CSC 252: Computer Organization
Spring 2018: Lecture 6

Instructor: Yuhao Zhu

Department of Computer Science
University of Rochester

Action Items:

- **Assignment 2 is out**

Announcement

- Programming Assignment 2 is out
  - Due on **Feb 16, 11:59 PM**
  - You may still have 3 slip days…

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  - Due on **Feb 16, 11:59 PM**
  - You may still have 3 slip days…
- Read the instructions before getting started!!!
  - You get 1/4 point off for every wrong answer
  - Maxed out at 10

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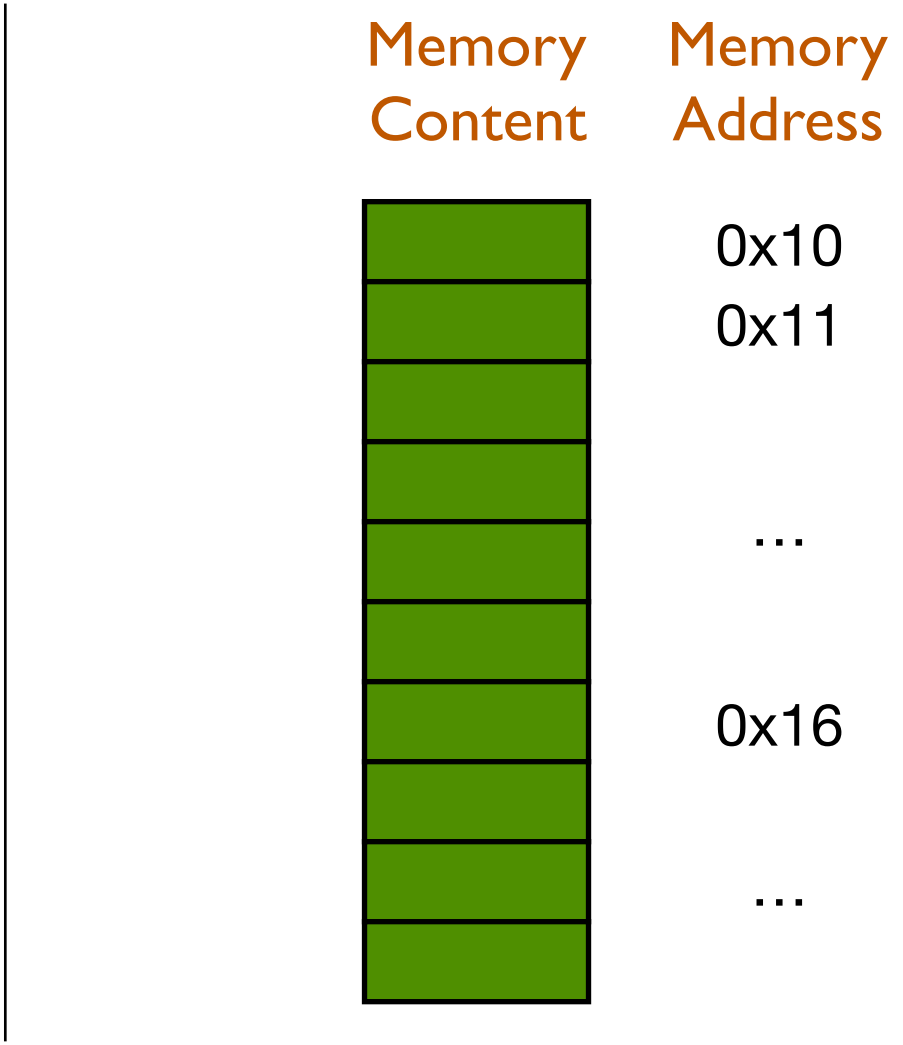

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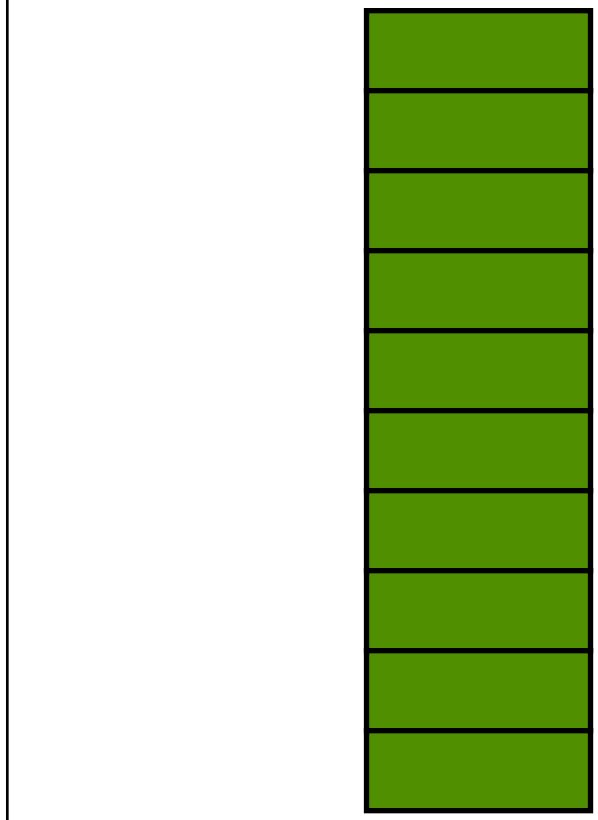

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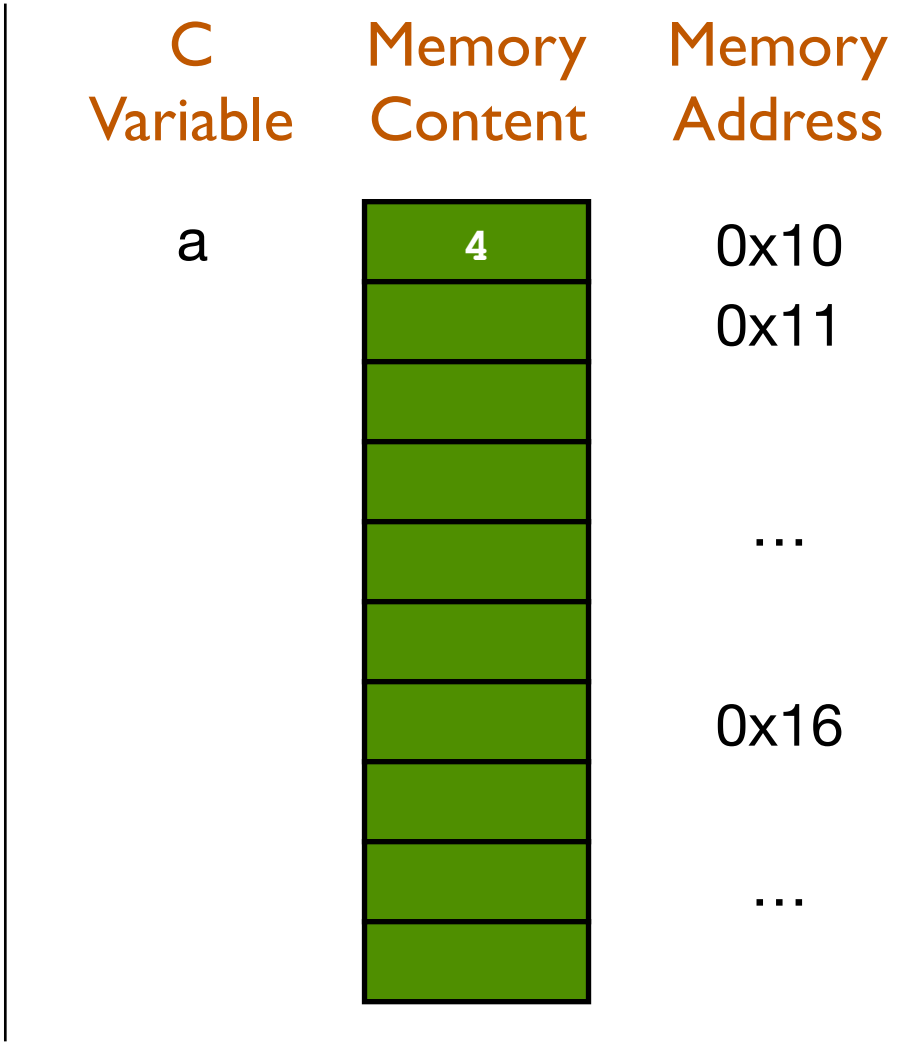

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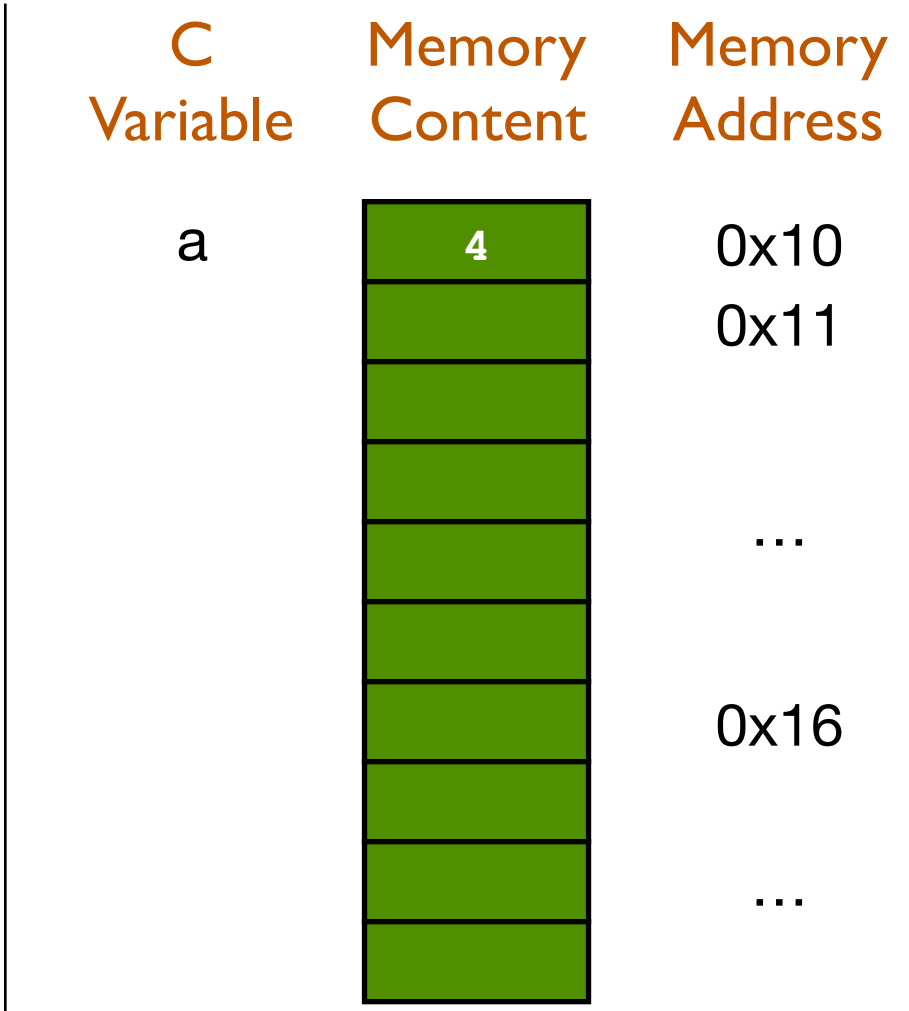

