assembly 2

last time

AT&T syntax

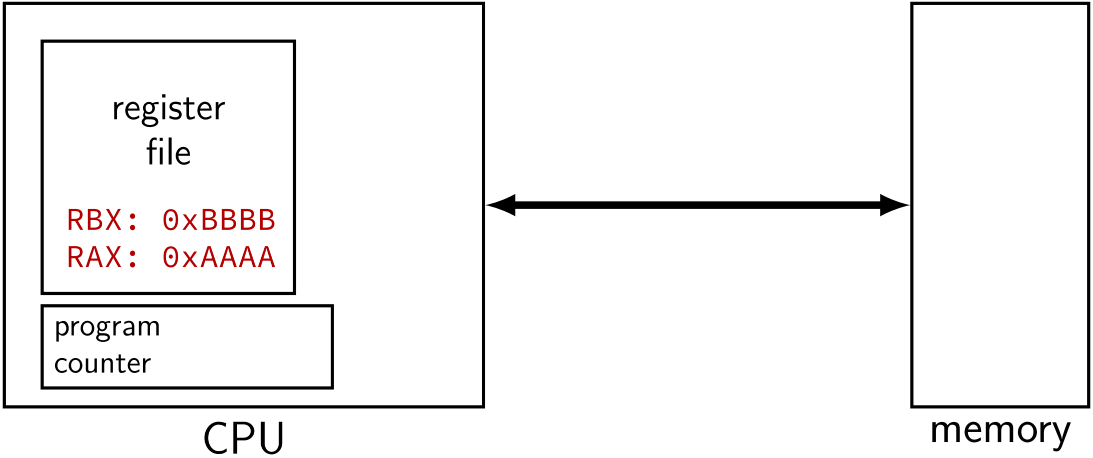
- destination last
- disp(base, index, scale) for memory access
- labels ≈ addresses
- $ for constants (otherwise memory access)

overlapping register rules

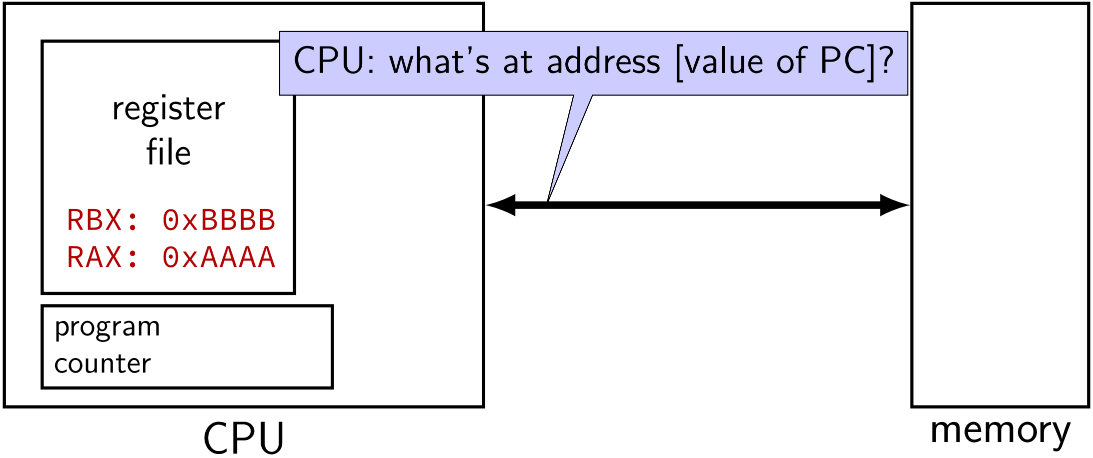
calling convention

- caller saved (must save before calling function)
- callee saved (functions must save before using)

quiz Q1


register file
RBX: 0xBBBB
RAX: 0xAAAA
program counter
CPU
memory

quiz Q1



CPU: what's at address [value of PC]?

