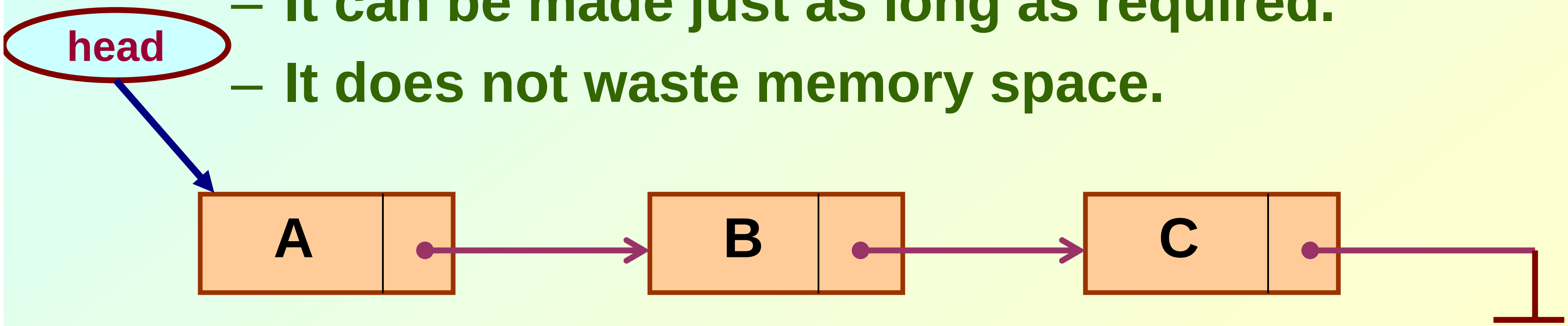
Linked List

Introduction

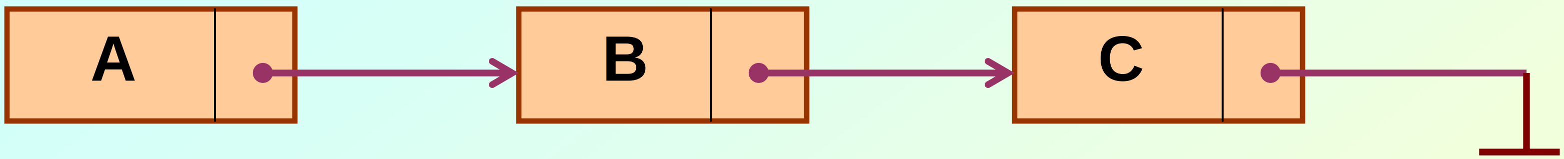
- A linked list is a data structure which can change during execution.
  - Successive elements are connected by pointers.
  - Last element points to `NULL`.
  - It can grow or shrink in size during execution of a program.
  - It can be made just as long as required.
  - It does not waste memory space.

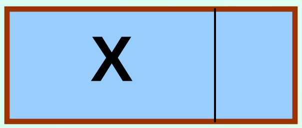


- **Keeping track of a linked list:**
  - **Must know the pointer to the first element of the list (called *start*, *head*, etc.).**

