Integers

- Example of storing `0x1234567` at `0x100`

	0x100	0x101	0x102	0x103
Big endian	01	23	45	67
Little endian	67	45	23	01

- $\lceil x/2^k \rceil$ is given by `(x + (1 << k) - 1) >> k`
- $x/2^k$ is given by `(x<0 ?  x+(1<<k)-1 :  x) >> k`

Bitwise Operations

- **Logical shift** – Fills left end with zeros (unsigned)
- **Arithmetic shift** – Sign-extends left end (signed)

Floating Point

- Contains 3 parts `sign,exp,frac`
- 3 parts of `float`: 1+8+23=32; `double`: 1+11+52=64
- Lacks common +*rules `a*b*c != a*(b*c), a+b+c != a+(b+c), a*(b+c) != a*b + a*c`
- $V = (-1)^s \times M \times 2^E$
- Sign bit s 1-bit , 0 for $V >= 0$, 1 for $V <= 0$
- Exponent E, k-bit `exp` field
- Significand (mantissa) M – $0 \leq M < 1$ or $1 \leq M < 2$, represented by n-bit `frac` field $(f_{n-1} \cdots f_1 f_0)$
- Normalized values
  - `exp` is neither all zeros nor all ones
  - $E = e-$Bias where e is the unsigned number in `exp` and Bias $= 2^{k-1} - 1$
  - `frac` represents $0 \leq f < 1$ with $0.f_{n-1} \cdots f_1 f_0$ and $M = 1 + f$
1	10000000	10101010101010101010101
$(-1) \times 2^1 \times 1.10101010101010101010101$		
- Denormalized values
  - `exp` all zeros
  - Exponent value is $E = 1 - Bias$, $M = f$ (no leading 1)
0	00000000	10101010101010101010101
$1 \times 2^{1-01111111} \times 0.10101010101010101010101$		
- Special values
  - Exponent field is all ones
  - Fraction field all zeros can represent $\pm\infty$, depending on sign bit
  - Nonzero fraction field is NaN
  - $+\infty = 0, 11111111, 00000000000000000000000$
  - every conditional expression with `NaN` is 0
  - `NaN == NaN` is 0
  - every arithmetic expression with `NaN` is `NaN`
  - `NaN * 0` is `NaN`
  - forcibly trans `inf` or `NaN` to `int` gets int_{min}
- Rounding
  - Rounds to the nearest even
  - `BBGRXXXX` can round to `BBG` or `BBG+1`
  - `G` – Guard bit; least significant bit of result
  - `R` – Round bit; first bit removed
  - `XXXX` – Sticky bit; OR of remaining bits
  - Round up conditions:
    - Round $= 0 \rightarrow$ `BBG`
    - Round $= 1$, Sticky $= 1 \rightarrow$ `BBG+1`
    - Round $= 1$, Sticky $= 0$, Guard $= 0 \rightarrow$ `BBG`
    - Round $= 1$, Sticky $= 0$, Guard $= 1 \rightarrow$ `BBG+1`
    - $1.010\underline{0}11 \rightarrow 1.010$, $1.010\underline{1}01 \rightarrow 1.011$
    - $1.010\underline{1}00 \rightarrow 1.010$, $1.011\underline{1}00 \rightarrow 1.100$
- Multiplication
  - $(-1)^{s_1} M_1 2^{E_1} \times (-1)^{s_2} M_2 2^{E_2}$
    $= (-1)^{s_1 \hat{} s_2} (M_1 \times M_2) 2^{E_1 + E_2}$
  - If $M_1 \times M_2 \geq 2$, $M = M_1 \times M_2/2$,$E = E_1 + E_2 + 1$
  - If E out of range, overflow to `inf`
  - Round M to fit `frac` precision

