Pointer & Structure

In this chapter, we are going to explore two very powerful data structures. One of them is *pointer* and another one is *structure* or `struct` in short. We will start with the basic concept of pointer. Later we will dive deeper with lots of examples and their explanations using pointer. Finally, we will be ending this chapter by learning about structures and how powerful they are.

1.1 Pointer

Pointer deals with the address or location in the memory of the computer/ machine assigned to a certain value/ variable in the program. We are going to start by learning about the basics of pointer variables and finish the topic strongly with some advanced examples.

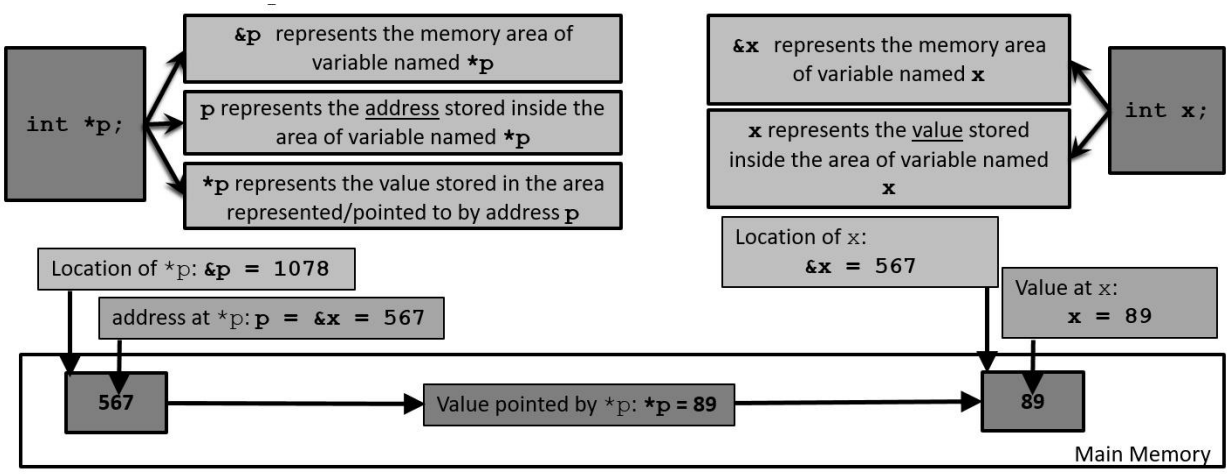
1.1.1 Variable

The computer accesses its memory not by using variable names but by using a memory map where each location of memory is uniquely defined by a number, called the address. Pointers are a very powerful, but primitive facility to avail that address.

To understand pointer let us go through the concept of variables once more. A variable is an area of memory that has been given a name. For example, `int x;` is an area of memory that has been given the name `x`. The instruction `x=10;` stores the data value `10` in the area of memory named `x`. The instruction `&x` returns the address of the location of variable `x`.

A pointer is a variable that stores the location of a memory/ variable. A pointer has to be declared. For example, `int *p;` Adding an asterisk (called the dereferencing operator) in front of a variable's name declares it to be a pointer to the declared type. Here, `int *p;` is a pointer – which can store an address of a memory location where an integer value can be stored or which can store an address of the memory location of an integer variable. For example, `int *p, q;` declares `p`, a pointer to `int`, and `q` an `int` and the instruction: `p=&q;` stores the address of `q` in `p`. After this instruction, conceptually, `p` is pointing at `q`.

After declaring a pointer `*p` variable, it can be used like any other variable. That is, `p` stores the address or pointer, to another variable; `&p` gives the address of the pointer variable itself, and `*p` is the value stored in the variable that `p` points at. The following figure illustrates the use of pointer in detail.



We can also take a look at an example in C++ below with output to better understand the basic use of pointers in programming language

```
1 // Understanding pointer variable
2 void main( void )
3 {
4  int x = 10;
5  int *p = &x;
6  int y = *p;
7  cout <<"Address of integer variable x: "<< &x <<"\n";
8  cout <<"Value stored in the memory area of x: "<< x <<"\n";
9  cout <<"Address of integer pointer variable *p: "<< &p <<"\n";
10 cout <<"Address stored in the area of pointer *p: "<< p<<"\n";
11 cout <<"Address of integer variable y: "<< &y <<"\n";
12 cout <<"Value pointed to by the pointer *p: "<< *p <<"\n";
13 cout <<"Value stored in the memory area of variable y: "<< y <<"\n";
14 }
```

```
Address of integer variable x: 0x8fbbfff0
Value stored in the memory area of x: 10
Address of integer pointer variable *p: 0x8fbbfff4
Address stored in the area of pointer *p: 0x8fbbfff0
Address of integer variable y: 0x8fbbfff8
Value pointed to by the pointer *p: 10
Value stored in the memory area of variable y: 10
```

variable	Memory Address	value	
int x	0x8f86fff0	10	x=10 &x=0x8f86fff0
	0x8f86fff1		
	0x8f86fff2		
	0x8f86fff3		
int *p	0x8f86fff4	0x8f86fff0	p=0x8f86fff0 &p=0x8f86fff4 *p=*(0x8f86fff0) =*(&x)=x=10
	0x8f86fff5		
	0x8f86fff6		
	0x8f86fff7		
int y	0x8f86fff8	10	y=*p=10 &y=0x8f86fff8
	0x8f86fff9		
	0x8f86fffa		
	0x8f86fffb		

