Computer Architecture (Practical Class)
Pointers in C

Luís Nogueira

Departamento de Engenharia Informática
Instituto Superior de Engenharia do Porto

lmn@isep.ipp.pt

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Introduction

- A program sees memory as one large array containing bytes
- We do not use the term "index" when refering to a memory location. We use the term *address*
- When you declare a variable, you are reserving one or more continuous bytes of memory
- Each declared variable has an *address*, which indicates where the variable data starts in the memory
- In IA-32 addresses are 32 bits long, thus can vary between 0 and 4GB
- In x86-64 addresses are 64 bits long, pottentially varying between 0 and 16 EB (exabytes) (2^{64})
- Current x86-64 CPUs actually use 48-bit address lines, theoretically allowing 256 terabytes of physical RAM

Pointers

- C has special variables, called *pointers*, that are used to store memory addresses
- Pointers are declared like normal variables, with a type associated to it (we will see how this is used later)

Pointers always have the same size

- The size of an address of the underlying architecture (64 bits = 8 bytes in x86-64)

- Pointers allow direct access to memory, making it possible to change the values in the memory addresses stored in the pointers
- Some tasks are easier/more efficient to implement when using pointers, and some (such as dynamic memory allocation) are only possible using pointers

Pointers: Use and notation

- Just like any variable in C, a pointer must be declared before being used
- A pointer is declared using `type *` before the variable identifier:

```
int *ptr1; // declares a pointer to an integer
char *ptr2; // declares a pointer to a char
```

- To obtain the address of a variable, use '&' before its identifier:

```
int x;
char c;
ptr1 = &x; // store the address of x in ptr1
ptr2 = &c; // store the address of c in ptr2
```

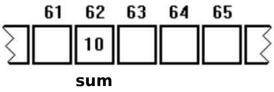
- The *dereference operator* '*' accesses the value at a memory address:

```
*ptr1 = 10; // assign 10 to the value pointed by prt1
*ptr2 = 'X'; // assign 'X' to the value pointed by prt2
```

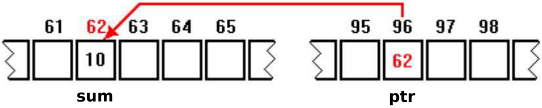
Important note

For the sake of simplicity, in the following schemes, an address is represented in only one byte. DO NOT forget that real addresses always occuppy eight bytes in x86-64

```
char sum;
char *ptr;
sum = 10;
```

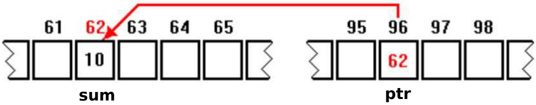



```
ptr = &sum;
```

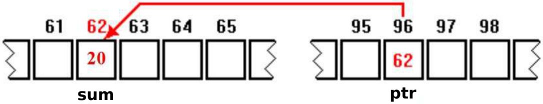


Content of a variable and its address (2/2)

- To access the contents of a memory address in a pointer, use the * operator:




```
*ptr = 20;
```



Pointers should always be initialized to a valid address before being used

- Using an uninitialized pointer has undefined behaviour!

- Wrong way[1]:

```
int x;
int *ptr; // uninitialized pointer

*ptr=22: // this is a very bad idea!
```

- Correct way:

```
int x;
int *ptr;

ptr=&x; // now is initialized to the address of x
*ptr=22: // assign 22 to the memory addressed by ptr (x)
```

[1] This code will, most likely, result in a segmentation fault. A segmentation fault occurs when a program tries to access an invalid memory address. The operating system detects this and terminates the program.

