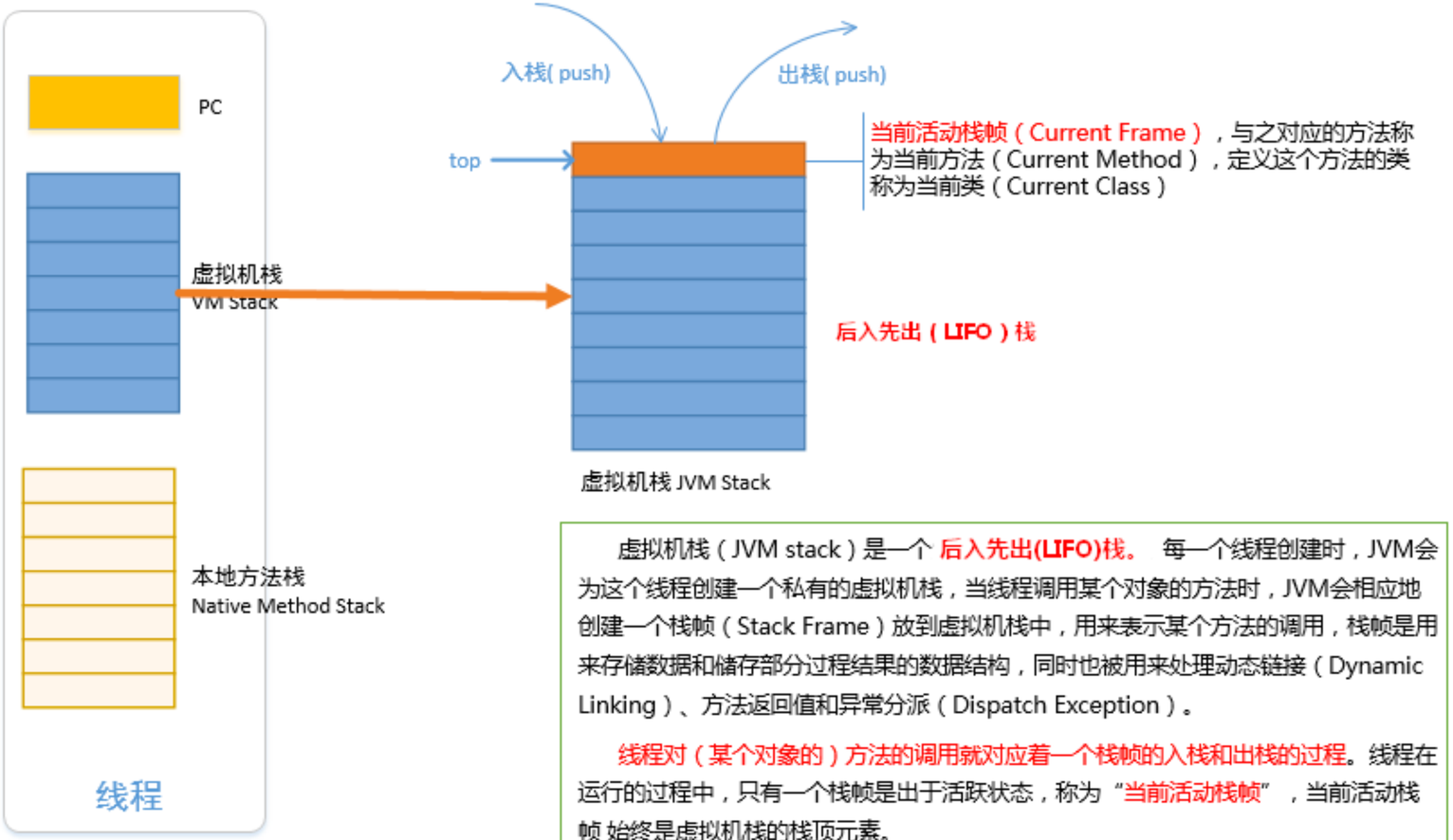
运行时常量池

- 存放编译器生成的
  - 各种字面量
    - numeric literals
    - string literals
  - 符号引用
    - class references
    - field references
    - method references

The constant pool contains the following types:

`Integer`	A 4 byte int constant
`Long`	An 8 byte long constant
`Float`	A 4 byte float constant
`Double`	A 8 byte double constant
`String`	A String constant that points at another Utf8 entry in the constant pool which contains the actual bytes
`Utf8`	A stream of bytes representing a Utf8 encoded sequence of characters
`Class`	A Class constant that points at another Utf8 entry in the constant pool which contains the fully qualified class name in the internal JVM format (this is used by the dynamic linking process)
`NameAndType`	A colon separated pair of values each pointing at other entries in the constant pool. The first value (before the colon) points at a Utf8 string entry that is the method or field name. The second value points at a Utf8 entry that represents the type, in the case of a field this is the fully qualified class name, in the case of a method this is a list of fully qualified class names one per parameter.
`Fieldref`, `Methodref`, `InterfaceMethodref`	A dot separated pair of values each pointing at other entries in the constant pool. The first value (before the dot) points at a Class entry. The second value points at a NameAndType entry.

Topic 2. 虚拟机栈是什么？虚拟机栈里有什么？



虚拟机栈（JVM stack）是一个 后入先出(LIFO)栈。 每一个线程创建时，JVM会为这个线程创建一个私有的虚拟机栈，当线程调用某个对象的方法时，JVM会相应地创建一个栈帧（Stack Frame）放到虚拟机栈中，用来表示某个方法的调用，栈帧是用来存储数据和储存部分过程结果的数据结构，同时也被用来处理动态链接（Dynamic Linking）、方法返回值和异常分派（Dispatch Exception）。

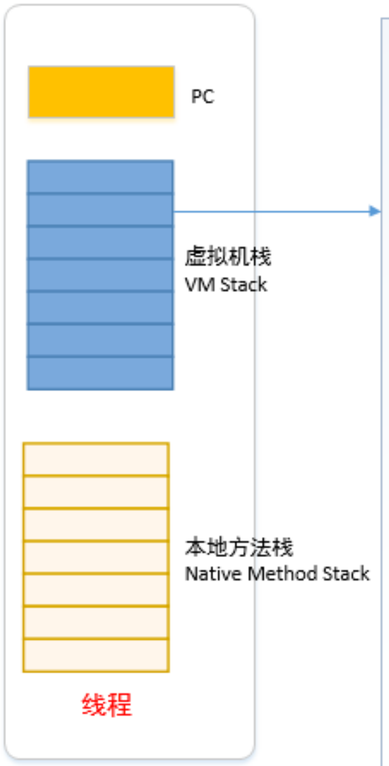
线程对（某个对象的）方法的调用就对应着一个栈帧的入栈和出栈的过程。线程在运行的过程中，只有一个栈帧是出于活跃状态，称为“当前活动栈帧”，当前活动栈帧 始终是虚拟机栈的栈顶元素。

TIPS：

在线程创建的时候，都会为其创建一个私有的虚拟机栈，即虚拟机栈的生命周期跟线程是一样的

Topic 3. 栈帧是什么？栈帧里有什么？

栈帧 Stack Frame



每一个栈帧里面都有一组局部变量列表，称为局部变量表。局部变量的数量在编译期就已经确认了，存储到了方法的 CODE 属性中

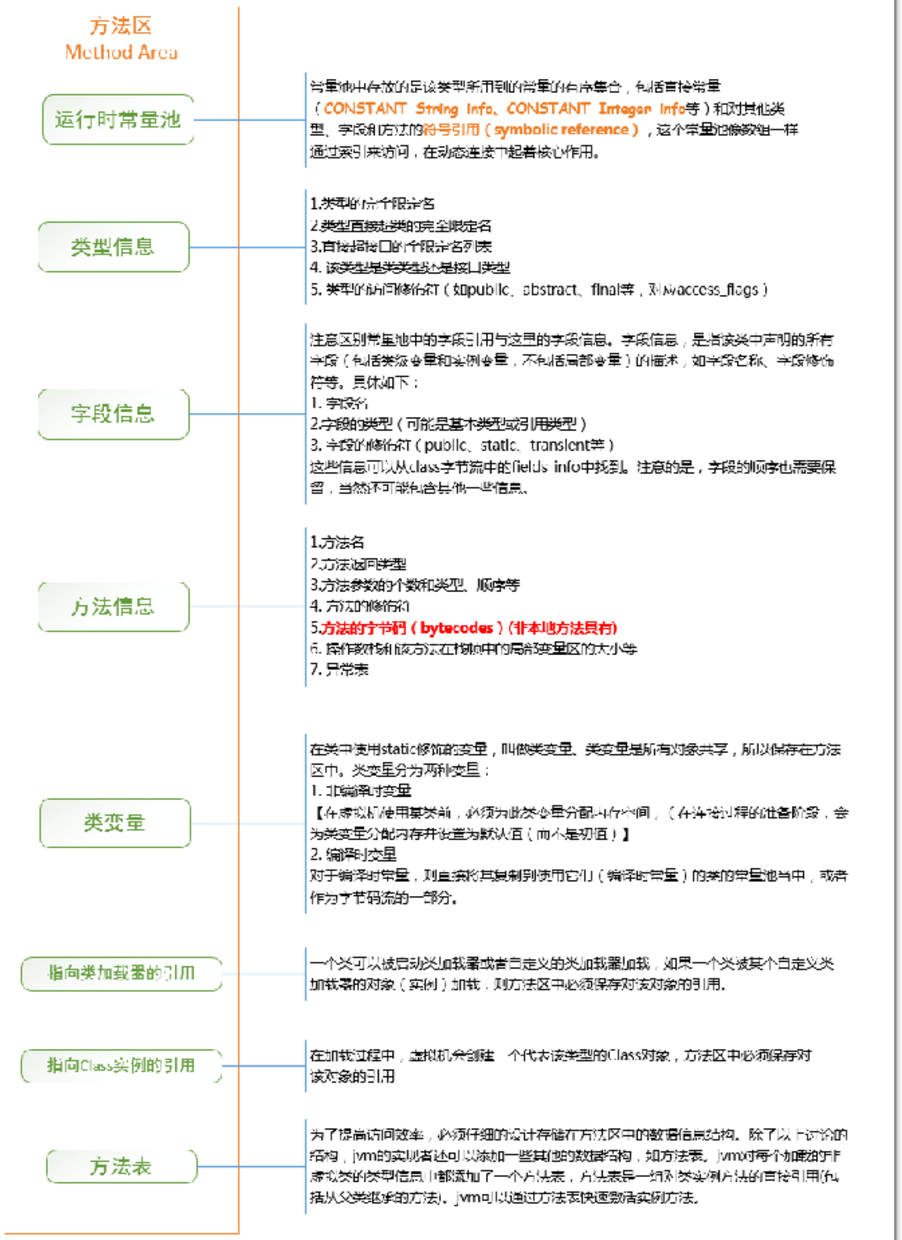
JVM底层字节码指令集是 **基于栈** 类型的，所有的操作码都是对操作数栈上的数据进行操作，对于每一个方法调用，JVM会建立一个操作数栈，以供计算使用。栈的深度在将源码编译成class文件时，就已经确定了，其深度属性存储在方法的 CODE 属性中。

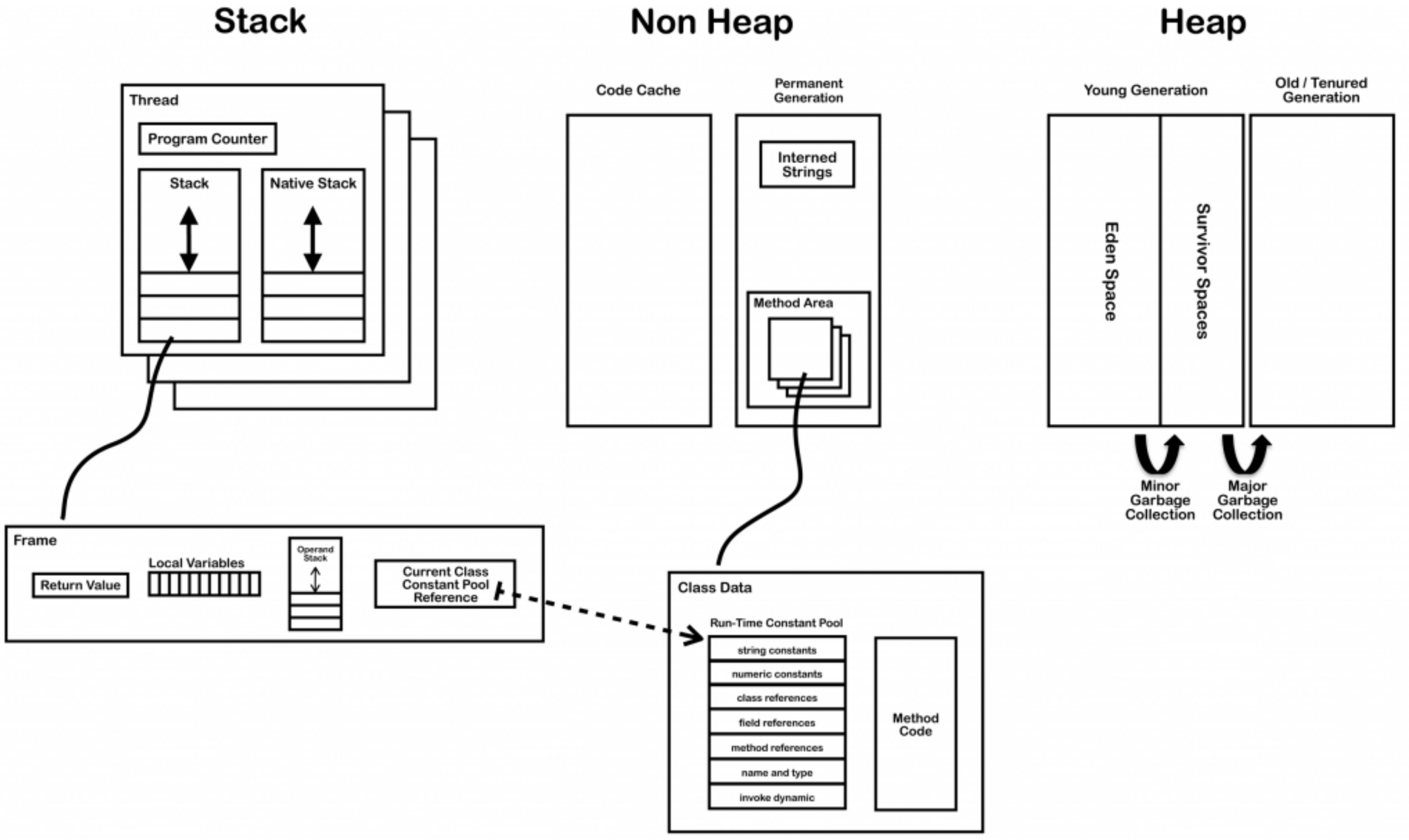
每一个栈帧内部都包含一个指向运行时常量池的引用来支持当前方法的代码实现动态链接（Dynamic Linking）。