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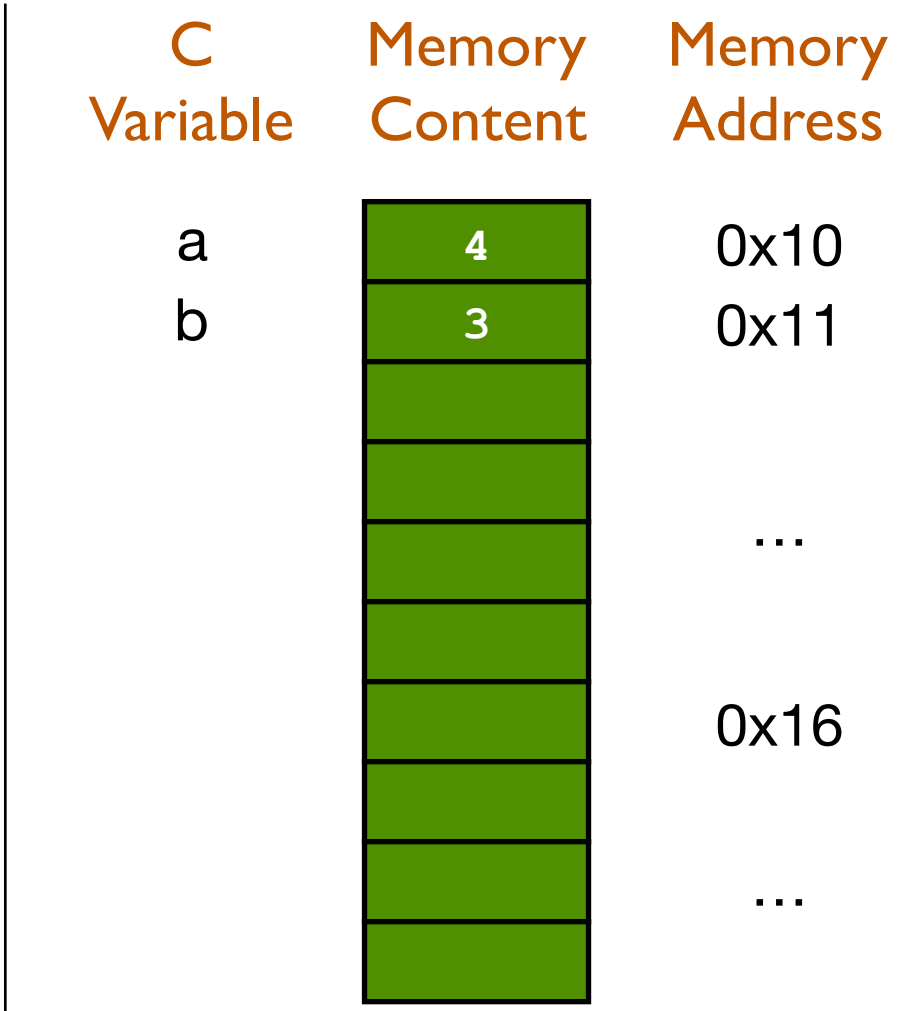

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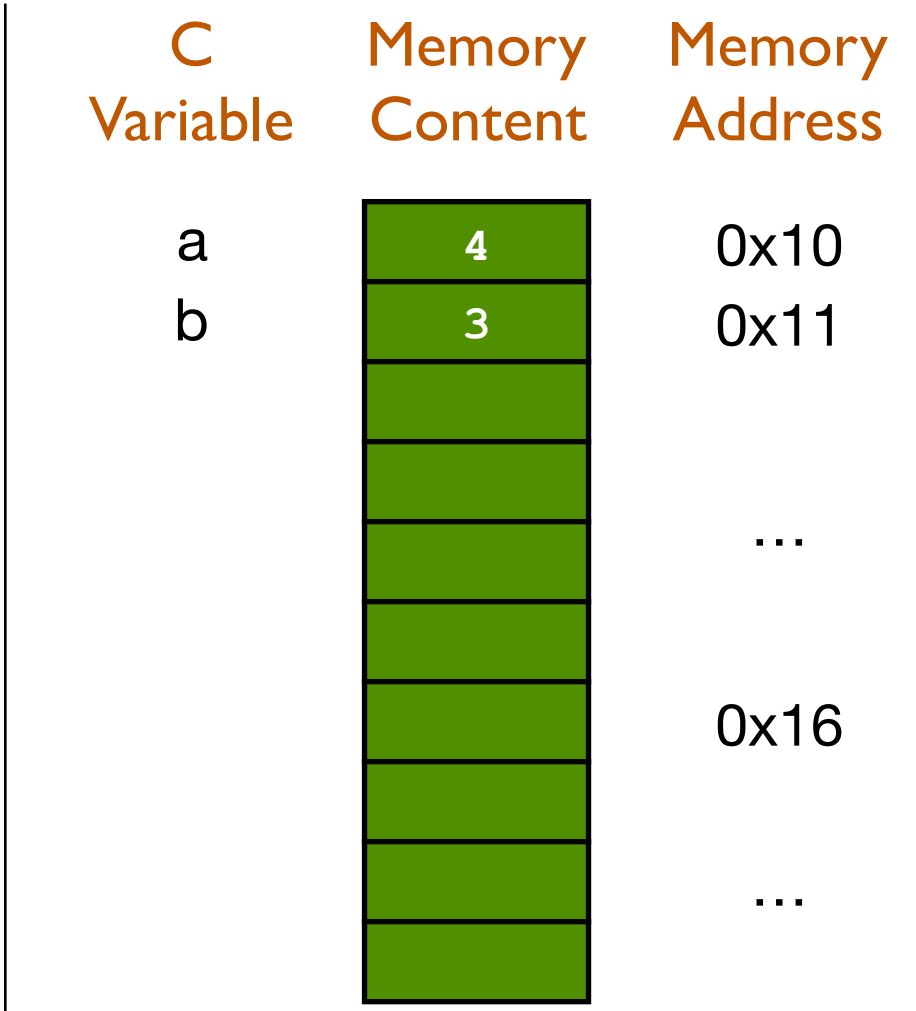

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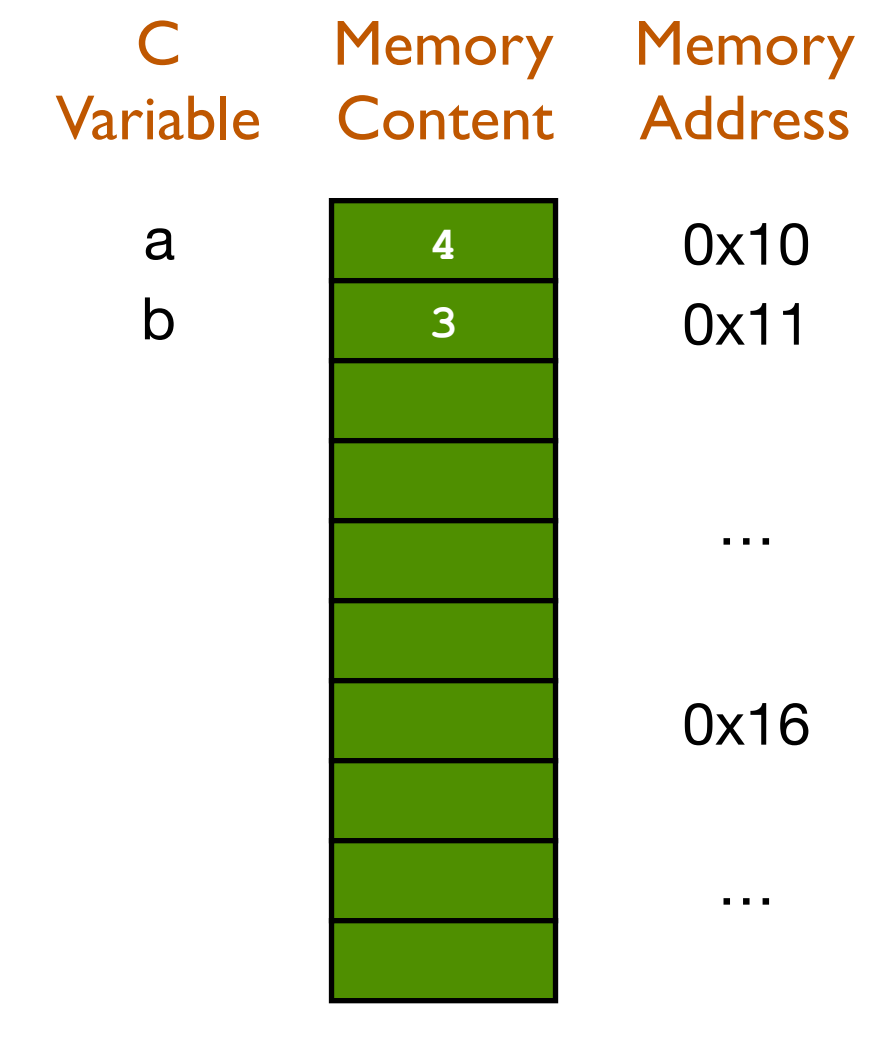