Big/Little Endian

- We have said that the memory is a large array of bytes... So, how do we store data larger than 1 byte?
- Easy: we divide the data into bytes and store it! But, this means we have two ways of storing data in memory:
  - Big Endian
    - Store the most significant byte in the smallest address.
    - Adopted in platforms by Sun, PPC Mac, transferring data on the Internet
  - Little Endian
    - Store the least significant byte in the smallest address.
    - Adopted by x86, ARM

Little Endian example

- Let us assume we want to store the number 305419896 (0x12345678):

31–24	23–16	15–8	7–0
0x12	0x34	0x56	0x78

- Byte by byte

7 6 5 4 3 2 1 0	
0x78	} Address x
0x56	} Address $x+1$
0x34	} Address $x+2$
0x12	} Address $x+3$

Big Endian example

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31–24	23–16	15–8	7–0
0x12	0x34	0x56	0x78

- Byte by byte

7 6 5 4 3 2 1 0	
0x12	} Address x
0x34	} Address $x + 1$
0x56	} Address $x + 2$
0x78	} Address $x + 3$

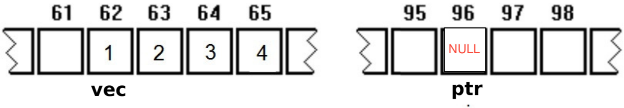
Data representation in x86-64

Listing 1: data-rep.c (http://codepad.org/leCxR8yX)

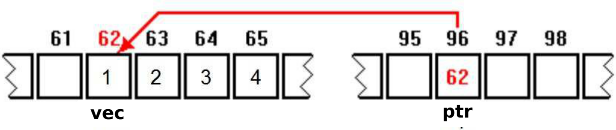
```
#include<stdio.h>
int main(){
    unsigned int i = 0xFFAAEEBB;
    short b = 0x1234;
    char c = 'A';
    unsigned int x = 0x12345678;
    // %p: Pointer address format specifier
    printf("i em %p\n",&i);
    printf("b em %p\n",&b);
    printf("c em %p\n",&c);
    printf("x em %p\n",&x);
    return 0;
}
```

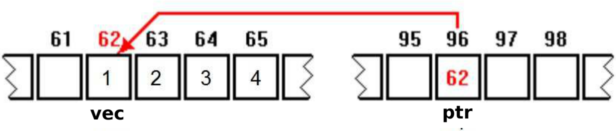
Variable	**Address**	**Memory** (byte by byte in hexadecimal)
i	0x7ffe9854fa7c	bb ee aa ff
b	0x7ffe9854fa7a	34 12
c	0x7ffe9854fa79	41
x	0x7ffe9854fa74	78 56 34 12

```
char vec[4] = {1,2,3,4};
char *ptr = NULL;
```




```
ptr = vec;  /* in the case of arrays, the identifier is the address;
               so, no need for '&' */
```





- You can do *pointer arithmetic*:

```
ptr++; // ptr now is a pointer to the second element of vec
printf("%hhd", *ptr); // will print "2"

ptr+=2; // ptr now is a pointer to the fourth element of vec
printf("%hhd", *ptr); // will print "4"
```

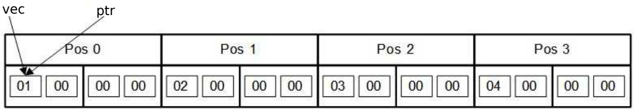
Pointer arithmetic (2/4)

- The type of the pointer is relevant when performing pointer arithmetic (the compiler decides on the number of bytes added or subtracted based on the pointer type)

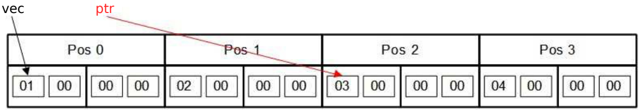
```
int *ptr_total; /*(4 Bytes increments/decrements in x86-64)*/
char *ptr_name; /*(1 Byte increments/decrements in x86-64)*/
```

- Example:

```
int vec[4] = {1,2,3,4};
int *ptr = vec;
```



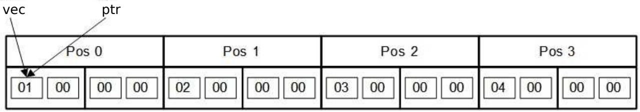

```
ptr = ptr+2;
```



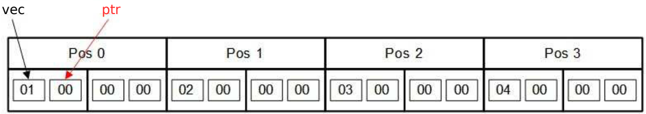
Pointer arithmetic (3/4)

- Now we make `ptr` a `char*`...

