컴파일러개론 9주차 실습

INTERMEDIATE REPRESENTATION – JAVA BYTECDOE

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공지, 질문 방법

- 강의자료, 동영상
  - 사이버캠퍼스 업로드 예정
- 공지
  - 카카오톡 오픈채팅, 사이버캠퍼스
    - https://open.kakao.com/o/gkfF7JMg
      - 오픈프로필 사용 가능
      - 참여코드: 2024cp01
- 질문
  - 수업시간, 카카오톡 오픈채팅에 질문
  - 과제 관련 질문은 제출기한 전날까지만 가능 (당일 질문은 답변 X)
  - 이메일
    - 이메일 제목은 "[컴파일러개론][분반] ...", 제목 반드시 준수
    - 교수님 : eschough@cnu.ac.kr
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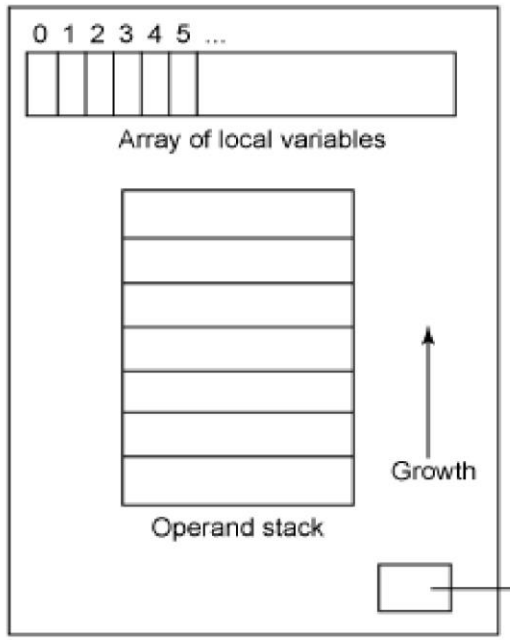
Java Bytecode

예 1) JVM Bytecode



- Bytecode (JVM)
  - IR of Java programs
  - stack machine-based architecture
  - in .class files, generated by
    "`javac test.java`"
  - to see mnemonics
    "`javap -c test.class`"

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javap: https://docs.oracle.com/javase/7/docs/technotes/tools/windows/javap.html

Example 1-1

Example 1-1

```
public Employee(String strName, int num)
{name = strName; idNumber = num; storeData(strName, num);}
Method Employee(java.lang.String,int)
0 aload_0 //push 'this' to stack
1 invokespecial #3 <Method java.lang.Object()> //call super
   class constructor
4 aload_0 //push 'this' to stack
5 aload_1 //push 'strName' to stack
6 putfield #5 <Field java.lang.String name> //push ref of
   'strName' to 'name' field of 'this'
9 aload_0 //push 'this' to stack
10 iload_2 //push 'num' to stack
11 putfield #4 <Field int idNumber> //push value of 'num' to
   'idNumber' field of 'this'
14 aload_0 //push 'this'
15 aload_1 //push ref of 'strName'
16 iload_2 //push ref of 'num'
17 invokespecial #6 <Method void
   storeData(java.lang.String, int)> //invoke a method
20 return
```

