CSED211 Lab 03

Instruction & GDB debugger

2019. 09. 18.

Announcement

- Assignment of Lab1 => Due date: 9/20(Fri) 23:59
  - No Penalty for late submission
- Other Assignments (including Lab2)
  - Late submission is allowed, but 10% penalty for a day
  - The maximum allowance is up to 3 days
  - If you submit your HW 3 days later, your score will be cut by 30%

Assembly Language: Instruction

Assembly Language

- Machine-friendly language
- Result of ‘compile’
- What machine really sees and runs

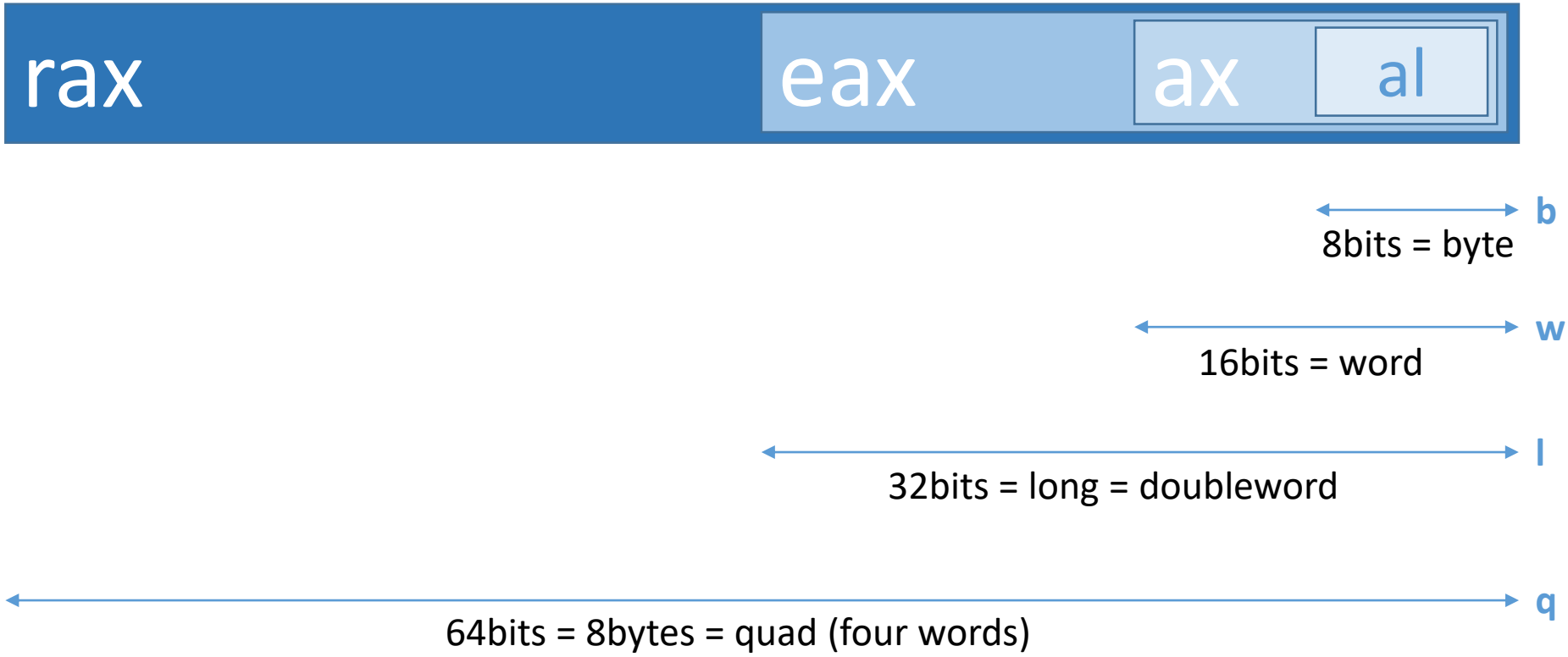
```
(gdb) disas add
Dump of assembler code for function add:
   0x00000000004004ed <+0>:     push   %rbp
   0x00000000004004ee <+1>:     mov    %rsp,%rbp
   0x00000000004004f1 <+4>:     mov    %edi,-0x4(%rbp)
   0x00000000004004f4 <+7>:     mov    %esi,-0x8(%rbp)
   0x00000000004004f7 <+10>:    mov    -0x8(%rbp),%eax
   0x00000000004004fa <+13>:    mov    -0x4(%rbp),%edx
   0x00000000004004fd <+16>:    add    %edx,%eax
   0x00000000004004ff <+18>:    pop    %rbp
   0x0000000000400500 <+19>:    retq
End of assembler dump.
```