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

Illustration: Insertion





Item to be inserted

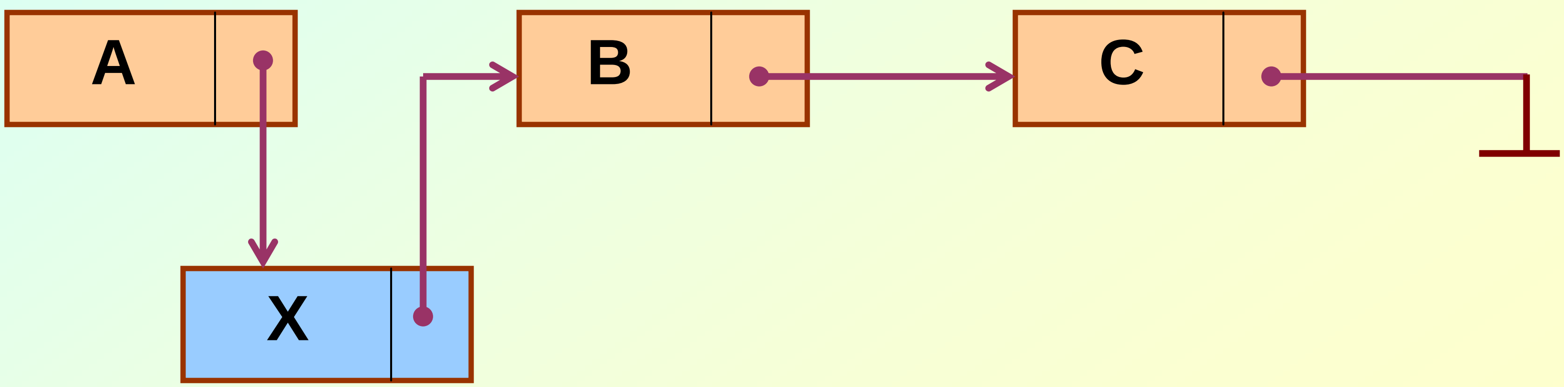
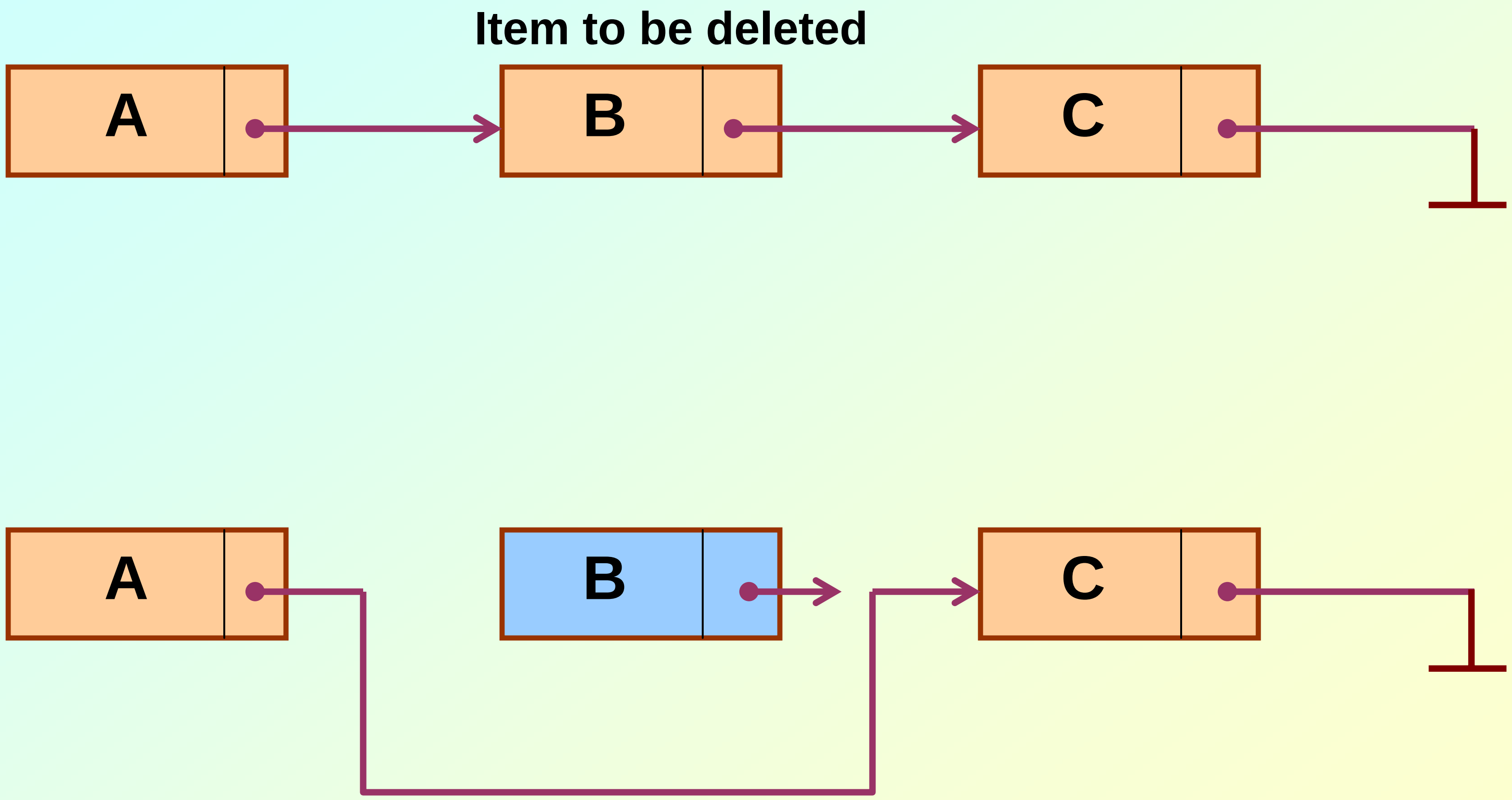


Illustration: Deletion



In essence ...

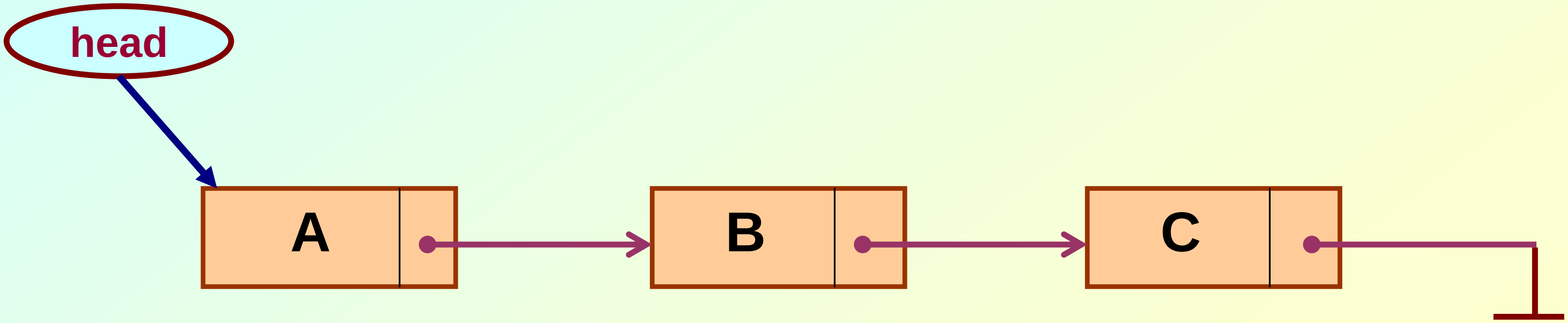
- **For insertion:**
  - **A record is created holding the new item.**
  - **The next pointer of the new record is set to link it to the item which is to follow it in the list.**
  - **The next pointer of the item which is to precede it must be modified to point to the new item.**
- **For deletion:**
  - **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.

