Introduction to the C Programming Language

Marius Hillenbrand
Operating Systems Group, Department of Computer Science

Introduction

- C
  - A general-purpose language
  - Developed beginning of 1970s
  - Designed for implementing system software
  - Widely used programming language
- Notable properties
  - Procedural language
  - Not type-safe, memory access and addressing via pointers
  - Compound operators (`++, --, +=, >>=, …`)
  - Compact notation:

```
int c=0,b;
while((b=fgetc(f))!=EOF)c+=(b==10)?1:0;
fseek(f,0,SEEK_SET);
```

Why C ?

- C is
  - Stonehenge

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Why C ?

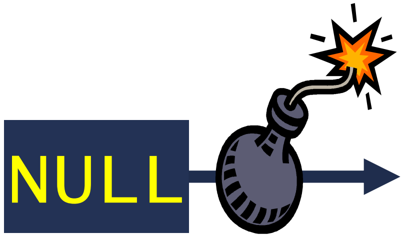
- Yes, *that* old.

- Exercise: Read up on the history of C

Why C ?

- C is
  - Stonehenge
  - not type-safe
  - not object-oriented
  - error-prone and tedious

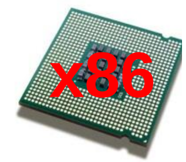
  - … PHP, Python, Java, Scala, C++, C#, Groovy, sooo much better

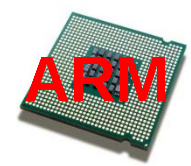


Why C ?

- But C is also
  - powerful
  - efficient
  - close to the machine
  - standards-compatible, portable
  - widely used for
    - OSes, embedded systems
    - libraries
    - anywhere where (space/time) efficiency matters
  - foundation for many follow-on languages (C++, C#, Java)











Introduction / Getting Help

- This lecture is NOT a complete reference to C.
- I assume you already know some Java or C.
- During assignments, get help as you need:
  - Library calls/ system calls, parameters, return values
  - UNIX man(ual) page. Start with `man man`.
  - man page sections (`man 1 ls`):
    - 1 commands (`ls, gcc, gdb`)
    - 2 system calls (`read, gettimeofday`)
    - 3 library calls (`printf, scanf`)
    - 5 file formats (`passwd`)
    - 7 miscellaneous (`signal`)
  - Search for man-pages: `apropos <word>`.

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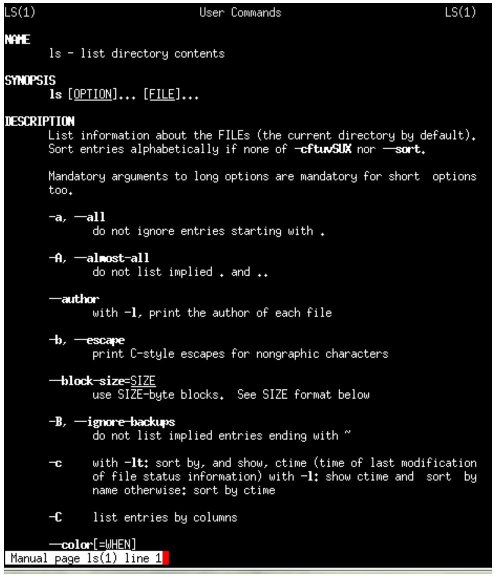


```
LS(1)                      User Commands                      LS(1)

NAME
       ls - list directory contents

SYNOPSIS
       ls [OPTION]... [FILE]...

DESCRIPTION
       List information about the FILEs (the current directory by default).
       Sort entries alphabetically if none of -cftuvSUX nor --sort.

       Mandatory arguments to long options are mandatory for short  options
       too.

       -a, --all
              do not ignore entries starting with .

       -A, --almost-all
              do not list implied . and ..

       --author
              with -l, print the author of each file

       -b, --escape
              print C-style escapes for nongraphic characters

       --block-size=SIZE
              use SIZE-byte blocks.  See SIZE format below

       -B, --ignore-backups
              do not list implied entries ending with ~

       -c     with -lt: sort by, and show, ctime (time of last modification
              of file status information) with -l: show ctime and  sort  by
              name otherwise: sort by ctime

       -C     list entries by columns

       --color[=WHEN]
Manual page ls(1) line 1
```

Getting Help

- C syntax/semantics
  - "The C Programming Language" by Kernighan and Ritchie ("K& R")
- Thorough guide to UNIX programming
  - "Advanced Programming in the UNIX Environment" by Stevens and Rago.
- KIT library has 35 copies of both books

Hello World!

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

- `#include` preprocessor (inserts contents of file).
- `stdio.h` contains the declaration of printf.
- `main` program starts here.
- `void` keyword for absence of arguments
- `{ }` basic blocks / scope delimiters.
- `printf` prints to the terminal.
- `‘\n’:` newline character.
- `return` leave function, give return value.

Compiling and running Hello World!

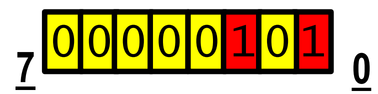
```
$ gcc helloworld.c -o helloworld
$ ./helloworld
Hello World!
```

- Compilation:
  - Generating binary executable from source code
  - Comprises two main steps (besides preprocessor)
    - Generating binary object file for each source code file
    - Linking binary object files, resolving all addresses
- Execution
  - Operating system launches binary executable
  - Contains processor instructions (arch-specific, eg. x86)
  - May load libraries as needed

Basic Data Types

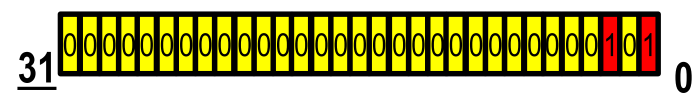
```
char c = 5; char c = ‘a’;
```

- char: one byte, usually for characters
  (1970: ASCII was fine)



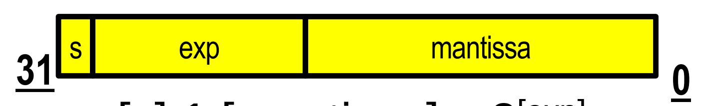

```
int i = 5; int i = 0xf; int i = ‘a’;
```

- int: usually 4 bytes, holds integers




```
float f = 5; float f = 5.5; double d = 5.98798;
```

- float: 4 bytes, floating point number
- double: 8 bytes, double precision floating point number



[s] 1.[mantissa] x $2^{[exp]}$

Basic Data Types

- Examples

```
int   i = 5/2;        // i = 2;
```

- integer logic, no decimal places, no rounding

```
float f = 5.0f/2;       // f = 2.5f
```

- decimal logic for float and double

```
char  a = ‘a’/2;     // a = 97 / 2 = 48
```

- remember, chars are one-byte numbers
- “character” meaning is interpreted by the console (ASCII table, ’a’ = 97)

signed vs. unsigned

- Can specify properties via keywords:

```
signed int i = -5;              // i=-5 (Two's complement)
unsigned int j = 100 - 200;     // j=4294967196
```

- **signed** or **unsigned** arithmetic (note the wrap)

```
short int i = 1024;             //-32768…32767
long  int j = 1024;            // -2147483648…2147483647
```

- **short** or **long** word size

	short int	int	long int	long long
32-bit architecture	16	32	32	64
64-bit architecture	16	32	64	128

- note: ranges and #bits vary with architecture (and OS)

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sizeof, inttypes.h, const, volatile

```
sizeof int; sizeof long int;  //4 and 4 on x86 32-bit
```

- Use **sizeof** to determine variable size in bytes

```
#include <inttypes.h>
int8_t i; uint32_t j;
```

- Use types from inttypes.h to be sure about sizes

```
const int i=5;
```

- variable is **const**ant, modification will raise compiler error

```
volatile int i=5;
```

- variable **volatile**, may be modified elsewhere
  - for example by different program in shared memory
  - important for CPU caches, registers and assumptions thereof

local vs. global variables

```
int m; // global variable
       // (outside a function)

int myroutine(int j) {
       int i=5;// local variable
       i = i+j;
       return i;
}
```