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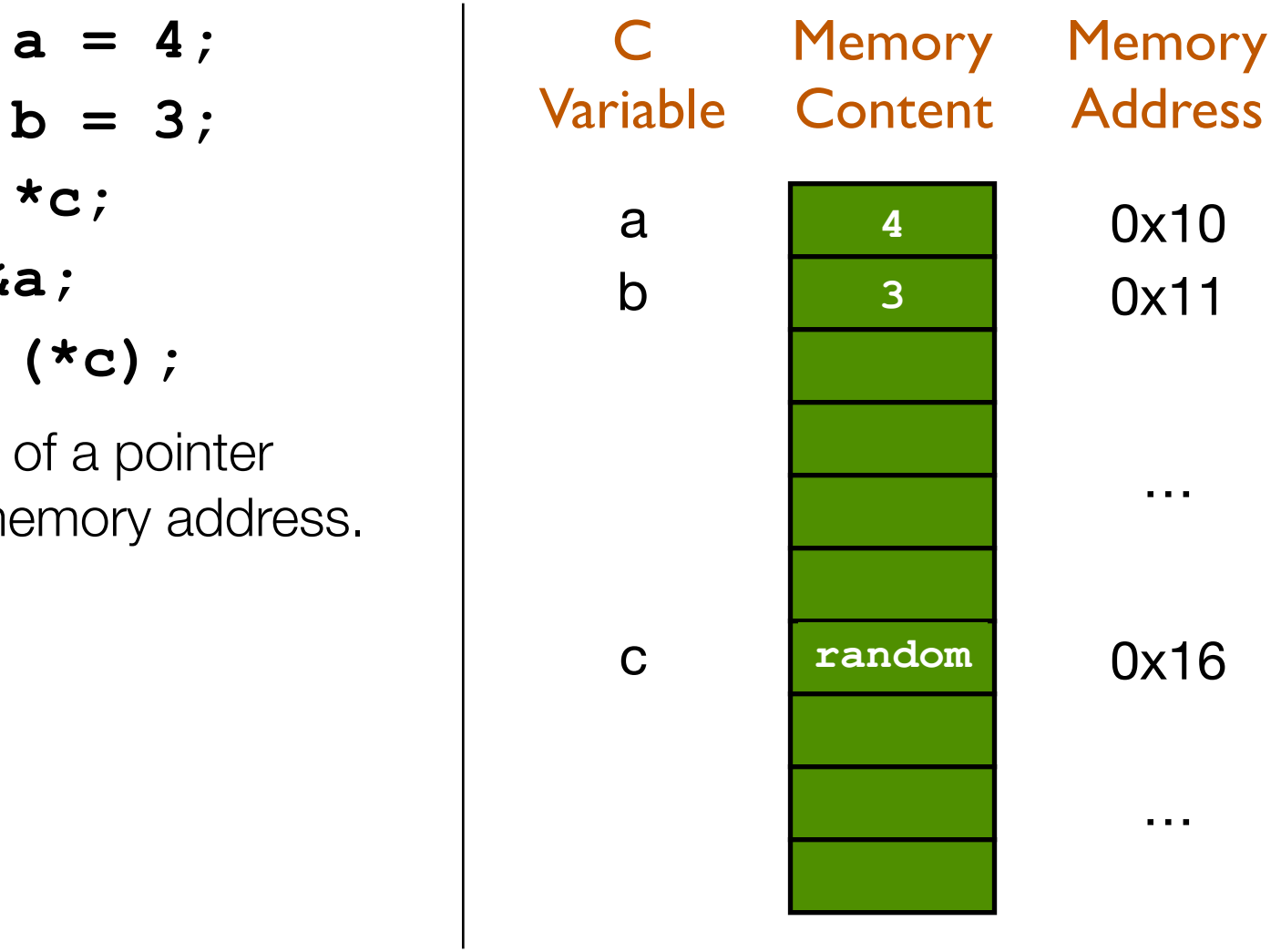

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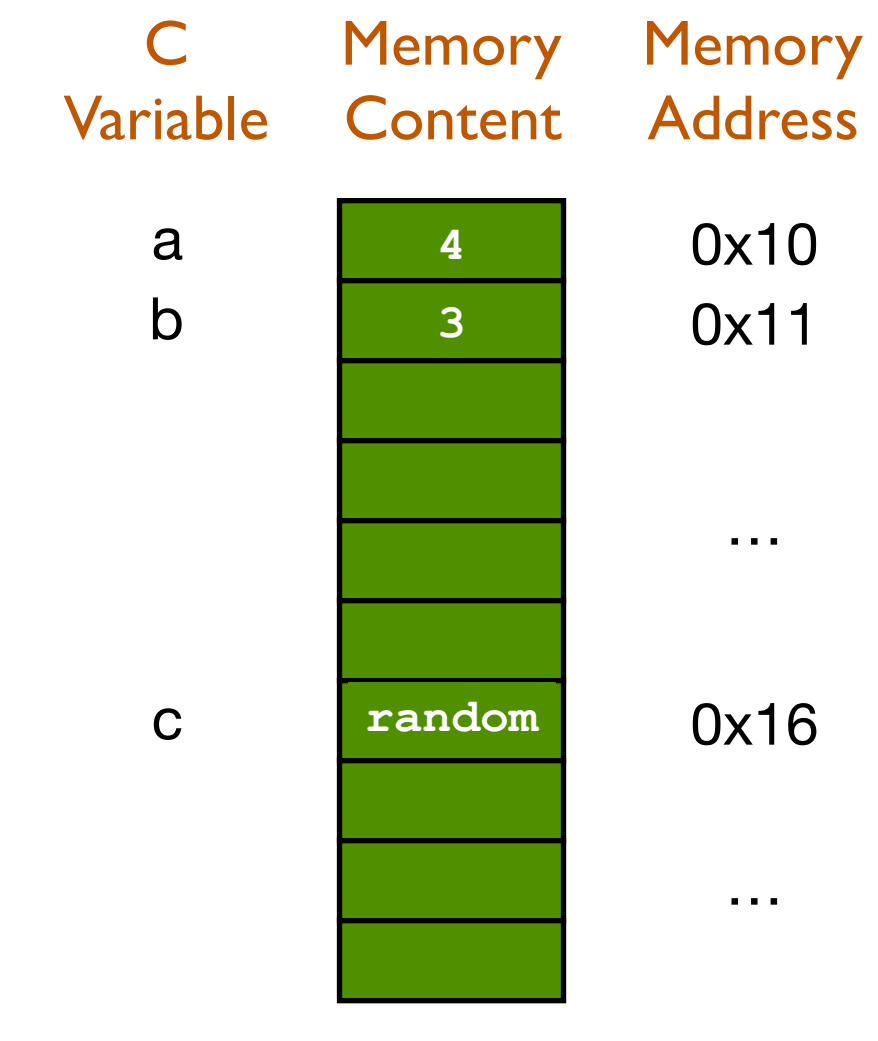

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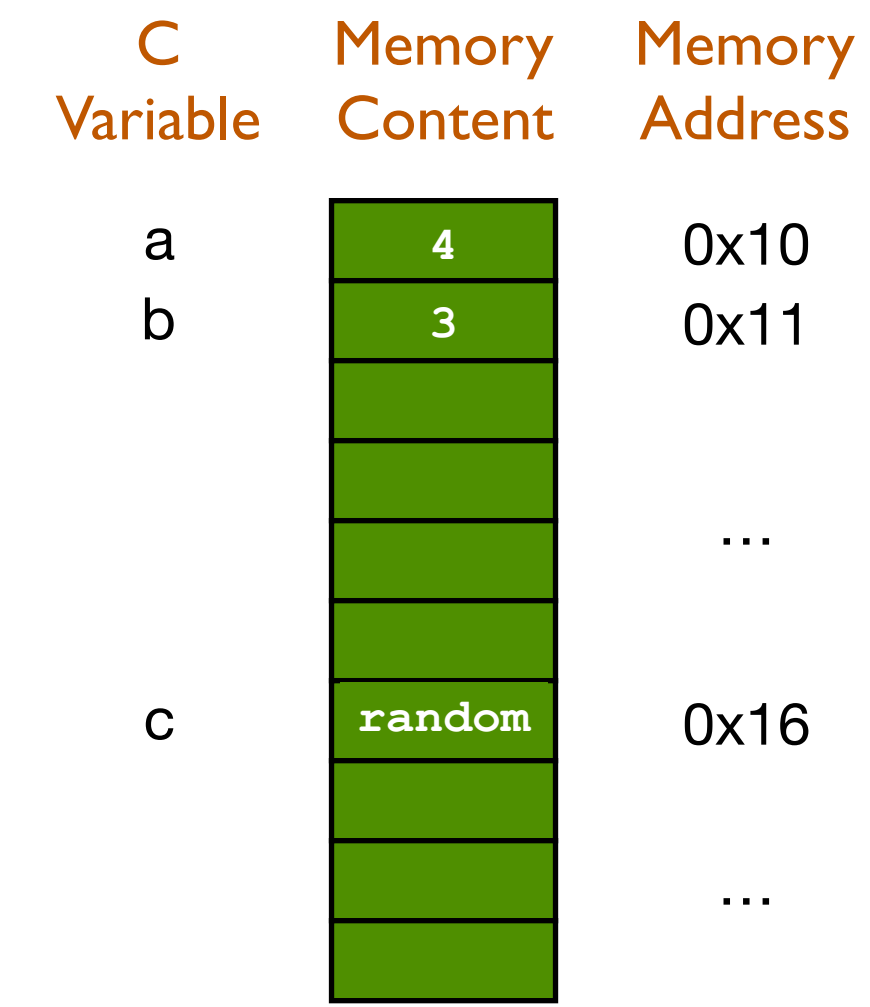

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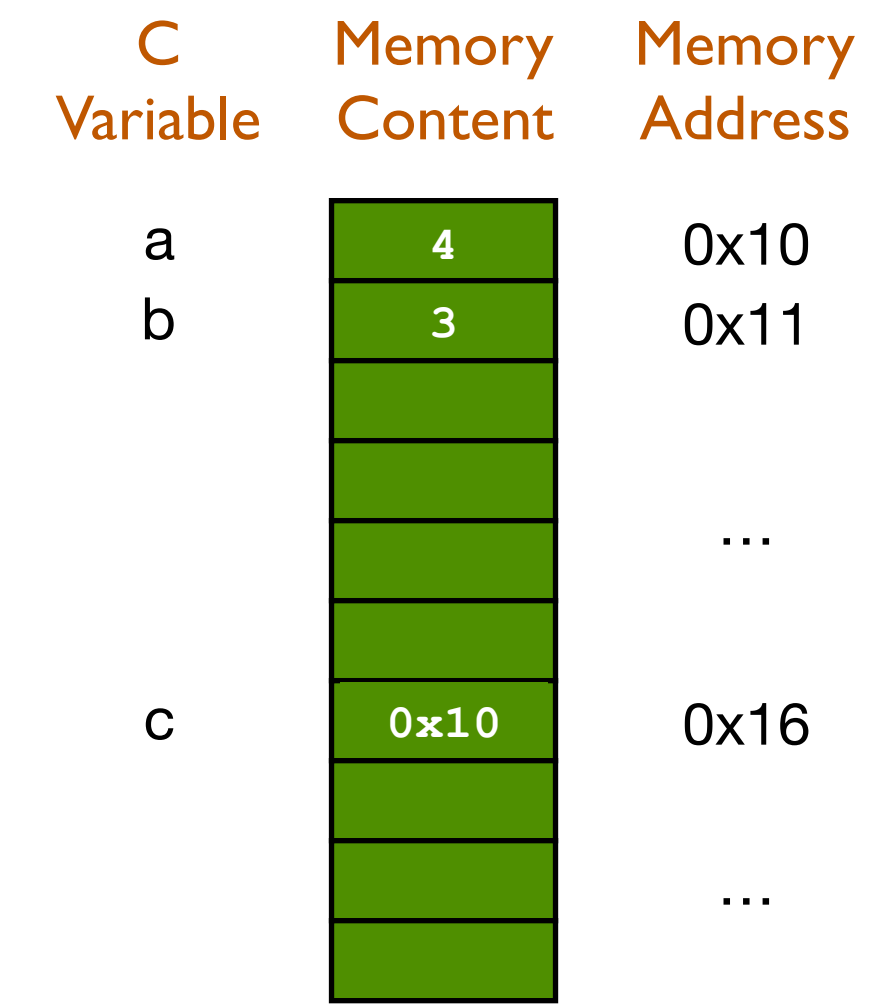

