Indian Institute of Information Technology Allahabad

Data Structures and Algorithms

Linked List

.. and other linked structures

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Lists

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- Array – one way to represent a list.
  - Constant time access given index of an element

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  - Deleting/Inserting an element requires shifting of elements.
  - Wasted space.

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  - Wasted space.

Polynomial: x^25 + 3x^7 – 4

Store in an array poly[26]
poly[i] contains coefficient of x^i

poly[0] = -4, poly[7] = 3, poly[25] = 1
poly[i] = 0 for all i != 0,7,25

Can we avoid storing so many 0's?
Store (0,-4), (7,3), (25,1) instead.
How do we 'link' these pairs?

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\n”);
        ...
        free (days) ;
}
```

Self-Referential Structures

A structure referencing itself – how?

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

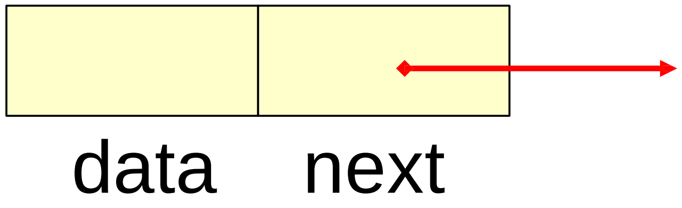
```
struct list {
        int data ;
        struct list *next ;
} ;
```

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



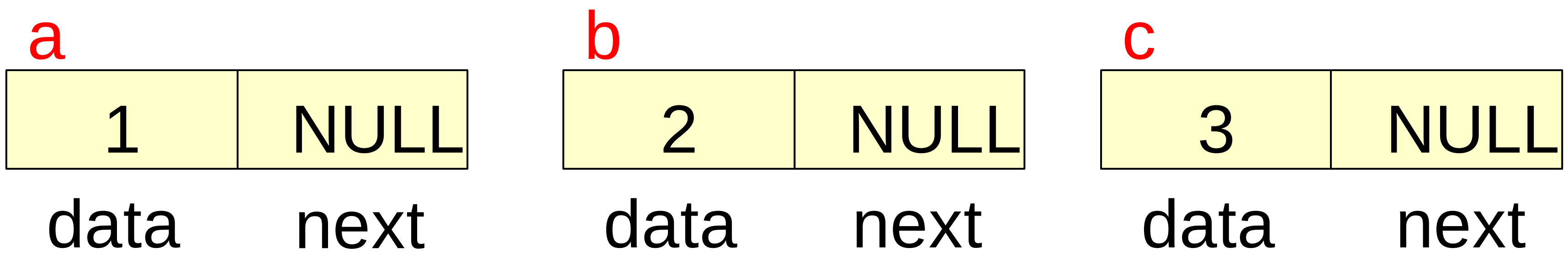
The pointer variable next contains either

- 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.

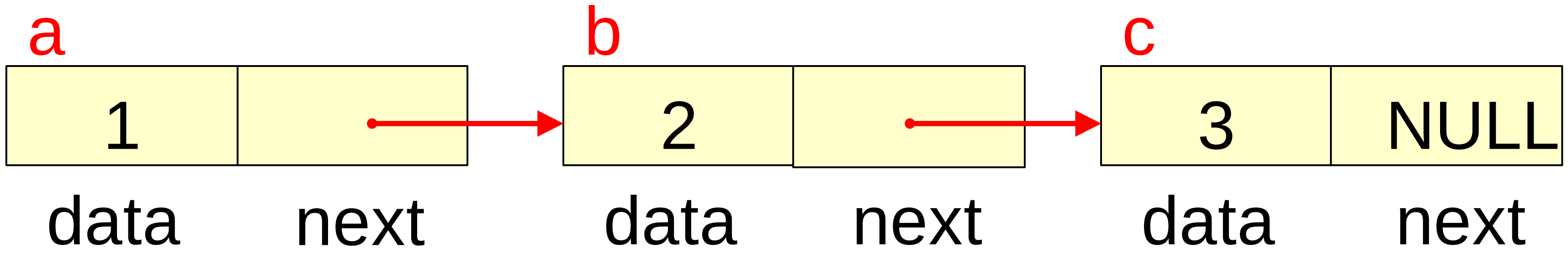
Pictorial Representation

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



Pictorial Representation

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



What are the values of :

- a.data
- a.next->data
- a.next->next->data

Pictorial Representation

a.next = &b;
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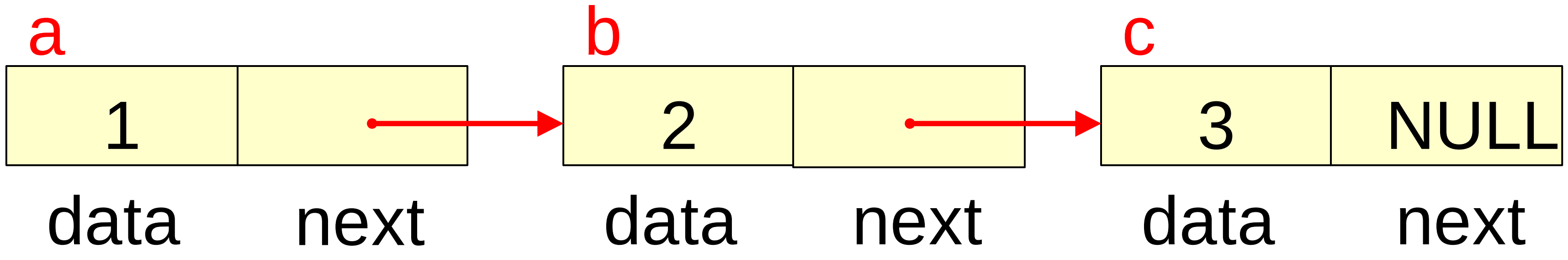


What are the values of :

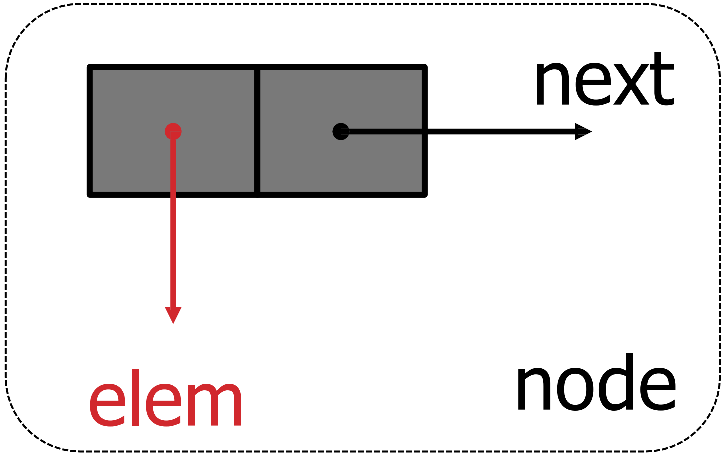
- a.data 1
- a.next->data 2
- a.next->next->data 3

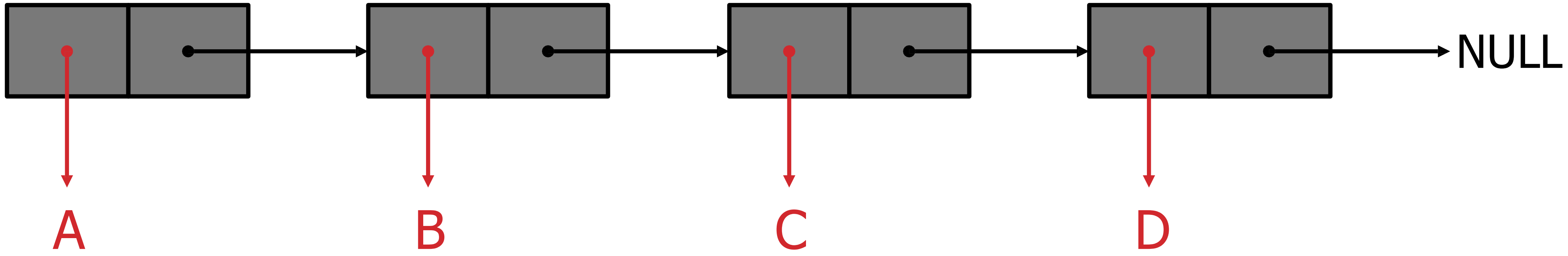
Linked Lists

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

Each node stores

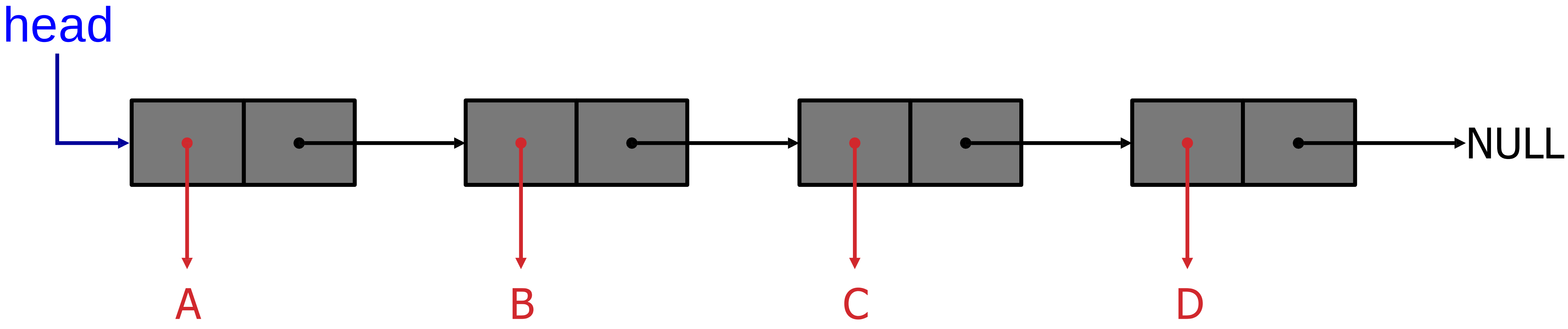
- element
- link to the next node





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.



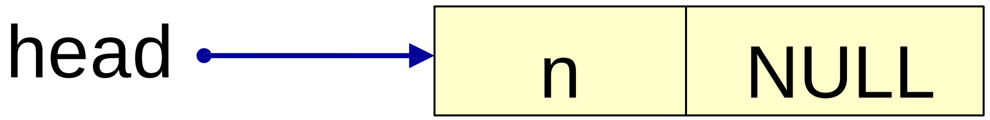
Header File: list.h

```
#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;
```

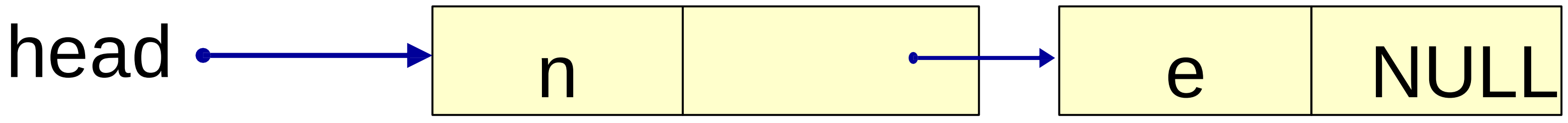
creates a single element list.



Storage Allocation

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

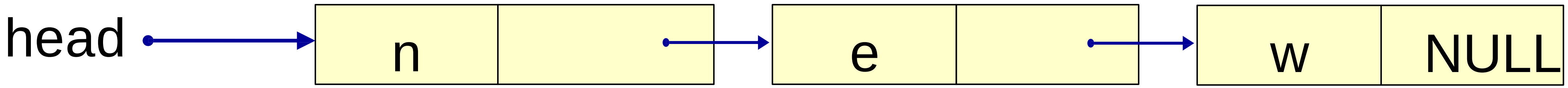
A second element is added.



Storage Allocation