Assembly Basics

- "word" refers to 16-bit data type, "double word" refers to 32-bit (int) and 'quad words" refers to 64-bit
- On 64-bit machines pointers are 8-byte quad words
- In operands, scaling factor s must be either 1, 2, 4, or 8
- `mov S, D` has the effect of $S \rightarrow D$

movq Src, Dest	C Analog
movq $0x4, %rax	tmp = 0x4
movq $-147, (%rax)	*p = -147
movq %rax, %rdx	tmp2 = tmp1
movq %rax, (%rdx)	*p = tmp
movq (%rax), %rdx	tmp = *p

- `movzbq` moves from byte to quad with zero-extended whereas `movsbq` does the same but sign-extended
- `leaq S, D` has the effect of $\&S \rightarrow D$
- `subq S, D` has the effect of $D - S \rightarrow D$
- `salq S, D` has the effect of $D \cdot 2^S \rightarrow D$

Opcodes of arithmetic operations

addq	+	xorq	$\oplus$	salq	also shlq <<		
subq	-	andq	&	sarq	Arithmetic >>		
imulq	$\times$	orq	|	shrq	Logical >>		
incq	++	decq	−−	negq	−	notq	$\sim$

Operands (3 types)

Type	Form	Operand value
Immediate	$\$Imm$	Imm
Register	r_a	$R[r_a]$
Memory	$Imm(r_b, r_i, s)$	M$[Imm + R[r_b] + R[r_i] \cdot s]$

16 general purpose registers storing 64-bit values

Type	64-bits	32-bits	16-bits	8-bits
Registers below are **caller saved**				
Return val	%rax	%eax	%ax	%al
1st arg	%rdi	%edi	%di	%dil
2nd arg	%rsi	%esi	%si	%sil
3rd arg	%rdx	%edx	%dx	%dl
4th arg	%rcx	%ecx	%cx	%cl
5th arg	%r8	%r8d	%r8w	%r8b
6th arg	%r9	%r9d	%r9w	%r9b
Caller	%r10	%r10d	%r10w	%r10b
Caller	%r11	%r11d	%r11w	%r11b
Registers below are **callee saved**				
Callee	%rbx	%ebx	%bx	%bl
Callee	%r12	%r12d	%r12w	%r12b
Callee	%r13	%r13d	%r13w	%r13b
Callee	%r14	%r14d	%r14w	%r14b
Callee	%r15	%r15d	%r15w	%r15b
Callee	%rbp	%ebp	%bp	%bpl
Stack ptr	%rsp	%esp	%sp	%spl

`%rsp` is the **top of the stack** and `%rbp` is the **bottom**

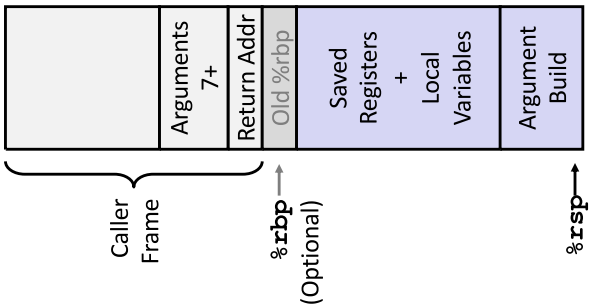
Conditional Control

- Carry flag (`CF`) – most recent op generated carry of most significant bit, detects overflow for unsigned
- Zero flag (`ZF`) – most recent op yielded zero
- Sign flag (`SF`) – most recent op yielded negative value
- Overflow flag (`OF`) – most recent op caused two's complement overflow
- `test` instruction behaves like `and` instructions but sets condition codes without altering source or destination often see `testq %rax,%rax` to check if return val is neg, zero, or pos
- `cmp` instruction behaves like `sub` but sets condition codes without altering source or destination.
- **Switch statement**: jump table stores the address of the target label in an array. jtab[i] $\rightarrow$ codeblock (x==i)

