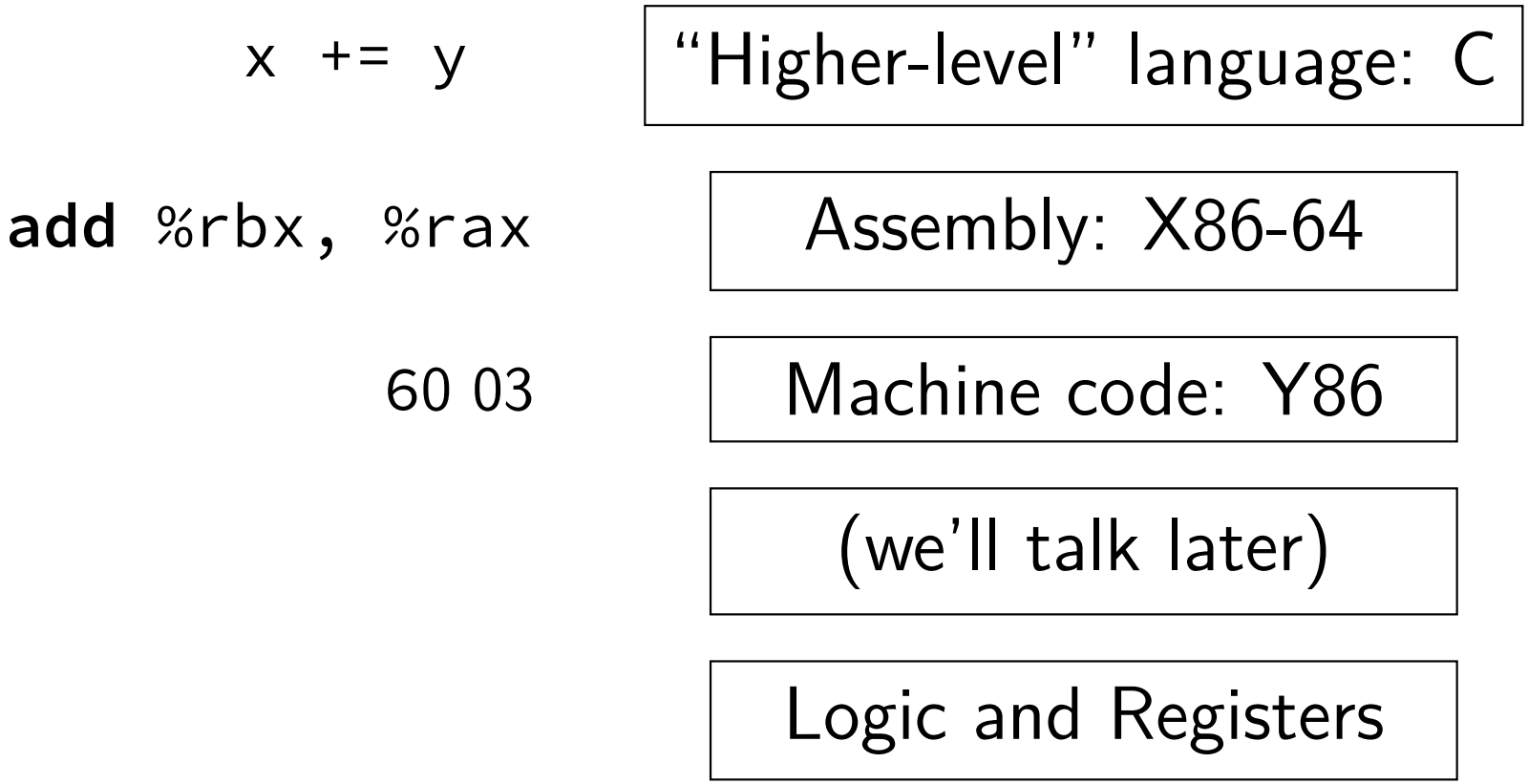
More C

Layers of Abstraction



selected anonymous feedback (1)

"If I finish the first lab before my lab time, do I still have to go?"

No.

"how much extra credit is offered per each phase?"

+2/30 (no explosions) or +1/30 (otherwise)

"Can we get key to previous quizzes?"

Sorry, I don't have a convenient way of getting pre-Fall-2016

Also, there's a small chance we mighty reuse quiz questions

selected anonymous feedback (2)

"The quiz questions are overly difficult, and Lab 1's 20 explosions rule is overly punitive. Bear in mind that some of us only have a few years of CS experience prior to this class."

bomblab notes

`b *0x12345678`

set breakpoint at address `0x12345678`

non-anonymous feedback

Last time

compile / assemble / link

x86-64 review

C data types, lack of bool

pointer arithmetic

arrays and pointers

Arrays and Pointers

`*(foo + bar)` exactly the same as `foo[bar]`

arrays 'decay' into pointers

Arrays: not quite pointers (1)

```
int array[100];
int *pointer;
```

Legal: `pointer = array;`

same as `pointer = &(array[0]);`

Arrays: not quite pointers (1)

```
int array[100];
int *pointer;
```

Legal: `pointer = array;`

same as `pointer = &(array[0]);`

Illegal: ~~`array = pointer;`~~

Arrays: not quite pointers (2)

```
int array[100];
int *pointer = array;

sizeof(array) == 400
```

size of all elements

Arrays: not quite pointers (2)

```
int array[100];
int *pointer = array;

sizeof(array) == 400
```

size of all elements

```
sizeof(pointer) == 8
```

size of address

Arrays: not quite pointers (2)

```
int array[100];
int *pointer = array;
```

`sizeof(array) == 400`

size of all elements

`sizeof(pointer) == 8`

size of address

`sizeof(&array[0]) == ???`

(`&array[0]` same as `&(array[0])`)

initializing array versus pointer

```
const char *pointer = "Hello, World!";
char array[] = "Hello, World!";
```

pointer — probably points to read-only data

array — copy of string (including \0)

Interlude: Command Line Tips

```
cr4bd@reiss-lenovo:~$ man man
```

man man

File Edit View Search Terminal Help

```
MAN(1)                          Manual pager utils                          MAN(1)

NAME
       man - an interface to the on-line reference manuals

SYNOPSIS
       man  [-C  file]  [-d]  [-D]  [--warnings[=warnings]] [-R encoding] [-L locale] [-m sys-
       tem[,...]]  [-M  path]  [-S  list]  [-e  extension]  [-i|-I]  [--regex|--wildcard]
       [--names-only]  [-a]  [-u]  [--no-subpages]  [-P  pager] [-r prompt] [-7] [-E encoding]
       [--no-hyphenation] [--no-justification] [-p  string]  [-t]  [-T[device]]  [-H[browser]]
       [-X[dpi]] [-Z] [[section] page ...] ...
       man -k [apropos options] regexp ...
       man -K [-w|-W] [-S list] [-i|-I] [--regex] [section] term ...
       man -f [whatis options] page ...
       man -l [-C file] [-d] [-D] [--warnings[=warnings]] [-R encoding] [-L locale] [-P pager]
       [-r prompt] [-7] [-E encoding] [-p string] [-t]  [-T[device]]  [-H[browser]]  [-X[dpi]]
       [-Z] file ...
       man -w|-W [-C file] [-d] [-D] page ...
       man -c [-C file] [-d] [-D] page ...
       man [-?V]

DESCRIPTION
       man is the system's manual pager.  Each page argument given to man is normally the name
       of a program, utility or function.  The manual page associated with each of these argu-
       ments  is  then  found  and displayed.  A section, if provided, will direct man to look
       only in that section of the manual.  The default action is to  search  in  all  of  the
       available sections following a pre-defined order ("1 n l 8 3 2 3posix 3pm 3perl 5 4 9 6
       7" by default, unless overridden by the SECTION directive in /etc/manpath.config),  and
       to show only the first page found, even if page exists in several sections.

 Manual page man(1) line 1 (press h for help or q to quit)
```

man man

File Edit View Search Terminal Help

EXAMPLES

man ls
Display the manual page for the item (program) ls.

man -a intro
Display, in succession, all of the available intro manual pages contained within the manual. It is possible to quit between successive displays or skip any of them.

man -t alias | lpr -Pps
Format the manual page referenced by `alias', usually a shell manual page, into the default **troff** or **groff** format and pipe it to the printer named ps. The default output for **groff** is usually PostScript. **man --help** should advise as to which processor is bound to the **-t** option.