若方法正常返回，当前栈帧承担着回复调用者状态的责任，其状态包括调用者的局部变量表、操作数栈和被正确增加过来表示执行了该方法调用指令的程序计数器等。使得调用者的代码能在被调用的方法返回并且返回值被推入调用者栈帧的操作数栈后继续正常地执行。

若在方法的执行过程中，某些指令导致了 Java 虚拟机抛出异常并且虚拟机抛出的异常在该方法中没有办法处理，或者在执行过程中遇到了 Athrow 字节码指令显式地抛出异常，并且在该方法内部没有把异常捕获住。如果方法异常调用完成，那一定不会有方法返回值返回给它的调用者。

Topic 4. 方法区是什么？方法区里有什么？




Stack
Non Heap
Heap
Thread
Program Counter
Stack
Native Stack
Code Cache
Permanent Generation
Interned Strings
Method Area
Young Generation
Old / Tenured Generation
Eden Space
Survivor Spaces
Minor Garbage Collection
Major Garbage Collection
Frame
Return Value
Local Variables
Operand Stack
Current Class Constant Pool Reference
Class Data
Run-Time Constant Pool
string constants
numeric constants
class references
field references
method references
name and type
invoke dynamic
Method Code

String.intern()

```
public class RuntimeConstantPoolOOM {
    public static void main(String[] args){
        String str1 = new StringBuilder("计算机").append("软件").toString();
        System.out.println(str1.intern() == str1);

        String str2 = new StringBuilder("ja").append("va").toString();
        System.out.println(str2.intern()== str2);
    }
}
```

解释

- jdk1.6
  - false
  - false
- idk 1.7
  - true
  - false
- http://www.jianshu.com/p/b98851899f37

栈帧中的局部变量表中的槽位是可以重用的

- public void localvar1(){
  - int a = 0;
  - System.out.println(a);
  - int b = 0;
- }
- public void localvar1(){
  - {
    - int a = 0;
    - System.out.println(a);
  - }
  - int b = 0;
- }

对垃圾回收的影响

- public void localvarGc1(){
  - byte[] a = new byte[6*1024*1024];
  - System.gc();
- }
- public void localvarGc2(){
  - byte[] a = new byte[6*1024*1024];
  - a = null;
  - System.gc();
- }
- public void localvarGc3(){
  - {
    - byte[] a = new byte[6*1024*1024];
    - System.gc();
  - }
- }
- public void localvarGc4(){
  - {
    - byte[] a = new byte[6*1024*1024];
  - }
  - int c = 10;
  - System.gc();
- }
- public void localvarGc5(){
  - localvarGc1();
  - System.gc();
- }

解释

1. 申请了一个6M大小的空间，赋值给b引用，然后调用gc函数，因为此时这个6M的空间还被b引用着，所以不能顺利gc；
2. 申请了一个6M大小的空间，赋值给b引用，然后将b重新赋值为null，此时这个6M的空间不再被b引用，所以可以顺利gc；
3. 申请了一个6M大小的空间，赋值给b引用，过了b的作用返回之后调用gc函数，但是因为此时b并没有被销毁，还存在于栈帧中，这个空间也还被b引用，所以不能顺利gc；
4. 申请了一个6M大小的空间，赋值给b引用，过了b的作用返回之后重新创建一个变量c，此时这个新的变量会复用已经失效的b变量的槽位，所以b被迫销毁了，所以6M的空间没有被任何变量引用，于是能够顺利gc；
5. 首先调用localVarGc1()，很显然不能顺利gc，函数调用结束之后再调用gc函数，此时因为localVarGc1这个函数的栈帧已经随着函数调用的结束而被销毁，b也就被销毁了，所以6M大小的空间不被任何对象引用，于是能够顺利gc。

4 字节码指令集

指令分类

- 指令可以基本分为以下几类：

- 存储指令 （例如：aload_0, istore）
- 算术与逻辑指令 （例如: ladd, fcmpl）
- 类型转换指令 （例如：i2b, d2i）
- 对象创建与操作指令 （例如：new, putfield）
- 堆栈操作指令 （例如：swap, dup2）
- 控制转移指令 （例如：ifeq, goto）
- 方法调用与返回指令 （例如：invokespecial, areturn)

前后缀

- 前/后缀 操作数类型
- i　整数
- l　长整数
- s　短整数
- b　字节
- c　字符
- f　单精度浮点数
- d　双精度浮点数
- z　布尔值
- a　引用

加载和存储指令

- 加载和存储指令用于将数据从栈帧的局部变量表和操作数栈之间来回传输。
- 1)将一个局部变量加载到操作数栈的指令包括：iload,iload_<n>，lload、lload_<n>、float、fload_<n>、dload、dload_<n>，aload、aload_<n>。
- 2)将一个数值从操作数栈存储到局部变量表的指令：istore,istore_<n>,lstore,lstore_<n>,fstore,fstore_<n>,dstore,dstore_<n>,astore,astore_<n>
- 3)将常量加载到操作数栈的指令：bipush,sipush,ldc,ldc_w,ldc2_w,aconst_null,iconst_ml,iconst_<i>,lconst_<l>,fconst_<f>,dconst_<d>
- 4)局部变量表的访问索引指令:wide
- 一部分以尖括号结尾的指令代表了一组指令，如iload_<i>，代表了iload_0,iload_1等，这几组指令都是带有一个操作数的通用指令。

运算指令

- 算术指令用于对两个操作数栈上的值进行某种特定运算，并把结果重新存入到操作栈顶。
- 1)加法指令:iadd,ladd,fadd,dadd
- 2)减法指令:isub,lsub,fsub,dsub
- 3)乘法指令:imul,lmul,fmul,dmul
- 4)除法指令:idiv,ldiv,fdiv,ddiv
- 5)求余指令:irem,lrem,frem,drem
- 6)取反指令:ineg,leng,fneg,dneg
- 7)位移指令:ishl,ishr,iushr,lshl,lshr,lushr
- 8)按位或指令:ior,lor
- 9)按位与指令:iand,land
- 10)按位异或指令:ixor,lxor
- 11)局部变量自增指令:iinc
- 12)比较指令:dcmpg,dcmpl,fcmpg,fcmpl,lcmp
- Java虚拟机没有明确规定整型数据溢出的情况，但规定了处理整型数据时，只有除法和求余指令出现除数为0时会导致虚拟机抛出异常。
- Java虚拟机要求在浮点数运算的时候，所有结果否必须舍入到适当的精度，如果有两种可表示的形式与该值一样，会优先选择最低有效位为零的。称之为最接近数舍入模式。
- 浮点数向整数转换的时候，Java虚拟机使用IEEE 754标准中的向零舍入模式，这种模式舍入的结果会导致数字被截断，所有小数部分的有效字节会被丢掉。

类型转换指令

- 类型转换指令将两种Java虚拟机数值类型相互转换，这些操作一般用于实现用户代码的显式类型转换操作。
- JVM直接就支持宽化类型转换(小范围类型向大范围类型转换)：
- 1)int类型到long,float,double类型
- 2)long类型到float,double类型
- 3)float到double类型
- 但在处理窄化类型转换时，必须显式使用转换指令来完成，这些指令包括：i2b、i2c、i2s、l2i、f2i、f2l、d2i、d2l和 d2f。
- 将int 或 long 窄化为整型T的时候，仅仅简单的把除了低位的N个字节以外的内容丢弃，N是T的长度。这有可能导致转换结果与输入值有不同的正负号。
- 在将一个浮点值窄化为整数类型T（仅限于 int 和 long 类型），将遵循以下转换规则：
- 1）如果浮点值是NaN， 呐转换结果就是int 或 long 类型的0
- 2）如果浮点值不是无穷大，浮点值使用IEEE 754 的向零舍入模式取整，获得整数v， 如果v在T表示范围之内，那就过就是v
- 3）否则，根据v的符号， 转换为T 所能表示的最大或者最小正数

对象创建于访问指令

- 虽然类实例和数组都是对象，Java虚拟机对类实例和数组的创建与操作使用了不同的字节码指令。
- 1)创建实例的指令:new
- 2)创建数组的指令:newarray,anewarray,multianewarray
- 3)访问字段指令:getfield,putfield,getstatic,putstatic
- 4)把数组元素加载到操作数栈指令:baload,caload,saload,iaload,laload,faload,daload,aaload
- 5)将操作数栈的数值存储到数组元素中执行:bastore,castore,castore,sastore,iastore,fastore,dastore,aastore
- 6)取数组长度指令:arraylength JVM支持方法级同步和方法内部一段指令序列同步，这两种都是通过moniter实现的。
- 7)检查实例类型指令:instanceof,checkcast

操作数栈管理指令

- 如同操作一个普通数据结构中的堆栈那样，Java 虚拟机提供了一些用于直接操作操作数栈的指令，包括：
- 1）将操作数栈的栈顶一个或两个元素出栈：pop、pop2
- 2）复制栈顶一个或两个数值并将复制值或双份的复制值重新压入栈顶：dup、dup2、dup_x1、dup2_x1、dup_x2、dup2_x2。
- 3）将栈最顶端的两个数值互换：swap

控制转移指令

- 让JVM有条件或无条件从指定指令而不是控制转移指令的下一条指令继续执行程序。控制转移指令包括：
- 1)条件分支:ifeq,iflt,ifle,ifne,ifgt,ifge,ifnull,ifnotnull,if_cmpeq,if_icmpne,if_icmlt,if_icmpgt等
- 2)复合条件分支:tableswitch,lookupswitch
- 3)无条件分支:goto,goto_w,jsr,jsr_w,ret

- JVM中有专门的指令集处理int和reference类型的条件分支比较操作，为了可以无明显标示一个实体值是否是null,有专门的指令检测null 值。boolean类型和byte类型,char类型和short类型的条件分支比较操作，都使用int类型的比较指令完成，而 long,float,double条件分支比较操作，由相应类型的比较运算指令，运算指令会返回一个整型值到操作数栈中，随后再执行int类型的条件比较操作完成整个分支跳转。各种类型的比较都最终会转化为int类型的比较操作

方法调用和返回指令

- invokevirtual指令:调用对象的实例方法，根据对象的实际类型进行分派(虚拟机分派)。
- invokeinterface指令:调用接口方法，在运行时搜索一个实现这个接口方法的对象，找出合适的方法进行调用。
- invokespecial:调用需要特殊处理的实例方法，包括实例初始化方法，私有方法和父类方法
- invokestatic:调用类方法(static)
- 方法返回指令是根据返回值的类型区分的，包括ireturn(返回值是boolean,byte,char,short和 int),lreturn,freturn,drturn和areturn，另外一个return供void方法，实例初始化方法，类和接口的类初始化i方法使用。

异常处理指令

- 在Java程序中显式抛出异常的操作（throw语句）都有athrow 指令来实现，除了用throw 语句显示抛出异常情况外，Java虚拟机规范还规定了许多运行时异常会在其他Java虚拟机指令检测到异常状况时自动抛出。