- global variables (e.g., int m)
  - lifetime: while program runs
  - placed on pre-defined place in memory
- basic block / function-local variables (e.g., int i)
  - lifetime: during invocation of myroutine
  - placed on stack or in registers

local variables vs. static

```
int myroutine(int j) {
       int i=5;
       i = i+j;
       return i;
}

k = myroutine(1); // k = 6;
k = myroutine(1); // k = 6:
```

```
int myroutine(int j) {
       static int i=5;
       i = i+j;
       return i;
}

k = myroutine(1); //  k = 6;
k = myroutine(1); //  k = 7:
```

- basic block / function-local variables (eg. int i)
  - placed on stack or in registers
- **not so if** variable **static**
  - (if applied to local variables within function or basic block)
  - makes variable persistent across multiple invocations
  - lifetime: while program runs, like global variables

Characters, strings, printf

- In C, characters are encoded as 1-byte “numbers” (char)

```
char c = ‘a’;
putc(c);
```

- Console driver translates those numbers into characters
- Uses ASCII table for that purpose

```
printf(“Hello”);
```

- Library call ‘printf’ from stdlib.h to print strings

```
int i=5; float f=2.5;
printf(“The numbers are i=%d f=%f”, i, f);
```

- Comprised of a format string and arguments
- Format string may contain format identifiers (%d)
- man 3 printf

Characters, strings, printf

- remember, characters are just “numbers”
- ASCII table translates those numbers (man ascii)

```
char c = ‘a’;
char c = ‘a’ + 1;  // c = ‘b’, since ‘b’ follows ‘a’ in ASCII
```

- Assign characters to variables via single quote '
- Can calculate with characters

```
\n      newline                          \”      double quote
\t      tab                              \0      NULL, end of string
\’      single quote
```

- Special ASCII characters encoded via leading backslash

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Characters, strings, printf

- remember, characters are just “numbers”
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char c = ‘a’;
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\n      newline                    \”      double quote
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\’      single quote
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- Special ASCII characters encoded via leading backslash

Karlsruhe Institute of Technology

DESCRIPTION

ASCII is the American Standard Code for Information Interchange. It is a 7-bit code. Many 8-bit codes (such as ISO 8859-1, the Linux default character set) contain ASCII as their lower half. The international counterpart of ASCII is known as ISO 646.

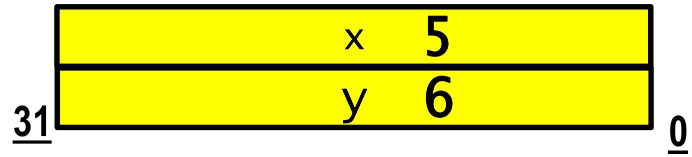
The following table contains the 128 ASCII characters.

C program '\X' escapes are noted.

Oct	Dec	Hex	Char	Oct	Dec	Hex	Char
000	0	00	NUL '\0'	100	64	40	@
001	1	01	SOH (start of heading)	101	65	41	A
002	2	02	STX (start of text)	102	66	42	B
003	3	03	ETX (end of text)	103	67	43	C
004	4	04	EOT (end of transmission)	104	68	44	D
005	5	05	ENQ (enquiry)	105	69	45	E
006	6	06	ACK (acknowledge)	106	70	46	F
007	7	07	BEL '\a' (bell)	107	71	47	G
010	8	08	BS '\b' (backspace)	110	72	48	H
011	9	09	HT '\t' (horizontal tab)	111	73	49	I
012	10	0A	LF '\n' (new line)	112	74	4A	J
013	11	0B	VT '\v' (vertical tab)	113	75	4B	K
014	12	0C	FF '\f' (form feed)	114	76	4C	L
015	13	0D	CR '\r' (carriage ret)	115	77	4D	M
016	14	0E	SO (shift out)	116	78	4E	N
017	15	0F	SI (shift in)	117	79	4F	O
020	16	10	DLE (data link escape)	120	80	50	P
021	17	11	DC1 (device control 1)	121	81	51	Q
022	18	12	DC2 (device control 2)	122	82	52	R
023	19	13	DC3 (device control 3)	123	83	53	S
024	20	14	DC4 (device control 4)	124	84	54	T
025	21	15	NAK (negative ack.)	125	85	55	U
026	22	16	SYN (synchronous idle)	126	86	56	V
027	23	17	ETB (end of trans. blk)	127	87	57	W
030	24	18	CAN (cancel)	130	88	58	X
031	25	19	EM (end of medium)	131	89	59	Y
032	26	1A	SUB (substitute)	132	90	5A	Z
033	27	1B	ESC (escape)	133	91	5B	[
034	28	1C	FS (file separator)	134	92	5C	\ '\\'
035	29	1D	GS (group separator)	135	93	5D	]
036	30	1E	RS (record separator)	136	94	5E	^
037	31	1F	US (unit separator)	137	95	5F	_
040	32	20	SPACE	140	96	60	`
041	33	21	!	141	97	61	a
042	34	22	"	142	98	62	b
043	35	23	#	143	99	63	c
044	36	24	$	144	100	64	d
045	37	25	%	145	101	65	e
046	38	26	&	146	102	66	f
047	39	27	'	147	103	67	g
050	40	28	(	150	104	68	h
051	41	29	)	151	105	69	i
052	42	2A	*	152	106	6A	j
053	43	2B	+	153	107	6B	k
054	44	2C	,	154	108	6C	l
055	45	2D	-	155	109	6D	m
056	46	2E	.	156	110	6E	n
057	47	2F	/	157	111	6F	o
060	48	30	0	160	112	70	p
061	49	31	1	161	113	71	q
062	50	32	2	162	114	72	r
063	51	33	3	163	115	73	s
064	52	34	4	164	116	74	t
065	53	35	5	165	117	75	u
066	54	36	6	166	118	76	v
067	55	37	7	167	119	77	w
070	56	38	8	170	120	78	x
071	57	39	9	171	121	79	y
072	58	3A	:	172	122	7A	z
073	59	3B	;	173	123	7B	{
074	60	3C	<	174	124	7C	|
075	61	3D	=	175	125	7D	}
076	62	3E	>	176	126	7E	~
077	63	3F	?	177	127	7F	DEL

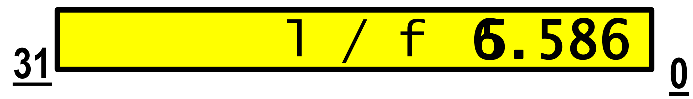
Compound data types

```
struct coordinate {
       int x;
       int y;
}
```



- **struct**ure: Collection of named variables of different types

```
union longorfloat {
       long l;
       float f;
}
```



- **union**: *single* variable that can have multiple types
- Note the difference between struct and union!

  sizeof c = 2*sizeof int vs. sizeof lf = max(sizeof float, sizeof long)

```
struct coordinate c;
c.x = 5;
c.y = 6;
```

```
union longorfloat lf;
lf.l = 5;
lf.f = 6.586;
```

- Members are accessed by name using **.** operator

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Functions

```
unsigned int sum(unsigned int a, unsigned int b) {
        return a+b;
}
```

- Functions encapsulate functionality (reuse)
- Functions structure code (reduced complexity)
- Functions must be **declared** and **defined**

```
unsigned int sum(unsigned int a, unsigned int b);
```

  - Declaration states the signature (return type, name, params)

    <return type> function name ([<arg1> [, <arg2>[. . .]]]);

```
unsigned int sum(unsigned int a, unsigned int b) {
        return a+b;
}
```

  - Definition states the implementation
  - Definition implicitly declares the function