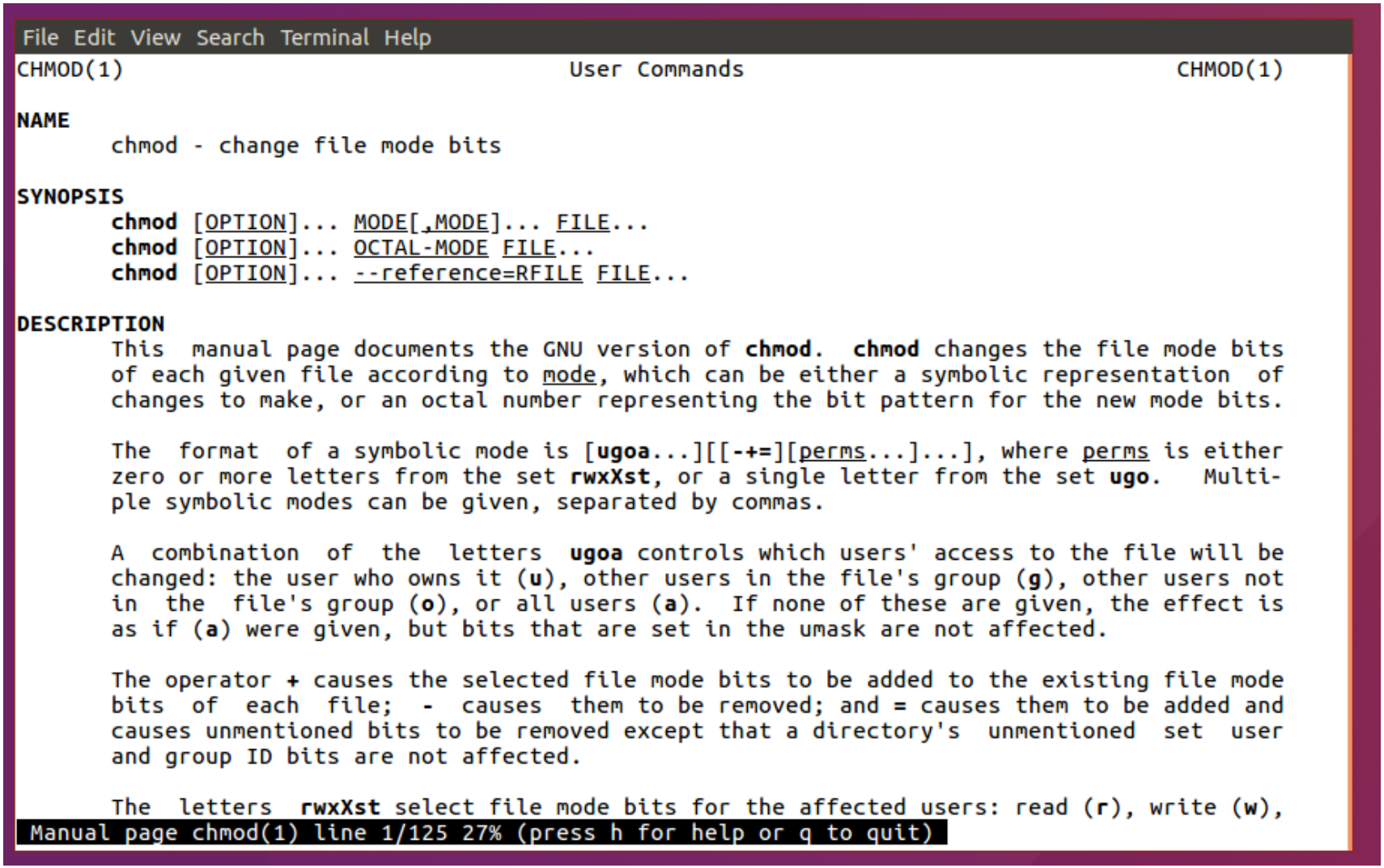
man -l -Tdvi ./foo.1x.gz **>** ./foo.1x.dvi
This command will decompress and format the nroff source manual page ./foo.1x.gz into a **device independent (dvi)** file. The redirection is necessary as the **-T** flag causes output to be directed to **stdout** with no pager. The output could be viewed with a program such as **xdvi** or further processed into PostScript using a program such as **dvips.**

man -k printf
Search the short descriptions and manual page names for the keyword printf as regular expression. Print out any matches. Equivalent to **apropos** printf.

man -f smail
Lookup the manual pages referenced by smail and print out the short descriptions of any found. Equivalent to **whatis** smail.

Manual page man(1) line 68 (press h for help or q to quit)

man chmod


File Edit View Search Terminal Help
CHMOD(1) User Commands CHMOD(1)
NAME
chmod - change file mode bits
SYNOPSIS
chmod [OPTION]... MODE[,MODE]... FILE...
chmod [OPTION]... OCTAL-MODE FILE...
chmod [OPTION]... --reference=RFILE FILE...
DESCRIPTION
This manual page documents the GNU version of chmod. chmod changes the file mode bits of each given file according to mode, which can be either a symbolic representation of changes to make, or an octal number representing the bit pattern for the new mode bits.
The format of a symbolic mode is [ugoa...][[-+=][perms...]...], where perms is either zero or more letters from the set rwxXst, or a single letter from the set ugo. Multiple symbolic modes can be given, separated by commas.
A combination of the letters ugoa controls which users' access to the file will be changed: the user who owns it (u), other users in the file's group (g), other users not in the file's group (o), or all users (a). If none of these are given, the effect is as if (a) were given, but bits that are set in the umask are not affected.
The operator + causes the selected file mode bits to be added to the existing file mode bits of each file; - causes them to be removed; and = causes them to be added and causes unmentioned bits to be removed except that a directory's unmentioned set user and group ID bits are not affected.
The letters rwxXst select file mode bits for the affected users: read (r), write (w),
Manual page chmod(1) line 1/125 27% (press h for help or q to quit)

chmod

```
chmod  --recursive  og-r  /home/USER
```

chmod

```
chmod  --recursive  og-r  /home/USER
```

others and group (student)

– remove

read

chmod

```
chmod  --recursive  og-r  /home/USER
```

user (yourself) / group / others

− remove / + add

read / write / execute or search

tar

the standard Linux/Unix file archive utility

Table of contents: `tar tf filename.tar`

eXtract: `tar xvf filename.tar`

Create: `tar cvf filename.tar directory`

(`v`: verbose; `f`: file — default is tape)

