Operating systems

Elements of C programming

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Command line arguments

Command line arguments (1/2)

The `main()` method can be used without arguments

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

or with two parameters argc, and argv (called *command line arguments*):

```
#include <stdio.h>
int main(int argc, char *argv[]) {
    int i;
    printf("argc = %d\n", argc);
    for (i = 0; i < argc; ++i)
        printf("argv[%d] = %s\n", i, argv[i]);
    return 0;
}
```

Command line arguments (2/2)

```
int main(int argc, char * argv[])
```

In the latter case:

- argc: gets the *number* of parameters in the command line
- argv: is an array of char pointers (i.e., strings) that correspond to command line *arguments*
  - argv[0]: program name
  - argv[i] with i > 0: program arguments

```
user@localhost[~]$ ./print_command_line_args myArg1 myArg2 myArg3
argc = 4
argv[0] = "./print_command_line_args";
argv[1] = "myArg1";
argv[2] = "myArg2";
argv[3] = "myArg3";
```

ASCII coding

ASCII coding (1/2)

- Character in C are represented by integers
- Constants 'a' and '+', for instance, have type `int`
- Several systems use the *American Standard Code for Information Interchange* (ASCII) for representing characters
- Example 1: character 'A' is represented by the integer 65

```
putchar(65);  // Prints character 'A'
putchar('A'); // Prints character 'A'
```

- Example 2: obtain the ASCII code of a given "character"

```
char value;
scanf("%c", &value);  // Input 'A'
printf("%c\n",value); // Prints character 'A'
printf("%d\n",value); // Prints 65 the ASCII code of character 'A'
```

ASCII coding (2/2)

DEC	HEX	CHAR	DEC	HEX	CHAR	DEC	HEX	CHAR	DEC	HEX	CHAR
0	00	Null char	32	20	Space	64	40	@	96	60	‘
1	01	Start of Heading	33	21	!	65	41	A	97	61	a
2	02	Start of Text	34	22	"	66	42	B	98	62	b
3	03	End of Text	35	23	#	67	43	C	99	63	c
4	04	End of Transmission	36	24	$	68	44	D	100	64	d
5	05	Enquiry	37	25	%	69	45	E	101	65	e
6	06	Acknowledgment	38	26	&	70	46	F	102	66	f
7	07	Bell	39	27	’	71	47	G	103	67	g
8	08	Back Space	40	28	(	72	48	H	104	68	h
9	09	Horizontal Tab	41	29	)	73	49	I	105	69	i
10	0A	Line Feed	42	2A	*	74	4A	J	106	6A	j
11	0B	Vertical Tab	43	2B	+	75	4B	K	107	6B	k
12	0C	Form Feed	44	2C	,	76	4C	L	108	6C	l
13	0D	Carriage Return	45	2D	-	77	4D	M	109	6D	m
14	0E	Shift Out / X-On	46	2E	.	78	4E	N	110	6E	n
15	0F	Shift In / X-Off	47	2F	/	79	4F	O	111	6F	o
16	10	Data Line Escape	48	30	0	80	50	P	112	70	p
17	11	Device Control 1	49	31	1	81	51	Q	113	71	q
18	12	Device Control 2	50	32	2	82	52	R	114	72	r
19	13	Device Control 3	51	33	3	83	53	S	115	73	s
20	14	Device Control 4	52	34	4	84	54	T	116	74	t
21	15	Negative Acknowledgement	53	35	5	85	55	U	117	75	u
22	16	Synchronous Idle	54	36	6	86	56	V	118	76	v
23	17	End of Transmit Block	55	37	7	87	57	W	119	77	w
24	18	Cancel	56	38	8	88	58	X	120	78	x
25	19	End of Medium	57	39	9	89	59	Y	121	79	y
26	1A	Substitute	58	3A	:	90	5A	Z	122	7A	z
27	1B	Escape	59	3B	;	91	5B	[	123	7B	{
28	1C	File Separator	60	3C	<	92	5C	\	124	7C	|
29	1D	Group Separator	61	3D	=	93	5D	]	125	7D	}
30	1E	Record Separator	62	3E	>	94	5E	∧	126	7E	~
31	1F	Unit Separator	63	3F	?	95	5F	_	127	7F	Delete