- 在Java虚拟机中，处理异常不是由字节码指令来实现的，而是采用异常表来完成的。

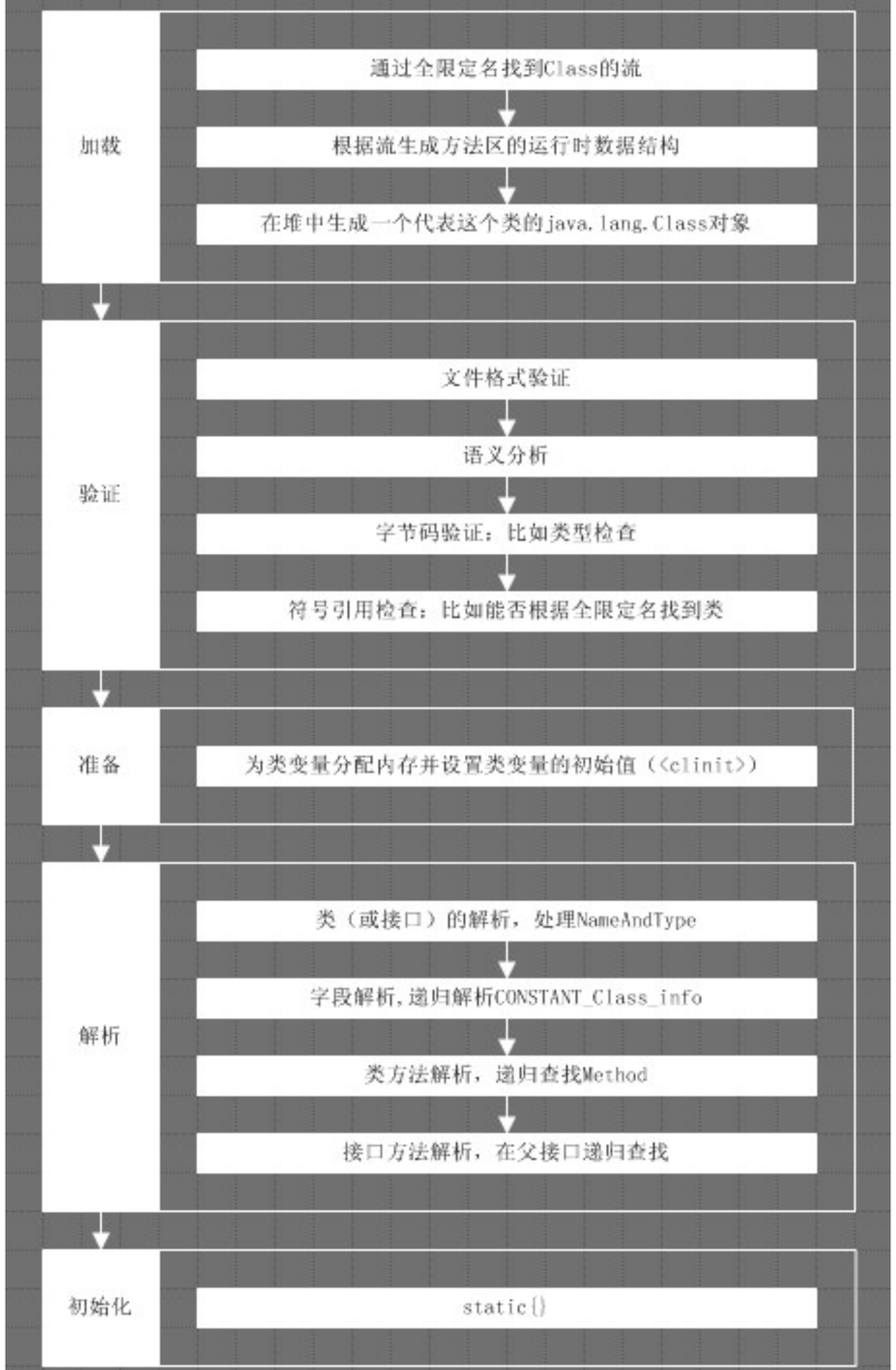
同步指令

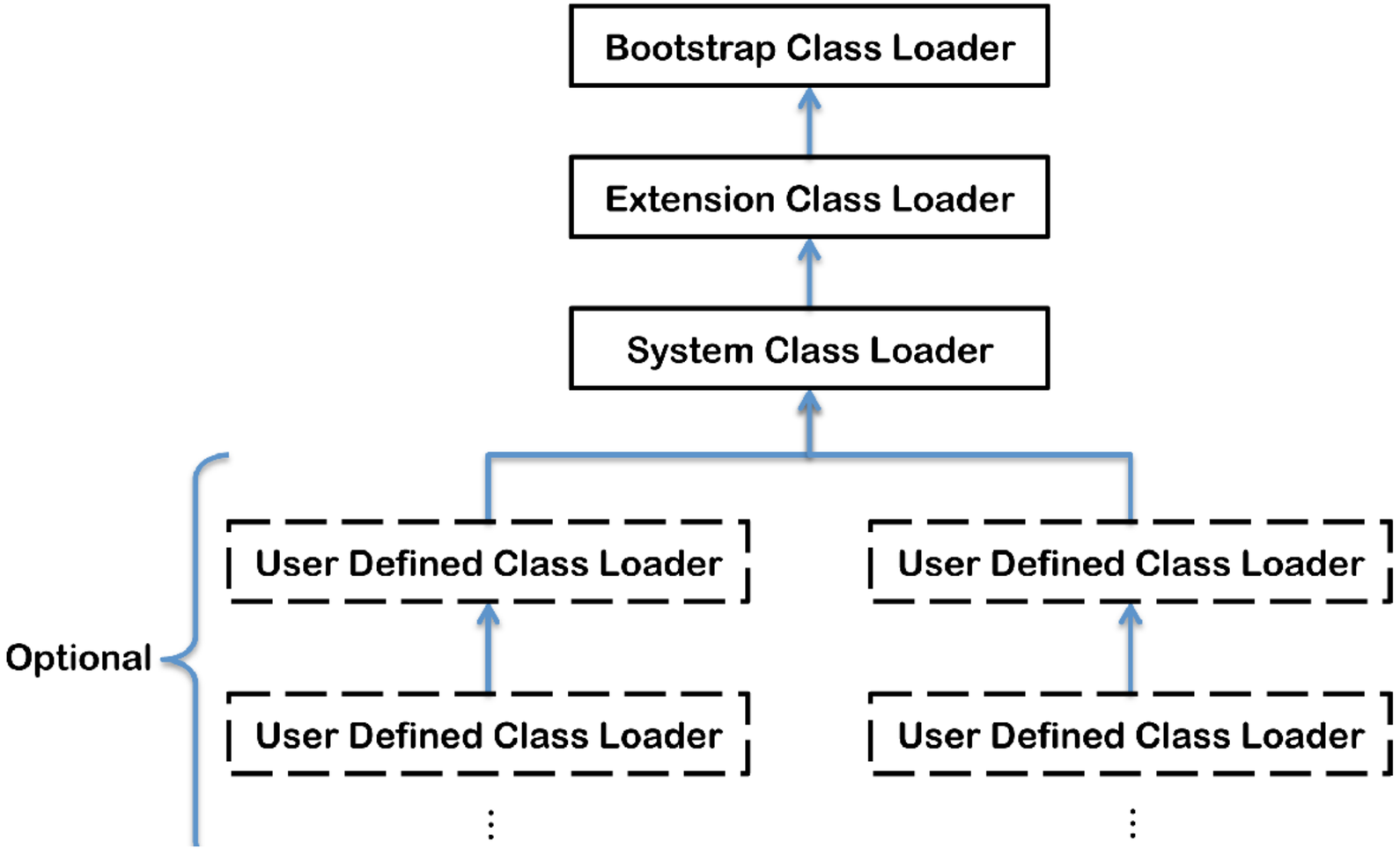
- 方法级的同步是隐式的，无需通过字节码指令来控制，它实现在方法调用和返回操作中。虚拟机从方法常量池中的方法标结构中的 ACC_SYNCHRONIZED标志区分是否是同步方法。方法调用时，调用指令会检查该标志是否被设置，若设置，执行线程持有moniter，然后执行方法，最后完成方法时释放moniter。
- 同步一段指令集序列，通常由synchronized块标示，JVM指令集中有monitorenter和monitorexit来支持synchronized语义。
- 结构化锁定是指方法调用期间每一个monitor退出都与前面monitor进入相匹配的情形。JVM通过以下两条规则来保证结结构化锁成立(T代表一线程，M代表一个monitor)：
- 1)T在方法执行时持有M的次数必须与T在方法完成时释放的M次数相等
- 2)任何时刻都不会出现T释放M的次数比T持有M的次数多的情况

