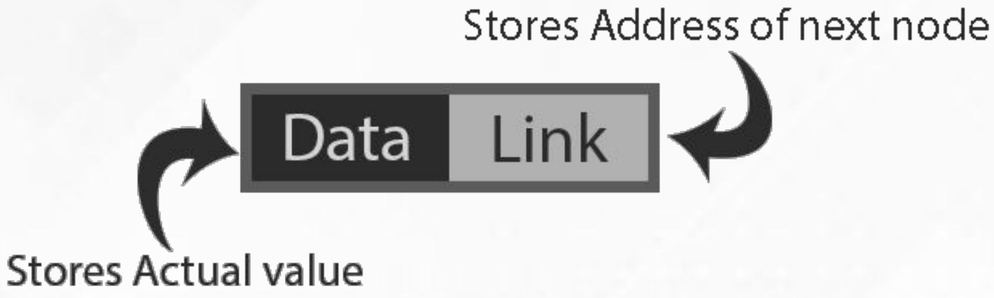
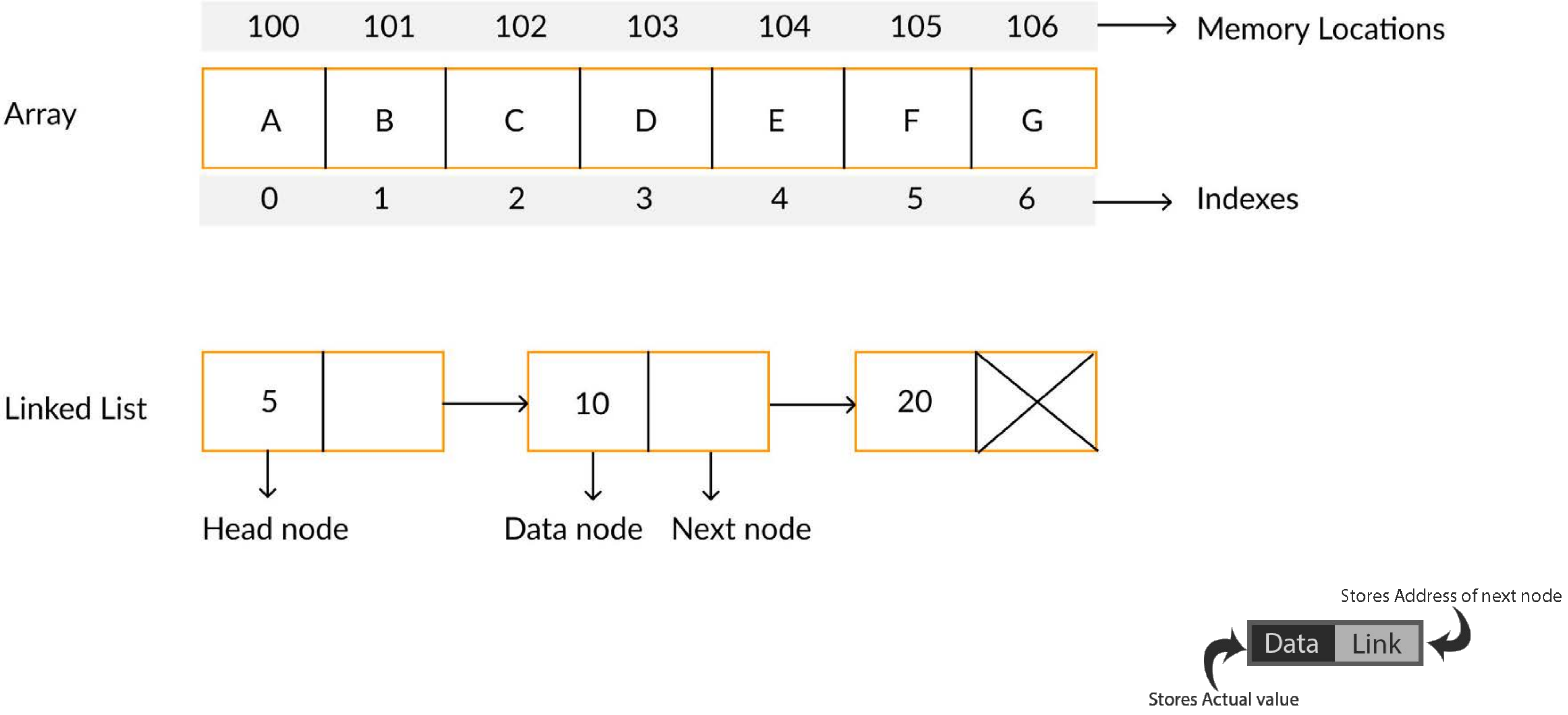
Unit-2

Linear Data Structure (Linked List)