Tab completion and history

Back To C

stdio.h

C does not have `<iostream>`

Instead `<stdio.h>`

stdio

```
cr4bd@power1
: /if22/cr4bd ; man stdio

…
STDIO(3)                  Linux Programmer's Manual                 STDIO(3)

NAME
       stdio - standard input/output library functions

SYNOPSIS
       #include <stdio.h>

       FILE *stdin;
       FILE *stdout;
       FILE *stderr;

DESCRIPTION
       The  standard  I/O  library  provides  a  simple  and  efficient
       buffered stream I/O interface.  Input and output is mapped  into
       logical  data  streams  and the physical I/O characteristics are
       concealed.  The functions and  macros  are  listed  below;  more
       information is available from the individual man pages.
```

stdio

```
STDIO(3)                  Linux Programmer's Manual                 STDIO(3)

NAME
       stdio - standard input/output library functions


…

   List of functions
       Function      Description
       ------------------------------------------------------------
       clearerr      check and reset stream status
       fclose        close a stream


…

       printf        formatted output conversion


…
```

printf

```
int custNo = 1000;
const char *name = "Jane␣Smith"
printf("Customer␣#%d : %s \n",
       custNo , name);
// "Customer #1000: Jane Smith"
// same as:
cout << "Customer␣#" << custNo
     << ":␣" << name << endl;
```

printf

```
int custNo = 1000;
const char *name = "Jane␣Smith"
printf("Customer␣#%d: %s \n",
       custNo, name);
// "Customer #1000: Jane Smith"
// same as:
cout << "Customer␣#" << custNo
     << ":␣" << name << endl;
```

printf

```
int custNo = 1000;
const char *name = "Jane␣Smith"
printf("Customer␣#%d : %s\n",
       custNo , name);
// "Customer #1000: Jane Smith"
// same as:
cout << "Customer␣#" << custNo
     << ":␣" << name << endl;
```

printf

```
int custNo = 1000;
const char *name = "Jane␣Smith"
printf("Customer␣#%d : %s \n",
       custNo , name);
// "Customer #1000: Jane Smith"
// same as:
cout << "Customer␣#" << custNo
     << ":␣" << name << endl;
```

format string must match types of argument

printf formats quick reference

Specifier	Argument Type	Example(s)
%s	char *	Hello, World!
%p	any pointer	0x4005d4
%d	int/short/char	42
%u	unsigned int/short/char	42
%x	unsigned int/short/char	2a
%ld	long	42
%f	double/float	42.000000
		0.000000
%e	double/float	4.200000e+01
		4.200000e-19
%g	double/float	42, 4.2e-19
%%	(no argument)	%

printf formats quick reference

Specifier	Argument Type	Example(s)
%s	char *	Hello, World!
%p	any pointer	0x4005d4
%d	int/short/char	42
%u		
%x		
%ld	long	42
%f	double/float	42.000000
		0.000000
%e	double/float	4.200000e+01
		4.200000e-19
%g	double/float	42, 4.2e-19
%%	(no argument)	%

detailed docs: `man 3 printf`

goto

```
    for (...) {
      for (...) {
        if (thingAt(i, j)) {
          goto found;
        }
      }
    }
    printf("not found!\n");
    return;
found:
    printf("found!\n");
```

goto

```
    for (...) {
      for (...) {
        if (thingAt(i, j)) {
          goto found;
        }
      }
    }
    printf("not found!\n");
    return;
found:
    printf("found!\n");
```

assembly:
`jmp found`

assembly:
`found:`

struct

```
struct rational {
    int numerator;
    int denominator;
};
// ...
struct rational two_and_a_half;
two_and_a_half.numerator = 5;
two_and_a_half.denominator = 2;
struct rational *pointer = &two_and_a_half;
printf("%d/%d\n",
       pointer->numerator,
       pointer->denominator);
```

struct

```
struct rational {
    int numerator;
    int denominator;
};
// ...
struct rational two_and_a_half;
two_and_a_half.numerator = 5;
two_and_a_half.denominator = 2;
struct rational *pointer = &two_and_a_half;
printf("%d/%d\n",
       pointer->numerator,
       pointer->denominator);
```

typedef struct (1)

```
struct other_name_for_rational {
    int numerator;
    int denominator;
};
typedef struct other_name_for_rational rational;
// ...
rational two_and_a_half;
two_and_a_half.numerator = 5;
two_and_a_half.denominator = 2;
rational *pointer = &two_and_a_half;
printf("%d/%d\n",
       pointer->numerator,
       pointer->denominator);
```

typedef struct (1)

```
struct other_name_for_rational {
    int numerator;
    int denominator;
};
typedef struct other_name_for_rational rational;
// ...
rational two_and_a_half;
two_and_a_half.numerator = 5;
two_and_a_half.denominator = 2;
rational *pointer = &two_and_a_half;
printf("%d/%d\n",
       pointer->numerator,
       pointer->denominator);
```

typedef struct (2)

```
struct other_name_for_rational {
    int numerator;
    int denominator;
};
typedef struct other_name_for_rational rational;

// same as:
typedef struct other_name_for_rational {
    int numerator;
    int denominator;
} rational;
```

typedef struct (2)

```
struct other_name_for_rational {
    int numerator;
    int denominator;
};
typedef struct other_name_for_rational rational;

// same as:
typedef struct other_name_for_rational {
    int numerator;
    int denominator;
} rational;
```

typedef struct (2)

```
struct other_name_for_rational {
    int numerator;
    int denominator;
};
typedef struct other_name_for_rational rational;

// same as:
typedef struct other_name_for_rational {
    int numerator;
    int denominator;
} rational;

// almost the same as:
typedef struct {
    int numerator;
    int denominator;
} rational;
```

linked lists / dynamic allocation

```
typedef struct list_t {
    int item;
    struct list_t *next;
} list;
// ...
```

linked lists / dynamic allocation

```
typedef struct list_t {
    int item;
    struct list_t *next;
} list;
// ...
```

linked lists / dynamic allocation

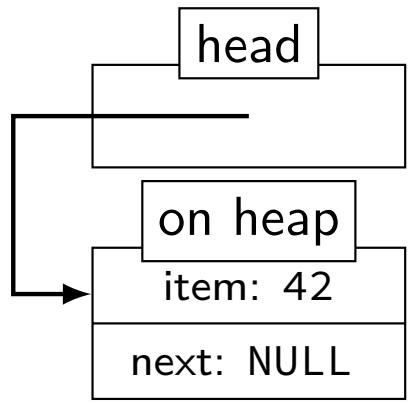
```
typedef struct list_t {
    int item;
    struct list_t *next;
} list;
// ...

  list* head = malloc(sizeof(list));
    /* C++: new list; */
  head->item = 42;
  head->next = NULL;
  // ...
  free(head);
    /* C++: delete list */
```

linked lists / dynamic allocation

```
typedef struct list_t {
    int item;
    struct list_t *next;
} list;
// ...

  list* head = malloc(sizeof(list));
    /* C++: new list; */
  head->item = 42;
  head->next = NULL;
  // ...
  free(head);
    /* C++: delete list */
```

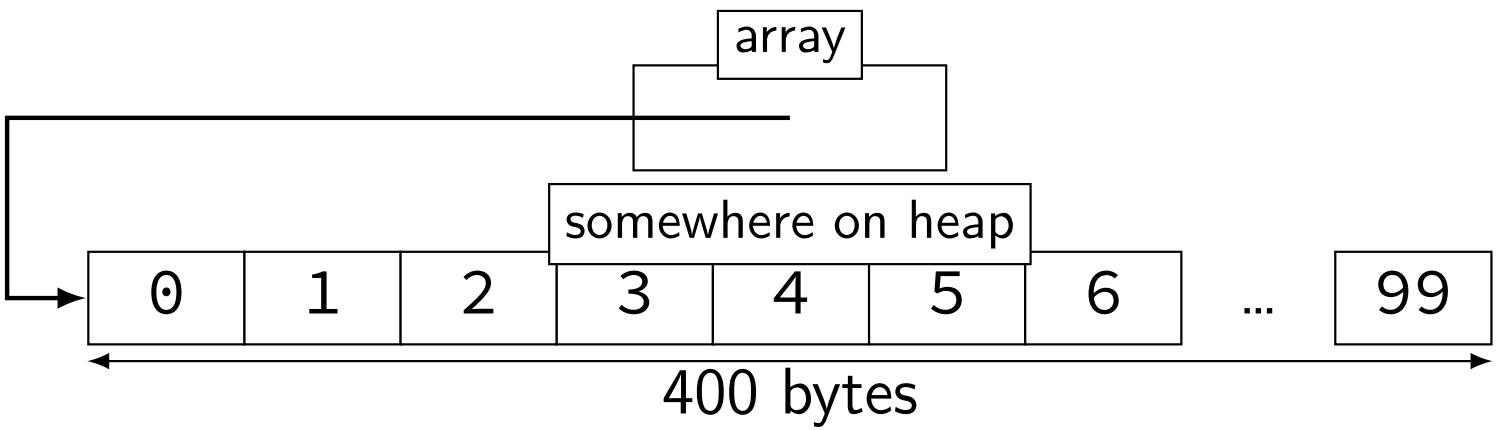


dynamic arrays

```
int *array = malloc(sizeof(int)*100);
  // C++: new int[100]
for (i = 0; i < 100; ++i) {
    array[i] = i;
}
// ...
free(array); // C++: delete[] array
```