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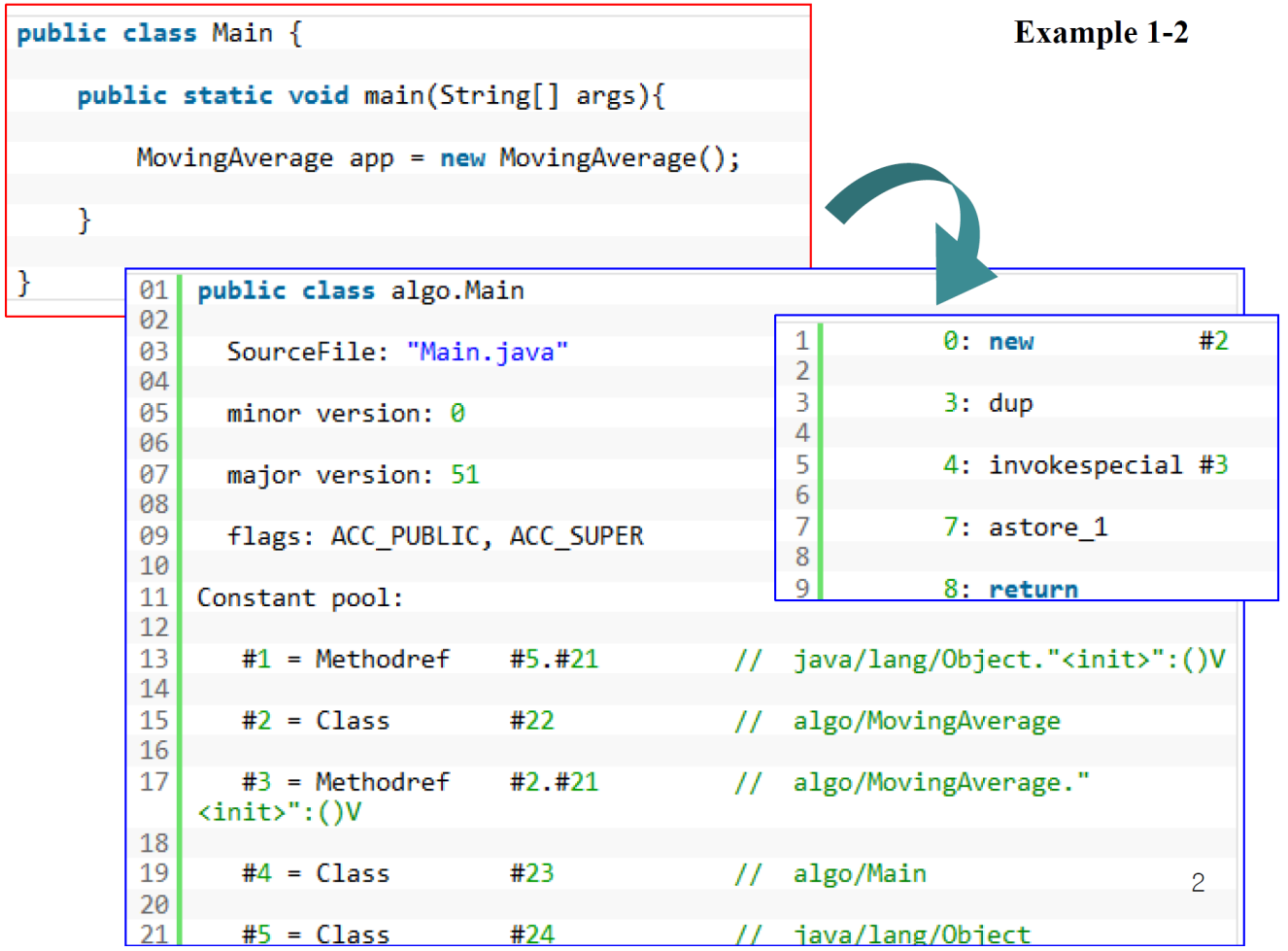
https://en.wikipedia.org/wiki/Java_bytecode_instruction_listings

Example 1-2



Example 1-2

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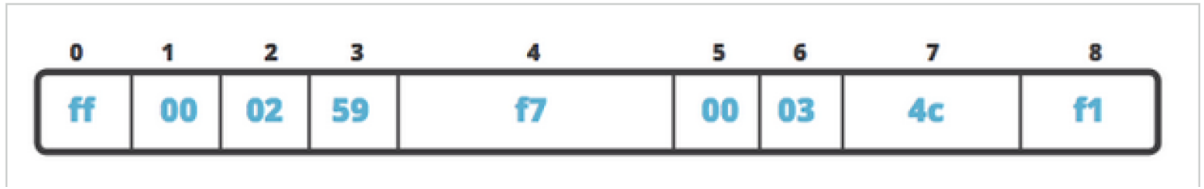
Example 1-2

```java
public class Main {

    public static void main(String[] args){

        MovingAverage app = new MovingAverage();

    }

}
```

```
0: new           #2

3: dup

4: invokespecial #3

7: astore_1

8: return
```