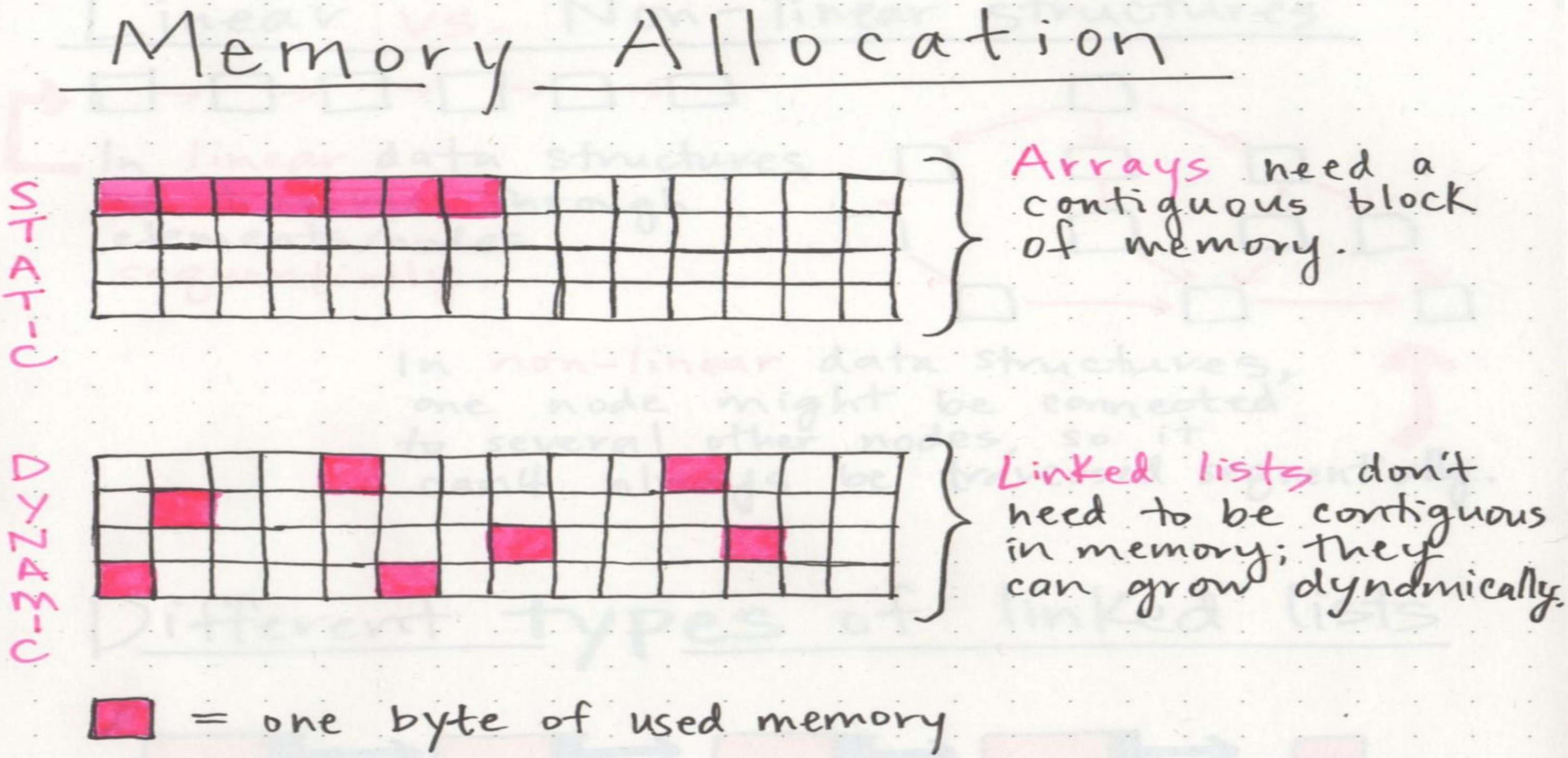


• Computer Engineering Department

Array v/s Linked List



Array v/s Linked List

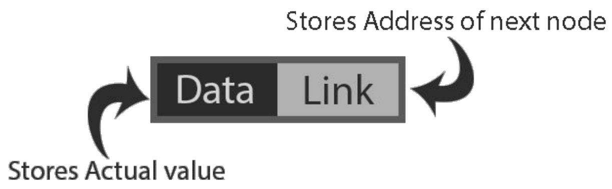


Array v/s Linked List

- Arrays and Linked Lists are both linear data structures.
- An array is a collection of elements of a similar data type.
- Linked List is an ordered collection of elements of the same type in which each element is connected to the next using pointers.
- Array elements can be accessed randomly using the array index.
- Random accessing is not possible in linked lists. The elements will have to be accessed sequentially.
- Data elements are stored in contiguous locations in memory.
- New elements can be stored anywhere and a reference is created for the new element using pointers.

Array v/s Linked List

- Insertion and Deletion operations are costlier since the memory locations are consecutive and fixed.
- Insertion and Deletion operations are fast and easy in a linked list.
- Memory is allocated during the compile time (Static memory allocation).
- Memory is allocated during the run-time (Dynamic memory allocation).
- Size of the array must be specified at the time of array declaration/initialization.
- Size of a Linked list grows/shrinks as and when new elements are inserted/deleted.



Array v/s Linked List

	Array	Linked List
Strength	• Random Access (Fast Search Time) • Less memory needed per element • Better cache locality	• Fast Insertion/Deletion Time • Dynamic Size • Efficient memory allocation/utilization
Weakness	• Slow Insertion/Deletion Time • Fixed Size • Inefficient memory allocation/utilization	• Slow Search Time • More memory needed per node as additional storage required for pointers

Advantages of Linked Lists

- Size of linked lists is not fixed, they can expand and shrink during run time.
- Insertion and Deletion Operations are fast and easier in Linked Lists.
- Memory allocation is done during run-time (no need to allocate any fixed memory).
- Data Structures like Stacks, Queues, and trees can be easily implemented using Linked list.

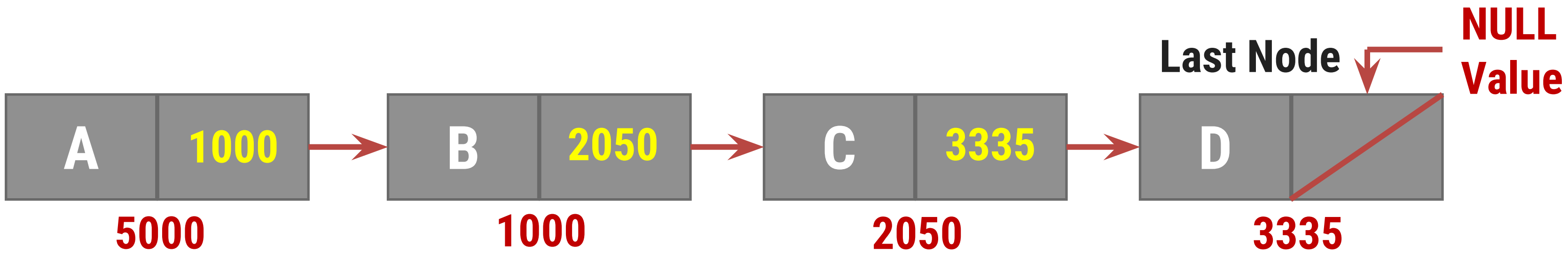
Disadvantages of Linked Lists

- Memory consumption is more in Linked Lists when compared to arrays. Because each node contains a pointer in linked list and it requires extra memory.
- Elements cannot be accessed at random in linked lists.
- Traversing from reverse is not possible in singly linked lists.

Linked Storage Representation

- There are many applications where **sequential allocation** method is **unacceptable** because of following characteristics
  - **Unpredictable storage** requirement
  - **Extensive manipulation** of stored data
- One method of obtaining the address of node is to store address in computer's main memory, we refer this addressing mode as **pointer of link addressing**.
- A simple way to represent a linear list is to expand each node to contain a link or pointer to the next node. This representation is called one-way chain or Singly Linked Linear List.

Linked Storage Representation



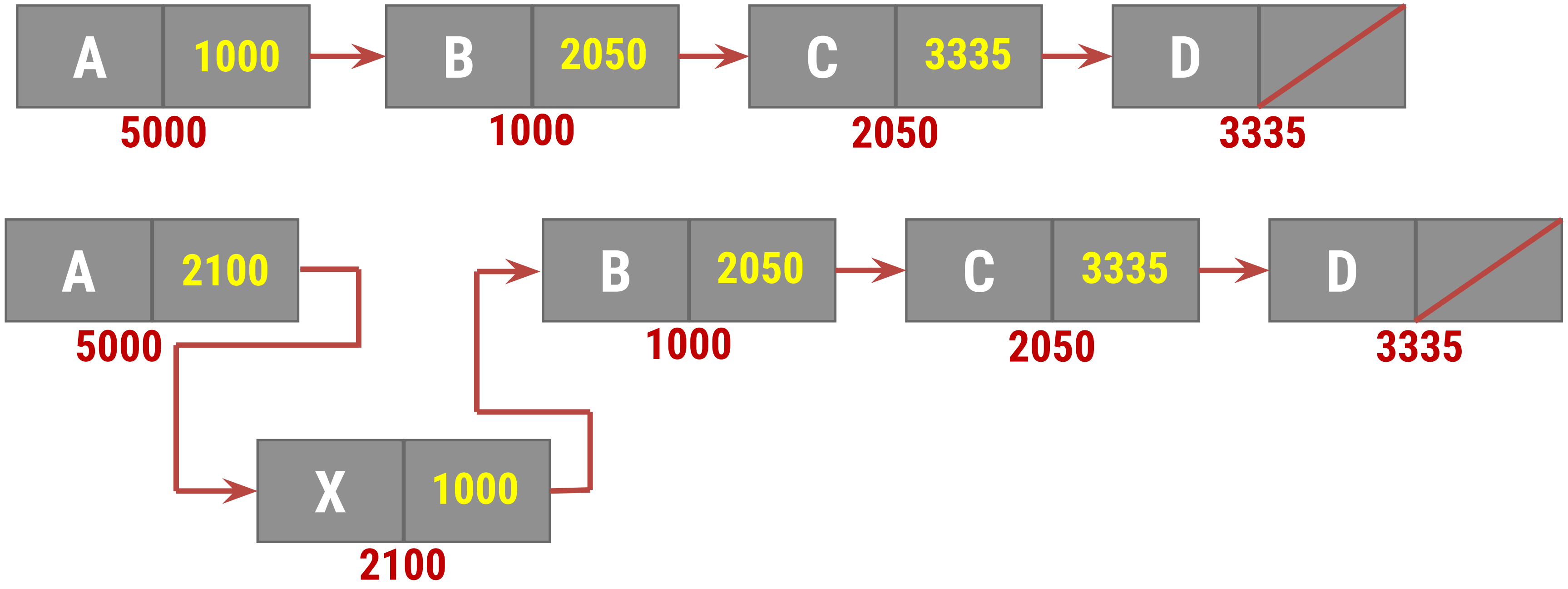
A linked List

- The linked allocation method of storage can result in both efficient use of computer storage and computer time.
    - A linked list is a **non-sequential collection** of data items.
    - Each **node** is **divided** into **two parts**, the **first part** represents the **information** of the element and the **second part** contains the **address of the next mode**.
    - The **last node** of the list does not have successor node, so **null value** is stored as the address.
    - It is possible for a list to have no nodes at all, such a list is called empty list.