register file

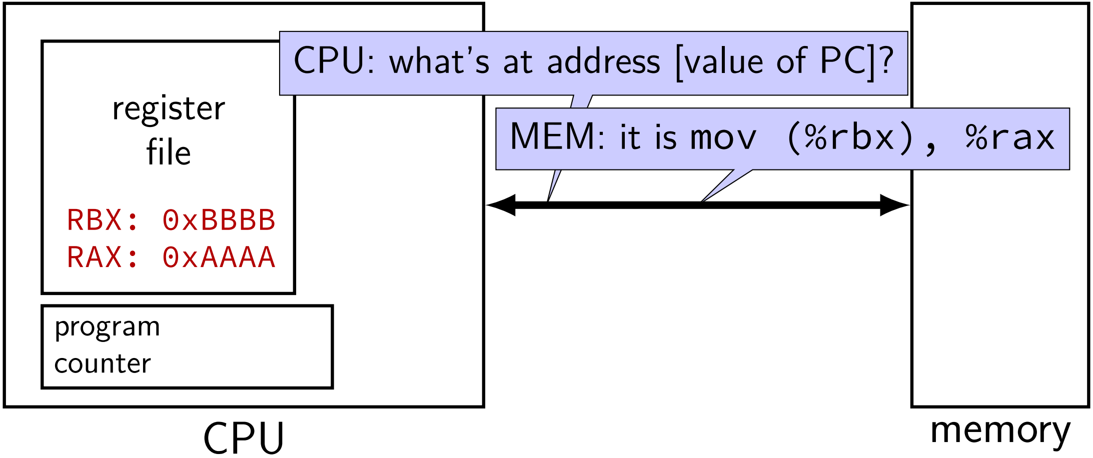
RBX: 0xBBBB
RAX: 0xAAAA

program counter

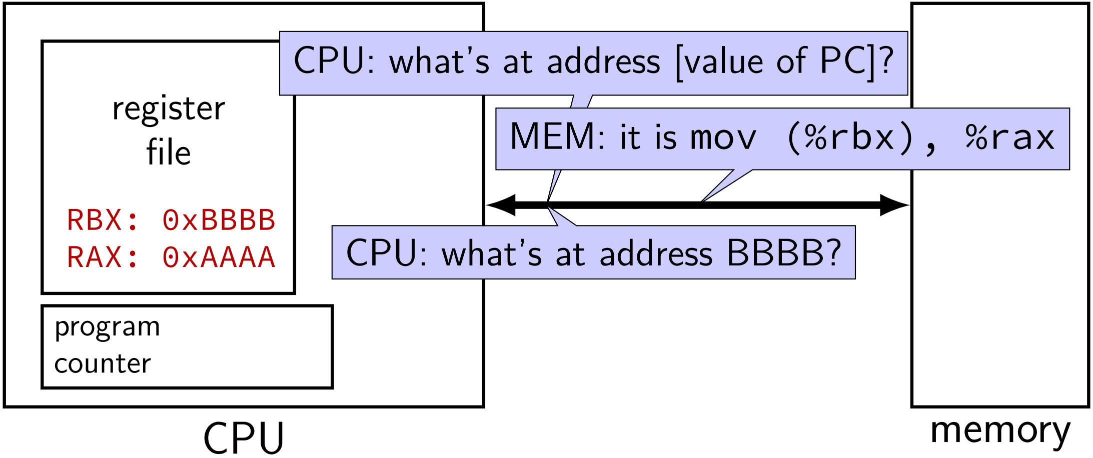
CPU

memory

quiz Q1


register file
RBX: 0xBBBB
RAX: 0xAAAA
program counter
CPU
memory
CPU: what's at address [value of PC]?
MEM: it is mov (%rbx), %rax

quiz Q1

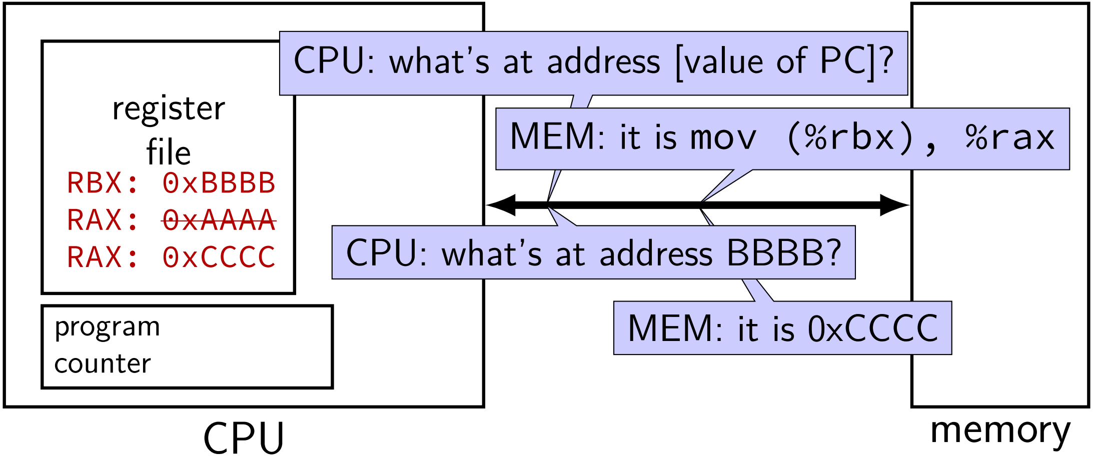


CPU: what’s at address [value of PC]?

MEM: it is `mov (%rbx), %rax`

CPU: what’s at address BBBB?

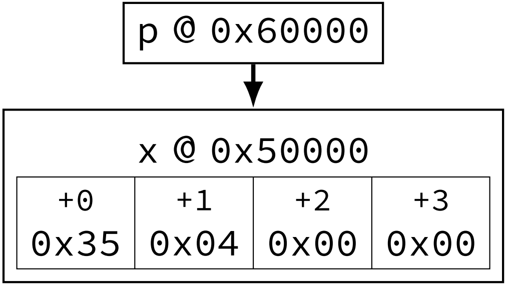
quiz Q1



register file
RBX: 0xBBBB
RAX: ~~0xAAAA~~
RAX: 0xCCCC
program counter
CPU
memory
CPU: what's at address [value of PC]?
MEM: it is mov (%rbx), %rax
CPU: what's at address BBBB?
MEM: it is 0xCCCC

quiz Q2-4

```
int x;
int *p;
x = 1077;
p = &x;
```



p @ 0x60000

x @ 0x50000

+0	+1	+2	+3
0x35	0x04	0x00	0x00

1077 = 0x435 = 0x00000435

Q6

desired: `c = str[x+2]`

```
c (%bl) <- memory @ str (%rax) + x (%rdi) + 2
```

✓ `movq $2, %r8; addq %rdi, %r8; movb (%rax, %r8, 1), %bl`

```
tmp (%r8) <- 2; tmp <- tmp + x; c <- memory @ str + tmp * 1
```

✓ `movq %rdi, %r8; addq $2, %r8; movb (%r8, %rax, 1), %bl`

```
tmp (%r8) <- x; tmp <- tmp + 2; c <- memory @ tmp + str * 1
```

using 'index' register for unintended purpose doesn't change computed address

...