```
head->next->next = (LINK) malloc (sizeof(ELEMENT));
head->next->next->d = 'w';
head->next->next->next = NULL;
```

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



List Operations

- How to initialize such a self referential structure (LIST),
- How to insert such a structure into the LIST,
- How to delete elements from it,
- How to search for an element in it,
- How to print it,
- How to free the space occupied by the LIST?

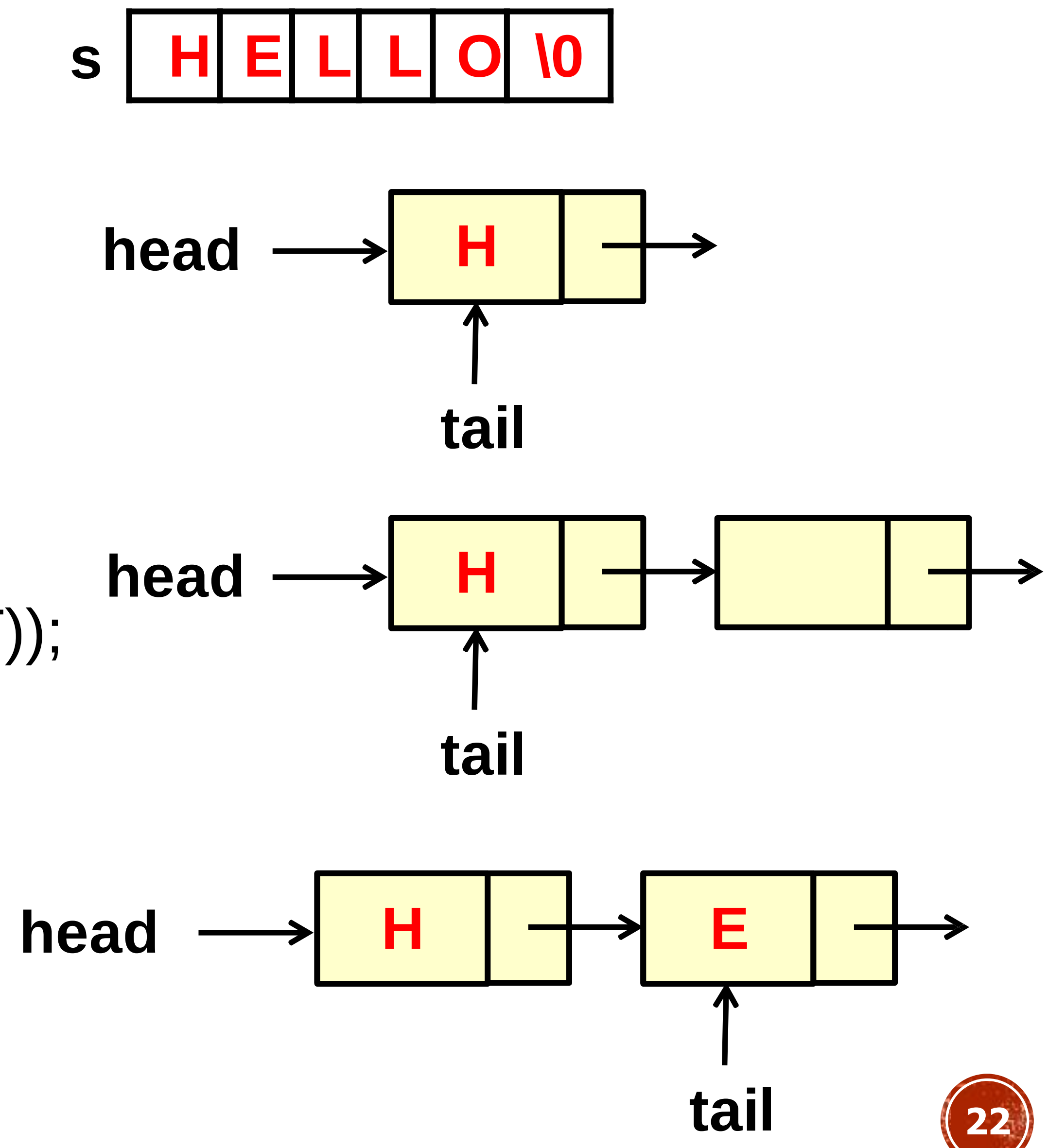
Produce a list from a string (Recursive Version)

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

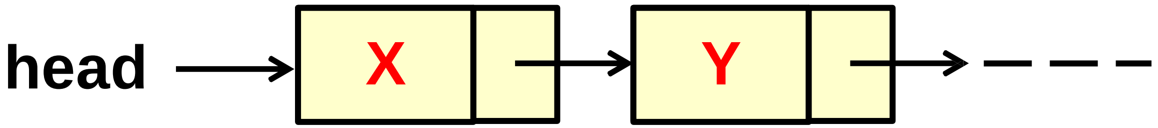
```
LINK StrToList (char s[ ]) {
LINK head ;
if (s[0] == '\0') return NULL ;
else{
        head = (LINK) malloc (sizeof(ELEMENT));
        head->d = s[0];
        head->next = StrToList (s+1);
        return head;
}
```

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



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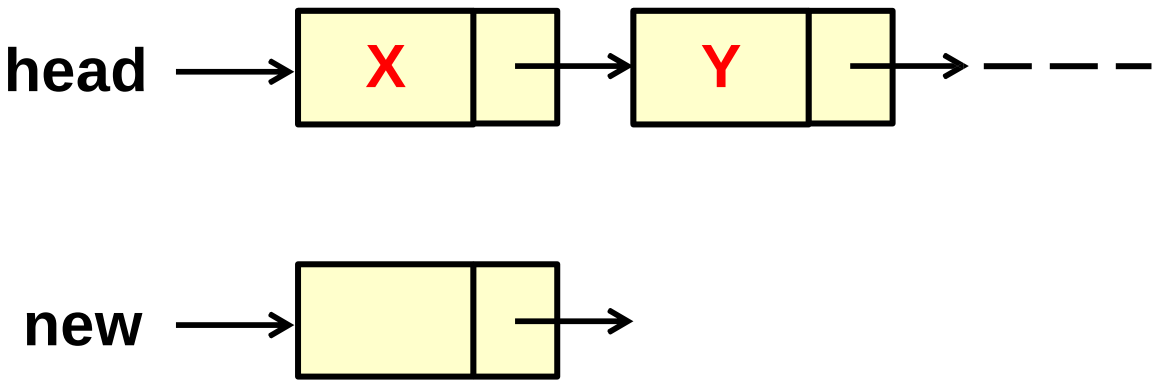
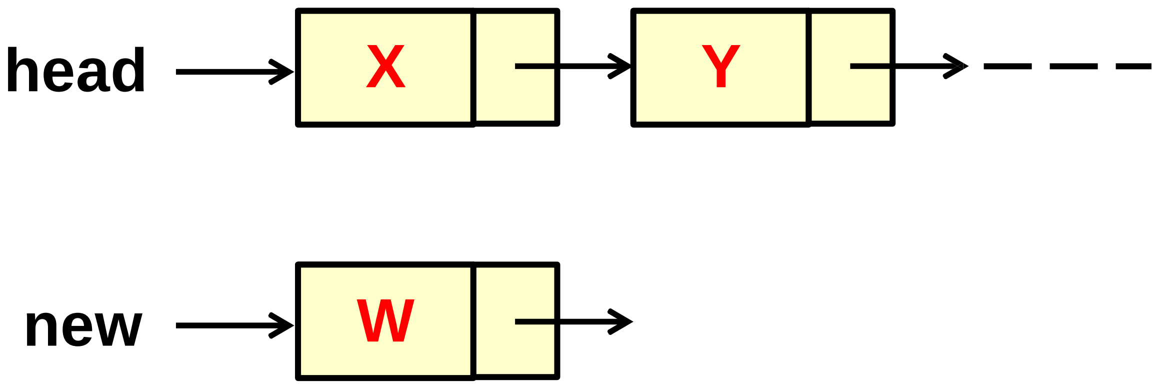


1. Allocate a new node

new = malloc(sizeof(ELEMENT));

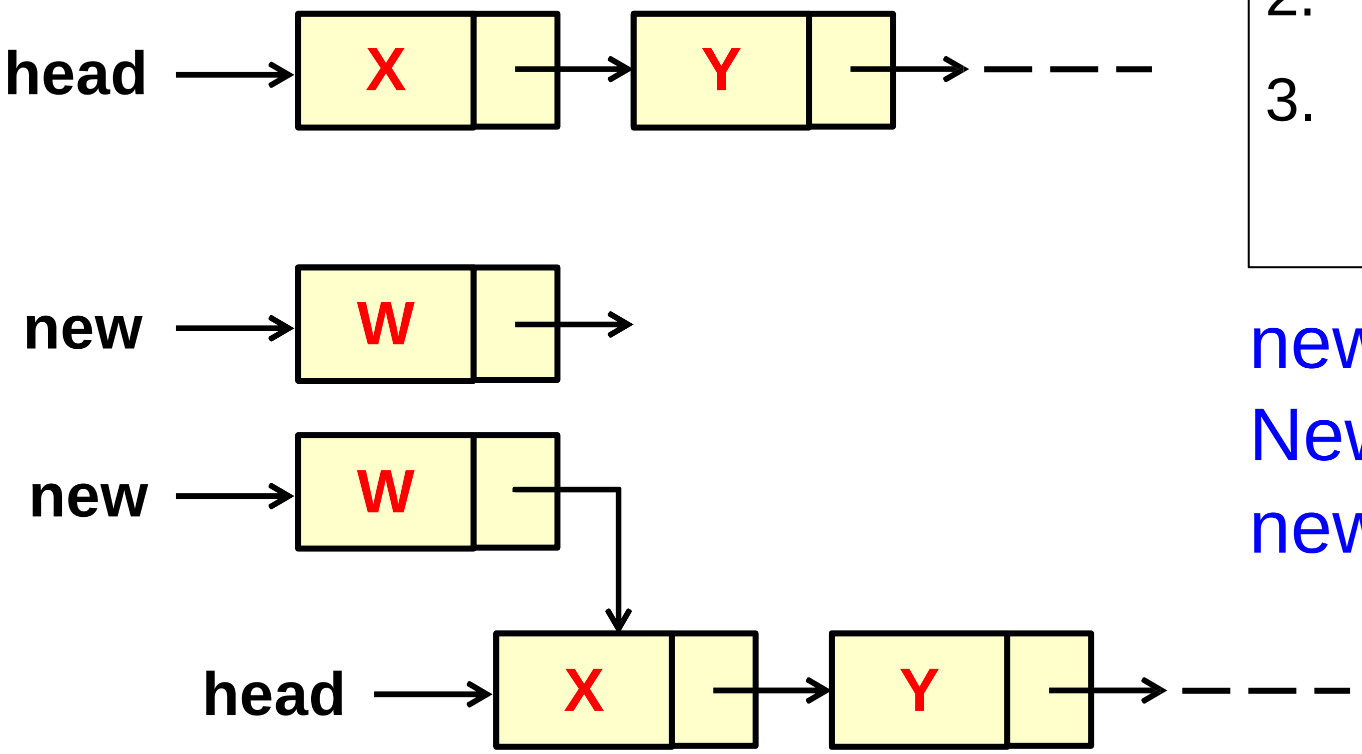
Inserting at the Head



1. Allocate a new node
2. Insert new element

new = malloc(sizeof(ELEMENT));
New->d = ‘W’;

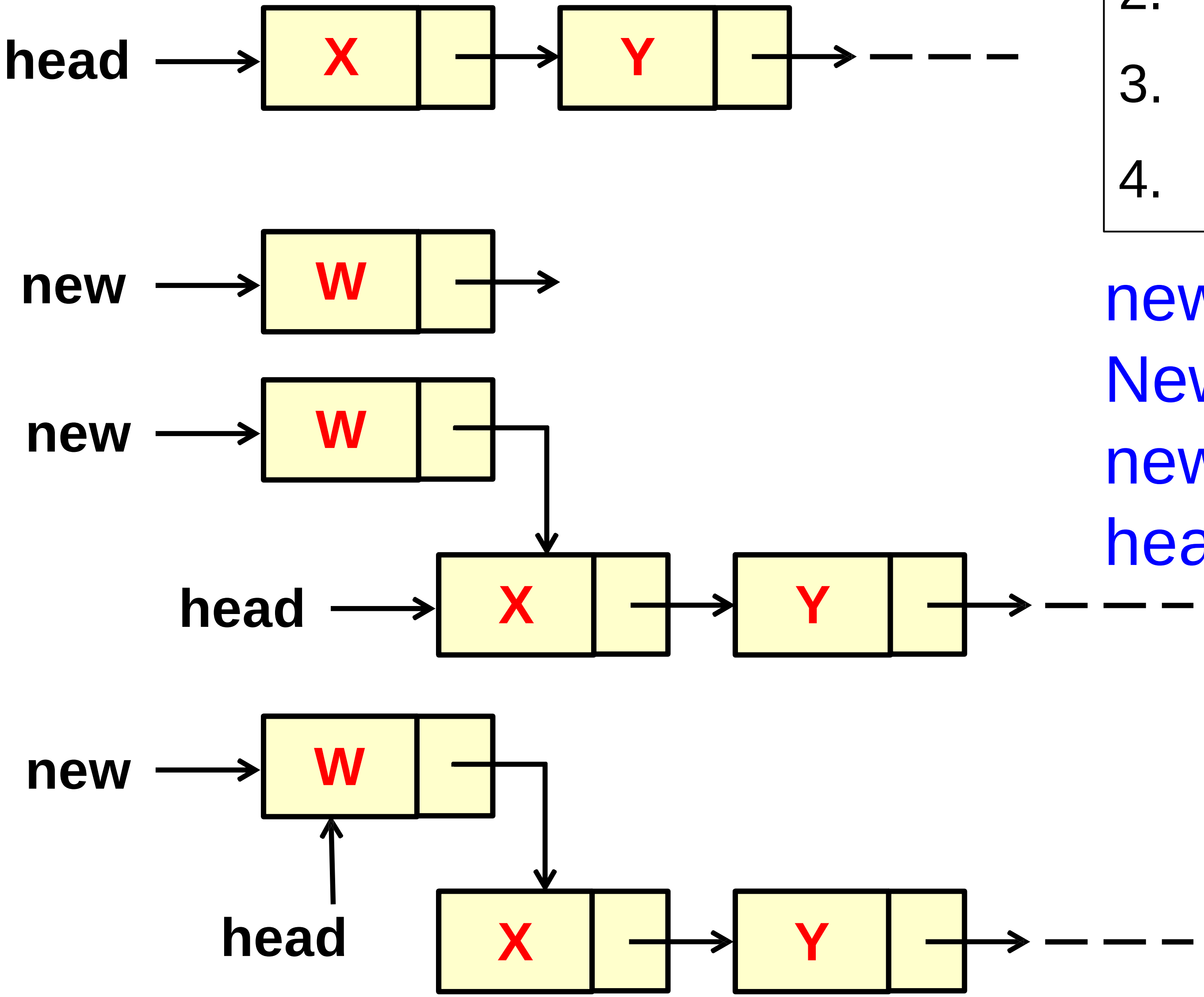
Inserting at the Head



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