5 虚拟机字节码执行

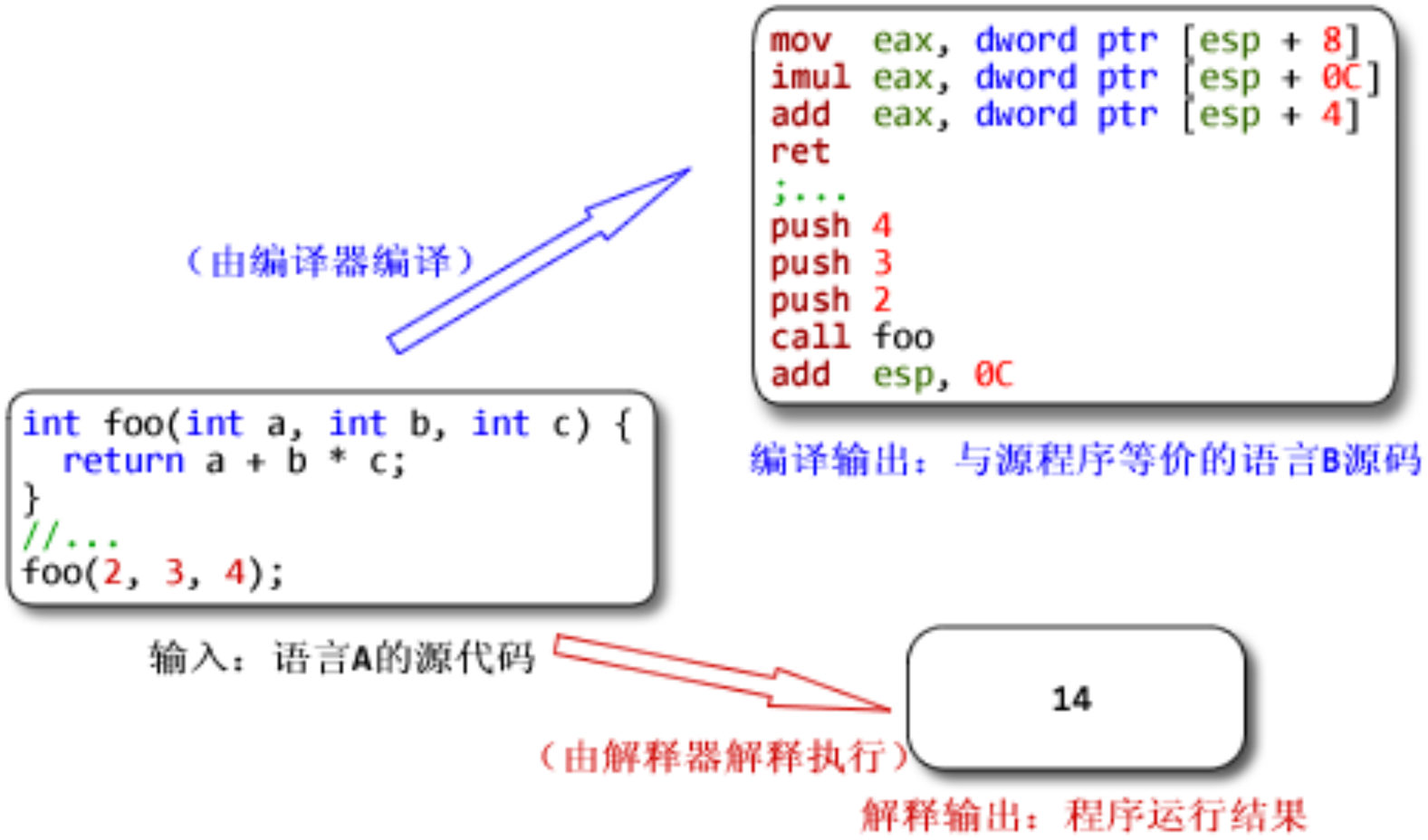
类的生命周期

- 加载
- 连接
  - 验证
  - 准备
  - 解析
- 初始化
- 使用
- 卸载

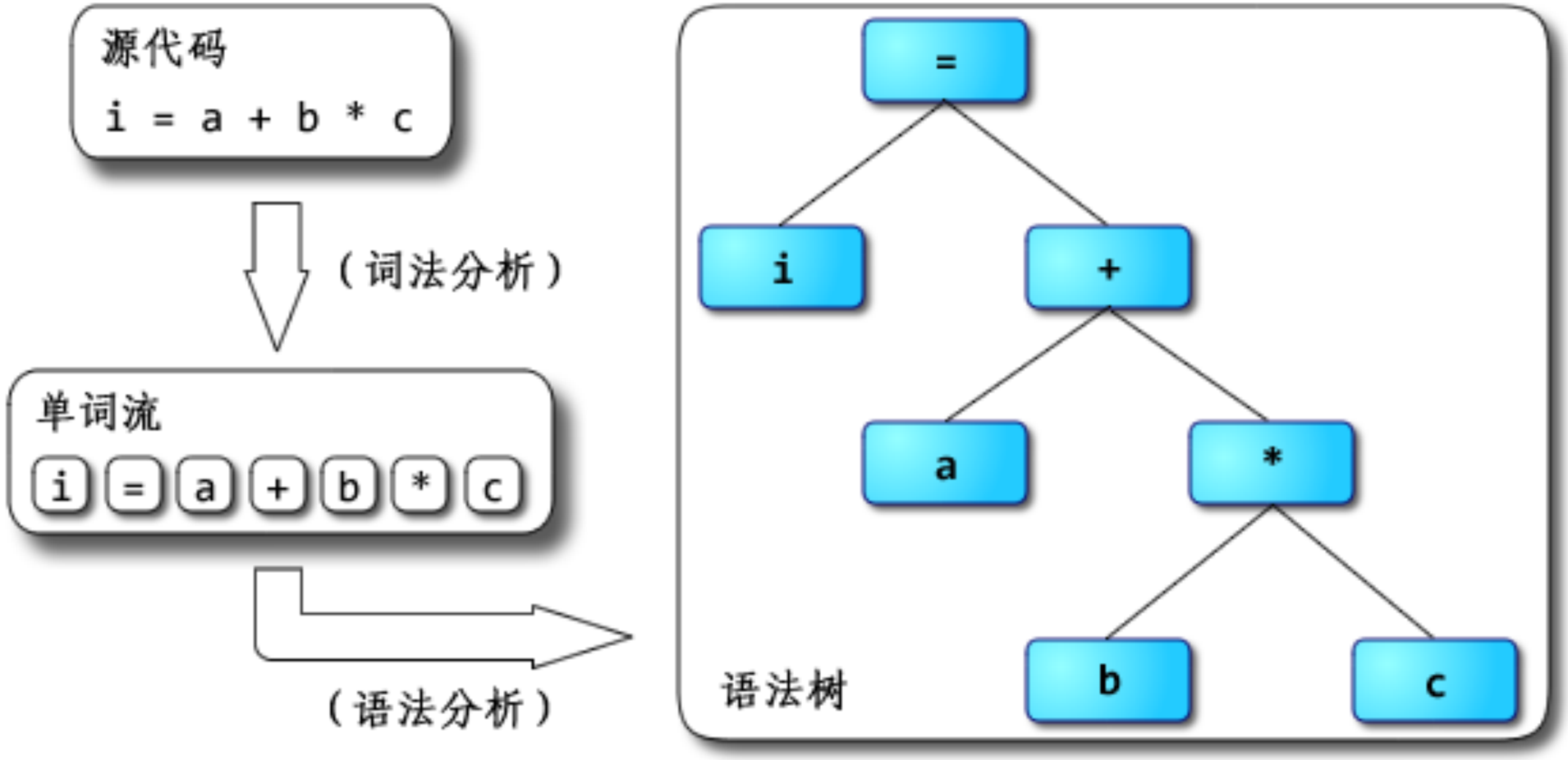

加载
通过全限定名找到Class的流
根据流生成方法区的运行时数据结构
在堆中生成一个代表这个类的java.lang.Class对象
验证
文件格式验证
语义分析
字节码验证：比如类型检查
符号引用检查：比如能否根据全限定名找到类
准备
为类变量分配内存并设置类变量的初始值（<clinit>）
解析
类（或接口）的解析，处理NameAndType
字段解析,递归解析CONSTANT_Class_info
类方法解析，递归查找Method
接口方法解析，在父接口递归查找
初始化
static{}


Bootstrap Class Loader
Extension Class Loader
System Class Loader
Optional
User Defined Class Loader
User Defined Class Loader
User Defined Class Loader
User Defined Class Loader

类加载


mov eax, dword ptr [esp + 8]
imul eax, dword ptr [esp + 0C]
add eax, dword ptr [esp + 4]
ret
;...
push 4
push 3
push 2
call foo
add esp, 0C
（由编译器编译）
编译输出：与源程序等价的语言B源码
int foo(int a, int b, int c) {
return a + b * c;
}
//...
foo(2, 3, 4);
输入：语言A的源代码
14
（由解释器解释执行）
解释输出：程序运行结果

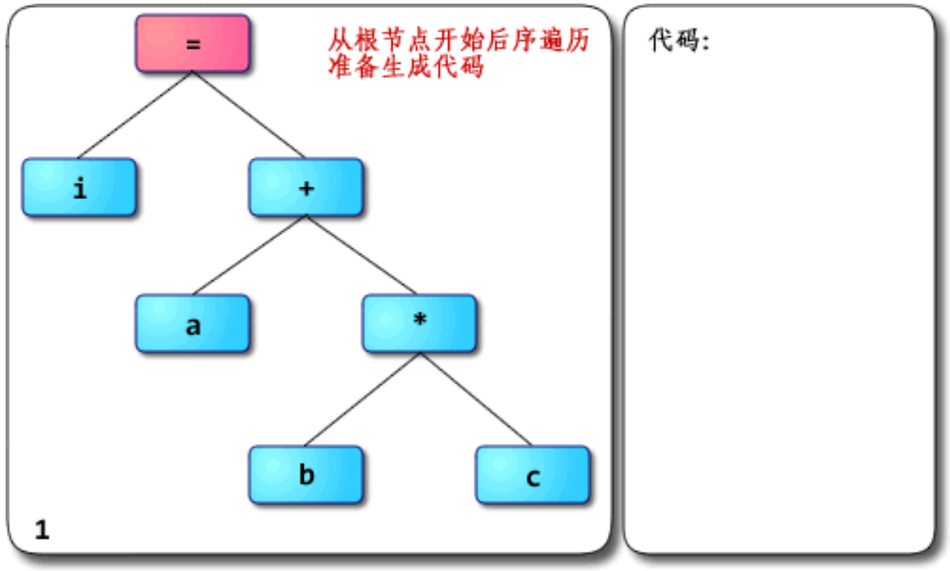
编译与解释



广义解析器

示例代码 1

```
public class EvalOrderDemo {
    public static void main(String[] args) {
        int[] arr = new int[1];
        int a = 1;
        int b = 2;
        arr[0] = a + b;
    }
}
```



生成字节码

Bytecode

- // 左子树：数组下标
- // a[0]
- aload_1
- iconst_0

- // 右子树：加法
- // a
- iload_2
- // b
- iload_3
- // +
- iadd

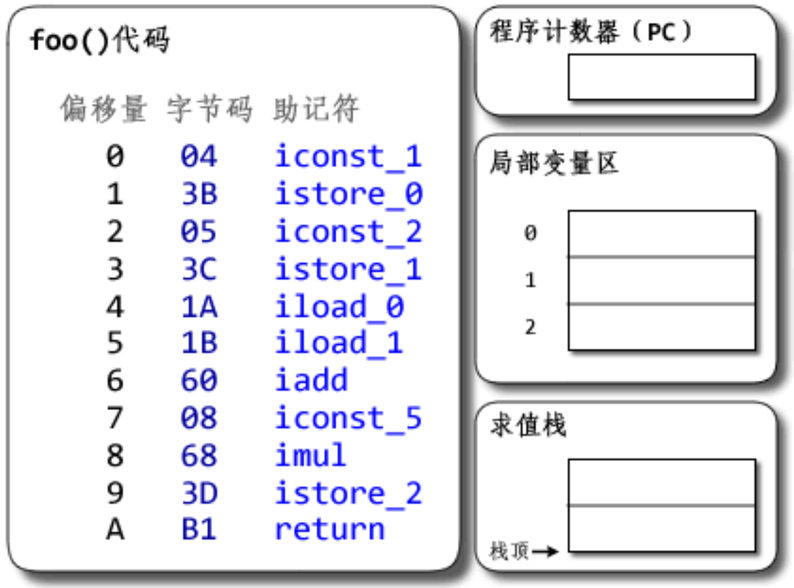
- // 根节点：赋值
- iastore

示例代码 2

```
public class Demo {
    public static void foo() {
        int a = 1;
        int b = 2;
        int c = (a + b) * 5;
    }
}
```

Bytecode

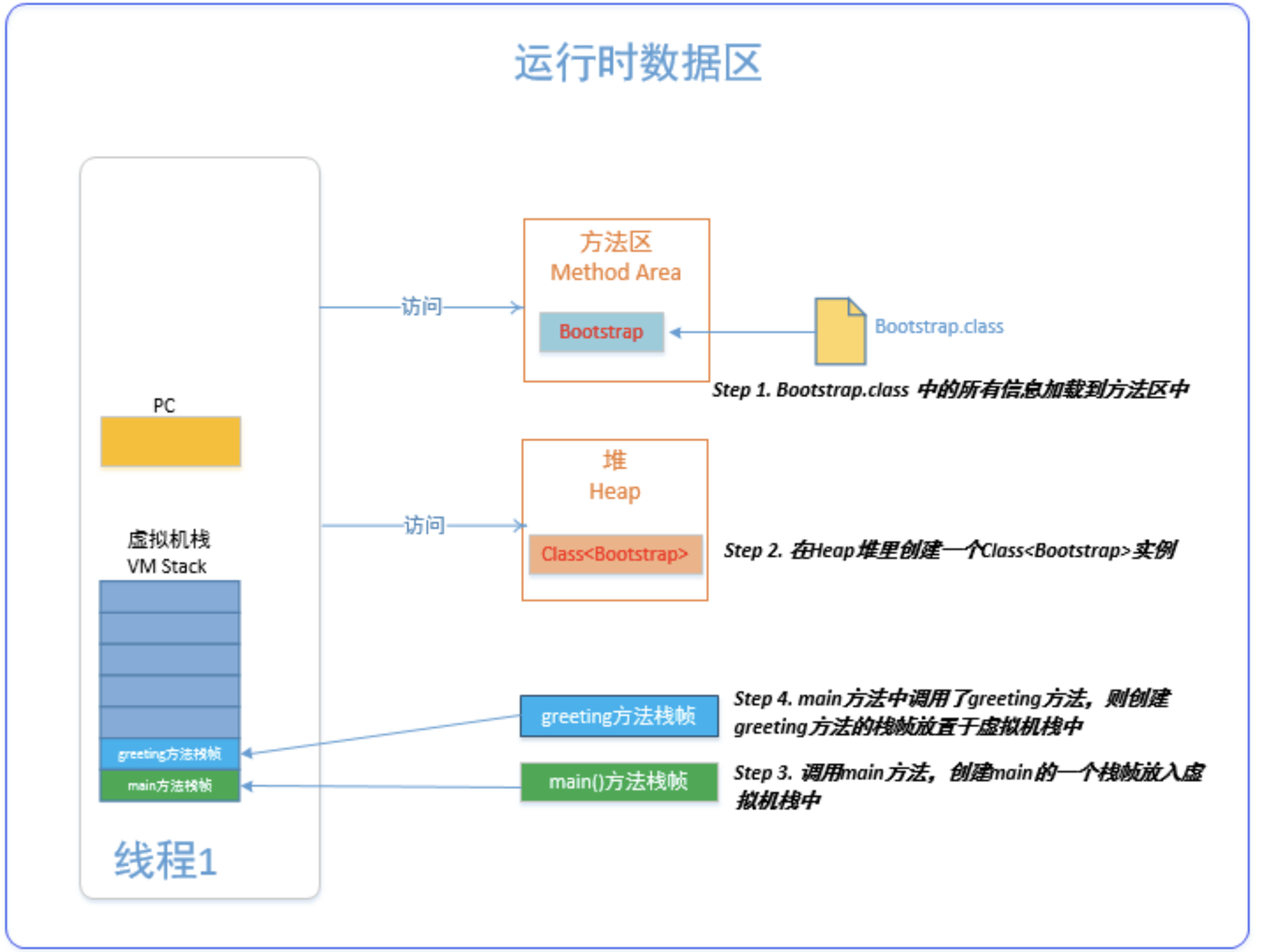
- 0: iconst_1
- 1: istore_0
- 2: iconst_2
- 3: istore_1
- 4: iload_0
- 5: iload_1
- 6: iadd
- 7: iconst_5
- 8: imul
- 9: istore_2
- 10: return


foo()代码
偏移量 字节码 助记符
0 04 iconst_1
1 3B istore_0
2 05 iconst_2
3 3C istore_1
4 1A iload_0
5 1B iload_1
6 60 iadd
7 08 iconst_5
8 68 imul
9 3D istore_2
A B1 return
程序计数器（PC）
局部变量区
0
1
2
求值栈
栈顶

栈架构

Sample Code

```
1.  package org.louis.jvm.codeset;
2.  /**
3.   * JVM 原理简单用例
4.   * @author louis
5.   *
6.   */
7.  public class Bootstrap {
8.
9.      public static void main(String[] args) {
10.         String name = "Louis";
11.         greeting(name);
12.     }
13.
14.     public static void greeting(String name)
15.     {
16.         System.out.println("Hello,"+name);
17.     }
18.
19.}
```


运行时数据区
方法区
Method Area
Bootstrap
访问
Bootstrap.class
Step 1. Bootstrap.class 中的所有信息加载到方法区中
PC
堆
Heap
访问
Class<Bootstrap>
Step 2. 在Heap堆里创建一个Class<Bootstrap>实例
虚拟机栈
VM Stack
greeting方法栈帧
main方法栈帧
Step 4. main方法中调用了greeting方法，则创建greeting方法的栈帧放置于虚拟机栈中
Step 3. 调用main方法，创建main的一个栈帧放入虚拟机栈中
线程1
Designed by LouLuan
http://blog.csdn.net/luanlouis

```java
public static void main(String[] args) {
    String name = "Louis";
    greeting(name);
}
```