dynamic arrays

```
int *array = malloc(sizeof(int)*100);
  // C++: new int[100]
for (i = 0; i < 100; ++i) {
    array[i] = i;
}
// ...
free(array); // C++: delete[] array
```



Miss vector? (1)

```
typedef struct range_t {
    int size;
    int *data;
} range;
```

Miss vector? (1)

```
typedef struct range_t {
    int size;
    int *data;
} range;

range vec;
vec.size = 100;
vec.data = malloc(sizeof(int) * 100);
// like: vector<int> vec(100);
```

Miss vector? (2)

```
typedef struct range_t {
    int size;
    int *data;
} range;

range vec2;
vec2.size = vec.size;
vec2.data = malloc(sizeof(int) * vec.size);
for (int i = 0; i < vec.size; ++i) {
    vec2.data[i] = vec.data[i];
}
// like: vector<int> vec2 = vec;
```

Miss vector? (2)

```
typedef struct range_t {
    int size;
    int *data;
} range;

range vec2;
vec2.size = vec.size;
vec2.data = malloc(sizeof(int) * vec.size);
for (int i = 0; i < vec.size; ++i) {
    vec2.data[i] = vec.data[i];
}
// like: vector<int> vec2 = vec;
```

Why not `range vec2 = vec`?

unsigned and signed types

type	min	max
`signed int` = `signed` = `int`	-2^{31}	$2^{31}-1$
`unsigned int` = `unsigned`	0	$2^{32}-1$
`signed long` = `long`	-2^{63}	$2^{63}-1$
`unsigned long`	0	$2^{64}-1$

⋮

unsigned/signed comparison trap

```
int x = -1;
unsigned int y = 0;
printf("%d\n", x < y);
```

unsigned/signed comparison trap

```
int x = -1;
unsigned int y = 0;
printf("%d\n", x < y);
```

result is 0

unsigned/signed comparison trap

```
int x = -1;
unsigned int y = 0;
printf("%d\n", x < y);
```

result is `0`

short solution: don't compare signed to unsigned:

```
(long) x < (long) y
```

```
int x = -1;
unsigned int y = 0;
printf("%d\n", x < y);
```

compiler converts both to same type first

`int` if all possible values fit

otherwise: first operand (x, y) type from this list:

`unsigned long`
`long`
`unsigned int`
`int`

C evolution and standards

1978: Kernighan and Ritchie publish *The C Programming Language* — "K&R C"

very different from moderm C

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- compiler option: `-ansi`, `-std=c90`
- looks mostly like modern C

C evolution and standards

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- very different from moderm C

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- compiler option: `-ansi`, `-std=c90`
- looks mostly like modern C

1999: ISO (and ANSI) update C standard — C99

- compiler option: `-std=c99`
- adds: declare variables in middle of block
- adds: `//` comments

C evolution and standards

1978: Kernighan and Ritchie publish *The C Programming Language* — "K&R C"

- very different from moderm C

1989: ANSI standardizes C — C89/C90/`-ansi`

- compiler option: `-ansi`, `-std=c90`
- looks mostly like modern C

1999: ISO (and ANSI) update C standard — C99

- compiler option: `-std=c99`
- adds: declare variables in middle of block
- adds: `//` comments

2011: Second ISO update — C11

Middle of blocks?

Examples of things not allowed in 1989 ANSI C:

```
printf("Before calling malloc()\n");
int *pointer = malloc(sizeof(int) * 100);


for (int x = 0; x < 10; ++x)
```

undefined behavior example (1)

```
#include <stdio.h>
#include <limits.h>
int test(int number) {
    return (number + 1) > number;
}

int main(void) {
    printf("%d\n", test(INT_MAX));
}
```

undefined behavior example (1)

```
#include <stdio.h>
#include <limits.h>
int test(int number) {
    return (number + 1) > number;
}

int main(void) {
    printf("%d\n", test(INT_MAX));
}
```

without optimizations: `0`

undefined behavior example (1)

```
#include <stdio.h>
#include <limits.h>
int test(int number) {
    return (number + 1) > number;
}

int main(void) {
    printf("%d\n", test(INT_MAX));
}
```

without optimizations: `0`

with optimizations: `1`

undefined behavior example (2)

```
int test(int number) {
    return (number + 1) > number;
}
```

Optimized:

```
test:
    movl    $1, %eax        ; eax ← 1
    ret
```

Less optimized:

```
test:
    leal    1(%rdi), %eax ; eax ← rdi + 1
    cmpl    %eax, %edi
    setl    %al           ; al ← eax < edi
    movzbl  %al, %eax     ; eax ← al
    ret
```

undefined behavior

compilers can do whatever they want

- what you expect
- crash your program
- ...

common types:

- signed integer overflow/underflow
- out-of-bounds pointers
- integer divide-by-zero
- writing read-only data
- out-of-bounds shift (later)

undefined versus varies

size of types is not undefined behavior

even though it varies between compilers

undefined behavior

- is inconsistent — even within same program
- need not be documented

Bit-twiddling

some truth tables

AND	**0**	**1**
0	0	0
1	0	1

&&, &

OR	**0**	**1**
0	0	1
1	1	1

||, |

XOR	**0**	**1**
0	0	1
1	1	0

(nothing), ^

Logical Operators

Treat value as true (1) or false (0)

Recall: false = 0 (only)

```
  1  &&  1   ==  1          1  ||  1   ==  1
  2  &&  4   ==  1          2  ||  4   ==  1
  1  &&  0   ==  0          1  ||  0   ==  1
  0  &&  0   ==  0          0  ||  0   ==  0
 -1  &&  -2  ==  1         -1  ||  -2  ==  1
 ""  &&  ""  ==  1         ""  ||  ""  ==  1
```

Short-Circuit (&&)

```c
#include <stdio.h>
int zero() { printf("zero()\n"); return 0; }
int one() { printf("one()\n"); return 1; }
int main() {
    printf("> %d\n", zero() && one());
    printf("> %d\n", one() && zero());
    return 0;
}
```

```
zero()
> 0
one()
zero()
> 0
```

AND	**0**	**1**
0	0	0
1	0	1

Short-Circuit (&&)

```
1 #include <stdio.h>
2 int zero() { printf("zero()\n"); return 0; }
3 int one() { printf("one()\n"); return 1; }
4 int main() {
5     printf("> %d\n", zero() && one());
6     printf("> %d\n", one() && zero());
7     return 0;
8 }
```

```
zero()
> 0
one()
zero()
> 0
```