Instructions of Byte Code

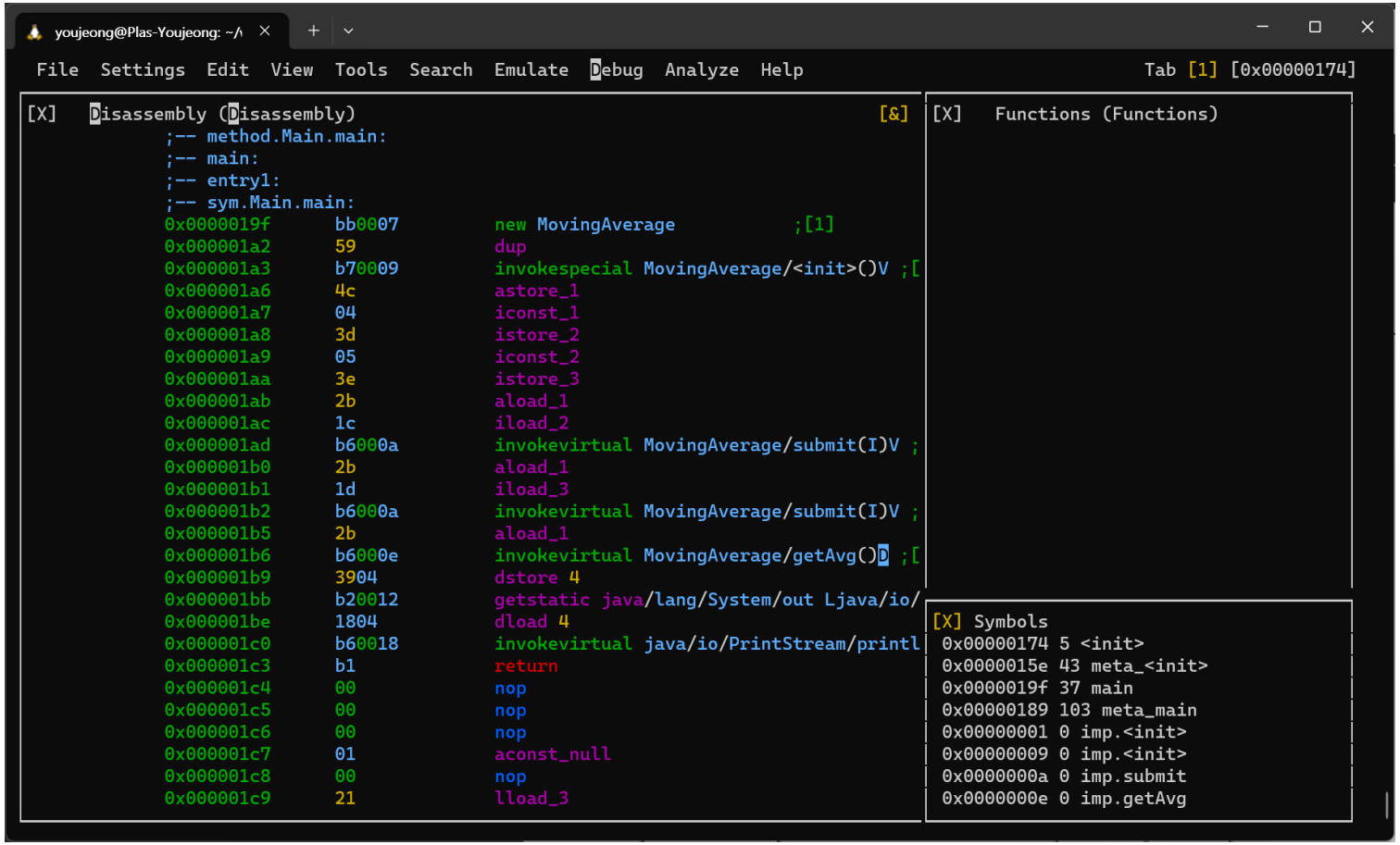
In Hex (after encoding)



