Linked Lists

.. and other linked structures

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Dynamic memory allocation: review

```
typedef struct {
        int hiTemp;
        int loTemp;
        double precip;
} WeatherData;

int main ( ) {
        int numdays;
        WeatherData  *days;
        scanf (“%d”, &numdays) ;
        days=(WeatherData *)malloc (sizeof(WeatherData)*numdays);
        if (days == NULL) printf (“Insufficient memory”);
        ...
        free (days) ;
}
```

Self Referential Structures

A structure referencing itself – how?

So, we need a pointer inside a structure that points to a structure of the same type.

```
struct list {
   int data;
   struct  list  *next;
};
```

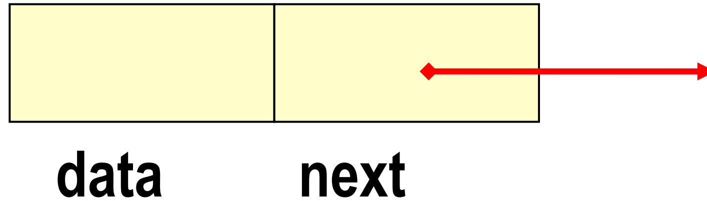
Self-referential structures

```
struct list {
        int data ;
        struct list * next ;
} ;
```

The pointer variable next is called a link.
Each structure is linked to a succeeding structure by next.

Pictorial representation

A structure of type **struct list**

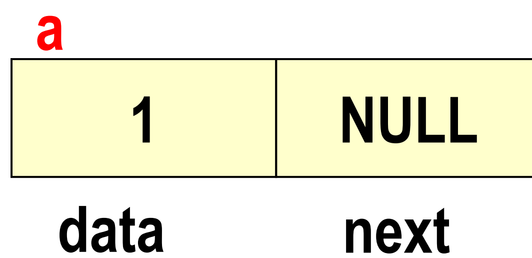


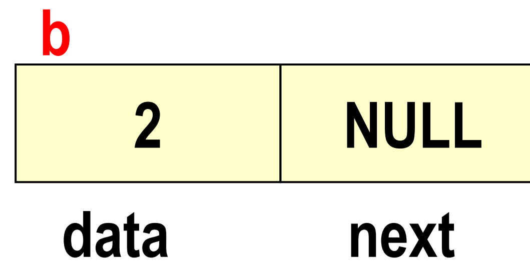
The pointer variable next contains either

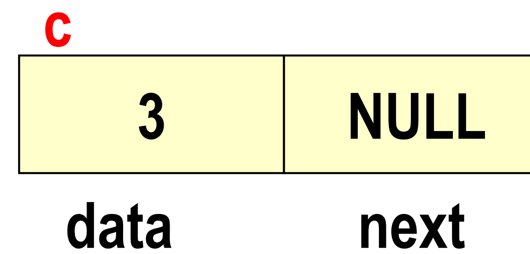
- an address of the location in memory of the successor list element
- or the special value NULL defined as 0.

NULL is used to denote the end of the list.

```
struct list a, b, c;

a.data = 1; b.data = 2; c.data = 3;
a.next = b.next = c.next = NULL;
```

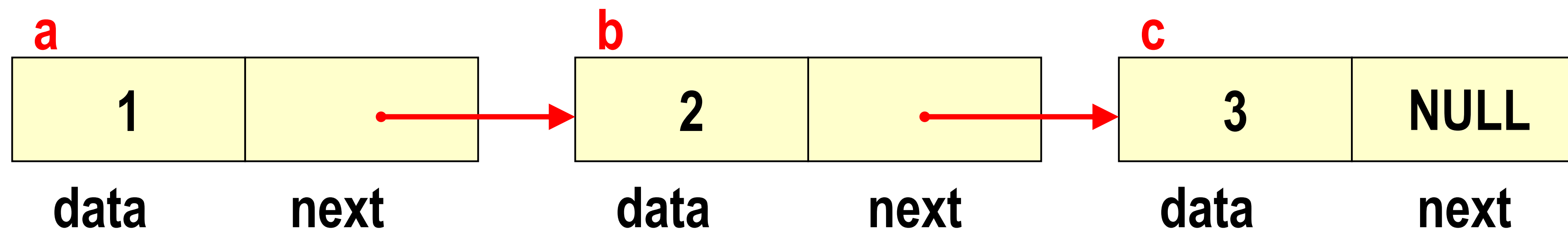






Chaining these together

```
a.next = &b;
b.next = &c;
```



What are the values of :

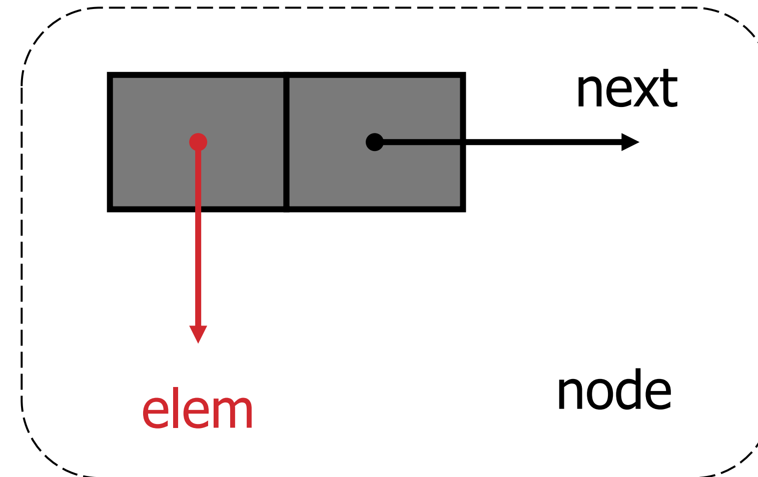
- a.next->data 2
- a.next->next->data 3

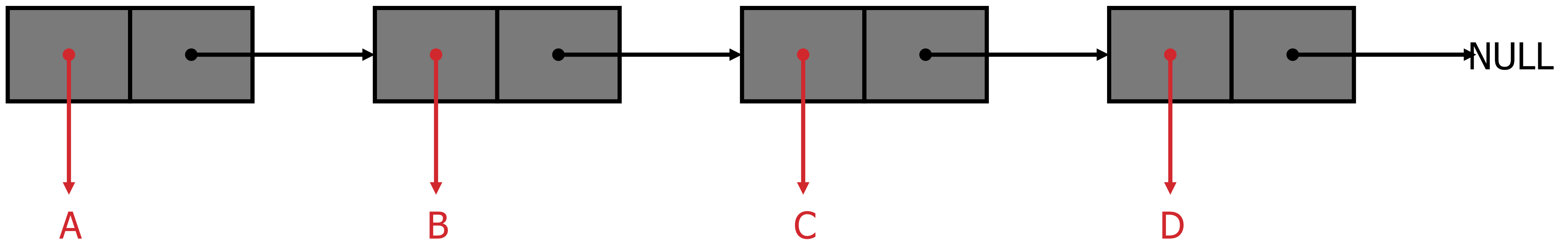
Linked Lists

A singly linked list is a concrete data structure consisting of a sequence of nodes

Each node stores

- element
- link to the next node



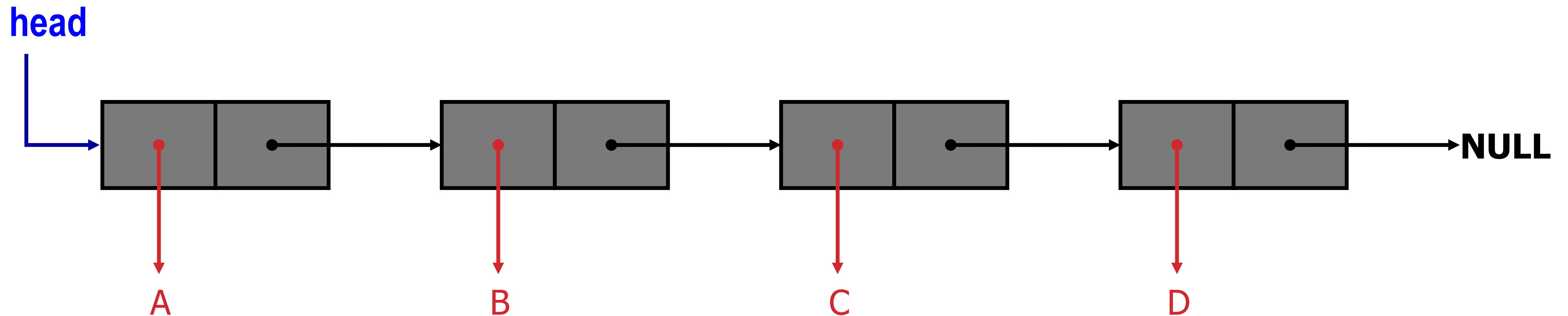


Linear Linked Lists

A head pointer addresses the first element of the list.