Registers

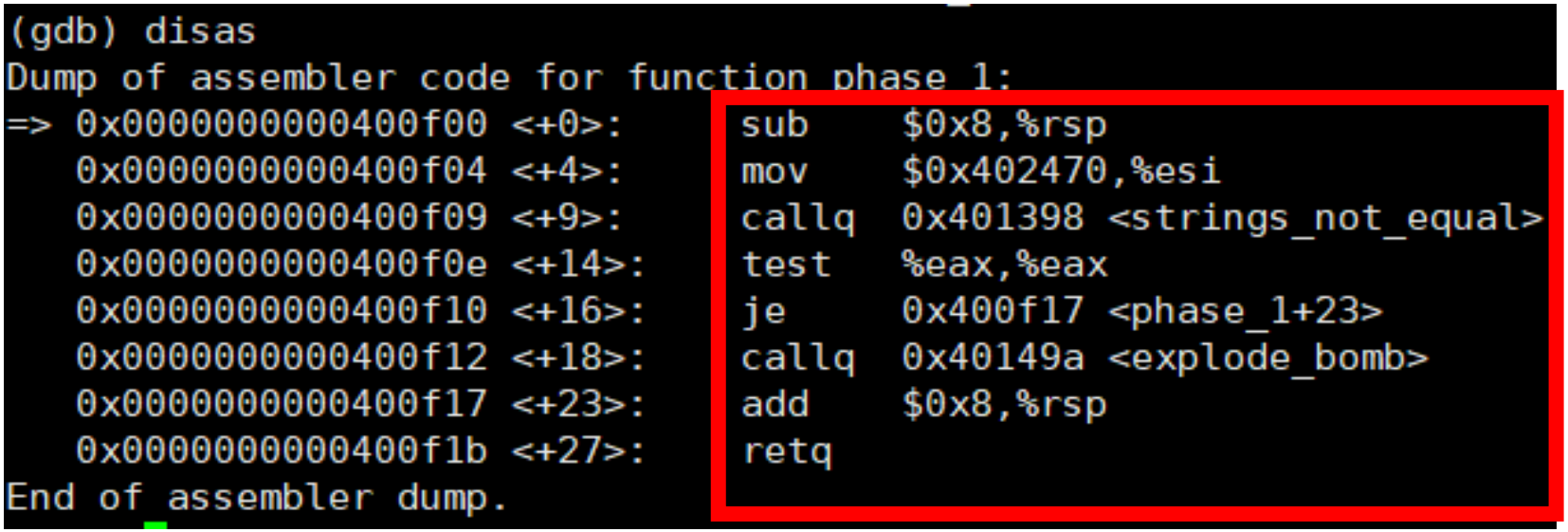
- A quickly accessible storage available to CPU
- General purpose registers:
  - rax (return value) → eax in 32bit
  - rbx (callee saved) → ebx in 32 bit
  - rcx (4th argument) → …
  - rdx (3rd argument)
  - rsi (2nd argument)
  - rdi (1st argument)
- Special purpose registers:
  - rsp (stack pointer)

Reference ***Figure 3.2***

Size of Registers



Assembly Instruction



Assembly Op Code

- Unit of operation
- Calculate and save the result to register/memory
- Binary operators:

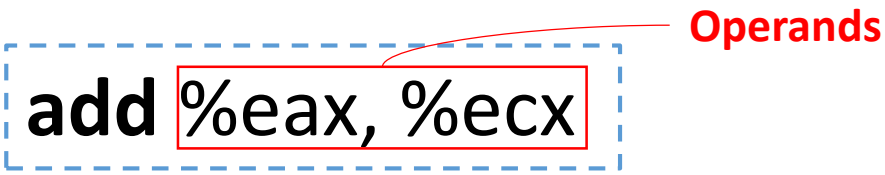
  OP SRC, DST ⇔ DST = ***OP***(SRC, DST)

  - mov, sub, add, cmp, …
  - e.g., **add** %eax, %ecx → ecx = eax **+** ecx
- Unary operators:

  OP DST ⇔ DST = ***OP***(DST)

  - inc, dec, neg, not, …

Assembly Operands



- Immediate
  - $0x8, $5, $-1
- Register
  - %rsp, %esi, %eax, %r14
- Memory
  - D(Rb, Ri, S)
  - 8(%ebx), 12(%ebx, %ecx, 4)

Reference ***Figure 3.3***

Assembly Basic – 1

- Data movement instructions

MOV a1, a2 (a2 = a1)

%rbp → p
(%rbp) → *p
20(%rbp) → *(p + 20)

Assembly Basic – 2

- Arithmetic instructions

ADD a1, a2

- a2 = a2 + a1

SUB a1, a2

- a2 = a2 - a1

IMUL a1, a2

- a2 = a2 * a1

Special Operations

- CLTQ (may see it in bomblab):
  - Convert long to quad : %rax = SignExtend(%eax)
  - eax = 0x05 → rax = 0x05
  - eax = 0x80000000 → rax = 0xffffffff 80000000
- LEA: load effective address
  - Does not dereference memory
  - Used as an arithmetic operator to perform memory address calculations
    - Commonly used for calculating offsets into an array in a loop
  - lea 7(%rdx, %rdx, 4), %rax ⇔ rax = 5 * rdx + 7

Control: Compare and Flags

- Condition codes:
  - CMP S1, S2 → executes R = S2 – S1, and set ***Flags***
  - TEST S1, S2 → executes R = S1 & S2, and set ***Flags***

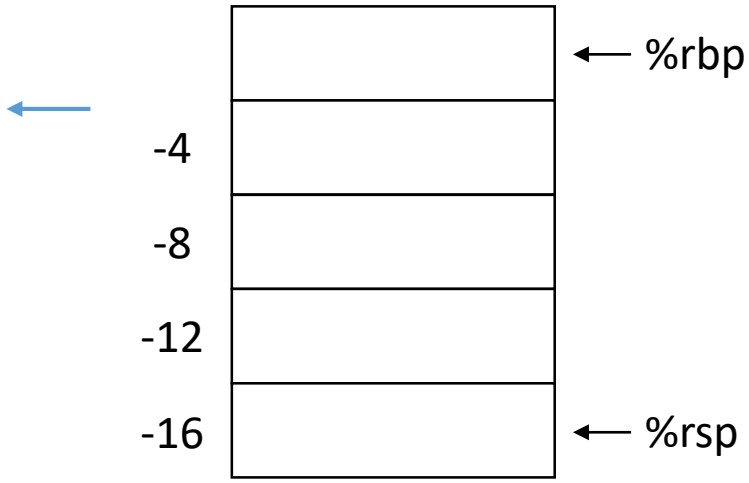
- Flags (about R = S1 + S2)
  - **CF** (Carry Flag) is set if **(unsigned) R < (unsigned) S1**
  - **ZF** (Zero Flag) is set if **R == 0**
  - **SF** (Sign Flag) is set if **R < 0**
  - **OF** (Overflow flag) is set if **(S1 < 0 == S2 < 0) && (R < 0 != S1 < 0)**

Control: Jumps

Instruction	Jump condition	Description
jmp *Label*	1	Direct jump
jmp **Operand*	1	Indirect jump
je *Label*	ZF	Equal / zero
jne *Label*	~ZF	Not equal / not zero
jg *Label*	~(SF^OF)&~ZF	Greater (>)
jge *Label*	~(SF^OF)	Greater or equal(>=)
jl *Label*	SF^OF	Less (<)
jle *Label*	(SF^OF)|ZF	Less or equal (<=)