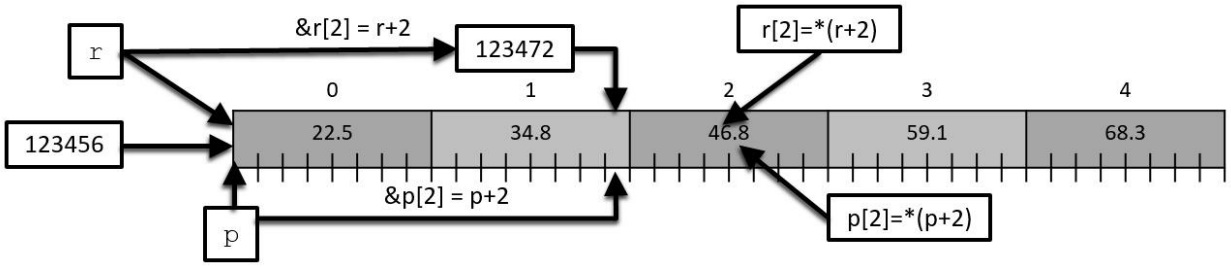
1.1.2 Pointer & Array

An array is simply a block of memory. An array can be accessed with pointers as well as with [] square brackets. The name of an array variable is a pointer to the first element in the array. So, any operation that can be achieved by an array subscription can also be done with pointers or vice-versa. The following example will clarify this idea. Take a look at the C++ code snippet below and its output.

```
1 void main( void )
2 {
3  float r[5] = {22.5,34.8,46.8,59.1,68.3};
4  cout <<"1st element: "<< r[0] <<"\n";
5  cout <<"1st element: "<< *r <<"\n";
6  cout <<"3rd element: "<< r[2] <<"\n";
7  cout <<"3rd element: "<< *(r+2)<<"\n";
8  float *p;
9  p = r; //&r[0]
10 cout <<"1st element: "<< p[0] <<"\n";
11 cout <<"1st element: "<< *p <<"\n";
12 cout <<"3rd element: "<< p[2]<<"\n";
13 cout <<"3rd element: "<< *(p+2)<<"\n";
14 for(int i=0; i<5; i++, p++)
15  cout <<"Element "<<(i+1)<<" is: "<<*p<<"\n";
16 }
```

```
1st element: 22.5
1st element: 22.5
3rd element: 46.8
3rd element: 46.8
1st element: 22.5
1st element: 22.5
3rd element: 46.8
3rd element: 46.8
Element 1 is: 22.5
Element 2 is: 34.8
Element 3 is: 46.8
Element 4 is: 59.1
Element 5 is: 68.3
```

In the above example, the array `float r[5];` or the pointer variable `*p` (after `p=r`) is a pointer to the first floating-point number in the declared array. The 1st element of the array, `22.3`, can be accessed by using: `r[0]`, `p[0]`, `*r`, or `*p`. The 3rd element, `46.8`, could be accessed by using: `r[2]`, `p[2]`, `*(r+2)` or `*(p+2)`. Now, let's examine the notation `(r+2)` and `(p+2)` below.



Assuming the starting address of the array numbers is 123456 –

```
r[0]=(r+0) starts at address,
   ⇨ r+0*sizeof(float)
   ⇨ 123456 + 0 * 8
   ⇨ 123456

r[1]=(r+1) starts at address,
   ⇨ r+1*sizeof(float)
   ⇨ 123456 + 1 * 8
   ⇨ 123464
```

```
r[2]=(r+2) starts at address,
   ⇨ r+2*sizeof(float)
   ⇨ 123456 + 2 * 8
   ⇨ 123472
```

1.1.3 Void Pointer

The `void` type of pointer is a special type of pointer which represents the absence of type. So, `void` pointers are pointers that point to a value that has no type (and thus also an undetermined length and undetermined dereference properties). This allows `void` pointers to point to any data type, `int`, `float`, `char`, `double`, or any type of array. But the data pointed by them cannot be directly dereferenced since we have no type to dereference to. So, we need to cast the address in the `void` pointer to some other pointer type that points to a concrete data type before dereferencing it. Let us look at the following example and try to understand how void pointer works here.

```
1  // increaser                                  Y, 1603
2  void increase(void *data, int psize){
3    if ( psize == sizeof(char) ){
4       char *pchar;
5       pchar=(char*)data;
6       ++(*pchar);
7    }
8    else if (psize == sizeof(int)){
9       int *pint;
10      pint=(int*)data;
11      ++(*pint);
12   }
13 }
14 void main (void){
15   char a = 'x';
16   int b = 1602;
17   increase (&a,sizeof(a));
18   increase (&b,sizeof(b));
19   cout << a << ", " << b << endl;
20 }
```