```
new = malloc(sizeof(ELEMENT));
New->d = 'W';
new-> next = head;
```

Inserting at the Head

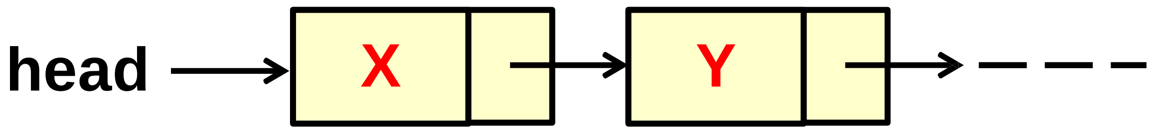


1. Allocate a new node
2. Insert new element
3. Make new node point to old head
4. Update head to point to new node

```
new = malloc(sizeof(ELEMENT));
New->d = 'W';
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



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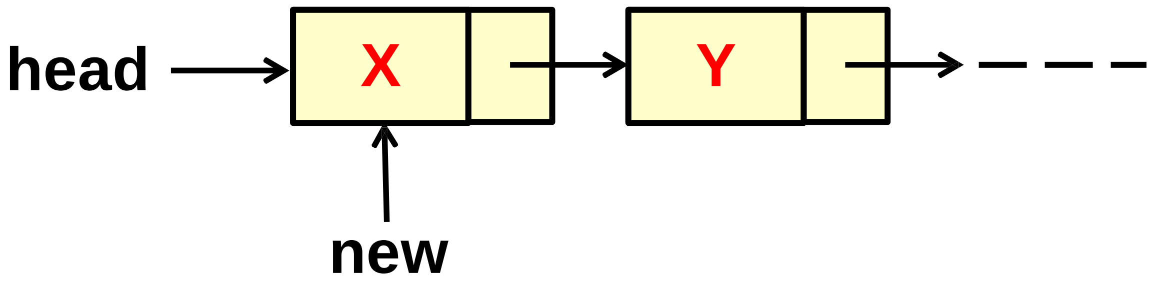

new = head;

Removing the Head

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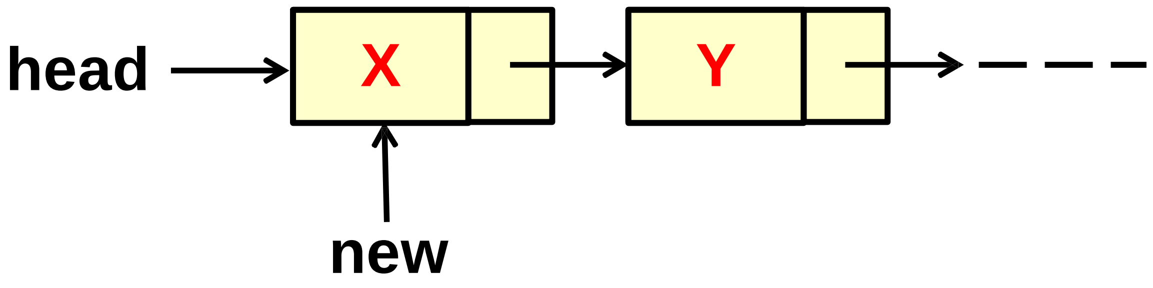
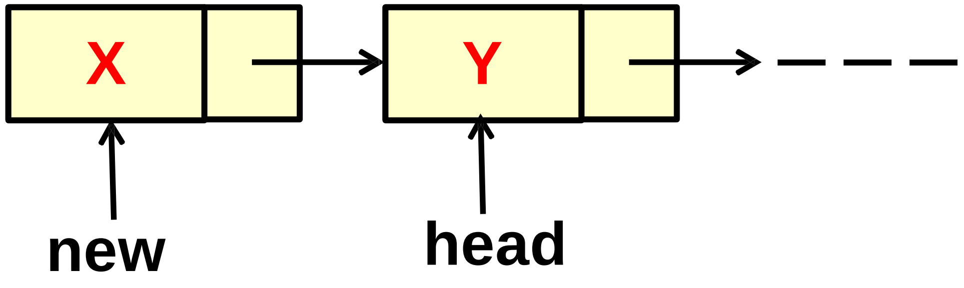


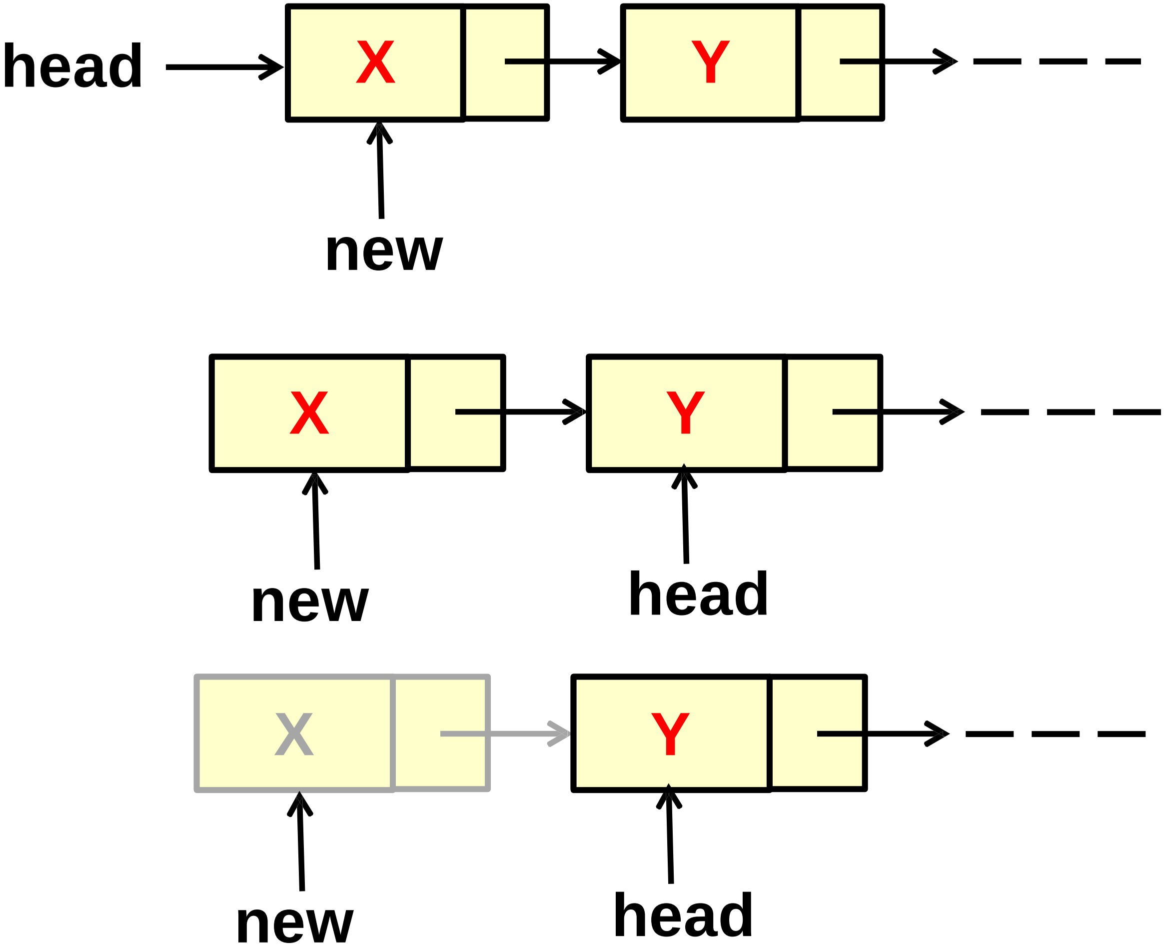
new = head;



head = new->next;

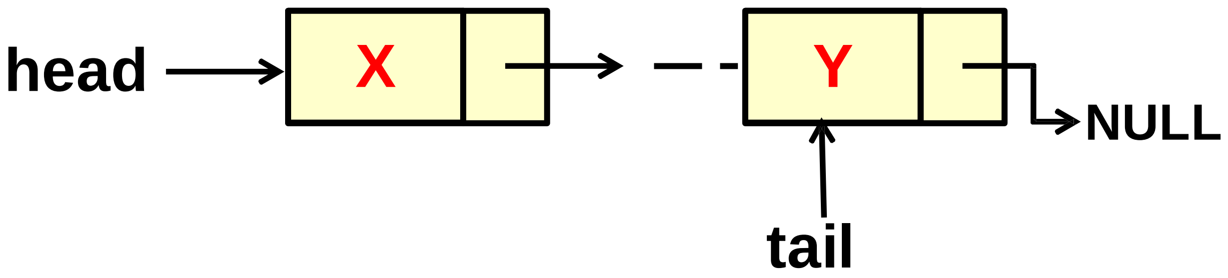
Removing the Head

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

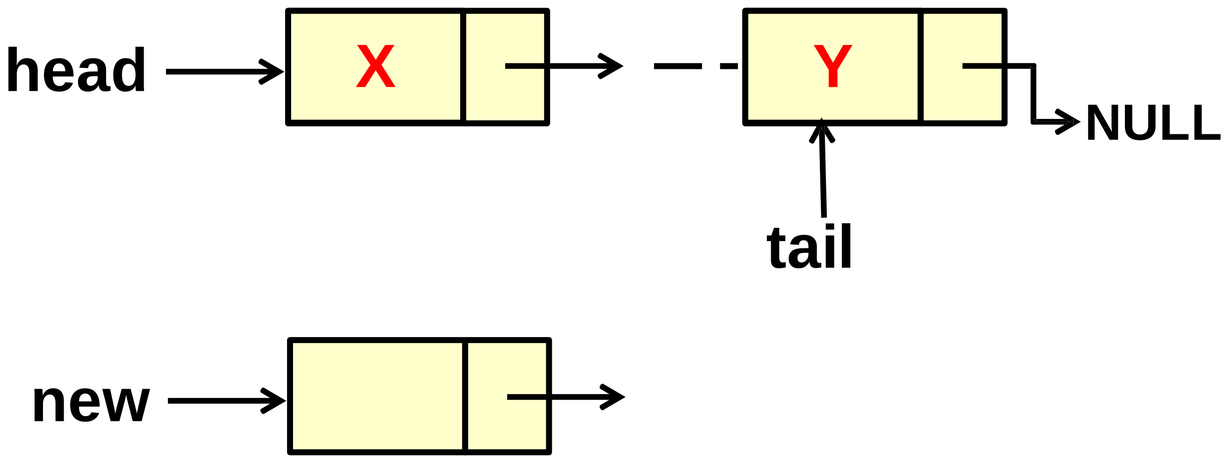



```
new = head;
head = new->next;
free(new);
```

