MASTERS OF COMPUTER APPLICATIONS

SEMESTER 1

PROGRAMMING & PROBLEM-SOLVING USING C

Unit 11

Advanced Dynamic Memory Allocation and Linked List

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1. INTRODUCTION

In the previous unit, you studied the preprocessor in C. You studied that the preprocessor is a program that processes the source code before it passes through the compiler, and hence, it can be used to make C an easy and efficient language. In this unit, you will study dynamic memory allocation techniques. You will also study the linked list, which is another useful application using C.

You can use an array when you want to process data of the same data type, and you know the size of the data. Sometimes, you may want to process the data, but you don't know what the size of the data is. An example of this is when you are reading from a file or keyboard, and you want to process the values. In such a case, an array is not useful because you don't know what the dimension of the array should be. C has the facility of dynamic memory allocation. Using this, you can allocate the memory for your storage. The Allocation is done at runtime. When your work is over, you can deallocate the memory. The allocation of memory is done using three functions: malloc, calloc, and realloc. These functions return the pointers to void, so they can be typecast to any data type, thus making the functions generic. These functions take the input as the size of the memory requirement.

1.1. Objectives:

At studying this unit, you should be able to:

- *Explain about the dynamic memory allocation*
- *Implement dynamic memory allocation functions like -malloc, calloc and realloc*
- *Explain the concept of linked lists*
- *Discuss the different operations on linked lists*

2. DYNAMIC MEMORY ALLOCATION

The process of allocating memory at run time is known as Dynamic Memory Allocation. Although C does not inherently have this facility, there are four library routines known as "Memory Management Functions" that can be used for allocating and freeing memory during program execution. They are listed in Table 11.1. These functions help us build complex application programs that use the available memory intelligently.

Table 1: Functions used for Dynamic Memory allocations and its tasks

Function	**Tasks**
malloc	Allocates the requested size of bytes and returns a pointer to the the first byte of the allocated space
calloc	Allocates space for an array of elements, initialises them to zero and then returns a pointer to the memory
free	Frees previously allocated space.
realloc	Modifies the size of previously allocated space

Figure 1 shows the conceptual view of the storage of a C program in memory.

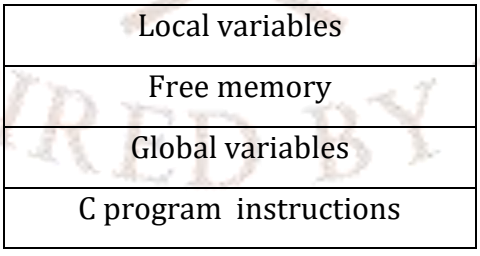


Figure 1: storage of a C program- a conceptual view

The program instructions and global and static variables are stored in a region known as *a permanent storage area, and the local variables are stored in another area called a stack*. The

memory space that is located between these two regions is available for dynamic allocation during the execution of the program. This free memory region is called the *heap*. The size of the heap keeps changing when the program is executed due to the creation and death of variables that are local to functions and blocks. Therefore, it is possible to encounter memory "overflow" during the dynamic allocation process.

2.1. Allocating Memory with malloc

A problem with many simple programs, including little teaching programs such as we've been writing so far, is that they tend to use fixed-size arrays, which may or may not be big enough. We have an array of 100 ints for the numbers which the user enters and wishes to find the average of them, what if the user enters 101 numbers? We have an array of 100 chars, which we pass to get a line to receive the user's input; what if the user types a line of 200 characters? If we're lucky, the relevant parts of the program check how much of an array they've used and print an error message or otherwise gracefully abort before overflowing the array. If we're not so lucky, a program may sail off the end of an array, overwriting other data and behaving quite badly. In either case, the user doesn't get his job done. How can we avoid the restrictions of fixed-size arrays?

The answers all involve the standard library function malloc. Very simply, malloc returns a pointer to *n* bytes of memory, which we can use to do anything we want. If we didn't want to read a line of input into a fixed-size array, we could use malloc instead. It takes the following form:

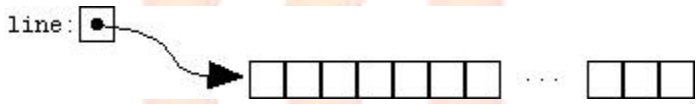
ptr=(*cast-type* *)malloc(*byte-size*)

Where ptr is a pointer of type *cast-type*, the malloc returns a pointer(of *cast-type*) to an area of memory with size *byte-size*.

Here is an example

```
#include <stdlib.h>

char *line;

int linelen = 100;

line = (char *)malloc(linelen);

/* incomplete -- malloc's return value not checked */ getline(line, linelen);
```

Malloc is declared in <stdlib.h>, so we #include that header in any program that calls malloc. A “byte'' in C is, by definition, an amount of storage suitable for storing one character, so the above invocation of malloc gives us exactly as many chars as we ask for. We could illustrate the resulting pointer like this:



The 100 bytes of memory (not all of which are shown) pointed to by line are those allocated by malloc. (They are brand-new memory, conceptually a bit different from the memory which the compiler arranges to have allocated automatically for our conventional variables. The 100 boxes in the figure don't have a name next to them because they're not stored for a variable we've declared.)