Example of Control

```
0x000000000040059d <+0>:     push   %rbp
0x000000000040059e <+1>:     mov    %rsp,%rbp
0x00000000004005a1 <+4>:     sub    $0x10,%rsp
0x00000000004005a5 <+8>:     mov    %edi,-0x4(%rbp)
0x00000000004005a8 <+11>:    cmpl   $0xd3,-0x4(%rbp)
0x00000000004005af <+18>:    jne    0x4005bb <print+30>
0x00000000004005b1 <+20>:    mov    $0x400674,%edi
0x00000000004005b6 <+25>:    callq  0x400470 <puts@plt>
0x00000000004005bb <+30>:    nop
0x00000000004005bc <+31>:    leaveq
0x00000000004005bd <+32>:    retq
```



Example of Control

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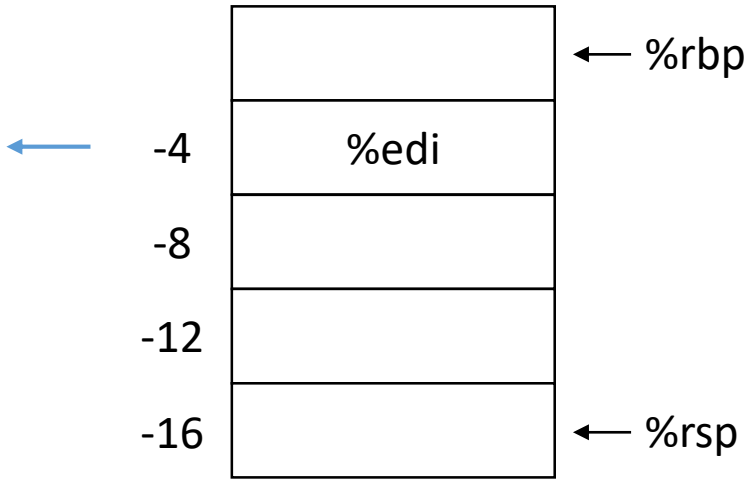

Example of Control

```
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0x00000000004005a1 <+4>:     sub    $0x10,%rsp
0x00000000004005a5 <+8>:     mov    %edi,-0x4(%rbp)
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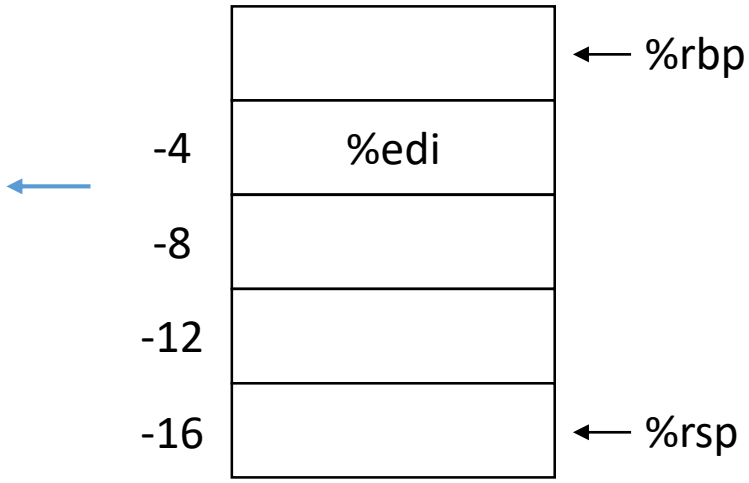
0x00000000004005af <+18>:    jne    0x4005bb <print+30>
0x00000000004005b1 <+20>:    mov    $0x400674,%edi
0x00000000004005b6 <+25>:    callq  0x400470 <puts@plt>
0x00000000004005bb <+30>:    nop
0x00000000004005bc <+31>:    leaveq
0x00000000004005bd <+32>:    retq
```