In the example above, we start with the `main` function where two variables `char a` and `int b` is created with the values `'x'` and `1602` respectively (line 15-16). Line 17 calls the function `increase` with the address of `a` and the size of `a` as parameters. `sizeof(a) = sizeof(char) = 1`, as char type is one byte long. Line 17 gives the control to the function `increase` and it creates two (parameter) variables `void *data` and `int psize` assigned with the address value of a and `sizeof(a) = 1` of main respectively. Though `*data` contains the address of `a` in `main`, this address cannot be accessed using `*data` with type mismatch. With the `true` value of the conditional statement `psize==sizeof(char)` another new pointer

variable `char *pchar` is created and is assigned the value `*data` (line 3-5). As `*data` has no type, it must be type casted to `(char*)` before being assigned (line 5).With the statement `++(*pchar);` pointer variable `*pchar`, pointing to `a` of `main`, is increased by one. So, the value of `a` in `main` is changed to `'y'` (the ASCII value is increased by one) (line 6). Before exiting the function `increase`, the variables created by `increase` is destroyed. Then the control goes back to the function `main` (in line 17). So, we see the value `a` in `main` is changed to `'y'`.

Line 18 calls the function `increase` with address of `b` and the size of `b` as parameters. Here, `sizeof(b) = sizeof(int) = 4`, as `int` type is four bytes long. Now the control goes to the function `increase` and it creates two (parameter) variables `void *data` and `int psize` assigned with the address value of `a` and `sizeof(b) = 4` of `main` respectively. With the `true` value of the conditional statement `psize==sizeof(int)`, a new pointer variable `int *pint` is created and assigned to the value, `*data` (line 8-10). Though `*data` contains the address of `b` in main, this address cannot be accessed using `*data` with type mismatch (line 10). As `*data` has no type, it must be type cast to `(int*)` before being assigned (line 10). With the statement `++(*pint);` pointer variable `*pint`, pointing to `b` of `main`, is increased by one. So, the value of `b` in the main is changed to `1603` (line 11). Before exiting the function `increase`, the variables created by `increase` is destroyed. Then the control goes back to the function `main` (in line 17). So, we see the value `b` is changed to `1063`.

1.1.4 NULL Pointer

A `NULL` pointer is a regular pointer of any pointer type which has a special value that indicates that it is not pointing to any valid reference or memory address. This value is the result of type-casting the integer value `zero` to any pointer type.

```
1 int *p;
2 p = 0;  //can also be written, p = NULL;
3 /* p has a null pointer value */
```

Do not confuse `NULL` pointers with `void` pointers. A `NULL` pointer is a value that any pointer may take to represent that it is pointing to "nowhere", while a `void` pointer is a special type of pointer that can point to somewhere without a specific type. One refers to the value stored in the pointer itself and the other to the type of data it points to.

1.1.5 Dynamic Memory Allocation

The exact size of an array is unknown until the compile-time, i.e., the time when a compiler compiles code written in a programming language into an executable form. The size of an array declared initially can be sometimes insufficient and sometimes more than required. Also, what if we need a variable amount of memory that can only be determined during runtime? Dynamic memory allocation allows a program to obtain more memory space while running or to release

space when no space is required. C++ integrates the operators `new` and `delete` for dynamic memory allocation.

To request dynamic memory we use the operator `new`. The operator `new` is followed by a data type specifier. If a sequence of more than one memory block is required, the data type specifier is followed by the number of these memory blocks within brackets `[]`. It returns a pointer to the beginning of the new block of memory allocated. Syntax:

```
1 pointer = new vtype;
2 pointer = new vtype [number_of_elements];
```

The first expression is used to allocate memory to contain one single element of type `vtype`. The second one is used to assign a block (an array) of elements of type `vtype`, where `number_of_elements` is an integer value representing the amount of these.

Since the necessity of dynamic memory is usually limited to specific moments within a program, once it is no longer needed it should be freed so that the memory becomes available again for other requests of dynamic memory. This is the purpose of the operator delete, whose format is:

```
1 delete pointer;
2 delete [] pointer;
```

The first expression should be used to delete memory allocated for a single element, and the second one for memory allocated for arrays of elements. The value passed as an argument to delete must be either a pointer to a memory block previously allocated with `new`, or a `null` pointer (in the case of a `null` pointer, `delete` produces no effect).

