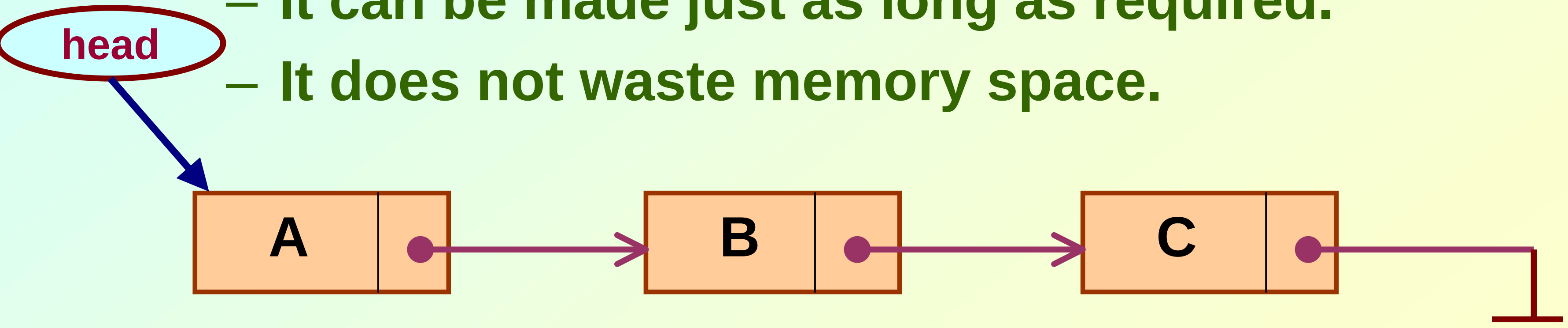
Linked List

Introduction

- **A linked list is a data structure which can change during execution.**
  - **Successive elements are connected by pointers.**
  - **Last element points to `NULL`.**
  - **It can grow or shrink in size during execution of a program.**
  - **It can be made just as long as required.**
  - **It does not waste memory space.**



- **Keeping track of a linked list:**
  - **Must know the pointer to the first element of the list (called *start*, *head*, etc.).**

- **Linked lists provide flexibility in allowing the items to be rearranged efficiently.**
  - **Insert an element.**
  - **Delete an element.**

Illustration: Insertion

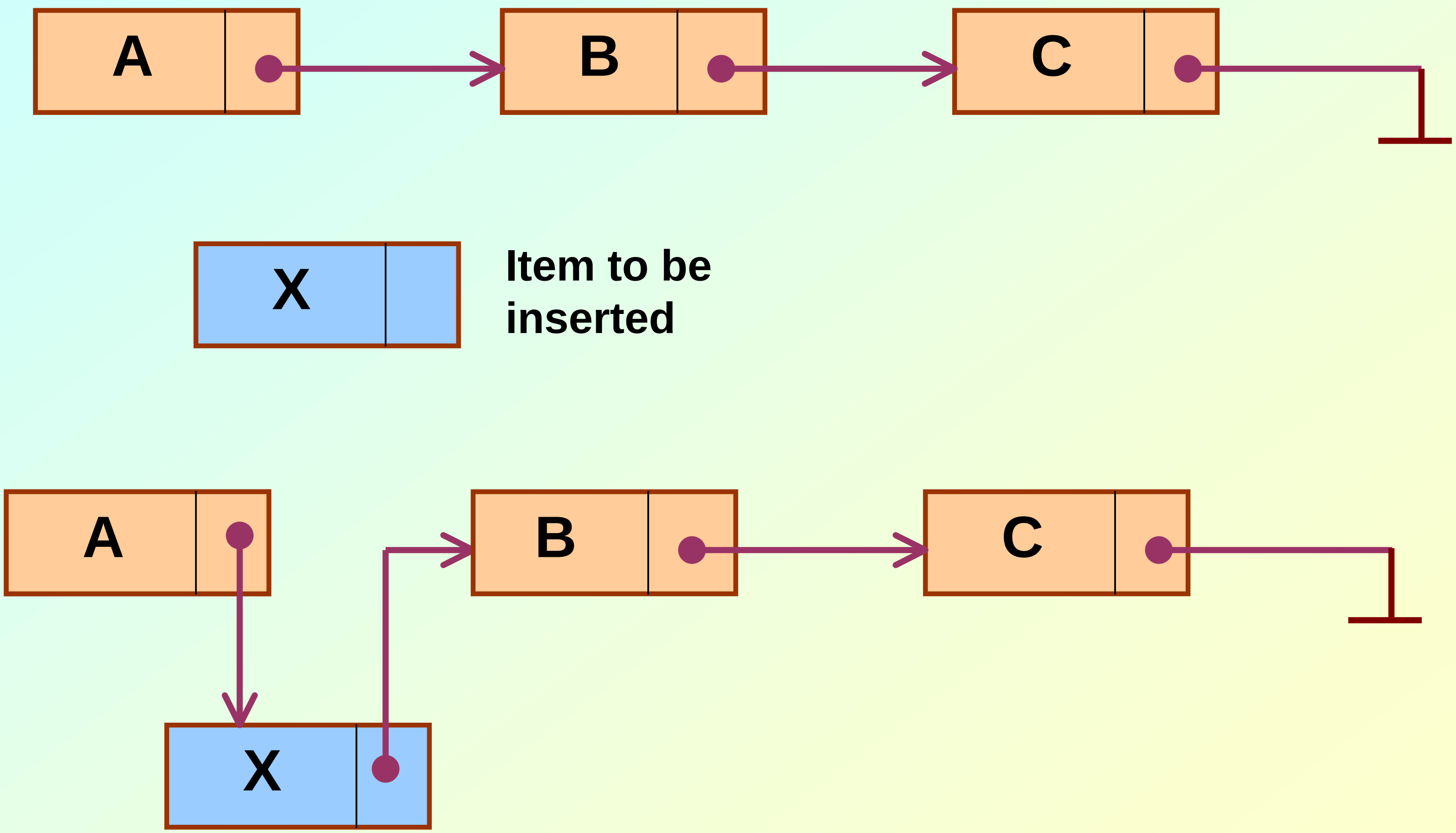
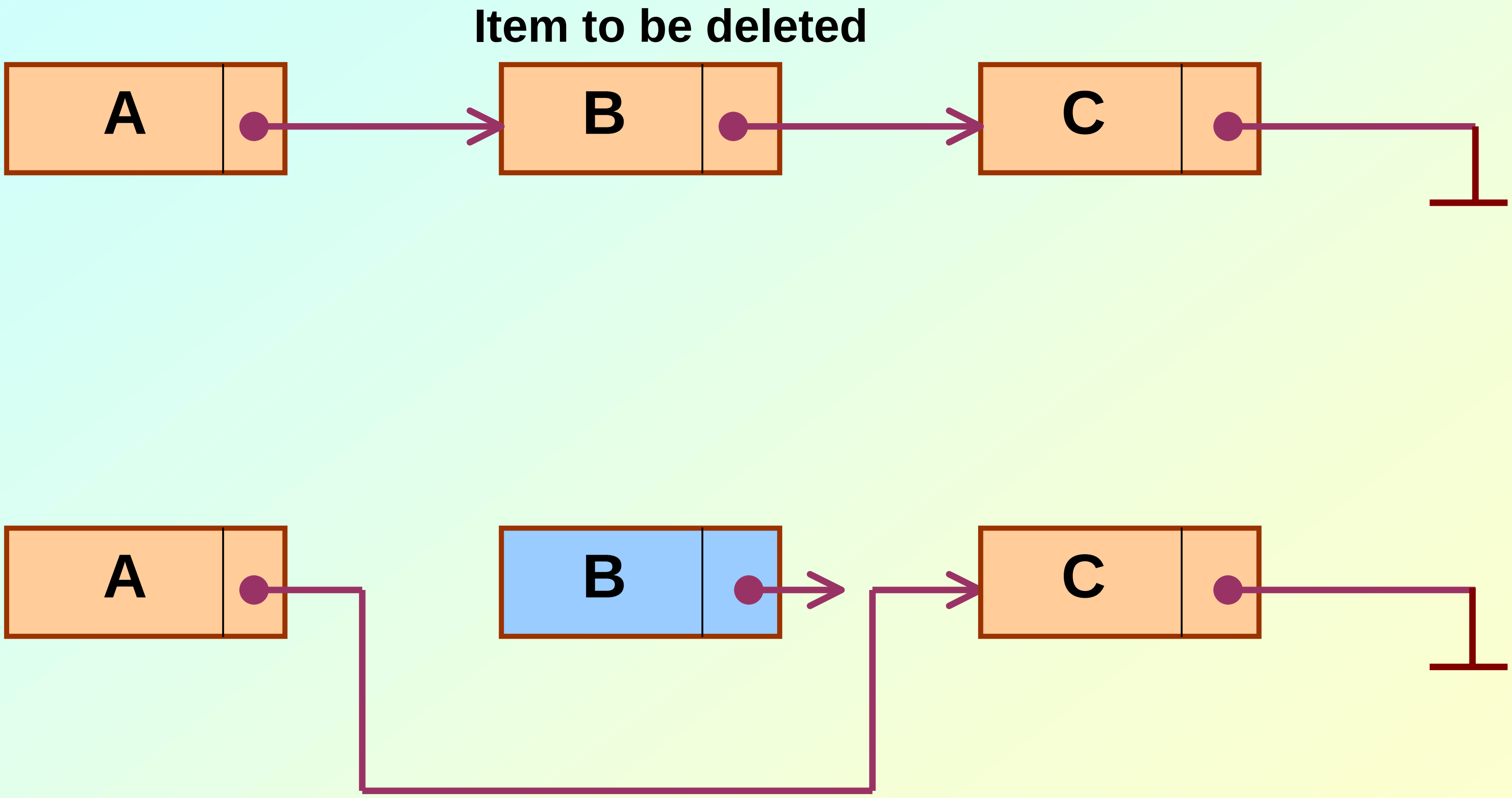


Illustration: Deletion



In essence ...