✗ `movq $0, %r8; addq 2(%rax, %rdi, 1), %r8; movb (%r8), %bl`

```
tmp <- 0; tmp <- tmp + memory @ str + x * 1 + 2; c <- memory @ tmp
```

reads correct value, but then uses the value as address instead of copying it into 'c'

on LEA

LEA = **L**oad **E**ffective **A**ddress

effective address = computed address for memory access

syntax looks like a **mov** from memory, but...

skips the memory access — just uses the address

(sort of like & operator in C?)

`leaq 4(%rax), %rax` ≈ `addq $4, %rax`

on LEA

LEA = **L**oad **E**ffective **A**ddress

effective address = computed address for memory access

syntax looks like a **mov** from memory, but...

skips the memory access — just uses the address

(sort of like & operator in C?)

`leaq 4(%rax), %rax` ≈ `addq $4, %rax`

“address of memory[rax + 4]” = rax + 4

LEA tricks

```
leaq (%rax,%rax,4), %rax
```

rax ← rax × 5

rax ← `address-of(memory[rax + rax * 4])`

```
leaq (%rbx,%rcx), %rdx
```

rdx ← rbx + rcx

rdx ←`address-of(memory[rbx + rcx])`

exercise: what is this function?

```
mystery:
    leal 0(,%rdi,8), %eax
    subl %edi, %eax
    ret
```

```
int mystery(int arg) { return ...; }
```

A. `arg * 9`   D. `-arg * 7`

B. `-arg * 9`   E. none of these

C. `arg * 8`   F. it has a different prototype

exercise: what is this function?

```
mystery:
    leal 0(,%rdi,8), %eax
    subl %edi, %eax
    ret
```

```
int mystery(int arg) { return ...; }
```

A. `arg * 9`

B. `-arg * 9`

C. `arg * 8`

D. `-arg * 7`

E. none of these

F. it has a different prototype

explanation

```
leal 0(,%rdi,8), %eax
```

compute 0 + [nothing] + %rdi (`arg`) × 8 = `arg` × 8

truncate arg × 8 from 64-bit to 32-bit

no effect since `arg` in C was 32-bit, not 64

```
subl %edi, %eax
```

"subtract first from second"

compute %eax (`arg` × 8) - %edi (`arg`) = `arg` × 7

return value is whatever's left in %eax

selected things we won't cover (today)

floating point; vector operations (multiple values at once)

special registers: %xmm0 through %xmm15

segmentation (special registers: %ds, %fs, %gs, …)

lots and lots of instructions

conditionals in x86 assembly

```
    if (rax != 0)
        foo();
```

```
    cmpq $0, %rax
    // ***
    je skip_call_foo
    call foo
skip_call_foo:
```

---

how does `je` know the result of the comparison?

what happens if we add extra instructions at the ***?

condition codes

x86 has condition codes

special registers set by (almost) all arithmetic instructions

- addq, subq, imulq, etc.

store info about last arithmetic result

- was it zero? was it negative? etc.

condition codes and jumps

`jg`, `jle`, etc. read condition codes

named based on interpreting result of subtraction

- alternate view: comparing result to 0

0: equal; negative: less than; positive: greater than

condition codes: closer look

ZF (“zero flag”) — was result zero? (sub/cmp: equal)

- e.g. JE (jump if equal) checks for ZF $= 1$

SF (“sign flag”) — was result negative? (sub/cmp: less)

- e.g. JL (jump if less than) checks for SF $= 1$ (plus extra case for overflow)
- e.g. JLE checks for SF $= 1$ or ZF $= 1$ (plus overflow)

(and some more, e.g. to handle overflow)

condition codes: closer look

`ZF` (“zero flag”) — was result zero? (sub/cmp: equal)

- e.g. JE (jump if equal) checks for ZF $= 1$

`SF` (“sign flag”) — was result negative? (sub/cmp: less)

- e.g. JL (jump if less than) checks for SF $= 1$ (plus extra case for overflow)
- e.g. JLE checks for SF $= 1$ or ZF $= 1$ (plus overflow)

`OF` (“overflow flag”) — did computation overflow (as signed)?

- we won't test on this/use it in later assignments
- signed conditional jumps: JL, JLE, JG, JGE, …

`CF` (“carry flag”) — did computation overflow (as unsigned)?

- we won't test on this/use it in later assignments
- unsigned conditional jumps: JB, JBE, JA, JAE, …

(and one more)

condition codes: closer look

`ZF` (“zero flag”) — was result zero? (sub/cmp: equal)

- e.g. JE (jump if equal) checks for ZF = 1

`SF` (“sign flag”) — was result negative? (sub/cmp: less)

- e.g. JL (jump if less than) checks for SF = 1 (plus extra case for overflow)
- e.g. JLE checks for SF = 1 or ZF = 1 (plus overflow)

`OF` (“overflow flag”) — did computation overflow (as signed)?