We have learned about dynamic programming and what the keywords `new` and `delete` do. Now, we will take a look at an example (C++ code snippet) below to better understand their functionalities. Run this in your IDE.

```
1 // new, delete
2 void main(void){
3     int n, i,*ptr, sum=0;
4     cout << "# of elements: ";
5     cin >> n;          //input 5
6     ptr = new (nothrow) int[n];
7     if(ptr==NULL){  //ptr==0
8       cout << "Error! not
9 allocated.";
10      return 1;
11    }
12    cout << "Enter elements:\n";
13    for(i=0;i<n;++i)
14    {   //input 2 6 7 4 3
15        cin >> *(ptr+i);  //ptr[i]
16        sum += *(ptr+i);
17    }
18    cout << "Sum = " << sum;
19    delete [] (ptr);
20    //memory de-allocated
  }
```

```
# of elements: 5
Enter elements:
2
6
7
4
3
Sum = 22
```

1.1.6 Pointer & Function

Passing arguments to functions by value, there is no direct way for the called function to alter a variable in the calling function. Pointer arguments enable a function to access and change objects in the function that called it. Let's consider the example below.

```
1 /* Swap two numbers using function. */
2 void swap(int *a, int *b);
3 void main(void){
4   int num1=5,num2=10;
5   swap(&num1,&num2);
6   /* address of num1, num2 is passed */
7   cout<<"Number1 = "<<num1<<"\n";
8   cout<<"Number2 = "<<num2;
9 }
10 void swap(int *a, int *b){
11 //a,b points to &num1,&num2 respectively
12   int t;
13   t = *a;
14   *a = *b;
15   *b = t;
16 }
```

```
Number1 = 10
Number2 = 5
```

The program starts with function `main` getting the control and creating two variables `num1` and `num2` with values `5` and `10` respectively (line 4). Function `main` calls the function `swap` with two parameter values `&num1` and `&num2` (line 5). So, the address of `num1` and `num2` is sent through the parameter of `swap`.

Now the control goes to the function `swap` and it creates two pointer (parameter) variables `*a` and `*b` assigned with the address values of `num1` and `num2` of main respectively. Another variable `t` is created (line 12). With the statement `t=*a;` variable `t` is assigned to the value, `num1` of `main`, pointed to by pointer `*a` (line 13). With the statement `*a = *b;` pointer variable `*a`, pointing to `num1` of `main`, is assigned to the value, `num2` in `main`, pointed to by pointer `*b` (line 14). With the statement `*b = t;` pointer variable `*b`, pointing to `num2` of `main`, is assigned to the value of `t` (line 15). Any changes we make to `*a` and `*b` in function `swap`, will change the values of `num1` and `num2` respectively in function `main` as `a` is pointing to `num1` and `b` is pointing to `num2`.

Before exiting the function `swap`, the variables created by `swap` is destroyed. Then the control goes back to the function `main` (in line 5). But nothing changes for the values of the variables `num1` and `num2` of main due to the destruction of the variables `*a` and `*b`. Because destruction only destroys the space provided for `*a` and `*b`. It does not destroy the space it was pointing to. Whatever changes were made in `swap` by `*a` and `*b`, they remain.

1.1.7 Pointer, Array & Function

We now know the strong relation pointers and arrays share. We have also seen previously that we can send pointer variables as function parameters. Now it is time for us to explore some examples of how these three might work together.

```
1 // arrays as parameters
2 void TwiceArray (int arg[], int length) {
3   for (int n=0; n<length; n++) arg[n] *= 2;
4 }
5 void PrintArray(const int arg[], int
6 length){
7   for (int n=0; n<length; n++)
8     cout<<arg[n];
9   cout<<endl;
10 }
11 void main (void){
12   int FirstArray[3] = {5, 10, 15};
13   int SecondArray[] = {2, 4, 6, 8, 10};
14   TwiceArray (FirstArray,3);
15   PrintArray (FirstArray,3);
16   PrintArray (SecondArray,5);
  }
```

In the above example, we start with the function `main` where two arrays, `FirstArray` with 3 elements and `SecondArray` with 5 elements, are declared, created, and initialized (line 11-12). Both these identifiers will hold the starting address/location of their elements. `FirstArray` holds the location of the first element, `&FirstArray[0]` and `SecondArray` holds the location of the first element, `&SecondArray[0]`.

Then, the `TwiceArray` is called with the parameters `FirstArray`, the starting location of the array itself or the location of the first element is passed to the parameter int `arg[]` and value `3` to the parameter length (line 13). The identifier `arg` holds the starting address of the `FirstArray` of the function `main`. As `arg` itself is an array, `arg` behaves like an array. The control is transferred from the function `main` to function `TwiceArray` (line 2).

Inside function `TwiceArray` another variable `n` is declared. Using `n` in *for-loop* 3 elements of `arg` are made twice of their original (line 3). As `arg` represents the array `FirstArray` on main, the 3 elements of the `FirstArray` are made twice. Hypothetically, `FirstArray[n] <- arg[n]*=2`.

Before exiting from the function `TwiceArray`, all the variables (`arg`, `length`, `n`) are destroyed and the control is returned to the `main` (line 13). Values of `FirstArray` changed in `TwiceArray` remain. Next, the function `PrintArray` is called to print the elements of the `FirstArray` and `SecondArray` consecutively. Here, it works as same in terms of parameter passing. Except for the parameter `arg` in `PrintArray` which is declared as a constant variable. As we do not need to change any elements of the array inside `PrintArray`, the parameter `arg` is declared as a constant variable. This is how any function (`main` in this example) can protect its data array (`FirstArray`) from being changed by another function (`PrintArray`).

