Computer Organization
Lab 1: RISC-V Programming

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Lab 1 : RISC-V Assembly Programming

- Factorial
- Bubble_sort
- Gcd
- Fibonacci

Register	ABI Name	Description	Saver
x0	zero	Hard-wired zero	—
x1	ra	Return address	Caller
x2	sp	Stack pointer	Callee
x3	gp	Global pointer	—
x4	tp	Thread pointer	—
x5	t0	Temporary/alternate link register	Caller
x6–7	t1–2	Temporaries	Caller
x8	s0/fp	Saved register/frame pointer	Callee
x9	s1	Saved register	Callee
x10–11	a0–1	Function arguments/return values	Caller
x12–17	a2–7	Function arguments	Caller
x18–27	s2–11	Saved registers	Callee
x28–31	t3–6	Temporaries	Caller
f0–7	ft0–7	FP temporaries	Caller
f8–9	fs0–1	FP saved registers	Callee
f10–11	fa0–1	FP arguments/return values	Caller
f12–17	fa2–7	FP arguments	Caller
f18–27	fs2–11	FP saved registers	Callee
f28–31	ft8–11	FP temporaries	Caller

Table 20.1: Assembler mnemonics for RISC-V integer and floating-point registers.

Table: System services.

Service	System Call Code	Arguments	Result
print_int	1	`$a0` = integer	
print_float	2	`$f12` = float	
print_double	3	`$f12` = double	
print_string	4	`$a0` = string	
read_int	5		integer (in `$v0`)
read_float	6		float (in `$f0`)
read_double	7		double (in `$f0`)
read_string	8	`$a0` = buffer, `$a1` = length	
sbrk	9	`$a0` = amount	address (in `$v0`)
exit	10		
print_character	11	`$a0` = character	
read_character	12		character (in `$v0`)
open	13	`$a0` = filename,	file descriptor (in `$v0`)
		`$a1` = flags, `$a2` = mode	
read	14	`$a0` = file descriptor,	bytes read (in `$v0`)
		`$a1` = buffer, `$a2` = count	
write	15	`$a0` = file descriptor,	bytes written (in `$v0`)
		`$a1` = buffer, `$a2` = count	
close	16	`$a0` = file descriptor	0 (in `$v0`)
exit2	17	`$a0` = value	

Revision

Register Operand Example

- C code:

```
f = (g + h) - (i + j);
```

  - f, …, j in x19, x20, …, x23

- Compiled RISC-V code:

```
add x5, x20, x21
add x6, x22, x23
sub x19, x5, x6
```

Revision

Memory Operand Example

- C code:

```
A[12] = h + A[8];
```

  - h in x21, base address of A in x22

- Compiled RISC-V code:
  - Index 8 requires offset of 64
    - 8 bytes per doubleword

```
ld      x9, 64(x22)
add     x9, x21, x9
sd      x9, 96(x22)
```

Revision

Immediate Operands

- Constant data specified in an instruction

```
addi x22, x22, 4
```

- ***Design Principle 3:*** Make the common case fast
  - Small constants are common
  - Immediate operand avoids a load instruction

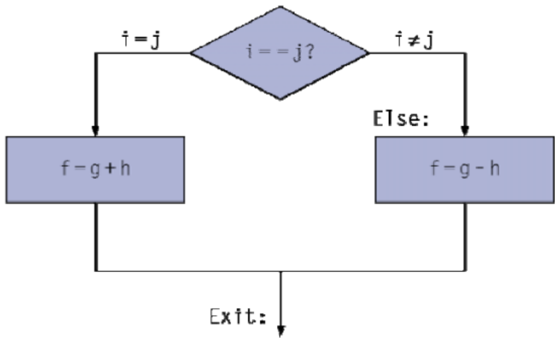
Revision

Compiling If Statements

- C code:

```
if (i==j) f = g+h;
else f = g-h;
```

  - f, g, … in x19, x20, …



- Compiled RISC-V code:

```
       bne x22, x23, Else
       add x19, x20, x21
       beq x0,x0,Exit // unconditional
Else:  sub x19, x20, x21
Exit:  …
```