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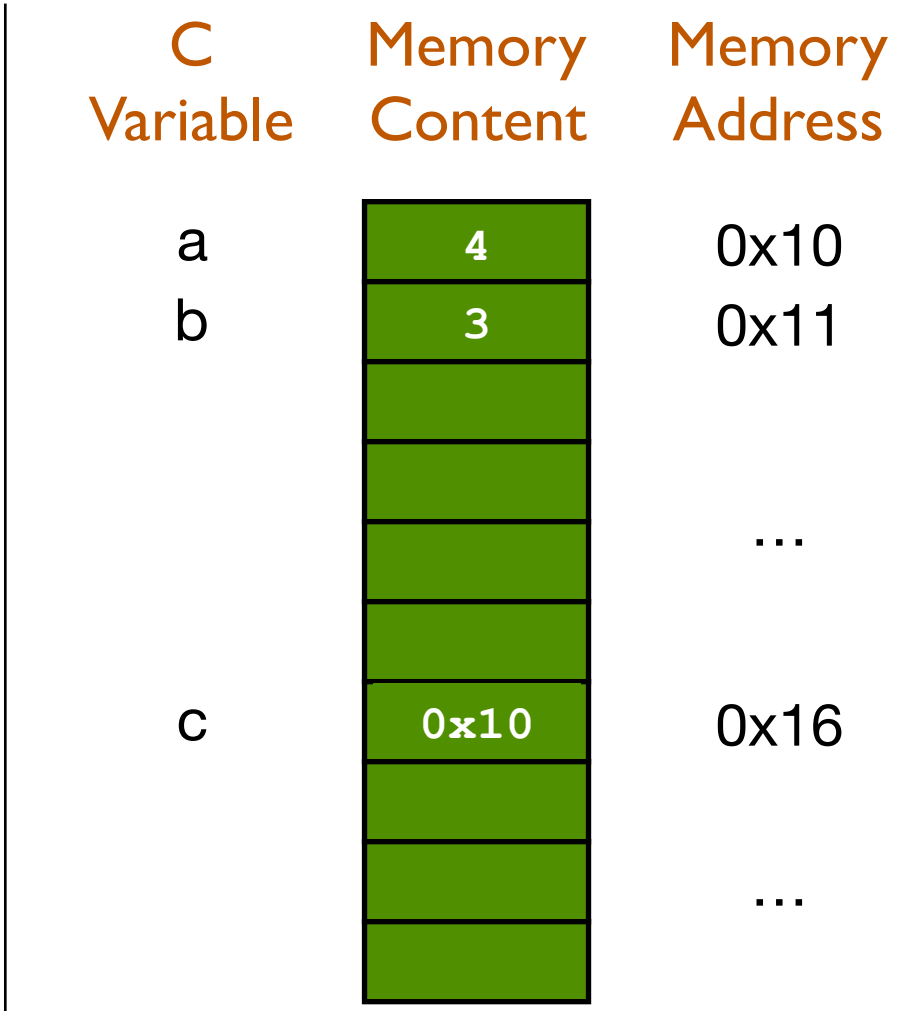

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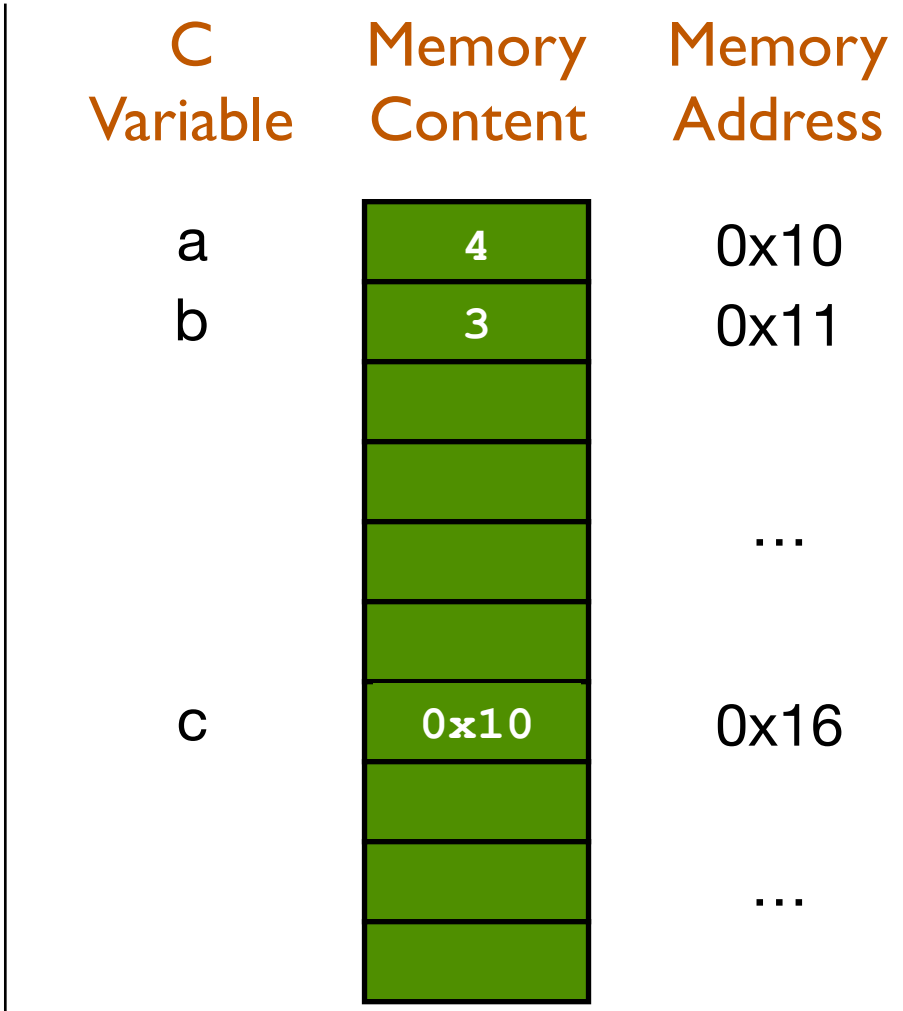

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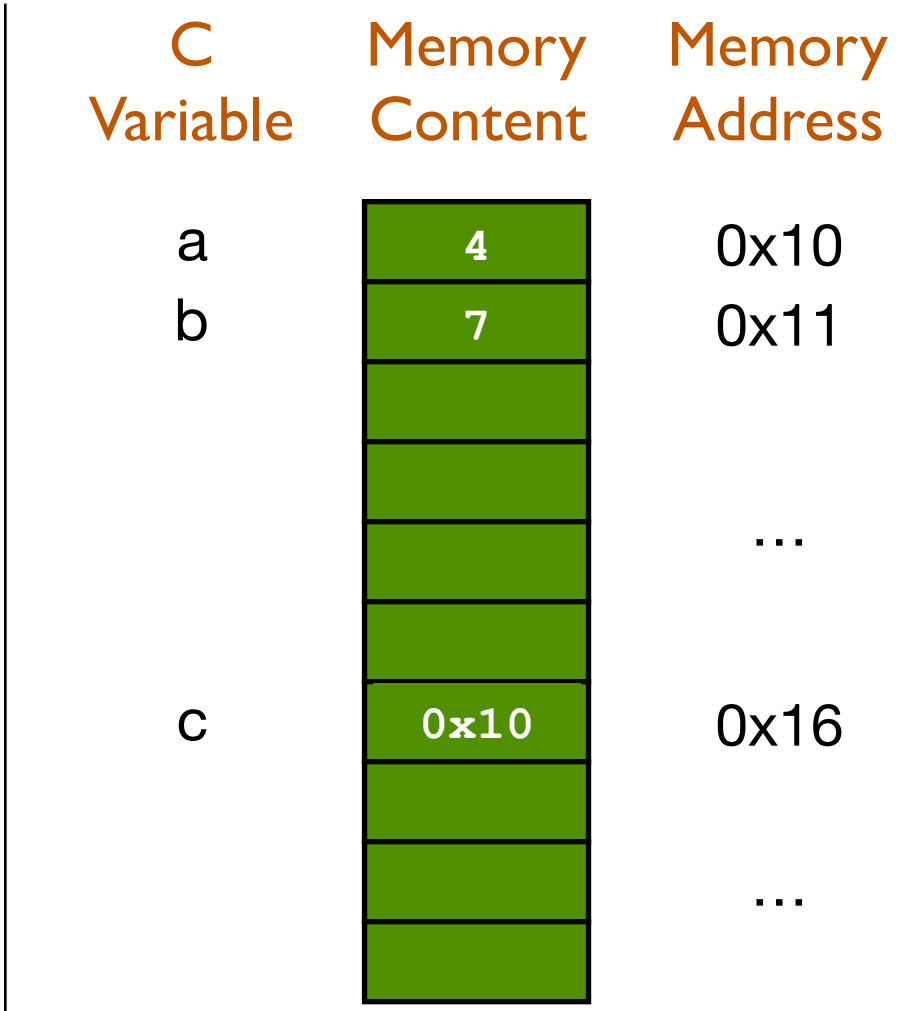

Memory Addressing Modes

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- Displacement: D(R)
  - Memory address: **Reg[R]+D**
  - Register R specifies start of memory region
  - Constant displacement D specifies offset

```
movq 8(%rbp),%rdx; // address = %rbp + 8
```