As a second example, we might have occasion to allocate a piece of memory and to copy a string into it with strcpy:

```
char *p = (char *)malloc(15);

/* incomplete -- malloc's return value not checked */

strcpy(p, "Hello, world!");
```

When copying strings, remember that all strings have a terminating \0 character. If you use strlen to count the characters in a string for you, that count will *not* include the trailing \0, so you must add one before calling malloc:

```
char *some string, *copy;
...
copy = (char *)malloc(strlen(somestring) + 1); /* +1 for \0
*/ /* incomplete -- malloc's return value not checked */
strcpy(copy, somestring);
```

What if we're not allocating characters but integers? If we want to allocate 100 ints, how many bytes is that? If we know how big ints are on our machine (i.e. depending on whether we're using a 16- or 32-bit machine), we could try to compute it ourselves, but it's much safer and more portable to let C compute it for us. C has a sizeof operator, which computes the size in Bytes of a variable or type. It's just what we need when calling malloc. To allocate space for 100 ints, we could call.

```
int *ip =(int *)malloc(100 * sizeof(int));
```

The use of the sizeof operator tends to look like a function call, but it's really an operator, and it does its work at compile time.

Since we can use array indexing syntax on pointers, we can treat a pointer variable after a call to malloc almost exactly as if it were an array. In particular, after the above call to malloc initialises ip to point at storage for 100 ints, we can access ip[0], ip[1], ... up to ip[99]. This way, we can get the effect of an array even if we don't know until run time how big the “array'' should be. (In a later section, we'll see how we might deal with the case where we're not even sure at the point we begin using it how big an “array'' will eventually have to be.)

Our examples so far have all had a significant omission: they have not checked malloc's return value. Obviously, no real computer has an infinite amount of memory available, so there is no guarantee that malloc will be able to give us as much memory as we ask for. If we call malloc(100000000), or if we call malloc(10) 10,000,000 times, we're probably going to run out of memory.

When malloc is unable to allocate the requested memory, it returns a *null pointer*. A null pointer, remember points definitively nowhere. It's a “not a pointer'' marker; it's not a pointer you can use. Therefore, whenever you call malloc, it's vital to check the returned pointer before using it! If you call malloc, and it returns a null pointer, and you go off and use that null pointer as if it pointed somewhere, your program probably won't last long. Instead, a program should immediately check for a null pointer, and if it receives one, it should, at the very least, print an error message and exit or perhaps figure out some way of proceeding without the memory it asked for. But it cannot go on to use the null pointer it got back from malloc in any way, because that null pointer by definition points nowhere. (“It cannot use a null pointer in any way'' means that the program cannot use the * or [] operators on such a pointer value or pass it to any function that expects a valid pointer.)

A call to malloc, with an error check, typically looks something like this:

```
int *ip = (int *)malloc(100 * sizeof(int));
if(ip == NULL)
{
printf("out of memory\n");
exit or return
}
```

After printing the error message, this code should return to its caller or exit from the program entirely; it cannot proceed with the code that would have used up.

Of course, in our examples so far, we've still limited ourselves to “fixed size'' regions of memory because we've been calling malloc with fixed arguments like 10 or 100. (Our call to getline is still limited to 100-character lines, or whatever number we set the linelen variable to; our ip variable still points at only 100 ints.) However, since the sizes are now values which can, in principle, be determined at run-time, we've at least moved beyond having to recompile the program (with a bigger array) to accommodate longer lines, and with a little more work, we could arrange that the “arrays'' automatically grew to be as large as required. (For example, we could write something like getline, which could read the longest input line actually seen).

2.2. Allocating memory with calloc

calloc is another memory allocation function that is normally used for requesting memory space at run time for storing derived data types such as arrays and structures. While malloc allocates a single block of storage space, calloc allocates multiple blocks of storage, each of the same size, and then sets all bytes to zero. The general form of calloc is:

ptr=(*cast-type* *)calloc(*n, elem-size*);

The above statement allocates contiguous space for n blocks, each of size *elem-size* bytes. All bytes are initialised to zero, and a pointer to the first byte of the allocated region is returned. If there is not enough space, a NULL pointer is returned.