Let us take a look at another example, where we will also know about another need of using dynamic memory allocation:

```
1 //Array Multiplication
2 int *ArrMul(int a[], int b[], int size){
3   int i,*c = new int[size]; //c[5]
4   for(i=0; i<size; i++) c[i] = a[i] * b[i];
5   return c;
6 }
7 void PrintArr(int *a, int size){
8   for(int i=0; i<size; i++) cout<<a[i]<<"\t";
9   cout << "\n ";
10 }
11 void main(void){
12   int *z, x[5]={1,2,3,4,5}, y[5]={5,6,7,8,9};
13   z = ArrMul(x, y, 5);
14   cout <<"First array:\n";
15   PrintArr( x, 5 );
16   cout <<"second array:\n";
17   PrintArr( y, 5 );
18   cout <<"result array:\n";
19   PrintArr( z, 5 );
20   delete [] (z); //memory deallocated. If you
21 look carefully, we are deallocating the same
   memory that we allocated, because that memory
   was passed to variable z from variable c;
   }
```

```
First array:
1   2   3   4   5
second array:
5   6   7   8   9
result array:
5   12  21  32  45
```

Two array `x` and `y` with five elements are multiplied index wise using the function `ArrMul`. Function `ArrMul` (line 2-6) dynamically allocates memory for the resultant array `c` of the multiplication.

Before exiting from function `ArrMul` the address stored in `*c` returned and all the variables created in `ArrMul` are destroyed. The control is transferred to `main` and `z` is assigned to the address value returned by `c` of `ArrMul` (line 13). Then the arrays represented by `x`, `y`, and `z` are printed using function `PrintArr` (line 14-19). Line 20 de-allocates the memory allocated to `*c` in function `ArrMul` (line 3) and later returned to `*z` in function `main` (line 13). A dynamically allocated memory must be de-allocated.

Consider the case (example below), if dynamic array `*c` in `ArrMul` was declared as an array `c[5]`. That is, instead of int `*c = new int[size]` in line 3, if it was `int c[5]`, the following would happen.

```
1 //Array Multiplication
2 int *ArrMul(int a[], int b[], int size){
3   int i, c[5];
4   for(i=0; i<size; i++) c[i] = a[i] * b[i];
5   return c;
6 }
7 void PrintArr(int *a, int size){
8   for(int i=0; i<size; i++)
9 cout<<a[i]<<"\t";
10  cout << "\n ";
11 }
12 void main(void){
13  int *z,x[5]={1,2,3,4,5},y[5]={5,6,7,8,9};
14  z = ArrMul(x, y, 5);
15  cout <<"First array:\n";
16  PrintArr( x, 5 );
17  cout <<"second array:\n";
18  PrintArr( y, 5 );
19  cout <<"result array:\n";
20  PrintArr( z, 5 );
21 }
```

The address represented by `c` is returned and all the variables created in `ArrMul` are destroyed and control is transferred to main at the exit from `ArrMul`. The address represented by `c` is returned and all the variables created in `ArrMul` are destroyed and control is transferred to `main` at the exit from `ArrMul`. The pointer variable `*z` is assigned to the address value returned by `c` (line 14). Then, `PrintArr` finds an error when trying to print the array `z` (line 20), as the address represented by `z` has already been destroyed at the exit of the function `ArrMul`. So, while returning a pointer to any variable or memory area, we must make sure that the returned memory area is active or not destroyed after the return.

So far in this section, we have seen examples regarding 1D array. Let us explore the case when we need to send a 2D array as a parameter to a function. We can consider the following example of that case.

```
1  #include<iostream>
2  using namespace std;
3
4  void matrixAddition(int a[][2], int b[][2]){
5      int c[2][2];
6      for(int i=0; i<2; i++){
7          for(int j=0; j<2; j++){
8              c[i][j] = a[i][j] + b[i][j];
9              cout<<c[i][j]<<"\t";
10         }
11         cout<<endl;
12     }
13 }
14
15 int main(){
16     int m[][2] = {{1,2}, {3,4}};
17     int n[][2] = {{5,6}, {7,8}};
18     matrixAddition(m,n);
19     return 0;
20 }
```

The above example is about matrix addition where two 2D arrays `m` & `n` of the same size are sent to a function `matrixAddition` as a parameter where they are added by their similar indices and saved into another 2D array `c` of same size simultaneously. In the process, `c` is also printed out. There are some new things to take away from this example. First of all, to initialize a 2D array, mentioning the 1st dimension is optional. However, the 2nd dimension must be mentioned. Also, in line 4, when receiving the array address' sent to the `matrixAddition` function as a parameter, we may use only the 2nd dimension (1st dimension is optional).