Declaration vs. definition

- Example: declaration of function in other file

```
int sum(int a, int b)
{
        return a+b;
}
```

sum.c

```
#include <stdio.h>

int sum(int a, int b);

int main(void)
{
   printf ( ”%d\n”, sum(1,2));
   return 0;
}
```

main.c

Declaration vs. definition

- Use header file for frequently used declarations

```
int sum(int a, int b);
```

mymath.h

```
#include “mymath.h”


int sum(int a, b)
{
        return a+b;
}
```

sum.c

```
#include <stdio.h>
#include “mymath.h”

int main(void)
{
   printf ( ”%d\n”, sum(1,2));

   return 0;
}
```

main.c

Declaration vs. definition

- Use **extern** to declare global variables defined elsewhere

```
int sum(int a, int b);
extern float pi;
```

mymath.h

```
#include “mymath.h”

float pi=3.1415927;
int sum(int a, b)
{
        return a+b;
}
```

sum.c

```
#include <stdio.h>
#include “mymath.h”

int main(void)
{
   printf ( ”%d\n”, sum(1,2));
   printf ( ”%f\n”, pi);
   return 0;
}
```

main.c

Static declaration

- Use **static** to limit scope to current file
  (when applied to global variables and functions)

```
int sum(int a, int b);
extern float pi;
```

mymath.h

```
#include “mymath.h”

static float pi=3.1415927;
int sum(int a, b)
{
        return a+b;
}
```

sum.c

```
#include <stdio.h>
#include “mymath.h”

int main(void)
{
   printf ( ”%d\n”, sum(1,2));
   printf ( ”%f\n”, pi); X
   return 0;
}
```

main.c

Static declaration

- Use **static** to limit scope to current file
  (when applied to global variables and functions)

```
int sum(int a, int b);
```

mymath.h

```
#include “mymath.h”

static float pi=3.1415927;
int sum(int a, b)
{
        return a+b;
}
```

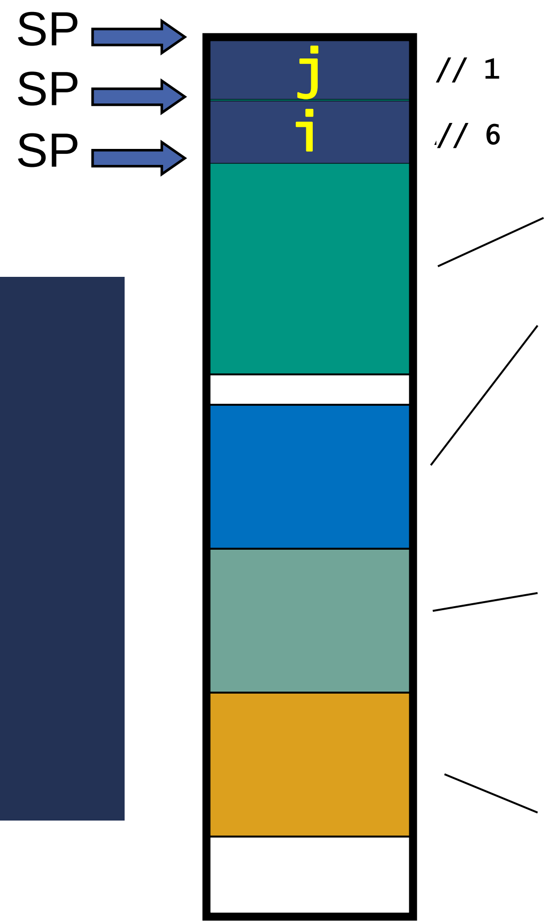
sum.c

```
#include <stdio.h>
#include “mymath.h”
static float pi=3.1415927;
int main(void)
{
   printf ( ”%d\n”, sum(1,2));
   printf ( ”%f\n”, pi); √
   return 0;
}
```

main.c

Stack/Heap/Data Segments and Variables

- A running program




```
int myroutine(int j) {
        int i=5;
        i = i+j;
        return i;
}

k = myroutine(1);
k = myroutine(1);
```

Stack:
Local Variables

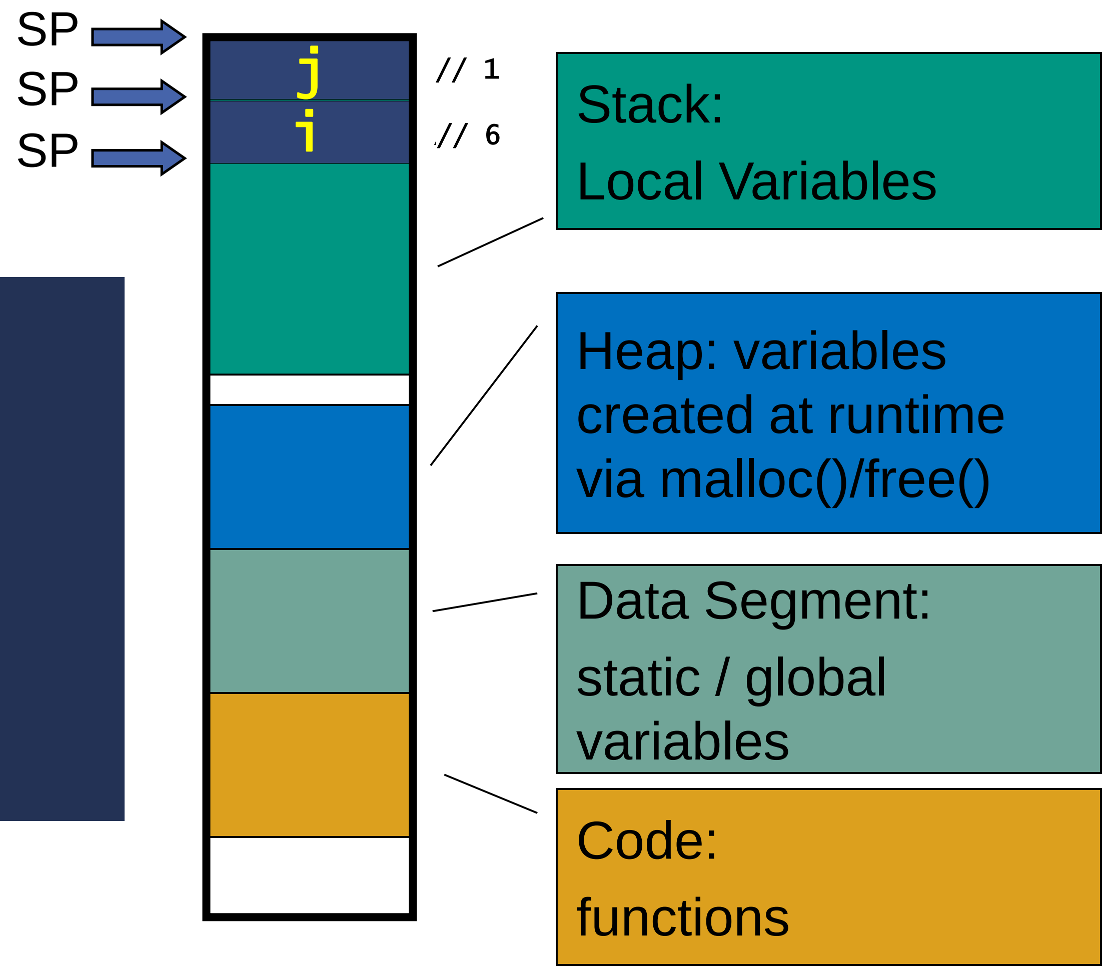
Heap: variables created at runtime via malloc()/free()

Data Segment:
static / global variables

Code:
functions

Stack/Heap/Data Segments and Variables

- A running program




```
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        int i=5;
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        return i;
}

k = myroutine(1);
k = myroutine(1);
```