Example 1-2

multianewarray	c5	1100 0101	3: indexbyte1, indexbyte2, dimensions	count1, [count2,...] → arrayref	create a new array of *dimensions* dimensions of type identified by class reference in constant pool *index* (indexbyte1 << 8 | indexbyte2); the sizes of each dimension is identified by *count1*, [*count2*, etc.]
new	bb	1011 1011	2: indexbyte1, indexbyte2	→ objectref	create new object of type identified by class reference in constant pool *index* (indexbyte1 << 8 | indexbyte2)
invokeinterface	b9	1011 1001	4: indexbyte1, indexbyte2, count, 0	objectref, [arg1, arg2, ...] → result	invokes an interface method on object *objectref* and puts the result on the stack (might be void); the interface method is identified by method reference *index* in constant pool (indexbyte1 << 8 | indexbyte2)
invokespecial	b7	1011 0111	2: indexbyte1, indexbyte2	objectref, [arg1, arg2, ...] → result	invoke instance method on object *objectref* and puts the result on the stack (might be void); the method is identified by method reference *index* in constant pool (indexbyte1 << 8 | indexbyte2)
invokestatic	b8	1011 1000	2: indexbyte1, indexbyte2	[arg1, arg2, ...] → result	invoke a static method and puts the result on the stack (might be void); the method is identified by method reference *index* in constant pool (indexbyte1 << 8 | indexbyte2)

Example 1-2


youjeong@Plas-Youjeong: ~/
File Settings Edit View Tools Search Emulate Debug Analyze Help
Tab [1] [0x00000174]
[X] Disassembly (Disassembly) [&]
;-- method.Main.main:
;-- main:
;-- entry1:
;-- sym.Main.main:
0x0000019f bb0007 new MovingAverage ;[1]
0x000001a2 59 dup
0x000001a3 b70009 invokespecial MovingAverage/<init>()V ;[
0x000001a6 4c astore_1
0x000001a7 04 iconst_1
0x000001a8 3d istore_2
0x000001a9 05 iconst_2
0x000001aa 3e istore_3
0x000001ab 2b aload_1
0x000001ac 1c iload_2
0x000001ad b6000a invokevirtual MovingAverage/submit(I)V ;
0x000001b0 2b aload_1
0x000001b1 1d iload_3
0x000001b2 b6000a invokevirtual MovingAverage/submit(I)V ;
0x000001b5 2b aload_1
0x000001b6 b6000e invokevirtual MovingAverage/getAvg()D ;[
0x000001b9 3904 dstore 4
0x000001bb b20012 getstatic java/lang/System/out Ljava/io/
0x000001be 1804 dload 4
0x000001c0 b60018 invokevirtual java/io/PrintStream/printl
0x000001c3 b1 return
0x000001c4 00 nop
0x000001c5 00 nop
0x000001c6 00 nop
0x000001c7 01 aconst_null
0x000001c8 00 nop
0x000001c9 21 lload_3
[X] Functions (Functions)
[X] Symbols
0x00000174 5 <init>
0x0000015e 43 meta_<init>
0x0000019f 37 main
0x00000189 103 meta_main
0x00000001 0 imp.<init>
0x00000009 0 imp.<init>
0x0000000a 0 imp.submit
0x0000000e 0 imp.getAvg