Program 11.1 Program to illustrate the use of malloc and calloc functions

```
#include <stdio.h>
#include <malloc.h>
main()
{
int *base;
int i;
int cnt=0;
```

```
int sum=0;
printf("how many integers you have to store \n"); scanf("%d",&cnt);
base = (int *)malloc(cnt * sizeof(int));
printf("the base of allocation is %16lu \n",base);
if(!base)
printf("unable to allocate size \n");
else
{
for(int j=0;j<cnt;j++)
*(base+j)=5;
}
sum = 0;
for(int j=0;j<cnt;j++)
sum = sum + *(base+j);
printf("total sum is %d\n",sum);
free(base);
printf("the base of allocation is %16lu \n",base);
base = (int *)malloc(cnt * sizeof(int));
printf("the base of allocation is %16lu \n",base);
base = (int *)malloc(cnt * sizeof(int));
printf("the base of allocation is %16lu \n",base);
base = (int *)calloc(10,2);
printf("the base of allocation is %16lu \n",base);
}
```

2.3. Freeing Memory

Memory allocated with malloc lasts as long as you want it to. It does not automatically disappear when a function returns, as automatic variables do, but it does not have to remain for the entire duration of your program, either. Just as you can use malloc to control exactly when and how much memory you allocate, you can also control exactly when you deallocate it.

In fact, many programs use memory on a transient basis. They allocate some memory and use it for a while but then reach a point where they don't need that particular piece anymore. Because memory is not inexhaustible, it's a good idea to deallocate (that is, release or *free*) the memory you're no longer using.

Dynamically allocated memory is deallocated with the free function. If p contains a pointer previously returned by malloc, you can call.

```
free(p);
```

Which will “give the memory back'' to the stock of memory (sometimes called the “arena'' or “pool'') from which malloc requests are satisfied. Calling free is sort of the ultimate in recycling: it costs you almost nothing, and the memory you give back is immediately usable by other parts of your program. (Theoretically, it may even be usable by other programs.)

(Freeing unused memory is a good idea, but it's not mandatory. When your program exits, any memory which it has allocated but not freed should be automatically released; if your computer were to somehow “lose'' memory just because your program forgot to free it, that would indicate a problem or deficiency in your operating system.)

Naturally, once you've freed some memory, you must remember not to use it any more. After calling

```
free(p);
```

It is probably the case that p still points to the same memory. However, since we've given it back, it's now “available,'' and a later call to malloc might give that memory to some other part of your program. If the variable p is a global variable or will otherwise stick around for

a while, one good way to record the fact that it's not to be used any more would be to set it to a null pointer:

```
free(p);
p = NULL;
```

Now, we don't even have the pointer to the freed memory any more, and (as long as we check to see that p is non-NULL before using it) we won't misuse any memory via the pointer p.

When thinking about malloc, free, and dynamically allocated memory in general, remember again the distinction between a pointer and what it points to. If you call malloc to allocate some memory and store the pointer that malloc gives you in a local pointer variable, what happens when the function containing the local pointer variable returns? If the local pointer variable has *automatic duration* (which is the default unless the variable is declared static), it will disappear when the function returns. But for the pointer variable to disappear says nothing about the memory pointed to! That memory still exists and, as far as malloc and free are concerned, is still allocated. The only thing that has disappeared is the pointer variable you had, which pointed to the allocated memory. (Furthermore, if it contained the only copy of the pointer you had, once it disappears, you'll have no way of freeing the memory and no way of using it, either. Using memory and freeing memory both require that you have at least one pointer to the memory!)

2.4. Reallocating Memory Blocks

Sometimes, you're not sure at first how much memory you'll need. For example, if you need to store a series of items you read from the user, and if the only way to know how many there are is to read them until the user types some “end'' signal, you'll have no way of knowing, as you begin reading and storing the first few, how many you'll have seen by the time you do see that “end'' marker. You might want to allocate room for, say, 100 items, and if the user enters a 101st item before entering the “end'' marker, you might wish for a way to say ”uh, malloc, remember those 100 items I asked for? Could I change my mind and have 200 instead?''

In fact, you can do exactly this with the realloc function. You hand realloc an old pointer (such as you received from an initial call to malloc) and a new size, and realloc does what it can to give you a chunk of memory big enough to hold the new size. For example, if we wanted the ip variable from an earlier example to point at 200 ints instead of 100, we could try calling.

```
ip = realloc(ip, 200 * sizeof(int));
```

Since you always want each block of dynamically-allocated memory to be contiguous (so that you can treat it as if it were an array), you and realloc have to worry about the case where realloc can't make the old block of memory bigger “in place,'' but rather have to relocate it elsewhere in order to find enough contiguous space for the new requested size. realloc does this by returning a new pointer. If realloc was able to make the old block of memory bigger, it returns the same pointer. If realloc has to go elsewhere to get enough contiguous memory, it returns a pointer to the new memory after copying your old data there. (In this case, after it makes the copy, it frees the old block.) Finally, if realloc can't find enough memory to satisfy the new request at all, it returns a null pointer. Therefore, you usually don't want to overwrite your old pointer with realloc's return value until you've tested it to make sure it's not a null pointer. You might use code like this:

```
int *newp;
newp = realloc(ip, 200 * sizeof(int));
if(newp != NULL)
ip = newp;
else{
printf("out of memory\n");
/* exit or return */
/* but ip still points at 100 ints */
}
```

If realloc returns something other than a null pointer, it succeeded, and we set ip to what it returned. (We've either set ip to what it used to be or to a new pointer, but in either case, it points to where our data is now.) If realloc returns a null pointer, however, we hang on to our old pointer in ip, which still points to our original 100 values.