- **For insertion:**
  - **A record is created holding the new item.**
  - **The next pointer of the new record is set to link it to the item which is to follow it in the list.**
  - **The next pointer of the item which is to precede it must be modified to point to the new item.**
- **For deletion:**
  - **The next pointer of the item immediately preceding the one to be deleted is altered, and made to point to the item following the deleted item.**

Array versus Linked Lists

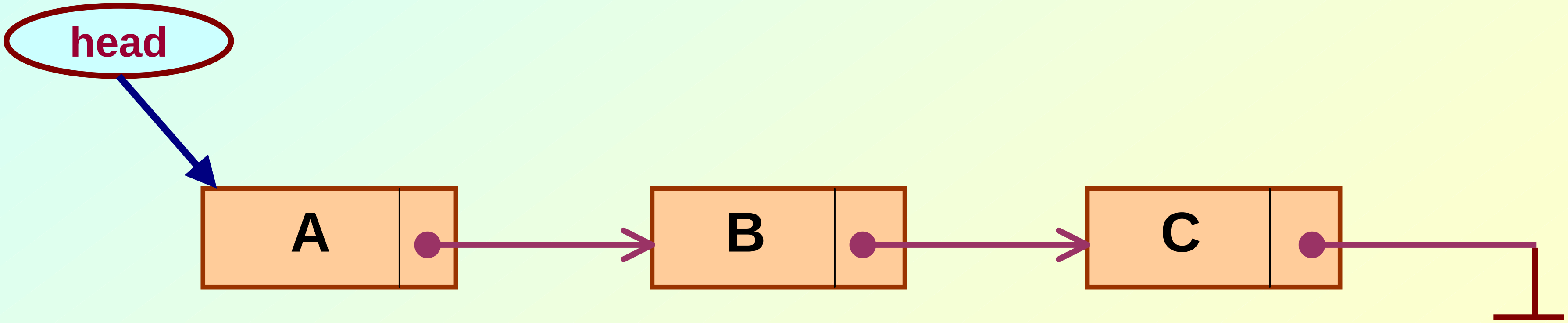
- Arrays are suitable for:
  - Inserting/deleting an element at the end.
  - Randomly accessing any element.
  - Searching the list for a particular value.
- Linked lists are suitable for:
  - Inserting an element.
  - Deleting an element.
  - Applications where sequential access is required.
  - In situations where the number of elements cannot be predicted beforehand.

Types of Lists

- Depending on the way in which the links are used to maintain adjacency, several different types of linked lists are possible.

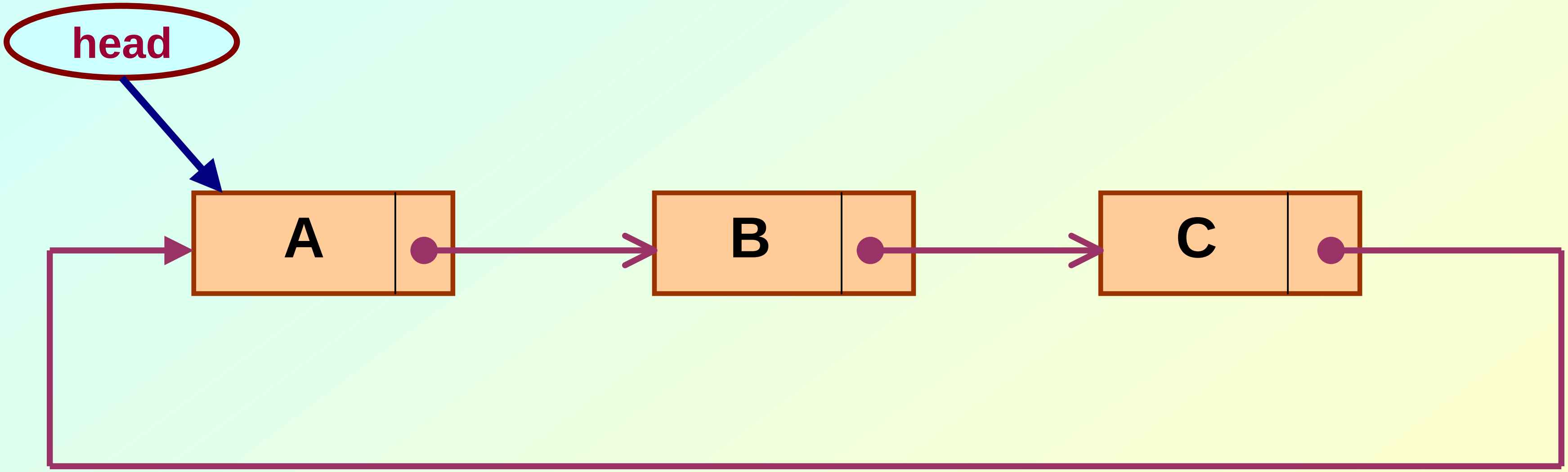
  – Linear singly-linked list (or simply linear list)

    - One we have discussed so far.



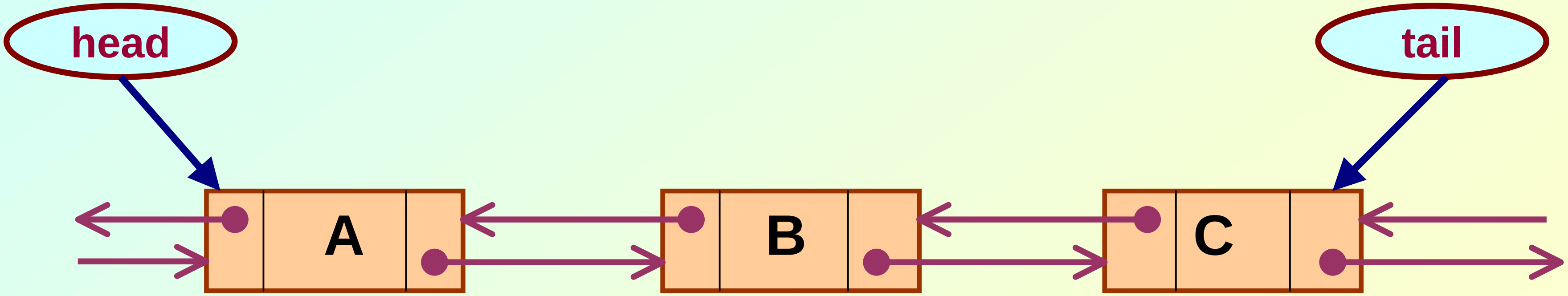
– **Circular linked list**

- **The pointer from the last element in the list points back to the first element.**



– Doubly linked list

- Pointers exist between adjacent nodes in both directions.
- The list can be traversed either forward or backward.
- Usually two pointers are maintained to keep track of the list, ***head*** and ***tail***.



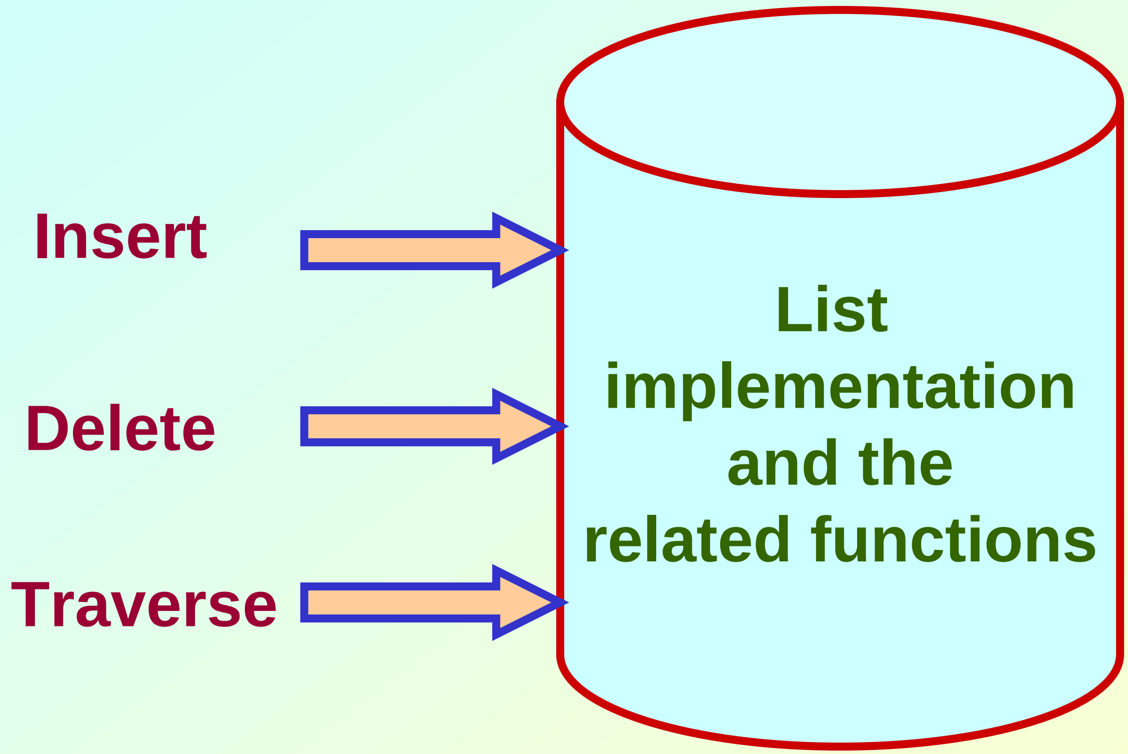
Basic Operations on a List

- Creating a list
- Traversing the list
- Inserting an item in the list
- Deleting an item from the list
- Concatenating two lists into one

