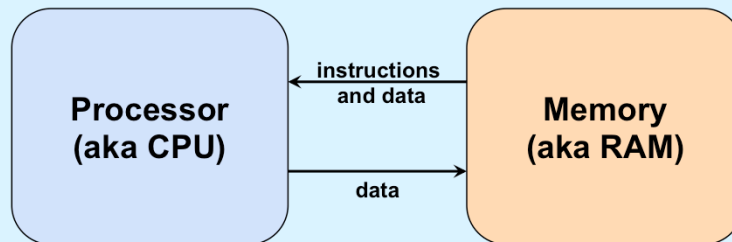


CS 33

Intro to Machine Programming

Machine Model



Memory

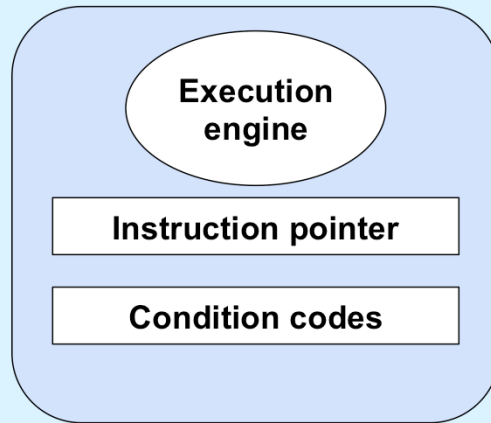
Instructions

Data

or

**Instructions
are Data**

Processor: Some Details



Processor: Basic Operation

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

Instructions ...

Op code	Operand1	Operand2	...
---------	----------	----------	-----

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
 - $\text{acc} += a$
 - » add b
 - $\text{acc} += b$

From C to Assembler ...

```
a = (b + c) * d;
```

```
mov    b,%acc  
add    c,%acc  
mul    d,%acc  
mov    %acc,a
```

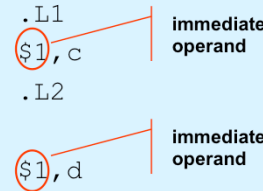
```
if (a<b)
```

```
    c = 1;
```

```
else
```

```
    d = 1;
```

```
    cmp    a,b  
    jge    .L1  
    mov    $1,c  
    jmp    .L2  
.L1  
    mov    $1,d  
.L2
```



immediate operand

immediate operand

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-complement value should be positive, but won't fit in the word, or should be negative, but won't fit in the word. Because of overflow, in the first case the result will appear to be negative and in the second case the result will appear to be positive.

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 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

- **Unconditional jump**
 - just do it
- **Conditional jump**
 - to jump or not to jump determined by condition-code flags
 - field in the op code indicates how this is computed
 - in assembler language, simply say
 - » je
 - jump on equal
 - » jne
 - jump on not equal
 - » jgt
 - jump on greater than
 - » etc.

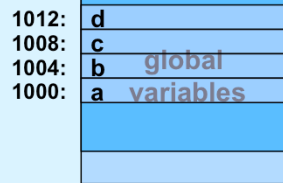
Addresses

```
int a, b, c, d;

int main() {
    a = (b + c) * d;
    ...
}
```

```
mov  b,%acc
add  c,%acc
mul  d,%acc
mov  %acc,a
```

```
mov  1004,%acc
add  1008,%acc
mul  1012,%acc
mov  %acc,1000
```



Memory

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.

Addresses

```
int b;
```

```
int func(int c, int d) {  
    int a;  
    a = (b + c) * d;  
    ...  
}
```

```
mov    ?, %acc  
add    ?, %acc  
mul    ?, %acc  
mov    %acc, ?
```

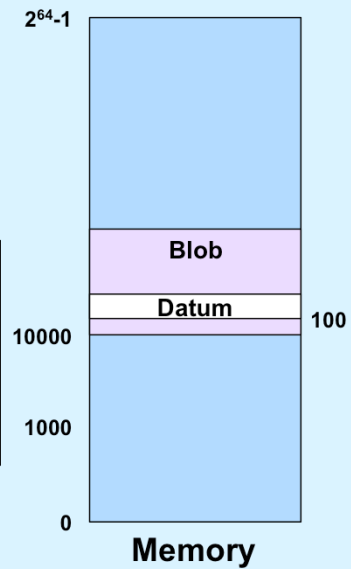
- One copy of *b* for duration of program's execution
 - *b*'s address is the same for each call to *func*
- Different copies of *a*, *c*, and *d* for each call to *func*
 - addresses are different in each call

Here we rearrange things a bit. *b* is a global variable, but *a* is a local variable within *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 *func*. Thus we somehow must modify the assembler code to take this into account.