Putting this all together, here is a piece of code which reads lines of text from the user, treats each line as an integer by calling atoi, and stores each integer in a dynamically-allocated "array'':

```
#define MAXLINE 100
char line[MAXLINE];
int *ip;
int n alloc, n items;
nalloc = 100;
ip = (int *)malloc(nalloc * sizeof(int)); /* initial allocation */ if(ip == NULL)
{
printf("out of memory\n");
exit(1);
}
nitems = 0;
while(getline(line, MAXLINE) != EOF)
{
if(nitems >= nalloc)
{                                                    /* increase allocation */
int *newp;
```

```
        nalloc += 100;
        newp = realloc(ip, nalloc * sizeof(int));
        if(newp == NULL)
        {
        printf("out of memory\n");
        exit(1);
        }
        ip = newp;
        }
        ip[nitems++] = atoi(line);
        }
```

We use two different variables to keep track of the “array'' pointed to by ip. nalloc is how many elements we've allocated, and nitems is how many of them are in use. Whenever we're about to store another item in the “array,'' if nitems >= nalloc, the old “array'' is full, and it's time to call realloc to make it bigger.

Finally, we might ask what the return type of malloc and realloc is, if they are able to return pointers to char or pointers to int or (though we haven't seen it yet) pointers to any other type. The answer is that both of these functions are declared (in <stdlib.h>) as returning a type we haven't seen, void * (that Is, pointer to void). We haven't really seen type void, either, but what's going on here is that void * is specially defined as a “generic'' pointer type, which may be used (strictly speaking, assigned to or from) any pointer type.

Fragmentation:

Fragmentation refers to the tendency of the heap to go from one large available block at the beginning to many small available blocks. It may be possible that, while the total amount of memory is larger than the amount requested, no single block is big enough to satisfy it.

For example, suppose we have a heap of size 20 and the following memory requests:

```
void* a = malloc(5);
void* b = malloc(5);
void* c = malloc(5);
void* d = malloc(5);
free(b);
free(d);
```

Theoretically, 10 bytes of memory are available, but the largest malloc we can handle is of size 5! This example is called external fragmentation, fragmentation where the available memory is broken into many small blocks rather than a few large ones. There's relatively little an allocator can do about external fragmentation, partly because we cannot move existing blocks.

Internal fragmentation occurs when an allocator reserves *more* space per block than is requested.

SELF-ASSESSMENT QUESTIONS - 1

1. The process of allocating memory at run time is known as _____.
2. malloc () function returns a pointer to an integer. (True/False)
3. For deallocating memory, you can use _____ function.
4. The function that is used to alter the size of a block previously allocated is _____.

3. POINTER SAFETY

The hard thing about pointers is not so much manipulating them as ensuring that the memory they point to is valid. When a pointer doesn't point where you think it does, if you inadvertently access or modify the memory it points to, you can damage other parts of your program or (in some cases) other programs or the operating system itself!

When we use pointers to simple variables, there's not much that can go wrong. When we use pointers in arrays and begin moving the pointers around, we have to be more careful to ensure that the moving pointers always stay within the bounds of the array(s). When we begin passing pointers to functions, and especially when we begin returning them from functions, we have to be more careful still because the code using the pointer may be far removed from the code that owns or allocates the memory.

One particular problem concerns functions that return pointers. Where is the memory to which the returned pointer points? Is it still around by the time the function returns? The strstr function (as described in the earlier unit) returns either a null pointer (which points definitively nowhere and which the caller presumably checks for) or it returns a pointer which points into the input string, which the caller supplied, which is pretty safe. One thing a function must *not* do, however, is return a pointer to one of its own local, automatic arrays. Remember that automatic variables (which include all non-static local variables), including automatic arrays, are deallocated and disappear when the function returns. If a function returns a pointer to a local array, that pointer will be invalid by the time the caller tries to use it.

Finally, when we're doing dynamic memory allocation with malloc, calloc, realloc, and free, we have to be most careful of all. Dynamic allocation gives us a lot more flexibility in how our programs use memory, although with that flexibility comes the responsibility that we manage dynamically allocated memory carefully. The possibilities for misdirected pointers and associated havoc are greatest in programs that make heavy use of dynamic memory allocation. You can reduce these possibilities by designing your program in such a way that it's easy to ensure that pointers are used correctly and that memory is always allocated and deallocated correctly. (If, on the other hand, your program is designed in such a way that

meeting these guarantees is a tedious nuisance, sooner or later, you'll forget or neglect to, and maintenance will be a nightmare.)

4. THE CONCEPT OF LINKED LIST

When dealing with many problems, we need a dynamic list, dynamic in the sense that the size requirement need not be known at compile time. Thus, the list may grow or shrink during runtime. A *linked list* is a data structure that is used to model such a dynamic list of data items, so the study of the linked lists as one of the data structures is important.