AND	**0**	**1**
0	0	0
1	0	1

Short-Circuit (&&)

```c
#include <stdio.h>
int zero() { printf("zero()\n"); return 0; }
int one() { printf("one()\n"); return 1; }
int main() {
    printf("> %d\n", zero() && one());
    printf("> %d\n", one() && zero());
    return 0;
}
```

```
zero()
> 0
one()
zero()
> 0
```

AND	**0**	**1**
0	0	0
1	0	1

Short-Circuit (&&)

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#include <stdio.h>
int zero() { printf("zero()\n"); return 0; }
int one() { printf("one()\n"); return 1; }
int main() {
    printf("> %d\n", zero() && one());
    printf("> %d\n", one() && zero());
    return 0;
}
```

```
zero()
> 0
one()
zero()
> 0
```

AND	**0**	**1**
0	0	0
1	0	1

Short-Circuit (&&)

```
1 #include <stdio.h>
2 int zero() { printf("zero()\n"); return 0; }
3 int one() { printf("one()\n"); return 1; }
4 int main() {
5     printf("> %d\n", zero() && one());
6     printf("> %d\n", one() && zero());
7     return 0;
8 }
```

```
zero()
> 0
one()
zero()
> 0
```

AND	**0**	**1**
0	0	0
1	0	1

Short-Circuit (||)

```c
#include <stdio.h>
int zero() { printf("zero()\n"); return 0; }
int one() { printf("one()\n"); return 1; }
int main() {
    printf("> %d\n", zero() || one());
    printf("> %d\n", one() || zero());
    return 0;
}
```

```
zero()
one()
> 1
one()
> 1
```

OR	**0**	**1**
0	0	1
1	1	1

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    return 0;
}
```

```
zero()
one()
> 1
one()
> 1
```

OR	**0**	**1**
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```
zero()
one()
> 1
one()
> 1
```

OR	**0**	**1**
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Short-Circuit (||)

```c
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    return 0;
}
```

```
zero()
one()
> 1
one()
> 1
```

OR	**0**	**1**
0	0	1
1	1	1

Short-Circuit (||)

```c
#include <stdio.h>
int zero() { printf("zero()\n"); return 0; }
int one() { printf("one()\n"); return 1; }
int main() {
    printf("> %d\n", zero() || one());
    printf("> %d\n", one() || zero());
    return 0;
}
```

```
zero()
one()
> 1
one()
> 1
```

OR	**0**	**1**
0	0	1
1	1	1

Bitwise AND — &

Treat value as array of bits

```
1 & 1 == 1

1 & 0 == 0

0 & 0 == 0

2 & 4 == 0

10 & 7 == 2
```

Bitwise AND — &

Treat value as array of bits

```
1 & 1 == 1

1 & 0 == 0

0 & 0 == 0

2 & 4 == 0

10 & 7 == 2
```

```
      …  0  0  1  0
&     …  0  1  0  0
-------------------
      …  0  0  0  0
```

Bitwise AND — &

Treat value as array of bits

```
1 & 1 == 1

1 & 0 == 0

0 & 0 == 0

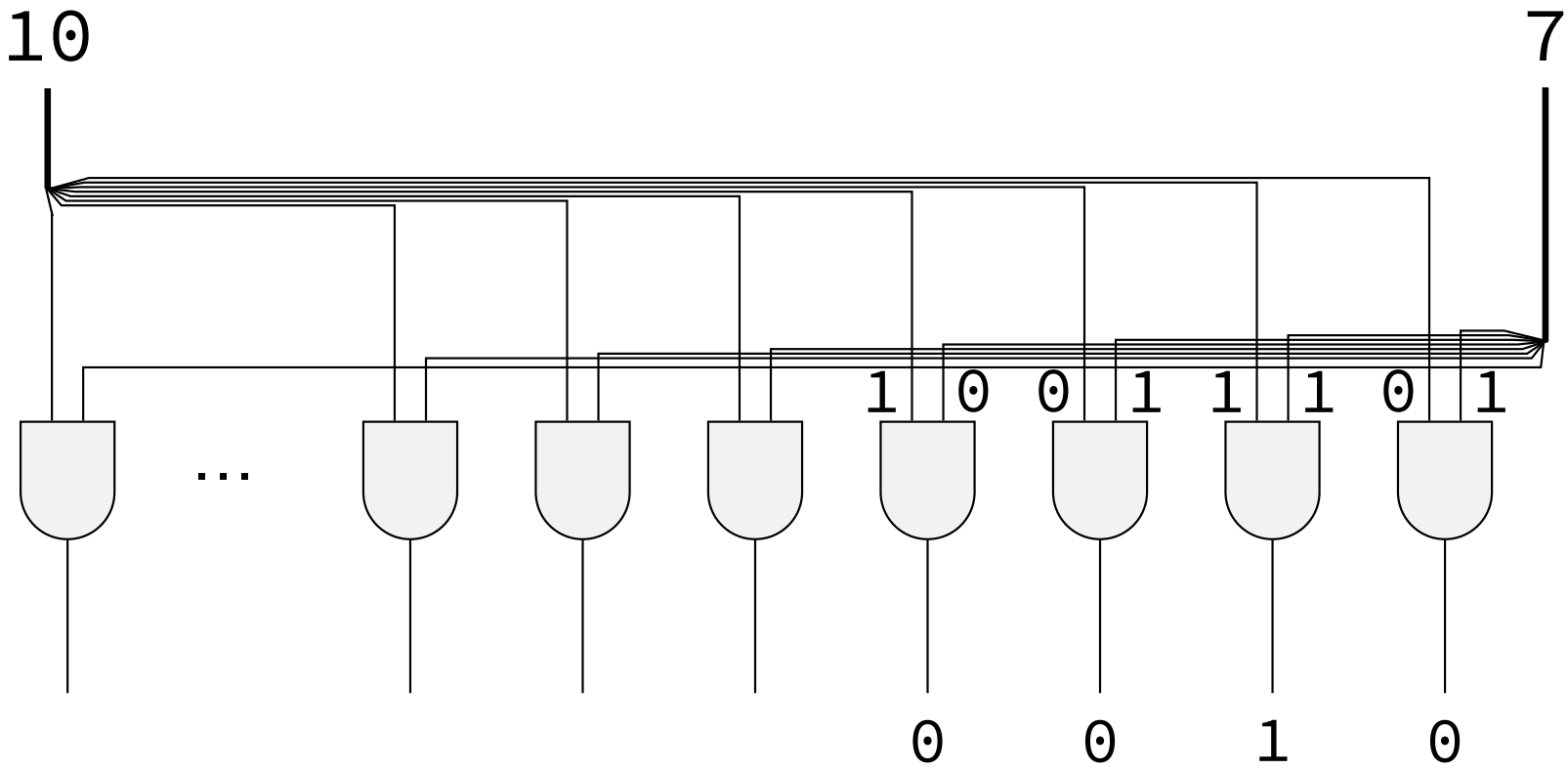
2 & 4 == 0

10 & 7 == 2
```

```
    …  0  0  1  0
&   …  0  1  0  0
-------------------
    …  0  0  0  0
```

```
    …  1  0  1  0
&   …  0  1  1  1
-------------------
    …  0  0  1  0
```

Bitwise hardware (`10 & 7 == 2`)



Bitwise OR — |

```
1 | 1 == 1

1 | 0 == 1

0 | 0 == 0

2 | 4 == 6

10 | 7 == 15
```

Bitwise OR — |

```
1 | 1 == 1

1 | 0 == 1

0 | 0 == 0

2 | 4 == 6

10 | 7 == 15
```

```
      … 0 0 1 0
  |   … 0 1 0 0
-------------------
      … 0 1 1 0
```

Bitwise OR — |