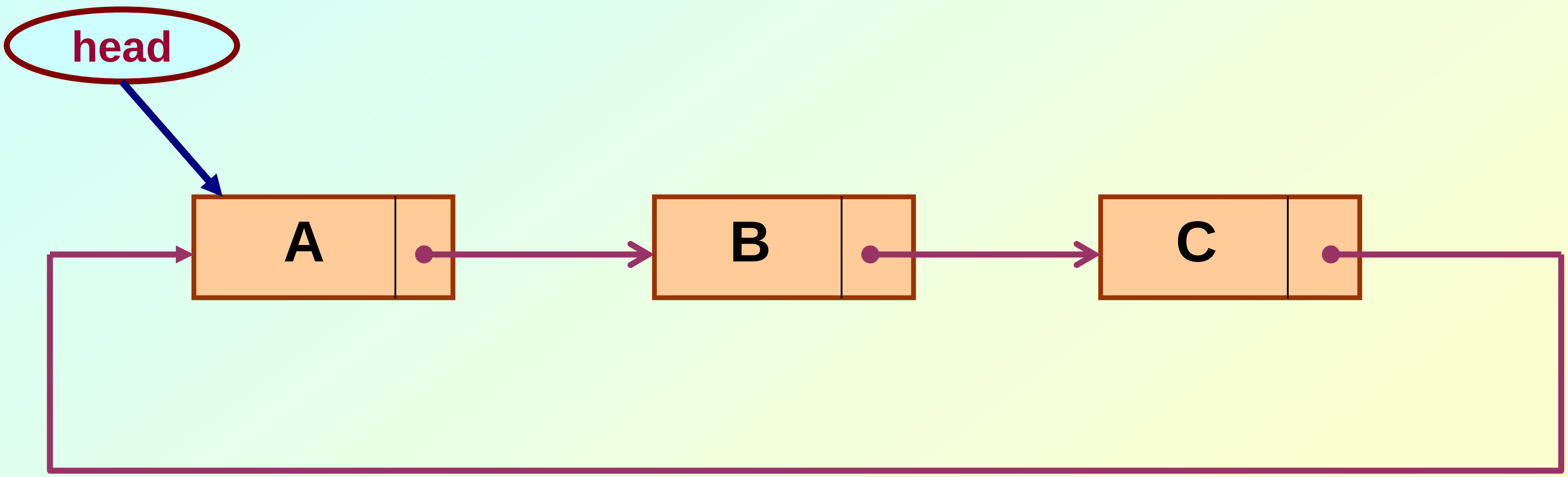
Types of Lists

- **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.**



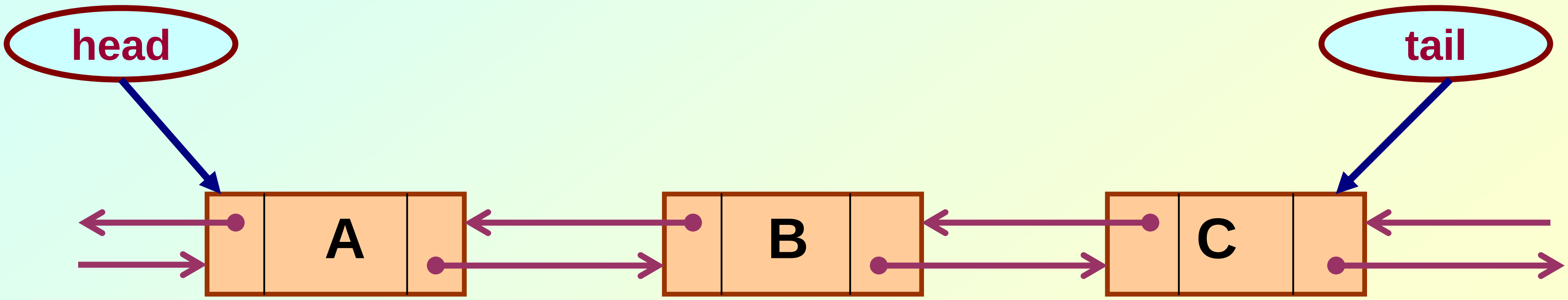
– **Circular linked list**

- **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*.**



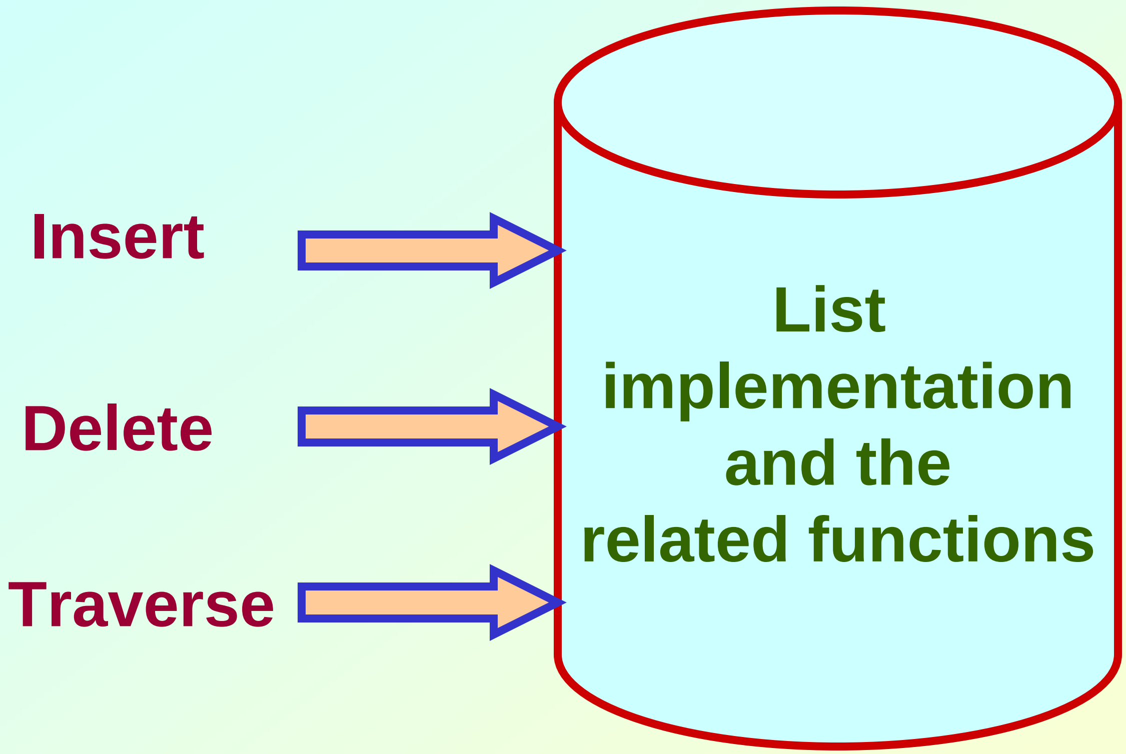
Basic Operations on a List

- 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;
            };
```

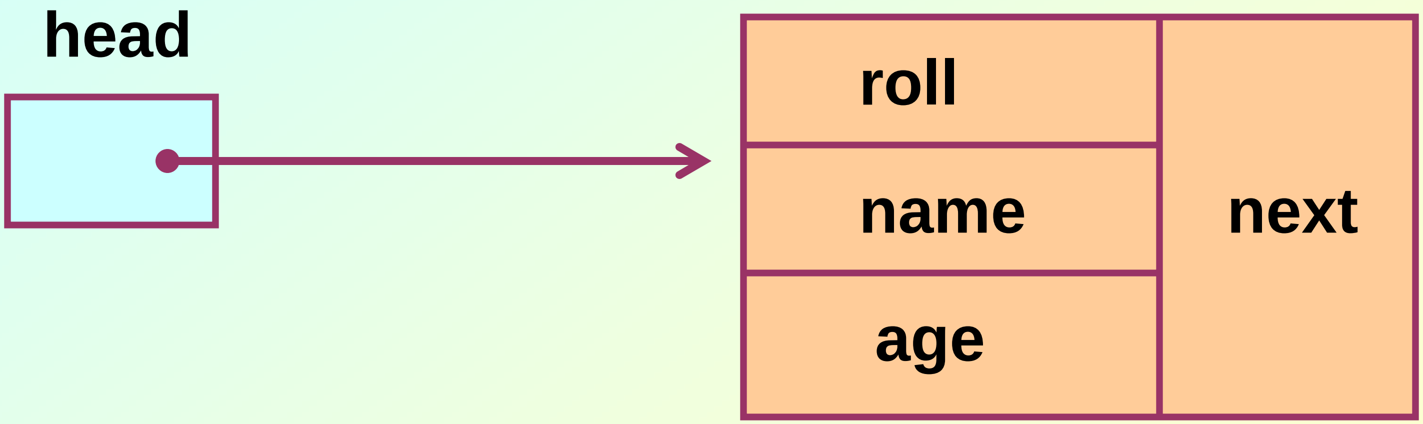
```
  /* A user-defined data type called “node” */
typedef struct stud node;
node *head;
```