Each element points at a successor element.

The last element has a link value NULL.



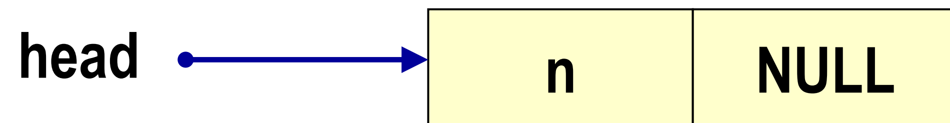
Header file : list.h

```
#include <stdio.h>
#include <stdlib.h>
typedef char DATA;
struct list {
        DATA d;
        struct list * next;
};
typedef struct list ELEMENT;
typedef ELEMENT *LINK;
```

Storage allocation

```
LINK head ;

head = (LINK) malloc (sizeof(ELEMENT));

head->d = 'n';

head->next = NULL;
```

creates a single element list.



Storage allocation

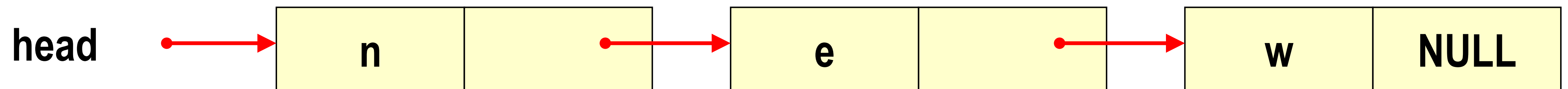
```
head->next = (LINK) malloc (sizeof(ELEMENT));
head->next->d = ‘e’;
head->next->next = NULL;
```

A second element is added.

Storage allocation

```
head->next->next = (LINK) malloc (sizeof(ELEMENT));

head->next->next->d = ‘w’;

head->next->next-> = NULL;
```

We have a 3 element list pointed to by head.
The list ends when next has the sentinel value NULL.



List operations

List operations

(i) How to initialize such a self referential structure (LIST),

(ii) How to insert such a structure into the LIST,

(iii) How to delete elements from it,

(iv) How to search for an element in it,

(v) How to print it,

(vi) How to free the space occupied by the LIST?

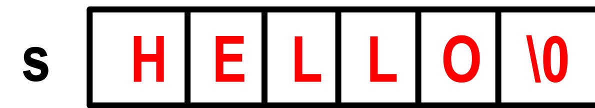
Produce a list from a string (*recursive version*)

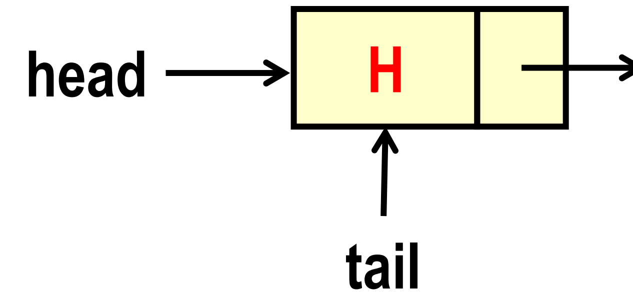
```
#include <stdio.h>
#include <stdlib.h>
typedef char DATA;
struct list {
        DATA d;
        struct list * next;
};
typedef struct list ELEMENT;
typedef ELEMENT *LINK;
```

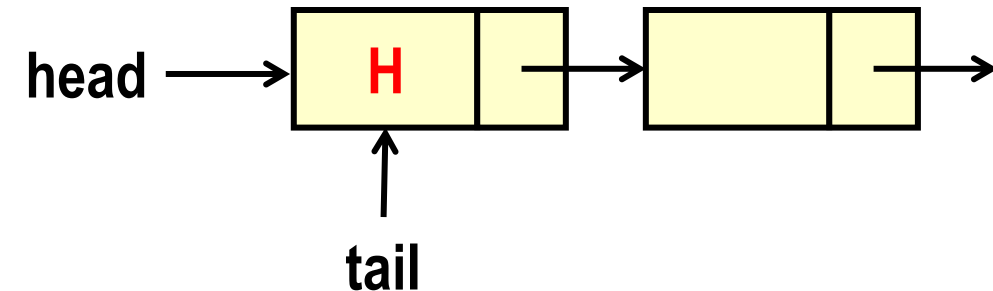
```
LINK StrToList (char s[ ]) {
        LINK head ;

        if (s[0] == '\0')  return NULL ;
        else   {
                head = (LINK) malloc (sizeof(ELEMENT));
                head->d = s[0];
                head->next = StrToList (s+1);
                return head;
        }
}
```

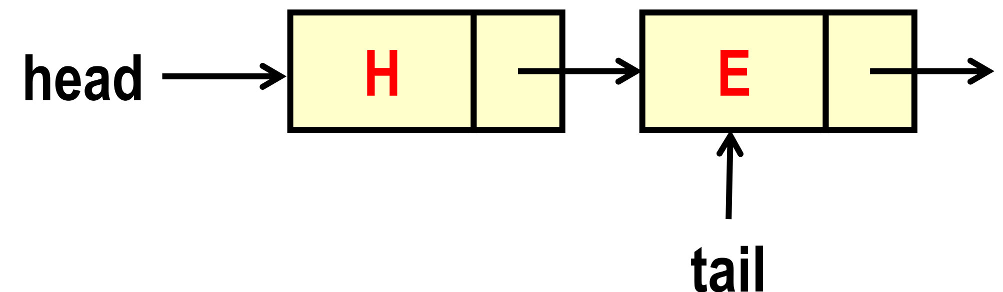
Produce a list from a string (*iterative version*)

```
LINK SToL (char s[ ]) {
  LINK head = NULL, tail;
  int  i;

  if (s[0] != '\0')   {
        head = (LINK) malloc (sizeof(ELEMENT));
        head->d = s[0];
        tail = head;

      for (i=1; s[i] != '\0'; i++)  {
            tail->next = (LINK) malloc(sizeof(ELEMENT));
            tail = tail->next;
            tail->d = s[i];
      }
      tail->next = NULL;
  }
  return head;
}
```