Pros & Cons of Linked Allocation

Insertion Operation

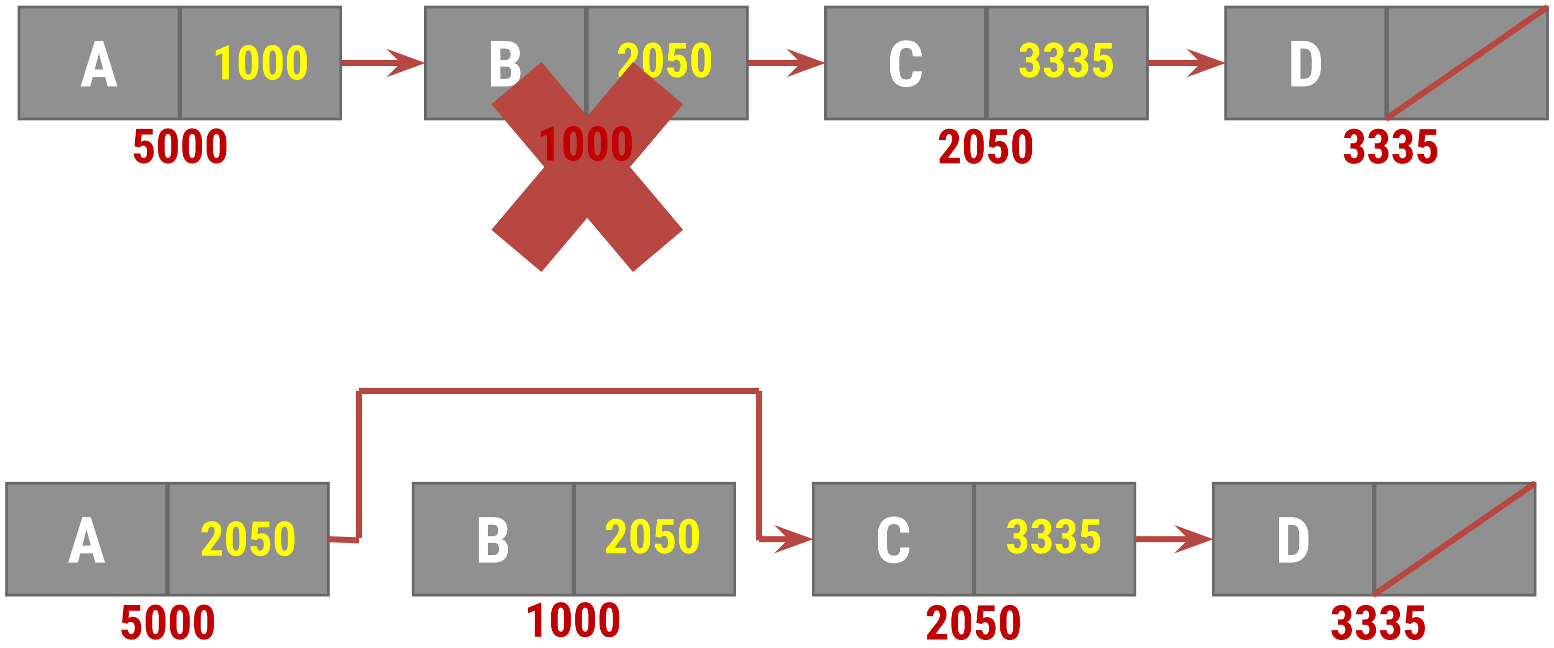
- We have an *n* elements in list and it is required to insert a new element between the first and second element, what to do with sequential allocation & linked allocation?
- Insertion operation is more efficient in Linked allocation.



Pros & Cons of Linked Allocation

Deletion Operation

- Deletion operation is more efficient in Linked Allocation



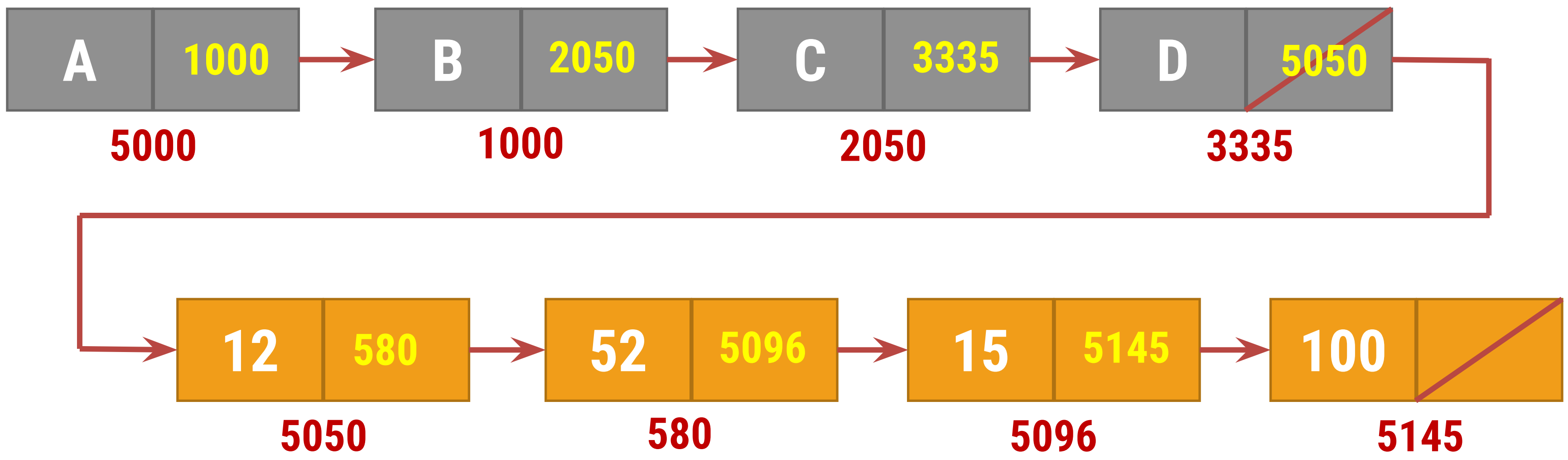
Pros & Cons of Linked Allocation

Search Operation

- **If particular node in the list is required**, it is necessary to follow links from the first node onwards until the desired node is found, in this situation **it is more time consuming** to go through linked list than a sequential list.
- Search operation is more time consuming in Linked Allocation.

Join Operation

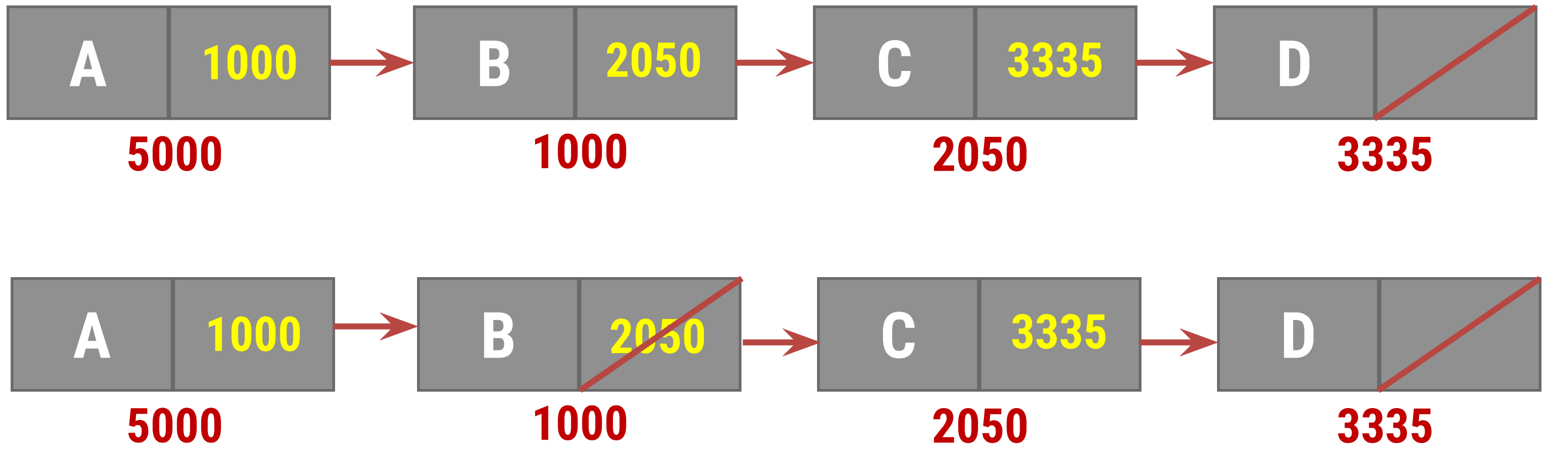
- Join operation is more efficient in Linked Allocation.