Creating a List

How to begin?

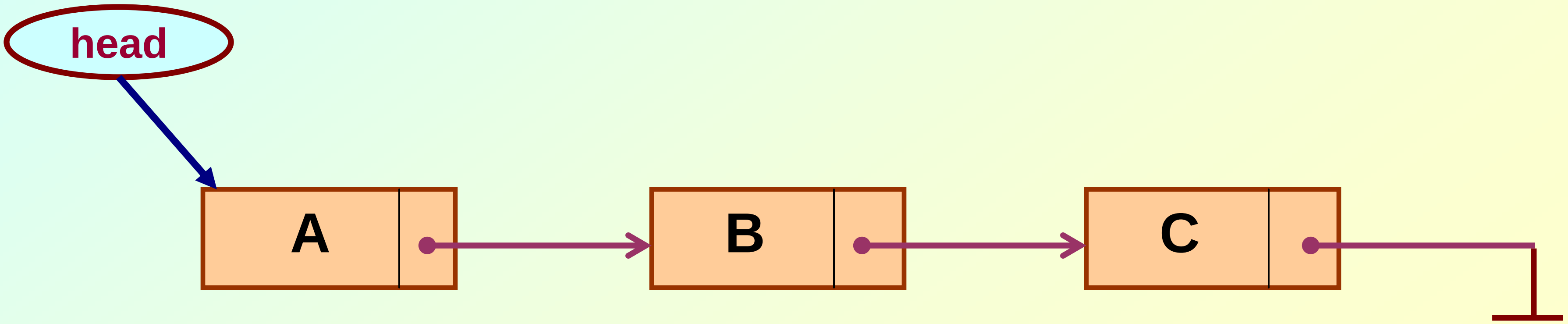
- To start with, we have to create a node (the first node), and make **head** point to it.

```
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 */
    ```

Abstract Data Types

Definition

- **An abstract data type (ADT) is a specification of a set of data and the set of operations that can be performed on the data.**
- **Such data type is abstract in the sense that it is independent of various concrete implementations.**
- **Some examples follow.**