```
1 | 1 == 1

1 | 0 == 1

0 | 0 == 0

2 | 4 == 6

10 | 7 == 15
```

```
    … 0 0 1 0
|   … 0 1 0 0
-------------
    … 0 1 1 0
```

```
    … 1 0 1 0
|   … 0 1 1 1
-------------
    … 1 1 1 1
```

Bitwise xor — ^

```
1 ^ 1 == 0

1 ^ 0 == 1

0 ^ 0 == 0

2 ^ 4 == 6

10 ^ 7 == 13
```

```
      … 0 0 1 0
^     … 0 1 0 0
-------------
      … 0 1 1 0
```

```
      … 1 0 1 0
^     … 0 1 1 1
-------------
      … 1 1 0 1
```

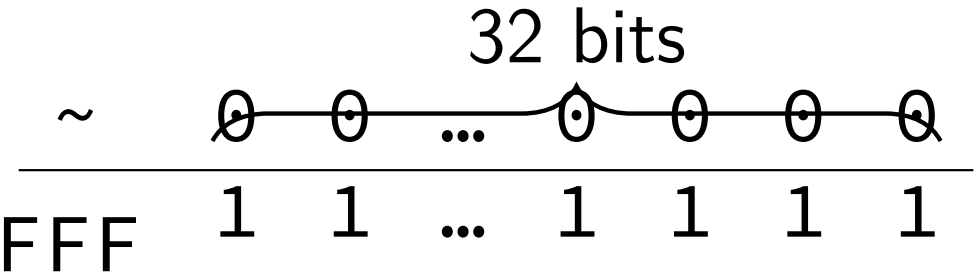
Negation / Not — ~

~ (‘complement’) is bitwise version of `!`:

```
!0 == 1

!notZero == 0

~0 == (int) 0xFFFFFFFF
```



Two's complement refresher

$$-1 = \begin{array}{cccccccc} -2^{31} & +2^{30} & +2^{29} & & +2^{2} & +2^{1} & +2^{0} \\ 1 & 1 & 1 & \ldots & 1 & 1 & 1 \end{array}$$

Two's complement refresher

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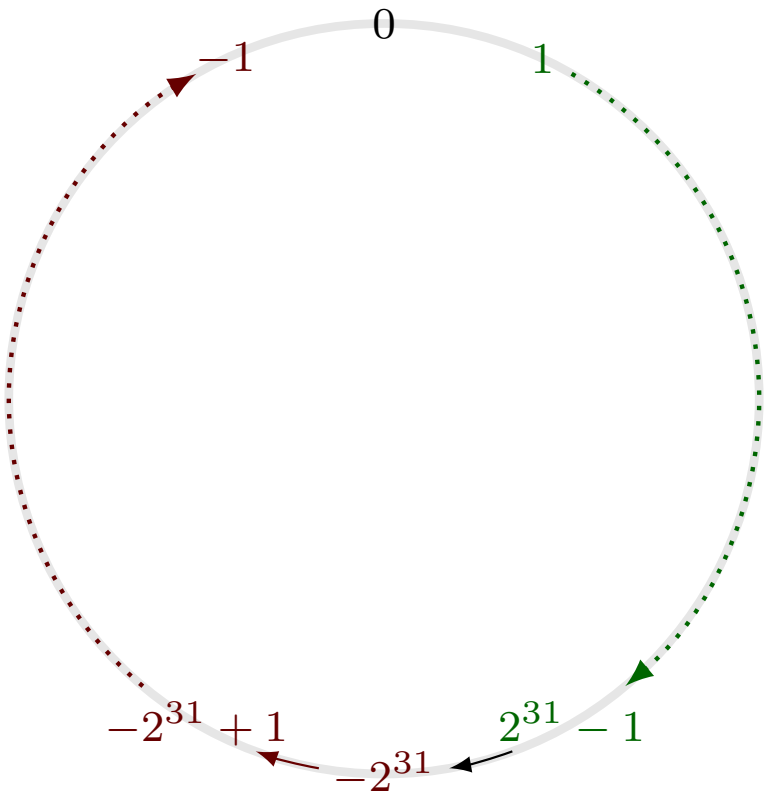
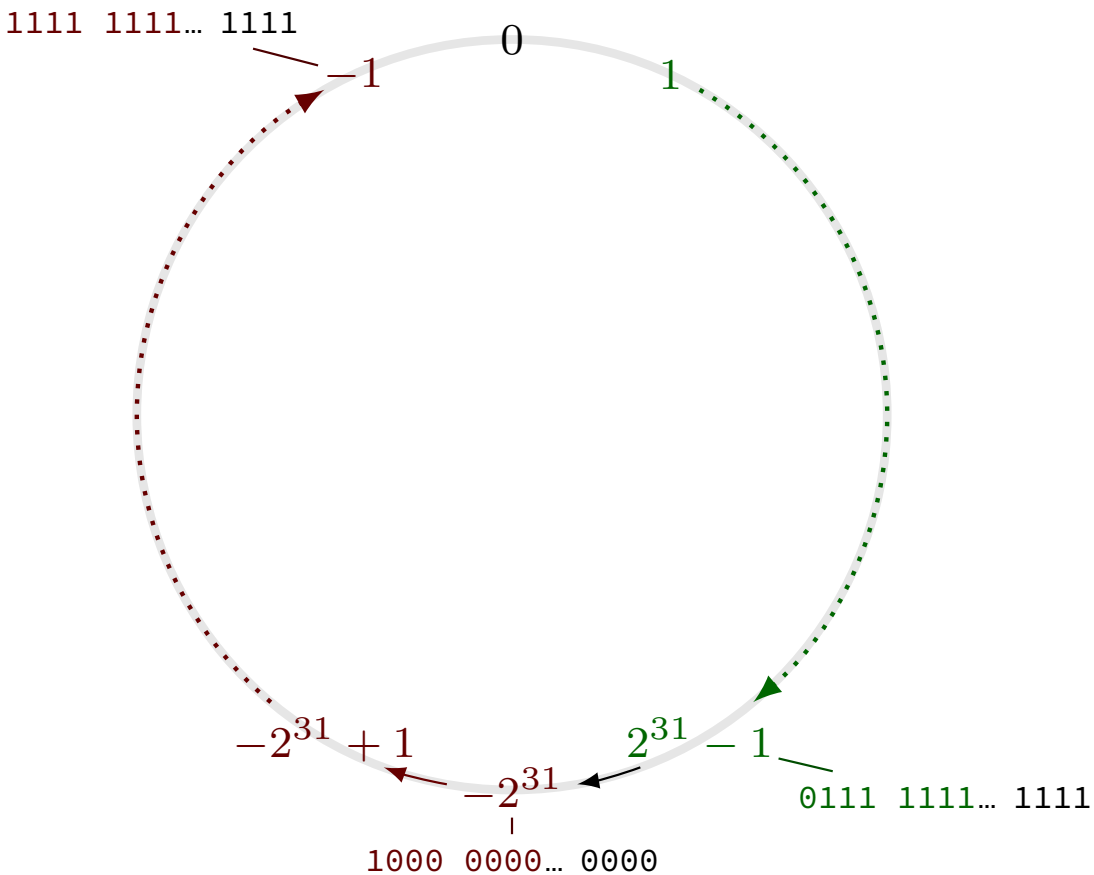


Two's complement refresher

$$-1 = \begin{array}{cccccccc} -2^{31} & +2^{30} & +2^{29} & & +2^{2} & +2^{1} & +2^{0} \\ 1 & 1 & 1 & \ldots & 1 & 1 & 1 \end{array}$$



Two's Complement and ~

`-x == ~x + 1` (flip the bits and add one)

Two's Complement and ~

`-x == ~x + 1` (flip the bits and add one)

`-x - 1 == ~x`

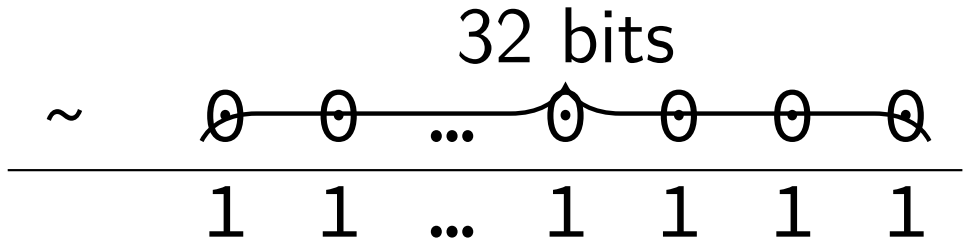
Negation / Not — ~

~ (‘complement’) is bitwise version of `!`:

```
!0 == 1

!notZero == 0

~0 == -1
```



Negation / Not — ~

~ (‘complement’) is bitwise version of `!`:

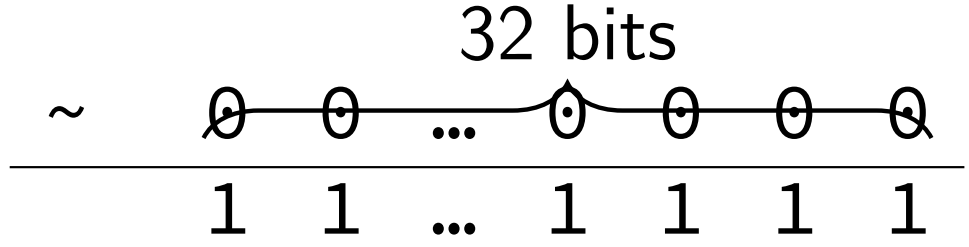
```
!0 == 1

!notZero == 0

~0 == −1

~2 == −3

~−7 == 6
```



Negation / Not — ~

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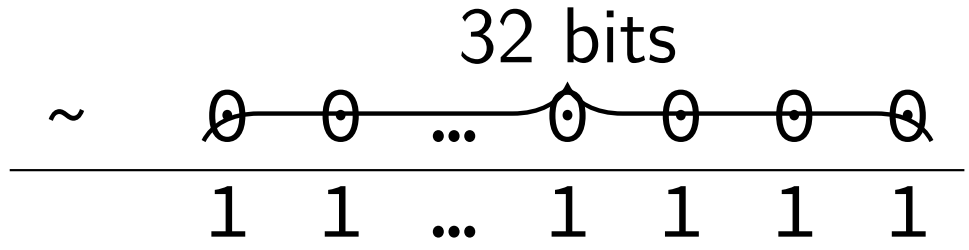


```
~((unsigned) 2) == 0xFFFFFFFD
```

Left shift

```
1 << 0 == 1          0000 0001
1 << 1 == 2          0000 0010
1 << 2 == 4          0000 0100

10 << 0 == 10        0000 1010
10 << 1 == 20        0001 0100
10 << 2 == 40        0010 1000
```

Left shift

```
1 << 0 == 1          0000 0001
1 << 1 == 2          0000 0010
1 << 2 == 4          0000 0100

10 << 0 == 10        0000 1010
10 << 1 == 20        0001 0100
10 << 2 == 40        0010 1000
```

$$x << y = x \times 2^y$$

Right shift

Undefined: ~~x <<= 1~~ Instead: `x >> 1`

```
1 >> 0 == 1          0000 0001
1 >> 1 == 0          0000 0000
1 >> 2 == 0          0000 0000

10 >> 0 == 10        0000 1010
10 >> 1 == 5         0000 0101
10 >> 2 == 2         0000 0010
```

Right shift

Undefined: ~~`x << -1`~~ Instead: `x >> 1`

```
1 >> 0 == 1          0000 0001
1 >> 1 == 0          0000 0000
1 >> 2 == 0          0000 0000

10 >> 0 == 10        0000 1010
10 >> 1 == 5         0000 0101
10 >> 2 == 2         0000 0010
```

$$x >> y = \lfloor x \times 2^{-y} \rfloor$$

Shifts and negative numbers

`-10 >> 1 == ???` (-10 = `1111 … 1111 0110`)

binary `?111 … 1111 1011`

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Option 1: binary `1111 … 1011` = $-5 = -10 \times 2^{-k}$

copy sign bit

Option 2: binary `0111 … 1011` = $2^{31} - 5$

always use zero

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arithmetic

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logical

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Option 1: binary `1111 … 1011` = $-5 = -10 \times 2^{-k}$

copy sign bit

arithmetic

Option 2: binary `0111 … 1011` = $2^{31} - 5$

always use zero

logical

Aside: implementation-defined behavior

C standard: negative `>> 1` is implementation-defined

compiler chooses

Arithmetic shift

```
−1 >> 0 == −1          1111 1111
−1 >> 1 == −1          1111 1111
−1 >> 2 == −1          1111 1111

−10 >> 0 == −10        1111 0110
−10 >> 1 == −5         1111 1011
−10 >> 2 == −3         1111 1101

10 >> 2 == 2           0000 0010
```

$$x >> y = \lfloor x \times 2^{-y} \rfloor$$

Arithmetic shift

```
−1 >> 0 == −1          1111 1111
−1 >> 1 == −1          1111 1111
−1 >> 2 == −1          1111 1111

−10 >> 0 == −10        1111 0110
−10 >> 1 == −5         1111 1011
−10 >> 2 == −3         1111 1101

10 >> 2 == 2           0000 0010
```

$$x \texttt{ >> } y = \lfloor x \times 2^{-y} \rfloor$$

signed versus unsigned types

```
/*signed*/ int x = -10;
/* arithmetic: */
x >> 1 == -5
x >> 4 == -1

unsigned int y = 0xFFFFFFF6;
/* logical */
y >> 1 == 0x7FFFFFFB
y >> 4 == 0x0FFFFFFF
```

Sign-extension vs. zero-extension

```
signed char x = -10;     //          1111 0110
int y = x;               // 1111.. 1111 0110
printf("%d\n", y);       // outputs "-10"

unsigned char x = 0xF6; //          1111 0110
int y = x;               // 0000.. 1111 0110
printf("%d\n", y);       // outputs "246"
```

Aside: integer promotions

```
unsigned short number = 1;
unsigned short offset = 20;
printf("0x%x\n", number << offset);
```

Outputs (on lab machines)?

A. `0x100000` (2^{20})

B. `0x0`

C. Undefined behavior — varies

Aside: integer promotions

```
unsigned short number = 1;
unsigned short offset = 20;
printf("0x%x\n", number << offset);
```

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Aside: integer promotions

```
unsigned short number = 1;
unsigned short offset = 20;
printf("0x%x\n", number << offset);
```

Outputs (on lab machines)?

A. `0x100000` (2^{20})

B. `0x0`

C. Undefined behavior — varies

integers types smaller than **`int`** converted to **`int`**

Shifts: undefined behavior

`0 >> 32` is undefined behavior

`0 << 32` is undefined behavior

`(long) 0 << 32` is okay

`(long) 0 << 64` is undefined behavior

Summary

`struct` — functionless classes

`typedef struct` or write **`struct`** `typeName`

`malloc`, `free` instead of new/delete.

undefined behavior — who knows what'll happen

logical operators — &&, ||, !: only care if 0/not 0

bitwise operators — &, |, ^, ~: all bits in parallel

Summary

`struct` — functionless classes

`typedef struct` or write **`struct`** `typeName`

`malloc`, `free` instead of new/delete.

undefined behavior — who knows what'll happen

logical operators — &&, ||, !: only care if 0/not 0

bitwise operators — &, |, ^, ~: all bits in parallel

bitshift — <<, >>: same as multiplying by $2^{\pm x}$

arithmetic right shift — borrow sign bit

Backup Slides

What's in those files?

hello.c