Inserting at the Tail



Inserting at the Tail

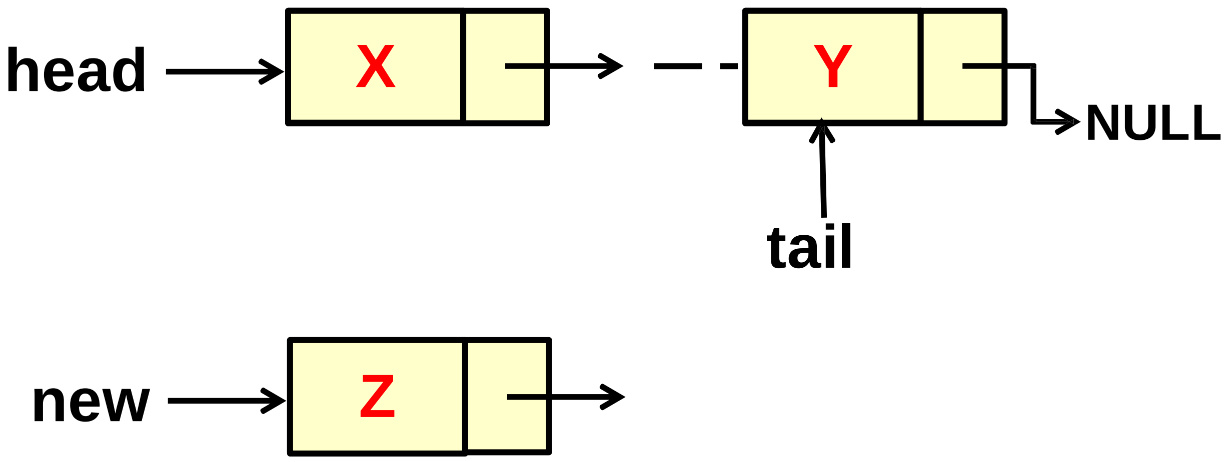


1. Allocate a new node

new = malloc(sizeof(ELEMENT));

Inserting at the Tail

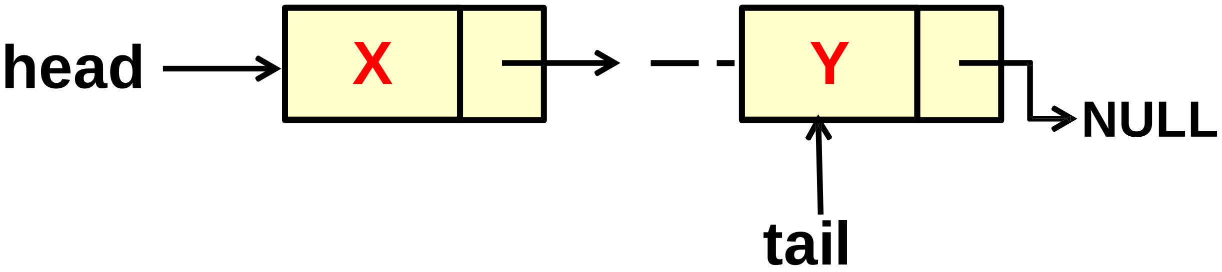
1. Allocate a new node
2. Insert new element



new = malloc(sizeof(ELEMENT));
new->d = ‘Z’;

Inserting at the Tail

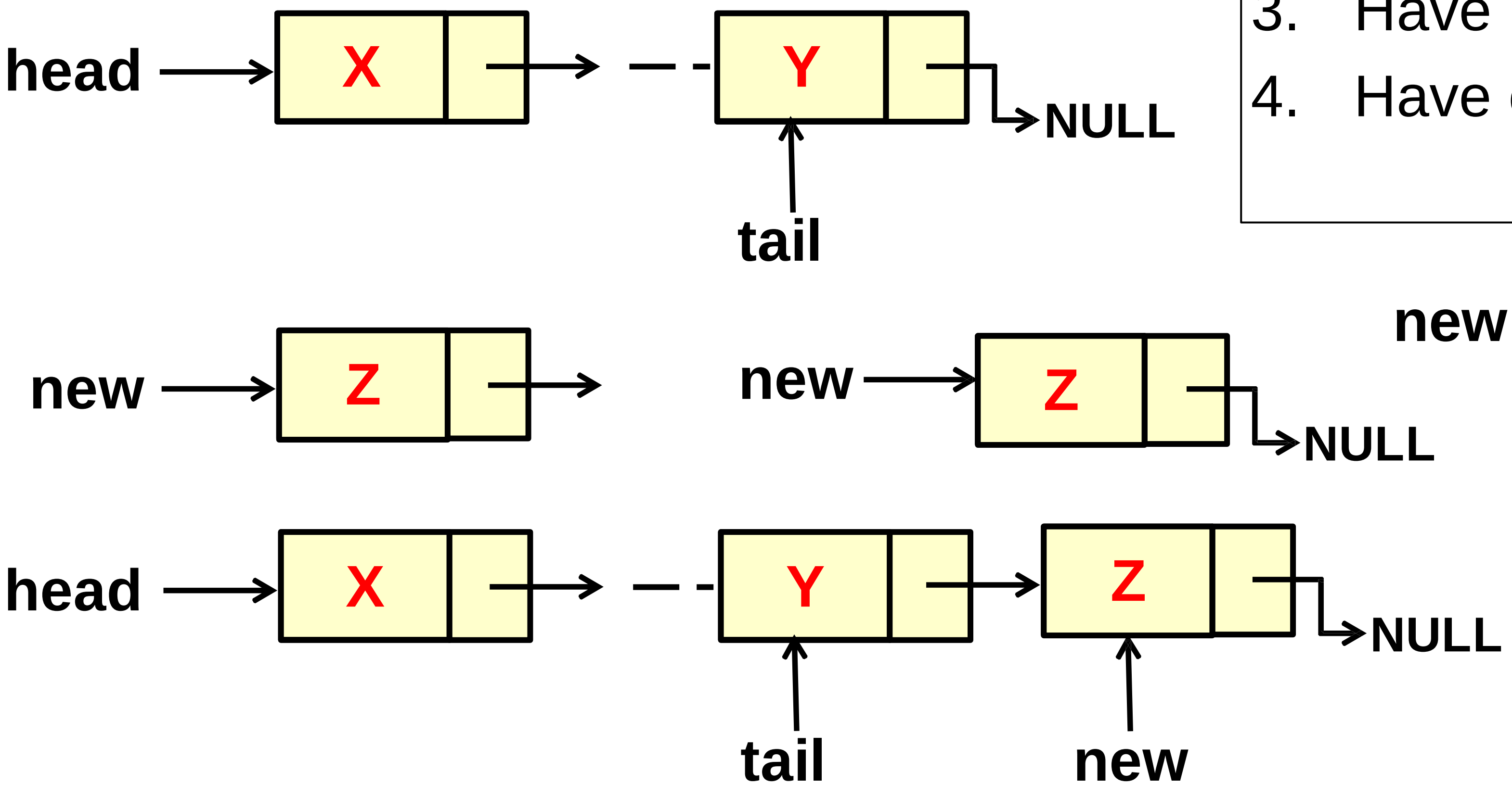
1. Allocate a new node
2. Insert new element
3. Have new node point to null




```
new = malloc(sizeof(ELEMENT));
new->d = 'Z';
new->next = NULL;
```

Inserting at the Tail

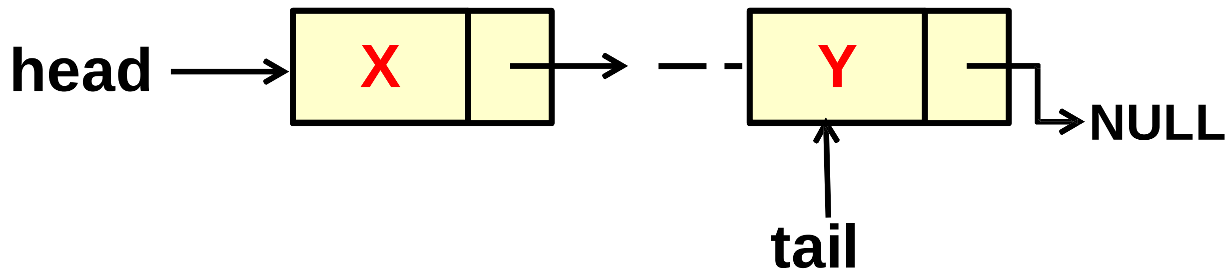
1. Allocate a new node
2. Insert new element
3. Have new node point to null
4. Have old last node point to new node



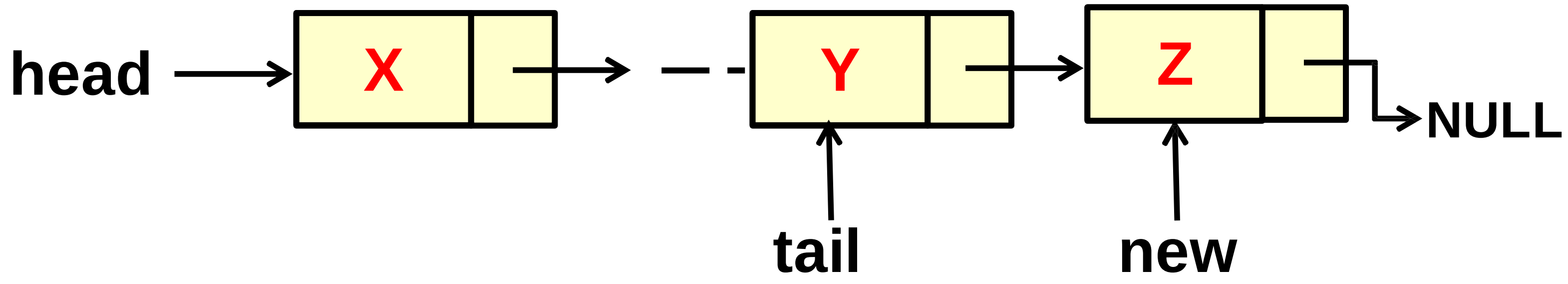

```
new = malloc(sizeof(ELEMENT));
new->d = ‘Z’;
new->next = NULL;

tail->next = new;
```

Inserting at the Tail

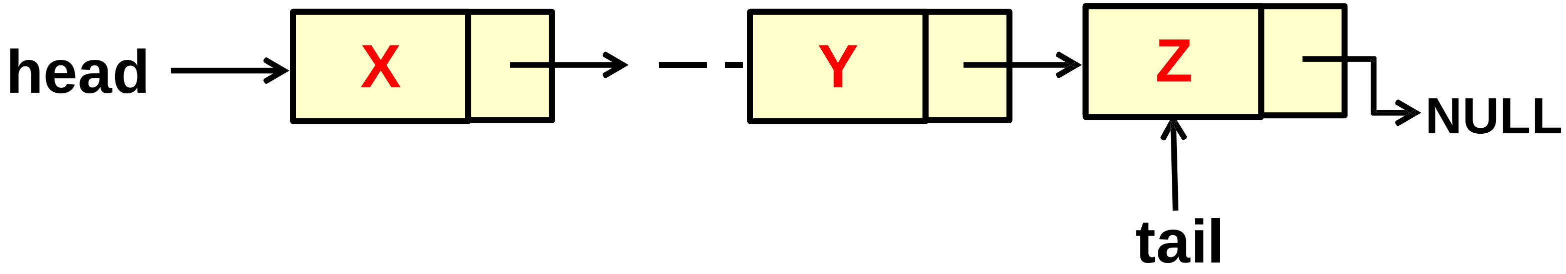
1. Allocate a new node
2. Insert new element
3. Have new node point to null
4. Have old last node point to new node
5. Update tail to point to new node




```
new = malloc(sizeof(ELEMENT));
new->d = 'Z';
new->next = NULL;
```



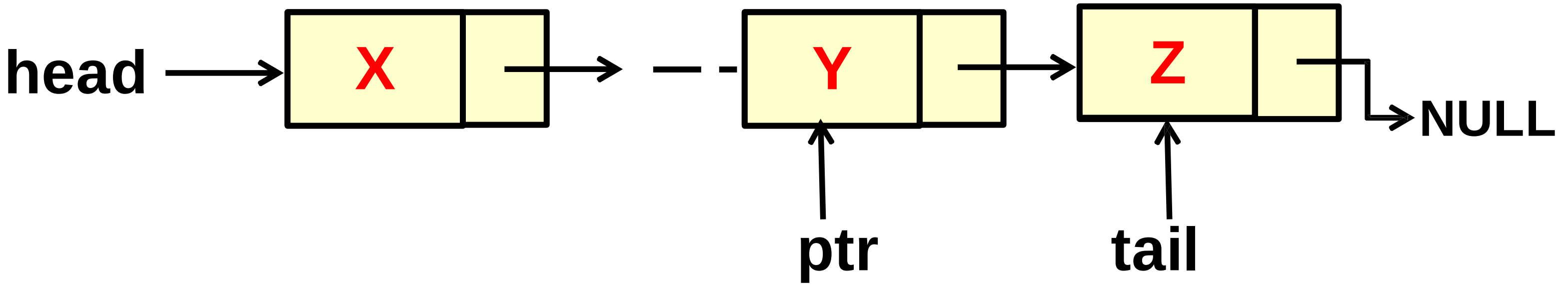

```
tail->next = new;
```




```
tail = new;
```