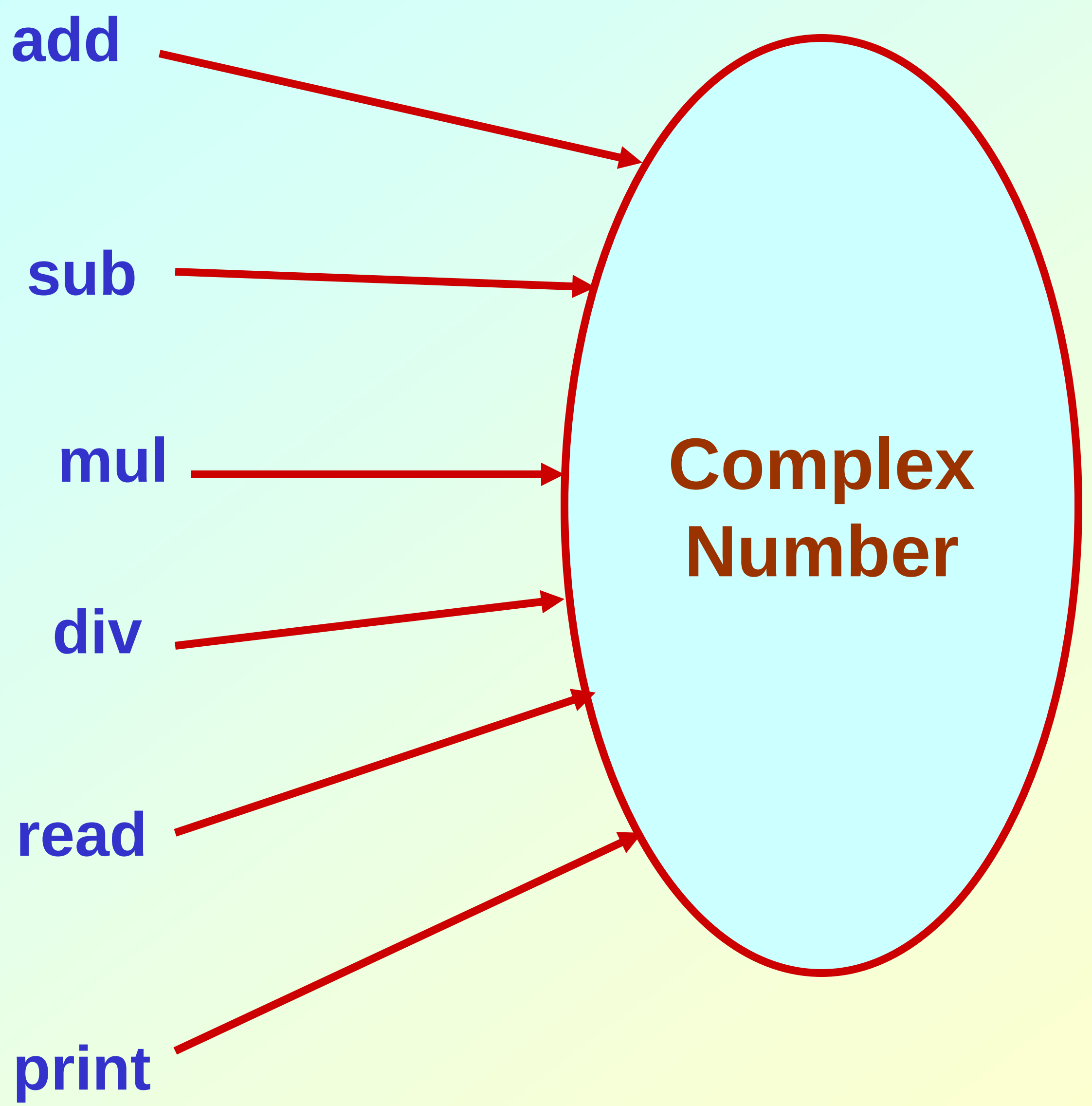
Example 1 :: Complex numbers

```
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

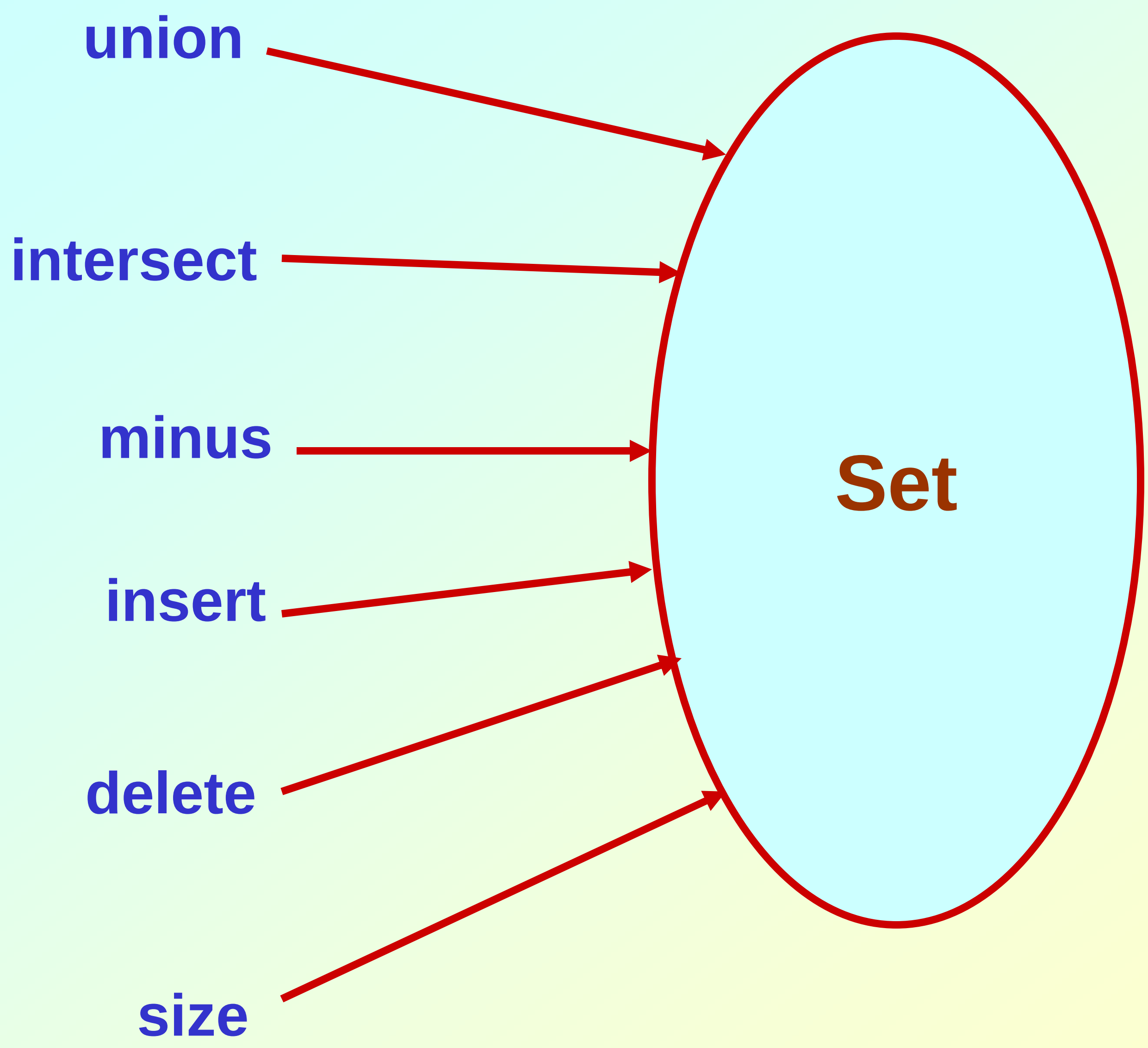
Example 2 :: Set manipulation