- we won't test on this/use it in later assignments
- signed conditional jumps: JL, JLE, JG, JGE, …

`CF` (“carry flag”) — did computation overflow (as unsigned)?

- we won't test on this/use it in later assignments
- unsigned conditional jumps: JB, JBE, JA, JAE, …

(and one more)

condition codes (and other flags) in GDB

```
(gdb) info registers
rax            0x0                 0
rbx            0x555555555150      93824992235856
rcx            0x555555555150      93824992235856
...
rip            0x55555555513a      0x55555555513a <
eflags         0x246               [ PF ZF IF ]
cs             0x33                51
ss             0x2b                43
...
```

ZF = 1 (listed); SF, OF, CF clear

some other flags that you can lookup (PF, IF) also shown

condition codes example (1)

```
movq $−10, %rax
movq $20, %rbx
subq %rax, %rbx // %rbx - %rax = 30
  // result > 0: %rbx was > %rax
jle foo // not taken; 30 > 0
```

condition codes example (1)

```
movq $−10, %rax
movq $20, %rbx
subq %rax, %rbx // %rbx - %rax = 30
  // result > 0: %rbx was > %rax
jle foo // not taken; 30 > 0
```

30: SF = 0 (not negative), ZF = 0 (not zero)

condition codes example (1b)

```
    movq $−10, %rax
    movq $20, %rbx
    subq %rax, %rbx // %rbx - %rax = 30
    jle foo // not taken; 30 > 0
```

30: SF = 0 (not negative), ZF = 0 (not zero)

```
    movq $20, %rax
    movq $20, %rbx
    subq %rax, %rbx // %rbx - %rax = 0
    jle foo // taken; 0 <= 0
```

0: SF = 0 (not negative), ZF = 1 (zero)

```
    movq $0, %rax
    movq $−10, %rbx
    subq %rax, %rbx // %rbx - %rax = -10
    jle foo // taken; -10 <= 0
```

-10: SF = 1 (negative), ZF = 0 (not zero)

condition codes and cmpq

"last arithmetic result"???

then what is cmp, etc.?

`cmp` does subtraction (but doesn't store result)

similar `test` does bitwise-and

`testq %rax, %rax` — result is %rax

what sets condition codes

most instructions that compute something set condition codes

some instructions only set condition codes:

- `cmp` ∼ `sub`
- `test` ∼ `and` (bitwise and — later)
- `testq %rax, %rax` — result is %rax

some instructions don't change condition codes:

- `lea`, `mov`
- control flow: `jmp`, `call`, `ret`, `jle`, etc.

how do you know? — check processor's manual

condition codes example (2)

```
movq $–10, %rax  // rax <- (-10)
movq $20, %rbx   // rbx <- 20
cmpq %rax, %rbx  // set cond codes w/ rbx - rax
jle foo // not taken; %rbx - %rax > 0
```

condition codes example (2)

```
movq $−10, %rax  // rax <- (-10)
movq $20, %rbx   // rbx <- 20
cmpq %rax, %rbx  // set cond codes w/ rbx - rax
jle foo // not taken; %rbx - %rax > 0
```

%rbx - %rax = 30: SF = 0 (not negative), ZF = 0 (not zero)

omitting the cmp

```
    movq $99, %r12              // x (r12) <- 99
start_loop:
    call foo                    // foo()
    subq $1, %r12               // x (r12) <- x - 1
    cmpq $0, %r12
    // compute x (r12) - 0 + set cond. codes
    jge  start_loop             // r12 >= 0?
                                // or result >= 0?
```

```
    movq $99, %r12              // x (r12) <- 99
start_loop:
    call foo                    // foo()
    subq $1, %r12               // x (r12) <- x - 1
    jge  start_loop             // new r12 >= 0?
```

condition code exercise

```
movq %rcx, %rdx
subq $1, %rdx
addq %rdx, %rcx
```

Assuming no overflow, possible values of SF, ZF?

A. SF = 0, ZF = 0
B. SF = 1, ZF = 0
C. SF = 0, ZF = 1
D. SF = 1, ZF = 1

condition code exercise

```
movq %rcx, %rdx
subq $1, %rdx
addq %rdx, %rcx
```

~~Assuming no overflow,~~ possible values of SF, ZF?

A. SF = 0, ZF = 0
B. SF = 1, ZF = 0
C. SF = 0, ZF = 1
D. SF = 1, ZF = 1

exercise

(ignoring overflow) `jge` is taken (jumps to target) when

A. ZF $= 1$
B. SF $= 1$
C. SF $= 1$ and ZF $= 0$
D. SF $= 1$ or ZF $= 1$
E. SF $= 0$
F. something else

if-to-assembly (1)

```
if (b >= 42) {
    a += 10;
} else {
    a *= b;
}
```

if-to-assembly (1)

```
if (b >= 42) {
    a += 10;
} else {
    a *= b;
}
```

```
            if (b < 42) goto after_then;
            a += 10;
            goto after_else;
after_then: a *= b;
after_else:
```

if-to-assembly (2)

```
if (b >= 42) {
    a += 10;
} else {
    a *= b;
}
```

```
// a is in %rax, b is in %rbx
    cmpq $42, %rbx   // computes rbx - 42 to 0
                     // i.e compare rbx to 42
    jl after_then    // jump if rbx - 42 < 0
                     // AKA rbx < 42
    addq $10, %rax   // a += 10
    jmp after_else
after_then:
    imulq %rbx, %rax // rax = rax * rbx
after_else:
```

exercise

```
    subq %rax, %rbx
    addq %rbx, %rcx
    je after
    addq %rax, %rcx
after:
```

Same as which of these C snippets? (rax = var. assigned to register %rax, etc.)