List is an Abstract Data Type

- **What is an abstract data type?**
  - **It is a data type defined by the user.**
  - **Typically more complex than simple data types like *int*, *float*, etc.**
- **Why abstract?**
  - **Because details of the implementation are hidden.**
  - **When you do some operation on the list, say insert an element, you just call a function.**
  - **Details of how the list is implemented or how the insert function is written is no longer required.**

Conceptual Idea



Example: Working with linked list

- **Consider the structure of a node as follows:**

```
struct stud {
              int   roll;
              char  name[25];
              int   age;
              struct stud *next;
            };
```

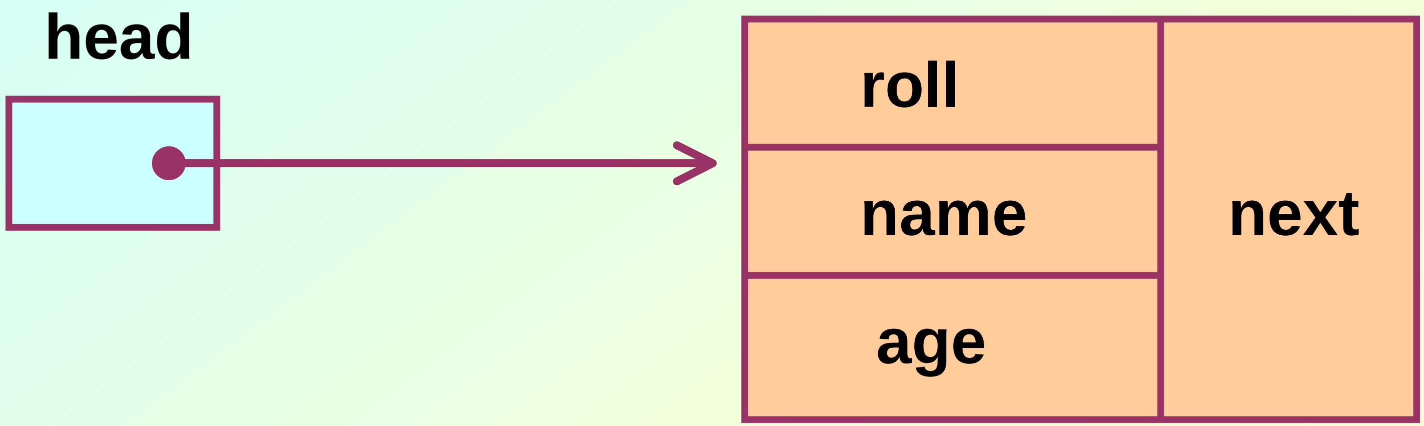
```
  /* A user-defined data type called "node" */

typedef struct stud node;
node *head;
```

Creating a List

How to begin?

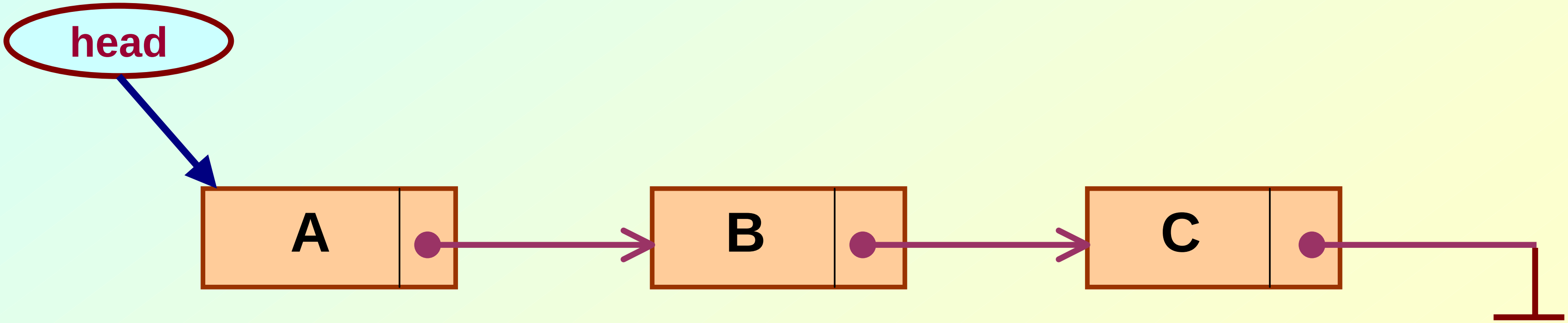
- To start with, we have to create a node (the first node), and make **head** point to it.

```
head = (node *) malloc(sizeof(node));
```



Contd.

- If there are n number of nodes in the initial linked list:
  - Allocate n records, one by one.
  - Read in the fields of the records.
  - Modify the links of the records so that the chain is formed.



```
node *create_list()
{
    int  k, n;
    node  *p, *head;

    printf  ("\n How many elements to enter?");
     scanf ("%d", &n);

    for  (k=0; k<n; k++)
    {
        if (k == 0) {
          head = (node *) malloc(sizeof(node));
          p = head;
        }
        else {
               p->next  = (node *) malloc(sizeof(node));
               p = p->next;
             }

        scanf ("%d %s %d", &p->roll, p->name, &p->age);
    }

    p->next  =  NULL;
    return (head);
}
```

- **To be called from `main()` function as:**

```
node *head;
………
head = create_list();
```

Traversing the List

What is to be done?

- **Once the linked list has been constructed and *head* points to the first node of the list,**
  - **Follow the pointers.**
  - **Display the contents of the nodes as they are traversed.**
  - **Stop when the *next* pointer points to NULL.**

```
void display (node *head)
{
  int  count = 1;
  node  *p;

  p = head;
  while (p != NULL)
  {
    printf ("\nNode %d: %d %s %d", count,
                   p->roll, p->name, p->age);
    count++;
    p = p->next;
  }
  printf ("\n");
}
```

- To be called from `main()` function as:

```
node *head;
………
display (head);
```

Inserting a Node in a List

How to do?

- **The problem is to insert a node *before a specified node*.**
  - **Specified means some value is given for the node (called *key*).**
  - **In this example, we consider it to be `roll`.**
- **Convention followed:**
  - **If the value of roll is given as *negative*, the node will be inserted at the *end* of the list.**

Contd.

- **When a node is added at the beginning,**
  - **Only one next pointer needs to be modified.**
    - ***head*** **is made to point to the new node.**
    - **New node points to the previously first element.**
- **When a node is added at the end,**
  - **Two next pointers need to be modified.**
    - **Last node now points to the new node.**
    - **New node points to NULL.**
- **When a node is added in the middle,**
  - **Two next pointers need to be modified.**
    - **Previous node now points to the new node.**
    - **New node points to the next node.**

```
void insert (node **head)
{
    int  k = 0, rno;
    node *p, *q, *new;

    new = (node *) malloc(sizeof(node));

    printf ("\nData to be inserted: ");
      scanf ("%d %s %d", &new->roll, new->name, &new->age);
    printf ("\nInsert before roll (-ve for end):");
      scanf ("%d", &rno);

    p = *head;

    if (p->roll == rno)        /* At the beginning */
    {
        new->next = p;
        *head = new;
    }
```

```
  else
    {
       while ((p != NULL) && (p->roll != rno))
        {
            q = p;
            p = p->next;
        }

        if  (p == NULL)        /* At the end */
        {
            q->next = new;
            new->next = NULL;
        }
        else if  (p->roll  == rno)
                              /* In the middle */
                {
                    q->next = new;
                    new->next = p;
                }
    }
}
```

The pointers q and p always point to consecutive nodes.

- **To be called from `main()` function as:**

```
node *head;
………
insert (&head);
```

Deleting a node from the list

What is to be done?