Compare 0xd3 and %edi

Example of Control

```
0x000000000040059d <+0>:     push   %rbp
0x000000000040059e <+1>:     mov    %rsp,%rbp
0x00000000004005a1 <+4>:     sub    $0x10,%rsp
0x00000000004005a5 <+8>:     mov    %edi,-0x4(%rbp)
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0x00000000004005b1 <+20>:    mov    $0x400674,%edi
0x00000000004005b6 <+25>:    callq  0x400470 <puts@plt>
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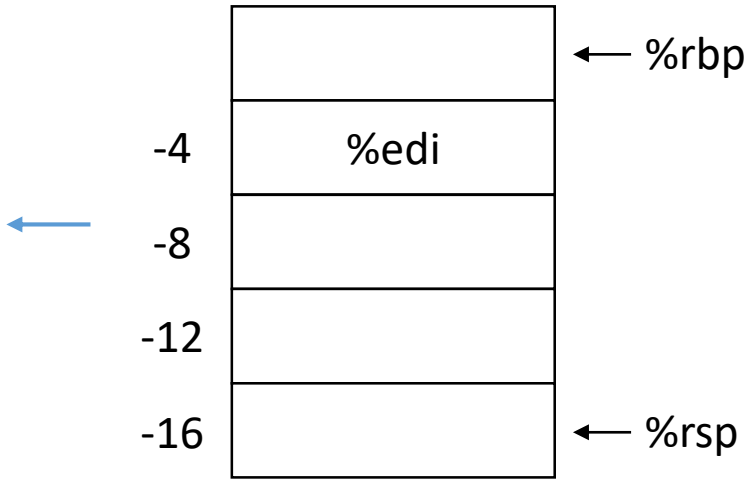


Compare 0xd3 and %edi

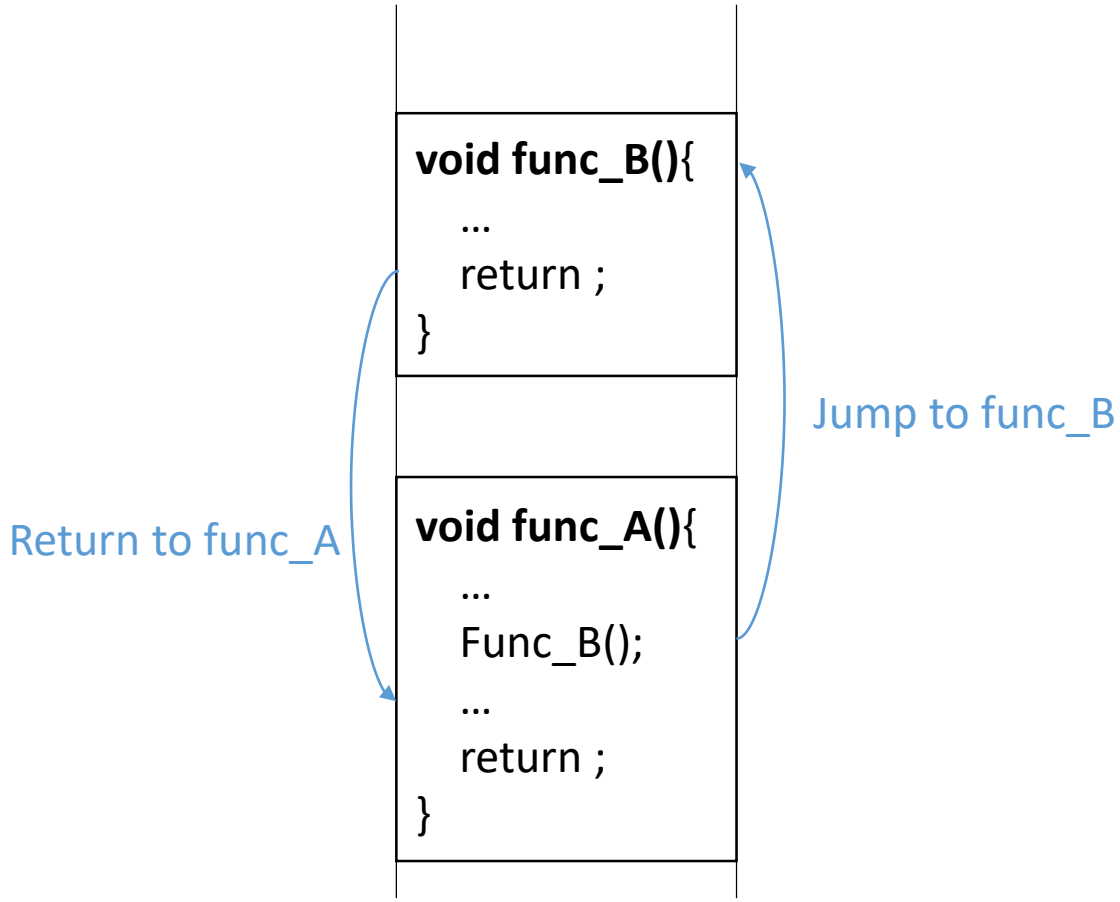
→ if not equal, jump to <print+30>

Stack

- Data structure to manage execution control flow
  - Located in memory
  - Variables can be stored in stack
  - Last in, First out (LIFO)
  - Stack grows downward
    - %rbp: previous stack pointer
    - %rsp: current stack pointer
  - **PUSH**, **POP** instruction
    - PUSH: push new data on the top
    - POP: pop (take out) the top data of stack

Function Call Procedure (1/2)