A

```
rbx -= rax;
rcx += rbx;
if (rcx == 0) {
    rcx += rax;
}
```

B

```
rbx -= rax;
rcx += rbx;
if (rbx == rcx) {
    rcx += rax;
}
```

C

```
rbx -= rax;
rcx += rbx;
if (rbx + rcx == 0) {
    rcx += rax;
}
```

D

```
rcx += (rbx - rax);
if (rcx == (rbx - rax)) {
    rcx += rax;
}
```

exercise

```
    subq %rax, %rbx
    addq %rbx, %rcx
    je after
    addq %rax, %rcx
after:
```

would be correct with flipped compare

Same as which of these C snippets? (rax = var. assigned to register %rax, etc.)

A ✗

```
    rbx -= rax;
    rcx += rbx;
    if (rcx != 0) {
        rcx += rax;
    }
```

B ✗

```
    rbx -= rax;
    rcx += rbx;
    if (rbx == rcx) {
        rcx += rax;
    }
```

C ✗

```
rbx -= rax;
rcx += rbx;
if (rbx + rcx == 0) {
    rcx += rax;
}
```

D ✗

```
rcx += (rbx - rax);
if (rcx == (rbx - rax)) {
    rcx += rax;
}
```

while-to-assembly (1)

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

while-to-assembly (1)

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

```
start_loop:
    if (x < 0) goto end_loop;
    foo()
    x--;
    goto start_loop:
end_loop:
```

while-to-assembly (2)

```
start_loop:
    if (x < 0) goto end_loop;
    foo()
    x--;
    goto start_loop:
end_loop:
```

```
start_loop:
    cmpq $0, %r12
    jl end_loop // jump if r12 - 0 < 0
    call foo
    subq $1, %r12
    jmp start_loop
```

while exercise

```
while (b < 10) { foo(); b += 1; }
```

Assume b is in callee-saved register %rbx. Which are correct assembly translations?

```
// version A
start_loop:
   call foo
   addq $1, %rbx
   cmpq $10, %rbx
   jl start_loop
```

```
// version B
start_loop:
   cmpq $10, %rbx
   jge end_loop
   call foo
   addq $1, %rbx
   jmp start_loop
end_loop:
```

```
// version C
start_loop:
   movq $10, %rax
   subq %rbx, %rax
   jge end_loop
   call foo
   addq $1, %rbx
   jmp start_loop
end_loop:
```

while exercise: translating?

```
while (b < 10) {
    foo();
    b += 1;
}
```

while exercise: translating?

```
while (b < 10) {
    foo();
    b += 1;
}
```

```
start_loop: if (b < 10) goto end_loop;
            foo();
            b += 1;
            goto start_loop;
end_loop:
```

while — levels of optimization

```
while (b < 10) { foo(); b += 1; }
```

```
start_loop:
  cmpq $10, %rbx
  jge end_loop
  call foo
  addq $1, %rbx
  jmp start_loop
end_loop:
    ...
    ...
    ...
    ...
```

while — levels of optimization

```
while (b < 10) { foo(); b += 1; }
```

```
start_loop:
  cmpq $10, %rbx
  jge end_loop
  call foo
  addq $1, %rbx
  jmp start_loop
end_loop:
    ...
    ...
    ...
    ...
```

```
  cmpq $10, %rbx
  jge end_loop
start_loop:
  call foo
  addq $1, %rbx
  cmpq $10, %rbx
  jne start_loop
end_loop:
    ...
    ...
    ...
```

while — levels of optimization

```
while (b < 10) { foo(); b += 1; }
```

```
start_loop:
  cmpq $10, %rbx
  jge end_loop
  call foo
  addq $1, %rbx
  jmp start_loop
end_loop:
    ...
    ...
    ...
    ...
```

```
  cmpq $10, %rbx
  jge end_loop
start_loop:
  call foo
  addq $1, %rbx
  cmpq $10, %rbx
  jne start_loop
end_loop:
    ...
    ...
    ...
```

```
  cmpq $10, %rbx
  jge end_loop
  movq $10, %rax
  subq %rbx, %rax
  movq %rax, %rbx
start_loop:
  call foo
  decq %rbx
  jne start_loop
  movq $10, %rbx
end_loop:
```

compiling switches (1)

```
switch (a) {
    case 1: ...; break;
    case 2: ...; break;
    ...
    default: ...
}
```

```
    // same as if statement?
    cmpq $1, %rax
    je code_for_1
    cmpq $2, %rax
    je code_for_2
    cmpq $3, %rax
    je code_for_3
    ...
    jmp code_for_default
```