Complete Memory Addressing Modes

- Most General Form: D(Rb,Ri,S)
  - Memory address: Reg[Rb] + S * Reg[Ri] + D
  - E.g., **`8(%eax, %ebx, 4)`**; // address = **`%eax`** + 4 * **`%ebx`** + 8
  - D: Constant “displacement”
  - Rb: Base register: Any of 16 integer registers
  - Ri: Index register: Any, except for %rsp
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- Special Cases

(Rb,Ri)	Reg[Rb]+Reg[Ri]
D(Rb,Ri)	Reg[Rb]+Reg[Ri]+D
(Rb,Ri,S)	Reg[Rb]+S*Reg[Ri]

Address Computation Examples

`%rdx`	`0xf000`
`%rcx`	`0x0100`

Expression	Address Computation	Address
`0x8(%rdx)`		
`(%rdx,%rcx)`		
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`0x80(,%rdx,2)`	`2*0xf000 + 0x80`	`0x1e080`

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- Uses
  - Computing addresses without a memory reference
    - E.g., translation of p = &x[i];

Address Computation Instruction

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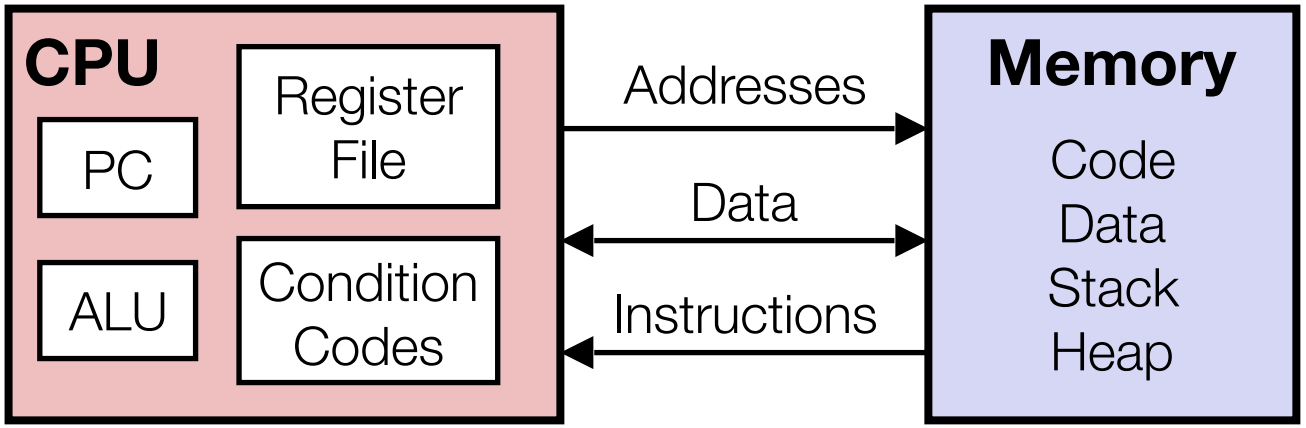
Converted to
ASM by compiler:

```
leaq (%rdi,%rdi,2), %rax # t <- x+x*2
salq $2, %rax            # return t<<2
```

Assembly Program Instructions

Assembly Programmer's Perspective of a Computer



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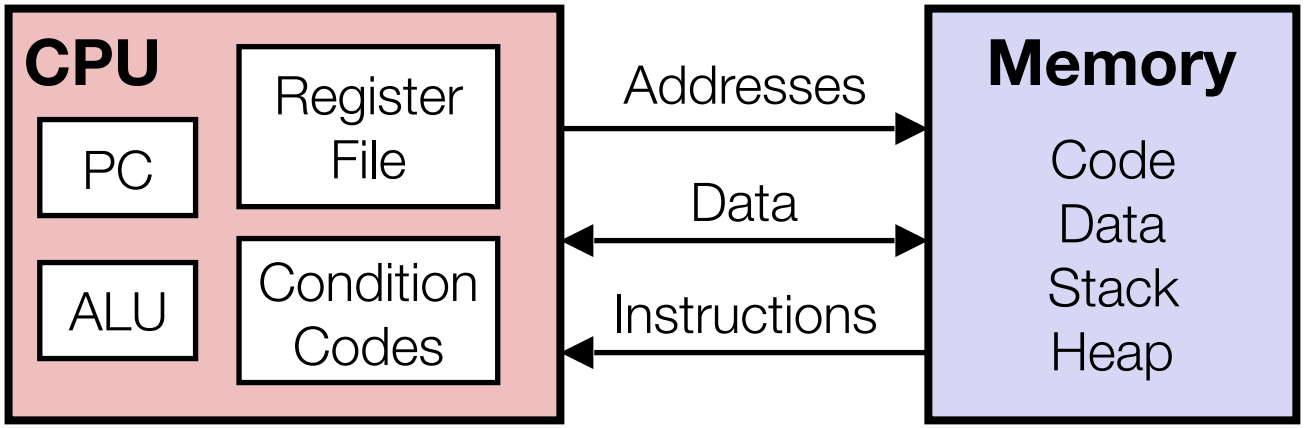

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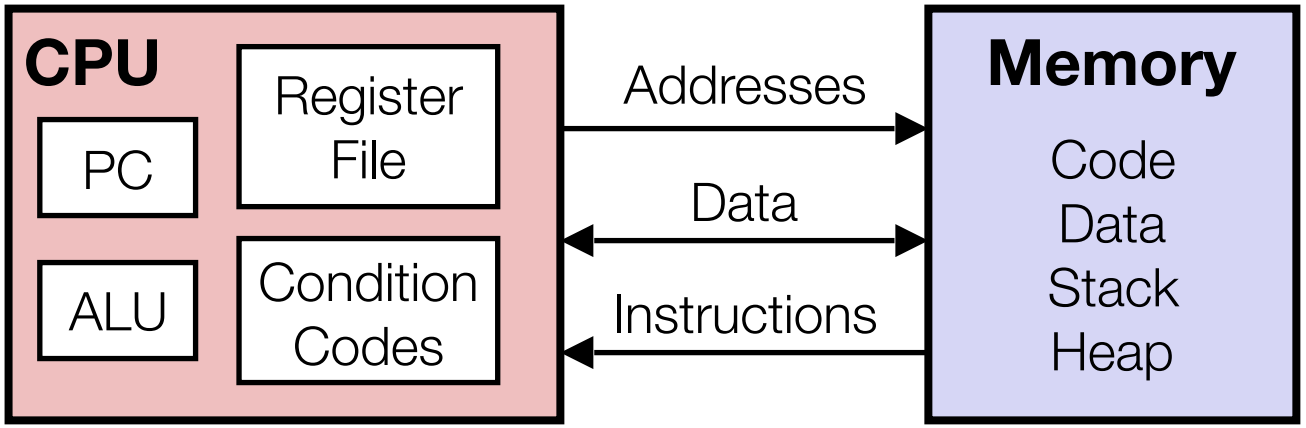

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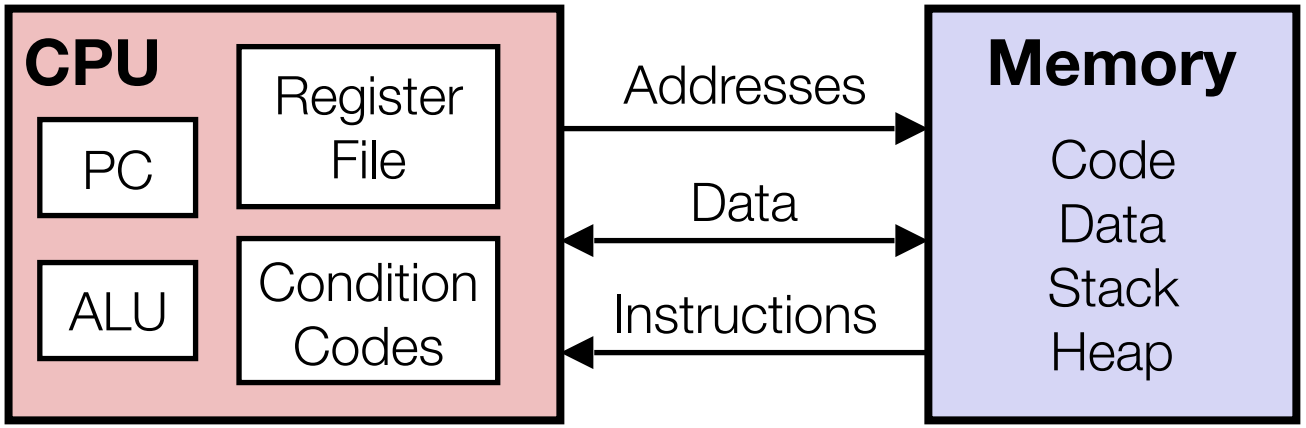

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  - C constructs: +, -, >>, etc.
- *Control Instruction*: Alter the sequence of instructions (by changing PC)
  - **`jmp`**, **`call`**
  - C constructs: **`if-else`**, **`do-while`**, function call, etc.