Pros & Cons of Linked Allocation

Split Operation

- Split operation is more efficient in Linked Allocation



- Linked list require **more memory** compared to array because along with value it stores pointer to next node.
- Linked lists are among the simplest and most common data structures. They can be used to implement other data structures like stacks, queues, and symbolic expressions, etc…

Operations & Type of Linked List

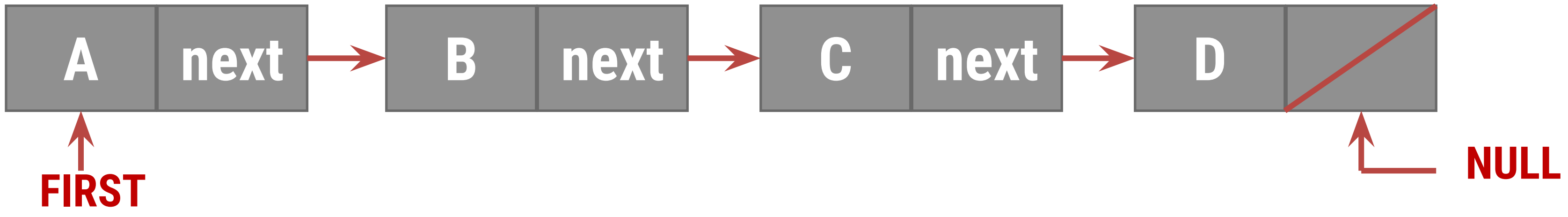
Operations on Linked List

- Insert
  - Insert at first position
  - Insert at last position
  - Insert into ordered list
- Delete
- Traverse list (Print list)
- Copy linked list

Types of Linked List

- Singly Linked List
- Circular Linked List
- Doubly Linked List

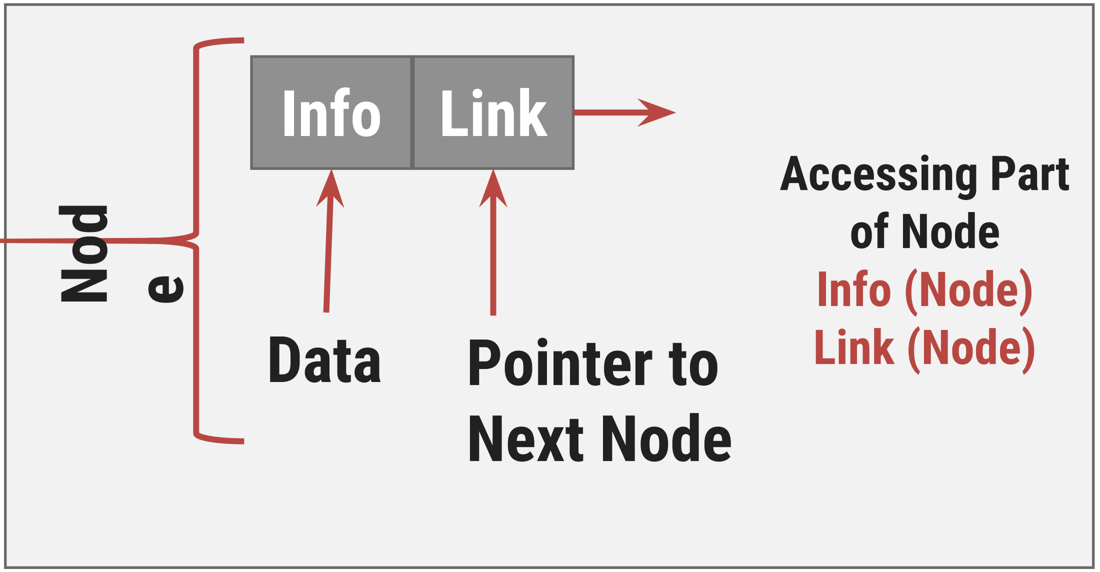
Singly Linked List



- It is basic type of linked list.
- Each node contains data and pointer to next node.
- Last node's pointer is null.
- First node address is available with pointer variable **FIRST**.
- **Limitation** of singly linked list is **we can traverse only in one direction**, forward direction.

Node Structure of Singly List

Typical Node



C Structure to represent a node

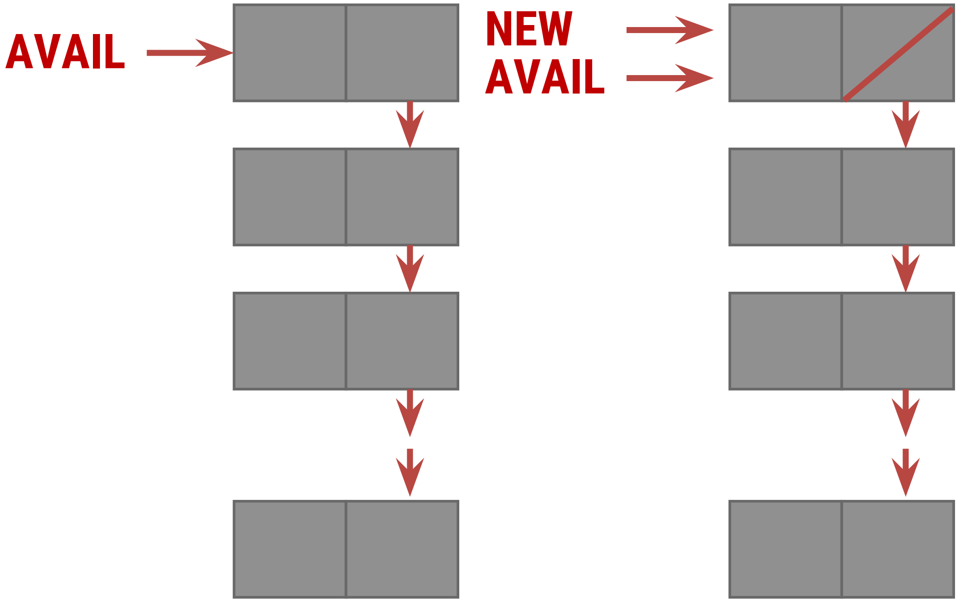
```
struct node
{
            int info;
            struct node *link;
};
```

Algorithms for singly linked list

1. Insert at first position
2. Insert at last position
3. Insert in Ordered Linked list
4. Delete Element
5. Copy Linked List

Availability Stack

- A **pool** or list **of free nodes**, which we refer to as the **availability stack** is maintained in conjunction with linked allocation.
- Whenever a node is to be inserted in a list, a free node is taken from the availability stack and linked to the new list.
- On other end, the deleted node from the list is added to the availability stack.