Example 1-3

```
public static void main(String[] args) {

  MovingAverage ma = new MovingAverage();


  int num1 = 1;

  int num2 = 2;


  ma.submit(num1);

  ma.submit(num2);


  double avg = ma.getAvg();

}
```

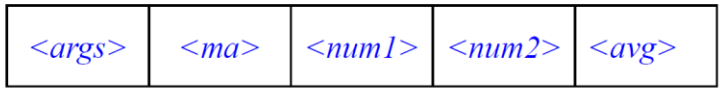
Example 1-3

Example 1-3

```
public static void main(String[] args) {
  MovingAverage ma = new MovingAverage();

  int num1 = 1;
  int num2 = 2;
  ----------------------------------
  ma.submit(num1);
  ma.submit(num2);

  double avg = ma.getAvg();
}
```

```
Code:0: new  #2    // class algo/MovingAverage
3: dup
4: invokespecial #3  // Method algo/MovingAverage."<init>":()V
7: astore_1    스택에서 값을 가져옴
8: iconst_1
9: istore_2
10: iconst_2
11: istore_3
```

Array of ***Local Variables***



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Example 1-3

```
public static void main(String[] args) {
  MovingAverage ma = new MovingAverage();

  int num1 = 1;
  int num2 = 2;

  ma.submit(num1);
  ma.submit(num2);
  ----------------------------------------------------------------------------
  double avg = ma.getAvg();
}
```

```
12: aload_1
13: iload_2
14: i2d
15: invokevirtual #4        // Method algo/MovingAverage.submit:(D)V
18: aload_1
19: iload_3
20: i2d
21: invokevirtual #4        // Method algo/MovingAverage.submit:(D)V
```

```
24: aload_1
25: invokevirtual #5        // Method algo/MovingAverage.getAvg:()D
28: dstore     4
```

Array of ***Local Variables***

<args>	<ma>	<num1>	<num2>	<avg>	...
_0	_1	_2	_3	_4	

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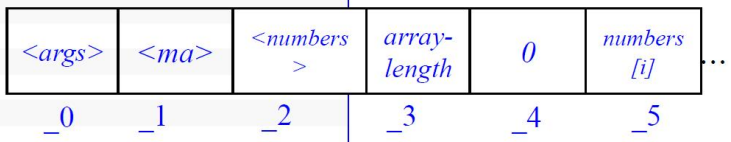
Example 1-4

```
0: new #2 // class algo/MovingAverage
3: dup
4: invokespecial #3 // Method algo/MovingAverage."<init>":()V
7: astore_1
8: getstatic #4 // Field numbers:[I
11: astore_2
12: aload_2
13: arraylength
14: istore_3
15: iconst_0
16: istore 4
18: iload 4
20: iload_3
21: if_icmpge 43
24: aload_2
25: iload 4
27: iaload
28: istore 5
```

```
30: aload_1
31: iload 5
33: i2d
34: invokevirtual #5 // Method algo/MovingAverage.submit:(D)V
37: iinc 4, 1
40: goto 18
43: return
```

Example 1-4



https://cs.au.dk/~mis/dOvs/jvmspec/ref-_iaload.html
https://cs.au.dk/~mis/dOvs/jvmspec/ref-iinc.html

Example 1-5

```
0: new #2 // class algo/MovingAverage
3: dup
4: invokespecial #3 // Method algo/MovingAverage."<init>":()V
7: astore_1
8: getstatic #4 // Field numbers:[I
11: astore_2
12: aload_2
13: arraylength
14: istore_3
15: iconst_0
16: istore 4
18: iload 4
20: iload_3
21: if_icmpge 43
24: aload_2
25: iload 4
27: iaload
28: istore 5
```

```
MovingAverage ma = new MovingAverage();
for (int number : numbers) {
    ma.submit(number);
}
```

```
30: aload_1
31: iload 5
33: i2d
34: invokevirtual #5 // Method algo/MovingAverage.submit:(D)V
37: iinc 4, 1
40: goto 18
43: return
```