编译后

入参数量：1
局部变量数量：2
操作数栈大小：1
机器指令：12 10 4c 2b b8 20 12 b1

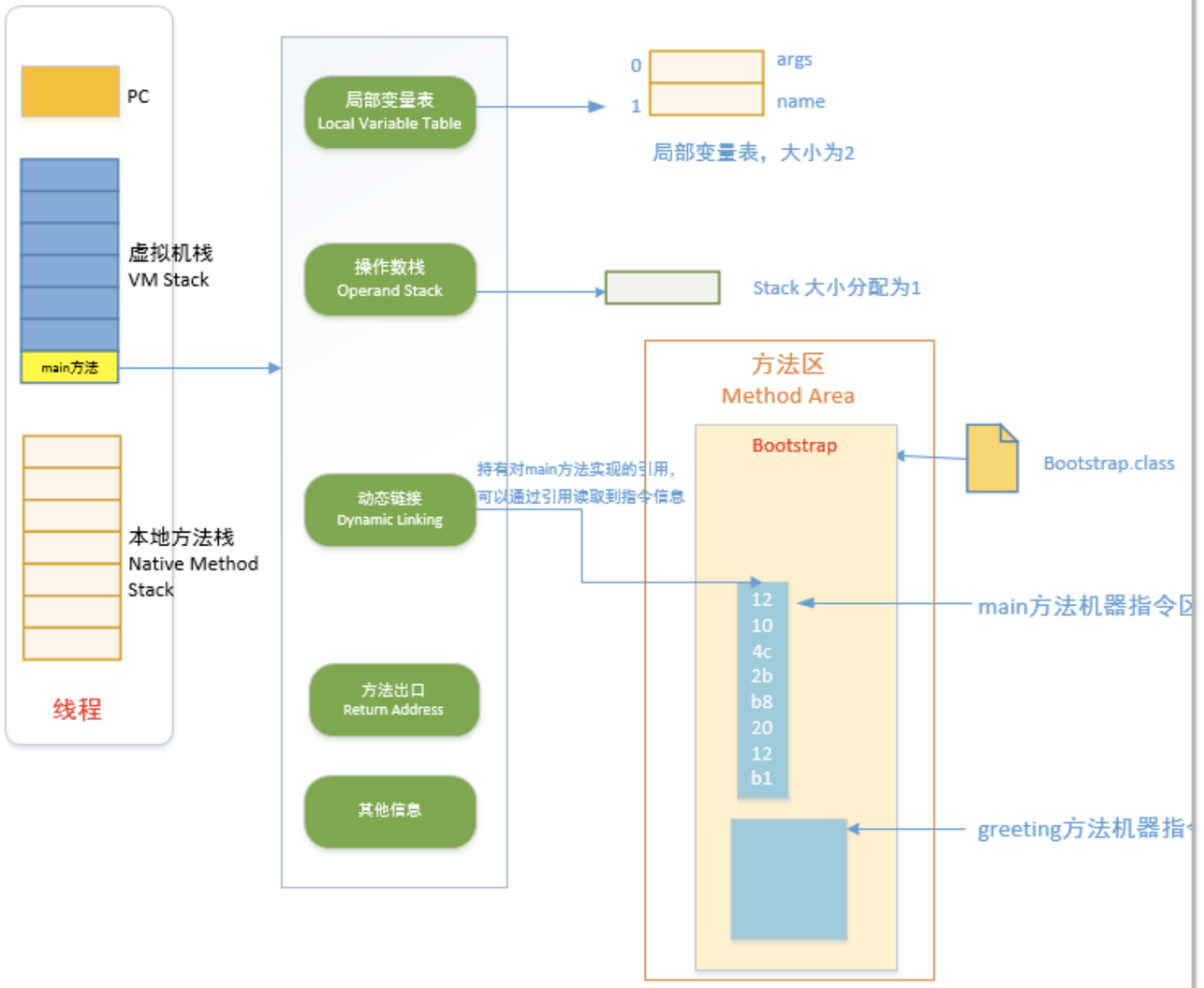
```java
public static void greeting(String name)
{
    System.out.println("Hello,"+name);
}
```

编译后

入参数量：1
局部变量数量：1
操作数栈大小：4
机器指令：b2 20 1a bb 20 20 59 12 22 b7 20 24 2a b6 20 26 b6

Designed by LouLuan
http://blog.csdn.net/luanlouis

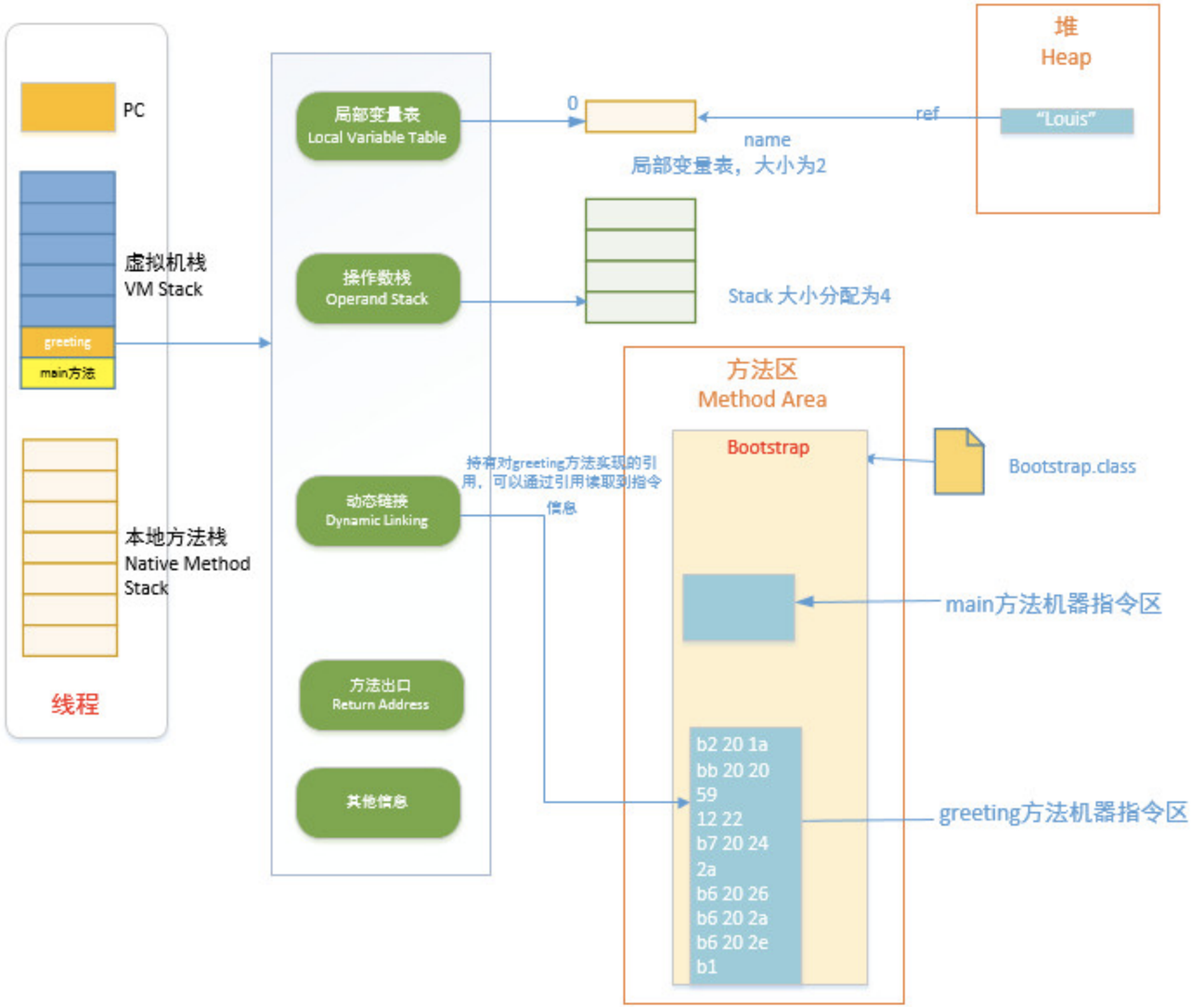
main方法的栈帧信息 Stack Frame



main()

```
public static void main(java.lang.String[]);
    descriptor: ([Ljava/lang/String;)V
    flags: ACC_PUBLIC, ACC_STATIC
    Code:
      stack=1, locals=2, args_size=1
         0: ldc           #2                  // String Louis
         2: astore_1
         3: aload_1
         4: invokestatic  #3                  // Method greeting:(Ljava/lang/String;)V
         7: return
      LineNumberTable:
        line 10: 0
        line 11: 3
        line 12: 7
```

greeting方法的栈帧信息 Stack Frame



Designed by LouLuan
http://blog.csdn.net/luanlouis

greeting()

```
public static void greeting(java.lang.String);
  descriptor: (Ljava/lang/String;)V
  flags: ACC_PUBLIC, ACC_STATIC
  Code:
    stack=3, locals=1, args_size=1
       0: getstatic     #4                  // Field java/lang/System.out:Ljava/io/PrintStream;
       3: new           #5                  // class java/lang/StringBuilder
       6: dup
       7: invokespecial #6                  // Method java/lang/StringBuilder."<init>":()V
      10: ldc           #7                  // String Hello,
      12: invokevirtual #8                  // Method java/lang/StringBuilder.append:(Ljava/lang/String;)Ljava/lang/StringBuilder;
      15: aload_0
      16: invokevirtual #8                  // Method java/lang/StringBuilder.append:(Ljava/lang/String;)Ljava/lang/StringBuilder;
      19: invokevirtual #9                  // Method java/lang/StringBuilder.toString:()Ljava/lang/String;
      22: invokevirtual #10                 // Method java/io/PrintStream.println:(Ljava/lang/String;)V
      25: return
    LineNumberTable:
      line 16: 0
      line 17: 25
```

机器指令是用来告诉机器做什么的指令。操作码是鉴别是什么指令， 而操作数相当于执行相应的指令所需要的参数。

greeting方法机器指令案例

机器指令	操作码	操作数1	操作数2	操作数3	助记符及解释	
b2 20 1a	b2	20	1a		getstatic	#26
bb 20 20	bb	20	20		new	#32
59	59				dup	
12 22	12	22			ldc	#34
b7 20 24	b7	20	24		invokespecial	#36
2a	2a				aload_0	
b6 20 26	b6	20	26		invokevirtual	#38
b6 20 2a	b6	20	2a		invokevirtual	#42
b6 20 2e	b6	20	2e		invokevirtual	#46
b1	b1				return	

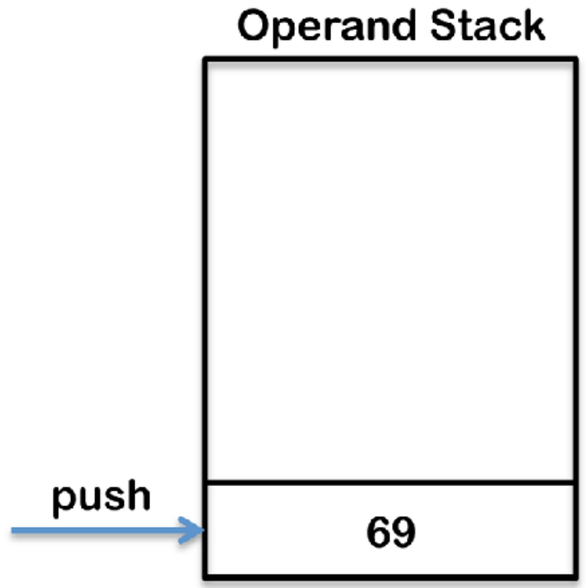
Designed by LouLuan
http://blog.csdn.net/luanlouis