compiling switches (2)

```
switch (a) {
    case 1: ...; break;
    case 2: ...; break;
    ...
    case 100: ...; break;
    default: ...
}
```

```
    // binary search
    cmpq $50, %rax
    jl code_for_less_than_50
    cmpq $75, %rax
    jl code_for_50_to_75
    ...
code_for_less_than_50:
    cmpq $25, %rax
    jl less_than_25_cases
    ...
```

compiling switches (3a)

```
switch (a) {
    case 1: ...; break;
    case 2: ...; break;
    ...
    case 100: ...; break;
    default: ...
}
```

```
// jump table
cmpq $100, %rax
jg code_for_default
cmpq $1, %rax
jl code_for_default
jmp *table - 8(,%rax,8)
```

```
table:
  // not instructions
  // .quad = 64-bit (4 x 16) constant
  .quad code_for_1
  .quad code_for_2
  .quad code_for_3
  .quad code_for_4
    ...
```

compiling switches (3b)

```
jmp *table-8(,%rax,8)
```

suppose RAX $= 2$,
`table` located at 0x12500

compiling switches (3b)

```
jmp *table-8(,%rax,8)
```

suppose RAX = 2,
table located at 0x12500

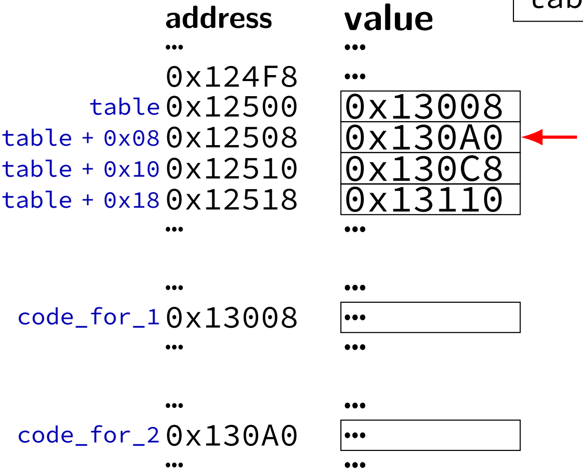
	address	value
	...	...
	0x124F8	...
table	0x12500	0x13008
table + 0x08	0x12508	0x130A0
table + 0x10	0x12510	0x130C8
table + 0x18	0x12518	0x13110
	...	...
	...	...
code_for_1	0x13008	...
	...	...
	...	...
code_for_2	0x130A0	...
	...	...

table — list of code addresses

compiling switches (3b)

```
jmp *table-8(,%rax,8)
```

suppose RAX $= 2$,
`table` located at 0x12500



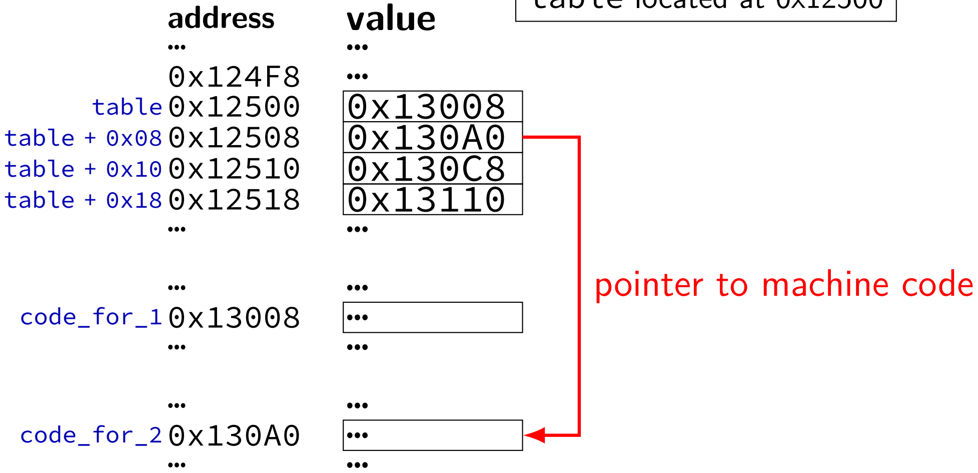
	address	value
	...	...
	0x124F8	...
table	0x12500	0x13008
table + 0x08	0x12508	0x130A0
table + 0x10	0x12510	0x130C8
table + 0x18	0x12518	0x13110
	...	...
	...	...
code_for_1	0x13008	...
	...	...
	...	...
code_for_2	0x130A0	...
	...	...

$$(\text{table} - 8) + \text{rax} \times 8 = \texttt{0x124F8} + \texttt{0x10} = \texttt{0x12508}$$

compiling switches (3b)

```
jmp *table-8(,%rax,8)
```

suppose RAX = 2,
table located at 0x12500



	address	value
	...	...
	0x124F8	...
table	0x12500	0x13008
table + 0x08	0x12508	0x130A0
table + 0x10	0x12510	0x130C8
table + 0x18	0x12518	0x13110
	...	...
	...	...
code_for_1	0x13008	...
	...	...
	...	...
code_for_2	0x130A0	...
	...	...