Bitwise operators

Bitwise operators

- Bitwise operators work on integer expressions represented as strings of bits
- These operators are system dependent
- In the following we analyze operators for systems having
  - bytes of 8 bits
  - integers of 4 bytes
  - two's complement notation for integers
  - ASCII coding for chars
- **Logical operators:**

  `~` : unary complement (bitwise)
  `&` : and (bitwise)
  `^` : xor (bitwise)
  `|` : or (bitwise)

- **Shift operators:**

  `<<` : shift to the left
  `>>` : shift to the right

Unary complement (bitwise)

- The unary complement inverts every bit in the binary representation of the operand
- Example 1:
  - Integer representation of the operand:

    ```
    int a = 70707;
    ```
  - Its binary representation:

    ```
    00000000 00000001 00010100 00110011
    ```
  - Its unary complement (`~a`):

    ```
    11111111 11111110 11101011 11001100
    ```
  - The integer representation of `~a`:

    ```
    -70708
    ```

Two's complement

- The two's complement of an integer n is:
  - If $n \geq 0$: the standard binary representation (in base 2) of n
  - If $n < 0$: the unary complement of the standard binary representation of $-n$, summed to one,
- Example 2:
  - Integer number:

    ```
    int n = 7;
    ```
  - Binary representation of `n`:

    ```
    00000000 00000111
    ```
- Example 3:
  - Integer number:

    ```
    int n = -7;
    ```
  - Binary representation of `-n`:

    ```
    00000000 00000111
    ```
  - Unary complement of `-n` (`~(-n)`):

    ```
    11111111 11111000
    ```
  - Two's complement of `n` (`~(-n) + 1`):

    ```
    11111111 11111001
    ```

And, xor, or (bitwise)

- And (&), xor (^), or (|) are binary operators having integer arguments.
- Truth tables

AND

A	B	Output
0	0	0
0	1	0
1	0	0
1	1	1

OR

A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1

XOR

A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0

- Example 4:

`a`	`00000000 00000000 10000010 00110101`	(33333)
`b`	`11111111 11111110 11010000 00101111`	(-77777)
`a & b`	`00000000 00000000 10000000 00100101`	(32805)
`a ^ b`	`11111111 11111110 01010010 00011010`	(-110054)
`a | b`	`11111111 11111110 11010010 00111111`	(-77249)
`~(a | b)`	`00000000 00000001 00101101 11000000`	(77248)
`~a & ~b`	`00000000 00000001 00101101 11000000`	(77248)

Left shift

- `expr1 << expr2`: shifts the binary representation of `expr1`, of `expr2` positions to the left. It inserts zeros on the right.
- Example 5:
  - Let us take this as example:
    `int c='Z';`
  - which in ASCII representation corresponds to 90
  - Let us now apply the left shift operation:

`c`	00000000	00000000	00000000	01011010
`c << 1`	00000000	00000000	00000000	10110100
`c << 4`	00000000	00000000	00000101	10100000
`c << 31`	00000000	00000000	00000000	00000000

- **Notice:** even if `c` is a character (1 byte), it is cast to `int`. Both arguments of the shift operator are always cast to `int`.

Right shift

- `expr1 >> expr2`: shifts the binary representation of `expr1`, of `expr2` positions to the right. If `expr1` is an `unsigned` then the shift operator inserts `zeros` on the left, while if `expr1` is a `signed` number then it may insert `zeros` or `ones` (i.e., the *sign bit*), depending on the specific machine.
- Examples 6:
  - `int a = 1 << 31;`

    ```
    a      | 10000000 00000000 00000000 00000000
    a >> 3 | 11110000 00000000 00000000 00000000
    ```
  - To preserve the sign bit, it inserts **ones**.
- Examples 7:
  - `unsigned b = 1 << 31;`

    ```
    b      | 10000000 00000000 00000000 00000000
    b >> 3 | 00010000 00000000 00000000 00000000
    ```
  - We are working with an **unsigned**, thus it fills with **zeros**.

Masks

- A **mask** is a constant or a variable used to extract some bits from another variable or expression.
- Since constant 1 has binary representation

  `00000000 00000000 00000000 00000001`

  it can be used to determine the less significant bit of another expression.
- What does this code print? (Example 8)

```
int i, mask = 1;
for (i = 0; i < 10; ++i)
  printf("%d", i & mask)
```

- Expression `(1 << 2)` may be used instead as a mask to extract the third bit from the right (less-significant).
- The value of expression `((v & (1 << 2)) ? 1 : 0)` is 1 if the third less-significant bit of `v` is 1, otherwise it is 0 (Example 9).