Stack/Heap/Data Segments and Variables

- A running program

```
int myroutine(int j) {
       static int i = 5;
       i = i+j;
       return i;
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k = myroutine(1);
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```

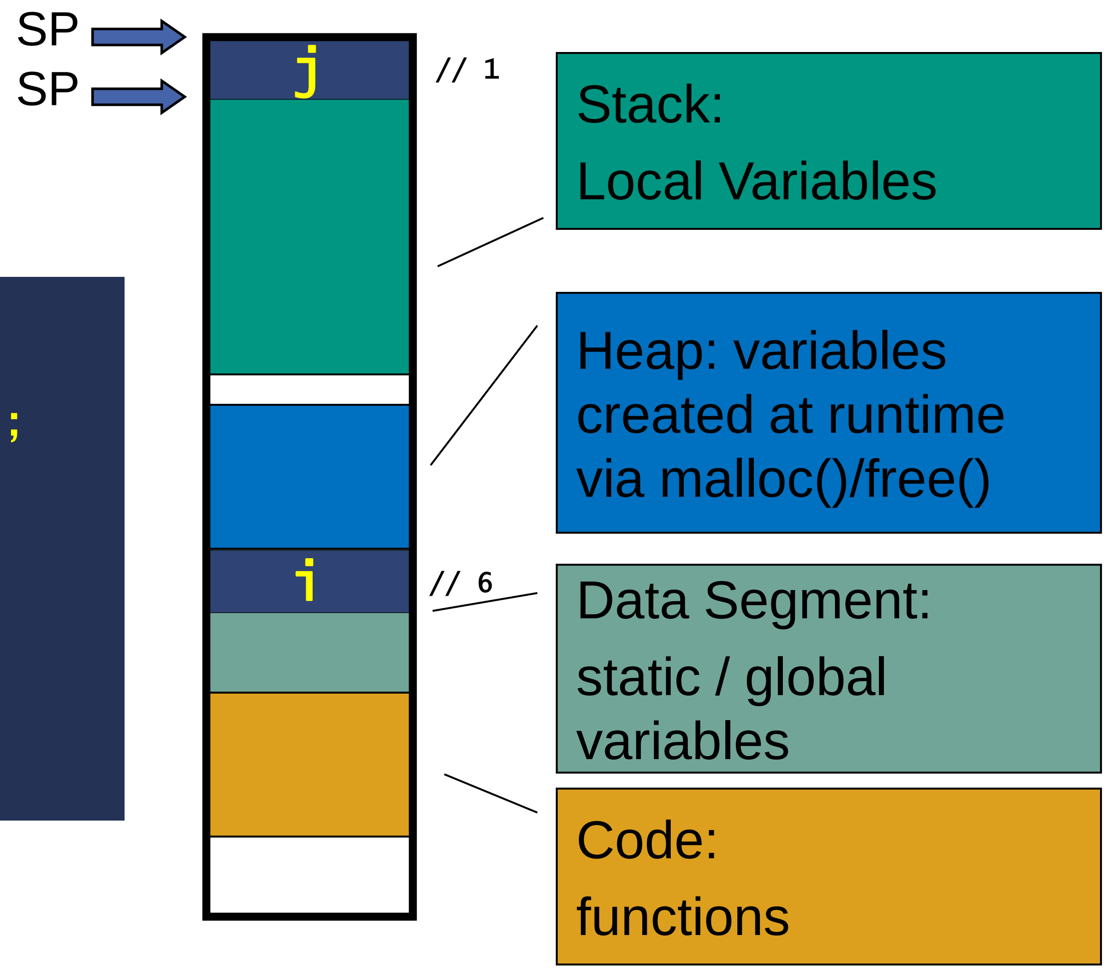

Stack/Heap/Data Segments and Variables

- A running program

```c
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        static int i = 5;
        i = i+j;
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}

k = myroutine(1);
k = myroutine(1);
```
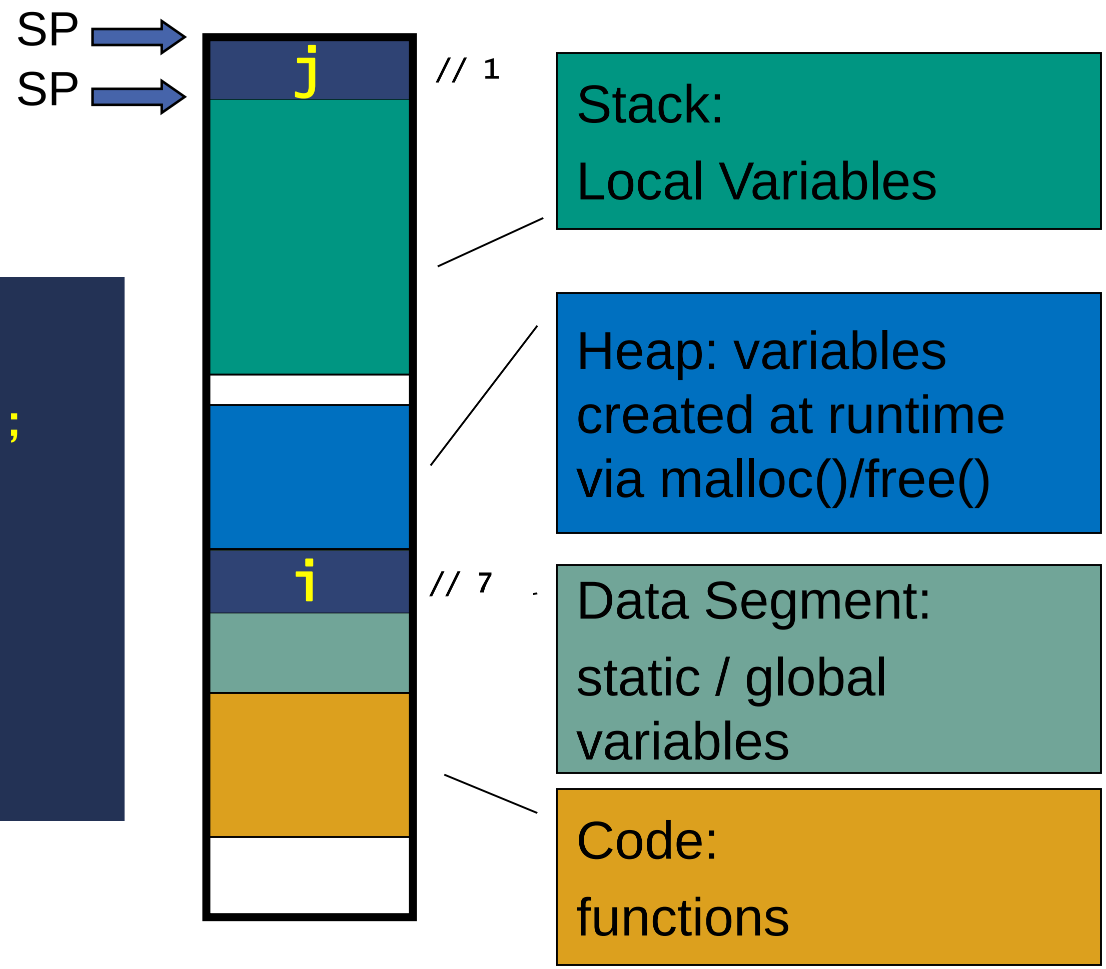



Function overloading

```
int sum(int a, int b) {
        return a+b;
}

int sum(int a, int b, int c) {
        return a+b+c;
}
```

X

- NO function overloading in C

```
sum.c:8:5: error: conflicting types for 'sum'
sum.c:4:5: note: previous definition of 'sum' was here
```

```
int sum(int *summands, int size) {
        int sum = 0;
        int s = 0;
        for (s=0; s < size; s++)
                sum += *(summands+s);
        return sum;
}
```

- Use arrays or pointers ☺

Pointer

- Pointer: data type pointing to a value

```
int *p;
```

- pointer to an integer variable
- holds a memory address to a variable of type int

```
int a = 5;
int *q = &a;
```

- can be assigned the address of an existing variable

```
int *p;
struct coordinate *c;
void *r;
```

- typically has a type, void denotes absence of type

```
int i  = *q;     // c = dereference(q) => 5
int x  = (*c).x; // x = dereference(c), member x
int x2 = c->x;   // short form of (*c).x
```

- can be dereferenced

Pointer

- Pointer: data type pointing to a value

```
int a=5;
```

```
int *p = &a;
```

```
int *q = 32;
```

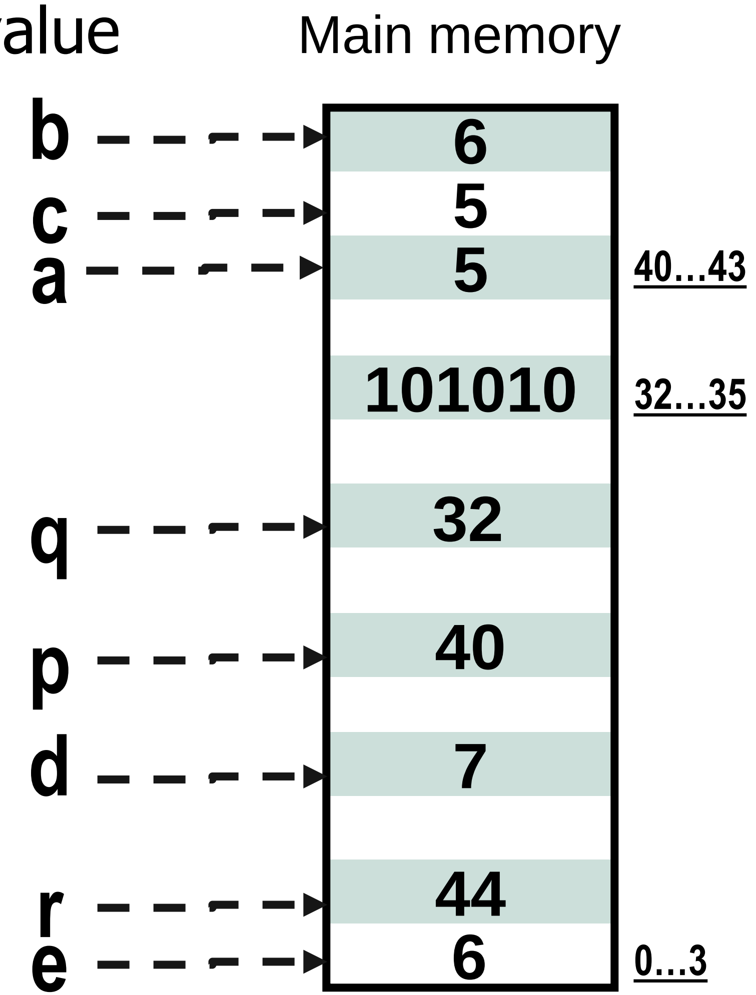
```
int b = a+1;
```