Today: Compute and Control Instructions

- Arithmetic & logical operations
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Some Arithmetic Operations (2 Operands)

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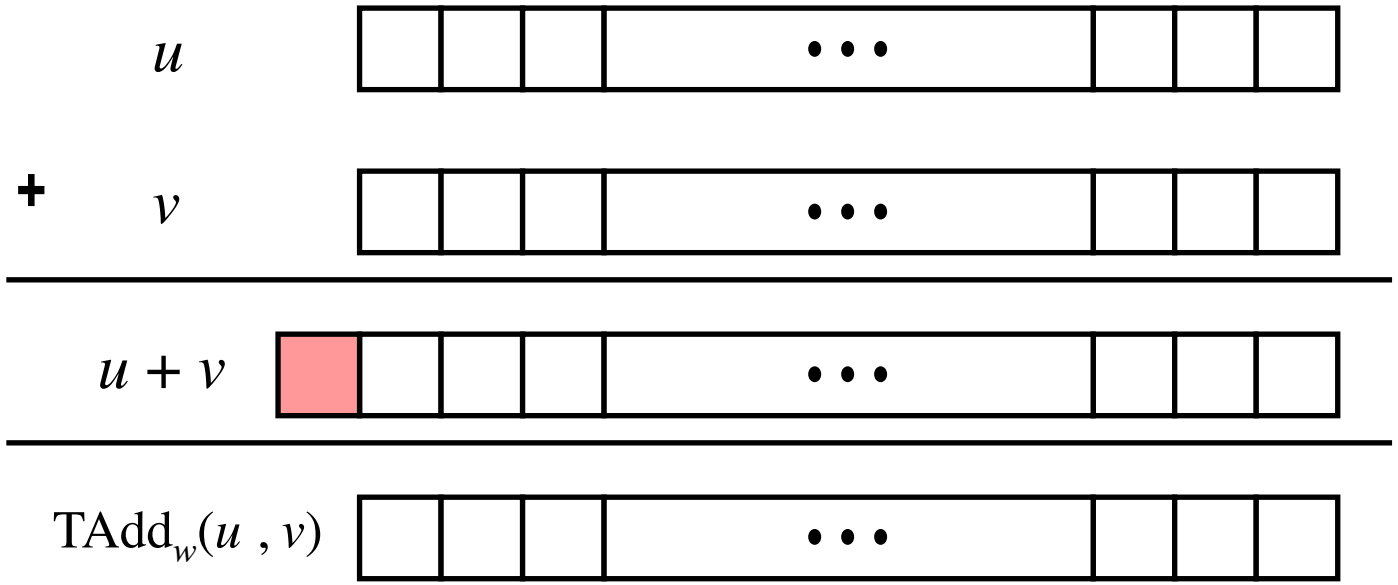

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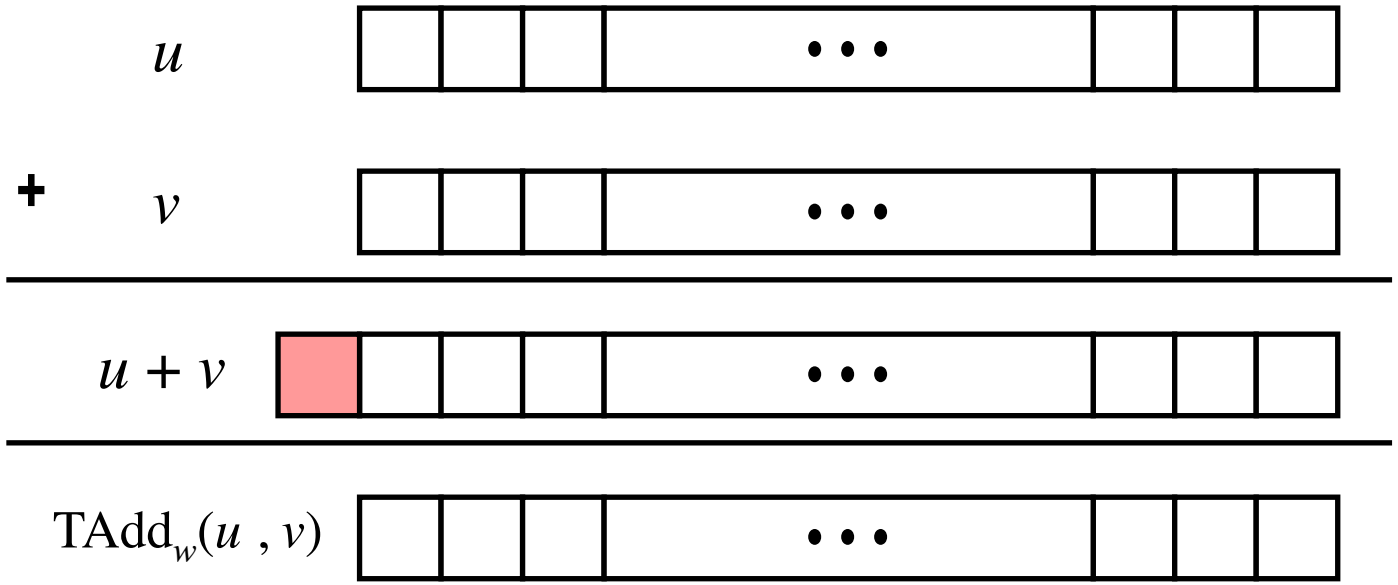

addq %rax, %rbx

%rbx = %rax + %rbx
Truncation if overflow,
set carry bit (more later…)

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Format	Computation	Notes
addq src, dest	Dest = Dest + Src	
subq src, dest	Dest = Dest - Src	
imulq src, dest	Dest = Dest * Src	
salq src, dest	Dest = Dest << Src	Also called **shlq**
sarq src, dest	Dest = Dest >> Src	Arithmetic shift
shrq src, dest	Dest = Dest >> Src	Logical shift
xorq src, dest	Dest = Dest ^ Src	
andq src, dest	Dest = Dest & Src	
orq src, dest	Dest = Dest | Src	

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Signed

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   -1
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Bit-level	Signed	Unsigned
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+) 101	+) -3	+) 5
111	-1	7

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Some Arithmetic Operations (1 Operand)

- Unary Instructions (one operand)

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`decq` `dest`	Dest = Dest - 1
`negq` `dest`	Dest = -Dest
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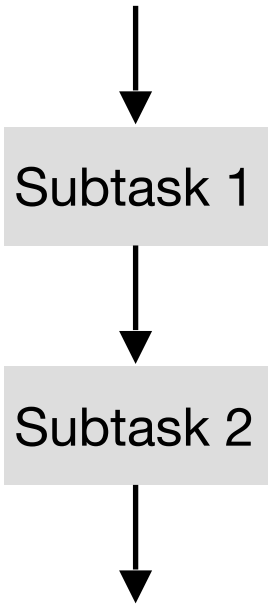


```
a = x + y;
y = a - c;
…
```

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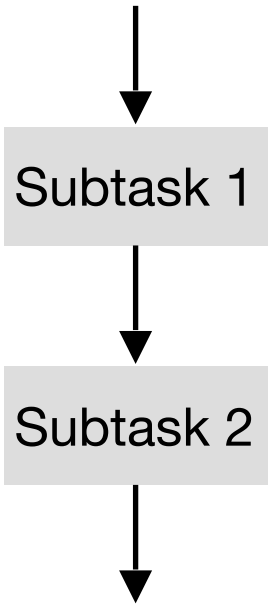


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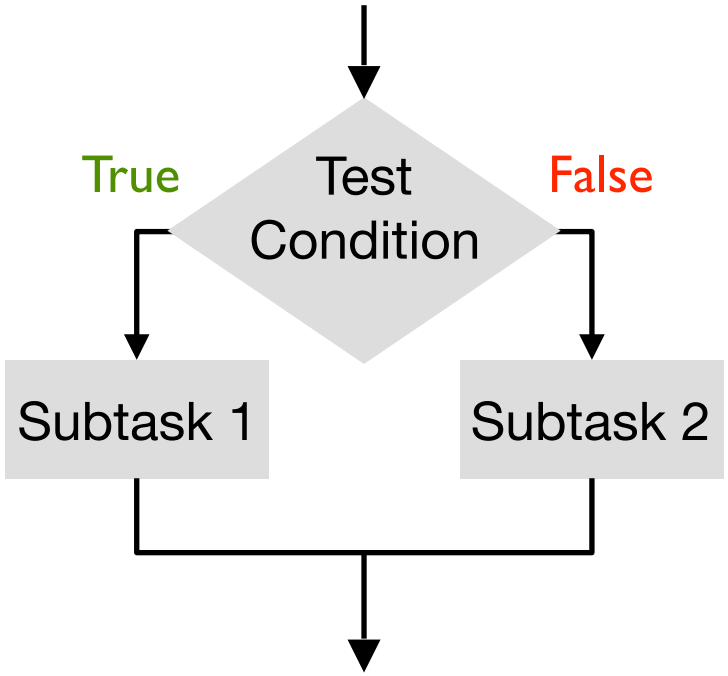
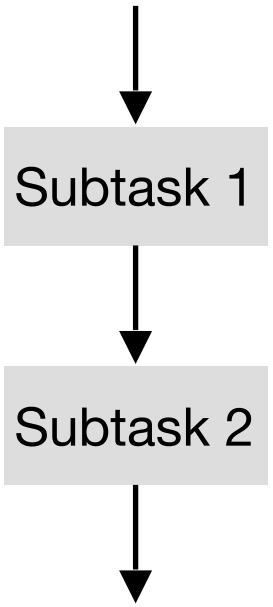
Conditional




```
if (x > y) r = x - y;
else r = y - x;
```

