Meet & Greet!

Come hang out with your TAs and Fellow Students
(& eat free insomnia cookies)

When : Friday, Sept. 29th. 5-6 pm
Where : 3rd Floor Atrium, CIT
CS 33

Intro to Machine Programming
Machine Model

Processor (aka CPU)

Memory (aka RAM)

instructions and data

data
Generally we think of their being two sorts of memory: that containing instructions and that containing data. Programs, in general, don’t modify their own instructions on the fly. In reality, there’s only one sort of memory, which holds everything. However, we arrange so that memory holding instructions cannot be modified and that, usually, memory holding data cannot be executed as instructions.

Of course, programs such as compilers and linkers produce executable code as data, but they don’t directly execute it.
Processor: Some Details

- Execution engine
- Instruction pointer
- Condition codes
Processor: Basic Operation

while (forever) {
  fetch instruction IP points at
  decode instruction
  fetch operands
  execute
  store results
  update IP and condition code
}

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Instructions ...

<table>
<thead>
<tr>
<th>Op code</th>
<th>Operand1</th>
<th>Operand2</th>
<th>...</th>
</tr>
</thead>
</table>
Operands

- **Form**
  - immediate vs. reference
    - value vs. address
- **How many?**
  - 3
    - add a,b,c
      - c = a + b
  - 2
    - add a,b
      - b += a
Operands (continued)

- Accumulator
  - special memory in the processor
    » known as a register
    » fast access
  - allows single-operand instructions
    » add a
      • acc += a
    » add b
      • acc += b
Note we’re using the accumulator in two-operand instructions. The “%” makes it clear that “acc” is a register. The “$” indicates that what follows is an immediate operand; i.e., it’s a value to be used as is, rather than as an address or a register.
Condition Codes

• Set of flags giving status of most recent operation:
  – zero flag
    » result was or was not zero
  – sign flag
    » for signed arithmetic interpretation: sign bit is or is not set
  – overflow flag
    » for signed arithmetic interpretation
  – carry flag (generated by carry or borrow out of most-significant bit)
    » for unsigned arithmetic interpretation

• Set implicitly by arithmetic instructions
• Set explicitly by compare instruction
  – cmp a,b
    » sets flags based on result of b-a

We have one set of arithmetic instructions that work with both unsigned and signed (two’s complement) interpretations of the bit values in a word.
The overflow flag is set when the result, interpreted as a two’s-complement value should be positive, but won’t fit in the word and thus becomes a negative number, or should be negative, but won’t fit in the word and thus becomes a positive number.
Quiz 1

- Set of flags giving status of most recent operation:
  - zero flag
    » result was or was not zero
  - sign flag
    » for signed arithmetic interpretation: sign bit is or is not set
  - overflow flag
    » for signed arithmetic interpretation
  - carry flag (generated by carry or borrow out of most-significant bit)
    » for unsigned arithmetic interpretation

- Set explicitly by compare instruction
  - cmp a,b
    » sets flags based on result of b-a

Which flags are set to one by “cmp 2,1”?

a) overflow flag only
b) carry flag only
c) sign and carry flags only
d) sign and overflow flags only
e) sign, overflow, and carry flags
Jump instructions cause the processor to start executing instructions at some specified address. For conditional jump instructions, whether to jump or not is determined by the values of the condition codes. Fortunately, rather than having to specify explicitly those values, one may use mnemonics as shown in the slide.
In the C code above, the assignment to \( a \) might be coded in assembler as shown in the box in the lower left. But this brings up the question, where are the values represented by \( a, b, c, \) and \( d \)? Variable names are part of the C language, not assembler. Let’s assume that these global variables are located at addresses 1000, 1004, 1008, and 1012, as shown on the right. Thus correct assembler language would be as in the middle box, which deals with addresses, not variable names. Note that “mov 1004,%acc” means to copy the contents of location 1004 to the accumulator register; it does not mean to copy the integer 1004 into the register!

Beginning with this slide, whenever we draw pictures of memory, lower memory addresses are at the bottom, higher addresses are at the top. This is the opposite of how we’ve been drawing pictures of memory in previous slides.
Here we rearrange things a bit.  \( b \) is a global variable, but \( a \) is a local variable within \( \text{func} \), and \( c \) and \( d \) are arguments.  The issue here is that the locations associated with \( a \), \( c \), and \( d \) will, in general, be different for each call to \( \text{func} \).  Thus we somehow must modify the assembler code to take this into account.
Relative Addresses

- **Absolute address**
  - actual location in memory

- **Relative address**
  - offset from some other location

  - Blob's absolute address is 10000
  - Datum's relative address (to Blob) is 100
    - its absolute address is 10100
Here we load the value 10,000 into the base register (recall that the “$” means what follows is a literal value; a “%” sign means that what follows is the name of a register), then store the value 10 into the memory location 10100 (the contents of the base register plus 100): the notation $n(%base)$ means the address obtained by adding $n$ to the contents of the base register.
Here we return to our earlier example. We assume that, as part of the call to `func`, the base register is loaded with the address of the beginning of `func`'s current stack frame, and that the local variable `a` and the parameters `c` and `d` are located within the frame. Thus we refer to them by their offset from the beginning of the stack frame, which are assumed to be `a_rel`, `c_rel`, and `d_rel`. Note that since the stack grows from higher addresses to lower addresses, these offsets are negative. Note that the first assembler instruction copies the contents of location 1000 into `%acc.`
Quiz 2

Suppose the value in base is 10,000 and c_rel is -8. What is the address of c?

a) 9992
b) 9996
c) 10,004
d) 10,008

```
mov 1000,%acc
add c_rel(%base),%acc
mul d_rel(%base),%acc
mov %acc,a_rel(%base)
```
We've now seen four registers: the instruction pointer, the accumulator, the base register, and the condition codes. The accumulator is used to hold intermediate results for arithmetic; the base register is used to hold addresses for relative addressing. There's no particular reason why the accumulator can't be used as the base register and vice versa: thus they may be used interchangeably. Furthermore, it is useful to have more than two such dual-purpose registers. As we will see, the x86 architecture has eight such registers; the x86-64 architecture has 16.