Assembly (Slides T2-T3)

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Brief Intro of Assembly

high level languages (e.g. `.cpp`) --compiler--> assembly languages (`.s`) --assembler--> machine code (`.o`) --linker--> executable machine code (`.elf`) --formatter--> machine code for a target processor (e.g. `.exe`)

When to Use

- Avoid uncertainties of execution time and size brought by compilers
- To speed up or reduce the size of a program
- Use with high level languages

Shortcomings

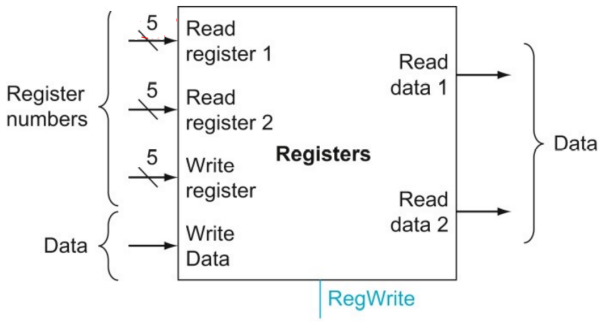
- Can be time consuming
- No assembler optimization
- Different computers support different assemblers
- Hard to debug:(

We will focus on RISC-V 32-bit ISA(Instruction Set Architecture) in this course!

Operands

Register Operands

Register size: 32 * 32bits register file, from `x0`, `x1`, to `x31`.



How is register used?
e.g.
c++ code:

```
a = b + c;
```

Assume `b` is put in `x5`, `c` is put in `x6`, and `a` is put in `x7`. Then the corresponding assembly is

```
add x7, x5, x6
```

Memory Operands

Big/Little Endian
Definition for big endian: Most-significant byte si at the smallest address
e.g. A word `0x11223344`

Endian	0x0fff0000	0x0fff0001	0x0fff0002	0x0fff0003
Little	44	33	22	11
Big	11	22	33	44

Memory Organizations
Array arrangement
e.g.

Word Address	0x0fff1110	0x0fff1114	0x0fff1118	0x0fff111C
Array (`A`) Index	0	1	2	3
Data Stored in `A` (32bit)	0x11111111	0x22222222	0x33333333	0x44444444

`A[2]` corresponds to the data stored in address `0x0fff1118`

Load and Store
e.g.
c++ code:

```
A[i] = B[j];
```

Assume `i` is in `x5`, `j` is in `x6`, base address of array `A` is in `x7`, and base address of array `B` is in `x28`. Then its corresponding assembly is

```
slli x5, x5, 2
add x5, x5, x7
slli x6, x6, 2
add x6, x6, x28
lw x29, 0(x6)
sw x29, 0(x5)
```

Immediate Operands

Involves constant data, like 0, 1, 2... or -1, -2...
Don't need to load data from memory or register file.

A useful constant: `x0`. Can not be overwritten and can be used to clear a register.

e.g. `addi`, `slli`...

Get Familiar with Other Operations!

Logical

`and`, `or`, `slli` ...
e.g.

```
and x5, x6, x7
```

Meaning: `x5 = x6 & x7`

```
slli x5, x6, 2
```

Meaning: `x5 = x6 << 2`

Arithmetic

`add`, `addi`...
(See the examples above)

Conditional

`beq`, `bne`, `blt`, `bge`
e.g.

```
beq x5, x6, ELSE
add x5, x0, x0
ELSE: ...
```

Meaning: If `x5 == x6`, neglect the code in the second line and execute the code after `ELSE:`

Load Upper Immediate

`lui`
e.g.

```
lui x5, 0x11111
```

Meaning: copy `0x11111` to bits `[31:12]` of register `x5`.

Load/Store

`sw`, `lw`, `lb`, `lbu`, `sb`...

```
lb x5, 0(x6)
```

Meaning: Load the byte stored in address `x6` into `x5` and sign extend to 32 bits.

Jump

`jal`

```
jal x1, ProcedureLabel1
```

Meaning: `x1` increases by 4 so that it becomes return address register. Program counter points to where the `ProcedureLabel1` represents.

`jalr(jr)`

```
jalr x0, offset(x1)
```

Meaning: Program counter points to where `offset+x1` represents (Usually the offset is 0).
In Ripes, `jalr` will cause error. Please use the following instruction instead.

```
jr x1
```

Program Counter (PC)

- A special register that points to the instruction to be executed next
- Each instruction is encoded as a 32bit word
- PC increase by 4 when go to fetch the next instruction

Stack Pointer

Used when you need to reserve some space in stack to store the important variables
e.g.

```
addi sp, sp, -12
...
# Several operations
...
addi sp, sp, 12
```

Function Call

General Steps

1. Before calling the function, place arguments to corresponding registers.
2. Jump to target function
3. In the function, reserve space to store important variables
4. Execute function operations
5. Recover the changed important variables and release the reserved space
6. Place calculation results in required registers
7. Return to place to function call

Leaf Functions

- Functions that do not call other functions
- Only save **saved registers** (`x8, x9, x18-x27`)

Non-Leaf Functions

- Functions call other functions
- Before calling other functions, make sure you save its return address (`x1`), argument registers (`x10, x11`...), and temporary registers needed after calling functions returned (`x5, x6`...)

Function Examples

*Please try all the examples in the lecture slides by yourselves!!!

Loop
c code:

```c
int add(int *a, int size) {
    //REQUIRES: size is positive integers
    int result = 0;
    for (int i = 0; i < size; i++) {
        result = result + a[i];
    }
    return result;
}
```

Assume two arguments `a` and `size` are stored in `x11` and `x12` respectively. And the returned result is stored in `x10`.
assembly:

```
ADD:
    addi x10, x0, 0 # Initialize the result
    add x5, x0, x11 # Initialize the address of the first word
    addi x6, x0, 0 # Initialize the counter (i)
LOOP:
    lw x7, 0(x5) # Load a[i]
    add x10, x10, x7
    addi x6, x6, 1
    addi x7, x7, 4
    bne x6, x12, LOOP
    jr x1
```

Recursion
c code:

```c
int fact (int n) {
    //REQUIRES: n is a positive integer
    if (n < 3) return n;
    else return n * fact(n-1);
}
```

assembly

```
fact:
    addi sp, sp, -8
    sw x1, 4(sp)
    sw x10, 0(sp)
    addi x5, x10, -3
    bge x5, x0, L1
    addi sp, sp, 8 # Why no need to restore x1 and x10?
    jr x1
L1:
    addi x10, x10, -1
    jal x1, fact
    addi x6, x10, 0 # Now what is the value stored in x10
    lw x10, 0(sp)
    lw x1, 4(sp)
    addi sp, sp, 8
    mul x10, x10, x6
    jr x1
```

Reference

[1] VE370 SU22 Slides T2

[2] VE370 FA21 Slides T3