```
int c = *p;
```

```
int d = (*p)+2;
```

```
int *r = p+1;
```

```
int e = *(p+2);
```



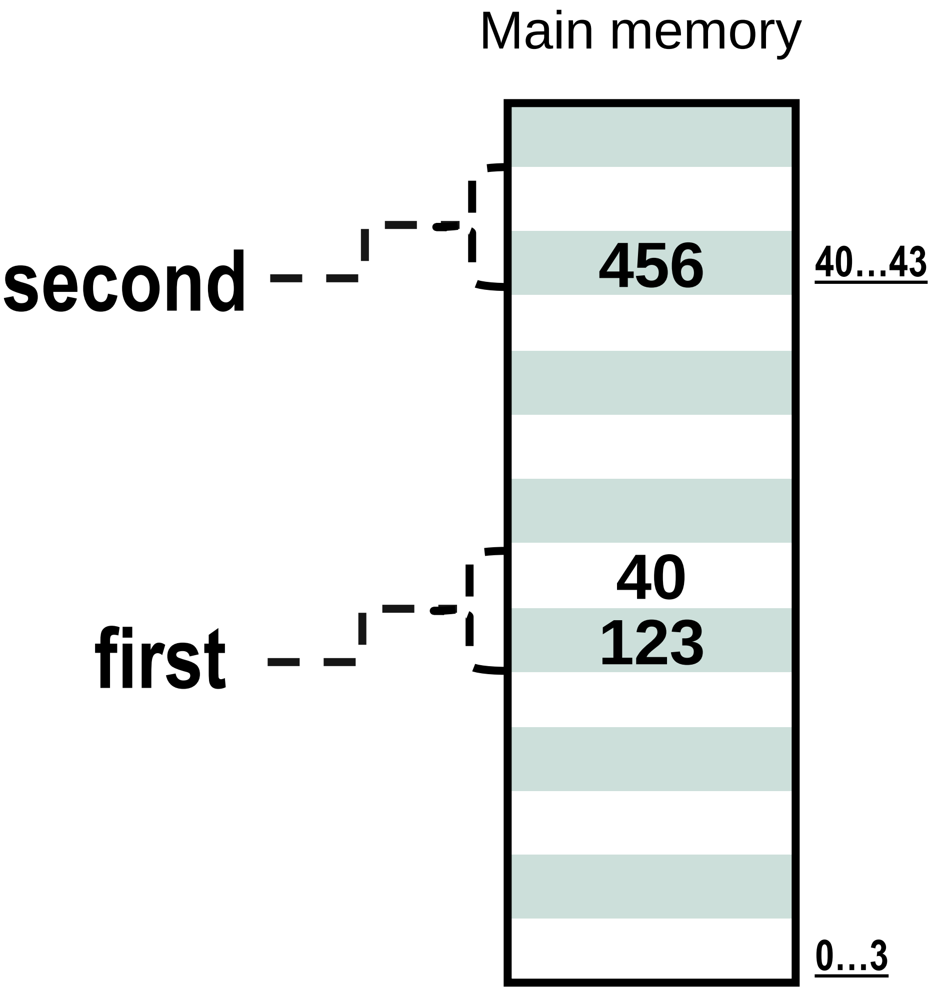
Pointer (explanations)

- A: integer variable initialized with value 5
- P: pointer to an integer variable, initialized to point to variable a
- Q: pointer to an integer variable, initialized with address 32
- B: integer variable, initialized to the value of a + 1
- C: integer variable, initialized to dereference(p), that is the value of the variable at the address in pointer p
- D: integer variable, initialized to the sum of dereference(p) and 2
- R: pointer to an integer variable, initialized by pointer arithmetic: pointing to the next element after the one p is pointing to. As both p and r are pointers to ints (4B), the address in r is that in p + 4
- E: integer variable. Here, we do pointer arithmetic before dereferencing: skip two elements (ints!) forward from the one that p is pointing to, dereference, and initialize e with that value

Example: linked list

- Linked list via next-pointer

```
struct ll {
  int item;
  struct ll *next;
};

struct ll first;
first.item = 123;

struct ll second;
second.item = 456;
first.next = &second;
```



Arrays

- Array: fixed number of variables *continuously laid out in memory*

```
int A[5];
```

- declare an array (and reserve space in memory)

```
A[4] = 25; A[0] = 24;
```

- assign 25 to last, 24 to first element

```
char C[] = { ‘a’, 5, 6, 7, ‘B’};
```

- initialize array, implicitly stating length

```
C[654] = ‘Z’; C[i++]
```

- NO bounds checking at compile or run time (but may raise protection fault)

```
char *p = C;
*(p+1) = ‘Z’; p[3] = ‘B’; char b = *p; // ‘a’
```

- declare pointer to array; address elements via pointer

Array vs. pointer

- Pointer: data type pointing to a value

```
int A[3] = { 4, 5 , 6 };
```

```
int *p = A;
```

```
A[2] = 7;
```

```
p[2] = 8;
```

```
A = A + 1;
```

✗

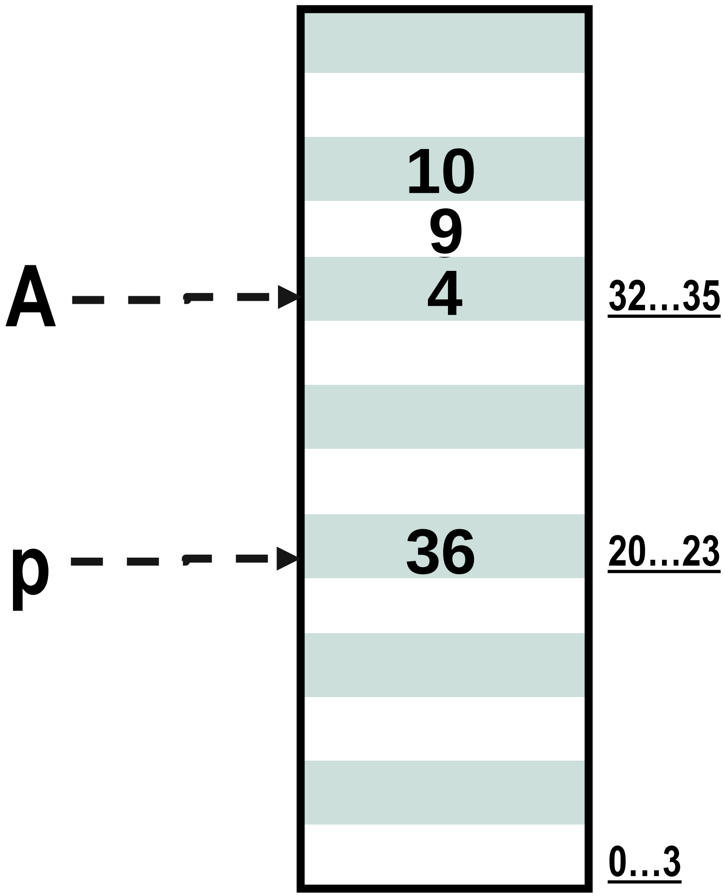
```
p = p + 1;
```

√