```
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);
```

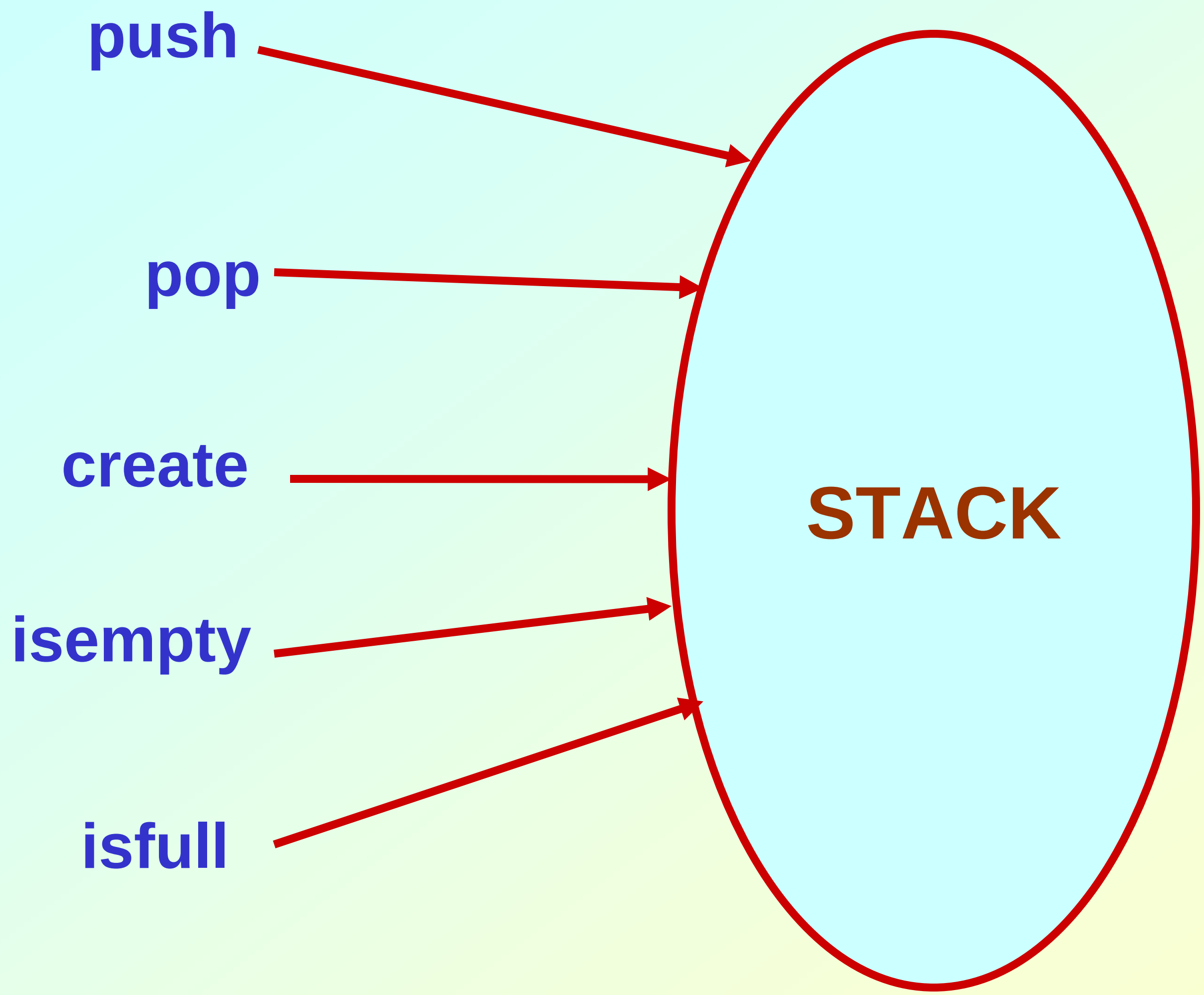
Function prototypes


union
intersect
minus
insert
delete
size
Set

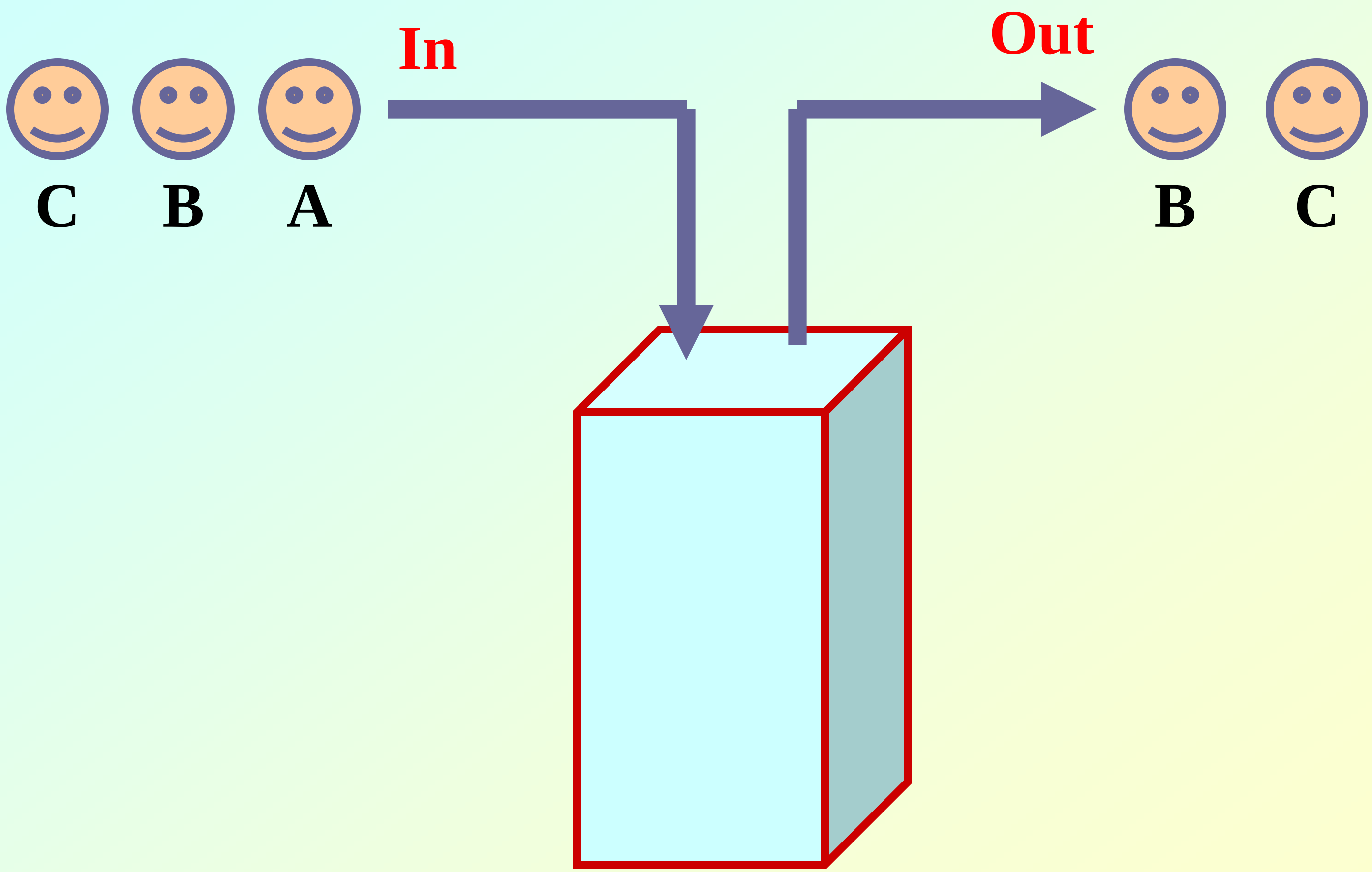
Example 3 :: Last-In-First-Out STACK

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

Visualization of a Stack



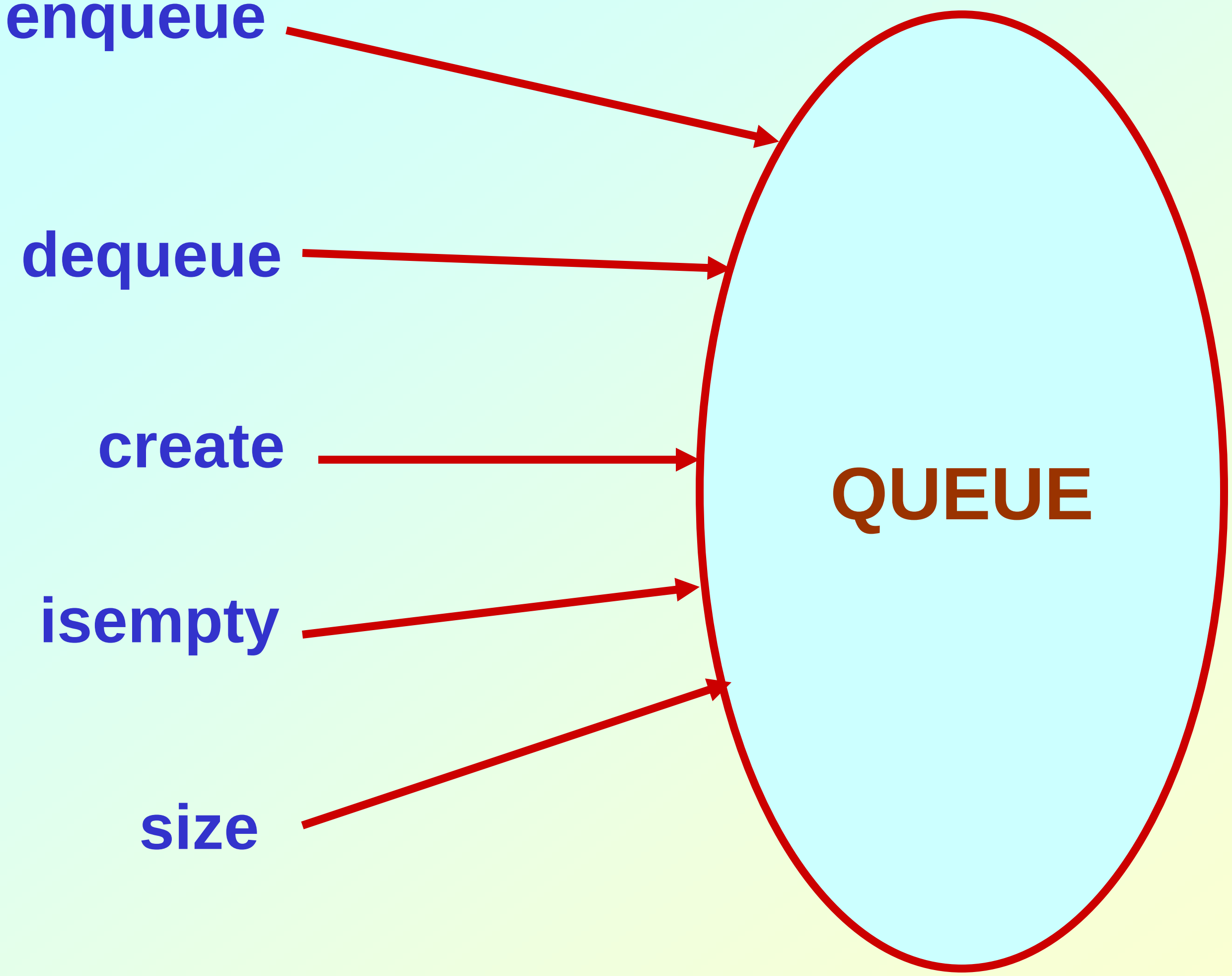
