香港中文大學
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CENG3420

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

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Spring 2023

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/

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

Categories

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

Integer Register-Immediate Instructions

- `addi, slti, sltiu, andi, ori, xori`
- `slli, srli, srai`
- `lui, auipc`

Integer Register-Register Operations

- `add`, `slt`, `sltu`, `and`, `or`, `xor` `sll`, `srl`, `sub`, `sra`

Unconditional Jumps

- `jal`, `jalr`

Conditional Branches

- `beq`, `bne`, `blt`, `bltu`, `bge`, `bgeu`

Load & Store Instructions

- `lb`, `lbu`, `lh`, `lhu`, `lw`
- `sb`, `sh`, `sw`

Environmental Call & Breakpoints

- `ecall`

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

```
_start:
    addi t0, t0, 0
    addi 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
```

Examples II

Example 2

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

Examples III

Example 3

Examples IV

```
_start:
    addi t0, t0, 0
    addi 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
    j end_if
else_if:
    sgt t4, t3, zero        # t4 = 1 if t3 > 0
    beq t4, zero, else
    j end_if
else:
    seqz t5, t4, zero       # t5 = 1 if t4 = 0
end_if:
    j end_if
```

Function Call Procedure

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).

Function Call Procedure – JAL I

Syntax

jal rd, offset

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).

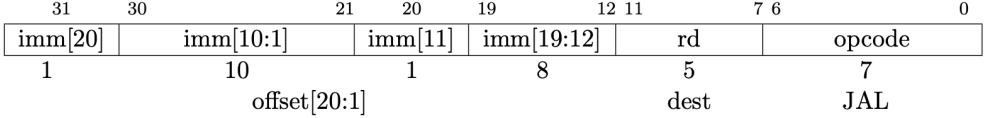
Function Call Procedure – JALR I

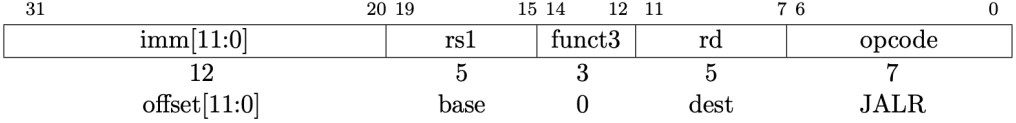
Syntax

jalr rd, offset

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`
```


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


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

More Examples of Function Call Procedure I

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)
```

More Examples of Function Call Procedure II

JR

A pseudo instruction for JALR

Syntax

jr rs1

Usage

```
label: li x28, 100      # assign 100 to x28
       li x5, 200       # assign 200 to x5
       li x6, 50        # assign 50 to x6
       jal ra, loop     # jump to loop
       li x2, 10        # assign 10 to x2
loop:  add x4, x28, x5  # assign x28 + x5 to x4
       sub x7, x6, x4   # assign x6 + x4 to x7
       jr ra            # jump to `ra + 0`
```

More Examples of Function Call Procedure III

Conditional Branches

Take `beq` as an example. If the values stored in `rs1` and `rs2` are equal, jump to `label`.

Syntax

beq rs1, rs2, label

Usage

```
beq x1, x0, loop # jump to loop when x1 equals to 0
```

Remark

Other conditional branches instructions: `bne, blt, bltu, bge, bgeu`...

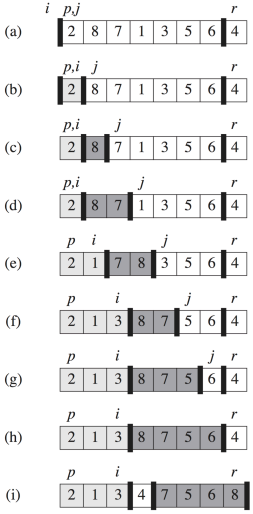
Array Partitioning

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).

```
1:  function PARTITION(A, lo, hi)
2:      pivot ← A[hi]
3:      i ← lo-1;
4:      for j = lo; j ≤ hi-1; j ← j+1 do
5:          if A[j] ≤ pivot then
6:              i ← i+1;
7:              swap A[i] with A[j];
8:          end if
9:      end for
10:     swap A[i+1] with A[hi];
11:     return i+1;
12: end function
```

Example of Partition



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

Lab 1-2 Assignment

Lab Assignment

An array `array1` contains the sequence `-1 22 8 35 5 4 11 2 1 78`, each element of which is *.word*. Rearrange the element order in this array such that,

1. All the elements smaller than the 3^{rd} element (i.e. 8) are on the left of it,
2. All the elements bigger than the 3^{rd} element (i.e. 8) are on the right of it.

Submission Method:

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

- We will upload a report template after we review the entire lectures of Lab1.

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);
        }
    }
}
```

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
```