```
void fun_A(){
    …
    fun_B();
    …
}
```



Function Call Procedure (2/2)

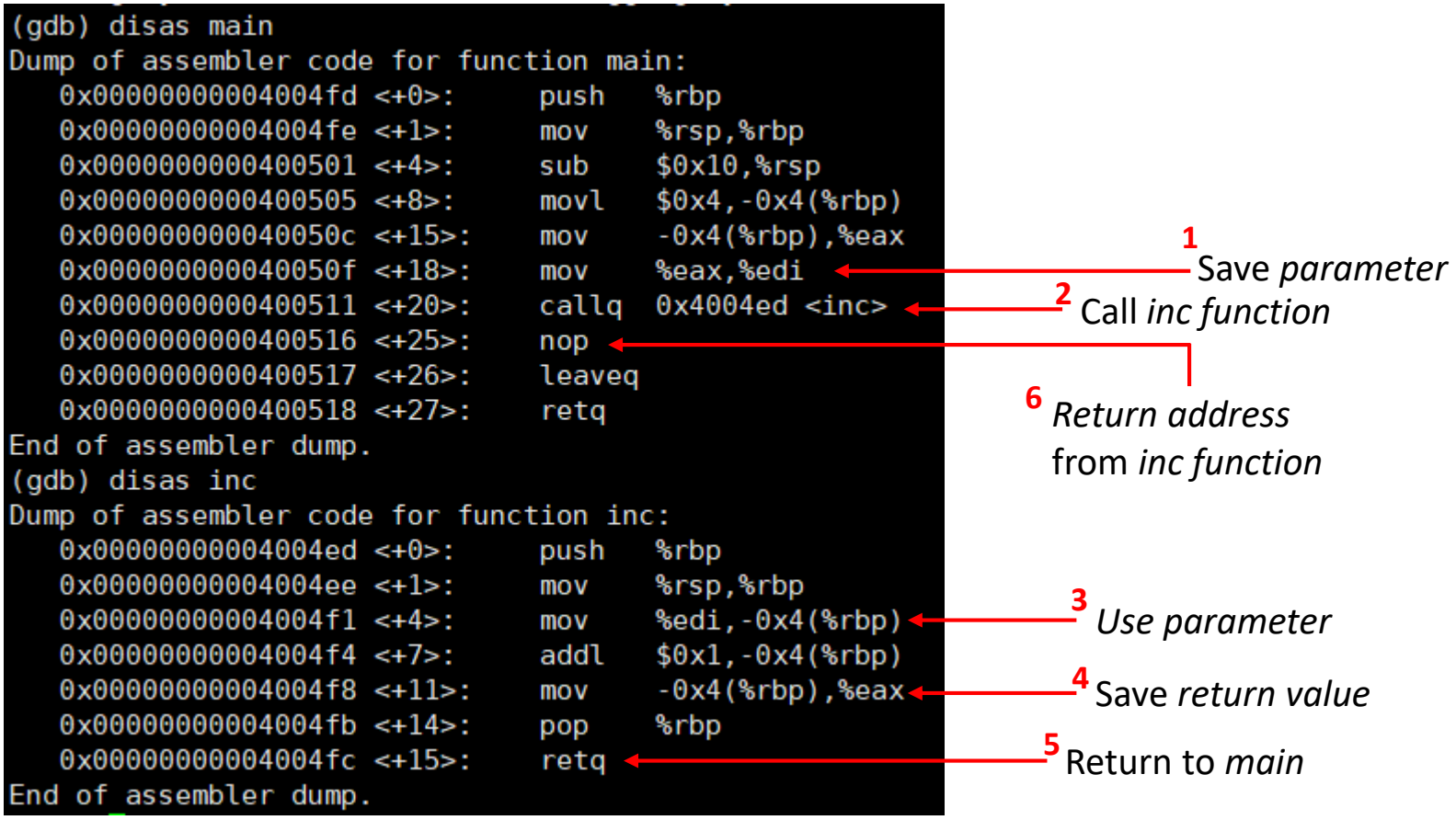
- Caller function
  - Function which calls function
- Callee function
  - Function which is called by caller function
- CALL and RET Instruction
  - CALL: saves return address on the stack and jump to the callee function
  - RET: transfers program control to a return address located on the top of the stack

Return Address & Function Parameter

- Return address
  1. Caller function calls Callee function and Callee function is executed
     - Call instruction stores the return address (next instruction address from call)
  2. Return to proper address in caller function with the return address

- Function parameter
  1. Store the parameter in register or stack
  2. Caller function calls Callee function.
  3. Callee function uses the register or stack data as parameter.

Example of Procedure



GDB

GDB

- The GNU Project debugger
- It runs on Linux systems
- It works for C, C++, Objective-C, Pascal, …

- To debug a program with GDB, include “-g” option when compile
  - gcc example.c –g –o example
- Execute GDB with an execution file
  - gdb example

GDB commands

- disas (Disassemble)
  - shows machine codes
  - disas *func* : shows the machine code of the function '*func*'
  - disas *10* : shows the machine code at the line '*10*'
  - disas **0x300* : shows the machine code at the address '*0x300*'
- l (List)
  - shows source codes
  - l *10* : shows the source code at the line '*10*'
  - l *func* : show source codes of the function '*func*'

GDB commands

- b (Break)
  - makes a breakpoint
  - b *func* : break before executing the function '*func*'
  - b *10* : break at the line '*10*'
  - b **0x300* : break at the address '*0x300*'
- cl (Clear)
  - deletes a breakpoint
  - same as above
- d (Delete)
  - deletes all breakpoints

GDB commands

- r (Run)
  - runs the program
  - r *arg1 arg2* : run the program with arguments '*arg1*' and '*arg2*'
- k (Kill)
  - kills currently running program
- n (Next)
  - executes the next instruction
  - n *6* : executes next 6 instructions
- c (Continue)
  - executes the instructions before the next breakpoint

GDB commands

- info (Information)
  - shows available symbols in the program
  - info functions : lists available functions at the current line
  - info variables : lists available global variables at the current line
  - info locals : lists available local variables at the current line

- p (Print)
  - prints the value of a variable
  - p *var* : prints the value of the variable '*var*'
  - p *func* : prints the address of the function '*func*'
  - p **0x300* : prints the value at the address '*0x300*'
  - p $*eax* : prints the value of the register '*eax*'
  - p/<format><expression>: print expression in format
    - e.g., p/c 0x61 → print 'a' which is character expression of 0x61

GDB commands

- X(check the memory)
  - x/<format> <address>: print contents of memory in format
    - e.g., x/s 0x4005a57 → print string stored in 0x4005a57
- More Information
  - GDB online manuals
    - https://sourceware.org/gdb/current/onlinedocs/gdb/
  - Feel free to ask Google

Objdump

- objdump –d example
  - You can check the assembly code
  - e.g. objdump –d practice_gdb

Practice

- Analyze the assembly code using GDB

- Let's print something by satisfying the control in *foo* function, avoiding *wrong_input* function