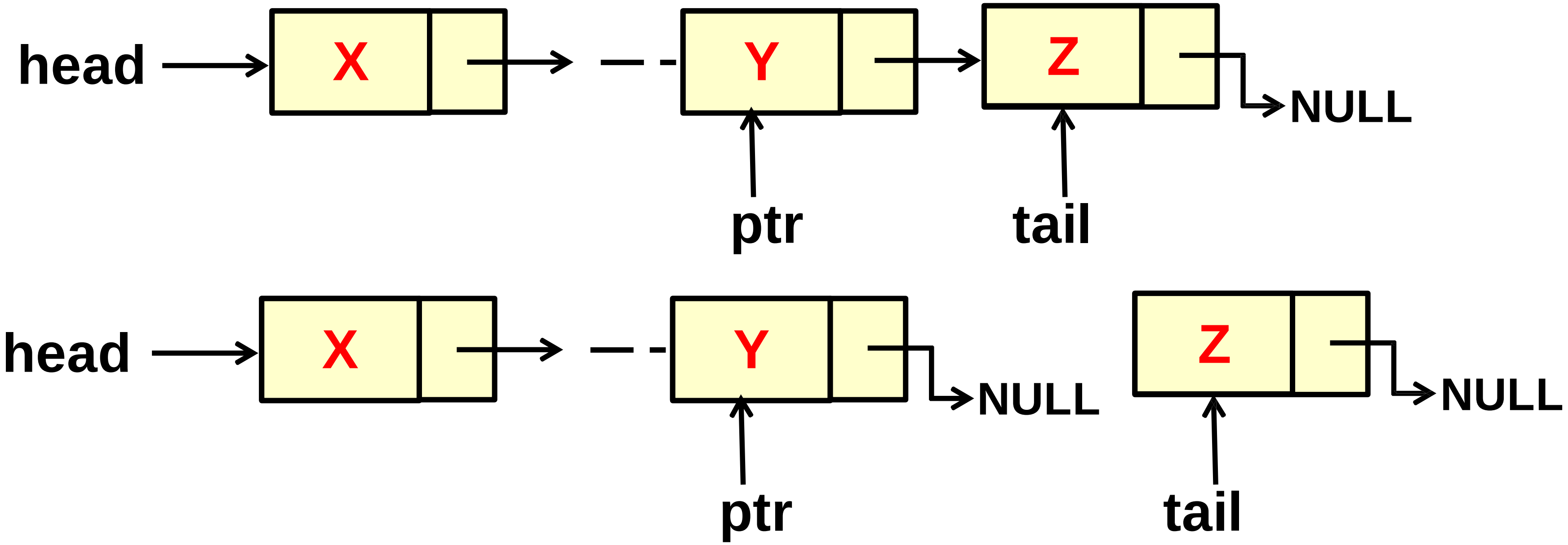
Removing the Tail

1. Bring ptr to the second last node



Removing the Tail

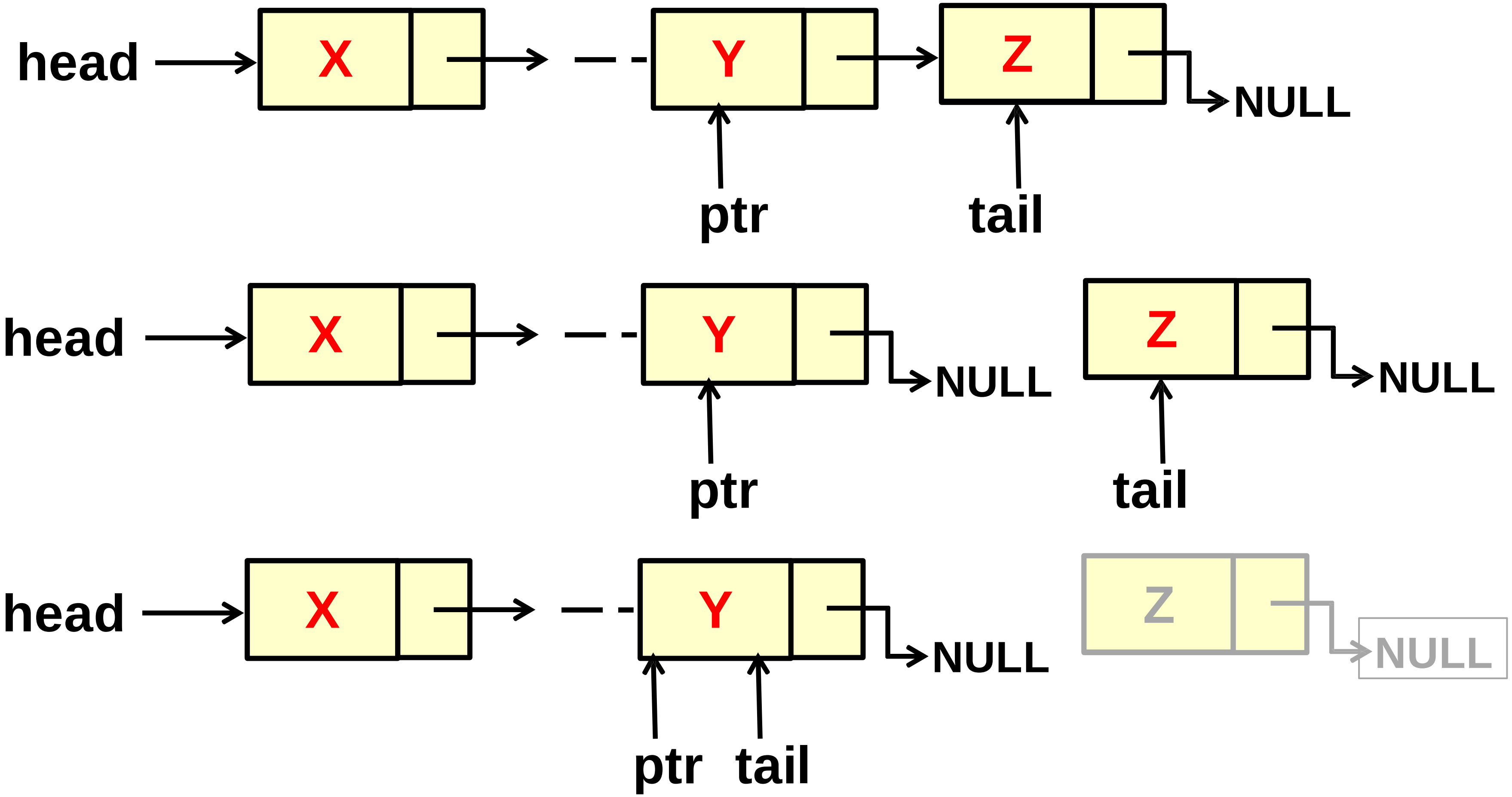
1. Bring ptr to the second last node
2. Make ptr->next equal to NULL



ptr->next = NULL;

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

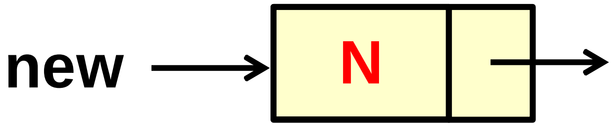


ptr->next = NULL;

free(tail);
tail = ptr;

Insertion into an ordered list

Create a *new* node containing the data

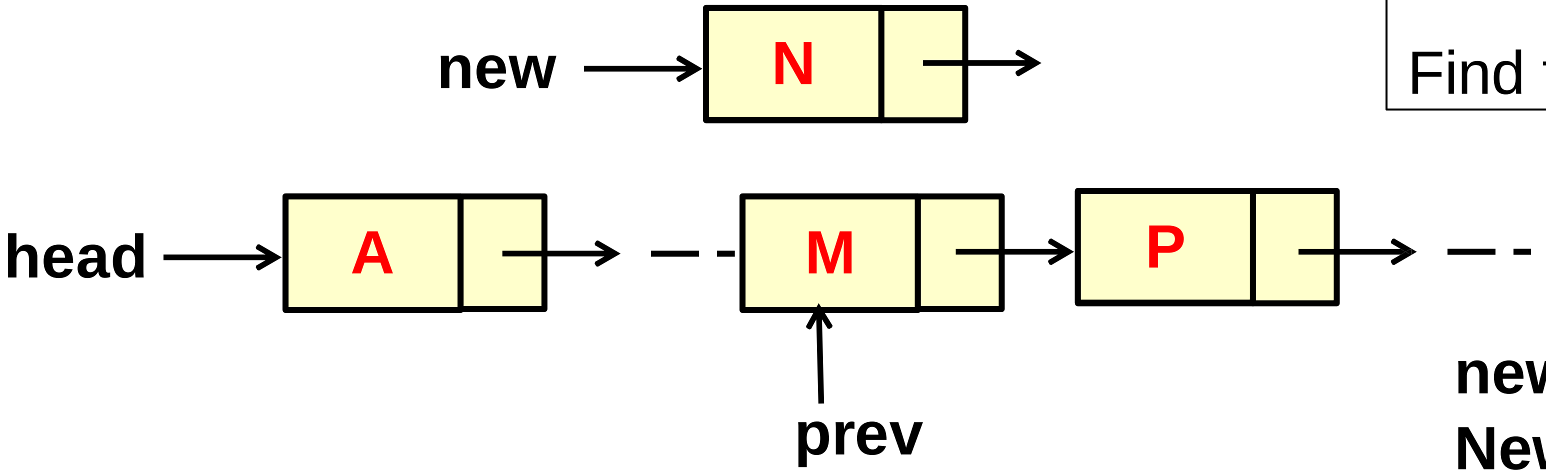


new = malloc(sizeof(ELEMENT));
New->d = 'N';

Insertion into an ordered list

Create a *new* node containing the data

Find the correct place in the list



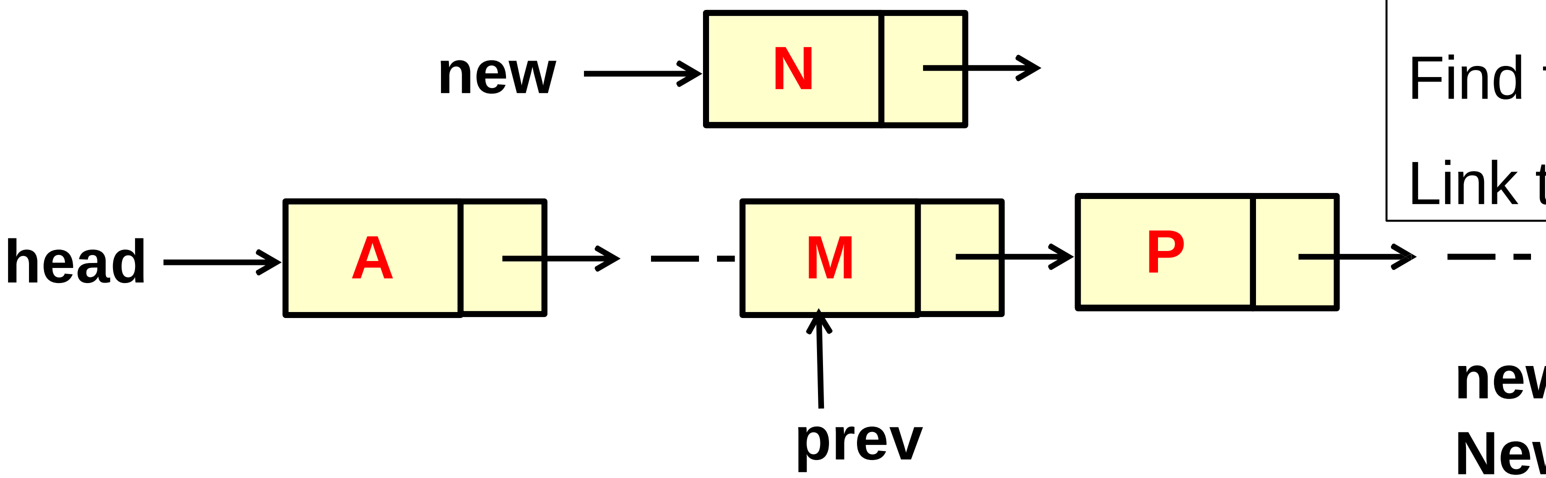
new = malloc(sizeof(ELEMENT));
New->d = ‘N’;

