COMP 8567 Advanced Systems Programming

Advanced C Programming Techniques
(Pointers and Functions)

Summer 2023

Outline

- Introduction
- Pointers
- Manipulation of pointers
- The special pointer NULL
- Pointer arithmetic + and –
- Pointers and arrays
- The pointer-to void type
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- Passing Parameters by value and reference
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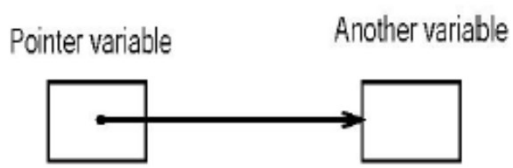
Introduction

Pointers are crucial to C, and they are mainly used to:

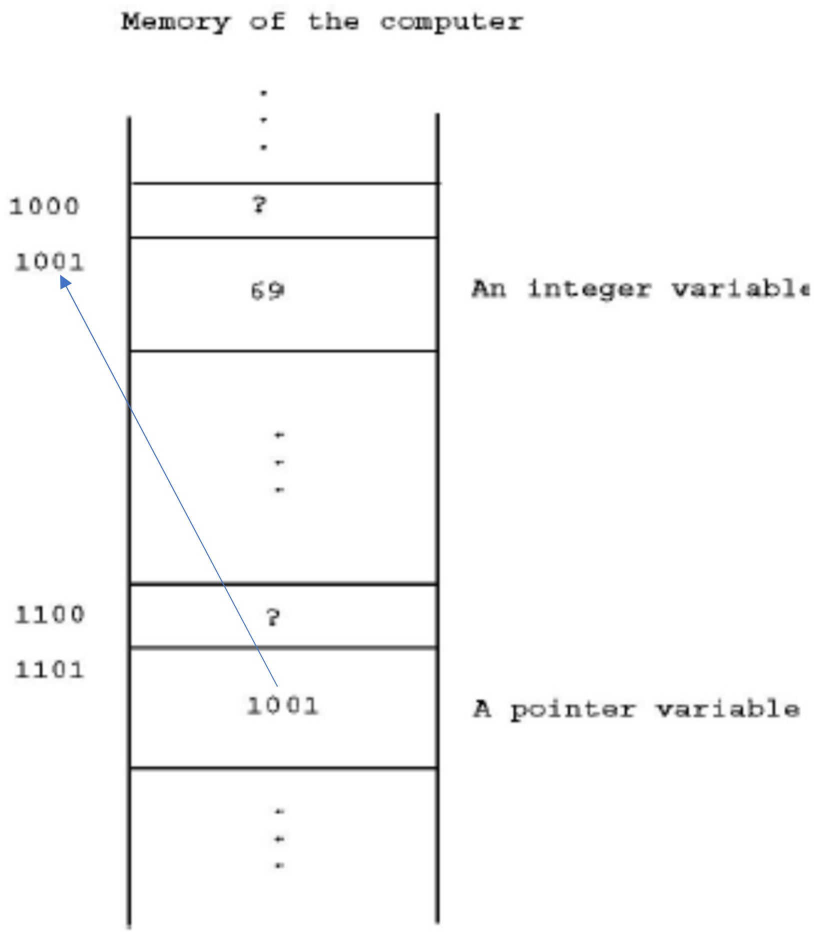
- Provide the means by which functions can modify their **calling arguments.**
- Support the **dynamic allocation** of memory.
- Refer to **a large data structure** in a simple manner.
- Support data structures such as **linked lists.**

Pointers are Addresses

- A pointer is a **<u>variable</u>** whose value is a memory addresses.
- A pointer variable is similar to other variables
  - It requires memory and stores a value.
- However, the purpose of a pointer is special.
- A data variable stores data (e.g. age).
- A pointer variable stores memory addresses (of variables)



A pointer contains/stores the **memory address** of another variable (hence it **points** to another variable)