`set D` and `jmp` suffixes

Instruction	Alias.	Cond.	Desc.
`-e`	`-z`	`ZF`	= /0
`-ne`	`-nz`	`~ZF`	! =/not zero
`-s`		`SF`	Neg
`-ns`		`~SF`	Nonneg
`-g`	`-nle`	`~(SF^OF)&~ZF`	signed >
`-ge`	`-nl`	`~(SF^OF)`	signed =>
`-l`	`-nge`	`SF^OF`	signed <
`-le`	`-ng`	`(SF^OF)|ZF`	signed <=
`-a`	`-nbe`	`~CF&~ZF`	unsigned >
`-ae`	`-nb`	`~CF`	unsigned >=
`-b`	`-nae`	`CF`	unsigned <
`-be`	`-na`	`CF|ZF`	unsigned <=

`cmpq B, A`, `jg L1` equals to `if (A > B) goto L1;`
`setne %al` sets `%al` to 1 if not equal, 0 otherwise



Machine Data

Data Alignment: K-byte object at addr multiple of K

Size (bytes)	Types
1	`char`
2	`short`
4	`int, float`
8	`long, double, char *`

Arrays: Element i at address `&A[0] + i * sizeof(type)`

- 1D array access: `movl (%rdx,%rcx,4),%eax` gets `A[%rcx]` for `int A[]`
- 2D row-major: `A[i][j]` at `&A + i*C*s + j*s` for `A[R][C]` with size s
- Multi-level arrays: Array of pointers e.g., `int *A[R]` for jagged arrays

Structs: Fields stored with alignment padding

- K-byte field must be at addr multiple of K
- Field alignment may require padding between fields
- Struct alignment = max alignment of any field
- Struct size = multiple of largest alignment requirement
- Example: `struct {char a; int b; char c;}` →

12 bytes

0	1	2	3	4	5	6	7	8	9	10	11
a	pad			b				c	pad		

- Nested structs: inner struct follows its own alignment rules
- Access field at offset d: `movq d(%rdi),%rax`

Unions: All fields share same memory location

- Size = largest member size
- All fields have offset 0 from base address
- Example: `union {int i; float f; char c[4];}`

occupies 4 bytes total

0	1	2	3
i (4 bytes)			
f (4 bytes)			
c[0]	c[1]	c[2]	c[3]

- Access any member using base address: `movl (%rdi), %eax`
- Used for type punning (e.g., `u.f = 1.0f; bits = u.i`) or memory optimization

GNU Debugger

Running

- `run`: Run the program
- `kill`: Kill the program
- `step`: Go to next line (Source C code)
- `next`: Go to next line (Source C code) but step over function calls
- `stepi`: Go to next instruction (Assembly code)
- `continue`: Continue running
- `finish`: Continue until current function returns

Breakpoints

- `break <where>`:
  - `break <function name>`
  - `break <file>:<line number>`
  - `break *<address>`
- `delete <num>`: eg: `delete 2` to delete breakpoint 2
- `clear`: Delete all breakpoints
- `enable / disable <num>`: Enable or disable
- `info breakpoints / registers / functions / locals / args / displays`

Variables and memory

- `print/format <what>`:
  - `print $register` – print register
  - `print $variable` – print variable
  - `print *(0x<address>)` – print memory
- `x/nfu <address>`:
  - `n`: Number of items to print (default 1)
  - `f`: Format (see below)
  - `u`: Size of each item:
    - `b`: Byte
    - `h`: Halfword (2 bytes)
    - `w`: Word (4 bytes)
    - `g`: Giant (8 bytes)

Format for printing

- `a`: Pointer
- `c`: Read as integer, print as character
- `d`: Integer, signed decimal (10)
- `f`: Floating point number
- `o`: Integer, Octal (8)
- `s`: Try to treat as C string
- `t`: Integer, binary (2)
- `u`: Integer, unsigned decimal (10)
- `x`: Integer, hexadecimal (16)

Initialize for Bomb Lab

```
# Compiling into asm (sum.s)
gcc -Og -S sum.c

# Disassembling Object Code
objdump -d sum > sum.asm

# .gdbinit
break phase_1
break initialize_bomb (send_msg / explode_bomb)
command
jump *(0x4014b9)
end
run ans.txt
```


Created at Wuhan University in Spring 2025
by TonyYin & Pittow2
https://github.com/TonyYin0418/csapp-cheat-sheet
Based on https://git.io/JcZ29