Example 1-5

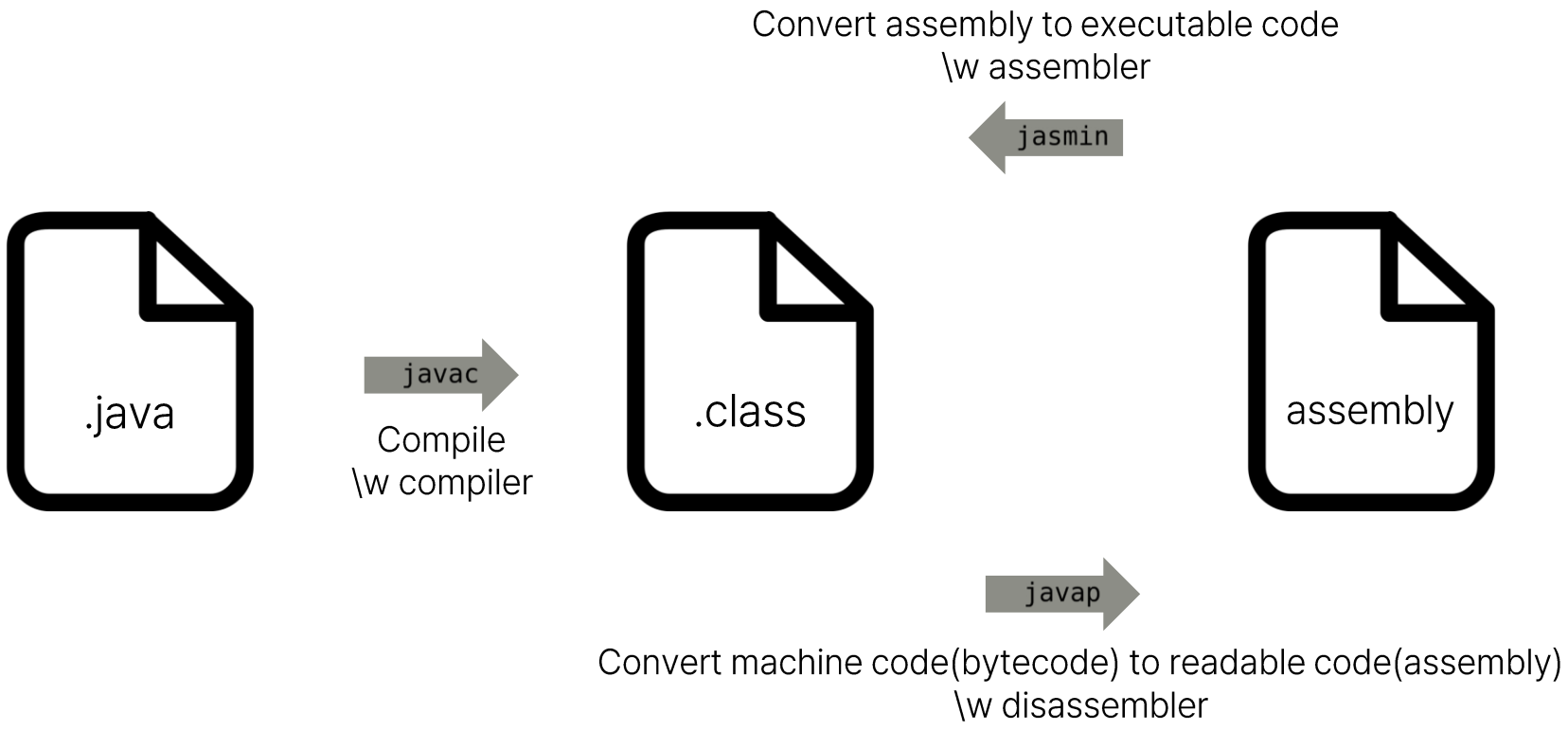
https://cs.au.dk/~mis/dOvs/jvmspec/ref-_iaload.html
https://cs.au.dk/~mis/dOvs/jvmspec/ref-iinc.html