- Syntax: ***base type *pointer name*;**
- where base type defines the type of variable the pointer can point to.
- Example : **int *ptr; float * p1; int *p2;**
  - ptr is a pointer to an integer variable.
  - p1 is a pointer to a float variable

Pointers- Simple Example //prelim.c

```
# include <stdio.h>

int main(void)
{

int *a; //a is a pointer variable to an integer
int b=100;
a=&b; // pointer variable a is assigned the address of b
*a=200; //dereferencing

printf("\nThe address of b is %d", &b);
printf("\nThe value of a is %d", a);

printf("\nThe value of b is %d", *a);

}
```

Manipulation of Pointers

Operators:

& : a unary operator that returns the address of its operand.

int a=10;

int *ptr; //ptr is a pointer to an integer

ptr=&a; //ptr now contains the address of the integer variable a

* : A unary operator used to **dereference** its operand (a pointer)

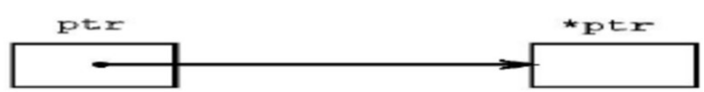
int a=10;

int *ptr;

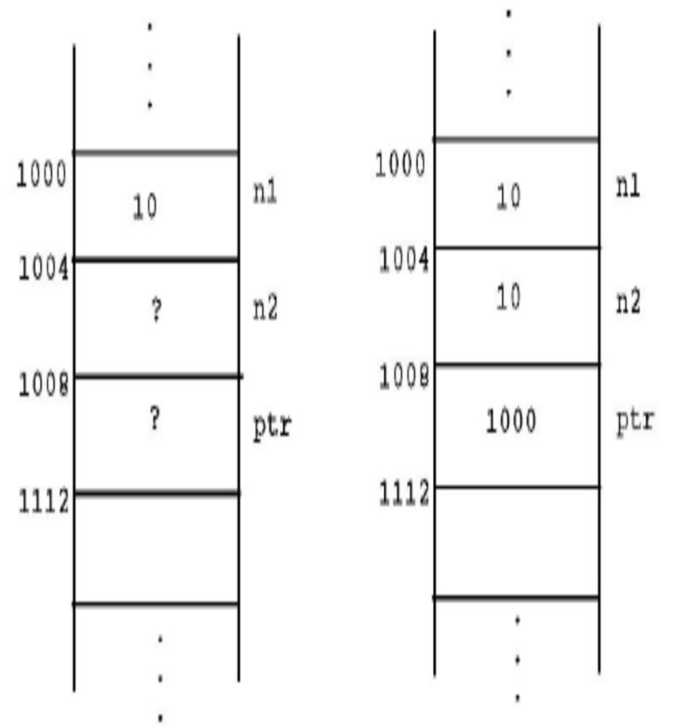
ptr=&a;

***ptr** refers to the **value of the variable** referenced by ptr (i.e variable **a**)

printf("%d",*ptr); //output =10



```
#include <stdio.h>
//ex1.c
int main(void) {

int n1=10, n2;   // 2 variables of type integer

int *ptr;        //a pointer to integer

ptr = &n1;       // ptr = address of num1

n2 = *ptr;    //n2 = value stored at the address pointed by ptr, i.e value of n1

printf("\n n1:%d  n2:%d  *ptr:%d \n\n", n1, n2, *ptr);

return(0);
}
```



Decalaration of n1, n2 and ptr

The contents of n1, n2, and ptr before the end

Pointer Declaration and Assignments: Examples:

float z;

int x, y;

int *ptr1 = &x // Like any variable, pointers can be initialized at declaration time with the address of a compatible variable, but not with a constant

int *ptr2 = &y;

The syntax of the following assignments is correct:

ptr2 = ptr1;

/* ptr2 receives the contents of ptr1 which is the address of x in that case */

*ptr1 = *ptr2; // this is equivalent to x=y

*ptr2 = 4; // this is equivalent to y=4

x = *ptr2; // this is equivalent to x=y

However, the syntax of the following assignments is not correct:

ptr1 = x; // type mismatch: assigning a data value (integer) to a pointer

y = ptr1; // type mismatch: assigning an address to an integer variable

ptr1=&z; // this is wrong because ptr1 is supposed to point to an integer variable and z is declared as float.