1.1.8 Pointers & Initialization

Consider the statement `int *p;` which declares a pointer `p`, and like any other variable, this space will contain garbage (random numbers), because no statement like `p = &someint;` or `p = new int;` has yet been encountered which would give it a value.

Writing a statement `int *p=2000;` is syntactically correct as `p` will point to the 2000th byte of the memory. But it might fail as byte `2000` might be being used by some other program or maybe being used by some other data type variable of the same program. So such initialization or assignment must be avoided unless the address provided is guaranteed to be safe.

Let us take a look at one of the important differences between some pointer definitions. They are given below:

```
char amsg[] = "now is the time"; /* an array */
char *pmsg = "now is the time"; /* a pointer */
```

- Here, `amsg` is an array, just big enough to hold the sequence of characters and `'\0'` that initializes it. Individual characters within the array may be changed but `amsg` will always refer to the same storage and size after declaration and initialization.
- On the other hand, `pmsg` is a pointer, initialized to point to a string constant; the pointer may subsequently be modified to point elsewhere, but the result is undefined if you try to modify the string contents.

1.2 Structure

The array takes simple data types like `int`, `char`, `double`, etc. and organizes them into a linear array of elements all of the same type. Now, consider a record card that records name, age, and salary. The name would have to be stored as a `string`, the age could be `int` and salary could be `float`. As this record is about one person, it would be best if they are all stored under one variable. At the moment the only way we can work with this collection of data is as separate variables. This isn't as convenient as a single data structure using a single name and so the C++ language provides *structure*. A *structure* is an aggregate data type built using elements of other types.

1.2.1 Defining Structure in C++

In general "structure" in C++ is defined as follows:

```
struct name{
  list of component variables
};
```

Here `struct` is the keyword, `name` is an identifier defining the structure name, `list of component variables` declares as much different type of variables as needed. The structure name works as the new data type defined by the user. The definition ends with a semicolon. For example, suppose we need to store a name, age, and salary as a single structure. You would first define the new data type using:

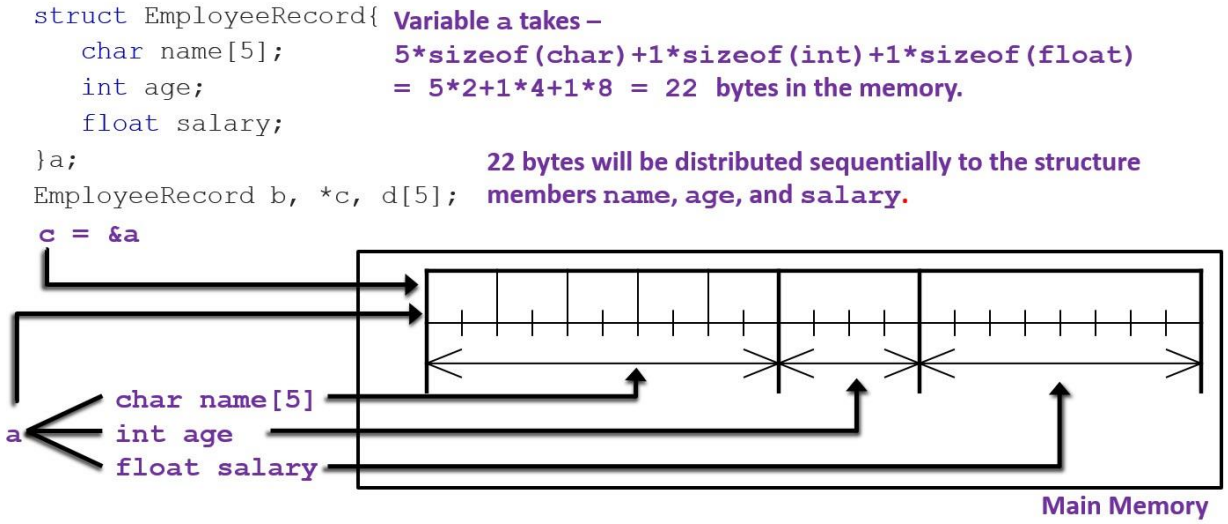
```
struct EmployeeRecord{
   char name[5];
   int age;
   float salary;
};
```

So, `EmployeeRecord` is the new user-defined data type and a variable `b` of type `EmployeeRecord` can hold a total of 22 bytes of information [5 consecutive characters (5*2=10 bytes), followed by an integer (4 bytes), and a floating-point number (8 bytes)]. Just like when we