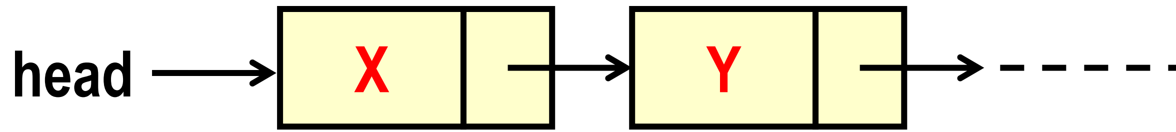




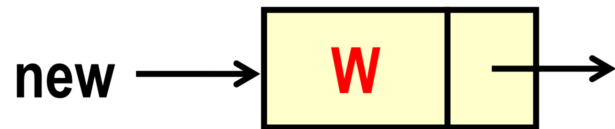




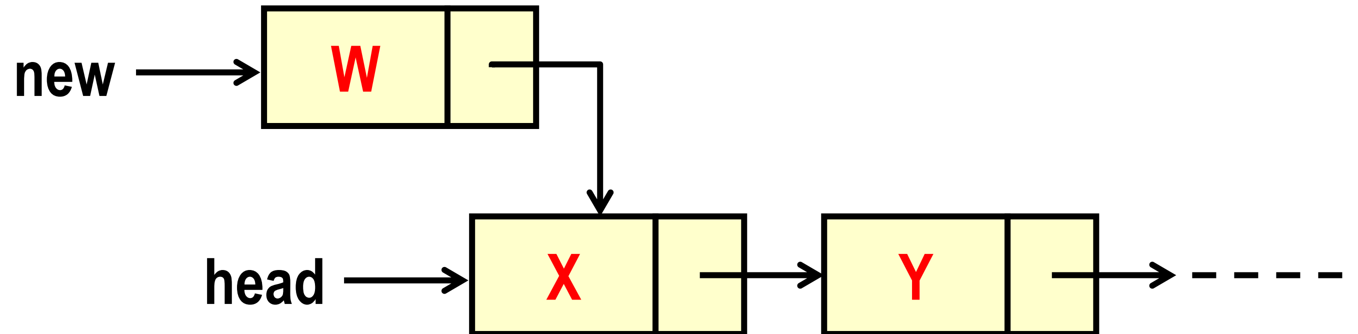
Inserting at the Head



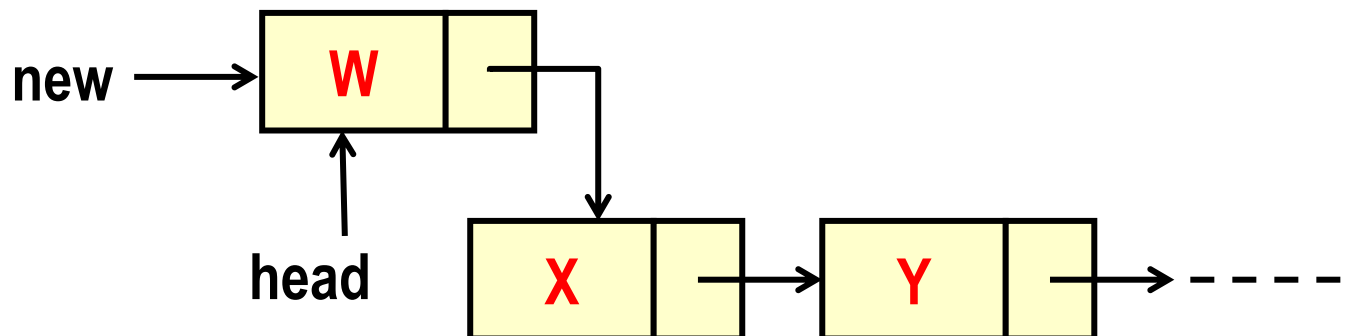
1. Allocate a new node
2. Insert new element
3. Make new node point to old head
4. Update head to point to new node




```
new = (LINK) malloc(sizeof(ELEMENT));
```



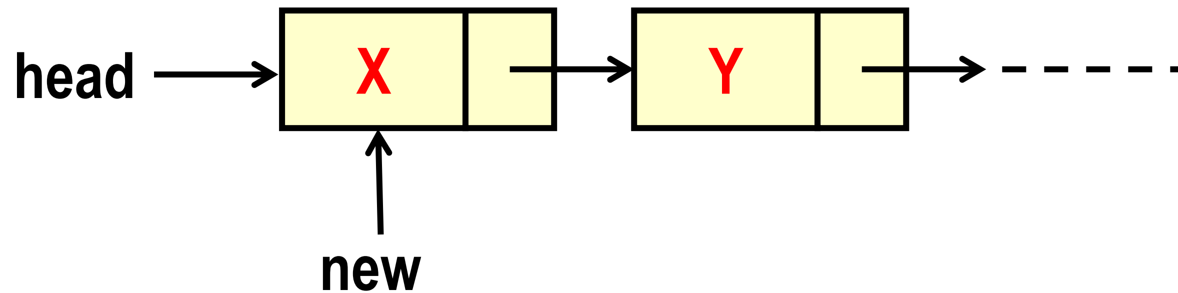

```
new-> next = head;
```



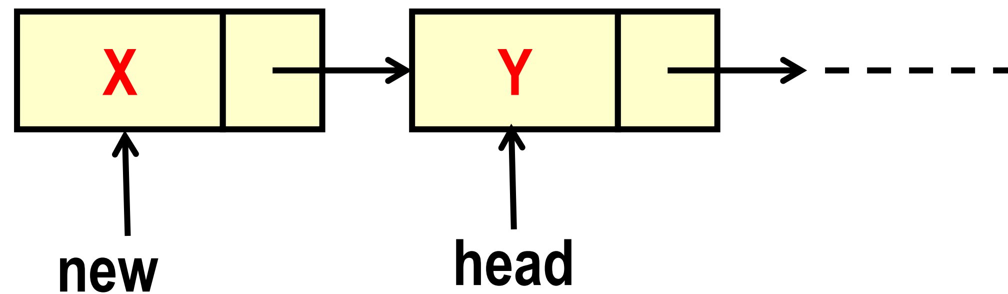

```
head = new;
```

Removing the Head

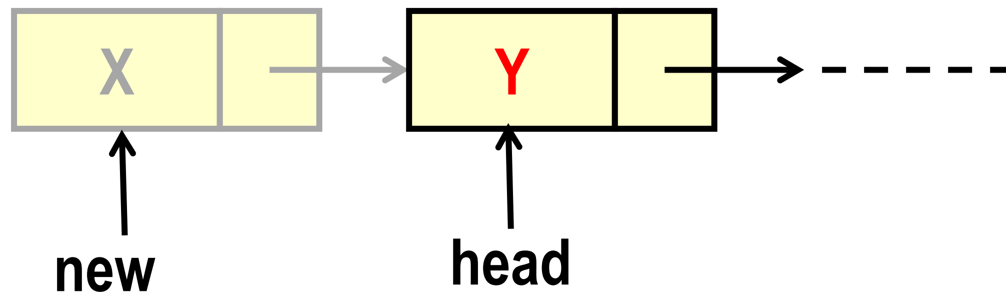
1. Update head to point to next node in the list
2. Allow garbage collector to reclaim the former first node



new = head;



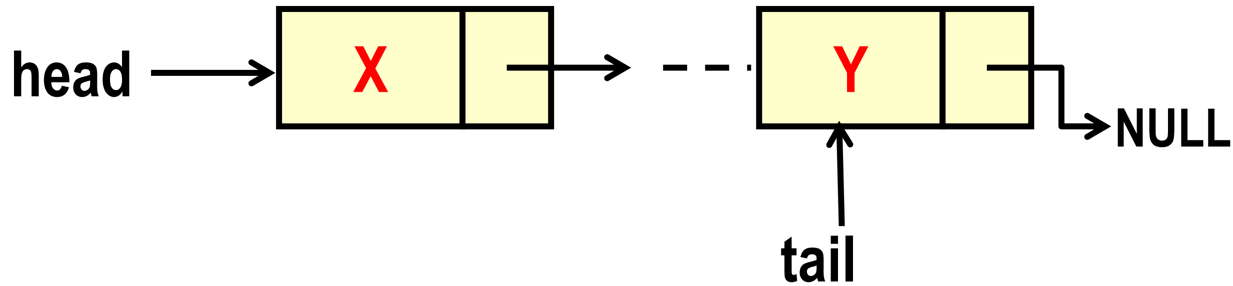
head = new->next;



free(new);