```
(gdb) disas main
Dump of assembler code for function main:
   0x00000000004005ed <+0>:     push   %rbp
   0x00000000004005ee <+1>:     mov    %rsp,%rbp
   0x00000000004005f1 <+4>:     sub    $0x10,%rsp
   0x00000000004005f5 <+8>:     mov    $0x4006f4,%edi
   0x00000000004005fa <+13>:    callq  0x4004b0 <puts@plt>
   0x00000000004005ff <+18>:    mov    $0x40070a,%edi
   0x0000000000400604 <+23>:    mov    $0x0,%eax
   0x0000000000400609 <+28>:    callq  0x4004c0 <printf@plt>
   0x000000000040060e <+33>:    lea    -0x4(%rbp),%rax
   0x0000000000400612 <+37>:    mov    %rax,%rsi
   0x0000000000400615 <+40>:    mov    $0x400713,%edi
   0x000000000040061a <+45>:    mov    $0x0,%eax
   0x000000000040061f <+50>:    callq  0x4004f0 <__isoc99_scanf@plt>
   0x0000000000400624 <+55>:    mov    -0x4(%rbp),%eax
   0x0000000000400627 <+58>:    mov    %eax,%edi
   0x0000000000400629 <+60>:    callq  0x400630 <foo>
   0x000000000040062e <+65>:    leaveq
   0x000000000040062f <+66>:    retq
End of assembler dump.
```