pointer to machine code

computed jumps

```
  cmpq $100, %rax
  jg code_for_default
  cmpq $1, %rax
  jl code_for_default
  // jump to memory[table + rax * 8]
    // table of pointers to instructions
  jmp *table(,%rax,8)
  // intel: jmp QWORD PTR[rax*8 + table]
  ...
table:
  .quad code_for_1
  .quad code_for_2
  .quad code_for_3
  ...
```

backup slides

control-flow enforcement

“Control-flow Enforcement”

instruction set extension proposed by Intel

and at least partially supported by AMD

includes *shadow stacks* and *indirect branch tracking*

control-flow enforcement

“Control-flow Enforcement”

instruction set extension proposed by Intel

and at least partially supported by AMD

includes *shadow stacks* and *indirect branch tracking*

indirect branch tracking: you’ll see evidence of in Bomb assignment

control-flow enforcement

“Control-flow Enforcement”

instruction set extension proposed by Intel

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includes *shadow stacks* and *indirect branch tracking*

indirect branch tracking: you’ll see evidence of in Bomb assignment

restricts jmps/calls/etc.

must have constant target or go to `endbr`(anch) instruction

- exception: `notrack` can mark jmps/calls/etc. that should not be restricted
- for historical reasons, `notrack` might be written `ds`

indirect branch tracking examples

when indirect branch tracking is enabled:

not allowed:

```
    mov $target, %rax
    jmp *%rax
    ...
target:
    add $10, %rcx
```

okay:

```
    jmp target
    ...
target:
    add $10, %rcx
```

okay:

```
    jmp target
    ...
target:
    endbr64
    add $10, %rcx
```

okay:

```
    mov $target, %rax
    notrack jmp *%rax
    // might also be wri
    //    ds jmp *%rax
    ...
target:
    add $10, %rcx
```

condition codes example plus overflow (1)

```
movq $−10, %rax
  // same as: mov $0xFFFFFFFFFFFFFFF6, %rax
movq $20, %rbx
cmpq %rax, %rbx
  // %rbx - %rax
jle foo // not taken; signed: 30 > 0
jbe foo // taken; unsigned: very negative <= 0
```

as signed: 30: SF $= 0$ (not negative), ZF $= 0$ (not zero)

as unsigned: $20 - (2^{64} - 10) = \xcancel{-2^{64} - 30}\ 30$ (overflow!)

- `OF` $= 0$ (false)   no overflow as signed
- `CF` $= 1$ (true)   overflow as unsigned

`jbe` (jump below/equal) uses CF to give correct result w/ overflow

condition codes example plus overflow (2)

```
movq $5000000000000000000, %rax
movq $6000000000000000000, %rbx
addq %rax, %rbx
  // %rbx + %rax = (incorrect) -74467440737095516
  // %rbx + %rax = 11000000000000000000 (unsigned
jle foo // not taken; true signed result > 0
jbe foo // not taken; true unsigned result > 0
```

SF = 1 (negative as signed), ZF = 0 (not zero)

OF = 1 (true) overflow as signed

CF = 0 (false) overflow as unsigned

jle uses OF to realize true result is positive, even though SF is set

do-while-to-assembly (1)

```
int x = 99;
do {
    foo()
    x--;
} while (x >= 0);
```

do-while-to-assembly (1)

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int x = 99;
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```

```
    int x = 99;
start_loop:
    foo()
    x--;
    if (x >= 0) goto start_loop;
```

do-while-to-assembly (2)

```
int x = 99;
do {
    foo()
    x--;
} while (x >= 0);
```

```
    movq $99, %r12 // register for x
start_loop:
    call foo
    subq $1, %r12
    cmpq $0, %r12
    // computes r12 - 0 = r12
    jge start_loop // jump if r12 - 0 >= 0
```

condition codes examples (4)

```
movq $20, %rbx
addq $−20, %rbx // result is 0
movq $1, %rax   // irrelevant to cond. codes
je   foo        // taken, result is 0
```

condition codes example: no cmp (3)

```
movq $−10, %rax  // rax <- (-10)
movq $20, %rbx   // rbx <- 20
subq %rax, %rbx  // rbx <- rbx - rax = 30
jle  foo // not taken, %rbx - %rax > 0


movq $20, %rbx   // rbx <- 20
addq $−20, %rbx  // rbx <- rbx + (-20) = 0
je   foo         // taken, result is 0
                 // x - y = 0 -> x = y
```

condition codes: exercise with overflow (1)

```
    // 2^63 - 1
    movq $0x7FFFFFFFFFFFFFFF, %rax
    // 2^63 (unsigned); -2**63 (signed)
    movq $0x8000000000000000, %rbx
    cmpq %rax, %rbx
  // result = %rbx - %rax
```

$\text{ZF} = \ ?$

$\text{SF} = \ ?$

$\text{OF} = \ ?$

$\text{CF} = \ ?$

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as signed: $-2^{63} - \left(2^{63} - 1\right) = \cancel{-2^{64} + 1}\ 1$ (overflow)

as unsigned: $2^{63} - \left(2^{63} - 1\right) = 1$

$\mathtt{ZF} = 0$ (false) not zero rax and rbx not equal

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$\mathrm{ZF} = 0$ (false)	not zero	rax and rbx not equal
$\mathrm{SF} = 0$ (false)	not negative	rax <= rbx (if correct)

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as unsigned: $2^{63} - \left(2^{63} - 1\right) = 1$