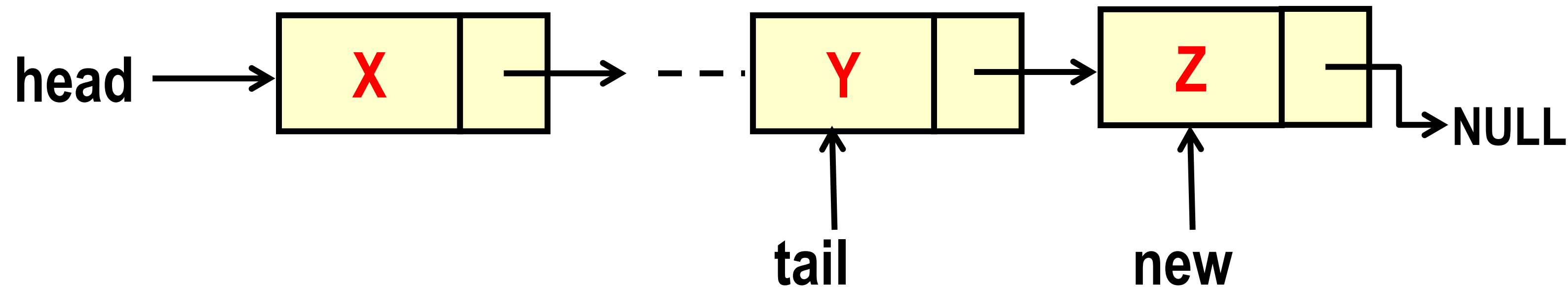
Inserting at the Tail

1. Allocate a new node
2. Insert new element
3. Have new node point to null
4. Have old last node point to new node
5. Update tail to point to new node

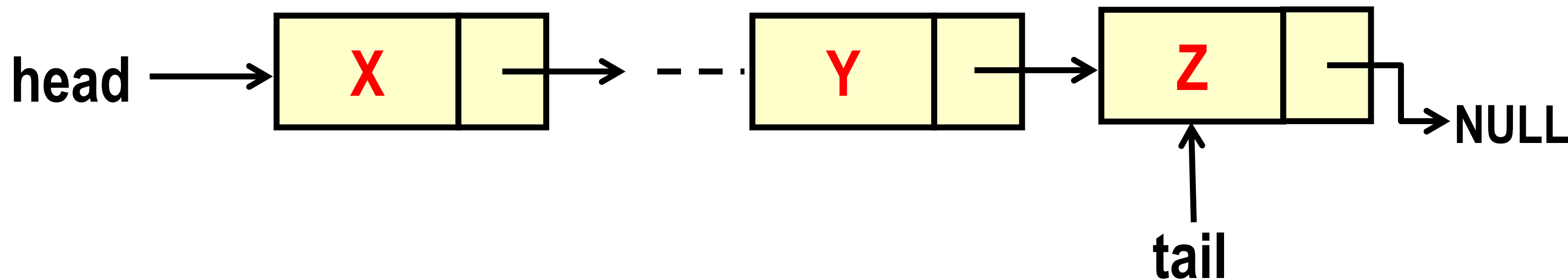


new = (LINK) malloc(sizeof(ELEMENT))

new->next = NULL;



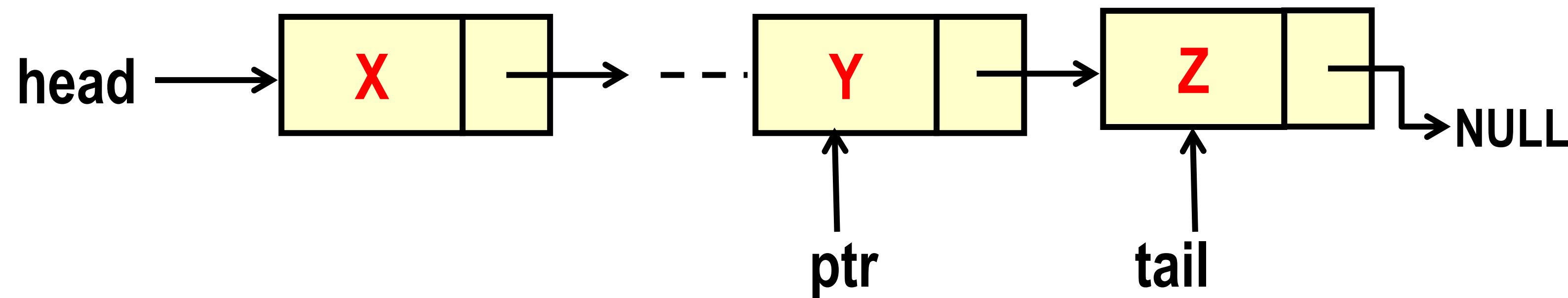
tail->next = new;

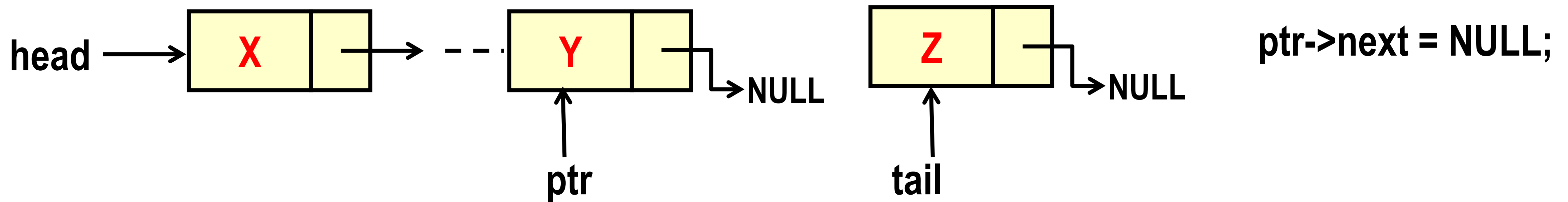


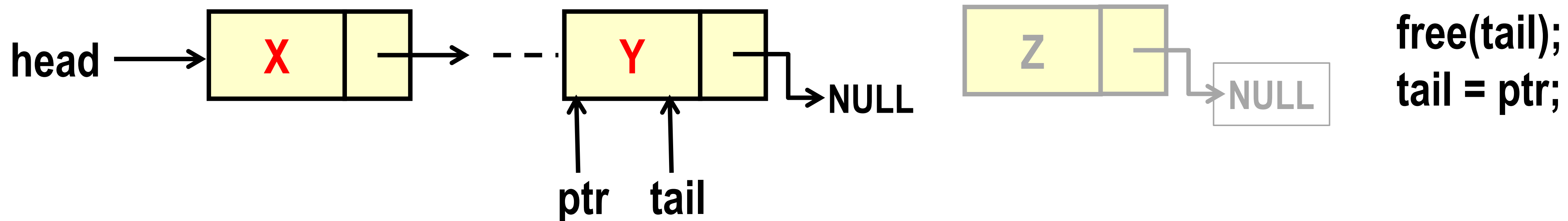
tail = new;