Check for free node in Availability Stack

IF AVAIL is NULL
THEN Write('Availability Stack Underflow')
Return

Obtain Address of next free node

NEW ← AVAIL

Remove free node from Availability Stack

AVAIL ← LINK(AVAIL)

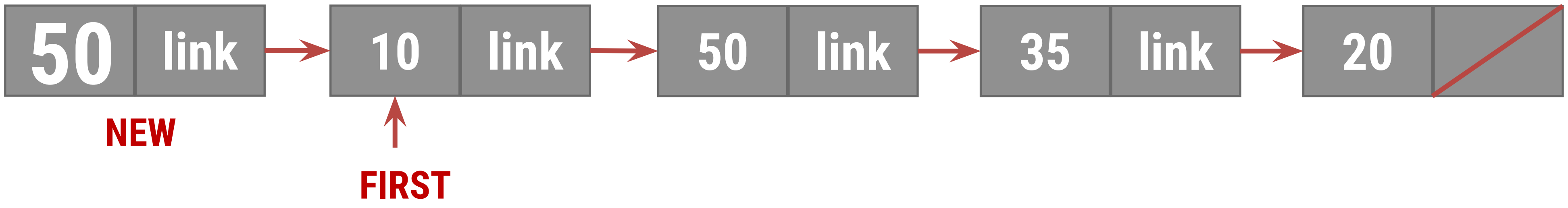
Function: INSERT(X, First)

- This function **inserts a new node at the first position** of Singly linked list.
- This function returns address of **FIRST** node.
- **X** is a new element to be inserted.
- **FIRST** is a **pointer to the first element** of a Singly linked linear list.
- Typical node contains **INFO** and **LINK** fields.
- **AVAIL** is a pointer to the top element of the availability stack.
- **NEW** is a temporary pointer variable.

Function: INSERT(X,FIRST) Cont…

```
1. [Underflow?]
     IF     AVAIL = NULL
     Then   Write (“Availability Stack Underflow”)
            Return(FIRST)
2. [Obtain address of next free Node]
     NEW ⍰ AVAIL
3. [Remove free node from availability Stack]
     AVAIL ⍰ LINK(AVAIL)
4. [Initialize fields of new node and its link to the list]
     INFO(NEW) ⍰ X
     LINK (NEW) ⍰ FIRST
5. [Return address of new node]
     Return (NEW)
```

Example: INSERT(50, FIRST)



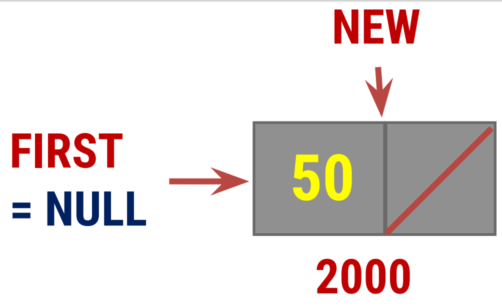
FIRST ← INSERT (X, FIRST)

```
4. [Initialize fields of new node and its link to the list]
     INFO(NEW) ← X
     LINK (NEW) ← FIRST
5. [Return address of new node]
     Return (NEW)
```

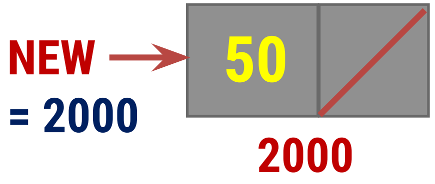
Function: INSEND(X, FIRST)

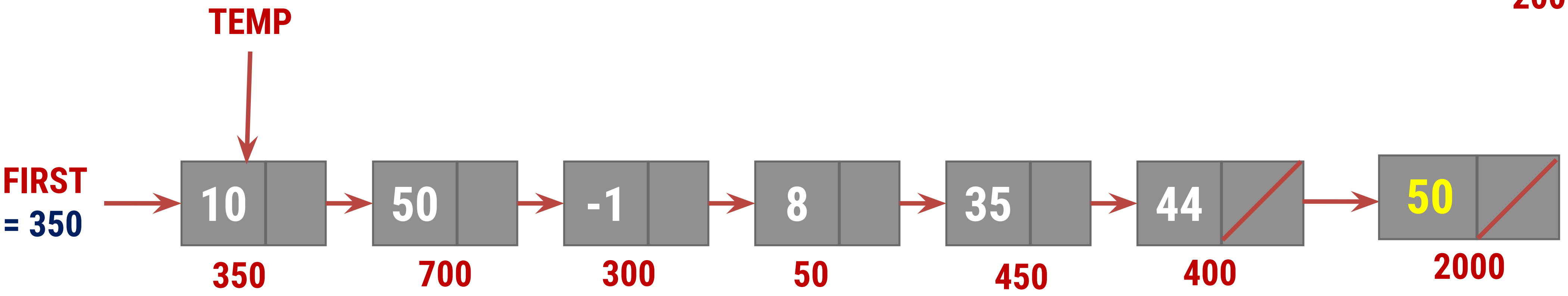
- This function **inserts** a new node at the **last position** of linked list.
- This function returns address of **FIRST** node.
- **X** is a new element to be inserted.
- **FIRST** is a **pointer to the first element** of a Singly linked linear list.
- Typical node contains **INFO** and **LINK** fields.
- **AVAIL** is a pointer to the top element of the availability stack.
- **NEW** is a temporary pointer variable.

Function: INSEND(50, FIRST)



If FIRST == NULL
then FIRST = 2000





LINK(400) = NULL

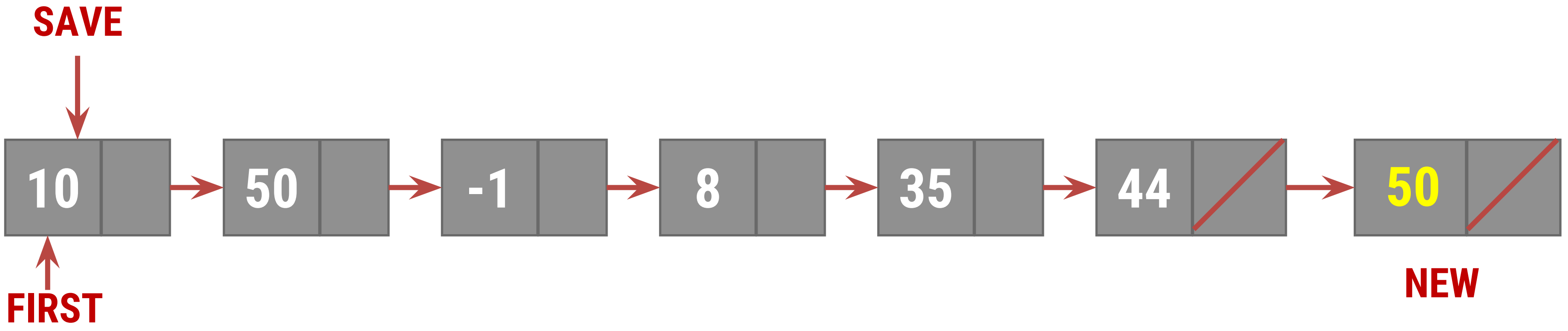
If FIRST != NULL
then TEMP = FIRST = 350
while (LINK(TEMP) != NULL)
TEMP = LINK (TEMP)
LINK(TEMP) = NEW

Function: INSEND(X, First) Cont…

```
1. [Underflow?]
    If      AVAIL = NULL
    Then    Write (“Availability
            Stack Underflow”)
            Return(FIRST)

2. [Obtain address of next free Node]
    NEW ← AVAIL

3. [Remove free node from availability
   Stack]
    AVAIL ← LINK(AVAIL)

4. [Initialize fields of new node]
    INFO(NEW) ← X
    LINK (NEW) ← NULL

5. [Is the list empty?]
    If      FIRST = NULL
    Then    Return (NEW)

6. [Initialize search for a last node]
    TEMP← FIRST

7. [Search for end of list]
    Repeat while LINK (TEMP) ≠ NULL
   TEMP ← LINK (TEMP)

8. [Set link field of last node to NEW]
    LINK (TEMP) ← NEW

9. [Return first node pointer]
    Return (FIRST)
```