Contd.

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

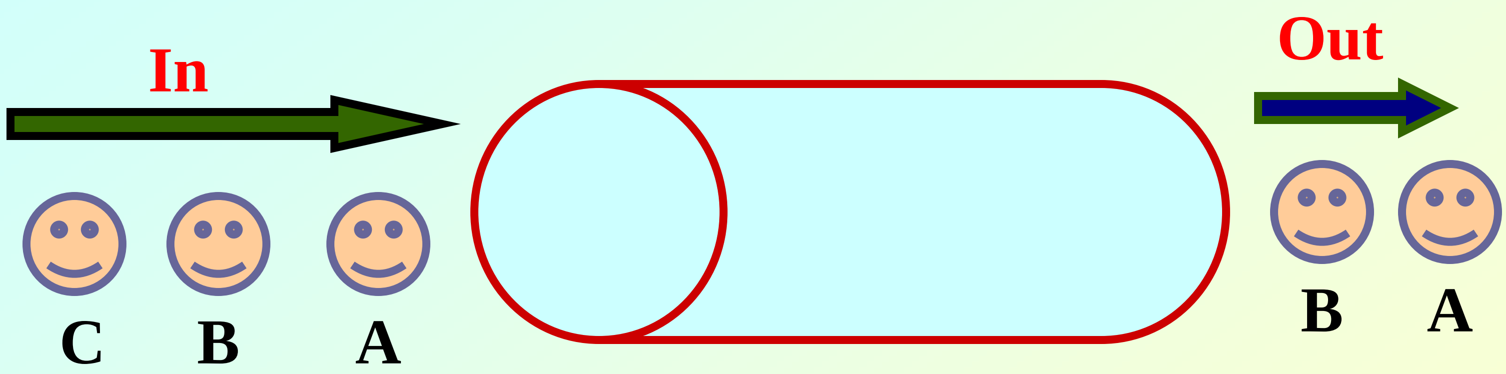
Example 4 :: First-In-First-Out QUEUE

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

Visualization of a Queue



Stack Implementation

a) Using arrays
b) Using linked list

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