- **Here also we are required to delete a specified node.**
  - **Say, the node whose `roll` field is given.**
- **Here also three conditions arise:**
  - **Deleting the first node.**
  - **Deleting the last node.**
  - **Deleting an intermediate node.**

```
void  delete (node **head)
{
    int  rno;
    node  *p, *q;

    printf ("\nDelete for roll :");
      scanf ("%d", &rno);

    p = *head;
    if  (p->roll == rno)
             /* Delete the first element */
    {
        *head = p->next;
        free (p);
    }
```

```
 else
    {
        while  ((p != NULL) && (p->roll != rno))
        {
            q = p;
            p  =  p->next;
        }

        if  (p == NULL)      /* Element not found */
           printf ("\nNo match :: deletion failed");

        else if (p->roll == rno)
                          /* Delete any other element */
             {
                 q->next  =  p->next;
                 free (p);
             }
    }
}
```

Few Exercises to Try Out

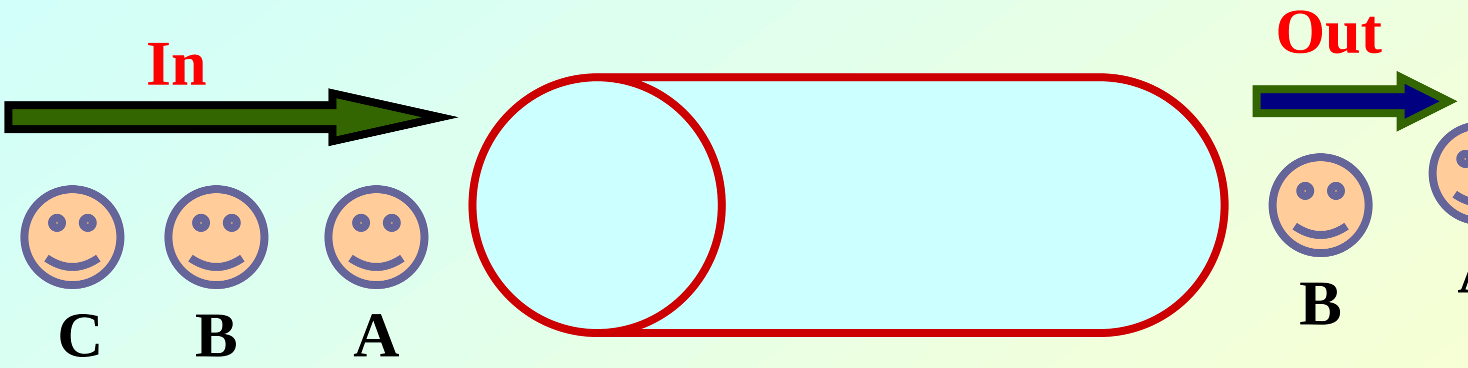
- **Write a function to:**
  - Concatenate two given list into one big list.

    `node  *concatenate (node *head1, node *head2);`
  - Insert an element in a linked list in sorted order. The function will be called for every element to be inserted.

    `void  insert_sorted (node **head,  node *element);`
  - Always insert elements at one end, and delete elements from the other end (first-in first-out QUEUE).

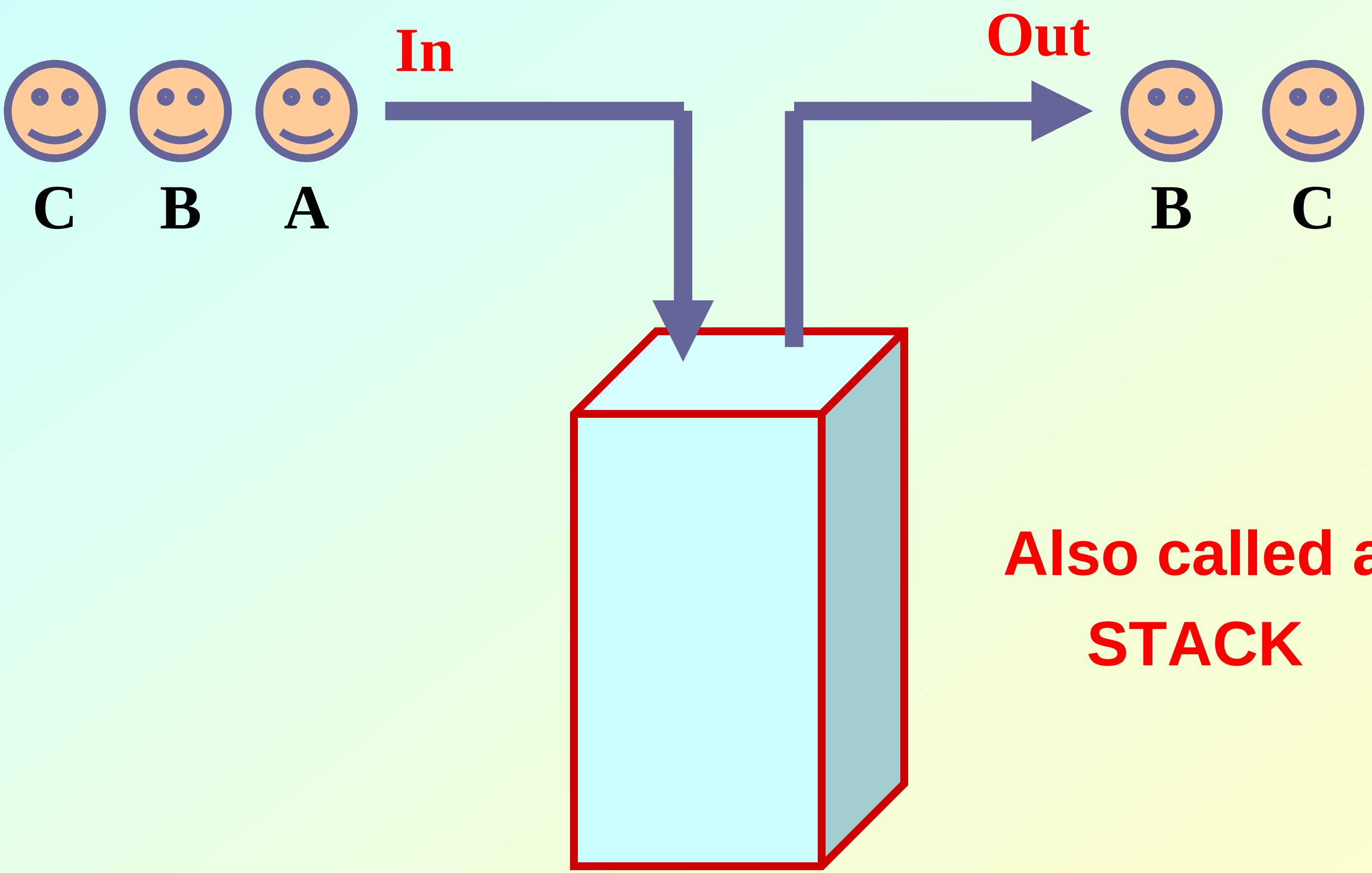
```
void  insert_q (node **head,  node *element)
node  *delete_q (node **head)   /* Return the deleted node */
```

A First-in First-out (FIFO) List



Also called a QUEUE

A Last-in First-out (LIFO) List



Also called a STACK

Abstract Data Types

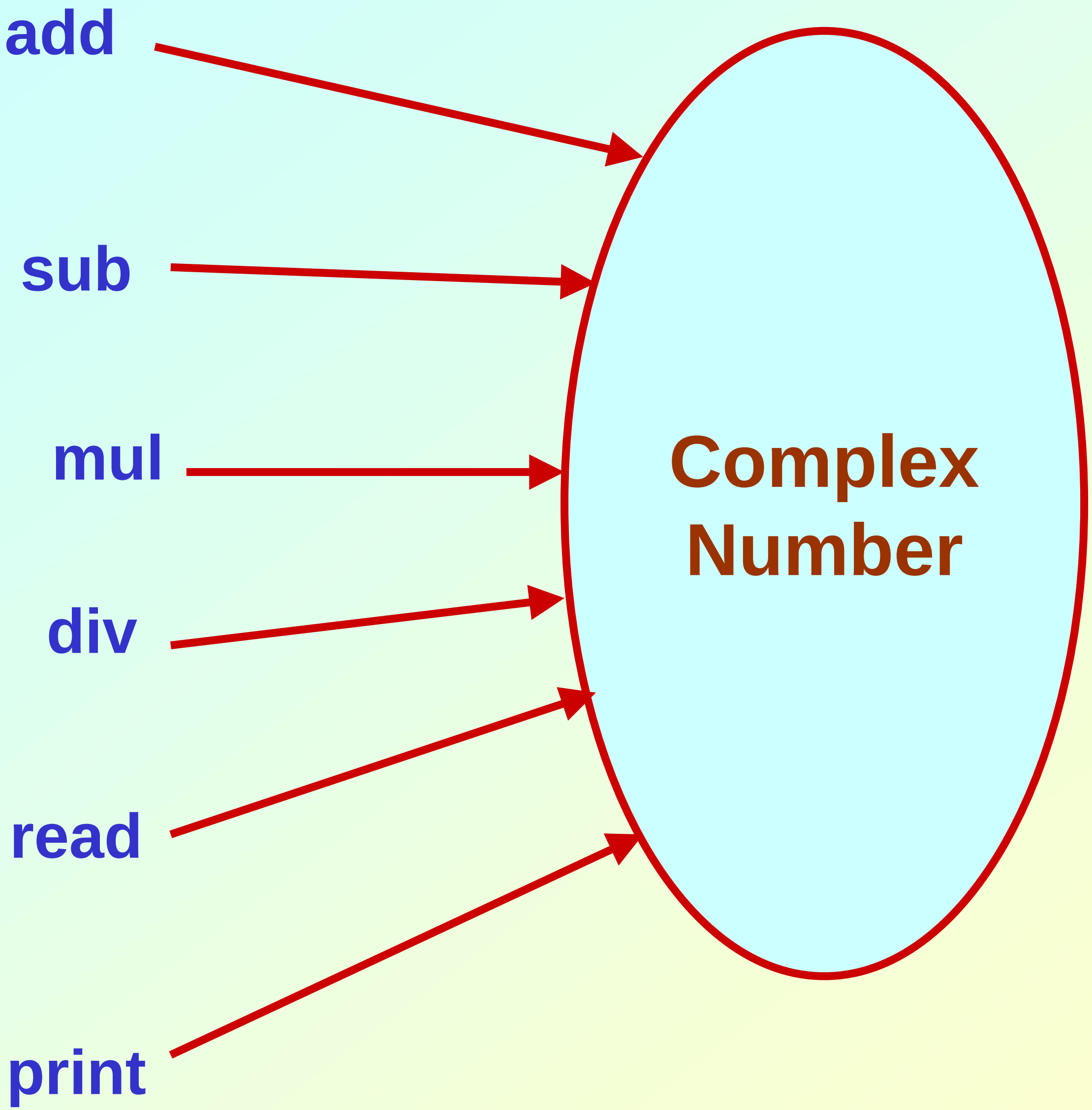
Example 1 :: Complex numbers

```
struct cplx {
              float  re;
              float  im;
            }
typedef struct cplx complex;
```