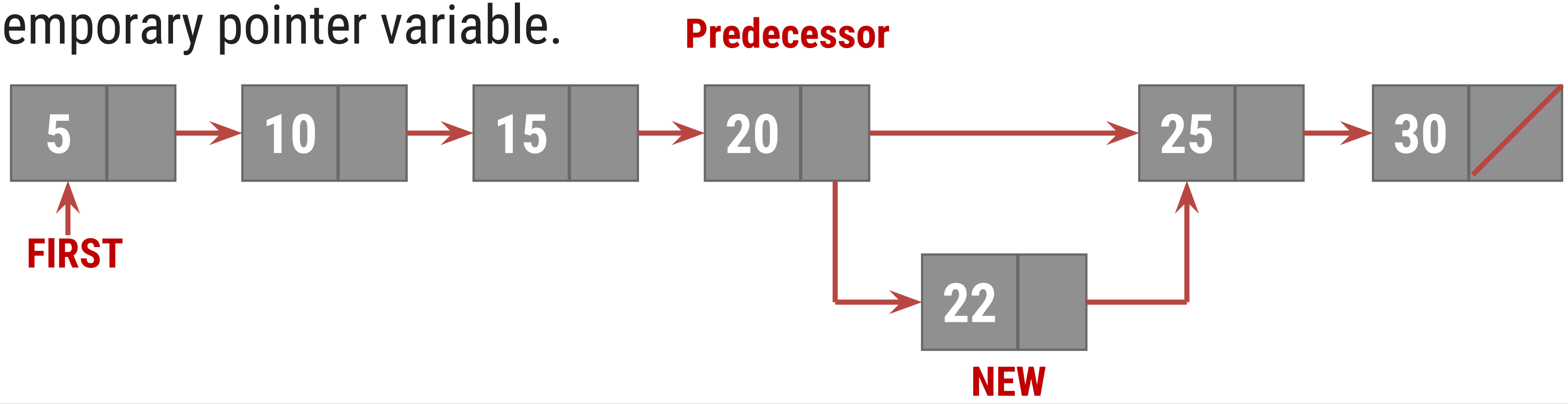
Function: INSEND(50, FIRST)

```
4. [Initialize fields of new node]
     INFO(NEW) ⍰ X
     LINK (NEW) ⍰ NULL

5. [Is the list empty?]
     If    FIRST = NULL
     Then  Return (NEW)

6. [Initialize search for a last node]
     SAVE⍰ FIRST

7. [Search for end of list]
     Repeat while LINK (SAVE) ≠ NULL
        SAVE ⍰ LINK (SAVE)

8. [Set link field of last node to NEW]
     LINK (SAVE) ⍰ NEW

9. [Return first node pointer]
     Return (FIRST)
```



Function: INSORD(X, FIRST)

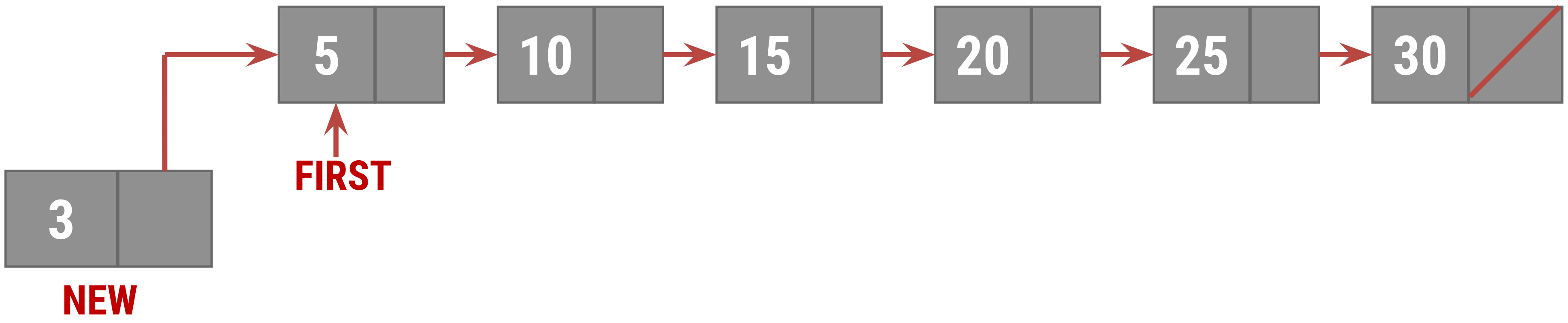
- This function **inserts** a new node such that linked list preserves the ordering of the terms in **increasing order** of their **INFO** field.
- This function returns address of **FIRST** node.
- **X** is a new element to be inserted.
- **FIRST** is a **pointer to the first element** of a Singly linked linear list.
- Typical node contains **INFO** and **LINK** fields.
- **AVAIL** is a pointer to the top element of the availability stack.
- **NEW** is a temporary pointer variable.



Function: INSORD(X, FIRST)

```
1. [Underflow?]
    IF     AVAIL = NULL
    THEN   Write (“Availability
           Stack Underflow”)
           Return(FIRST)
2. [Obtain address of next free Node]
    NEW ⍰ AVAIL
3. [Remove free node from availability
   Stack]
    AVAIL ⍰ LINK(AVAIL)
4. [Initialize fields of new node]
    INFO(NEW) ⍰ X
5. [Is the list empty?]
    IF    FIRST = NULL
    THEN   LINK(NEW) ⍰ NULL
       Return (NEW)
6. [Does the new node precede all other
   node in the list?]
    IF    INFO(NEW) ≤ INFO (FIRST)
    THEN LINK (NEW) ⍰ FIRST
     Return (NEW)
7. [Initialize temporary pointer]
   SAVE ⍰ FIRST
8. [Search for predecessor of new node]
    Repeat while LINK (SAVE) ≠ NULL
    & INFO(NEW) ≥ INFO(LINK(SAVE))
   SAVE ⍰ LINK (SAVE)
9. [Set link field of NEW node and its
   predecessor]
    LINK (NEW) ⍰ LINK (SAVE)
    LINK (SAVE) ⍰ NEW
10. [Return first node pointer]
    Return (FIRST)
```

Function: INSORD(3, FIRST)




```
6. [Does the new node precede all other node in the list?]
     IF    INFO(NEW) ≤ INFO (FIRST)
     THEN LINK (NEW) ⍰ FIRST
        Return (NEW)
```

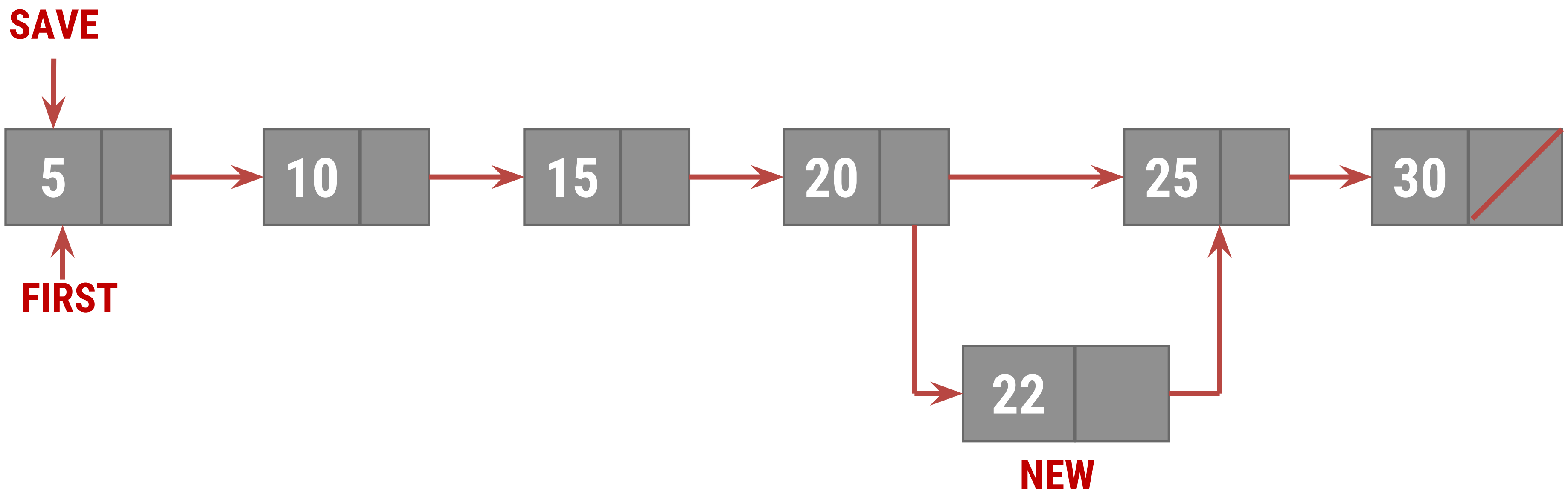
Function: INSORD(22, FIRST)