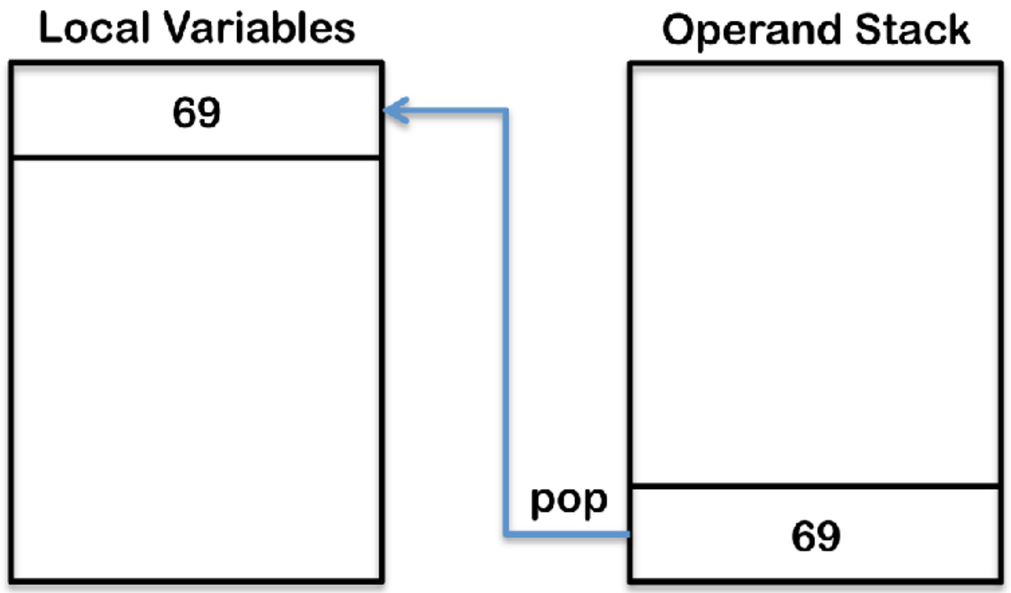
6 Java指令与字节码

变量

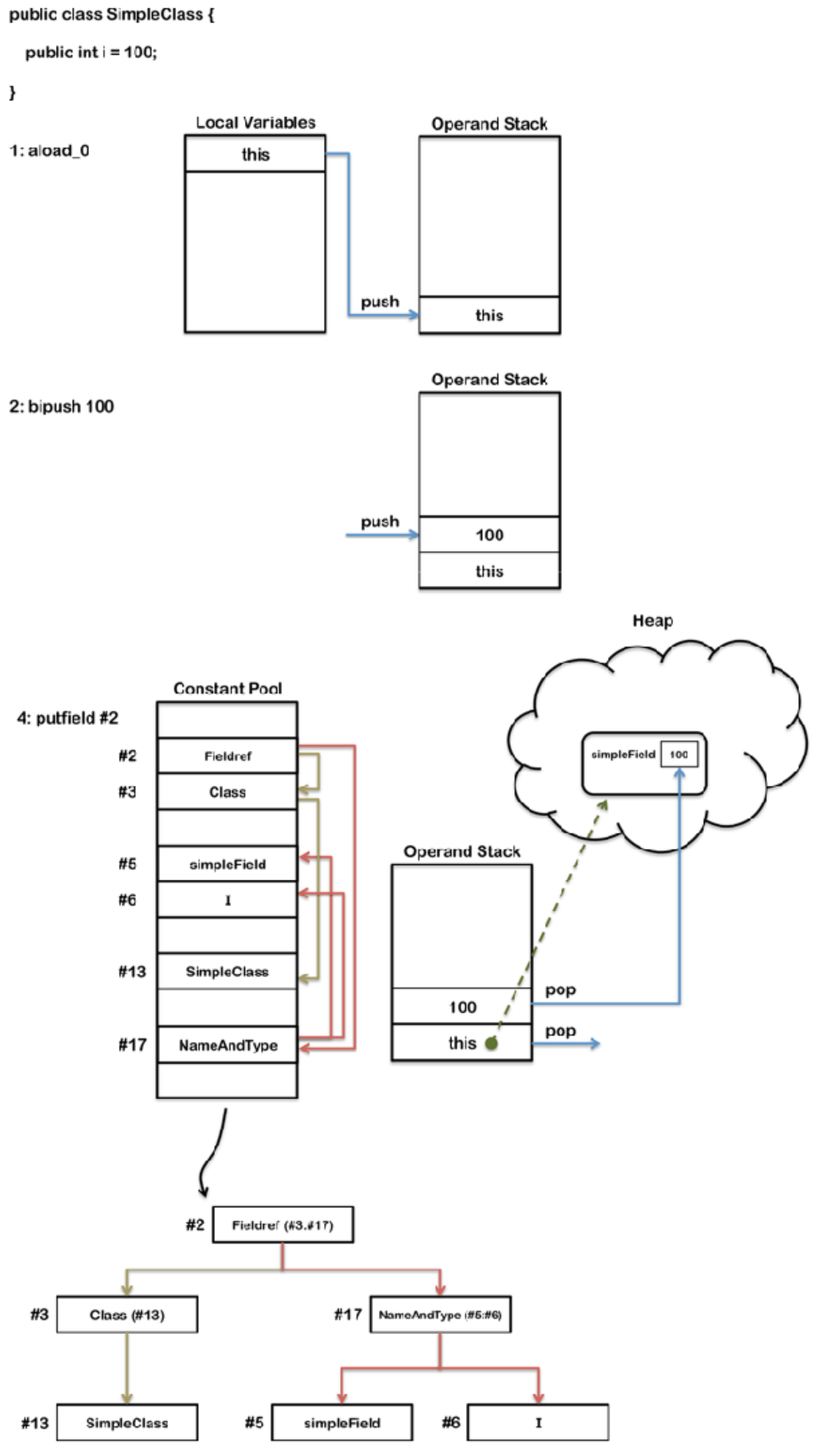
局部变量

```
int i = 69;

0: bipush 69

2: istore_0
```





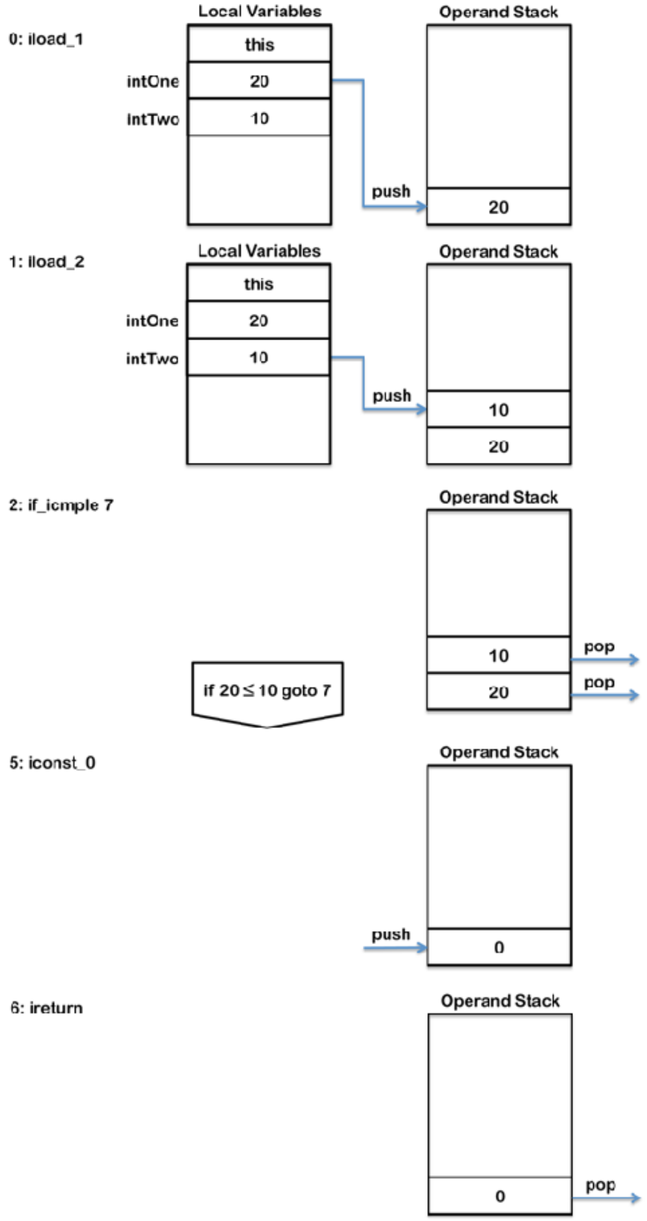
成员变量


public class SimpleClass {
public int i = 100;
}
1: aload_0
Local Variables
this
Operand Stack
push
this
2: bipush 100
Operand Stack
push
100
this
Heap
simpleField
100
4: putfield #2
Constant Pool
#2
Fieldref
#3
Class
#5
simpleField
#6
I
#13
SimpleClass
#17
NameAndType
Operand Stack
100
this
pop
pop
#2
Fieldref (#3.#17)
#3
Class (#13)
#17
NameAndType (#5:#6)
#13
SimpleClass
#5
simpleField
#6
I

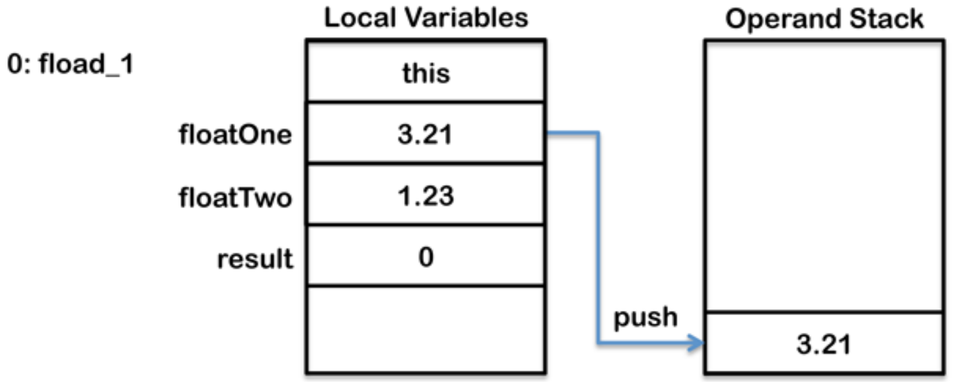
条件语句

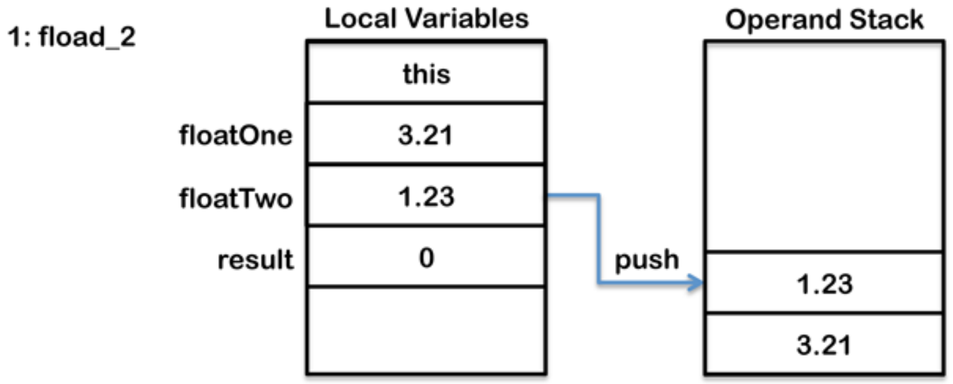
if else

```
public int greaterThen(int intOne, int intTwo) {
    if (intOne > intTwo) {
        return 0;
    } else {
        return 1;
    }
}

greaterThen(10, 20);
```



```
public int greaterThen(float floatOne, float floatTwo) {
    int result;
    if (floatOne > floatTwo) {
       result = 1;
    } else {
       result = 2;
    }
    return result;
}

greateThen(3.21, 1.23);
```

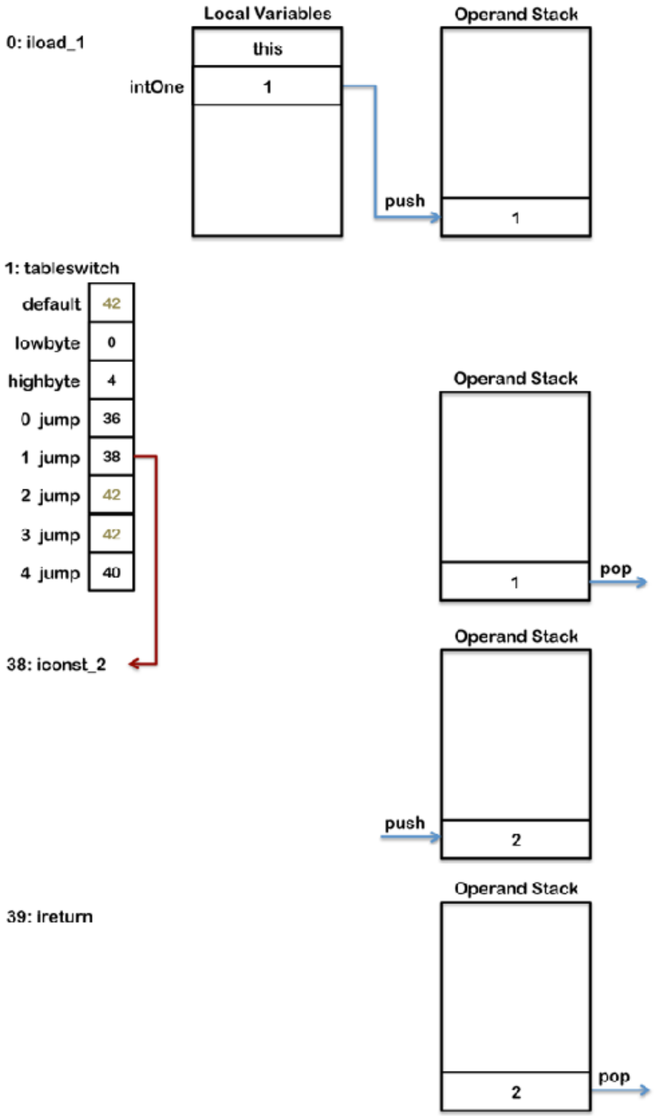




if else

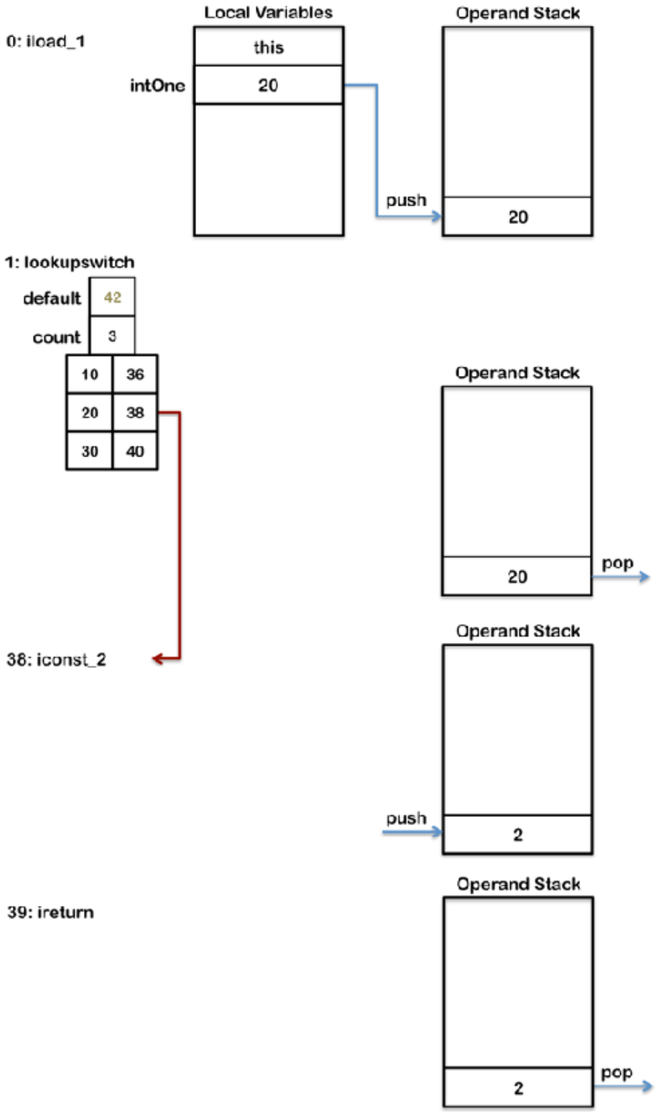
Switch

```
public int simpleSwitch(int intOne) {
    switch (intOne) {
      case 0:
        return 3;
      case 1:
        return 2;
      case 4:
        return 1;
      default:
        return -1;
    }
}

simpleSwitch(1);
```