Special Pointer NULL //nullp.c

We sometimes need to indicate that a pointer is not pointing to any valid data. For that purpose, the **constant NULL** is defined in **stdlib.h** and can be used in a C program.

A common use of NULL: When a function returning a pointer wants to indicate a failure operation, the function can return NULL to specifically indicate a failure

Example :

```
int *afunction();     /* a function that returns a pointer to an integer */
int *ptr;             /* a pointer to integer */
ptr = afunction();
if (ptr == NULL)      /* afunction() was unsuccessful */
{take-appropriate-action}
```

Pointer Arithmetic

When a pointer is incremented (or decremented), it will point to the memory location of the next (or previous) element of its base type.

Example :

Assume that ptr, a pointer to int, contains the address 200 and n is an integer.

Also assume that the size of an integer is 4 bytes.

ptr+1 will contain the address 200 + 4=204.

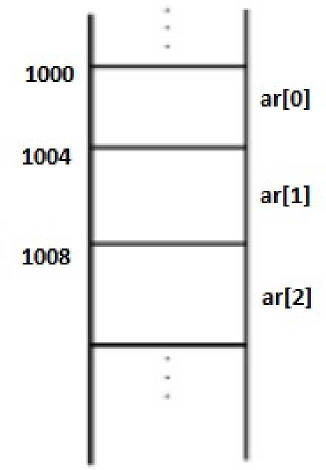
ptr- 1 will contain the address 200 - 4=196.

ptr = ptr + n ptr will contain the address 200 + nx4. //ptr=ptr+2 = ptr+2x4= 208

ptr = ptr - n ptr will contain the addres 200 - nx4. //ptr=ptr-2=ptr-2x4=192

```c
//ex3.c
#include <stdio.h>
int main(void)
{
	int a=100;
	int *p=&a;
	printf("\nThe address of p1 %d\n",p);
	p=p+1;
	printf("\nThe address of  p1+1  is %d\n",p);
	p=p-1;
	printf("\nThe address of  p1-1   is %d\n",p);
	p=p+2;
	printf("\nThe address of  p1+2  is %d\n",p);
	p=p-2;
	printf("\nThe address of  p1-2  is %d\n",p);
}
```

Pointers and Arrays



- Pointers and arrays are closely related.
- In particular, the name of an array is the address of the array's first element.
- For example, the declaration **int ar[3]** reserves 3 consecutive units of memory. Each unit has the same size, size of an integer (e.g., 4 bytes).

&ar[0] = 1000, &ar[1] = 1004, &ar[2] = 1008.
In general, &ar[i] = ar + i 4(size of integer).
ar corresponds to the address 1000.
ar is
a pointer except that it is a <u>constant</u>.

//ex9.c

Pointers and arrays are interchangeable!

Consider the example :

```
main(){
int ar[4] = {5, 10, 15, 20};
int *ptr;
int i;
for (i=0; i<4; i++)
printf(``%d ``, ar[i]);

ptr=ar;   /* Equivalent to ptr=&ar[0] */
for (i=0; i<4; i++)
printf(``%d ``, ptr[i]);
}
```

Important : Because the name of an array is a constant pointer, it is illegal to make the following assignment ar =ptr   (ptr=ar is fine!)

```c
#include <stdio.h> //ex10.c
int main(void){
int ar[4] = {5, 10, 15, 20};
int *ptr; int i;

for (i=0; i<4; i++) {
printf("Using dereferencing %d\n", *(ar+i)); //Print the value of each array element using deferefencing
printf("Using array index %d\n", ar[i]);
}

//Print the values of the array by assigning ptr=ar using dereferencing
ptr=ar; /* Equivalent to ptr=&ar[0] */
for (i=0; i<4; i++){
printf("Using dereferencing %d\n", *(ptr+i));
printf("Using array index %d\n", ptr[i]);
}}
```