Structure definition

```
complex *add (complex a, complex b);
complex *sub (complex a, complex b);
complex *mul (complex a, complex b);
complex *div (complex a, complex b);
complex *read();
void print (complex a);
```

Function prototypes


add
sub
mul
div
read
print
Complex
Number

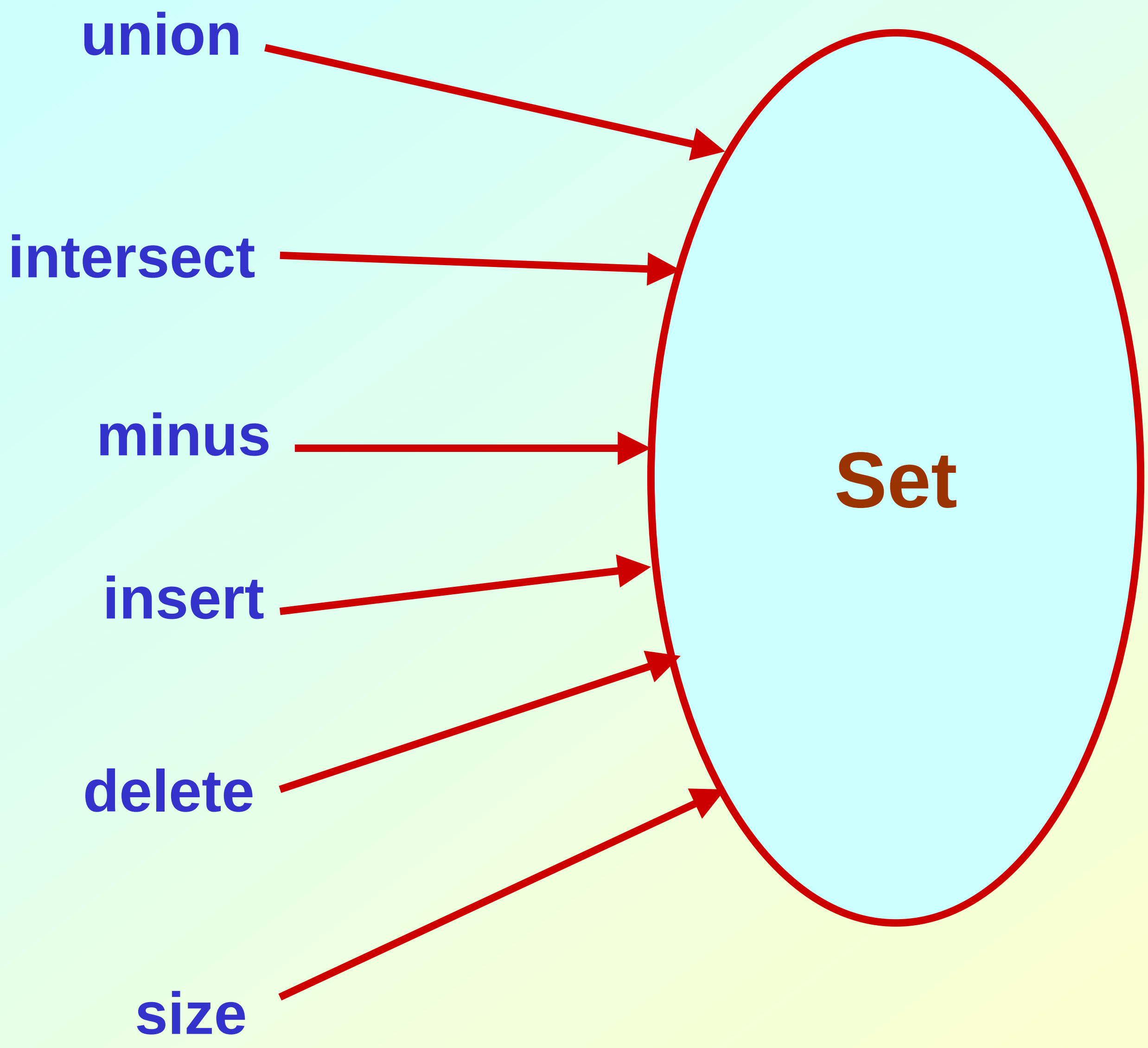
Example 2 :: Set manipulation

```
struct node {
              int element;
              struct node *next;
            }
typedef struct node set;
```

Structure definition

```
set *union (set a, set b);
set *intersect (set a, set b);
set *minus (set a, set b);
void insert (set a, int x);
void delete (set a, int x);
int size (set a);
```

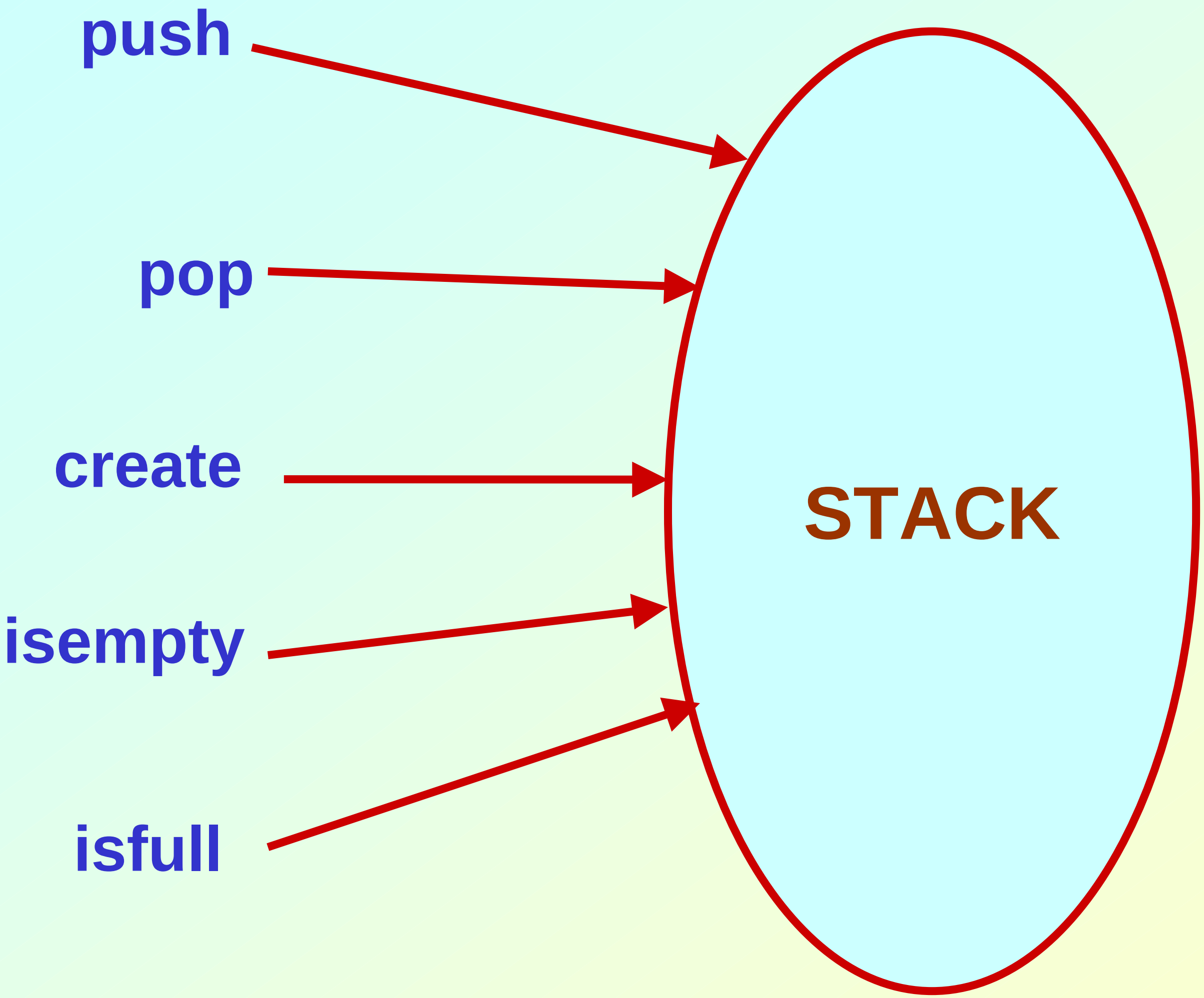
Function prototypes


union
intersect
minus
insert
delete
size
Set

Example 3 :: Last-In-First-Out STACK

Assume:: stack contains integer elements

```
void push (stack *s, int element);
                    /* Insert an element in the stack */
int pop (stack *s);
                    /* Remove and return the top element */
void create (stack  *s);
                    /* Create a new stack */
int isempty (stack *s);
                    /* Check if stack is empty */
int isfull (stack *s);
                    /* Check if stack is full */
```


