香港中文大學
The Chinese University of Hong Kong

CENG3420

Lab 1-2: RISC-V Assembly Language Programing II

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Spring 2025

Outline

1. Recap
2. Function Call Procedure
3. Array Partitioning
4. Lab 1-2 Assignment

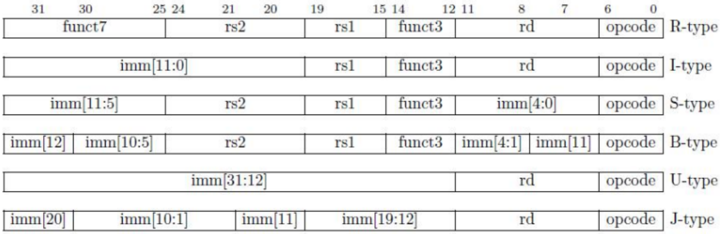
Recap

- The RISC-V Instruction Set Manual Volume I: Unprivileged ISA
  `https://riscv.org/technical/specifications/`
- (For your reference): Supported instructions for RV32I `https://github.com/TheThirdOne/rars/wiki/Supported-Instructions`

In all labs. of CENG3420, we focus on RV32I instructions.

Categories

- Functional:
  - Integer Computational Instructions
  - Control Transfer Instructions
  - Load & Store Instructions
  - Environmental Call & Breakpoints
  - Memory Ordering Instructions
  - HINT Instructions
- Encoding:



Integer Register-Immediate Instructions

- (I-type) `addi`, `slti`, `sltiu`, `andi`, `ori`, `xori`
- (I-type) `slli`, `srli`, `srai`
- (U-type) `lui`, `auipc`

Integer Register-Register Operations

- (R-type) `add`, `slt`, `sltu`, `and`, `or`, `xor` `sll`, `srl`, `sub`, `sra`

Unconditional Jumps

- (J-type) `jal`
- (I-type) `jalr`

Conditional Branches

- (B-type) `beq`, `bne`, `blt`, `bltu`, `bge`, `bgeu`

Load & Store Instructions

- (I-type) `lb`, `lbu`, `lh`, `lhu`, `lw`
- (S-type) `sb`, `sh`, `sw`

Object File Section

- `.text`, `.data`, `.rodata`

Definition & Exporting of Symbols

- `.globl`, `.local`, `.equ`

Object File Section

- `.align`, `.balign`, `.p2align`

Emitting Data

- `.byte`, `.2byte`, `.4byte`, `.8byte`, `.half`, `.word`, `.dword`, `.asciz`, `.string`, `.zero`

Declaration

```
.data
a:   .word 1 2 3 4 5
```

Remark

- "a" denotes the address of the first element of the array.
- We can access through rest of the elements with *.word* offset (*i.e.*, 4 bytes). (What should be the offset for the 2^{nd} element in the array above?)

Examples I

Example 1: Register Initialization and Loading Immediate Values

```
_start:
    andi t0, t0, 0       # Make it zero
    andi t1, t1, 0
    andi t2, t2, 0
    li t0, 0xFF          # Load a 8-bit number
    li t1, 0xFFFF        # Load a 32-bit number
    li t2, 0xFFFFFFFF    # Load a 64-bit number
```

Example 2: Arithmetic Operations

```
_start:
    andi t0, t0, 0
    andi t1, t1, 0
    andi t2, t2, 0
    li t0, 0x1A352A9C    # t0 = 0x1A352A9C
    li t1, 0x1B2D4C6A    # t1 = 0x1B2D4C6A
    add t2, t0, t1       # t2 = t1 + t0
```

Examples III

Example 3: Conditional Branching

```
_start:
    andi t0, t0, 0
    andi t1, t1, 0
    andi t2, t2, 0
    andi t3, t3, 0
    andi t4, t4, 0
    andi t5, t5, 0
    li t0, 2                   # t0 = 2
    li t3, -2                  # t3 = -2
    slt t1, t0, zero           # t1 = 1 if t0 < 0
    beq t1, zero, else_if      # Branch if t1 equals zero
    j end_if                   # Unconditional jump to end_if
else_if:
    sgt t4, t3, zero           # t4 = 1 if t3 > 0
    beq t4, zero, else         # Branch if t4 equals zero
    j end_if                   # Unconditional jump to end_if
else:
    seqz t5, t4, zero          # t5 = 1 if t4 = 0
end_if:
    j program_end
```

Function Call Procedure

Example I

Code Example

```c
int sum(int a, int b)
{
    return a + b;
}
int main()
{
    int c;
    c = sum(3, 5);
    return c;
}
```

Code Example

```
sum:
    addi    sp,sp,-32
    sw      s0,28(sp)
    addi    s0,sp,32
    ... ...
    add     a5,a4,a5
    mv      a0,a5
    lw      s0,28(sp)
    addi    sp,sp,32
    jr      ra
main:
    ... ...
    addi    s0,sp,32
    li      a1,5
    li      a0,3
    jal     ra, sum # or call sum
    ... ...
```

Example I

Code Example

```
main:
    addi    sp,sp,-32   # allocate space for local variables
    sw      ra,28(sp)   # save the return address of the caller
    li      a1,5        # second argument of sum(3, 5)
    li      a0,3        # first argument of sum(3, 5)
    jal     ra, sum     # call sum(3, 5)
    sw      a0,12(sp)   # save a0 (the returned value) to 12(sp)
    lw      a5,12(sp)   # load the value in 12(sp)
    addi    a0,a5,0     # the value to return is put in a0
    lw      ra,28(sp)   # restore the return address of the caller
    addi    sp,sp,32    # restore the stack pointer
    jr      ra          # return
```

- You can try to simplify the code

Function Call Procedure

JAL

- The JAL instruction (unconditional jump instruction) is used to implement a software calling.
- The address of the instruction following JAL (pc+4) is saved into register `rd`.
- The target address is given as a PC-relative offset (the offset is sign-extended, multiplied by 2, and added to the value of the PC).