```
#include <stdio.h>
int main(void) {
  puts("Hello, World!");
  return 0;
}
```

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hello.s

```
    .text
main:
    sub  $8, %rsp
    mov  .Lstr, %rdi
    call puts
    xor  %eax, %eax
    add  $8, %rsp
    ret

    .data
.Lstr: .string "Hello, World!"
```

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hello.o

text (code) segment:

```
48 83 EC 08 BF 00 00 00 00 E8 00 00
00 00 31 C0 48 83 C4 08 C3
```

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data segment:

```
48 65 6C 6C 6F 2C 20 57 6F 72 6C 00
```

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    call puts
    xor  %eax, %eax
    add  $8, %rsp
    ret

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.Lstr: .string "Hello, World!"
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48 83 EC 08 BF 00 00 00 00 E8 00 00
00 00 31 C0 48 83 C4 08 C3
```

data segment:

```
48 65 6C 6C 6F 2C 20 57 6F 72 6C 00
```

relocations:

take 0s at	*and replace with*
text, byte 6 ( )	data segment, byte 0
text, byte 10 ( )	address of puts

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    xor  %eax, %eax
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```
48 83 EC 08 BF 00 00 00 00 E8 00 00
00 00 31 C0 48 83 C4 08 C3
```

data segment:

```
48 65 6C 6C 6F 2C 20 57 6F 72 6C 00
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relocations:

take 0s at	*and replace with*
text, byte 6 ( )	data segment, byte 0
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symbol table:

main	text byte 0

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int main(void) {
  puts("Hello, World!");
  return 0;
}
```

hello.s

```
    .text
main:
    sub  $8, %rsp
    mov  .Lstr, %rdi
    call puts
    xor  %eax, %eax
    add  $8, %rsp
    ret

    .data
.Lstr: .string "Hello, World!"
```

hello.o

text (code) segment:

```
48 83 EC 08 BF 00 00 00 00 E8 00 00
00 00 31 C0 48 83 C4 08 C3
```

data segment:

```
48 65 6C 6C 6F 2C 20 57 6F 72 6C 00
```

relocations:

take 0s at	*and replace with*
text, byte 6 ( )	data segment, byte 0
text, byte 10 ( )	address of puts

symbol table:

main	text byte 0

+ stdio.o

hello.exe

What's in those files?

hello.c

```
#include <stdio.h>
int main(void) {
  puts("Hello, World!");
  return 0;
}
```

hello.s

```
    .text
main:
    sub  $8, %rsp
    mov  .Lstr, %rdi
    call puts
    xor  %eax, %eax
    add  $8, %rsp
    ret

    .data
.Lstr: .string "Hello, World!"
```

hello.o

text (code) segment:

```
48 83 EC 08 BF 00 00 00 00 E8 00 00
00 00 31 C0 48 83 C4 08 C3
```

data segment:

```
48 65 6C 6C 6F 2C 20 57 6F 72 6C 00
```

relocations:

take 0s at	*and replace with*
text, byte 6 ( )	data segment, byte 0
text, byte 10 ( )	address of puts

symbol table:

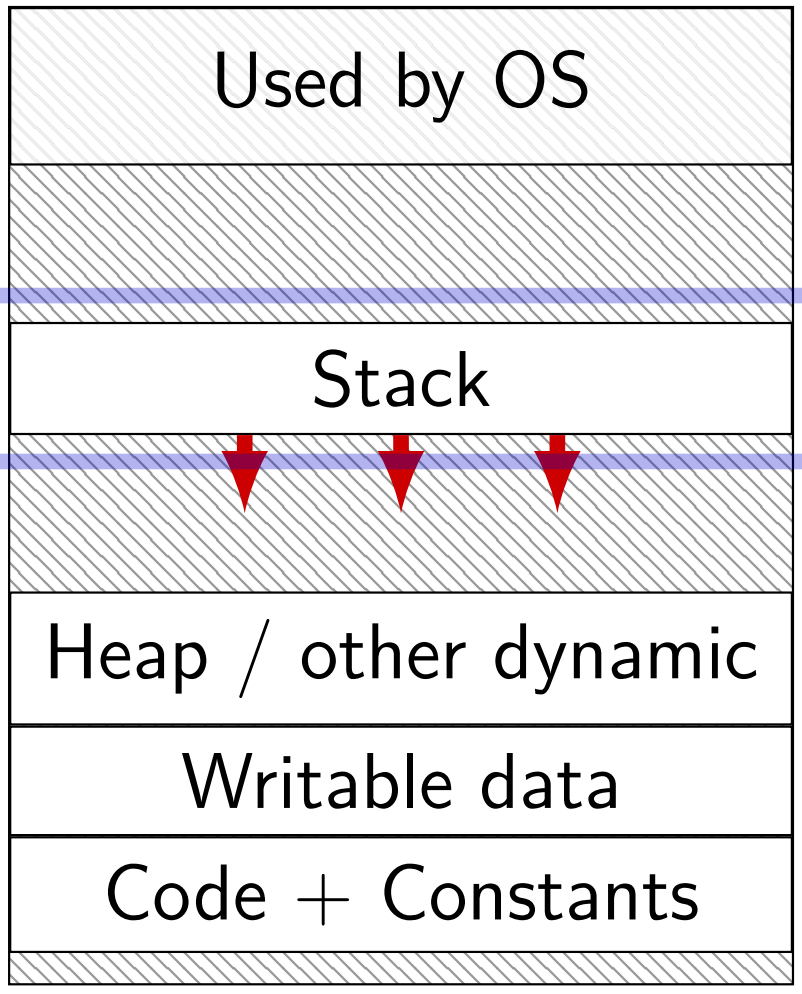
main	text byte 0

+ stdio.o

hello.exe

```
48 83 EC 08 BF A7 02 04 00
E8 08 4A 04 00 31 C0 48
83 C4 08 C3 ...
...(code from stdio.o) ...
48 65 6C 6C 6F 2C 20 57 6F
72 6C 00 ...
...(data from stdio.o) ...
```

Program Memory (x86-64 Linux)



0xFFFF FFFF FFFF FFFF

0xFFFF 8000 0000 0000

0x7F…

stack grows down

"top" has smallest address

0x0000 0000 0040 0000

Arrays: not quite pointers (1)

```
int array[100];
int *pointer;
```

Legal: `pointer = array;`

same as `pointer = &(array[0]);`

Arrays: not quite pointers (1)

```
int array[100];
int *pointer;
```

Legal: `pointer = array;`

same as `pointer = &(array[0]);`

Illegal: ~~`array = pointer;`~~

Arrays: not quite pointers (2)

```
int array[100];
int *pointer = array;

sizeof(array) == 400
```

size of all elements

Arrays: not quite pointers (2)

```
int array[100];
int *pointer = array;

sizeof(array) == 400
```

size of all elements

```
sizeof(pointer) == 8
```

size of address

Arrays: not quite pointers (2)

```
int array[100];
int *pointer = array;

sizeof(array) == 400
```

size of all elements

```
sizeof(pointer) == 8
```

size of address

```
sizeof(&array[0]) == ???
```

(`&array[0]` same as `&(array[0])`)

chmod

```
chmod --recursive og-r /home/USER
```

chmod

```
chmod --recursive og-r /home/USER
```

others and group (student)

– remove

read

chmod

```
chmod --recursive og-r /home/USER
```

user (yourself) / group / others

− remove / + add

read / write / execute or search

tar

the standard Linux/Unix file archive utility

Table of contents: `tar tf filename.tar`

eXtract: `tar xvf filename.tar`

Create: `tar cvf filename.tar directory`

(`v`: verbose; `f`: file — default is tape)