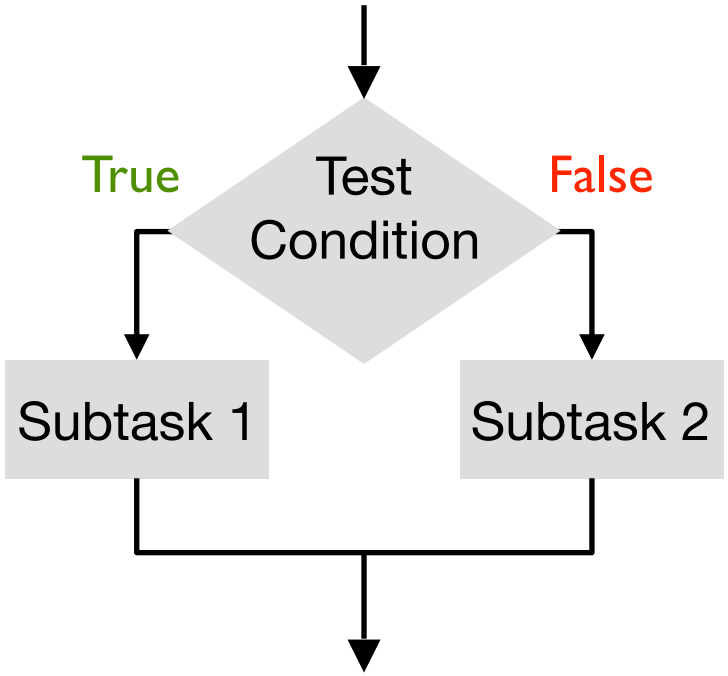
Three Basic Programming Constructs

Sequential



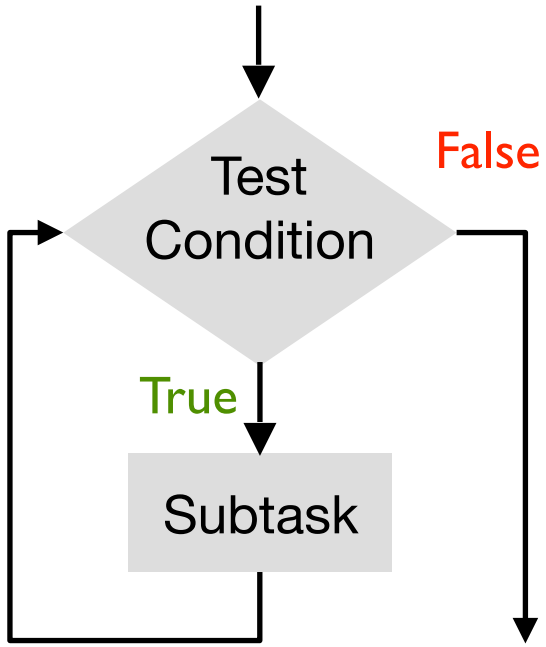

```
a = x + y;
y = a - c;
…
```

Conditional



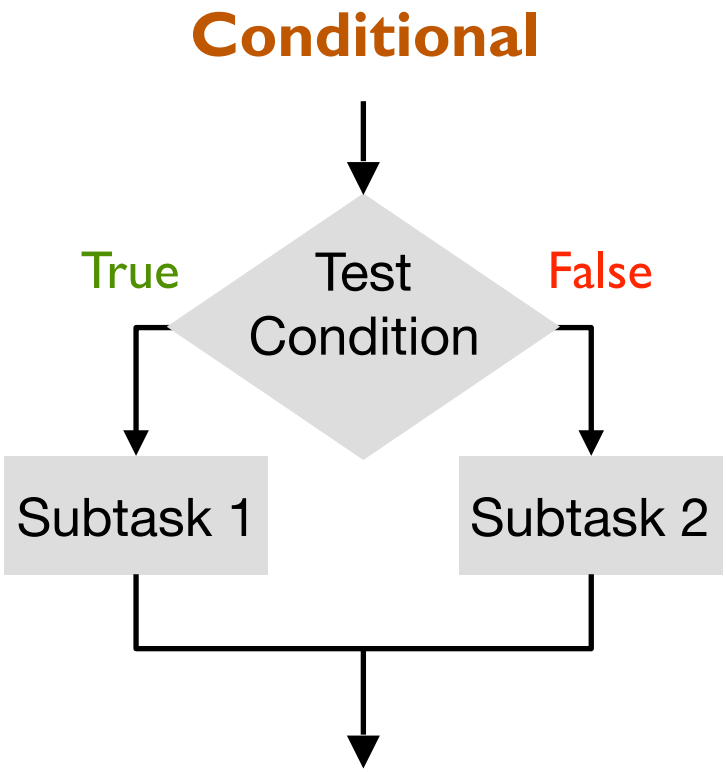

```
if (x > y) r = x - y;
else r = y - x;
```

Iterative




```
while (x > 0) {
  x--;
}
```

Three Basic Programming Constructs

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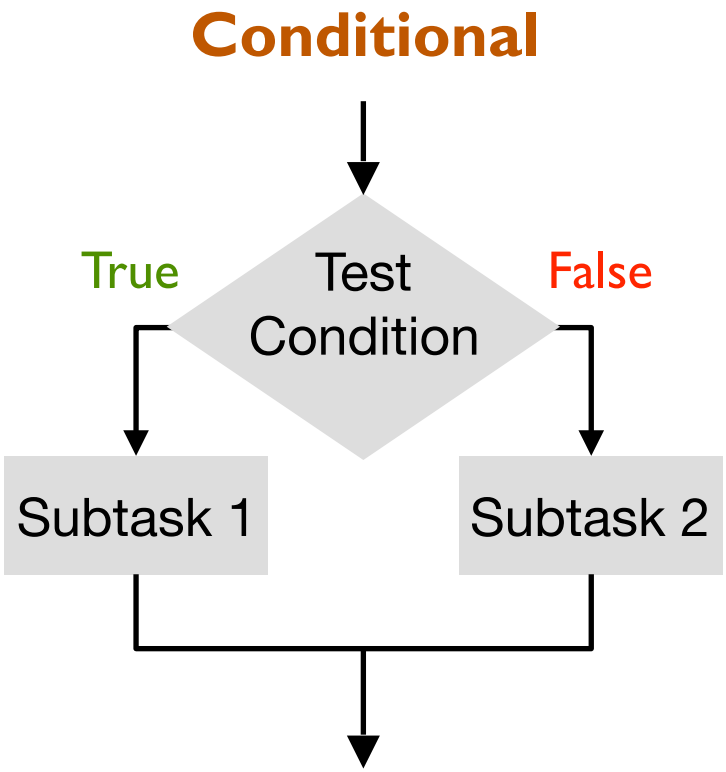
Three Basic Programming Constructs

- Both conditional and iterative programming requires altering the sequence of instructions (control flow)

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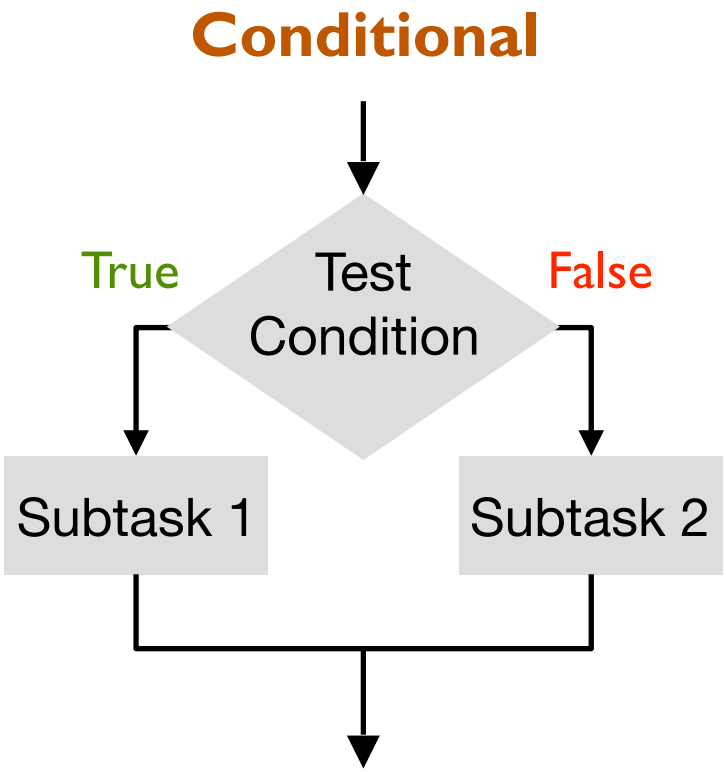


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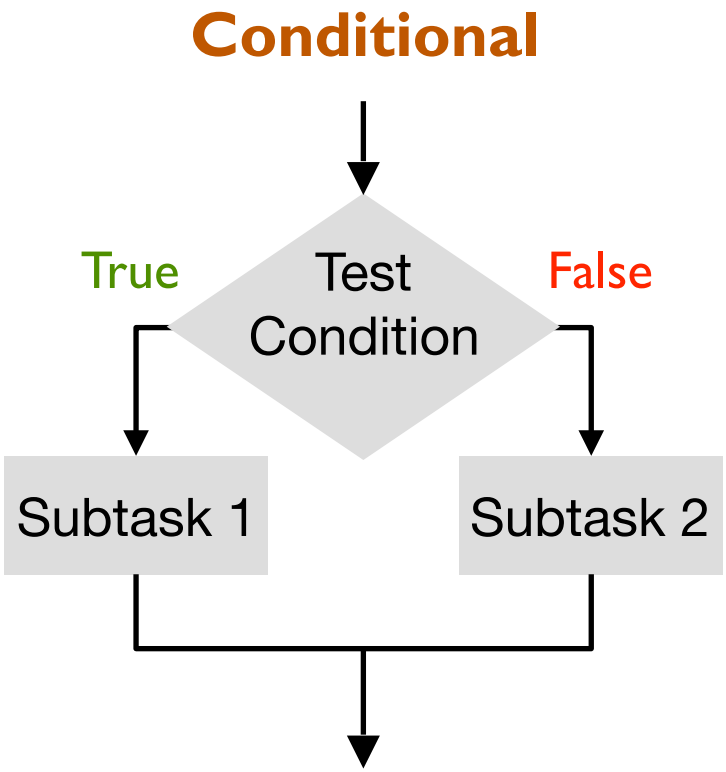
Three Basic Programming Constructs

- Both conditional and iterative programming requires altering the sequence of instructions (control flow)
- We need a set of *control instructions* to do so
- Two fundamental questions:
  - How to test condition and how to represent test results?
  - How to alter control flow according to the test results?

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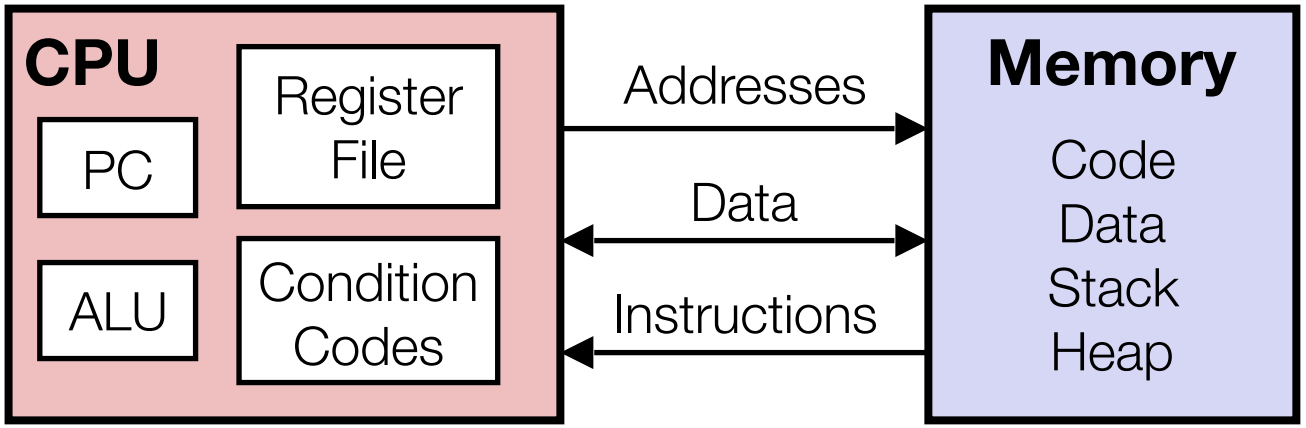
Condition Codes Hold Test Results