Macros

The `#define` directive

- The *C preprocessor* enables the inclusion of header files, macro expansions, conditional compilation, and line control in C programs.
- The `#define` directive allows the definition of *macros* within the source code.
- This directive may have two forms:
  1. `#define identifier tokenString`
  2. `#define identifier(param1,..., paramN) tokenString`

  where `tokenString` is optional.
- Macros are often used to *substitute* function calls with *inline code* which improves efficiency.

The #define directive: Form 1

- When the preprocessor finds a #define of the first form

  `#define identifier tokenString`

  it substitutes every occurrence of identifier in the rest of the code with `tokenString`, except for the occurrences in quotes.
- Examples:

```
#define SECONDS_PER_DAY  (60 * 60 * 24)
#define PI 3.14159
#define C 299792.458 // Light speed in Km/sec
#define EOF (-1)
#define MAXINT 2147483647
#define ITERS 50
```

- Symbolic constants improve the readability of the code
- Syntactic sugar: it is also possible to modify the C syntax using these kind of constants
  Example: `#define EQ ==`

The #define directive: Form 2 (1/2)

- The general syntax is

  `#define identifier(param1,..., paramN) tokenString`

- There must be no space between the first identifier and the first bracket
- The list of parameters may contain between 0 and several identifiers
- Example:

```
#define SQ(x) ((x) * (x))
```

the x identifier is a parameter which is substituted in the subsequent text (i.e., `((x) * (x))`)

The #define directive: Form 2 (2/2)

- String substitution is performed by the preprocessor, for instance:

```
SQ(7 + w)
// is substituted by
((7 + w)  *  (7 + w))
```

and

```
SQ(SQ(*p))
// is substituted by
((((*p)  *  (*p)))  *  (((*p)  *  (*p))))
```

The #define directive: Brackets (1/2)

- Notice: brackets are important to avoid undesired expansions
- Example 1:

```
// Macro definition:
#define  SQ(x)  x * x

// Macro usage:
SQ(a + b)

// Macro expansion:
a + b * a + b // ERROR! Different from ((a + b) * (a + b))
```

- Notice: macro definitions do not end with a semicolon

The #define directive: Brackets (2/2)

- Example 2:

```
// Macro definition:
#define  SQ(x)  (x) * (x)

// Macro usage:
4 / SQ(2)

// Macro expansion:
4 / (2) * (2) // ERROR! Different from 4 / ((2) * (2))
```

Macros: advanced concepts

- Macro definitions may use both functions and other macros
- Example:

```
#define  SQ(x)    ((x) * (x))
#define CUBE(x)  (SQ(x) * (x))
```

- The preprocessor directive

`#undef identifier`

deletes a macro definition.

Structures

Structures: definition and variable declaration (1/2)

- Structures are *derived* data structures for *heterogeneous* data
- The structure components are said *members*. Each member has a name
- Structure definition (example)

```
struct card {
  int pips;  // 1,...,13
  char suit; // 'c'(clubs), 'd'(diamonds), 'h'(hearts), 's'(spades)
};
```

Structures: definition and variable declaration (2/2)

- Struct *variable declaration* (example 1):

```c
struct card {
  int pips;  // 1,...,13
  char suit; // 'c'(clubs), 'd'(diamonds), 'h'(hearts), 's'(spades)
};

struct card c1, c2;
```

- Struct *variable declaration* (example 2):

```c
struct card {
  int pips;  // 1,...,13
  char suit; // 'c'(clubs), 'd'(diamonds), 'h'(hearts), 's'(spades)
} c1, c2;
```

Typedef

- To simplify the declaration of struct variables, it is a good practice to define a new type using the operator `typedef`.
- Syntax:

  `typedef data_type new_name;`

- Example with structures:

```
// Definition of new type name "card" from type "struct card"
typedef struct card card;
// Usage of the new type
card c3, c4, c5;
```

Struct members (1/4)

- Struct members can be accessed by the dot "." operator.
- Example:

```
c1.pips = 3;
c1.suit = 's';
```