An array is represented in memory using sequential mapping, which has the property that elements are a fixed distance apart. But this has the following disadvantage: It makes insertion or deletion at any arbitrary position in an array a costly operation because this involves the movement of some of the existing elements.

When we want to represent several lists by using arrays of varying sizes, we either have to represent each list using a separate array of maximum size or each of the lists using one single array. The first one will lead to storage wastage, and the second will involve a lot of data movement.

So, we have to use an alternative representation to overcome these disadvantages. One alternative is a linked representation. In a linked representation, it is not necessary that the elements be at a fixed distance apart. Instead, we can place elements anywhere in memory, but to make it a part of the same list, an element is required to be linked with a previous element of the list. This can be done by storing the address of the next element in the previous element itself. This requires that every element be capable of holding the data as well as the address of the next element. Thus, every element must be a structure with a minimum of two fields, one for holding the data value, which we call a data field, and the other for holding the address of the next element, which we call a link field.

Therefore, a linked list is a list of elements in which the elements of the list can be placed anywhere in memory, and these elements are linked with each other using an explicit link

field, that is, by storing the address of the next element in the link field of the previous element.

Program 11.2: Here is a program for building and printing the elements of the linked list

```
#include <stdio.h>
#include <stdlib.h> struct node
{
int data;
struct node *link; };
struct node *insert(struct node *p, int n)
{
struct node *temp;
/* if the existing list is empty, then insert a new node as the
starting node */
if(p==NULL)
{
    p=(struct node *)malloc(sizeof(struct node));
    /* creates new node data value passes as parameter */
if(p==NULL)
{
printf("Error\n");
exit(0);
}
```

```
p-> data = n;
        p-> link = p;
        /* makes the pointer point to itself because it is a circular list*/
}
else
{
temp = p;
/* traverses the existing list to get the pointer to the last node of it */
while (temp-> link != p)
temp = temp-> link;
temp-> link = (struct node *)malloc(sizeof(struct node)); /*
creates a new node using data value passes as a parameter and puts its address in the link field of the last node of the existing list*/
if(temp -> link == NULL)
{
printf("Error\n");
exit(0);
}
temp = temp-> link;
temp-> data = n;
temp-> link = p;
}
return (p);
}
```

```
void printlist ( struct node *p )
{
struct node *temp;
temp = p;
printf("The data values in the list are\n");
if(p!= NULL)
{
do
{
printf("%d\t",temp->data);
temp=temp->link;
} while (temp!= p);
}
else
printf("The list is empty\n");
}
void main()
{
int n;
int x;
struct node *start = NULL ;
printf("Enter the nodes to be created \n");
scanf("%d",&n);
while ( n -- > 0 )
```

```
{
printf( "Enter the data values to be placed in a node\n"); scanf("%d",&x);
start = insert ( start, x );
}
printf("The created list is\n");
printlist ( start );
}
```

4.1. Inserting a node by using Recursive Programs

A linked list is a recursive data structure. A *recursive data structure* is a data structure that has the same form regardless of the size of the data. You can easily write recursive programs for such data structures.

Program 11.3

```
#include <stdio.h>
#include <stdlib.h> struct node
{
int data;
struct node *link; };
struct node *insert(struct node *p, int n)
{
struct node *temp;
if(p==NULL)
{
```

```
p=(struct node *)malloc(sizeof(struct node));
if(p==NULL)
{
printf("Error\n");
exit(0);
}
p-> data = n;
p-> link = NULL;
}
else
        p->link = insert(p->link,n);
        /* the while loop replaced by recursive call */
return (p);
}
void printlist ( struct node *p )
{
printf("The data values in the list are\n");
while (p!= NULL)
{
printf("%d\t",p-> data);
p = p-> link;
}
}
```

```
void main()
{
int n;
int x;
struct node *start = NULL ;
printf("Enter the nodes to be created \n");
scanf("%d",&n);
while ( n- - 0 )
{
printf( "Enter the data values to be placed in a node\n");
scanf("%d",&x);
start = insert ( start, x );
}
printf("The created list is\n");
printlist ( start );
}
```

4.2. Sorting and reversing a linked list

To sort a linked list, first, we traverse the list, searching for the node with a minimum data value. Then, we remove that node and append it to another list which is initially empty. We repeat this process with the remaining list until the list becomes empty, and at the end, we return a pointer to the beginning of the list to which all the nodes are moved.

To reverse a list, we maintain a pointer each to the previous and the next node; then, we make the link field of the current node point to the previous, make the previous equal to the current, and the current equal to the next.