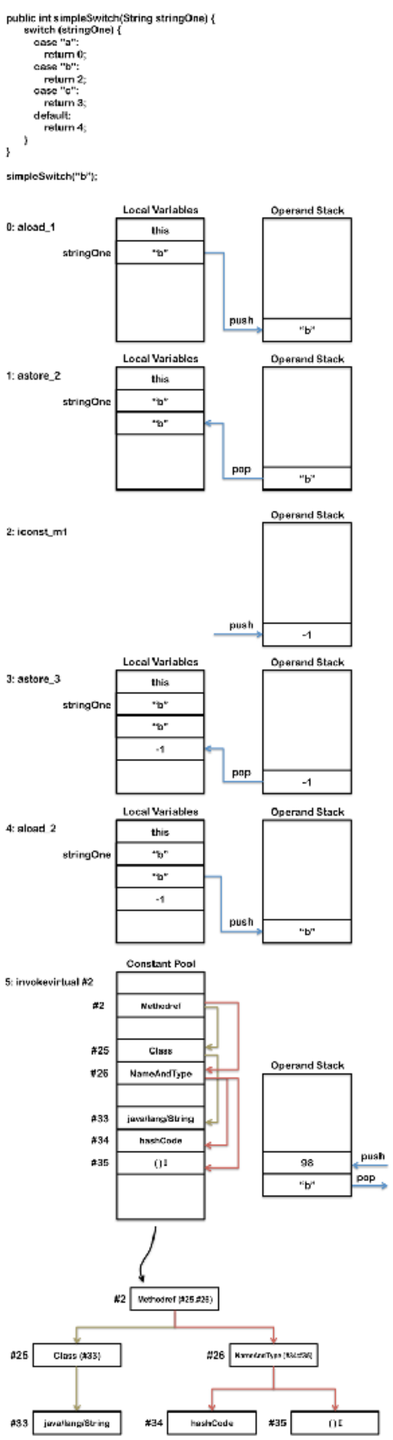


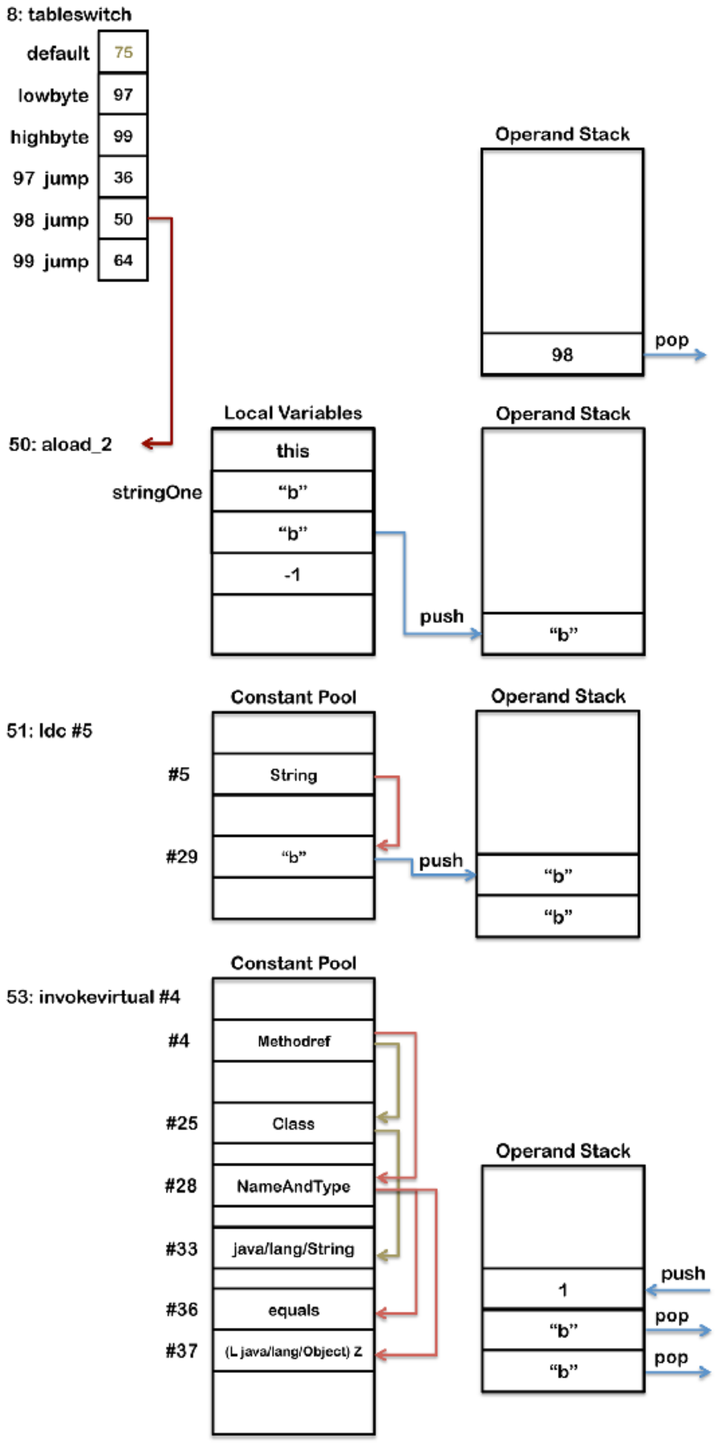
Switch

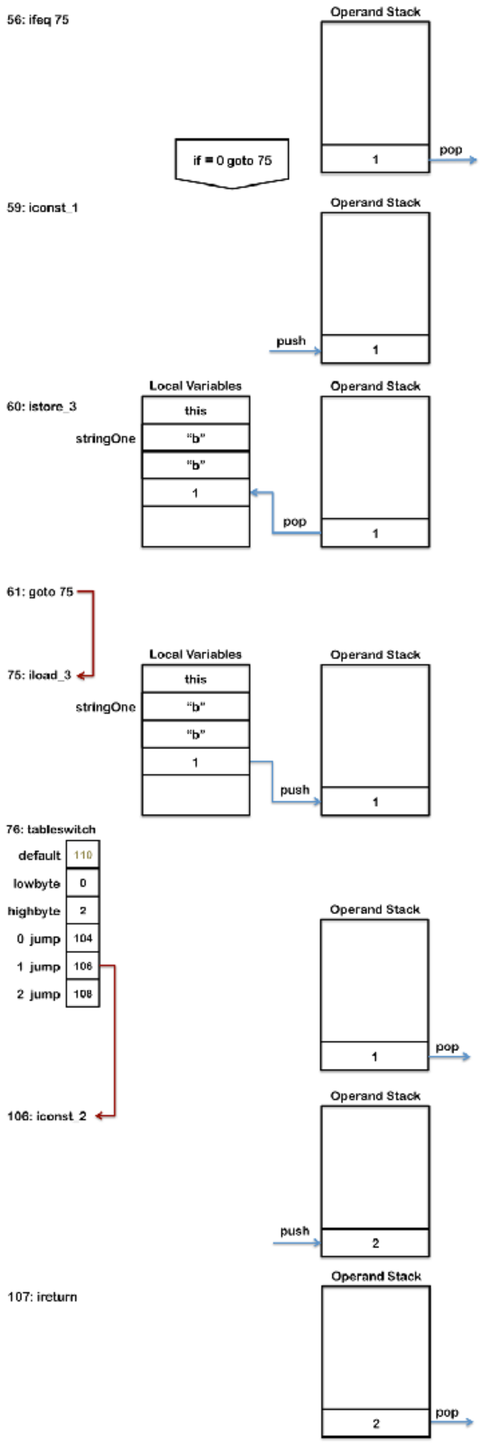
```
public int simpleSwitch(int intOne) {
    switch (intOne) {
      case 10:
        return 1;
      case 20:
        return 2;
      case 30:
        return 3;
      default:
        return -1;
    }
}

simpleSwitch(20);
```



Sting switch



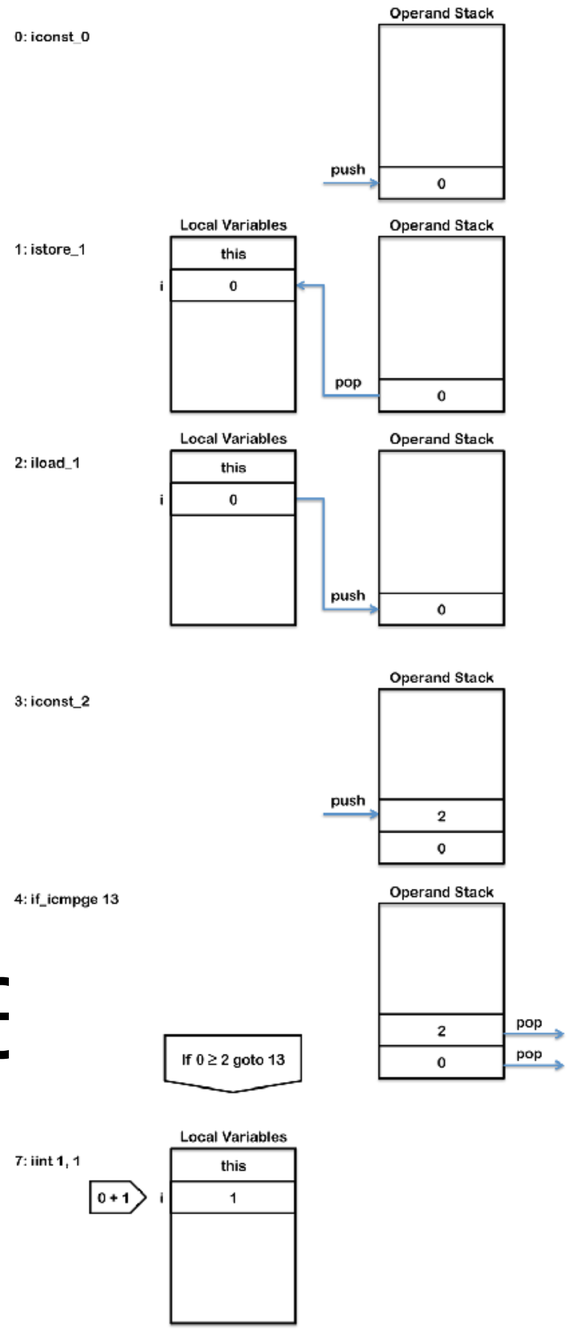

8: tableswitch
default 75
lowbyte 97
highbyte 99
97 jump 36
98 jump 50
99 jump 64
Operand Stack
98
pop
50: aload_2
Local Variables
this
stringOne
“b”
“b”
-1
push
Operand Stack
“b”
51: ldc #5
Constant Pool
#5
String
#29
“b”
push
Operand Stack
“b”
“b”
53: invokevirtual #4
Constant Pool
#4
Methodref
#25
Class
#28
NameAndType
#33
java/lang/String
#36
equals
#37
(Ljava/lang/Object)Z
Operand Stack
1
“b”
“b”
push
pop
pop

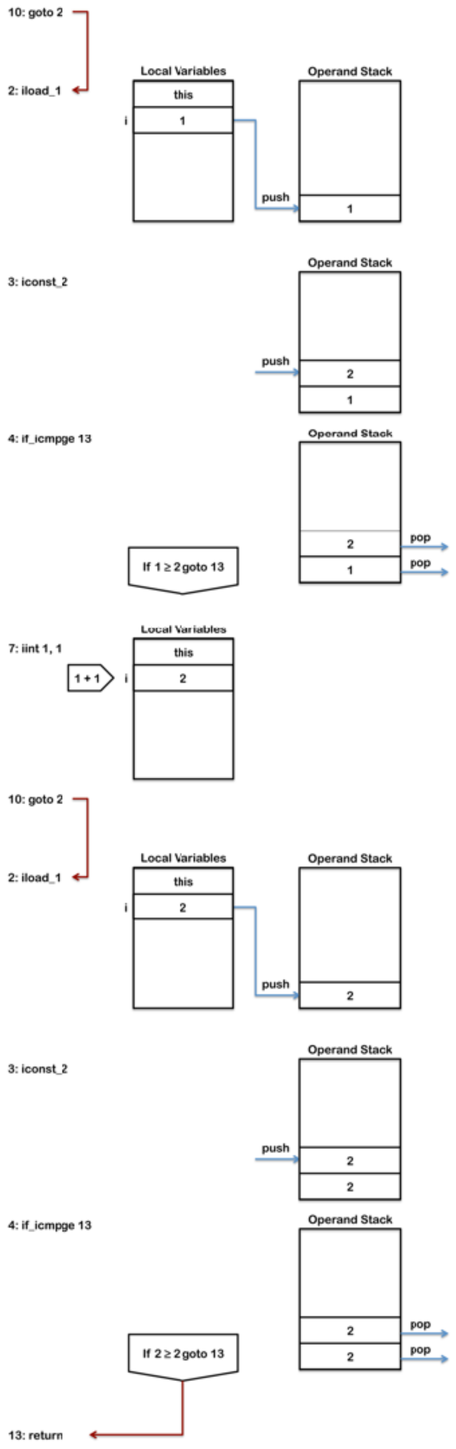

56: ifeq 75
Operand Stack
if = 0 goto 75
1
pop
59: iconst_1
Operand Stack
push
1
60: istore_3
Local Variables
Operand Stack
this
stringOne
"b"
"b"
1
pop
1
61: goto 75
75: iload_3
Local Variables
Operand Stack
this
stringOne
"b"
"b"
1
push
1
76: tableswitch
default 110
lowbyte 0
highbyte 2
0 jump 104
1 jump 106
2 jump 108
Operand Stack
1
pop
106: iconst_2
Operand Stack
push
2
107: ireturn
Operand Stack
2
pop