```
*p = 9;
```

```
p[1] = 10;
```

Main memory



Strings

- String: array of characters terminated by NULL (0)

```
char A[] = { ‘J’, ‘a’, ‘n’, ‘\0’ };
char A[] = “Jan”; // prepared these slides!
```

- declare and initialize string

```
const char *p= “Jan”;
```

- declare const char pointer to string

```
A[2] = ‘b’;
```

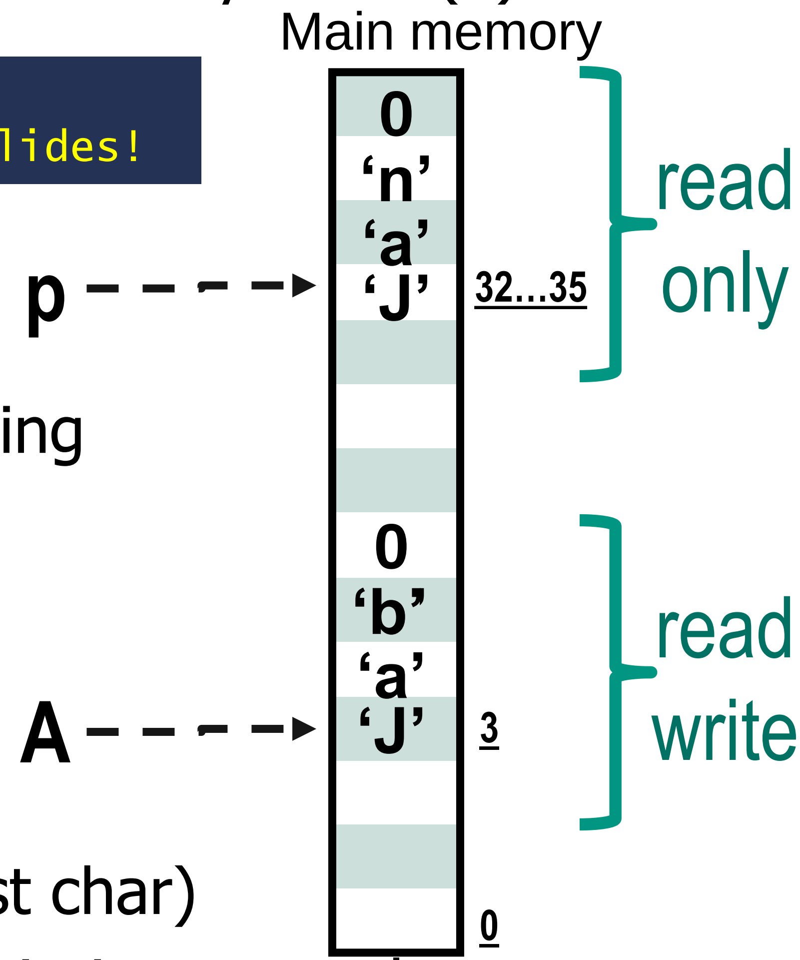
√

- valid assignment

```
p[2] = ‘b’;
*(p+2) = ‘b’;
```

X

- both fail at compile time (p const char)
- Remember: pointer data type pointing to a value



Common string functions

```
#include <string.h>
```

- can be found in a UNIX header file

```
size_t strnlen(const char *s, size_t maxlen)
```

- length of a string (up to n)

```
int strncmp(const char *s1, const char *s2, size_t n);
```

- compare two strings (up to n), return >0,0,<0

```
int strncpy(char *dest, const char *src, size_t n);
```

- copy a string (up to n)

```
char *strtok(char *str, const char *delim);
```

- tokenize a string (e.g., split line into words)

My first C routine

```
char* strncpy(char *dest, const char *src, size_t n){

  size_t i; // return type of sizeof, defined in stddef.h

  for (i = 0 ; i < n && src[i] != '\0' ; i++)
    dest[i] = src[i];
  for ( ; i < n ; i++)
    dest[i] = '\0';
  return dest;
}
```

- Copies string src to dest up to n
- Uses a “for”-loop that
  - ends when n has been reached or src ends (whichever first)
  - copies, character-wise, src into dest
- Uses a second “for”-loop that zeroes out the rest of dest

Arithmetic and bitwise operators

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```
a + b    a - b    a * b    a / b    a % b
a++;     a--;     a+=5;    a*=3;    a %=1;
```

- arithmetic operators and their short forms

```
a=5;
if (a++ == 5) printf(“Yes”);
```

```
a=5;
if (++a == 5) printf(“Yes”);
```

- note the difference between pre- and post-increment

```
a & b    a | b    a >> b    a << b    a ^ b    ~a
```

Bits (7 … 0)		Bits (7 … 0)	
0 0 0 0 0 1 0 1	`a // 5`	0 0 0 0 0 1 1 1	`a	b // 7`
0 0 0 0 0 1 1 0	`b // 6`	0 0 0 0 0 0 1 0	`a >> 1 // 2`
0 0 0 0 0 1 0 0	`a & b // 4`	0 0 0 0 0 0 1 1	`a ^ b // 3`

- logical operators often used for bit, address calculations

C routine using bit logic

```c
uint8_t  bit_function(uint8_t val) {

        uint8_t mask = ~(1<<5);
        return val & mask;

}
```

Bits (7 … 0)	Expression
0 0 0 0 0 0 0 1	`1`
0 0 1 0 0 0 0 0	`1<<5`
1 1 0 1 1 1 1 1	`~(1<<5)     // mask`
0 0 1 1 0 0 0 1	`val         // 49`
0 0 0 1 0 0 0 1	`val & mask // 17`

- mask out bit number 5

Loops, if-then-else

```
if ( a == b )
 printf("Equal");
else
 printf("Different");
```

```
if ( a == b )
 printf("Equal");
else {
 printf("Different"); return 0;
}
```

- {} only needed for multiple statements

```
int i;
for (i=10; i>=10; i--)
 printf("%d", i+1);
```

```
int i=10;
while (i--)
  printf("foo");
```

```
int i=0;
do
  printf("bar");
while(i++ != 0);
```

- do-while-statement executed at least once

```
for (;;) {
  i = read();
  if (i>0)
    break;
  if (i==0)
    continue;
  do_something();
}
```

- with for-loops, can leave out any of initializer/expression/modifier
- use break and continue to exit/skip

Expressions

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```
if (<expression>)
while (<expression>)
for (<initializer>; <expression>; <modifier>)
```

- Operators and operands build expressions

```
if (n = 1)
```
```
while (n--)
```
```
for (n=10;n>0;n-=c)
```

- Assignments are expressions

```
if (n > 0)
```
```
while (n++ < 0)
```
```
while (n != 0)
```

- Comparisons are expressions
  - (n++ < 0) extends to 1 if n < 0 and to 0 otherwise, then increments n

```
if (n == 0)
```
```
if (n = 0)
```
```
if ((n = read()) < 0)
```

  - Note the difference between == and = !
  - Expressions can be nested (last example)

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Logical operators

```
if ( a == 0 || b == 0)
```

```
if ( a > 0 && b < 0 )
```

```
if (!(a == 0))
```

- || logical OR
- && logical AND
- ! logical NOT

```
a = 0; b = 1;
if ( a == 0 || b == 0)
```

```
a = 0; b = 1;
if ( a != 0 && (b == read()) )
```

- Note: operators are evaluated in non-strict manner
  - First example: b == 0 never evaluated
  - Second example: b == read() never evaluated

All C operators (in order of precedence)

()	[]	->	.							
!	++	--	+y	-y	*z	&=	(type)		sizeof	
*	/	%								
+	-									
<<	>>									
<	<=	>	>=							
==	!=									
&										
^										
|										
&&										
||										
?	:									
=	+=	-=	*=	/=	%=	&=	~=	|=	<<=	>>=
,										

Switch/case

```
char a = read();

switch (a) {
  case '1':
    handle_1();
    break;
  case '2':
    handle_2();
    //break
  default:
    handle_other();
    break;
}
```

- Use **switch/case** to differentiate multiple cases.
- Note: need break statement to exit switch-loop
- If not given, code will fall through
- Example: with a == '2', code will execute both handle_2() and handle_other()

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Type casting

```
int i = 5;
float f = (float) i;
```

```
int i;
char c = (char) i;
```

- Explicit type casting (possibly losing precision)

```
char c = 5;
int  i = c;
```

```
float f = 0.555f;
double d = f;
```

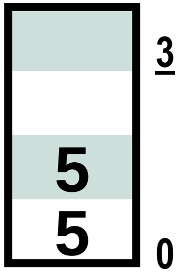
- Some types are casted implicitly (if no precision loss)

```
int i = 5;
float f = (float) (i / 2);
```

```
int i = 5;
float f = ((float) i) / 2;
```

- Watch out for precedence!