7. [Initialize temporary pointer]
SAVE ← FIRST

8. [Search for predecessor of new node]
Repeat while LINK (SAVE) ≠ NULL
& INFO(NEW) ≥ INFO(LINK(SAVE))
SAVE ← LINK (SAVE)

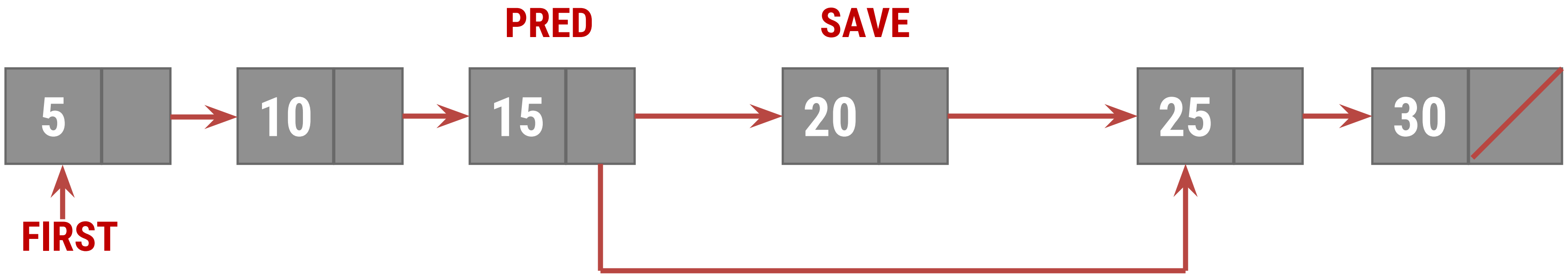
9. [Set link field of NEW node and its predecessor]
LINK (NEW) ← LINK (SAVE)
LINK (SAVE) ← NEW

10. [Return first node pointer]
Return (FIRST)



Procedure: DELETE(X, FIRST)

- This algorithm **delete** a node whose address is given by variable **X**.
- **FIRST** is a **pointer to the first element** of a Singly linked linear list.
- Typical node contains **INFO** and **LINK** fields.
- **SAVE** & **PRED** are temporary pointer variable.



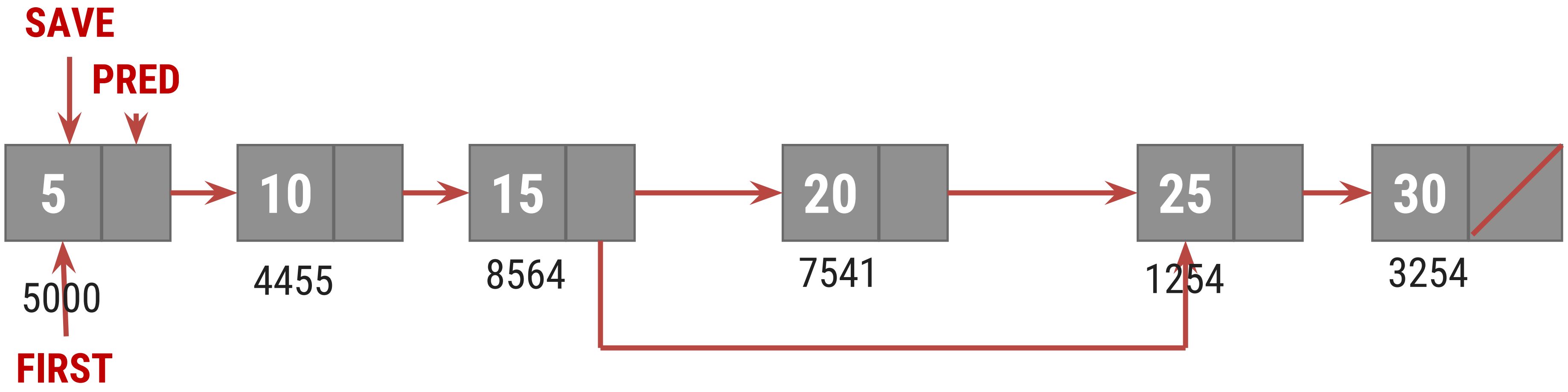
Procedure: DELETE(X, FIRST)

```
1. [Is Empty list?]
    IF   FIRST = NULL
    THEN write ('Underflow')
      Return
2. [Initialize search for X]
    SAVE ⍰ FIRST
3. [Find X]
    Repeat thru step-5
     while SAVE ≠ X and
     LINK (SAVE) ≠ NULL
4. [Update predecessor marker]
    PRED ⍰ SAVE
5. [Move to next node]
    SAVE ⍰ LINK(SAVE)
6. [End of the list?]
    If   SAVE ≠ X
    THEN write ('Node not found')
         Return
7. [Delete X]
    If   X = FIRST
    THEN FIRST ⍰ LINK(FIRST)
    ELSE LINK (PRED) ⍰ LINK (X)
8. [Free Deleted Node]
    Free (X)
```

Procedure: DELETE(7541, FIRST)

```
2. [Initialize search for X]
     SAVE ⍰ FIRST
3. [Find X]
     Repeat thru step-5
    while SAVE ≠ X and
    LINK (SAVE) ≠ NULL
4. [Update predecessor marker]
     PRED ⍰ SAVE
5. [Move to next node]
     SAVE ⍰ LINK(SAVE)
```

```
6. [End of the list?]
     If    SAVE ≠ X
     THEN Write (‘Node not found’)
          Return
7. [Delete X]
     If    X = FIRST
     THEN FIRST ⍰ LINK(FIRST)
     ELSE LINK (PRED) ⍰ LINK (X)
8. [Free Deleted Node]
     Free (X)
```



Function: COUNT_NODES(FIRST)

- This function **counts** number of nodes of the linked list and returns **COUNT**.
- **FIRST** is a **pointer to the first element** of a Singly linked linear list.
- Typical node contains **INFO** and **LINK** fields.
- **SAVE** is a Temporary pointer variable.

```
1. [Is list Empty?]
     IF     FIRST = NULL
     Then   COUNT ▯ 0
           Return(COUNT)
2. [Initialize loop for a last node
   to update count]
     SAVE▯ FIRST
```

```
3. [Go for end of list]
    Repeat while LINK (SAVE) ≠ NULL
   SAVE ▯ LINK (SAVE)
   COUNT ▯ COUNT + 1
4. [Return Count]
    Return (COUNT)
```

Function: COPY (FIRST)