循环语句

while

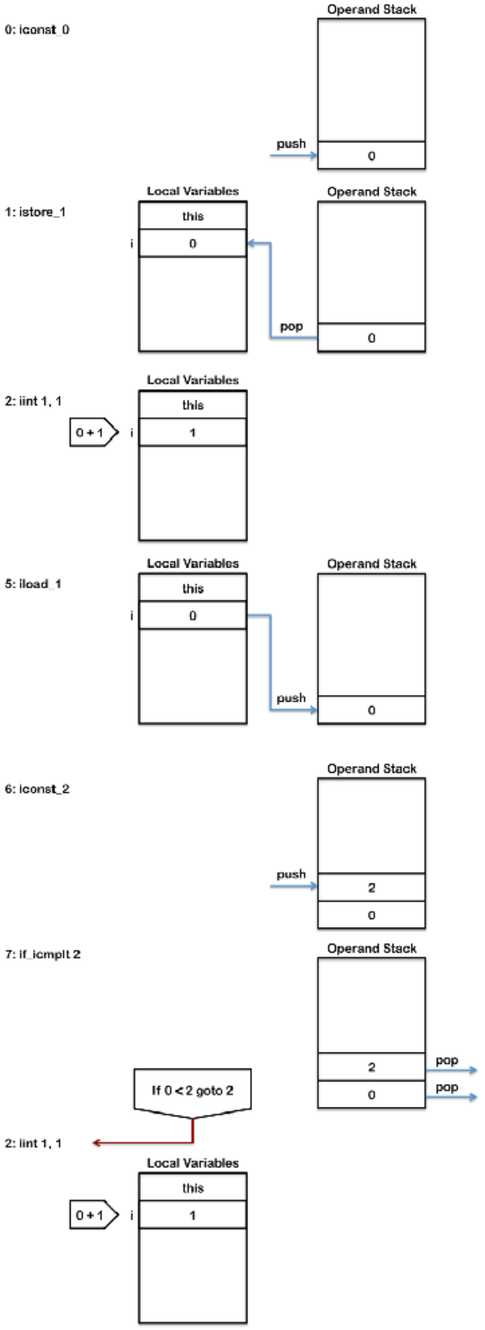
```
public void whileLoop() {
    int i = 0;
    while (i < 10) {
        i++;
    }
}
```

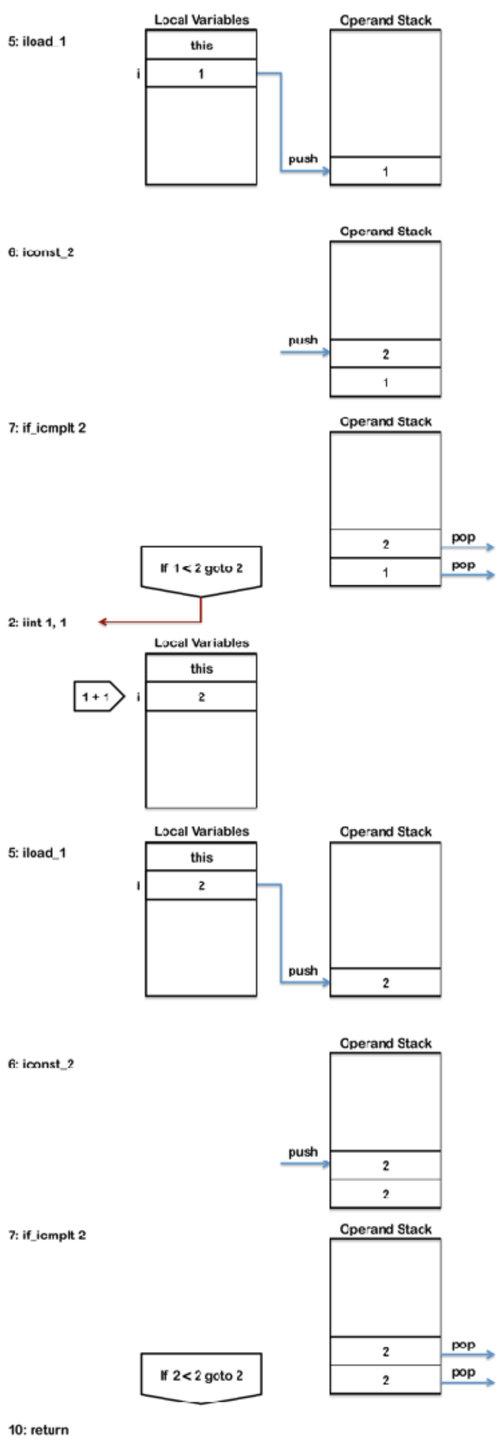



10: goto 2
2: iload_1
Local Variables
this
i
1
Operand Stack
push
1
3: iconst_2
Operand Stack
push
2
1
4: if_icmpge 13
Operand Stack
2
1
pop
pop
If 1 ≥ 2 goto 13
7: iint 1, 1
Local Variables
this
1 + 1
i
2
10: goto 2
2: iload_1
Local Variables
this
i
2
Operand Stack
push
2
3: iconst_2
Operand Stack
push
2
2
4: if_icmpge 13
Operand Stack
2
2
pop
pop
If 2 ≥ 2 goto 13
13: return

do while

```
public void doWhileLoop() {
    int i = 0;
    do {
        i++;
    } while (i < 2);
}
```




5: iload_1
Local Variables
this
i
1
Operand Stack
push
1
6: iconst_2
Operand Stack
push
2
1
7: if_icmplt 2
Operand Stack
2
pop
1
pop
If 1 < 2 goto 2
2: iinc 1, 1
Local Variables
this
1 + 1
i
2
5: iload_1
Local Variables
this
i
2
Operand Stack
push
2
6: iconst_2
Operand Stack
push
2
2
7: if_icmplt 2
Operand Stack
2
pop
2
pop
If 2 < 2 goto 2
10: return

方法的调用

方法的调用

- Java虚拟机里面提供四种方法调用字节码指令
  - invokestatic：静态方法
  - invokespecial：实例构造器<init>方法，私有方法和父类方法
  - invokevirtual：虚方法
  - invokeinterface：接口方法，会在运行时再确定一个实现此接口的对象
  - invokedynamic:随着JDK 7的发布，字节码指令集终于迎来了第一位新成员——invokedynamic指令。这条新增加的指令是JDK 7实现“动态类型语言（Dynamically Typed Language）”支持而进行的改进之一。

Hello World

```
$ javap -verbose -c -private HelloWorld
Compiled from "HelloWorld.java"
public class HelloWorld extends java.lang.Object
        SourceFile: "HelloWorld.java"
        minor version: 0
        major version: 50
        Constant pool:
const #1 = Method #6.#15; // java/lang/Object."<init>":()V
const #2 = Field #16.#17; // java/lang/System.out:Ljava/io/
PrintStream;
const #3 = String #18; // Hello, world!
const #4 = Method #19.#20; // java/io/PrintStream.println:
(Ljava/lang/String;)V
const #5 = class #21; // HelloWorld
const #6 = class #22; // java/lang/Object
const #7 = Asciz <init>;
const #8 = Asciz ()V;
const #9 = Asciz Code;
const #10 = Asciz LineNumberTable;
const #11 = Asciz main;
const #12 = Asciz ([Ljava/lang/String;)V;
const #13 = Asciz SourceFile;
const #14 = Asciz HelloWorld.java;
const #15 = NameAndType #7:#8;// "<init>":()V
const #16 = class #23; // java/lang/System
const #17 = NameAndType #24:#25;// out:Ljava/io/
PrintStream;
const #18 = Asciz Hello, world!;
const #19 = class #26; // java/io/PrintStream
const #20 = NameAndType #27:#28;// println:(Ljava/lang/
String;)V
const #21 = Asciz HelloWorld;
const #22 = Asciz java/lang/Object;
const #23 = Asciz java/lang/System;
const #24 = Asciz out;
const #25 = Asciz Ljava/io/PrintStream;;
const #26 = Asciz java/io/PrintStream;
const #27 = Asciz println;
const #28 = Asciz (Ljava/lang/String;)V;

{
public HelloWorld();
        Code:
                Stack=1, Locals=1, Args_size=1
                0: aload_0
                1: invokespecial #1; //Method java/lang/
Object."<init>":()V
                4: return

        LineNumberTable:
                line 1: 0

public static void main(java.lang.String[]);
        Code:
                Stack=2, Locals=1, Args_size=1
                0: getstatic #2; //Field java/lang/
System.out:Ljava/io/PrintStream;
                3: ldc #3; //String Hello, world!
                5: invokevirtual #4; //Method java/io/
PrintStream.println:(Ljava/lang/String;)V
                8: return
        LineNumberTable:
                line 5: 0
                line 6: 8
}
```

实例文件

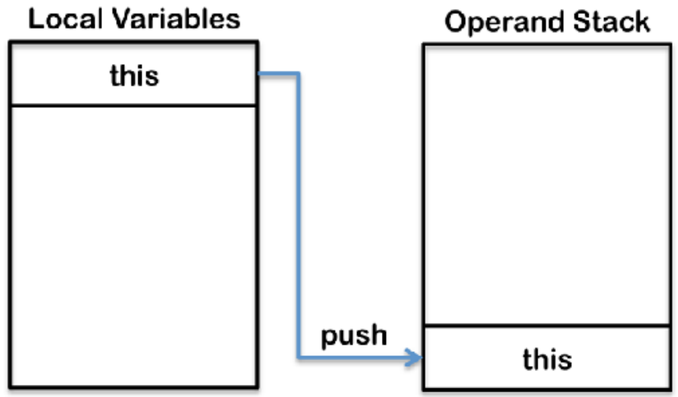
- package org.fenixsoft.clazz;

- public class TestClass{
-
- private int m;

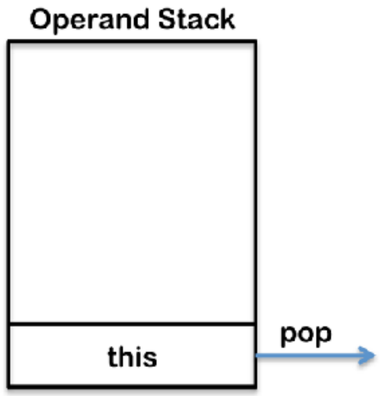
- public int inc(){
- return m+1;
- }
- }

SimpleClass()

0: aload_0



1: invokespecial #1



invokespecial

```
promote:~ qinliu$ javap -verbose TestClass
警告: 二进制文件TestClass包含org.fenixsoft.clazz.TestClass
Classfile /Users/qinliu/TestClass.class
  Last modified 2015-4-15; size 295 bytes
  MD5 checksum 81f2ab948a7a3068839b61a8f91f634b
  Compiled from "TestClass.java"
public class org.fenixsoft.clazz.TestClass
  minor version: 0
  major version: 52
  flags: ACC_PUBLIC, ACC_SUPER
Constant pool:
   #1 = Methodref          #4.#15         // java/lang/Object."<init>":()V
   #2 = Fieldref           #3.#16         // org/fenixsoft/clazz/TestClass.m:I
   #3 = Class              #17            // org/fenixsoft/clazz/TestClass
   #4 = Class              #18            // java/lang/Object
   #5 = Utf8               m
   #6 = Utf8               I
   #7 = Utf8               <init>
   #8 = Utf8               ()V
   #9 = Utf8               Code
  #10 = Utf8               LineNumberTable
  #11 = Utf8               inc
  #12 = Utf8               ()I
  #13 = Utf8               SourceFile
  #14 = Utf8               TestClass.java
  #15 = NameAndType        #7:#8          // "<init>":()V
  #16 = NameAndType        #5:#6          // m:I
  #17 = Utf8               org/fenixsoft/clazz/TestClass
  #18 = Utf8               java/lang/Object
{
  public org.fenixsoft.clazz.TestClass();
    descriptor: ()V
    flags: ACC_PUBLIC
    Code:
      stack=1, locals=1, args_size=1
         0: aload_0
         1: invokespecial #1                  // Method java/lang/Object."<init>":()V
         4: return
      LineNumberTable:
        line 3: 0

  public int inc();
    descriptor: ()I
    flags: ACC_PUBLIC
    Code:
      stack=2, locals=1, args_size=1
         0: aload_0
         1: getfield      #2                  // Field m:I
         4: iconst_1
         5: iadd
         6: ireturn
      LineNumberTable:
        line 8: 0
}
```