Assembly Programmer's Perspective of a Computer



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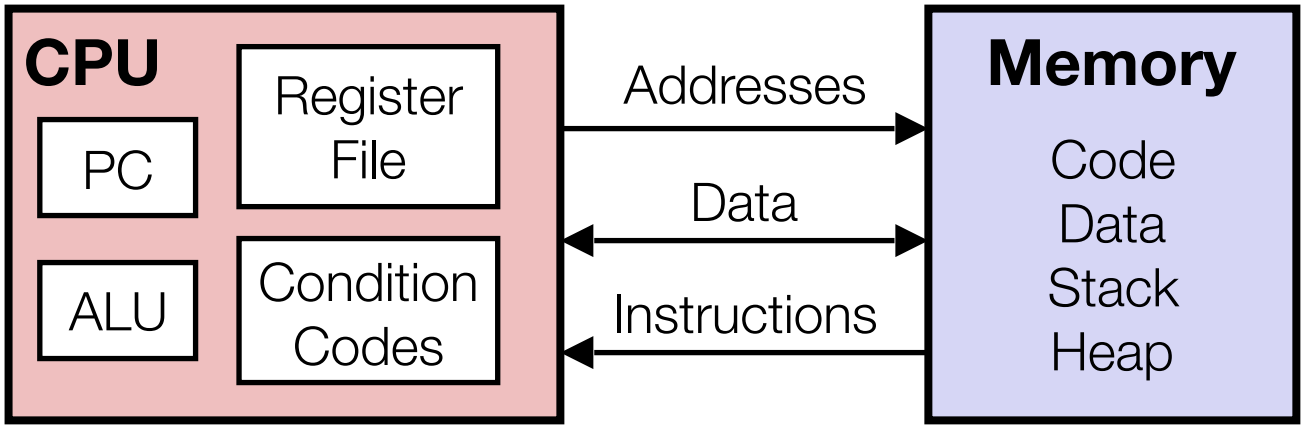

- Condition Codes
  - Hold the status of most recent test
  - 4 common condition codes in x86-64
  - A set of special registers (more often: bits in one single register)
  - Sometimes also called: Status Register, Flag Register

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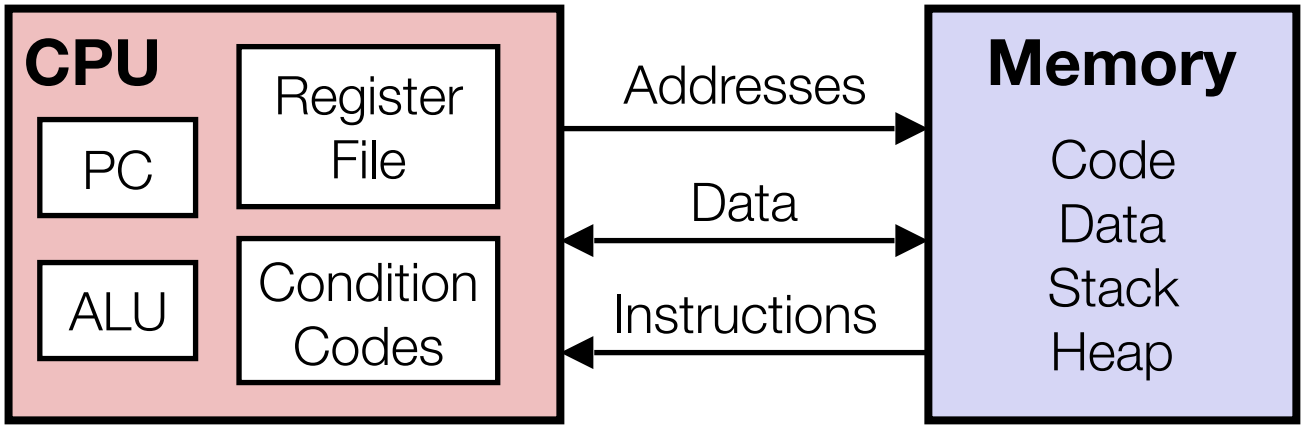

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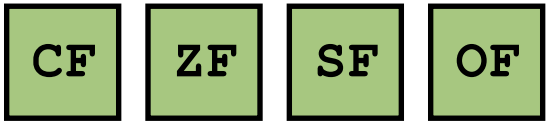

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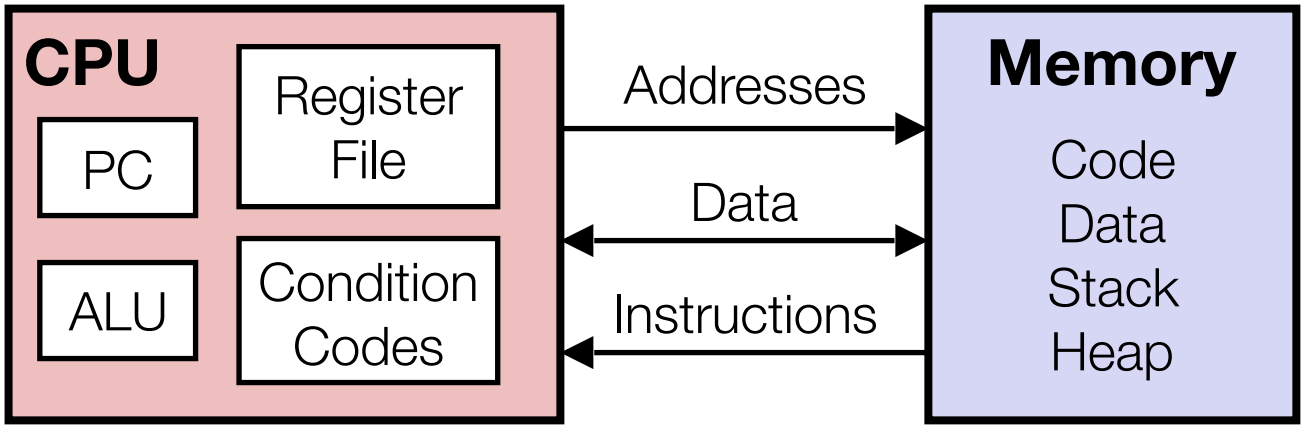

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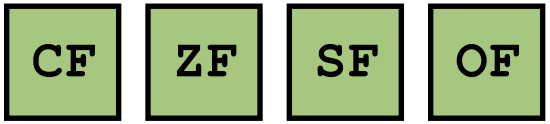

CF Carry Flag (for unsigned)

ZF Zero Flag

SF Sign Flag

OF Overflow Flag (for signed)

Explicit Set Condition Codes: Compare

`cmpq` *Src2*, *Src1*

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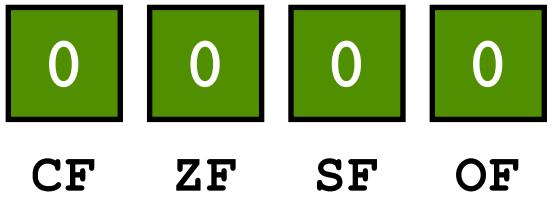
(assuming 8-bit word size here)



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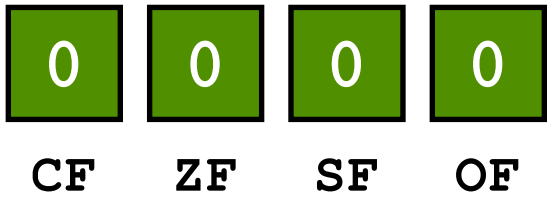

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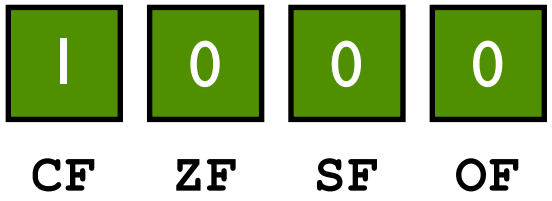

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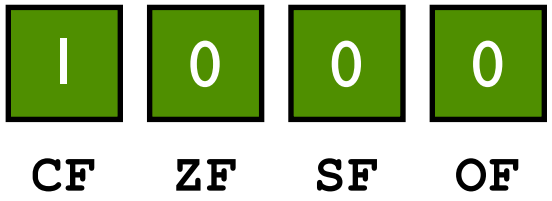

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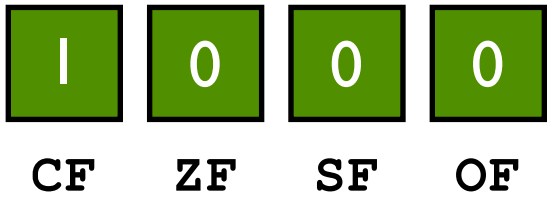

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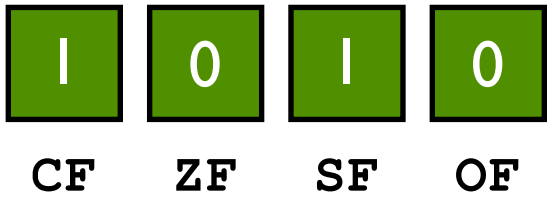

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  - **SF (Sign Flag):** set if `(a-b)<0` (i.e., most significant bit is 1)
  - **OF (Overflow Flag)** set if `a-b` overflows (treat *a* and *b* as signed)
    `(a>0 && b<0 && (a-b)<0) || (a<0 && b>0 && (a-b)>0)`

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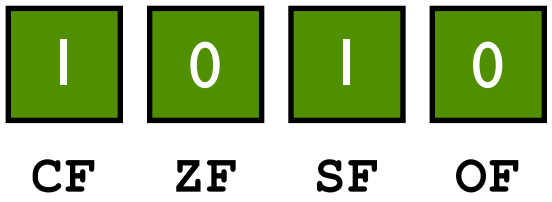

Explicit Set Condition Codes: Test

`testq` *Src2*, *Src1*

- Explicit Setting by Test Instruction
  - **`test b,a`** like computing `a&b`, but instead of setting the result, it sets condition codes
  - **ZF (Zero Flag):** set if `a & b == 0`
  - **SF (Sign Flag):** set if `a & b < 0`
  - OF and CF are always set to 0

Implicit Set Condition Codes

`addq` *Src*, *Dest*

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  - **OF** set if signed overflow

```
(a>0 && b>0 && t<0) || (a<0 && b<0 && t>=0)
```

Today: Compute and Control Instructions

- Arithmetic & logical operations
- Control: Condition codes
- Conditional branches (**`if`**... **`else`**...)
- Loops (**`for`**, **`while`**)
- Switch Statements (**`case`**... **`switch`**...)

Conditional Branch Example

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```
long absdiff
  (long x, long y)
{
  long result;
  if (x > y)
    result = x-y;
  else
    result = y-x;
  return result;
}
```

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gcc -Og -S -fno-if-conversion control.c
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absdiff:
    cmpq    %rsi,%rdi # x:y
    jle     .L4
    movq    %rdi,%rax
    subq    %rsi,%rax
    ret
.L4:                  # x <= y
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Register	Use(s)
%rdi	x
%rsi	y
%rax	Return value

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Labels are symbolic names used to refer to instruction addresses.