Insertion into an ordered list

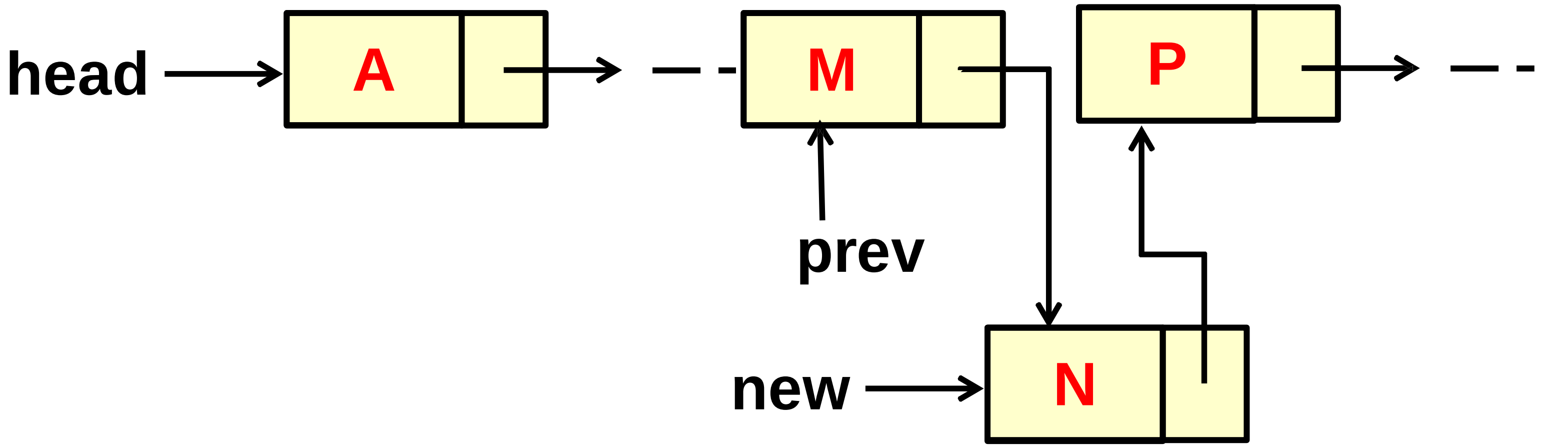
Create a *new* node containing the data

Find the correct place in the list, and

Link the *new* node at this place.




```
new = malloc(sizeof(ELEMENT));
New->d = 'N';
```



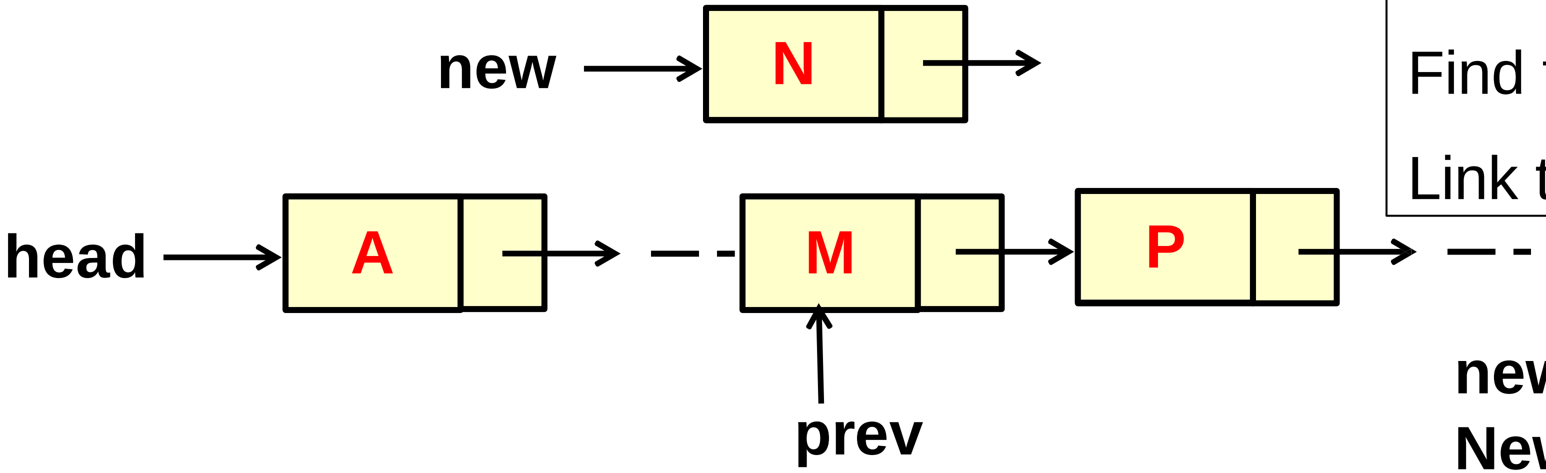

```
new->next = prev->next;
prev->next = new;
```

Insertion into an ordered list

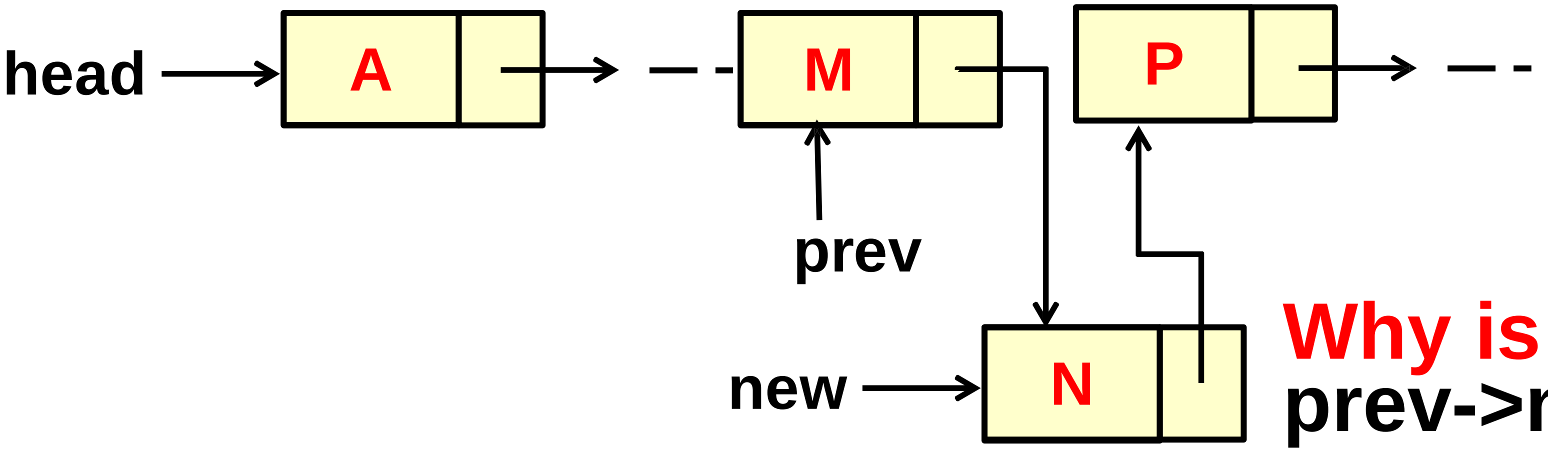
Create a *new* node containing the data

Find the correct place in the list, and

Link the *new* node at this place.



new = malloc(sizeof(ELEMENT));
New->d = 'N';



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

Why is the following not okay?
prev->next = new;
new->next = prev->next;

Insertion Function

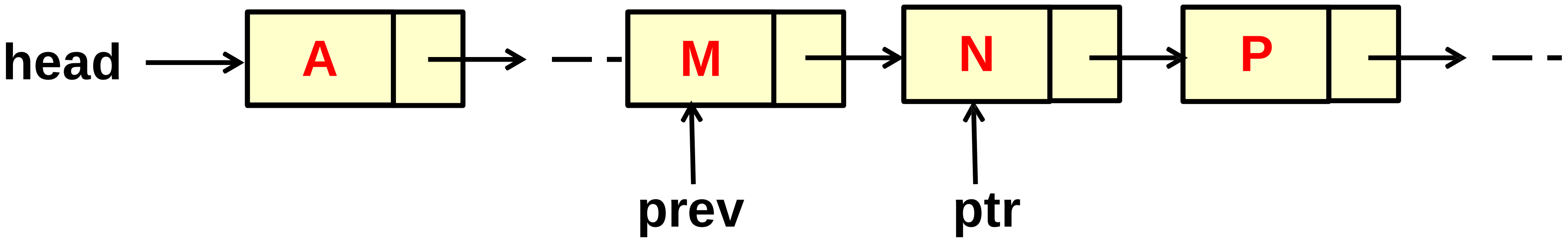
```
#include <stdio.h>
#include <stdlib.h>
struct list {
     int data;
     struct list *next;
};
typedef struct list ELEMENT;
typedef ELEMENT * LINK;

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

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

Deletion

Steps:

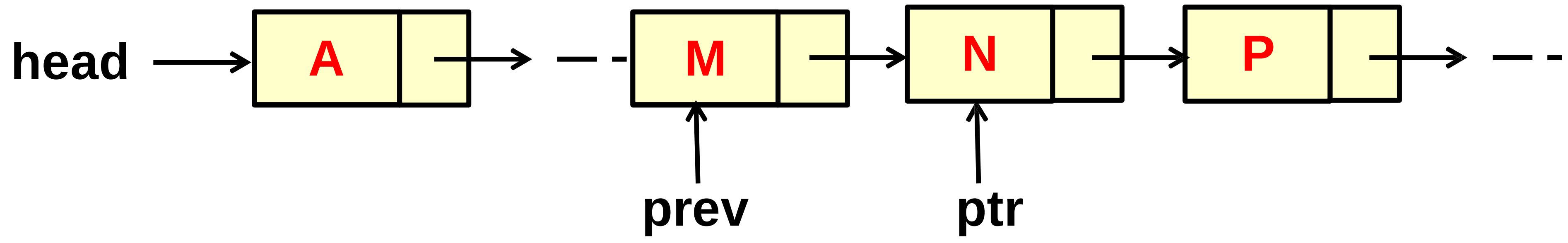
- Finding the data item in the list



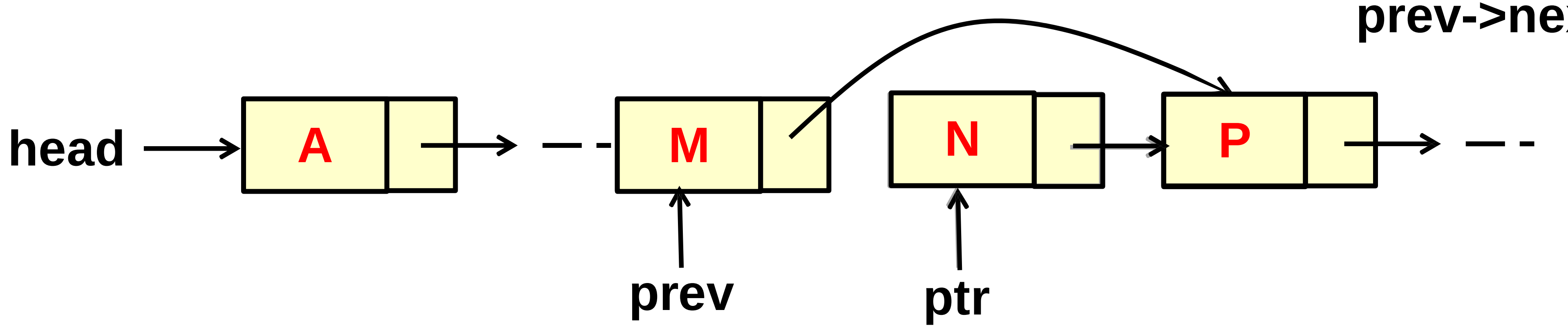
Deletion

Steps:

- Finding the data item in the list, and
- Linking out this node

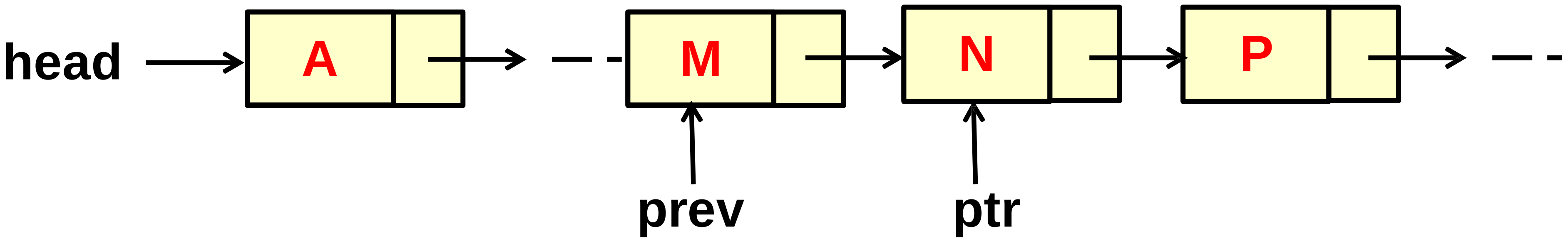


prev->next = ptr->next;

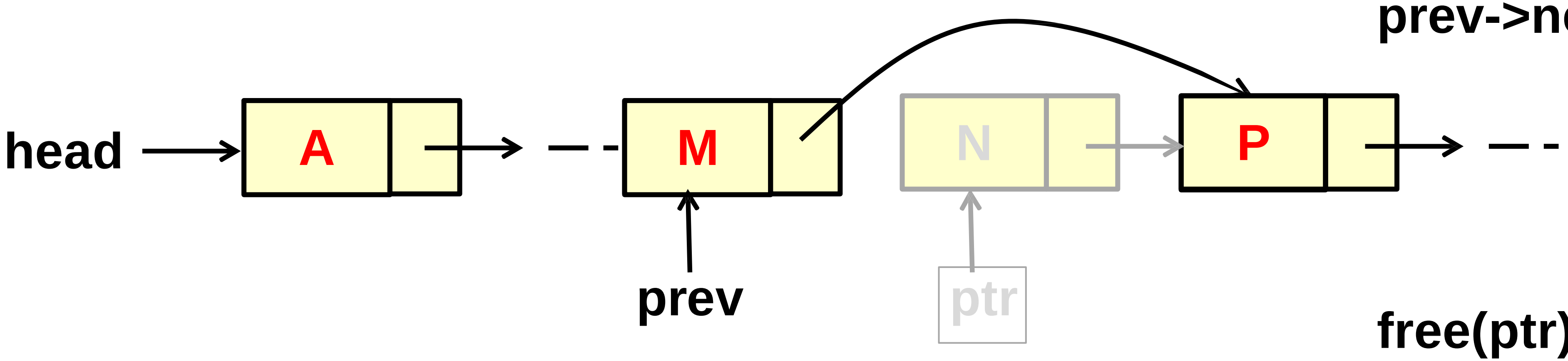


Deletion

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;

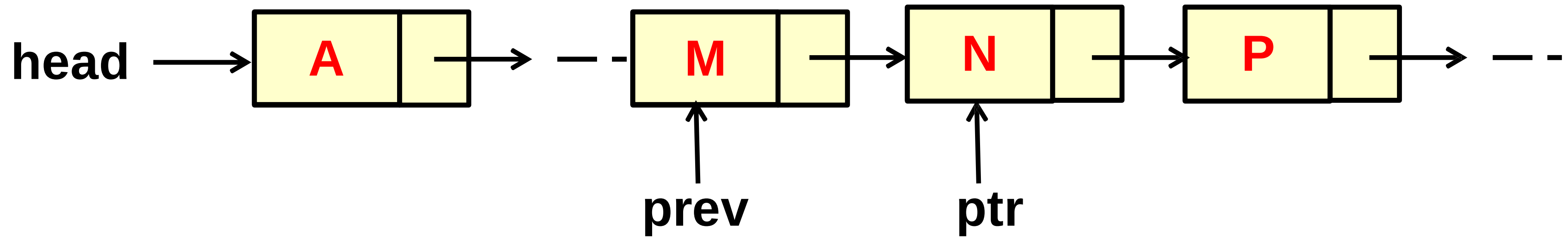


free(ptr);

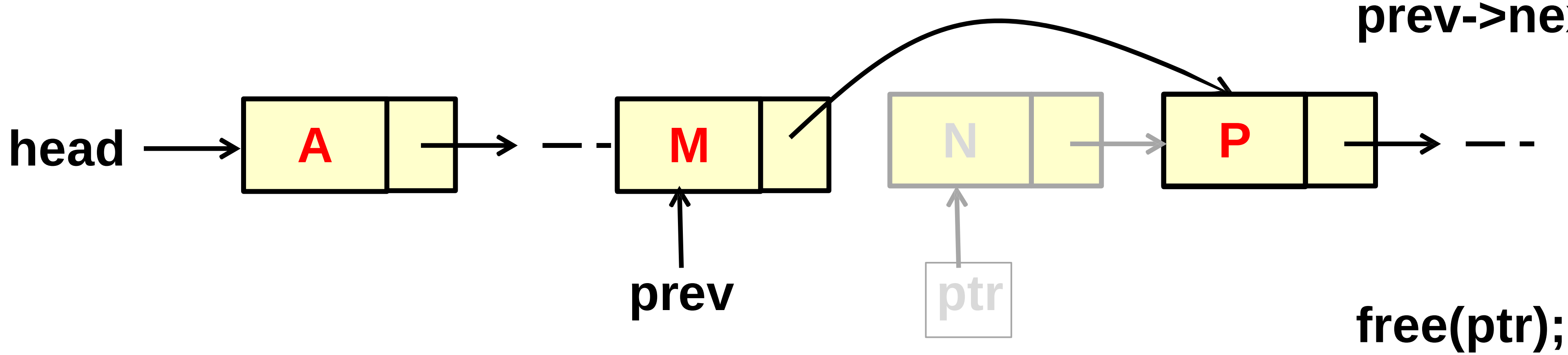
Deletion

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 val, LINK ptr) {
    LINK prev, first;

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

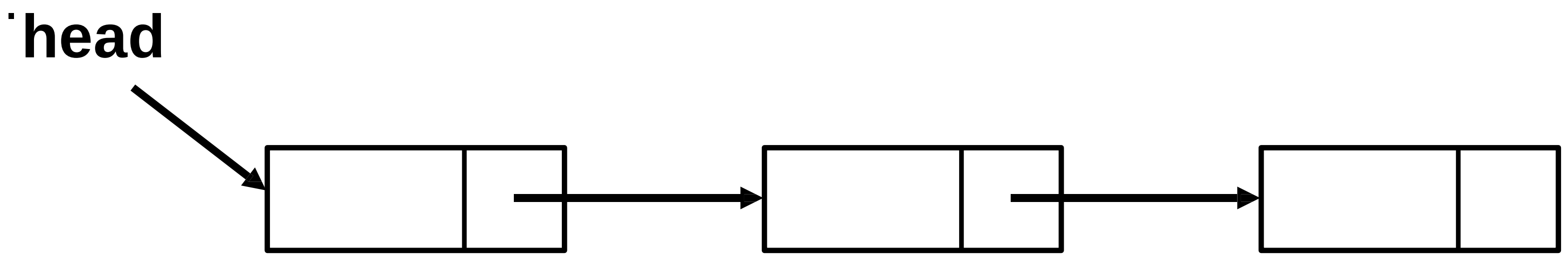
Linear Searching for a data element in a list