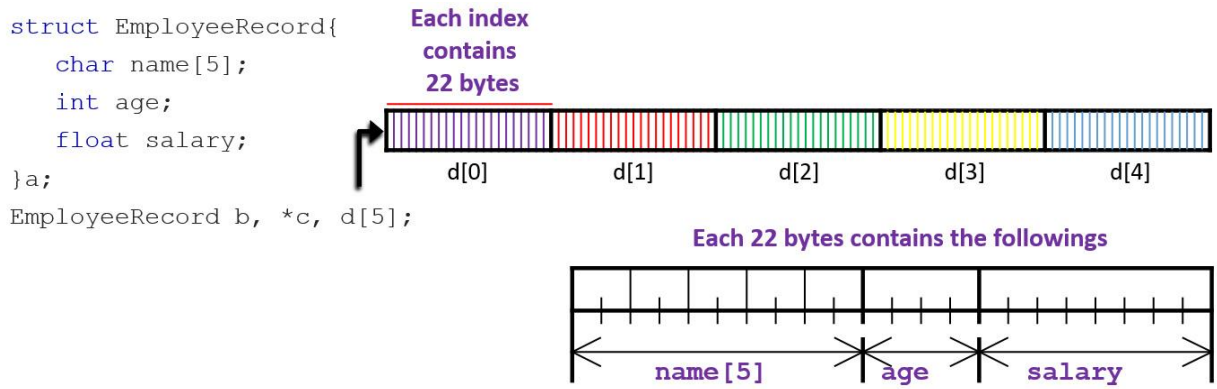
say an `int` is a compiler defined data type and a variable `x` of type `int` can hold 4 bytes of an integer number.

1.2.2 Declaring Variable of a Structure

As we can declare variables for compiler defined data types (example: `int a, b, *c, d[50];`), we can do the same for user-defined data type created using `struct`.



In the above example, it is illustrated in detail how much memory is required for a variable of type `EmployeeRecord`. Also, the use of pointer is available for structure variables like any other variable of any type. Understandably, to store the address of a `struct` variable, the type of the pointer variable should be the same as the `struct` variable. In this case, `EmployeeRecord`.



Above, we can see the illustration of the memory arrangement of an array `d[5]` of type `EmployeeRecord`. As each `EmployeeRecord` is of 22 bytes in size, an array of 5 elements of such type should hold 110 bytes of data.

1.2.3 Accessing & Initializing Structure Member/ Variable

The dot (.) or combination of dash-line and greater-than sign (->) is used as operator to refer to members of struct. For example,

```
struct EmployeeRecord{
   char name[5];
   int age;
   float salary;
};
EmployeeRecord x, y[5], *p;
x.age = 22;
x.salary = 1234.56;
strcpy(x.name, "Sam");
y[2].age = 22;
p = &x;
p->age = 22;
```

In the above example, variable `x` is of type `EmployeeRecord`, `x.age` is of type `int`, `x.salary` is of type `float`, `x.name` is of type `char[5]`, `y[2].age` is of type `int` where `y[2]` is of type `EmployeeRecord` and represents the 3rd element, and `p->age` is of type `int` where `p` is a pointer pointing to variable `x` of type `EmplyeeRecord`. Operator (->) is used for a pointer variable of struct instead of (.). Here, `p->age` can be represented as `(*p).age` also. Member variables can be used in any manner appropriate for their data type.

To initialize a `struct` variable, follow the `struct` variable name with an equal sign, followed by a list of initializers enclosed in braces in sequential order of definition. For example,

```
EmployeeRecord x = {"Sam", 22, 1234.56};
```

Here, `"Sam"` is copied to the member `name` referred to as `x.xame`, `22` is copied to the member `age` referred to as `x.age`, and `1234.56` is copied to the member `salary` referred to as `x.salary`.

1.2.4 Some Facts About Structure

No memory (as data) is allocated for defining `struct`. Memory is allocated when its instances/variables are created. Hence `struct` stand-alone is a template… and it cannot be initialized. You need to declare a variable of type `struct`. No arithmetic or logical operation is possible on the `struct` variables unless defined by the operator overloading. For example, for `EmployeeRecord a, b;` any expression like `a == b` or `a + b`, etc. is not possible. But `a.age = b.age` is possible as both of these are of type `int`. Only assignment operation works. i.e. `a = b`; call-by-value, call-by-reference, return-with-value, return-with-reference, array-as-parameter – all works with a `struct` variable same as the normal variable concept using function in C++.

1.2.5 Nested Structure

Like any number and type of variables declared inside a structure, another structure can also be declared/defined inside another structure. We are going to take a look at two separate examples to get an idea of how that might work.

```
Example 1:
struct Appointment{
  struct AppDate{
    int day, month, year;
  }dt;

  struct AppTime{
    int minute, hour;
  }tm;

  char venue[100];
};
```

```
Example 2:
struct DateOfBirth{
  int day, month, year;
};

struct Employee{
  char EmpName[100];
  DateOfBirth dob;
};
```

In *example 1*, `AppDate` and `AppTime` is defined inside the structure `Appointment`. Here, `dt` is a variable for the structure `AppDate`. And, `tm` is a variable for the structure `AppTime`. Both `dt` and `tm` is declared inside the structure `Appointment`. We cannot access `dt` and `tm` directly from outside the structure `Appointment` because their scope is only limited to the scope of `Appointment`. As `dt` and `tm` were declared inside the structure `Appointment`, they are not directly globally accessible; only locally accessible inside `Appointment`. However, we can access `dt` and `tm`, indirectly through a variable of `Appointment`. For instance, if we declare a variable `Appointment x;`, then we can use `x` to access `dt` and `tm` like `x.dt` and `x.tm`. Also, as `AppDate` and `AppTime` both are defined inside `Appointment`, they are unable to declare their variables anywhere outside `Appointment`, again because of their scope being limited to `Appointment`.