Therefore, the code needed to reverse the list is

```
Prev = NULL;
While (curr != NULL)
{
Next = curr->link;
Curr -> link = prev;
Prev = curr;
Curr = next;
}
```

Program 11.4: Example in sorting lists.

```
#include <stdio.h>
#include <stdlib.h> struct node
{
int data;
struct node *link;
};
struct node *insert(struct node *p, int n)
{
```

```
struct node *temp;
if(p==NULL)
{
p=(struct node *)malloc(sizeof(struct node));
if(p==NULL)
{
printf("Error\n");
exit(0);
}
p-> data = n;
p-> link = NULL;
}
else
{
temp = p;
while (temp-> link!= NULL)
temp = temp-> link;
temp-> link = (struct node *)malloc(sizeof(struct node));
if(temp -> link == NULL)
{
printf("Error\n");
exit(0);
}
```

```
temp = temp-> link;
temp-> data = n;
temp-> link = null;
}
return(p);
}
void printlist ( struct node *p )
{
printf("The data values in the list are\n");
while (p!= NULL)
{
printf("%d\t",p-> data);
p = p-> link;
}
}
/* a function to sort reverse list */
struct node *reverse(struct node *p)
{
struct node *prev, *curr;
prev = NULL;
curr = p;
while (curr != NULL)
{
```

```
p = p-> link;
curr-> link = prev;
prev = curr;
curr = p;
}
return(prev);
}
/* a function to sort a list */
struct node *sortlist(struct node *p)
{
struct node *temp1,*temp2,*min,*prev,*q;
q = NULL;
while(p != NULL)
{
prev = NULL;
min = temp1 = p;
temp2 = p -> link;
while ( temp2 != NULL )
{
if(min -> data > temp2 -> data)
{
min = temp2;
prev = temp1;
}
```

```
temp1 = temp2;
temp2 = temp2-> link;
}
if(prev == NULL)
p = min -> link;
else
prev -> link = min -> link;
min -> link = NULL;
if( q == NULL)
    q = min;
    /* moves the node with the lowest data value in the list pointed
    to by p to the list pointed to by q as a first node*/
else
{
temp1 = q;
   /* traverses the list pointed to by q to get a pointer to its last node */
while( temp1 -> link != NULL)
temp1 = temp1 -> link;
        temp1 -> link = min;
        /* moves the node with the lowest data value in the
        list pointed to by p to the list pointed to by q at
        the end of the list pointed by q*/
}
}
```

```
return (q);
}
void main()
{
int n;
int x;
struct node *start = NULL ;
printf("Enter the nodes to be created \n");
scanf("%d",&n);
while ( n- > 0 )
{
printf( "Enter the data values to be placed in a node\n");
scanf("%d",&x);
start = insert ( start,x);
}
printf("The created list is\n");
printlist ( start );
start = sortlist(start);
printf("The sorted list is\n");
printlist ( start );
start = reverse(start);
printf("The reversed list is\n");
printlist ( start );
}
```

4.3. Deleting the specified node in a singly linked list

To delete a node, first, we determine the node number to be deleted (this is based on the assumption that the nodes of the list are numbered serially from 1 to n). The list is then traversed to get a pointer to the node whose number is given, as well as a pointer to a node that appears before the node to be deleted. Then, the link field of the node that appears before the node to be deleted is made to point to the node that appears after the node to be deleted, and the node to be deleted is freed.

Program 11.5: Example of working with nodes.

```
#include <stdio.h>
#include <stdlib.h>
struct node *delet ( struct node *, int );
int length ( struct node * );
struct node
{
int data;
struct node *link;
};
struct node *insert(struct node *p, int n)
{
struct node *temp;
if(p==NULL)
{
```

```
p=(struct node *)malloc(sizeof(struct node));
if(p==NULL)
{
printf("Error\n");
exit(0);
}
p-> data = n;
p-> link = NULL;
}
else
{
temp = p;
while (temp-> link != NULL)
temp = temp-> link;
temp-> link = (struct node *)malloc(sizeof(struct node));
if(temp -> link == NULL)
{
printf("Error\n");
exit(0);
}
temp = temp-> link;
temp-> data = n;
temp-> link = NULL;
```

```
}
return (p);
}
void printlist ( struct node *p )
{
printf("The data values in the list are\n");
while (p!= NULL)
{
printf("%d\t",p-> data);
p = p-> link;
}
}
void main()
{
int n;
int x;
struct node *start = NULL;
printf("Enter the nodes to be created \n");
scanf("%d",&n);
while ( n-- > 0 )
{
printf( "Enter the data values to be placed in a node\n"); scanf("%d",&x);
start = insert ( start, x );
```

```
}
printf(" The list before deletion id\n");
printlist ( start );
printf("% \n Enter the node no \n");
scanf ( " %d",&n);
start = delet (start , n );
printf(" The list after deletion is\n");
printlist ( start );
}
/* a function to delete the specified node*/
struct node *delet ( struct node *p, int node_no )
{
struct node *prev, *curr ;
int i;
if (p == NULL )
{
printf("There is no node to be deleted \n");
}
else
{
if ( node_no > length (p))
{
printf("Error\n");
}
```

```
else
{
prev = NULL;
curr = p;
i = 1 ;
while ( i < node_no )
{
prev = curr;
curr = curr-> link;
i = i+1;
}
if ( prev == NULL )
{
P = curr -> link; free ( curr );
}
else
{
prev -> link = curr -> link ;
free ( curr );
}
}
}
return(p);
}
```

```
/* a function to compute the length of a linked list */ int length ( struct node *p ) {
int count = 0 ;
while ( p != NULL )
{
count++;
p = p->link;
}
return ( count ) ;
}
```

SELF-ASSESSMENT QUESTIONS - 2

5. A linked list is a data structure that is used to model a dynamic list of data items and is a collection of _____.
6. Linked list make use of _____ memory allocation technique.