31	30 21	20	19 12	11 7	6 0
imm[20]	imm[10:1]	imm[11]	imm[19:12]	rd	opcode
1	10	1	8	5	7
offset[20:1]				dest	JAL

Function Call Procedure – JAL

Syntax

jal rd, offset
jal rd, label

Usage

```
loop: addi x5, x4, 1      # assign x4 + 1 to x5
      jal x1, loop        # assign 'PC + 4' to x1 and jump to loop
```

Function Call Procedure

JALR

- The JALR instruction (indirect jump instruction) is used to implement a subroutine call.
- The address of the instruction following JAL (pc+4) is saved into register `rd`.
- The target address is given as a PC-relative offset (the offset is sign-extended and added to the value of the destination register).

31 — 20	19 — 15	14 — 12	11 — 7	6 — 0
imm[11:0]	rs1	funct3	rd	opcode
12	5	3	5	7
offset[11:0]	base	0	dest	JALR

Function Call Procedure – JALR

Syntax

jalr rd, offset(rs1)

Usage

```
      addi x1, x0, 3      # assign x0 + 3 to x1
loop: addi x5, x0, 1      # assign x0 + 1 to x5
      jalr x0, 64(x1)     # assign 'PC + 4' to x0 and jump to the address 'x1 + 64'
```

More Examples of Function Call Procedure

J

A pseudo instruction for JAL

Syntax

j label

Usage

```
loop: addi x5, x4, 1     # assign x4 + 1 to x5
      j loop             # assign 'PC + 4' to x0 and jump to loop
                         # (discard the return address)
```

JR

A pseudo instruction for JALR

Syntax

jr rs1

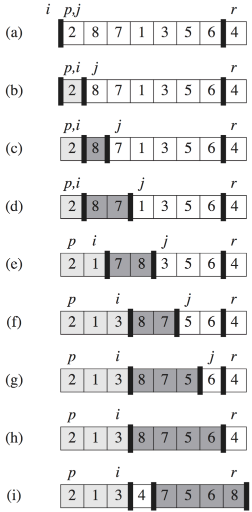
Array Partitioning

Partitioning

- Pick an element, called a pivot, from the array.
- Reorder the array so that all elements with values less than the pivot come before the pivot, while all elements with values greater than the pivot come after it (equal values can go either way).

```
function PARTITION(A, lo, hi)
    pivot ← A[hi]
    i ← lo-1;
    for j = lo; j ≤ hi-1; j ← j+1 do
        if A[j] ≤ pivot then
            i ← i+1;
            swap A[i] with A[j];
        end if
    end for
    swap A[i+1] with A[hi];
    return i+1;
end function
```

Example of Partition



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[1] In this example, p = lo and r = hi.

Lab 1-2 Assignment

Lab Assignment

An array `array1` contains the sequence `-3 22 32 9 5 2 11 2 1 69`, each element of which is *.word*. Rearrange the element order in this array such that,

1. All the elements smaller than the 4^{rd} element (i.e. 9) are on the left of it,
2. All the elements bigger than the 4^{rd} element (i.e. 9) are on the right of it.

And print the result (i.e. the partitioned sequence) to the terminal using syscall.

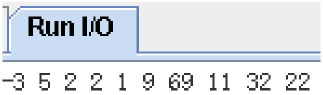
Submission Method:

Submit the source code and report after the whole lectures of Lab1 into **Blackboard**.

Lab Assignment

Declarations

- The given sequence `array1` is fixed. You do not need to write input syscall to get it from terminal.
- The pivot is fixed at the 4^{rd} element (i.e. 9). You also do not need to write input syscall to get it from terminal. (We will check whether the whole algorithm is implemented appropriately, your code should work with other pivots.)
- For the result (i.e. the partitioned sequence), please print it to the RARS terminal using syscall, as an example shown in the following figure:



Appendix-A Simple Sort Example

Swap v[k] and v[k+1]

Assume `a0` stores the address of the first element and `a1` stores k.

```
swap: sll t1, a1, 2       # get the offset of v[k] relative
    to v[0]
      add t1, a0, t1      # get the address of v[k]
      lw  t0, 0(t1)       # load the v[k] to t0
      lw  t2, 4(t1)       # load the v[k + 1] to t2
      sw  t2, 0(t1)       # store t2 to the v[k]
      sw  t0, 4(t1)       # store t0 to the v[k + 1]
```

Appendix-B Simple Sort Example

C style sort:

```
void sort(int v[], int n)
{
    int i, j;
    for(i = 0; i < n; i += 1)
    {
        for(j = i - 1; j >= 0 && v[j] > v[j + 1]; j -= 1)
        {
            swap(j + 1, j);
        }
    }
}
```

Appendix-C Save and Exit

Exit and restoring registers

```
exit1:
    lw   ra, 16(sp)
    lw   s3, 12(sp)
    lw   s2, 8(sp)
    lw   s1, 4(sp)
    lw   s0, 0(sp)
    addi sp, sp, 20
```