Relative Addresses

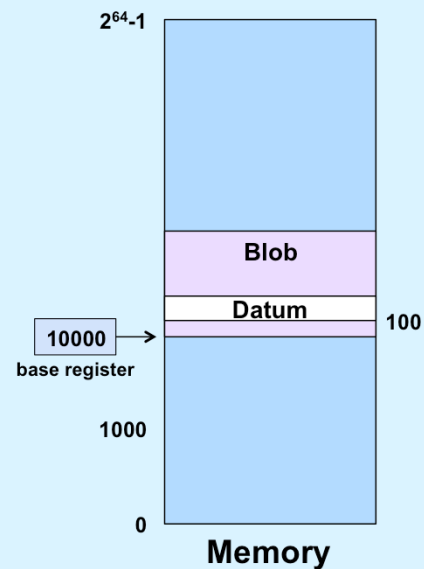
- **Absolute address**
 - actual location in memory
- **Relative address**
 - offset from some other location

- Blob's absolute address is 10000
- Datum's relative address (to Blob) is 100
 - its absolute address is 10100



Base Registers

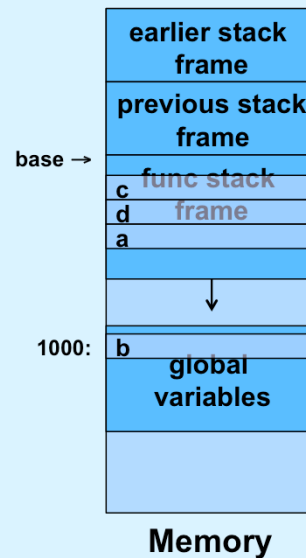
```
mov $10000, %base  
mov $10, 100(%base)
```



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.

Addresses

```
int b;  
  
int func(int c, int d) {  
    int a;  
    a = (b + c) * d;  
    ...  
}  
  
mov    1000,%acc  
add    c_rel(%base),%acc  
mul    d_rel(%base),%acc  
mov    %acc,a_rel(%base)
```



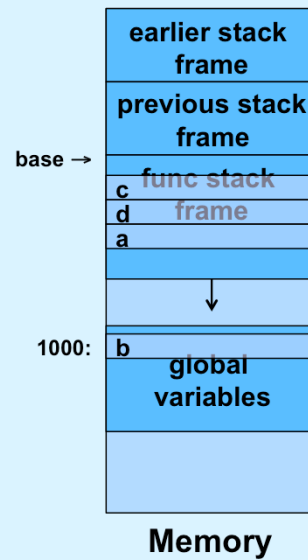
Here we return to our earlier example. We assume that, as part of the call to *func*, the base register is loaded with the address of the beginning of *func*'s current stack frame, and that the local variable *a* and the parameters *c* and *d* are located within the frame. Thus we refer to them by their 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

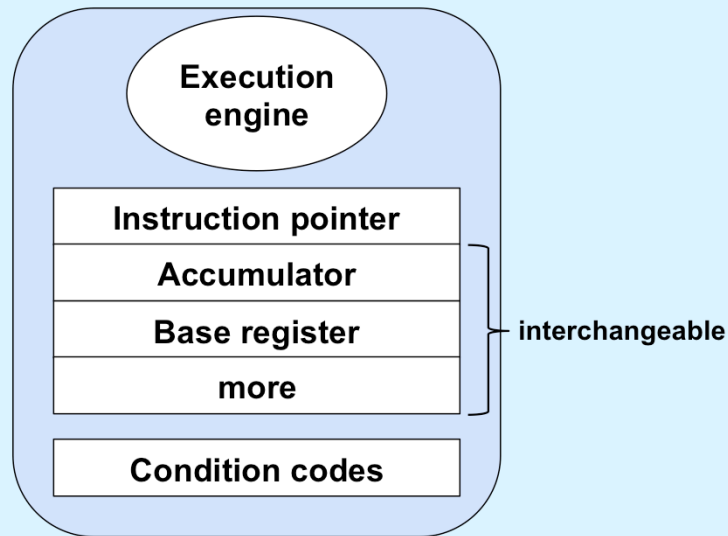
Suppose the value in *base* is 10,000 and *c_rel* is -8. What is the address of *c*?

- 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)
```



Registers



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.