4.4. Circular Linked Lists

In a circular Singly linked list, the last node of the list contains a pointer to the first node of the list. We can have a circular singly linked list as well as a circular doubly linked list. We traverse a circular singly linked list until we reach the same node where we started. The circular singly-liked list has no beginning and no ending. There is no null value present in the next part of any of the nodes.

Operations on Circular List

- Insertion at the beginning
- Insertion at the end
- Deletion at the beginning
- Deletion at the end
- Searching

Insertion at the beginning: Insertion at the beginning of a circular linked list is a common operation that involves adding a new node at the front of the list. This operation is crucial for maintaining the integrity and functionality of the circular linked list.

```
void beg_insert(int item)
{
struct node *ptr = (struct node *)malloc(sizeof(struct node));
struct node *temp;
if(ptr == NULL)
{
printf("\nOVERFLOW");
}
else
```

```
{
ptr -> data = item;
if(head == NULL)
{
head = ptr;
ptr -> next = head;
}
else
{
temp = head;
while(temp->next != head)
temp = temp->next;
ptr->next = head;
temp -> next = ptr;
head = ptr;
}
printf("\nNode Inserted\n");
}
```

Insertion at the end: Insertion at the end involves appending a new node to the existing list while ensuring that the circular structure is preserved. This process requires careful manipulation of pointers to adjust the connections between nodes effectively. Unlike linear linked lists, where the tail node points to null, in a circular linked list, the last node points back to the first node, forming a loop.

```
void lastinsert(struct node*ptr, struct node *temp, int item)
{
ptr = (struct node *)malloc(sizeof(struct node));
if(ptr == NULL)
{
        printf("\nOVERFLOW\n");
}
else
{
        ptr->data = item;
if(head == NULL)
{
head = ptr;
ptr -> next = head;
}
else
{
        temp = head;
        (temp -> next != head)
{
temp = temp -> next;
}
temp -> next = ptr;
ptr -> next = head;
}
}
```

Deletion at the beginning: This operation involves adjusting the pointers to maintain the integrity of the list while ensuring that no memory leaks occur. To efficiently delete the first node of a circular linked list, consider edge cases and potential pitfalls along the way.

```
void beg_delete()
{
struct node *ptr;
if(head == NULL)
{
        printf("\nUNDERFLOW\n");
}
else if(head->next == head)
{
        head = NULL;
        free(head);
        printf("\nNode Deleted\n");
}
else
{
        ptr = head;
while(ptr -> next != head)
        ptr = ptr -> next;
        ptr->next = head->next;
        free(head);
        head = ptr->next;
printf("\nNode Deleted\n");
}
}
```

Deletion at the end: Deletion at the end of a circular linked list involves removing the last node from the list. Since it's a circular linked list, the last node points to the first node, so deleting the last node requires updating the reference of the second-to-last node to point to the new last node.

```
void last_delete()
{
struct node *ptr, *preptr;
if(head==NULL)
{
printf("\nUNDERFLOW\n");
}
else if (head ->next == head)
{
head = NULL;
free(head);
printf("\nNode Deleted\n");
}
else
{
ptr = head;
while(ptr ->next != head)
{
preptr=ptr;
ptr = ptr->next;
}
```

```
preptr->next = ptr -> next;
free(ptr);
printf("\nNode Deleted\n");
}
}
```

Searching: Searching in a circular linked list involves traversing through the list to find a specific element or to determine whether an element exists within the list.

```
void search()
{
struct node *ptr;
int item,i=0,flag=1;
ptr = head;
if(ptr == NULL)
{
printf("\nEmpty List\n");
}
else
{
printf("\nEnter item which you want to search?\n");
scanf("%d",&item);
if(head ->data == item)
{
printf("item found at location %d",i+1);
flag=0;
```

```
return;
}
else
{
while (ptr->next != head)
{
if(ptr->data == item)
{
        printf("item found at location %d ",i+1);
        flag=0;
        return;
}
else
{
        flag=1;
}
i++;
ptr = ptr -> next;
}
}
if(flag != 0)
{
printf("Item not found\n");
return;
}
 }
```

Doubly Linked List:

A doubly linked list is a data structure composed of a sequence of elements called nodes. Each node contains two links, one pointing to the next node in the sequence and another pointing to the previous node. This structure allows for bidirectional traversal, meaning you can traverse the list both forwards and backwards.