In *example 2*, `dob` is a variable for the structure `DateOfBirth`. Here, `dob` is declared inside structure `Employee`. Here, the scope of `dob` is limited to Employee as it is declared inside `Employee`. We can access `dob` indirectly through any variable of `Employee`. On another note, unlike `AppDate` and `AppTime` in example 1, `DateOfBirth` is not defined inside a structure. Therefore, it is possible to declare its variable anywhere.

1.2.6 Self-referential Structure

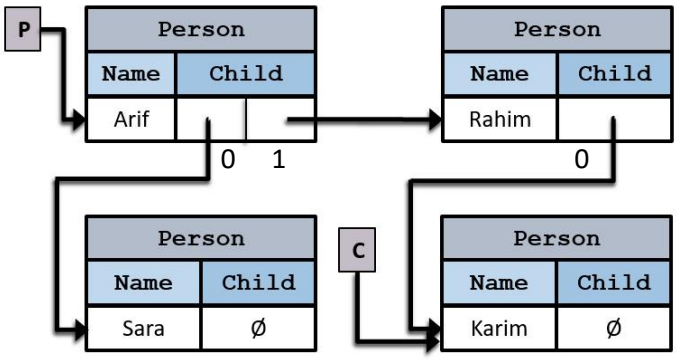
A structure member cannot be an instance of enclosing `struct`. However, a structure member can be a pointer to an instance of enclosing `struct`. This concept is called a self-referential structure. The concept of self-referential structure is used to implement some useful data structures such as linked-list, queue, stack, tree, etc. For example,

```
struct Person{
```

```
    char Name[30];
    Person *Child;
};
```

In the above example, `Person` contains a pointer variable `Child` of type `Person`. This illustrates the fact that every person may have a child which is also a person. We can illustrate a more detailed representation of the example by extending it with some variables `Person P, *C;` and their use:

```
Person P, *C;
strcpy(P.Name, "Arif");
C = P.Child = new Person[2];
strcpy(C[0].Name, "Sara");
C[0].Child = NULL;
strcpy(C[1].Name, "Rahim");
C = C[1].Child = new Person;
strcpy(C->Name, "Karim");
C->Child = NULL;
```



In the above illustration, we can simply say:

- Mr. Arif has two children – Rahim and Sara.
- Mr. Rahim has one child – Karim.
- Ms. Sara has no child.

1.3 Exercises

1. Explain the differences between NULL & Void pointers with appropriate examples.
2. What is the *dereferencing* operator? Use it in an example to explain how it works.
3. What is *dynamic memory allocation*? What operators are needed to allocate and deallocate memory during the runtime of a program?
4. Write a program in C++ to demonstrate the use of `&`(address of) and *(dereferencing) operator.
5. Assume the following definitions and initializations:

```
char c = 'T', d = 'S';
char *p1 = &c;
char *p2 = &d;
char *p3;
```

Assume further that the address of c is 6940, the address of d is 9772, and the address of e is 2224. What will be printed when the following statements are executed sequentially?

```
p3 = &d;
cout << "*p3 = " << *p3 << endl;   // (i)

p3 = p1;
```

```
cout << "*p3 = " << *p3              // (ii)
     << ", p3 = " << p3 << endl;    // (iii)

*p1 = *p2;
cout << "*p1 = " << *p1              // (iv)
     << ", p1 = " << p1 << endl;    // (v)
```

6. Consider the following statements:

```
int *p;
int i;
int k;
i = 42;
k = i;
p = &i;
```

After these statements, which of the following statements will change the value of i to 75?

a. k = 75
b. *k = 75
c. *p = 75
d. p = 75

7. Explain the error for the following statements:

```
int a = 95;
char *d = &a;
```

8. Write a function oddCount(int*, int) which receives an integer array and its size, and returns the number of odd numbers in the array.
9. Explain the *self-referential structure* with an appropriate example.
10. Explain the *nested structure* with appropriate examples.
11. Why do we need structure? State some of the major differences between structure and array with appropriate examples.
12. Can we send a `struct` variable as a parameter to a function? Try this out in your IDE and see if it works.
13. If you can successfully do what is told in *exercise 12*, go ahead and write a `Student` struct that will have the capability to store a student's name, CGPA, and credits completed. Take 10 students' info as input. Finally, create a function *printStudentInfo* that will print all the student info.

1.4 References

1. http://www.cplusplus.com/doc/tutorial/pointers/
2. http://www.cplusplus.com/doc/tutorial/structures/
3. http://www.cs.uregina.ca/Links/class-info/115/10-pointers/
4. https://condor.depaul.edu/ntomuro/courses/309/notes/pointer_exercises.html