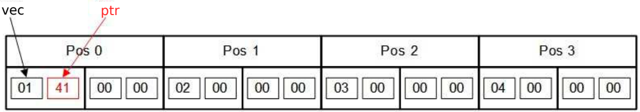
```
int vec[4] = {1,2,3,4};
char *ptr = (char *)vec; // a cast is needed to avoid a warning...
```




```
ptr = ptr+1;
```




```
*ptr = 'A';
```



- Active learning activity: What is the output of the following code ?
    - A. 1 2 3 4 5
    - B. 2 3 4 5 6
    - C. 1 3 5 7 9
    - D. None of the above.

Listing 2: pointer-arith.c (http://codepad.org/V3qmKQkp)

```c
#include<stdio.h>

int main(){
        char arr[]={1,2,3,4,5,6,7,8,9,10};
        short *ptr=(short*)arr; // cast is needed to avoid a warning...
        int i;
        for (i=0; i<5; i++) {
                arr[i] = *( ptr + i );
                printf("%hhd ", arr[i]);
        }
        return 0;
}
```

- Print data to the console using `printf` and `puts`

Listing 3: output.c (`http://codepad.org/swgi0sNG`)

```
#include<stdio.h>

int main()
{
        int a = 2, b = 3;
        int *c = &a, *d = &b;
        printf("Value: %d\n", *c); /*prints the value 2*/

        printf("Address: %p (%p)\n", &a, c);
        /* outputs the address of a*/

        if (*c == *d) puts("Same value"); // false
        *c = 3;
        if (*c == *d) puts("Now same value"); // true
        c = d;
        if (c == d) puts ("Now same address"); // true
        return 0;
}
```

Console I/O - Input

- Reading from the console can prove problematic... here are some solutions.

Listing 4: input.c (http://codepad.org/nmuqfS91)

```
#include<stdio.h>
#include <stdlib.h>
int main()
{
        int n1=-1, n2=-1, n3=-1;
        int *ptr = &n2;
        char buf[BUFSIZ], c;
        /* read integers using scanf(); pass the address of the var. */
        printf ("Enter a number: ");
        scanf("%d", &n1);
        printf ("Enter another number: ");
        scanf("%[^0-9]%d", buf, ptr); // garbage goes to buf...
        /* You will notice that scanf is a bit problematic...
           An option, is to read a string and convert as needed
           First, flush characters scanf() leaves in the input */
        while((c = getchar()) != '\n' && c != EOF) /* discard */;
        printf ("Enter yet another number: ");
        if (fgets(buf, sizeof(buf), stdin) != NULL) {
                n3 = atoi(buf); // returns 0 if conversion fails
                printf ("You entered %d %d %d\n", n1, n2, n3);
                return EXIT_SUCCESS;
        }
        return EXIT_FAILURE; /* if reaches here, fgets() failed */
}
```

Practice

1. Write the representation in memory, in Big endian and Little endian of the following values:
   1. 0x1188 (16 bits)
   2. 0xff3455b6 (32 bits)
   3. 0x28934def (32 bits)
2. Correct the following code:

Listing 5: exerc01.c

```
int main ()
{
  int * ptr ;
  int i;
  int soma=0;

  for (i=0; i<10; i++)
       {
        scanf("%d", ptr);
        soma = soma + *ptr;
        }
  printf("Soma= %d \n", soma);
  return 0;
}
```