Removing the Tail

1. Bring ptr to the second last node
2. Make ptr->next equal to NULL
3. Free tail
4. Make ptr the new tail





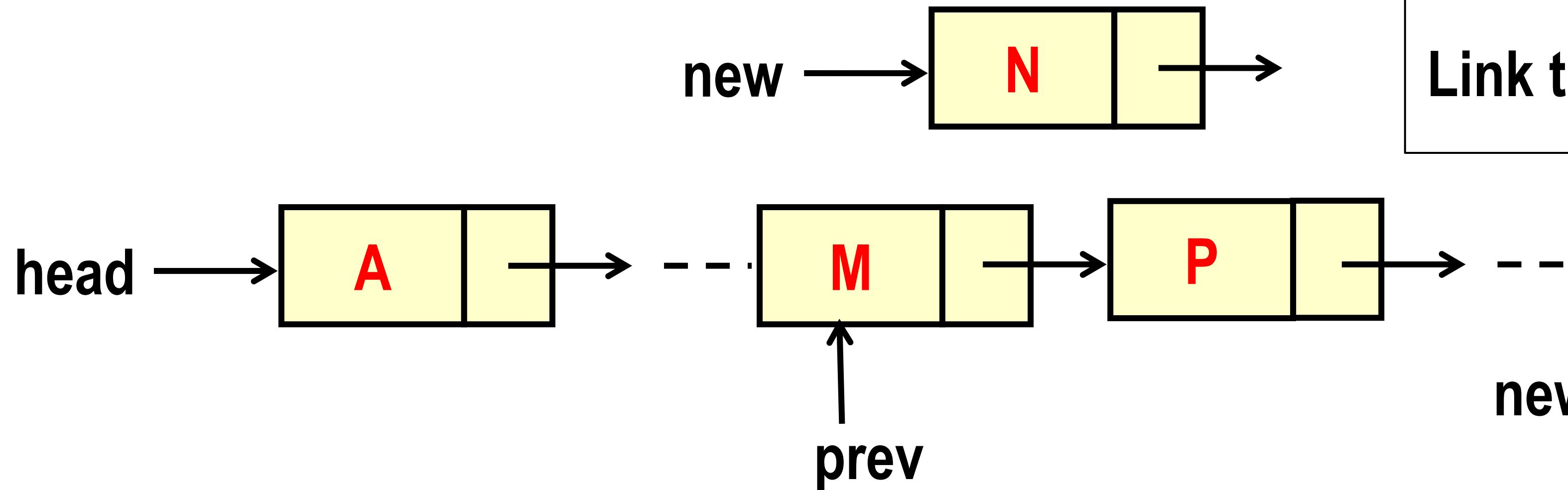


Insertion into an ordered list

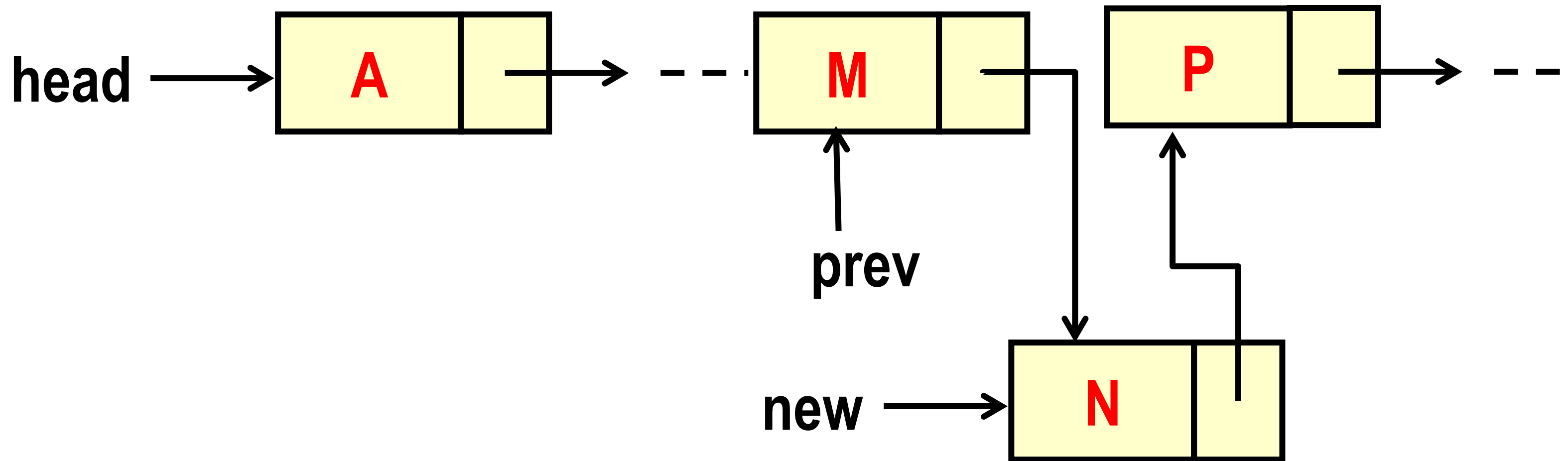
Create a *new* node containing the data

Find the correct place in the list, and

Link the *new* node at this place.



new = (LINK) malloc(sizeof(ELEMENT))




```
new->next = prev->next;
prev->next  = new;
```

Why is the following not okay?

```
prev->next  = new;
new->next = prev->next;
```

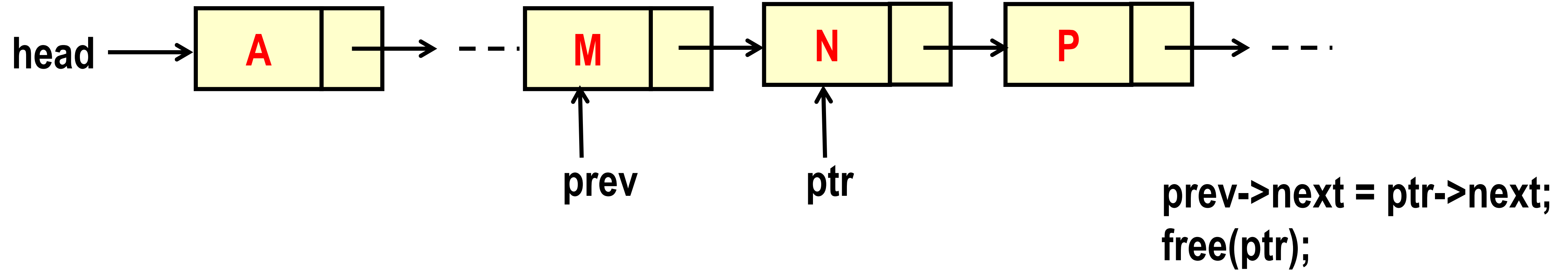
Insertion function

```
#include <stdio.h>
#include <stdlib.h>
struct list {
            int data;
            struct list * next;
};
typedef struct list ELEMENT;
typedef ELEMENT * LINK;

Listpointer create_node(int data)
{
   LINK new;
   new = (LINK) malloc (sizeof (ELEMENT));
   new -> data = data;
   return (new);
}
```

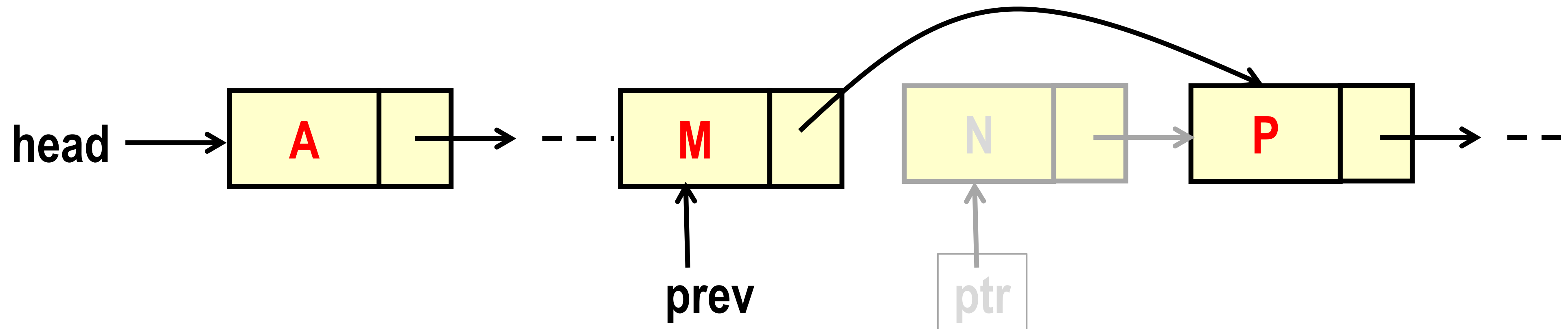
```
LINK insert (int data,  LINK ptr)
{    LINK new, prev, first;
    new = create_node(data);
    if (ptr == NULL || data < ptr -> value)
    {       // insert as new first node
            new -> next = ptr;
            return new;  // return pointer to first node
    }
    else {  //  not first one
            first = ptr;   // remember start
            prev = ptr;
            ptr = ptr-> next; // second
            while (ptr != NULL  && data > ptr -> data) {
                        prev = ptr; ptr  = ptr -> next;
            }
            prev -> next = new;  // link in
            new  -> next = ptr;    //new node
            return first;
}}
```

Deletion

Steps:
- Finding the data item in the list, and
- Linking out this node, and
- Freeing up this node as free space.



prev->next = ptr->next;
free(ptr);



What will happen if we did the following?

free(ptr);
prev->next = ptr->next;