```
#define MAXSIZE 100

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

ARRAY

```
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;
```

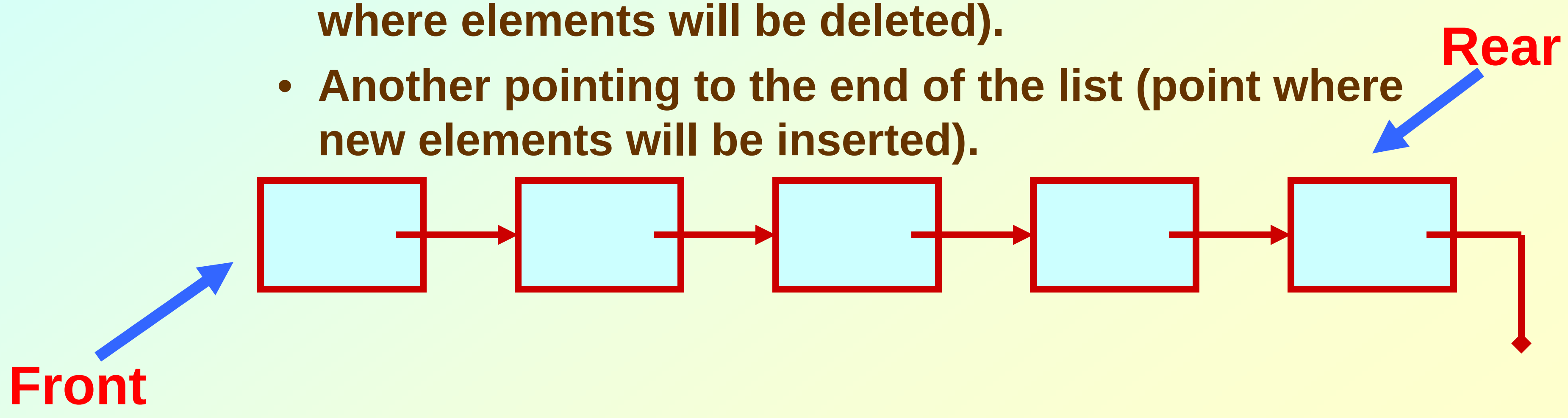
```
main()
{
  stack *A, *B;
  create(&A); create(&B);
  push(&A,10);
  push(&A,20);
```

```
  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).



Declaration

```
struct fifo {
            int  value;
            struct fifo *next;
         };
typedef struct fifo queue;

queue *front, *rear;
```

Creating a queue

```
void createq (queue **front, queue **rear)
{
   *front =  NULL;
   *rear  =  NULL;
}
```

Inserting an element in queue

```
void enqueue (queue **front, queue **rear, int x)
{
   queue *ptr;
   ptr = (queue *) malloc(sizeof(queue));

   if (*rear == NULL)    /* Queue is empty */
   {
      *front = ptr;
      *rear  = ptr;
      ptr->value = x;
      ptr->next = NULL;
   }
   else                  /* Queue is not empty */
   {
      (*rear)->next = ptr;
      *rear = ptr;
      ptr->value = x;
      ptr->next = NULL;
   }
}
```

Deleting an element from queue

```
int dequeue (queue **front, queue **rear)
{
   queue *old;   int k;

   if  (*front == NULL)              /* Queue is empty */
      printf  ("\n Queue is empty");
   else if (*front == *rear)         /* Single element */
        {
            k = (*front)->value;
            free (*front);    front = rear = NULL;
            return (k);
        }
        else
        {
            k = (*front)->value;   old = *front;
            *front = (*front)->next;
            free (old);
            return (k);
        }
  }
```

Checking if empty

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

Example main function

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

```
main()
{
  queue *Af, *Ar;
  create (&Af, &Ar);
  enqueue (&Af,&Ar,10);
  enqueue (&Af,&Ar,20);
```

```
  enqueue(&Af,&Ar,30);

  printf (“%d %d”,
        dequeue (&Af,&Ar),
        dequeue(&Af,&Ar));

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

Some Applications of Stack

Applications ….

- **Handling function calls and return**
- **Handling recursion**
- **Parenthesis matching**
- **Evaluation of expressions**
  - **Polish *postfix* and *prefix* notations**