```
int Search( LINK head, int element) {
   LINK temp;

   temp = head;
   while (temp != NULL) {
         if (temp -> data == element) return 1;
         temp = temp -> next;
   }
   return 0;
}
```

Printing a list

```
void print_list (LINK head) {
    LINK temp;
    temp = head;
    while(temp!=NULL) {
        if(temp->next ==NULL)
            printf("%d. END OF LIST \n", temp->data);
        else printf("%d -> ", temp->data);
        temp = temp->next;
    }
}
```

Printing a list backwards



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

Printing a list backwards – *recursively*

```
void PrintArray(LINK 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?

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;
                temp1->next = NULL;
                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;
}
```

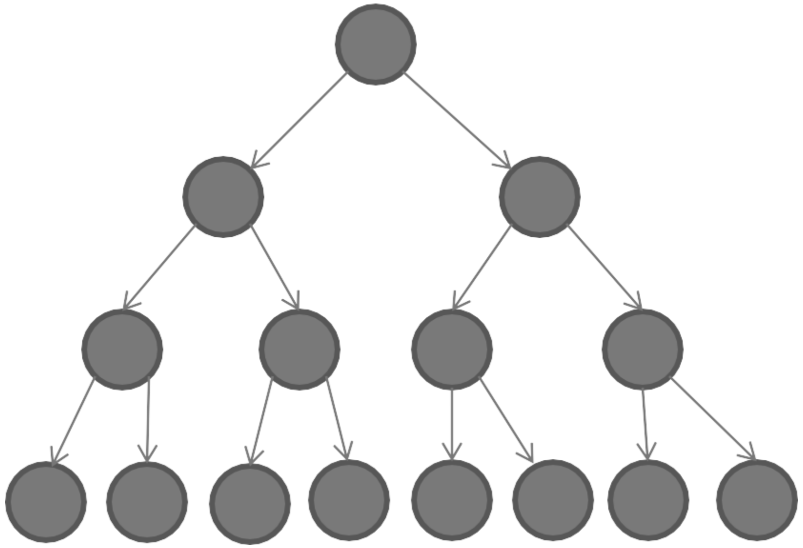
Concatenate two Lists

```
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

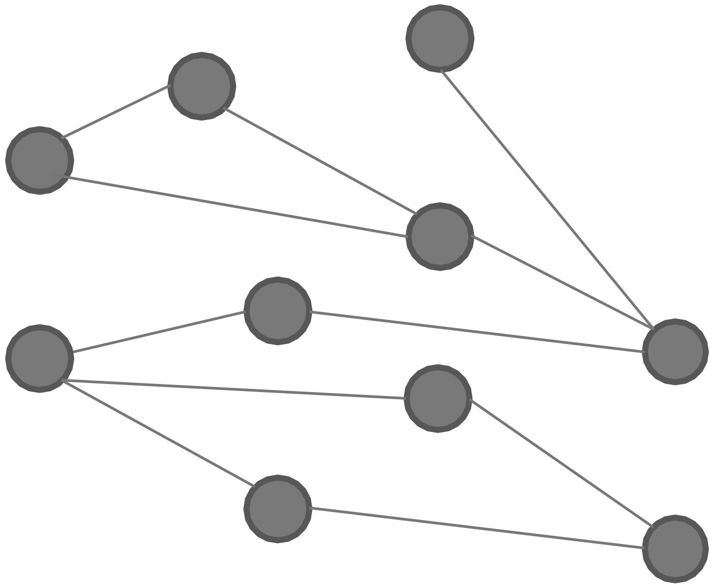
Binary Tree
(Height = 3)