push
pop
create
isempty
isfull
STACK

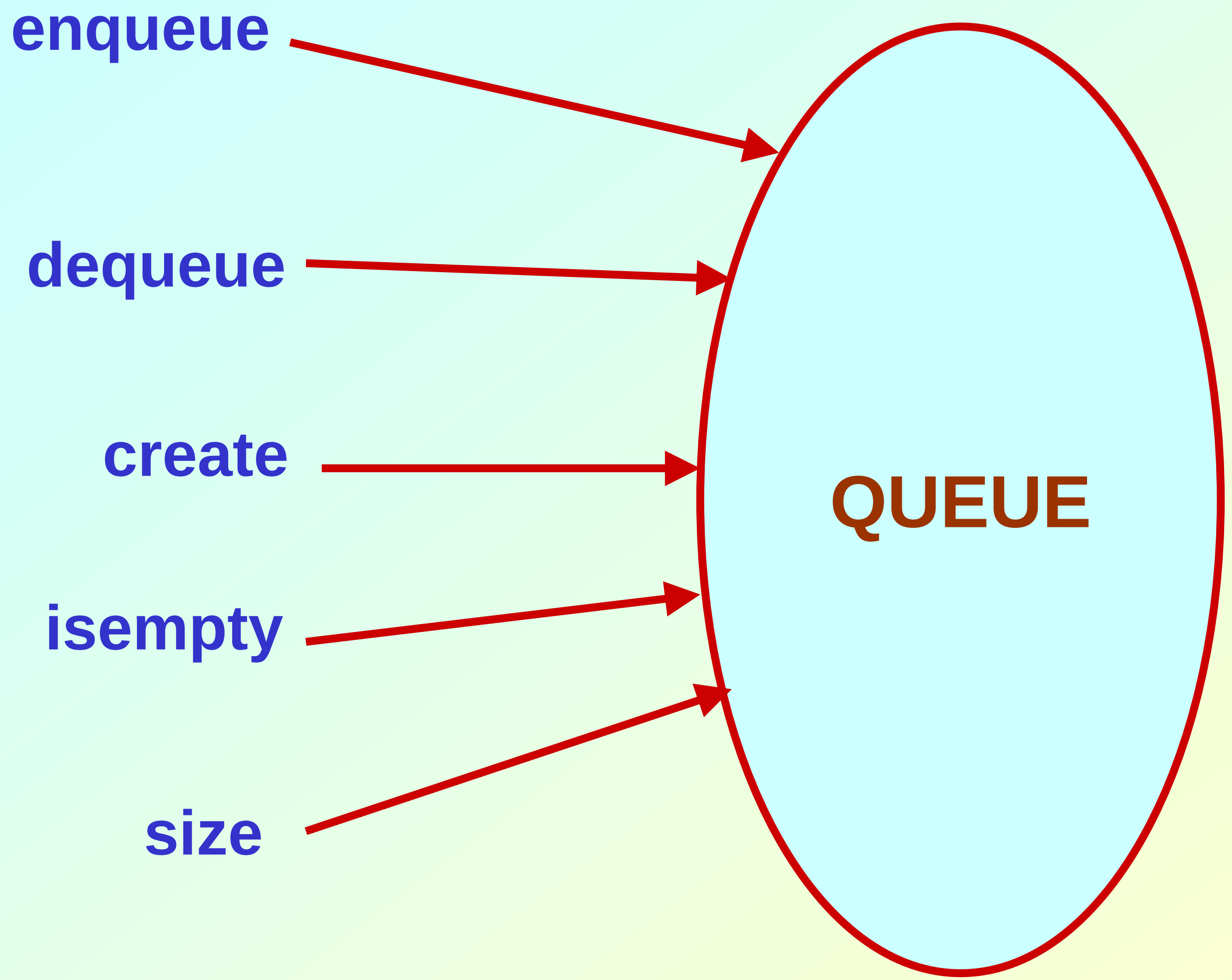
Contd.

- **We shall look into two different ways of implementing stack:**
  - **Using arrays**
  - **Using linked list**

Example 4 :: First-In-First-Out QUEUE

Assume:: queue contains integer elements

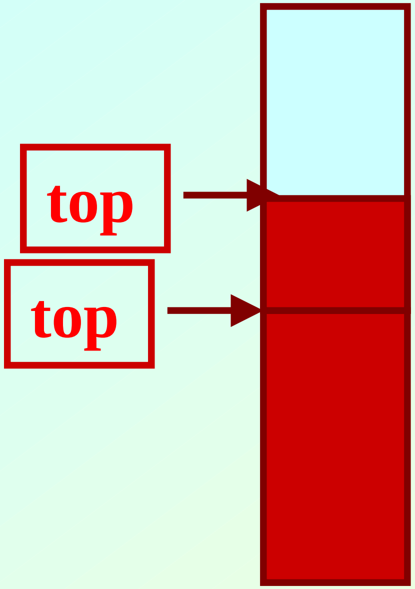
```
void enqueue (queue *q, int element);
                    /* Insert an element in the queue */
int dequeue (queue *q);
                    /* Remove an element from the queue */
queue *create();
                    /* Create a new queue */
int isempty (queue *q);
                    /* Check if queue is empty */
int size (queue *q);
                    /* Return the no. of elements in queue */
```


enqueue
dequeue
create
isempty
size
QUEUE

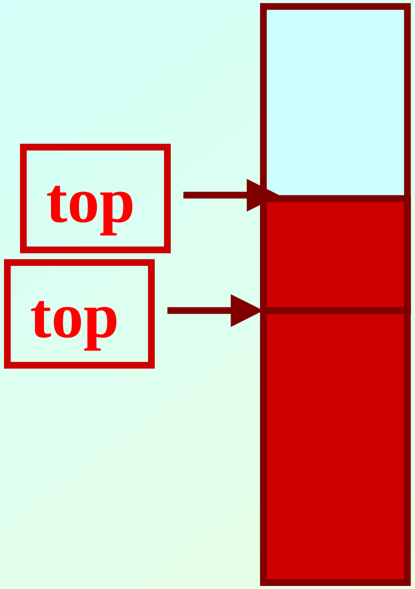
Stack Implementations: Using Array and Linked List