Assembler calculates addresses

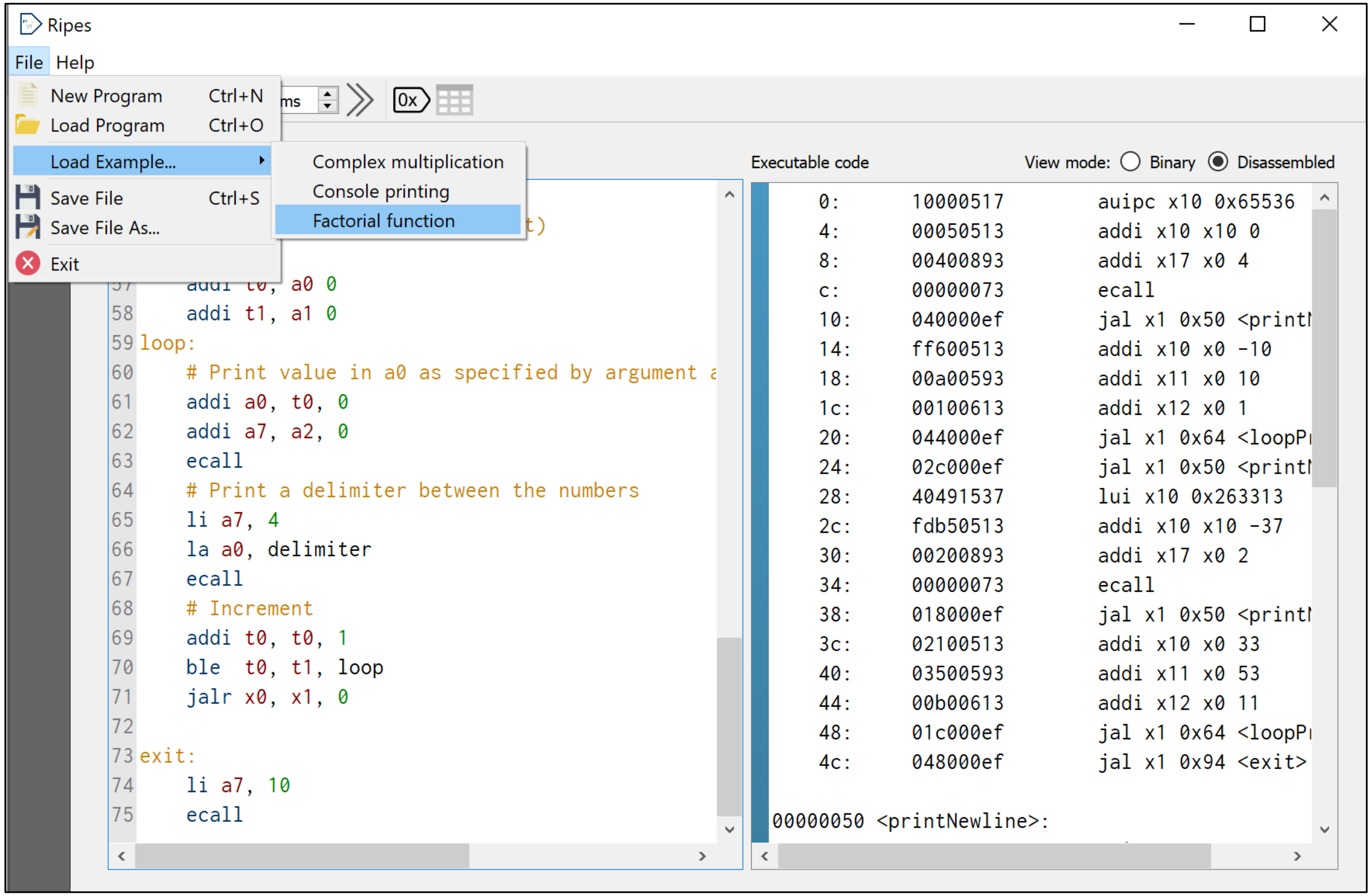
Revision Example

Leaf Procedure Example

- RISC-V code:

```
fact:
    addi sp,sp,-16      Save return address and n on stack
    sd   x1,8(sp)
    sd   x10,0(sp)
    addi x5,x10,-1      x5 = n - 1
    bge  x5,x0,L1       if n >= 1, go to L1
    addi x10,x0,1       Else, set return value to 1
    addi sp,sp,16       Pop stack, don't bother restoring values
    jalr x0,0(x1)       Return
L1: addi x10,x10,-1     n = n - 1
    jal  x1,fact        call fact(n-1)
    addi x6,x10,0       move result of fact(n - 1) to x6
    ld   x10,0(sp)      Restore caller's n
    ld   x1,8(sp)       Restore caller's return address
    addi sp,sp,16       Pop stack
    mul  x10,x10,x6     return n * fact(n-1)
    jalr x0,0(x1)       return
```