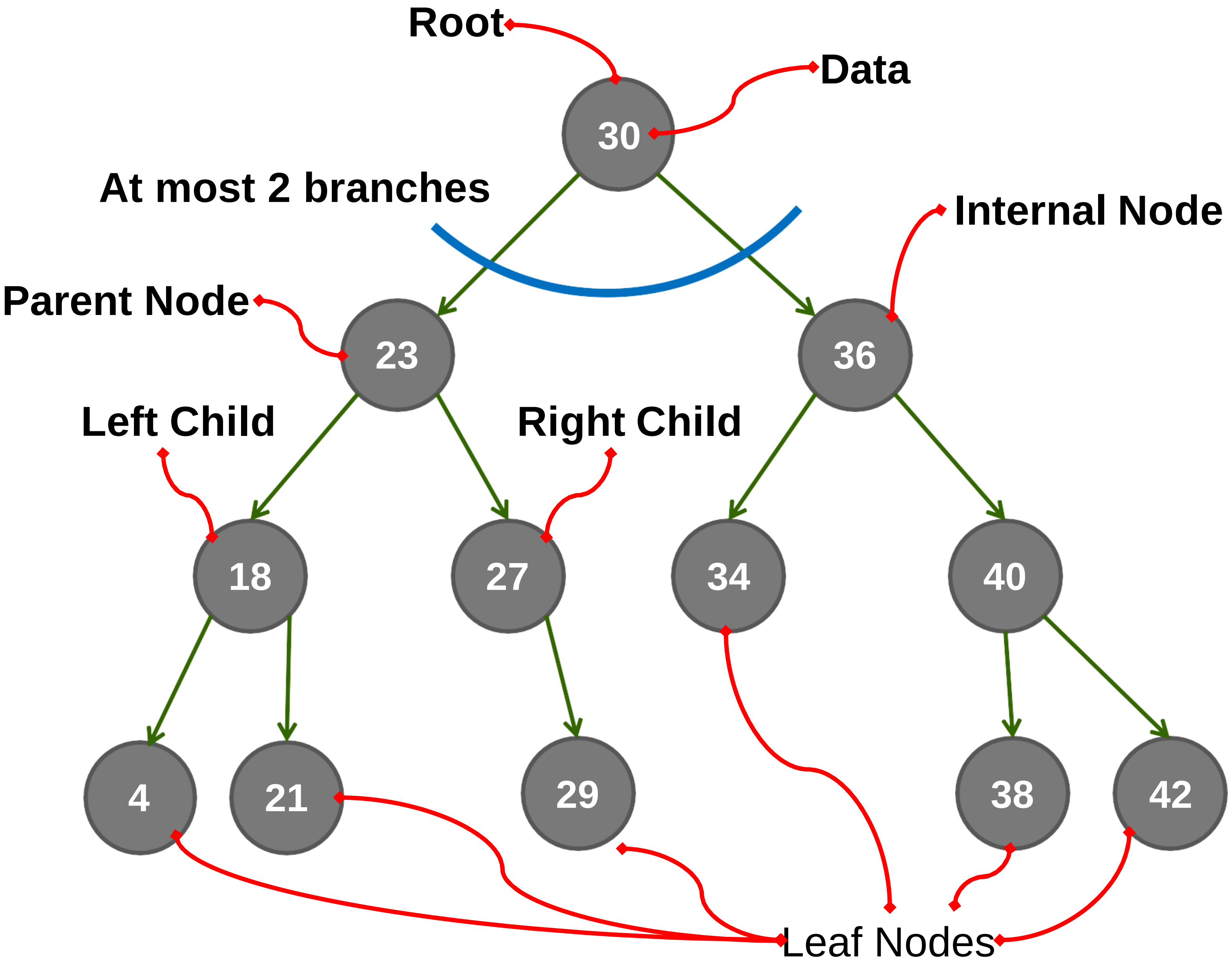
Sparse Matrix

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

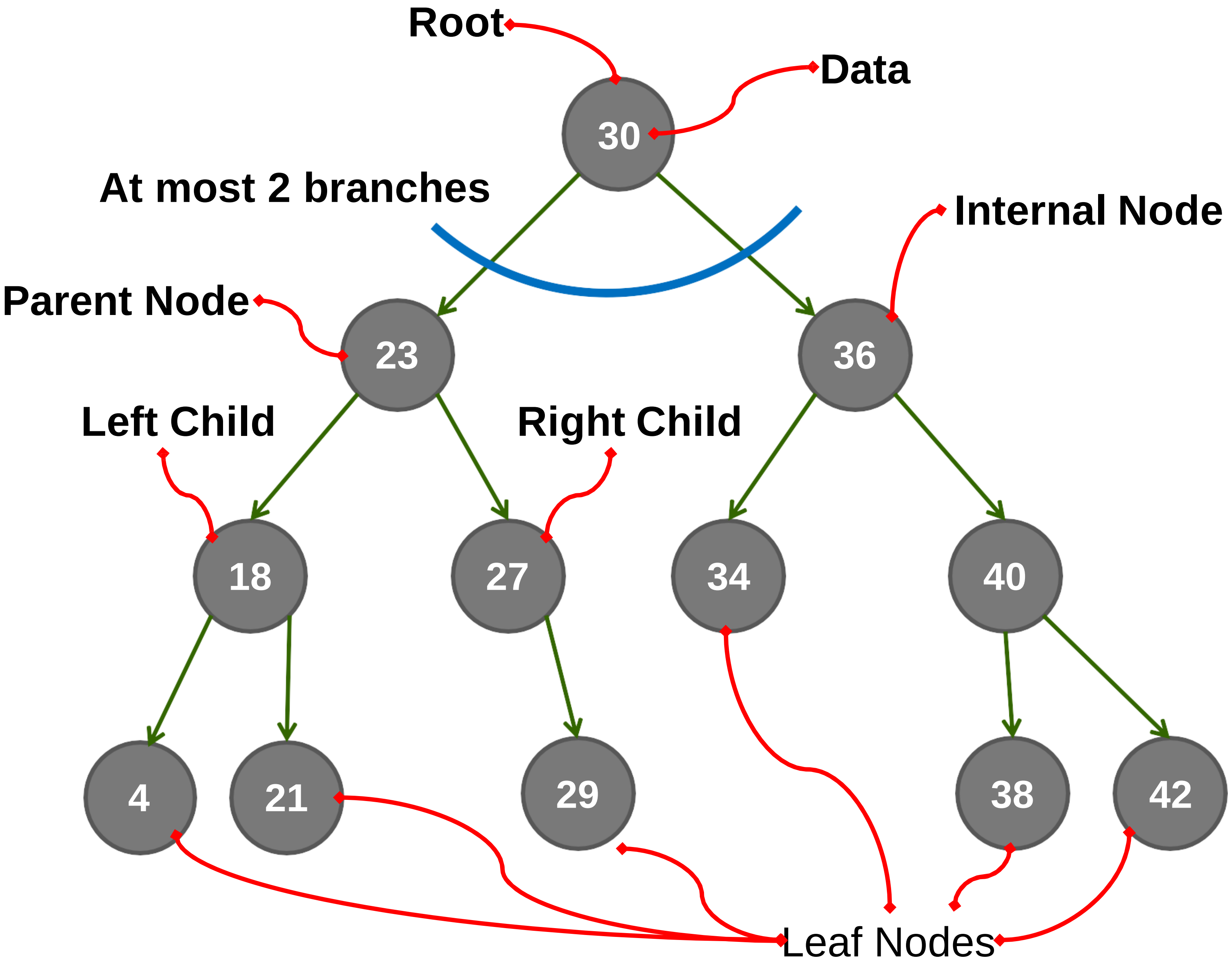
Graph
(Number of Vertices = 10)
(Number of Edges = 11)



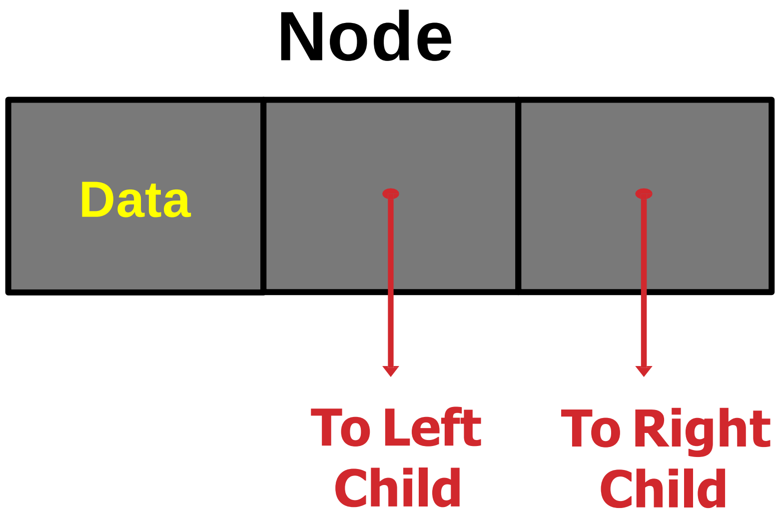
… And "Other" linked structures: Binary Trees



… 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)

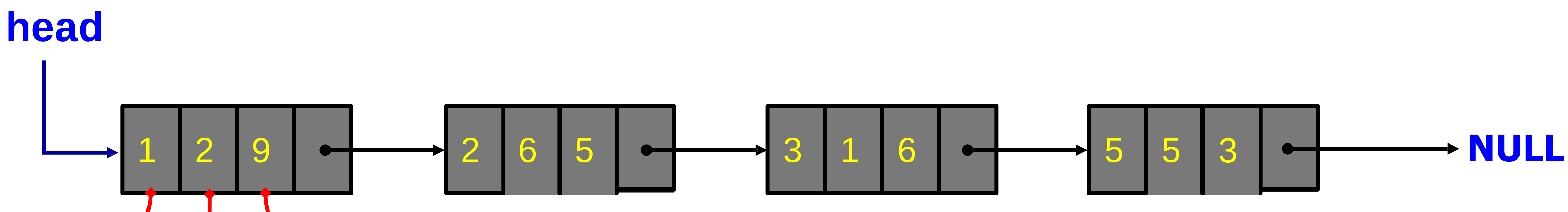
= 30 * sizeof(int) = 120Bytes (For integers of size 4 Bytes)

… 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;
}
```



Row Column Data

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

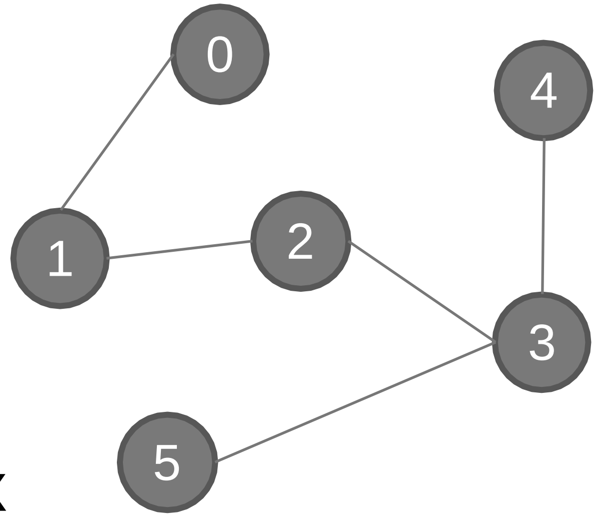
… And "Other" linked structures: Graphs

<u>Adjacency Matrix Representation:</u>

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

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

Adjacency Matrix for an undirected graph



Storage as a 2-D Array:

int G[6][6];

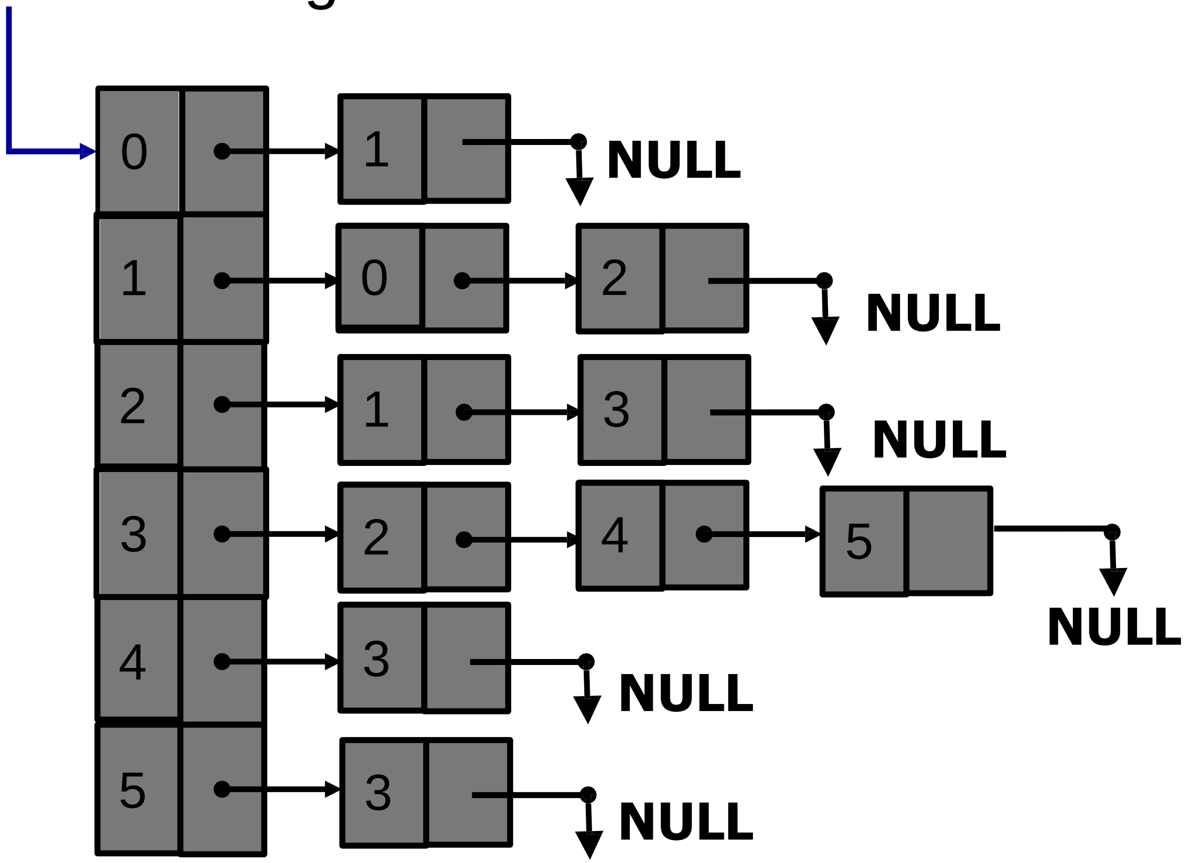
Storage required for 36 elements (with 6 vertices 5 edges)

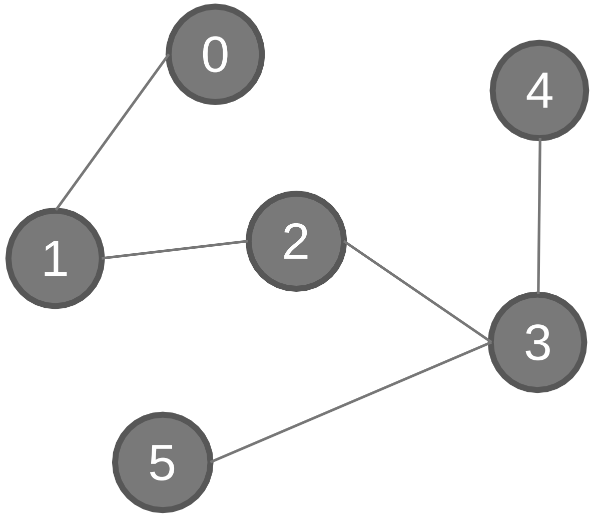
= 36 * sizeof(int) = 144Bytes (For integers of size 4 Bytes)

… 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)

Practice Problems

1. Concatenate two lists (iteratively)
2. Reverse a list
3. Delete the maximum element from a list
4. Rotate the list by k positions counter-clockwise
5. Write functions to create, insert, delete, display, search a sparse matrix

For each of the above, first create the linked list by reading in integers from the keyboard and inserting one by one to an empty list

Acknowledgement

- IIT Kharagpur

Thank You