Limitations of Pointer Arithmetic

- * , /, and % cannot be used with pointers.
- + and - are restricted : only **integer offsets** can be added to or subtracted from a pointer.
  - ptr1=ptr1+4;
  - ptr2=ptr2-3
- Two pointers **cannot** be added together
  - ptr3=ptr2+ptr2
- A pointer p1 can be subtracted from another pointer p2. The result is an integer, the number of elements(not bytes or addresses) between p1 and p2 (**offset**)
  - p1=p2-p3

Valid:
p1=p1-4
p2=p2-3
p3=p1-p2

```
//arrdiff.c
#include <stdio.h>
int main(void){
int ar[100]; int *p1, *p2;
p1=ar; p2=&ar[60];
printf("p2-p1(offset): %d\n", p2 - p1);
p1=&ar[30]; p2=&ar[80];
printf("p2-p1(offset): %d\n", p2 - p1);
}
```

Note: If p1 and p2 are pointers to integers containing addresses 300 and 400 respectively, p2 - p1 will be equal to (400 - 300)/4 = 25 assuming 4 bytes for the size of an integer.

Recap

- Introduction ✓
- Pointers ✓
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- The Special pointer NULL ✓
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The Pointer to Void Type

- A pointer variable ptr defined as **void * ptr** is a generic pointer variable (it can point to any type)
- Advantage : a pointer to void may be converted, without a cast operation, to a pointer to another data type.
- void *Malloc() //Pointer to Void

```
void *myfunction(); /* a fn that returns a generic ptr
int n1;
int *ptr1;
float n2;
float *ptr2;
ptr2 = &n1; /* Error */
ptr1 = &n1; /* OK */
ptr2 = &n2; /* OK */
ptr1 = myfunction(); // OK 'void *' is casted to 'int *' */
ptr2 = myfunction(); // OK, 'void *' is casted to 'float *'
```

Important : Pointers to void **cannot be dereferenced**

Example :

```
int n;
void *ptr=&n;
*ptr = 25;   /* Error */

void *ptr;
int a=200;
ptr=&a;
int *b;
b=ptr;
```

```c
# include <stdio.h>
//void.c
main()
{
void * ptr1;
int a=100;
ptr1=&a;
printf("\n The current address of the generic pointer ptr1 is %d\n", ptr1);

float b=20.32;

ptr1= &b;
printf("\n The current address of the generic pointer ptr1 is %d\n", ptr1);

//printf("%f",*ptr1); //generic pointers cannot be dereferenced

/*
float *temp;
temp =ptr1;
printf("%f",*temp);
*/
}
```

Dynamic Memory Allocation

There are 3 types of memory allocation in C:

Static allocation : a variable's memory is allocated and persists throughout the entire life of the program. This is the case of **global variables**.

Automatic allocation : When local variables are **declared inside a function**, the space for these variables is allocated when the function is called (starts) and is freed when the function terminates. This is also the case of parametric variables.

Dynamic allocation :

Allows a program at the execution time to allocate memory **when needed** and to **free it** when it is no longer needed. Advantage : it is often impossible to know, prior to the execution time, the size of memory needed in many cases. For example, the size of an array based on any input size n

- Through its standard library (include stdlib.h), C provides functions for allocating new memory from the heap (available unused storage).
- The most commonly used functions for managing dynamic memory are :
  - **void * malloc(int size)** : to allocate a block (number of bytes) of memory of a given **size** and returns a pointer to this newly allocated block.
  - **void free(void *ptr)** : to free a previously allocated block of memory.
- Note: **sizeof** is an operator often used with malloc. It returns the size in bytes of its operand(a data type name or a variable name). For instance, sizeof(char)=1   //so.c

Example : ex8.c

```
main(){
int *ptr1;
float *ptr2;

ptr1 = malloc (sizeof(int)); /* allocate space for an integer */

ptr2 = malloc (sizeof(float)); /* allocate space for a float */

*ptr1 = 20;
*ptr2 =13.5;
free(ptr1); /* free previously allocated space */
free(ptr2);
}
```

Dynamic Arrays

When the size of an array is not known before the execution time, allocating arrays dynamically is a good solution.