```
(gdb) disas foo
Dump of assembler code for function foo:
   0x0000000000400630 <+0>:     push   %rbp
   0x0000000000400631 <+1>:     mov    %rsp,%rbp
   0x0000000000400634 <+4>:     sub    $0x10,%rsp
   0x0000000000400638 <+8>:     mov    %edi,-0x4(%rbp)
   0x000000000040063b <+11>:    cmpl   $0xa87,-0x4(%rbp)
   0x0000000000400642 <+18>:    jne    0x400650 <foo+32>
   0x0000000000400644 <+20>:    mov    $0x400716,%edi
   0x0000000000400649 <+25>:    callq  0x4004b0 <puts@plt>
   0x000000000040064e <+30>:    jmp    0x40065a <foo+42>
   0x0000000000400650 <+32>:    mov    $0x0,%eax
   0x0000000000400655 <+37>:    callq  0x40065c <wrong_input>
   0x000000000040065a <+42>:    leaveq
   0x000000000040065b <+43>:    retq
End of assembler dump.
```

Step

1. >> tar –xvf practice_gdb.tar
2. >> gdb practice_gdb
3. (gdb) disas main
4. (gdb) disas foo
5. Analyze the control in *foo* function in order to call *printf()* function
6. Reversely trace which variable affect the control
7. Analyze which type of *scanf()* input

Assignment: Bomblab

- Disassemble the binary ./bomb and defuse the bomb!
- Solve 6 phase (*phase_1, phase_2, …, phase _6*) avoiding *explode_bomb*
- Find hidden phase
- Refer to the additional pdf file

- You will have to write the report in full detail for your next lab assignment!
- **Due date: 10/1(Tue) 23:59**

What to Do for *Bomblab*

- This Lab assignment may be difficult!, so …
- Read and understand *Chapter 3* in your textbook
  - *A practice problem* is really helpful for your understanding.
- Use and understand GDB
  - GDB is a useful debugger and will be used in the OS class (CSED312).
- Search what you have to know
  - Lab and class resources are not enough to refuse the binary bomb. If you want to know more, search it (in Google)!