$\mathtt{ZF} = 0$ (false)	not zero	rax and rbx not equal
$\mathtt{SF} = 0$ (false)	not negative	rax $<=$ rbx (if correct)
$\mathtt{OF} = 1$ (true)	overflow as signed	incorrect for signed
$\mathtt{CF} = 0$ (false)	no overflow as unsigned	correct for unsigned

recall: x86-64 general purpose registers

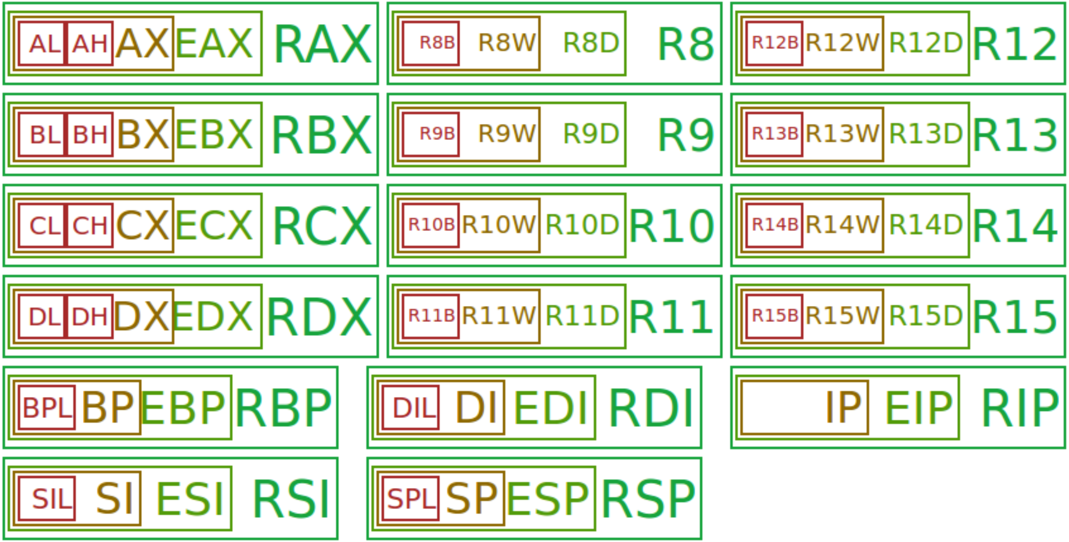


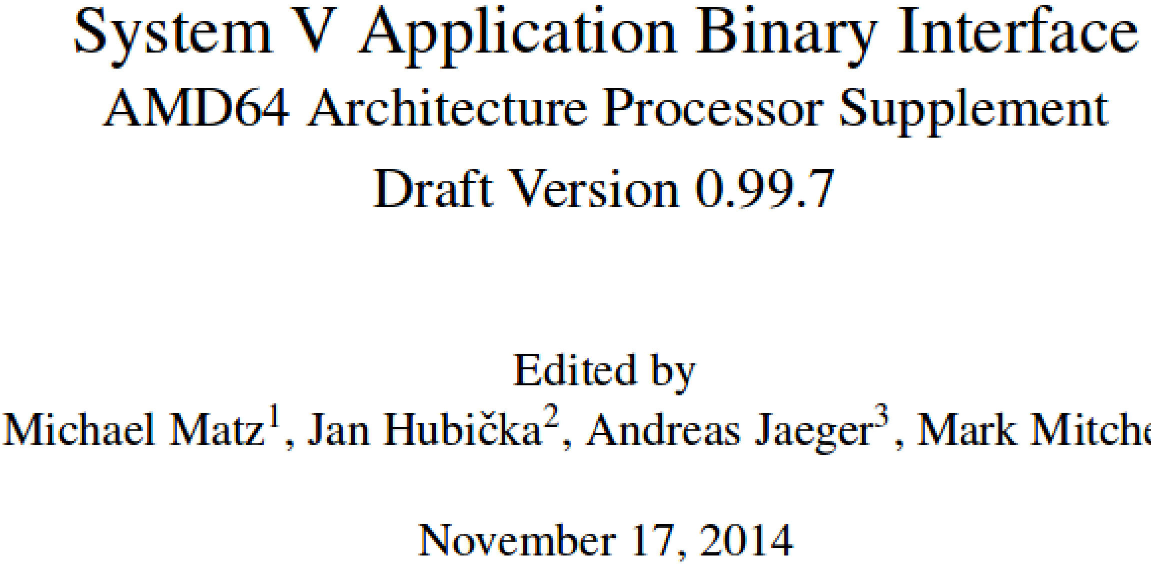
Figure: Immae via Wikipedia

authoriative source (1)

Intel® 64 and IA-32 Architectures
Software Developer's Manual

Combined Volumes:
1, 2A, 2B, 2C, 2D, 3A, 3B, 3C and 3D

authoriative source (2)



System V Application Binary Interface

AMD64 Architecture Processor Supplement

Draft Version 0.99.7

Edited by

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question

```
pushq $0x1
pushq $0x2
addq $0x3, 8(%rsp)
popq %rax
popq %rbx
```

What is value of `%rax` and `%rbx` after this?

a. `%rax` = `0x2`, `%rbx` = `0x4`
b. `%rax` = `0x5`, `%rbx` = `0x1`
c. `%rax` = `0x2`, `%rbx` = `0x1`
d. the snippet has invalid syntax or will crash
e. more information is needed
f. something else?

backup slides