Deletion function

```
//  delete the item from ascending list
LINK delete_item(int data, LINK ptr)  {
   LINK prev, first;

   first = ptr;          //  remember start
   if (ptr == NULL)  return  NULL;
   else  if (data == ptr -> data)  //  first node
   {
           ptr = ptr -> next;  //  second node
           free(first);        //  free up node
           return ptr;         //  second
   }
   else      //  check rest of list
   {     prev = ptr;
         ptr = ptr -> next;

         // find node to delete
         while (ptr != NULL && data > ptr->data) {
              prev = ptr;
              ptr   = ptr -> next;
         }
         if (ptr == NULL || data != ptr->data)  {
              // NOT found in ascending list
              return first;         //  original
         }
         else {          //  found, delete ptr node
              prev -> next = ptr -> next;
              free(ptr);            //  free node
              return first;         //  original
}}}
```

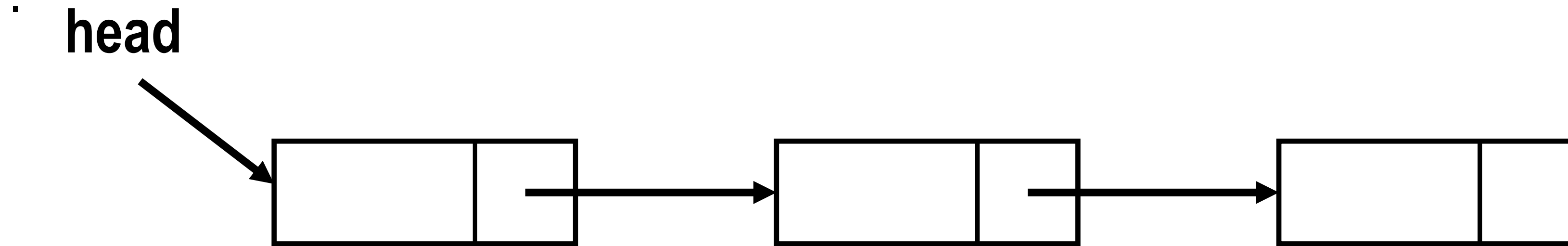
Searching for a data element in a list

```
int Search(ELEMENT *head, int element)  {

   ELEMENT *temp;

   temp = head;
   while (temp != NULL)  {
            if (temp -> x == element) return TRUE;
            temp = temp -> next;

    }
    return FALSE;
}
```

Printing a list

```
void Print (ELEMENT *head)
{
        ELEMENT *temp;
        temp = head;
        while (temp != NULL)   {
                printf("%d->", temp -> data);
                temp = temp -> next;
        }
}
```

Printing a list backwards



- How can you when the links are in forward direction ?
- Can you apply recursion?

Printing a list backwards – *recursively*

```
void PrintArray(ELEMENT *head)  {
        if(head -> next == NULL)   {          /* boundary condition to stop recursion */
                printf(" %d->",head -> data);
                return;
        }
        PrintArray(head -> next);             /* calling function recursively*/
        printf(" %d ->",head -> data);        /* Printing current element */
        return;
}
```

Freeing a list

- What will happen if we free the first node of the list without placing a pointer on the second?
- In each iteration temp1 points at the head of the list and temp2 points at the second node.

```
void Free(ELEMENT *head)  {
        ELEMENT *temp1, *temp2;
        temp1 = head;
        while(temp1 != NULL)  {
                temp2 = temp1 -> next;
                free(temp1);
                temp1 = temp2;
        }
}
```

Counting the number of nodes in a list

RECURSIVE APPROACH

```
int count (LINK head)  {
        if (head == NULL) return 0;
        return 1+count(head->next);
}
```

ITERATIVE APPROACH

```
int count (LINK head)  {
        int cnt = 0;
        for ( ; head != NULL; head=head->next)
                ++cnt;
        return cnt;
}
```

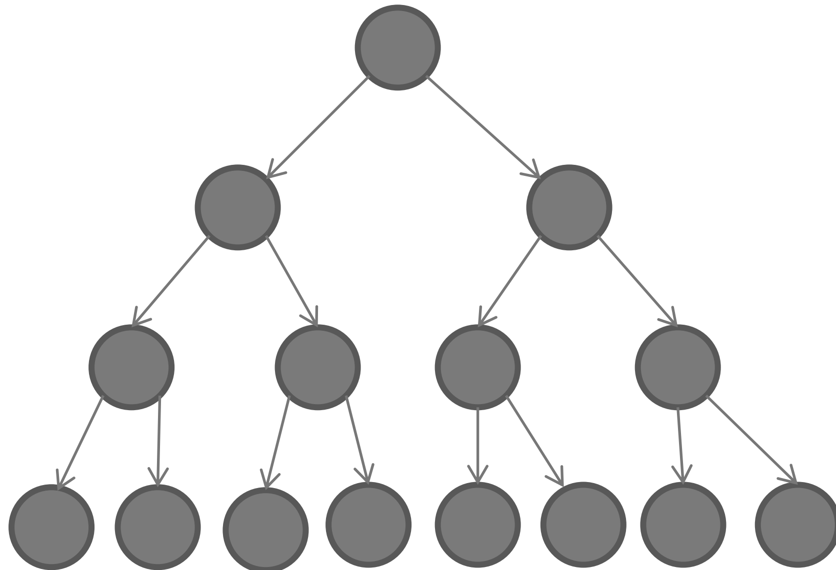
Concatenate two Lists

```
void concatenate  (LINK ahead, LINK bhead)    {
        if (ahead->next == NULL)
                ahead->next = bhead ;
        else
                concatenate (ahead->next, bhead);
}
```

… And "Other" linked structures

- Like Trees, Sparse Matrices and Graphs

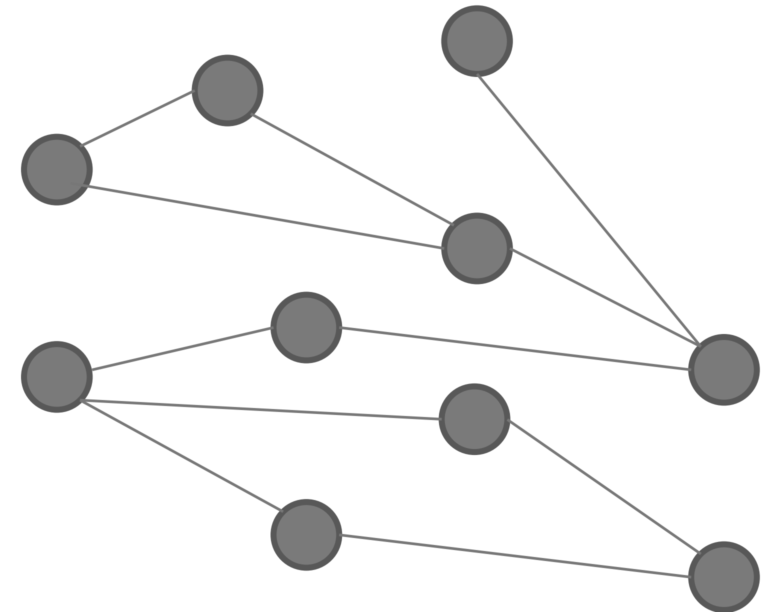
Binary Tree
(Height = 3)