```
int i = 5;
char *p = (char *) &i;
*(p+1) = 5;
```



- Casting pointers changes address calculation!

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Type casting

- Types form a hierarchy
  - "wider" vs. "shorter" types
  - unsigned int is wider than signed int

```
char c = 5; int i = 2;
int  j = c + i; // c gets cast to int first
```

- Operators cast parameters to widest type

```
unsigned int u = 4;
int          i = -20;
int j = i / u;
```

- Take care: cast for assignment after cast for operator
  - i gets cast to "wider" unsigned int
  - j is 1073741819

C preprocessor

- C preprocessor modifies *source* code
  - modified before compilation
  - based on preprocessor directives (usually start with #)

```
#include <stdio.h>
#include "mystdio.h"
```

- copies (literally!) contents of file to current file

- only works with strings in the source file
- completely ignores semantics of C

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Preprocessor search paths

`#include <file>`

- System include; search for file in:
  `/usr/local/include`
  libdir`/gcc/`*target*`/`*version*`/include`
  `/usr/`*target*`/include`
  `/usr/include`
  target: arch-specific path (i686-linux-gnu, x86_64-linux-gnu)
  version: gcc version (4.2.4, 4.6.1)
- Can add own paths with `–I`<*dir*>

`#include “file”`

- Local include; search in directory containing the *current file*
- Then in the paths specified by `–i<dir>`
- Then in system include paths described above

C preprocessor

```
#define PI 31415926535897
#define TRUE (1)
#define max(a,b) ((a > b) ? (a) : (b))
#define panic(str) do { printf(str); for (;;) } while(0);
```

- defines introduce replacements strings
  - Can have arguments (a,b, str)
  - Note: all based on string replacement!

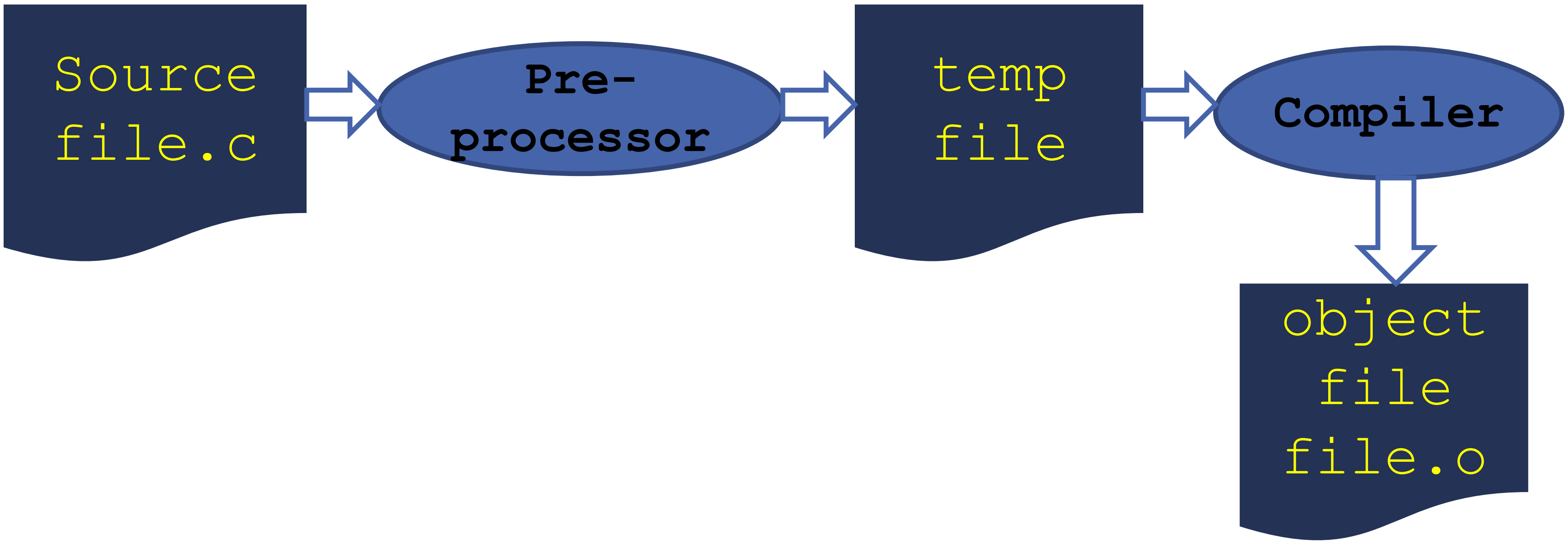
```
#ifdef __unix__
# include <unistd.h>
#elif defined _WIN32
# include <windows.h>
#endif
```

```
#define DEBUG
#ifdef DEBUG
#define TRACE(x) printf(x)
#else
#define TRACE(x)
#endif
```

- defines can help structuring the code
  - quickly switch on/off include based on architecture or config
  - often leads to source code cluttering

C preprocessor operation

- C preprocessor modifies *source* code
  - modified before compilation



C preprocessor substitution

- maintains list of *macros*

```
// preprocessor input
#define PI 3.141
#define DEBUG
```

PI	3.141
DEBUG	

- replaces each occurrence of a macro with its contents

```
printf("%f", radius * PI);
```

preprocessor output

```
printf("%f", radius * 3.141);
```

- suppresses directives and comments in output

C preprocessor conditionals

- maintains list of *macros*

```
// preprocessor input
#define PI 3.141
#define DEBUG
```

PI	3.141
DEBUG	

- conditionally includes or suppresses code

```
int i = j + 15;
#ifdef DEBUG
printf("i is %d\n", i);
#endif
```

preprocessor output

```
int i = j + 15;

printf("i is %d\n", i);
```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C preprocessor conditionals

- maintains list of *macros*

```
// preprocessor input
#define PI 3.141
```

PI	3.141

- conditionally includes or suppresses code

```
int i = j + 15;
#ifdef DEBUG
printf("I is %d\n", i);
#endif
float f = i * PI;
```

preprocessor output

```
int i = j + 15;



float f = i * PI;
```

- Supports if / else / else if constructs and logical operators
  - #if defined(DEBUG_LEVEL) && DEBUG_LEVEL > 2

Predefined macros

- compiler command line arguments

```
$ gcc -DDEBUG -o myprog myprog.c
```

- system-specific
  - __unix__
  - _WIN32
  - __STDC_VERSION__
- useful preprocessor variables
  - __LINE__
  - __FILE__
  - __DATE__

```
#define ASSERT(x) if(!(x)) {  \
   printf("Assertion failed in"\
        "file %s, line %d",    \
         __FILE__, __LINE__);  \
   exit(-1); }
```

Some notes on generated code

```
#include <stdio.h>

int  myvar = 5;
int main(void) {
    myvar += 5;
    printf("%d\n", myvar);
    return myvar;
}
```

- A program marginally more complex than Hello World

```
$ gcc -g -o myvar myvar.c
$ ./myvar
10
```

- Unsurprising result if compiled and run

```
$ objdump -dhxS myvar
```

- Let’s (briefly) look at the generated code
- objdump decodes and disassembles UNIX binaries

Some notes on generated code