9주차 실습: Java Bytecode 수기 작성

- Java 클래스 파일(.class 파일)
  - .java 파일의 컴파일 결과임
    - .java 파일 하나 당 .class 파일이 하나씩 생성됨
  - Java bytecode (JVM의 instructions)
  - JVM에 의해 실행 될 수 있음
    - 단독으로 실행될 수 있는 (Windows의) .exe과는 다르게 JVM을 통해서만 실행 가능
  - encoding 되어 있어서 사람이 읽을 수 없음 → 읽을 수 있는 형태인 JVM assembly로 표현 가능
- JVM Assembly Code
  - 이게 앞에서 계속 봐 왔던 것들

```
 0: new           #7                  // class MovingAverage
 3: dup
 4: invokespecial #9                  // Method MovingAverage."<init>":()V
 7: astore_1
 8: iconst_1
 9: istore_2
10: iconst_2
11: istore_3
12: aload_1
13: iload_2
14: invokevirtual #10                 // Method MovingAverage.submit:(I)V
17: aload_1
18: iload_3
19: invokevirtual #10                 // Method MovingAverage.submit:(I)V
22: aload_1
23: invokevirtual #14                 // Method MovingAverage.getAvg:()D
```

9주차 실습: Java Bytecode 수기 작성



9주차 실습: Java Bytecode 수기 작성

Example.java

```java
public class Example {
    2 usages
    int number;
    1 usage
    public Example(int number){
        this.number = number;
    }

    1 usage
    void printNumber(){
        System.out.println("print: " + this.number);
    }

    public static void main(String[] args) {
        Example example = new Example( number: 12);
        example.printNumber();
    }
}
```

write Java Code

compile

```
admin@Plas-Youjeong MINGW64 ~/IdeaProjects/java_byte_code/src
$ javac Example.java

admin@Plas-Youjeong MINGW64 ~/IdeaProjects/java_byte_code/src
$ javap -c Example.class
Compiled from "Example.java"
public class Example {
  public static void main(java.lang.String[]);
    Code:
       0: new           #8                  // class Example
       3: dup
       4: bipush        12
       6: invokespecial #29                 // Method "<init>":(I)V
       9: astore_1
      10: aload_1
      11: invokevirtual #32                 // Method printNumber:()V
      14: return
}
```