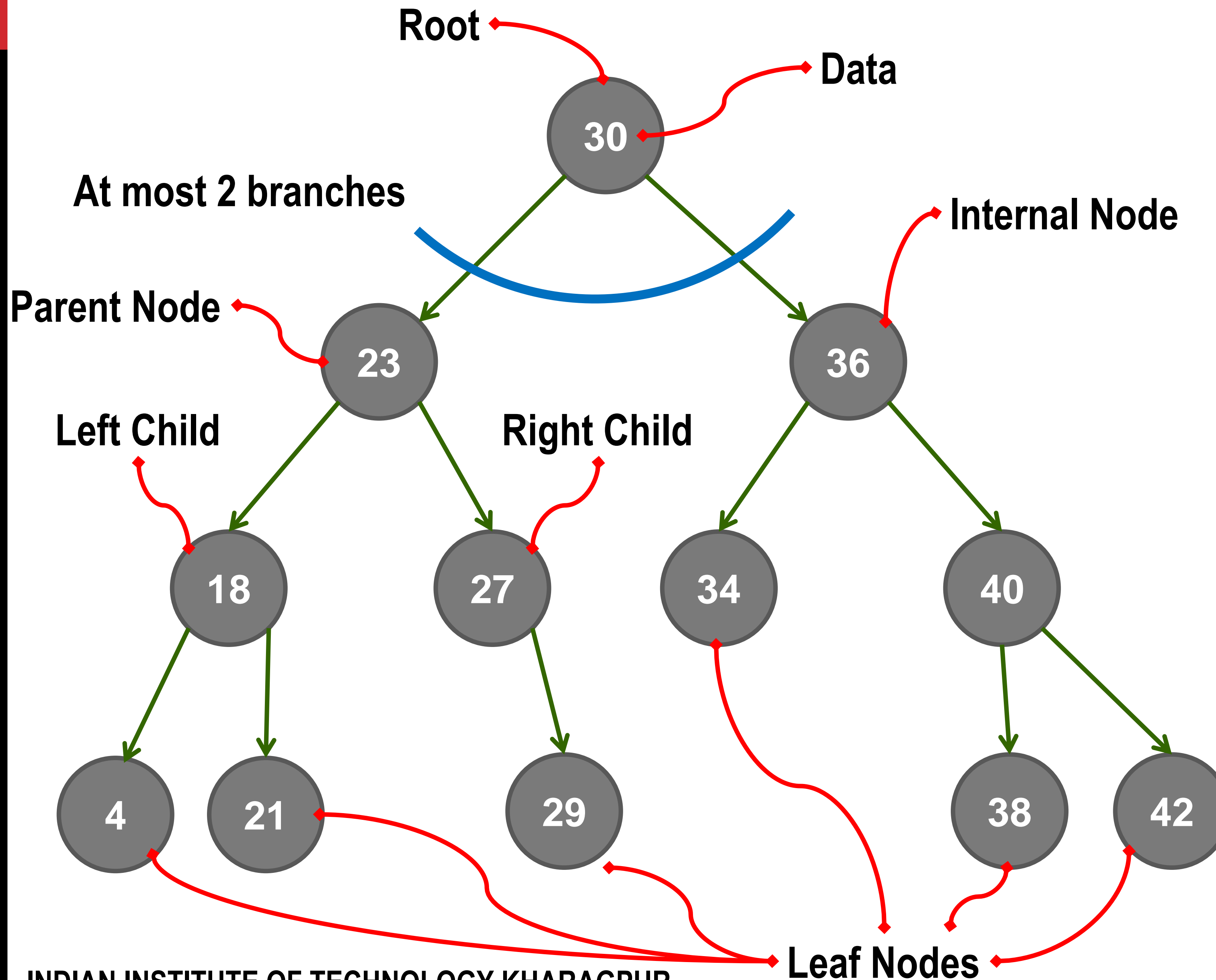
Sparse Matrix

$$\begin{bmatrix} 0 & 9 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 5 \\ 6 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 3 & 0 \end{bmatrix}$$

Graph
(Number of Vertices = 10)
(Number of Edges = 11)

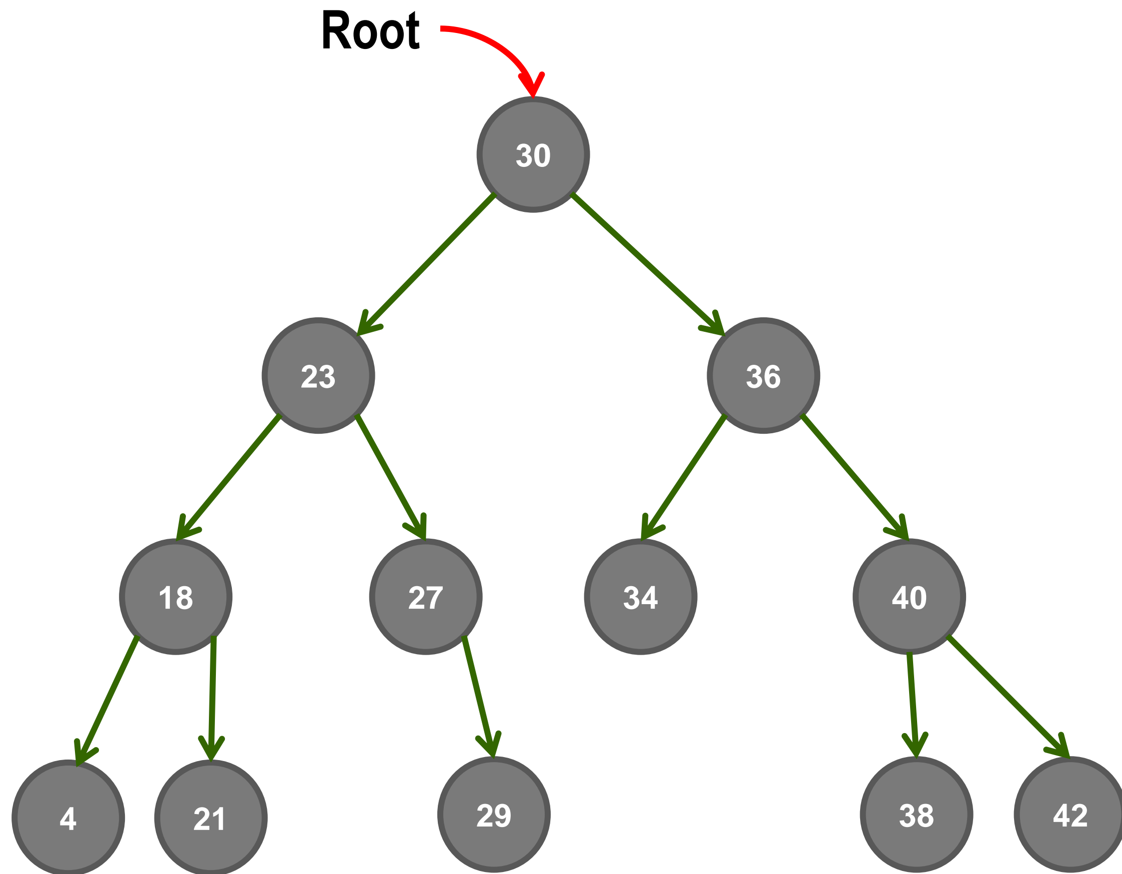


… And "Other" linked structures: Binary Trees

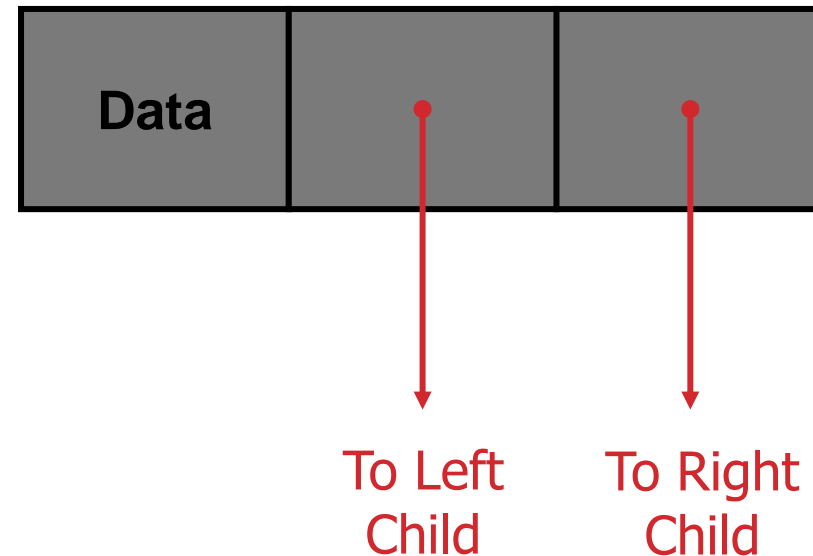



```
struct node {
        int data;
        struct node* left;
        struct node* right;
}
```