Struct members (2/4)

- Member names must be unique within a structure but the same names may be used in different structures.

```
struct fruit {
  char * name;
  int calories;
} a;

struct vegetable {
  char * name;
  int calories;
} b;

a.name = "apple";
b.name = "salad";
```

Struct members (3/4)

- When we deal with struct pointer variables, members are accessed by the "->" operator.
- Example:

```
struct complex {
  double re;
  double im;
}

typedef struct complex complex; // Typedef of complex

void add(complex *a, complex *b, complex *c) { // a = b + c
  a->re = b->re + c->re;
  a->im = b->im + c->im;
}
```

- Notice that a, b and c are pointers to structures.

Struct members (4/4)

- The -> operator (example):

```
struct student {
  char * last_name;
  int student_id;
  char grade;
}

struct student  tmp, *p = &tmp;

tmp.grade='A';
tmp.student_id=342;
tmp.last_name="Rossi";

printf("%c", tmp.grade);    // Prints: A
printf("%c", p->grade);     // Prints: A
```

Unions

Unions: definition and variable declaration (1/2)

- *Unions* are *derived* data structures for *heterogeneous* data (as structures) but their members share the *same memory*.
- An union type defines a series of *alternative values* that can be contained in the same portion of shared memory.
- Union definition (example):

```
union int_or_float { // Union definition
  int   i;
  float f;
}
typedef union int_or_float number; // Typedef of number

number a, b, c;  // Union variable definition
```

- The compiler allocates memory for the larger member.

Unions: definition and variable declaration (2/2)

- *Access* (example):

```
number n;
n.i=4444;
printf("i: %10d f: %16.10e\n", n.i, n.f);
// Prints: i:          4444      f: 6.227370375e-41

n.f=4444;
printf("i: %10d f: %16.10e\n", n.i, n.f);
// Prints: i: 1166729216      f: 4.4440000000e+03
```

Pointers

Pointers

- Variables are stored in memory using a certain number of bytes (dependent on variable type) and from a specific location (address)
- *Pointers* are used to store memory addresses and to access memory
- & operator: if v is a variable, then &v is the location (address) where *v* is stored in memory
- Pointer declaration (example): `int * p;`
- Usage of pointers (example):

```
int a = 1, b = 2, * p;
p = &a; // Pointer p contains the address of variable a
b = *p; // Variable b contains the content of the variable pointed by p
// Now b = a
```

Pointers: Arrays

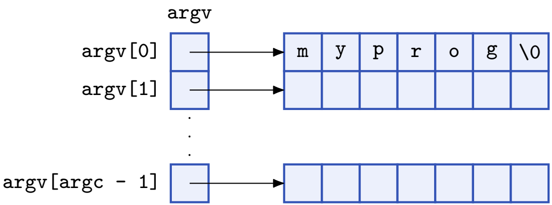
- Pointers and **arrays**

```c
int a[3];
a[0] = 5;
a[1] = 7;
a[2] = 9;
// a[i] is equivalent to *(a + i)
printf("%d == %d\n", a[1], *(a + 1)); // Prints: 7 == 7
```

- It is possible to use pointers notation with arrays and array notation with pointers

Multidimensional arrays: pointers to pointers

- Example: the `argv` argument of method `main` is an array of strings, and it can be seen as a pointer to pointers to char or a bi-dimensional array (`char * argv[]`):



Function pointers (1/2)

- Example

```c
int addInt(int n, int m) {
  return n + m;
}

int main(int argc, char * argv[]) {
  // Definition of funct pointer
  int (*functionPtr)(int,int);

  // Let functionPtr point to addInt
  functionPtr = &addInt;

  // Use the pointer sum == 5
  int sum = (*functionPtr)(2, 3);

  return 0;
}
```

Function pointers (2/2)

- Example

```
void fun(int a) {
  printf("Value of a is %d\n", a);
}

int main(int argc, char * argv[]) {
  // fun_ptr is a pointer to function fun()
  void (*fun_ptr)(int) = &fun;

  // Invoking fun() using fun_ptr
  (*fun_ptr)(10);

  return 0;
}
```

References

References

- Al Kelley, Ira Pohl. *C – Didattica e Programmazione.* Quarta edizione.Pearson. 2004.