The steps for creating a dynamic array are :

1. Declare a pointer with an appropriate base type.

2. Call malloc to allocate memory for the elements of the array. The argument of malloc is equal to the **desired size of the array multiplied by the size in bytes of each element of the array**.

3. Assign the result of malloc to the pointer variable.

```
#include <stdio.h>
#include <stdlib.h> //dynarr.c
int main(void) {
int *ar,n;
printf("\nEnter the number of elements in the array\n");
scanf("%d",&n);
ar=malloc(n*sizeof(int));

        for(int i=0;i<n;i++)
        {
        printf("Enter element %d\n", i);
        scanf("%d",&ar[i]);
        }
        printf("\nThe elements of the array are\n");
        for(int i=0;i<n;i++)
        {
        printf("\n%d",ar[i]);
        }
free(ar);
//End dynarr.c
}
```

Declared Array vs. Dynamic Array

Declared arrays vs. dynamic arrays

- The memory associated with a declared array is allocated automatically when the function containing the declaration is called whereas, the memory associated with a dynamic array is not allocated until malloc is called.
- The size of a declared array is a constant and must be known prior to the execution time whereas, the size of a dynamic array can be of any size and need not to be known in advance.

IMPORTANT: If the heap runs out of space, malloc will return a NULL instead of a pointer to void

ar = malloc(n * sizeof(float));

if (ar == NULL) // malloc has failed take-appropriate-action and suitable message has to be displayed

Passing Parameters by Address (Reference)

- One of the most common application of pointers in C is their use as function parameters, making it possible for a function to get the **address of actual parameters**.
- When an argument (parameter) is passed by address to a function, the latter receives the **address** of the actual argument which is passed as a **pointer from the calling function.**
- Passing by values creates **copies of the variables** and results in wastage of space and processing power
- **Pointers can be directly dereferenced and manipulated as required**
- Passing by reference is more efficient in terms of memory and speed.

Example: Passing by Reference

```
#include <stdio.h>
//pbyref.c

void swapnum(int *i, int *j) {
  int temp = *i;
  *i = *j;
  *j = temp;
}

int main(void) {
  int a = 10;
  int b = 20;
  swapnum(&a, &b);
  printf("\nPassing by reference\n");
  printf("After swapping, a is %d and b is %d\n", a, b);
  return 0;
}
```

Passing Functions as Parameters

- C allows functions to be passed as arguments.
- How to declare a pointer to functions?

Some Examples:

- Pointer to a function with no parameters and not returning anything.
  - void (*ptrFunc)();
- Pointer to a function with one integer parameter and returning a value **double**
  - double (*ptrFunc)(int)
  - ptrFunc=abc;
- Pointer to a function with two parameters (int, float) and returning a value **int**
  - int (*ptrFunc)(int,float);

```
#include <stdio.h> //ptof.c

int add(int a,int b)
{
return a+b;
}

int subtract(int a,int b)
{
return a-b;
}

int main(void)
{
int (*f1)(int, int);

f1=add;  //the address of the add function is assigned to pointer f1
int retvalue=f1(10,20);

printf("\nThe return value is %d\n",retvalue);

f1=subtract; //the address of the add function is assigned to pointer f1

retvalue=f1(10,20);
printf("\nThe return value is %d\n",retvalue);
}
```

```c
#include <stdio.h>
int print1()
{
   printf("\nHello World from print1!\n");
   return 0;
}
int print2()
{
   printf("\nHello World from print2!\n");
   return 0;
}
void helloworld(int (*fn)(),int (*fn1)())
{
fn();
 fn1();
}
```

```c
//fap.c
int main(void)
{
   helloworld(print1,print2);
   return (0);
}
```

- // fap9.c

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THANK YOU