… And "Other" linked structures: Binary Trees




```
struct node {
        int data;
        struct node* left;
        struct node* right;
}
```



… And "Other" linked structures: Sparse matrices

For the sparse matrix below:

$$\begin{bmatrix} 0 & 9 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 5 \\ 6 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 3 & 0 \end{bmatrix}$$

Storage as a 2-D Array:

```
int M[5][6];
```

Storage required for 30 elements (with only 4 non-zero entries)

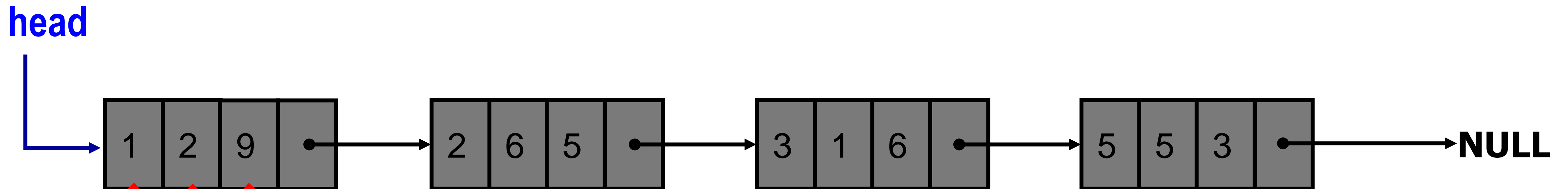
= 30 * sizeof(int) = 120Bytes (For integers of size 4 Bytes)

… And "Other" linked structures: Sparse matrices

Storage as a list of Tripples : (row, column, data)

$$\begin{bmatrix} 0 & 9 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 5 \\ 6 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 3 & 0 \end{bmatrix}$$

```
struct tripple {
        int row, column, data;
        struct tripple *next;
}
```



Storage required for 4 entries = (3 × sizeof(int) + sizeof(struct tripple*) × 4)
= (3 × 4 + 8) × 4
= 80 Bytes < 120 Bytes

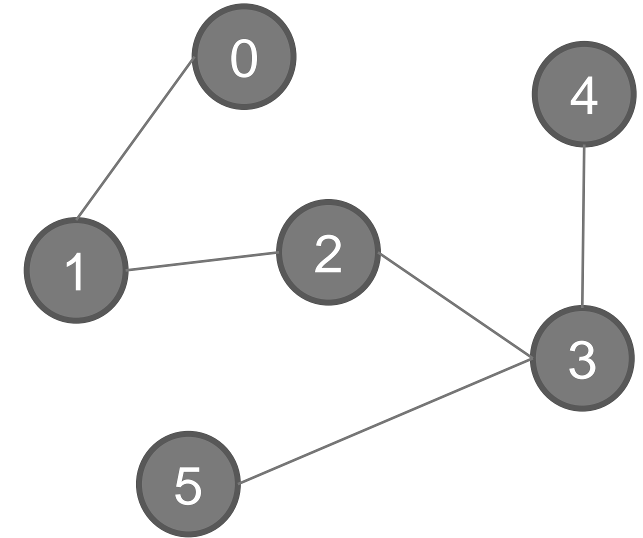
… And “Other” linked structures: Graphs

Adjacency Matrix Representation:

- Matrix location (i , j) indicates an edge between vertices “i” and “j”

$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

Adjacency Matrix
for an undirected graph



Storage as a 2-D Array:

int G[6][6];

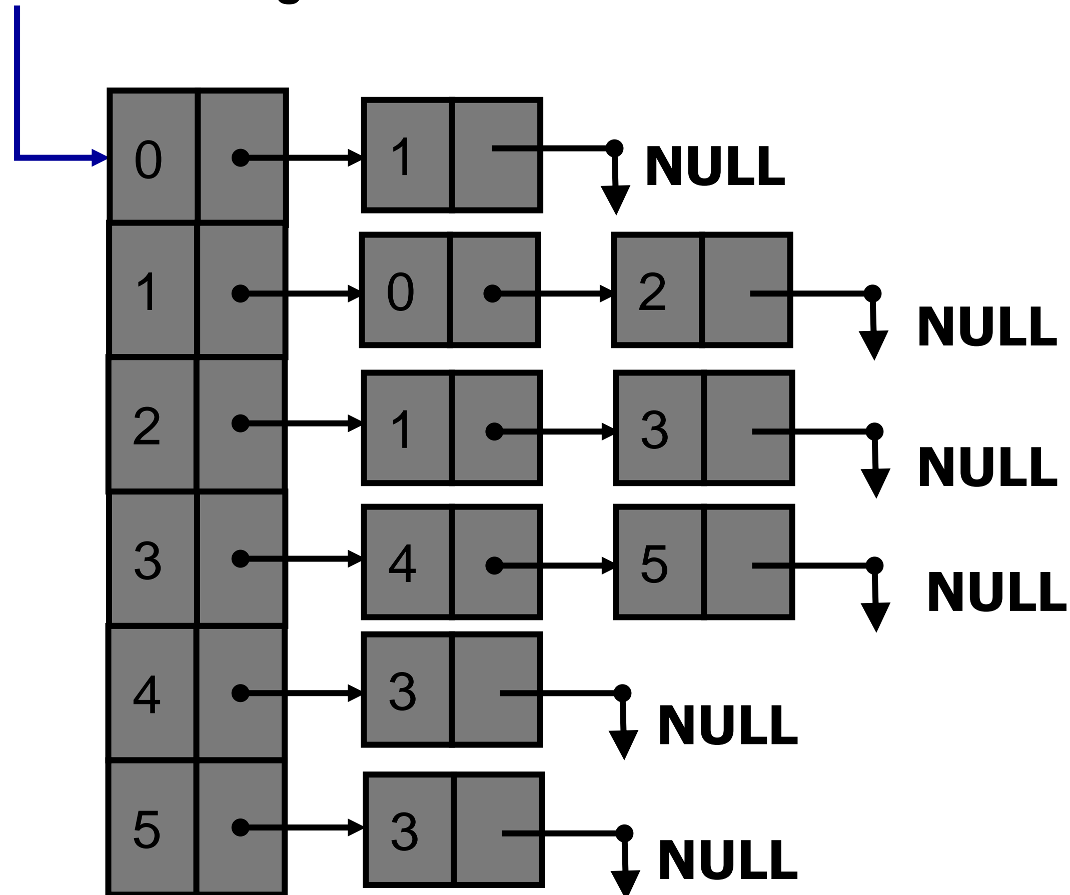
Storage required for 36 elements (with 6 vertices 5 edges)

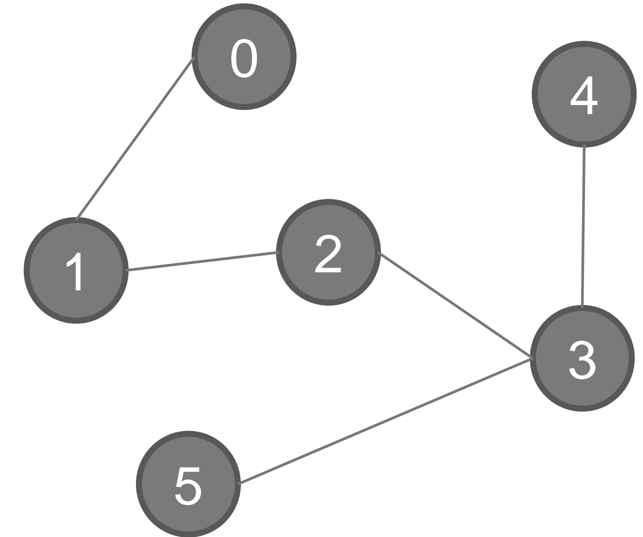
= 36 * sizeof(int) = 144Bytes (For integers of size 4 Bytes)

… And "Other" linked structures: Graphs

Adjacency List Representation:

- Each vertex's neighbours are maintained in a linked list






```
struct vertex{
        int id;
        struct vertex* next_adj;
}
```

Storage required = (| V | + sum of degree) * sizeof(structure)