Operations on Doubly Linked List

- Insertion at beginning
- Insertion at the end
- Insertion after the specified node
- Deletion at beginning
- Deletion at end

Insertion at the beginning: Inserting a node at the beginning of a doubly linked list involves Allocating memory for a new node. Set the data for the new node. Adjust pointers to link the new node properly. Update the head pointer to point to the new node if the list is not empty.

```
void insertbeginning(int item)
{
struct node *ptr = (struct node *)malloc(sizeof(struct node));
if(head==NULL)
{
ptr->next = NULL;
ptr->prev=NULL;
ptr->data=item;
head=ptr;
```

```
}
else
{
ptr->data=item;
ptr->prev=NULL;
ptr->next = head;
head->prev=ptr;
head=ptr;
}
}
```

Insertion at the end: Inserting a node at the end of a doubly linked list involves:

Create a new node with the given data. Traverse the list to reach the last node.

Update the pointers of the last node to point to the new node and the new node to point back to the last node. Handle the case where the list is empty.

```
void insertlast(int item)
{
struct node *ptr = (struct node *) malloc(sizeof(struct node));
struct node *temp;
ptr->data=item;
if(head == NULL)
{
ptr->next = NULL;
```

```
ptr->prev = NULL;
head = ptr;
}
else
{
temp = head;
while(temp->next!=NULL)
{
temp = temp->next;
}
temp->next = ptr;
ptr ->prev=temp;
ptr->next = NULL;
}
printf("\nNode Inserted\n");
}
```

Insertion after specified node:

To insert a node after a specified node in a doubly linked list:

Find the specified node after which you want to insert the new node.

Allocate memory for the new node. Adjust pointers to link the new node into the list. Update the pointers of adjacent nodes to maintain the integrity of the doubly linked list.

```
void insert_specified(int item)
{
struct node *ptr = (struct node *)malloc(sizeof(struct node));
struct node *temp;
int i, loc;
printf("\nEnter the location\n");
scanf("%d",&loc);
temp=head;
for(i=0;i<loc;i++)
{
temp = temp->next;
if(temp == NULL)
{
printf("\ncan't insert\n");
return;
}
}
ptr->data = item;
ptr->next = temp->next;
ptr -> prev = temp;
temp->next = ptr;
temp->next->prev=ptr;
printf("Node Inserted\n");
}
}
```

Deletion at the beginning: In a doubly linked list, deletion at the beginning involves removing the first node from the list. Since doubly linked lists allow traversal in both forward and backward directions, this operation can be performed efficiently.

```
void beginning_delete()
{
        struct node *ptr;
if(head == NULL)
{
        printf("\n UNDERFLOW\n");
}
else if(head->next == NULL)
```

```
{
        head = NULL;
        free(head);
        printf("\nNode Deleted\n");
}
else
{
        ptr = head;
        head = head -> next;
        head -> prev = NULL;
free(ptr);
printf("\nNode Deleted\n");
}
}
```

Deletion at the end: Deletion at the end in a doubly linked list involves removing the last node of the list efficiently. A doubly linked list is a data structure where each node contains a data element and two pointers: one pointing to the next node (forward pointer) and another pointing to the previous node (backward pointer). This structure allows traversal both forward and backwards.

```
void last_delete()
{
struct node *ptr;
if(head == NULL)
{
```

```
printf("\n UNDERFLOW\n");
}
else if(head->next == NULL)
{
head = NULL;
free(head);
printf("\nNode Deleted\n");
}
else
{
ptr = head;
if(ptr->next != NULL)
{
ptr = ptr -> next;
}
ptr -> prev -> next = NULL;
free(ptr);
printf("\nNode Deleted\n");
}
}
```

5. SUMMARY

The process of allocating memory at run time is known as Dynamic Memory Allocation. The allocation of memory is done using three functions: malloc, calloc, and realloc. These functions return the pointers to void, so they can be typecast to any data type, thus making the functions generic. The memory space that is used for dynamic allocation during the execution of the program is called the heap. When a pointer doesn't point where you think it does, if you inadvertently access or modify the memory it points to, you can damage other parts of your program. So, the safety of pointers is essential in dynamic memory allocation. Linked list is one of the applications of dynamic memory allocation.

6. TERMINAL QUESTIONS

1. Assuming that there is a structure definition with a structure tag student, write the malloc function to allocate space for the structure.
2. Write a structure definition to represent a node in the linked list with two data fields of type integer.
3. If ptr points to a node and the link is the address field of the node, how can you move from the node to the next node?
4. Explain about the linked list.
5. Explain the insertion and deletion operation on Circular Linked Lists.

7. ANSWERS TO SELF ASSESSMENT QUESTIONS

1. Dynamic Memory Allocation.
2. False
3. free()
4. realloc()
5. nodes.
6. dynamic

8. ANSWERS TO TERMINAL QUESTIONS

1. ptr=(struct student *) malloc(size of(struct student));
2. struct node

   {

   int data1; int data2; struct
   node *link;

   };
3. ptr=ptr->link;
4. A linked list is a data structure that is used to model a dynamic list of data items and is a collection of nodes. (Refer to section 4 for more details)
5. Refer to 4 section