javap \w –c option

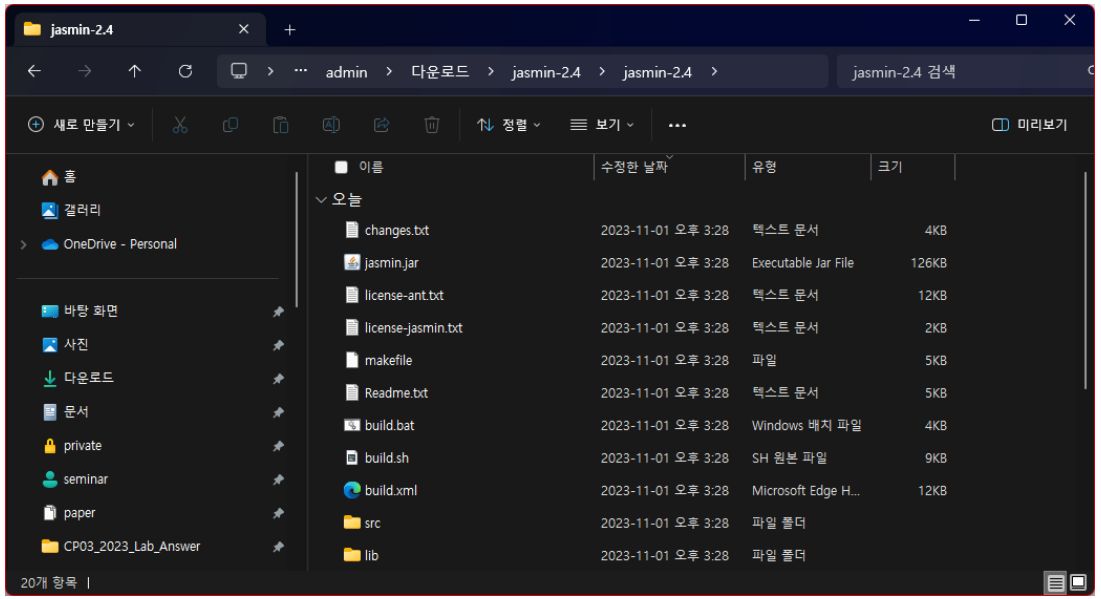
javap \w –v option (-verbose option)

```
admin@Plas-Youjeong MINGW64 ~/IdeaProjects/java_byte_code/src
$ javap -v Example.class
Classfile /C:/Users/admin/IdeaProjects/java_byte_code/src/Example.class
  Last modified 2023. 11. 1.; size 992 bytes
  SHA-256 checksum 638dd6087f23601d562f87c1eaf606fd294113d8377461a936cbdec5a27f77f3
  Compiled from "Example.java"
public class Example
  minor version: 0
  major version: 63
  flags: (0x0021) ACC_PUBLIC, ACC_SUPER
  this_class: #8                          // Example
  super_class: #2                         // java/lang/Object
  interfaces: 0, fields: 1, methods: 3, attributes: 3
Constant pool:
   #1 = Methodref          #2.#3          // java/lang/Object."<init>":()V
   #2 = Class              #4             // java/lang/Object
   #3 = NameAndType        #5:#6          // "<init>":()V
   #4 = Utf8               java/lang/Object
   #5 = Utf8               <init>
   #6 = Utf8               ()V
   #7 = Fieldref           #8.#9          // Example.number:I
   #8 = Class              #10            // Example
   #9 = NameAndType        #11:#12        // number:I
  #10 = Utf8               Example
  #11 = Utf8               number
  #12 = Utf8               I
  #13 = Fieldref           #14.#15        // java/lang/System.out:Ljava/io/PrintStream;
```

⋮

9주차 실습: Java Bytecode 수기 작성

download & unzip
http://jasmin.sourceforge.net/



Use jasmin (in the directory that has jasmin.jar)

```
C:\Users\admin\Downloads\jasmin-2.4\jasmin-2.4>java -jar jasmin.jar Test.j
Generated: Test.class

C:\Users\admin\Downloads\jasmin-2.4\jasmin-2.4>java Test
```

9주차 과제: Java Bytecode 수기작성

- 과제 1
  - JVM assembly code (Test.j)를 보고 Java 코드로 표현하기
  - 코드는 자료실에 별도 공지 (Test.j)
  - 수기 (손으로) 작성하여 촬영, 혹은 태블릿 이용하여 pdf 파일로 "손글씨"로 작성하여 사이버캠퍼스 제출
  - "pdf" 파일로 제출
- 과제 2
  - javap, jasmin 사용해보기
  - 올려준 JVM assembly 코드 (Test.j)를 jasmin으로 (.class) 파일로 변환 후 실행해보기
  - 본인이 수기로 작성한 과제1 결과물을 javac로 컴파일, javap로 disassemble 해서 결과 확인하기
  - 수행한 내용을 보고서로 작성해서 제출 [HW08_분반_학번_이름.pdf] (ex, HW08_00_202412345_홍길동.pdf)
  - 수행 과정 각 단계에 대한 터미널 화면(명령과 실행 결과)가 존재해야 하며, 사진만 첨부하여 제출하지 말 것 (설명 한 줄이라도 추가)
- 마감
  - **2024**년 **11**월 **8**일 금요일 **23**시 **59**분 **(**기한 엄수**)**
  - 추가 제출 기한 없음