STACK USING ARRAY

PUSH



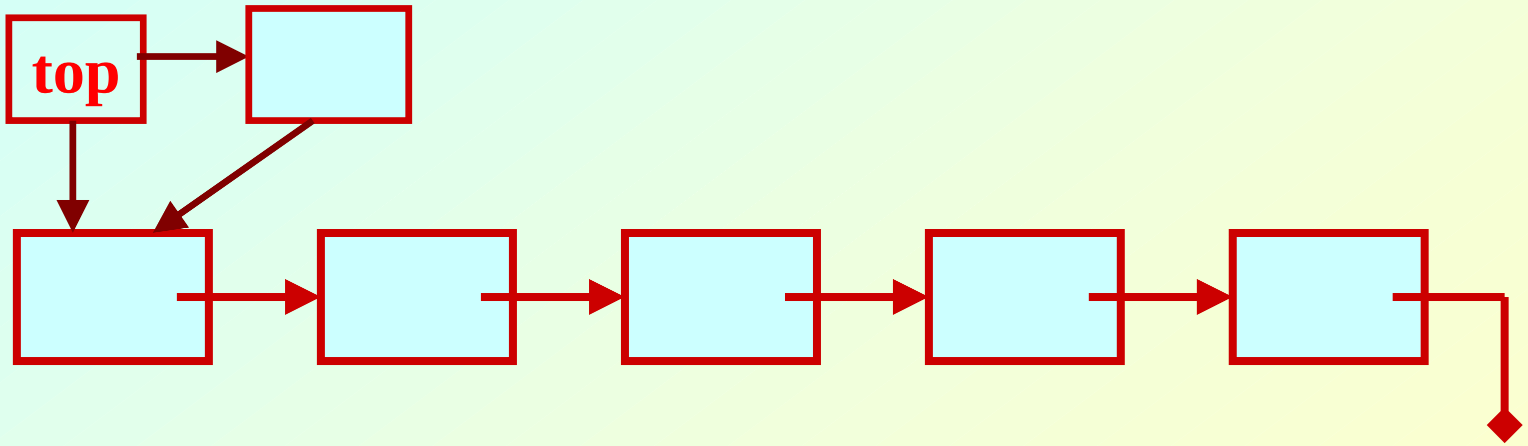
STACK USING ARRAY



POP

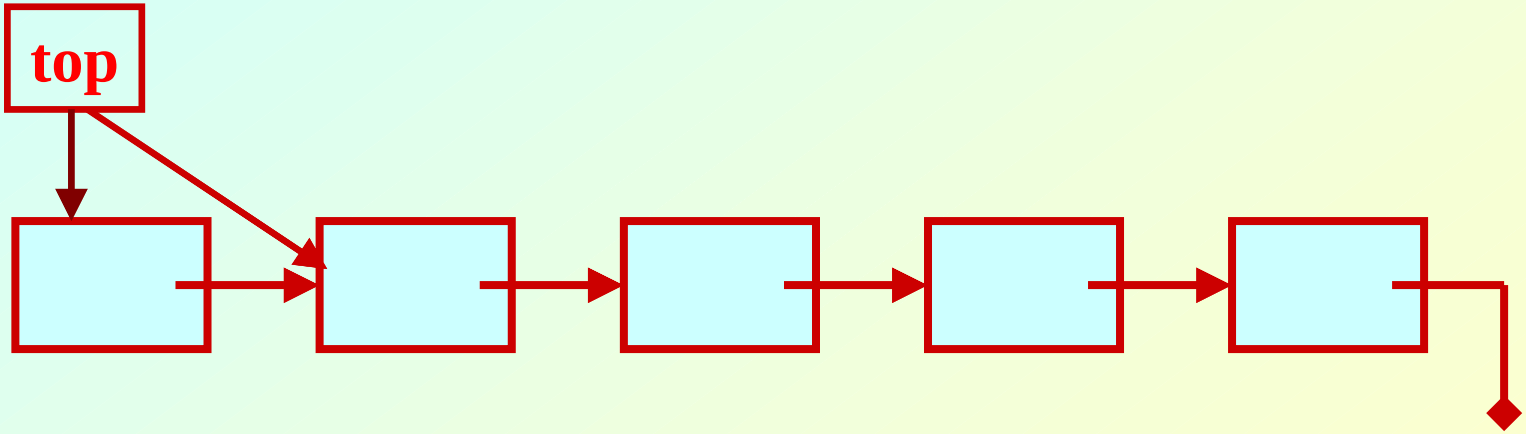
Stack: Linked List Structure

PUSH OPERATION



Stack: Linked List Structure

POP OPERATION



Basic Idea

- **In the array implementation, we would:**
  - Declare an array of fixed size (which determines the maximum size of the stack).
  - Keep a variable which always points to the “top” of the stack.
    - Contains the array index of the “top” element.
- **In the linked list implementation, we would:**
  - Maintain the stack as a linked list.
  - A pointer variable `top` points to the start of the list.
  - The first element of the linked list is considered as the stack top.

Declaration

```c
#define MAXSIZE 100

struct lifo
{
   int st[MAXSIZE];
   int  top;
};
typedef struct lifo
                stack;
stack s;
```

ARRAY

```c
struct lifo
{
   int value;
   struct lifo *next;
};
typedef struct lifo
                stack;

stack *top;
```

LINKED LIST

Stack Creation

```
void create (stack *s)
{
   s->top = -1;

   /* s->top points to
      last element
      pushed in;
      initially -1 */
}
```

ARRAY

```
void create (stack **top)
{
   *top = NULL;

   /* top points to NULL,
      indicating empty
      stack            */
}
```

LINKED LIST

Pushing an element into the stack

```
void push (stack *s, int element)
  {
     if (s->top == (MAXSIZE-1))
     {
         printf (“\n Stack overflow”);
         exit(-1);
     }
     else
     {
         s->top ++;
         s->st[s->top] = element;
     }
  }
```

ARRAY

```
void push (stack **top, int element)
{
    stack *new;

    new = (stack *) malloc(sizeof(stack));
    if (new == NULL)
    {
       printf (“\n Stack is full”);
       exit(-1);
    }

    new->value = element;
    new->next = *top;
    *top = new;
}
```

LINKED LIST

Popping an element from the stack

```
int pop (stack *s)
  {
     if (s->top == -1)
     {
        printf ("\n Stack underflow");
        exit(-1);
     }
     else
     {
        return (s->st[s->top--]);
     }
  }
```

ARRAY

```
int pop (stack **top)
{
    int t;
    stack *p;

    if (*top == NULL)
    {
        printf ("\n Stack is empty");
        exit(-1);
    }
    else
    {
        t = (*top)->value;
        p = *top;
        *top = (*top)->next;
        free (p);
        return t;
    }
}
```

LINKED LIST

Checking for stack empty

```
int isempty (stack *s)
{
   if (s->top == -1)
            return 1;
   else
            return (0);
}
```

ARRAY

```
int isempty (stack *top)
{
   if (top == NULL)
          return (1);
    else
          return (0);
}
```

LINKED LIST

Checking for stack full

```
int isfull (stack *s)
{
   if (s->top ==
            (MAXSIZE-1))
         return 1;
   else
         return (0);
}
```

ARRAY

- Not required for linked list implementation.
- In the `push()` function, we can check the return value of `malloc()`.
  - If -1, then memory cannot be allocated.

LINKED LIST

Example main function :: array

```
#include <stdio.h>
#define MAXSIZE 100

struct lifo
{
   int st[MAXSIZE];
   int  top;
};
typedef struct lifo stack;
```

```
main()
{
  stack A, B;
  create(&A);  create(&B);
  push(&A,10);
  push(&A,20);
```

```
   push(&A,30);
   push(&B,100);  push(&B,5);

   printf (“%d %d”, pop(&A),
               pop(&B));

   push (&A, pop(&B));

   if (isempty(&B))
     printf (“\n B is empty”);
}
```

Example main function :: linked list

```
#include <stdio.h>
struct lifo
{
   int value;
   struct lifo *next;
};
typedef struct lifo stack;
```

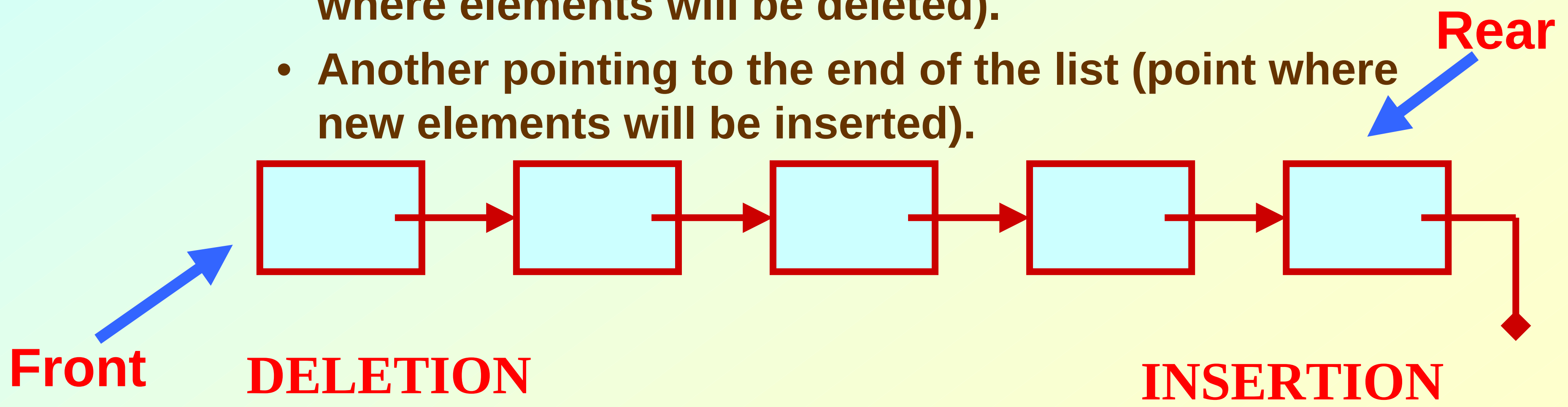
```
main()
{
  stack *A, *B;
  create(&A); create(&B);
  push(&A,10);
  push(&A,20);
```

```
  push(&A,30);
  push(&B,100);
  push(&B,5);

  printf (“%d %d”,
          pop(&A), pop(&B));

  push (&A, pop(&B));

  if (isempty(B))
    printf (“\n B is
  empty”);
}
```

Queue Implementation using Linked List

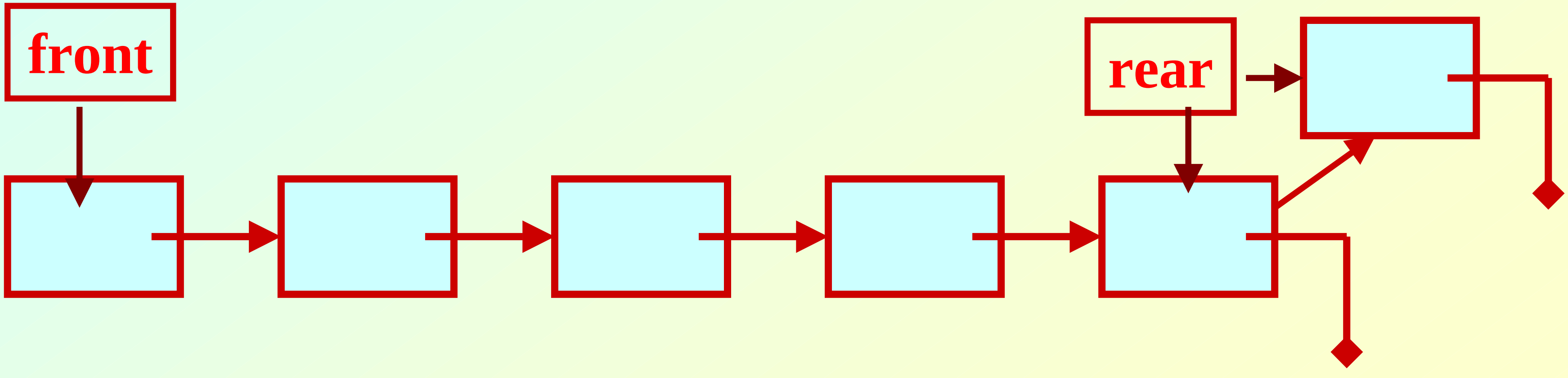
Basic Idea

- **Basic idea:**
  - Create a linked list to which items would be added to one end and deleted from the other end.
  - Two pointers will be maintained:
    - One pointing to the beginning of the list (point from where elements will be deleted).
    - Another pointing to the end of the list (point where new elements will be inserted).