Example


Ripes
File Help
New Program Ctrl+N
Load Program Ctrl+O
Load Example...
Save File Ctrl+S
Save File As...
Exit
Complex multiplication
Console printing
Factorial function
ms
0x
Executable code
View mode: Binary Disassembled
58 addi t1, a1 0
59 loop:
60 # Print value in a0 as specified by argument a
61 addi a0, t0, 0
62 addi a7, a2, 0
63 ecall
64 # Print a delimiter between the numbers
65 li a7, 4
66 la a0, delimiter
67 ecall
68 # Increment
69 addi t0, t0, 1
70 ble t0, t1, loop
71 jalr x0, x1, 0
72
73 exit:
74 li a7, 10
75 ecall
0: 10000517 auipc x10 0x65536
4: 00050513 addi x10 x10 0
8: 00400893 addi x17 x0 4
c: 00000073 ecall
10: 040000ef jal x1 0x50 <printN
14: ff600513 addi x10 x0 -10
18: 00a00593 addi x11 x0 10
1c: 00100613 addi x12 x0 1
20: 044000ef jal x1 0x64 <loopPr
24: 02c000ef jal x1 0x50 <printN
28: 40491537 lui x10 0x263313
2c: fdb50513 addi x10 x10 -37
30: 00200893 addi x17 x0 2
34: 00000073 ecall
38: 018000ef jal x1 0x50 <printN
3c: 02100513 addi x10 x0 33
40: 03500593 addi x11 x0 53
44: 00b00613 addi x12 x0 11
48: 01c000ef jal x1 0x64 <loopPr
4c: 048000ef jal x1 0x94 <exit>
00000050 <printNewline>:

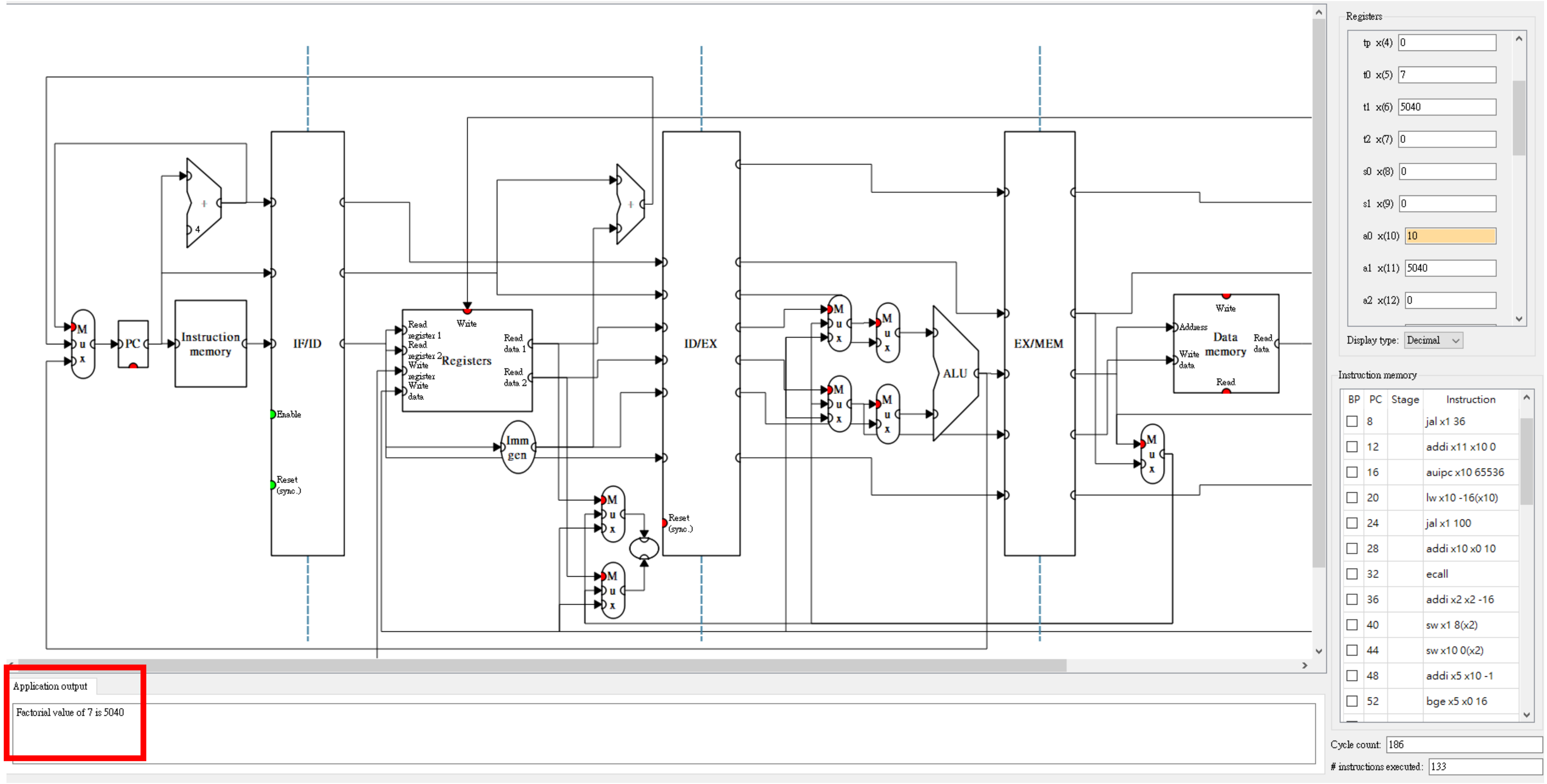
How to calculate the instruction

Example: factorial.s

- In this case, there are 121 instructions will be executed.
- There are 16 variables in stack at most.

```
main:
        lw      a0, argument            1
        jal     ra, fact                2

        # Print the result to console
        mv      a1, a0                  102
        lw      a0, argument            103
        jal     ra, printResult         104

        # Exit program
        li      a0, 10                  120
        ecall                           121

fact:
        addi    sp, sp, -16             3    10   17   24   31   38   45   52
        sw      ra, 8(sp)               4    11   18   25   32   39   46   53
        sw      a0, 0(sp)               5    12   19   26   33   40   47   54
        addi    t0, a0, -1              6    13   20   27   34   41   48   55
        bge     t0, zero, nfact         7    14   21   28   35   42   49   56

        addi    a0, zero, 1                                                57
        addi    sp, sp, 16                                                 58
        jalr    x0, x1, 0                                                  59

nfact:
        addi    a0, a0, -1              8    15   22   29   36   43   50
        jal     ra, fact                9    16   23   30   37   44   51

        addi    t1, a0, 0               96   90   84   78   72   66   60
        lw      a0, 0(sp)               97   91   85   79   73   67   61
        lw      ra, 8(sp)               98   92   86   80   74   68   62
        addi    sp, sp, 16              99   93   87   81   75   69   63

        mul     a0, a0, t1              100  94   88   82   76   70   64
        ret                             101  95   89   83   77   71   65
        #jalr x0, ra, 0
```

Demo



IF/ID
ID/EX
EX/MEM
PC
Instruction memory
Registers
Read register 1
Read register 2
Write register
Write data
Read data 1
Read data 2
Write
Imm gen
ALU
Data memory
Address
Read data
Read
Enable
Reset (sync.)
Registers
tp x(4) 0
t0 x(5) 7
t1 x(6) 5040
t2 x(7) 0
s0 x(8) 0
s1 x(9) 0
a0 x(10) 10
a1 x(11) 5040
a2 x(12) 0
Display type: Decimal
Instruction memory
BP PC Stage Instruction
8 jal x1 36
12 addi x11 x10 0
16 auipc x10 65536
20 lw x10 -16(x10)
24 jal x1 100
28 addi x10 x0 10
32 ecall
36 addi x2 x2 -16
40 sw x1 8(x2)
44 sw x10 0(x2)
48 addi x5 x10 -1
52 bge x5 x0 16
Application output
Factorial value of 7 is 5040
Cycle count: 186
instructions executed: 133