```
myvar:     file format elf32-i386
Myvar
...
SYMBOL TABLE:
0804a020 g     O .data  00000004              myvar
0804843c g     F .text  00000032              main
...
main():
/home/mhillen/tmp/myvar.c:5
#include <stdio.h>
int  myvar = 5;
int main(void) {
 804843c:       55                      push   %ebp
 804843d:       89 e5                   mov    %esp,%ebp
 804843f:       83 e4 f0                and    $0xfffffff0,%esp
 8048442:       83 ec 10                sub    $0x10,%esp
/home/mhillen/tmp/myvar.c:6
        myvar += 5;
 8048445:       a1 20 a0 04 08          mov    0x804a020,%eax
 804844a:       83 c0 05                add    $0x5,%eax
 804844d:       a3 20 a0 04 08          mov    %eax,0x804a020
/home/mhillen/tmp/myvar.c:7
        printf("%d\n", myvar);
 8048452:       a1 20 a0 04 08          mov    0x804a020,%eax
 8048457:       89 44 24 04             mov    %eax,0x4(%esp)
 804845b:       c7 04 24 00 85 04 08    movl   $0x8048500,(%esp)
 8048462:       e8 a9 fe ff ff          call   8048310 <printf@plt>
/home/mhillen/tmp/myvar.c:8
        return myvar;
 8048467:       a1 20 a0 04 08          mov    0x804a020,%eax
/home/mhillen/tmp/myvar.c:9
}
```

- Function and variable names
- Translate to addresses
- Code segment is called .text

- Read, modify, write myvar

- Function call

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Compiling and linking

```c
#include <stdio.h>

int  myvar = 5;
int main(void) {
    myvar += 5;
    printf("%d\n", myvar);
    return myvar;
}
```

myvar.c

```c
#include <stdio.h>

extern int  myvar;
int run_myvar2() {
    myvar += 10;
    printf("%d\n", myvar);
    return myvar;
}
```

myvar2.c

```
$ gcc -o myvar myvar.c myvar2.c
```

- Compiles and links two source files

```
$ gcc -c myvar.c myvar2.c
$ ls *.o
myvar.o myvar2.o
```

- gcc –c compiles but doesn't link
- generates two independent object files

Compiling and linking

```
myvar2.o:     file format elf32-i386
...
SYMBOL TABLE:
00000000         *UND*  00000000 val
 00000000 <run_myvar2>:
   0:
   55                      push   %ebp
   1:   89 e5                   mov    %esp,%ebp
   3:   83 ec 18                sub    $0x18,%esp
   6:   a1 00 00 00 00          mov    0x0,%eax
                   7: R_386_32     val
   b:   83 c0 05                add    $0x5,%eax
   e:   a3 00 00 00 00          mov    %eax,0x0
                   f: R_386_32     val
  13:   8b 15 00 00 00 00       mov    0x0,%edx
                   15: R_386_32    val
  19:   b8 00 00 00 00          mov    $0x0,%eax
                   1a: R_386_32    .rodata
  1e:   89 54 24 04             mov    %edx,0x4(%esp)
  22:   89 04 24                mov    %eax,(%esp)
  25:   e8 fc ff ff ff          call   26 <run_myvar2+0x26>
                   26: R_386_PC32  printf
  2a:   a1 00 00 00 00          mov    0x0,%eax
                   2b: R_386_32    val
  2f:   c9                      leave
  30:   c3                      ret
```

- Object file contains code, space requirements
- External symbols unresolved (00 00..)
- Final addresses unresolved

Linking

```
$ ld ... myvar.o myvar2.o –o myvar
```

- Linker (ld) "glues together" object files

```
$ gcc myvar.o myvar2.o –o myvar
```

- Needs arch-/OS-specific params, invoke via gcc

```
--build-id --eh-frame-hdr -m elf_x86_64 --hash-style=gnu -dynamic-linker /lib64/ld-linux-
x86-64.so.2 -z relro -o myvar /usr/lib/x86_64-linux-gnu/gcc/x86_64-linux-
gnu/4.5.2/../../../crt1.o /usr/lib/x86_64-linux-gnu/gcc/x86_64-linux-
gnu/4.5.2/../../../crti.o /usr/lib/x86_64-linux-gnu/gcc/x86_64-linux-gnu/4.5.2/crtbegin.o
-L/usr/lib/x86_64-linux-gnu/gcc/x86_64-linux-gnu/4.5.2 -L/usr/lib/x86_64-linux-
gnu/gcc/x86_64-linux-gnu/4.5.2/../../.. -L/usr/lib/x86_64-linux-gnu myvar2.o myvar.o -
lgcc --as-needed -lgcc_s --no-as-needed -lc -lgcc --as-needed -lgcc_s --no-as-needed
/usr/lib/x86_64-linux-gnu/gcc/x86_64-linux-gnu/4.5.2/crtend.o /usr/lib/x86_64-linux-
gnu/gcc/x86_64-linux-gnu/4.5.2/../../../crtn.o
```

- This is (sort of) how gcc invokes ld

Libraries

```c
#include <math.h>
#include <stdio.h>

int main(void) {
    float f = 0.555f;
    printf("%f", sqrt(f*4));
    return 0;
}
```

- Math header file contains declarations
- But not necessarily all definitions!

```
$ gcc math.c -o math
/tmp/ccsGM8Gi.o: In function `main':
math.c:(.text+0x34): undefined reference to `sqrt'
collect2: ld returned 1 exit status
```

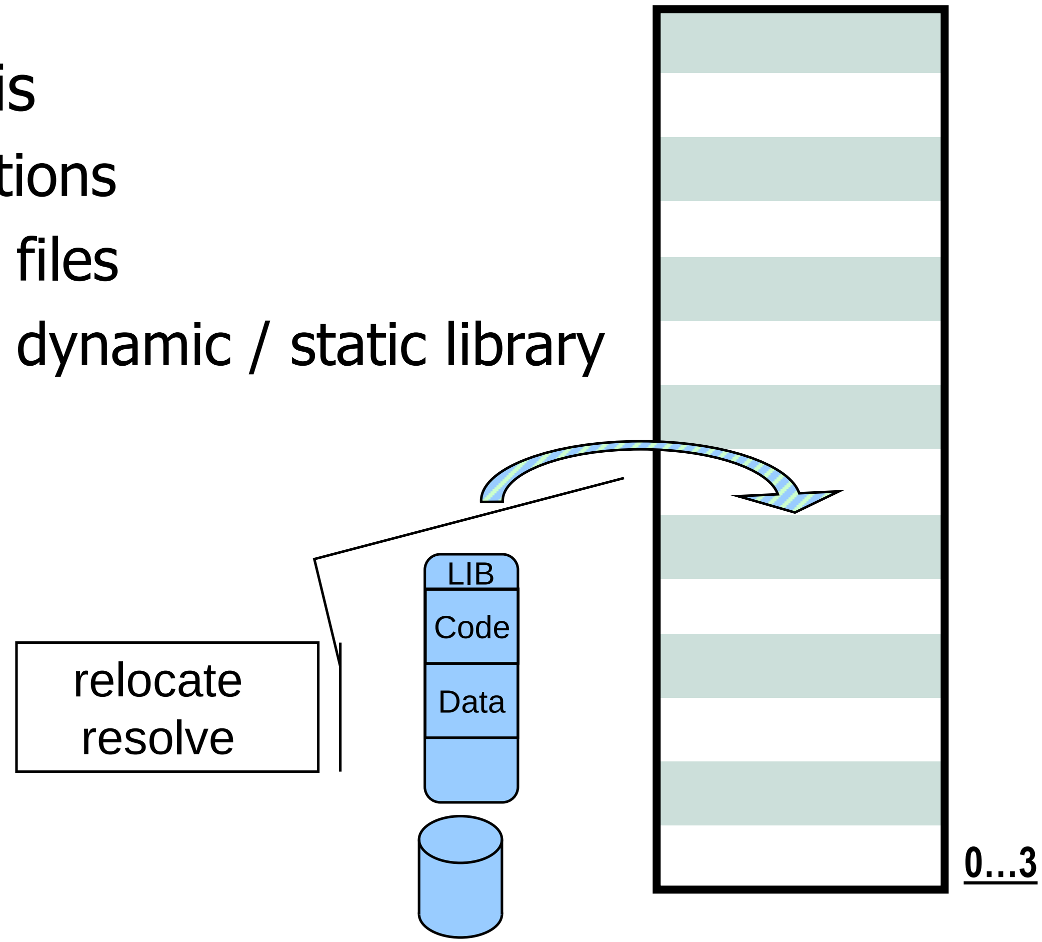
- Need to link math library

```
$ gcc math.c -o math -lm
```

Libraries

```
$gcc math.c -lm
```

- Technically, a library is
  - a collection of functions
  - contained in object files
  - glued together in a dynamic / static library



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