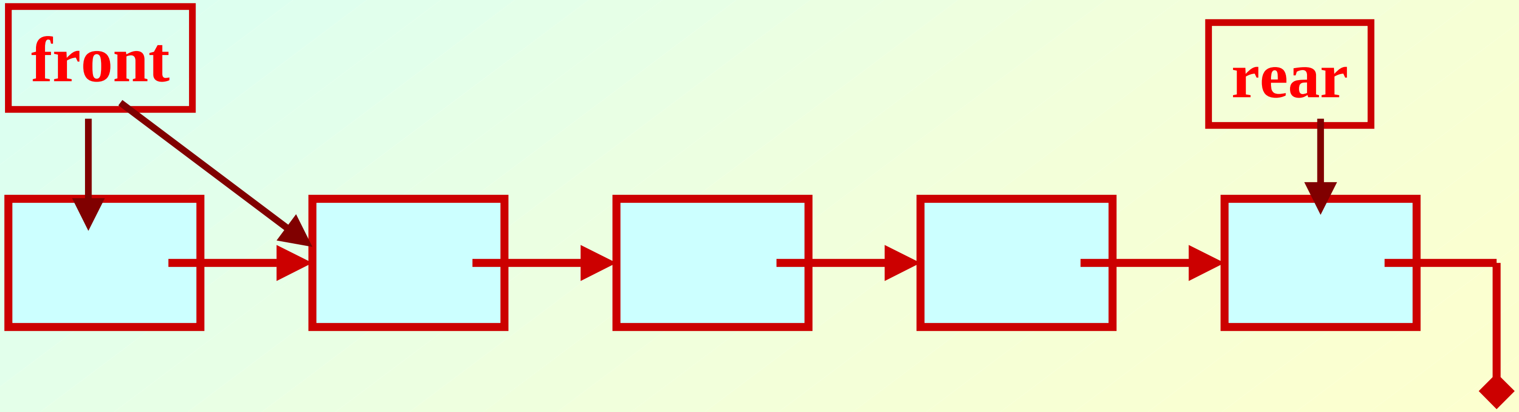
QUEUE: LINKED LIST STRUCTURE

ENQUEUE



QUEUE: LINKED LIST STRUCTURE

DEQUEUE



QUEUE using Linked List

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

struct node{
            char name[30];
            struct node *next;
          };

typedef struct node _QNODE;

typedef struct {
    _QNODE *queue_front, *queue_rear;
     } _QUEUE;
```

```
_QNODE *enqueue (_QUEUE *q, char x[])
{
_QNODE *temp;
temp= (_QNODE *)
        malloc (sizeof(_QNODE));
if (temp==NULL){
printf("Bad allocation \n");
return NULL;
}
strcpy(temp->name,x);
temp->next=NULL;
```

```
if(q->queue_rear==NULL)
{
q->queue_rear=temp;
q->queue_front=
     q->queue_rear;
}
else
{
q->queue_rear->next=temp;
q->queue_rear=temp;
}
return(q->queue_rear);
}
```

```
char  *dequeue(_QUEUE *q,char x[])
{
_QNODE *temp_pnt;

if(q->queue_front==NULL){
q->queue_rear=NULL;
printf("Queue is empty \n");
return(NULL);
}
```

```
else{
strcpy(x,q->queue_front->name);
temp_pnt=q->queue_front;
q->queue_front=
        q->queue_front->next;
free(temp_pnt);
if(q->queue_front==NULL)
q->queue_rear=NULL;
return(x);
 }
}
```

```
void init_queue(_QUEUE *q)
{
 q->queue_front= q->queue_rear=NULL;
}

int isEmpty(_QUEUE *q)
{
 if(q==NULL) return 1;
 else return 0;
}
```

```
main()
{
int i,j;
char command[5],val[30];
_QUEUE q;

 init_queue(&q);

command[0]='\0';
printf("For entering a name use 'enter <name>'\n");
printf("For  deleting  use 'delete' \n");
printf("To end the session use 'bye' \n");
while(strcmp(command,"bye")){
scanf("%s",command);
```

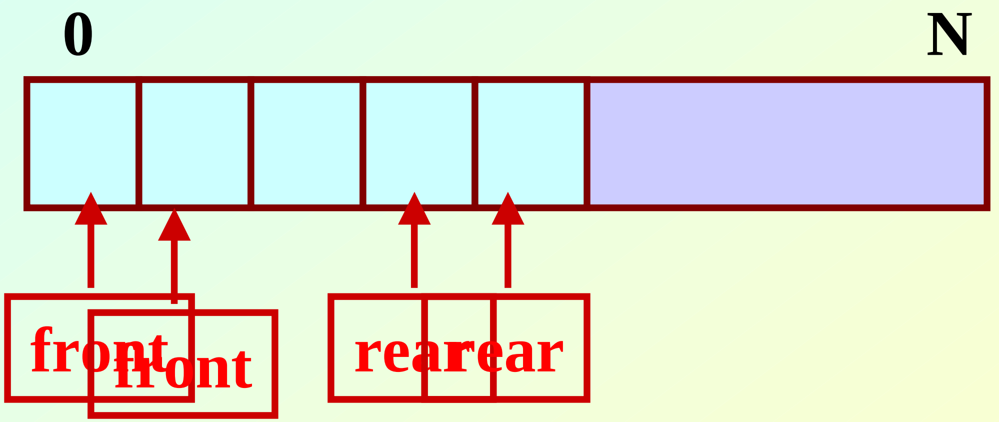
```
if(!strcmp(command,"enter")) {
scanf("%s",val);
if((enqueue(&q,val)==NULL))
printf("No more pushing please \n");
else printf("Name entered %s \n",val);
}
```

```
if(!strcmp(command,"delete")) {
if(!isEmpty(&q))
printf("%s \n",dequeue(&q,val));
else printf("Name deleted %s \n",val);
}
} /* while */
printf("End session \n");
}
```

Problem With Array Implementation

ENQUEUE DEQUEUE

Effective queuing storage area of array gets reduced.



Use of circular array indexing

Queue: Example with Array Implementation

```
#define MAX_SIZE  100

typedef struct { char name[30];
              } _ELEMENT;

typedef struct {
              _ELEMENT q_elem[MAX_SIZE];
               int rear;
               int front;
               int full,empty;
               } _QUEUE;
```

Queue Example: Contd.

```
void init_queue(_QUEUE *q)
{q->rear= q->front= 0;
 q->full=0; q->empty=1;
}

 int  IsFull(_QUEUE *q)
{return(q->full);}

 int  IsEmpty(_QUEUE *q)
{return(q->empty);}
```

Queue Example: Contd.

```
void AddQ(_QUEUE *q, _ELEMENT ob)
{
  if(IsFull(q)) {printf("Queue is Full \n"); return;}

  q->rear=(q->rear+1)%(MAX_SIZE);
  q->q_elem[q->rear]=ob;

  if(q->front==q->rear) q->full=1; else q->full=0;
  q->empty=0;

 return;
}
```

Queue Example: Contd.

```
_ELEMENT  DeleteQ(_QUEUE *q)
 {
  _ELEMENT temp;
   temp.name[0]='\0';

     if(IsEmpty(q)) {printf("Queue is EMPTY\n");return(temp);}

     q->front=(q->front+1)%(MAX_SIZE);
     temp=q->q_elem[q->front];

     if(q->rear==q->front) q->empty=1; else q->empty=0;
     q->full=0;

   return(temp);
 }
```

Queue Example: Contd.

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

main()
{
int i,j;
char command[5];
_ELEMENT ob;
_QUEUE A;

  init_queue(&A);

  command[0]='\0';
  printf("For adding a name use 'add [name]'\n");
  printf("For deleting  use 'delete' \n");
  printf("To end the session use 'bye' \n");
```

Queue Example: Contd.

```
while (strcmp(command,"bye")!=0){
    scanf("%s",command);

      if(strcmp(command,"add")==0) {
        scanf("%s",ob.name);
        if (IsFull(&A))
       printf("No more insertion please \n");
       else {
        AddQ(&A,ob);
         printf("Name inserted %s \n",ob.name);
            }
                                         }
```

Queue Example: Contd.

```
        if (strcmp(command,"delete")==0) {
            if (IsEmpty(&A))
                printf("Queue is empty \n");
                else {
                        ob=DeleteQ(&A);
                         printf("Name deleted %s \n",ob.name);
                        }
                                                  }
       }  /* End of while */
  printf("End session \n");
}
```