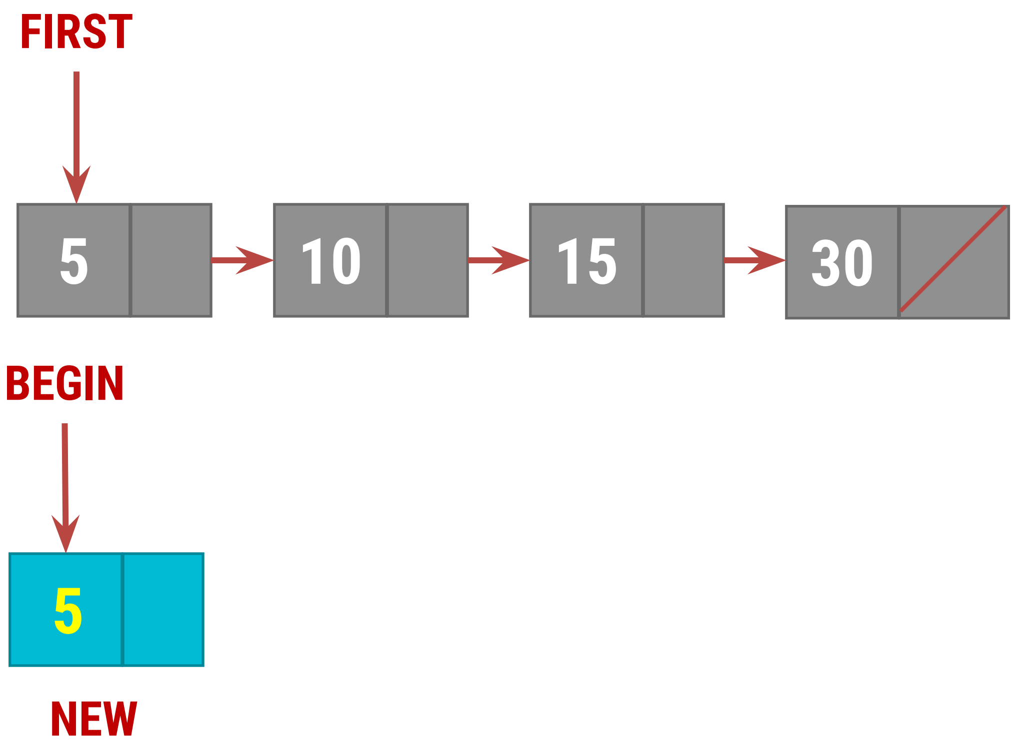
- This function **Copy** a Link List and creates new Linked List
- This function returns address of first node of newly created linked list.
- The **new list** is to contain **nodes** whose **information** and **pointer** fields are denoted by **FIELD** and **PTR**, respectively.
- The address of the **first node** in the newly created list is to be placed in **BEGIN**
- **FIRST** is a **pointer to the first element** of a Singly linked linear list.
- Typical node contains **INFO** and **LINK** fields.
- **AVAIL** is a pointer to the top element of the availability stack.
- **NEW, SAVE and PRED** are temporary pointer variables.

Function: COPY (FIRST)

```
1. [Is Empty list?]
    IF    FIRST = NULL
    THEN  Return(NULL)
2. [Copy first node]
    IF   AVAIL = NULL
    THEN write ('Underflow')
      Return (NULL)
    ELSE NEW⍰AVAIL
         AVAIL⍰LINK(AVAIL)
         FIELD(NEW)⍰INFO(FIRST)
         BEGIN ⍰NEW
3. [Initialize Traversal]
    SAVE ⍰ FIRST
4. [Move the next node if not at the end
   if list]
    Repeat thru step 6
       While LINK(SAVE) ≠ NULL
5. [Update predecessor and save pointer]
    PRED⍰NEW
    SAVE⍰LINK(SAVE)
6. [Copy Node]
    IF   AVAIL = NULL
    THEN write ('Underflow')
         Return (NULL)
    ELSE NEW ⍰ AVAIL
         AVAIL ⍰ LINK(AVAIL)
         FIELD(NEW)⍰INFO(SAVE)
         PTR(PRED)⍰NEW
7. [Set link of last node and return]
    PTR(NEW) ⍰ NULL
    Return(BEGIN)
```

Function: COPY (FIRST)

```
1. [Is Empty list?]
   IF     FIRST = NULL
   THEN   Return(NULL)
```

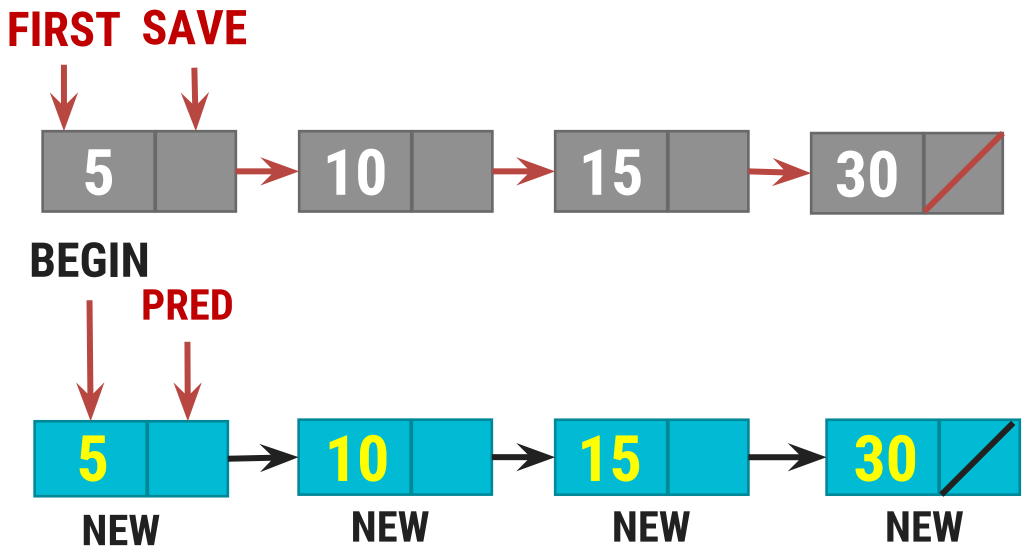



```
2. [Copy first node]
     IF   AVAIL = NULL
     THEN write ('Underflow')
          Return (0)
     ELSE NEW←AVAIL
          AVAIL←LINK(AVAIL)
          FIELD(NEW)←INFO(FIRST)
          BEGIN ←NEW
```

Function: COPY (FIRST)

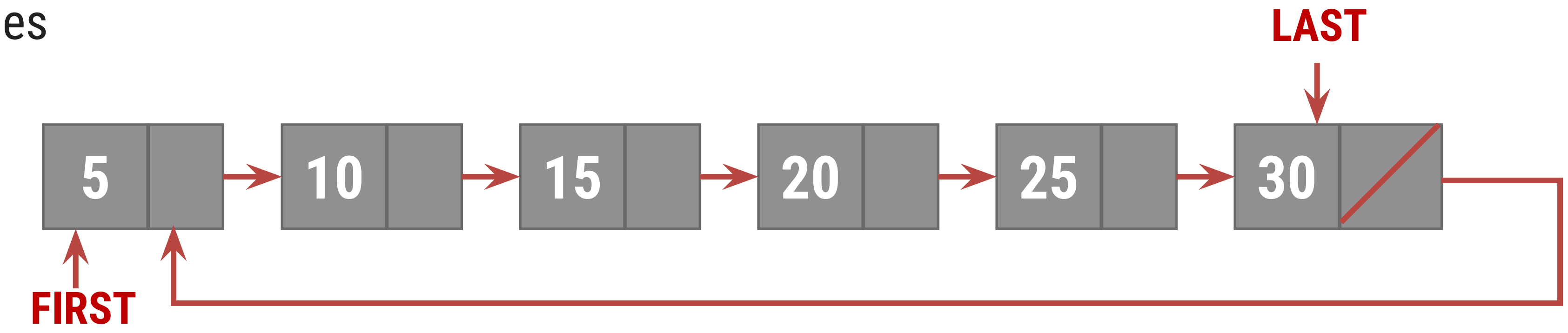
```
3. [Initialize Traversal]
     SAVE ⍰ FIRST
4. [Move the next node if not at the end
if list]
     Repeat thru step 6
        while LINK(SAVE) ≠ NULL
5. [Update predecessor and save pointer]
     PRED⍰NEW
     SAVE⍰LINK(SAVE)
```

```
6. [Copy Node]
     IF    AVAIL = NULL
     THEN  write (‘Underflow’)
           Return (0)
     ELSE  NEW ⍰ AVAIL
           AVAIL ⍰ LINK(AVAIL)
           FIELD(NEW)⍰INFO(SAVE)
           PTR(PRED)⍰NEW
7. [Set link of last node & return]
     PTR(NEW) ⍰ NULL
     Return(BEGIN)
```



Circularly Linked Linear List

- If we **replace NULL** pointer of the **last node** of Singly Linked Linear List with the **address of its first node**, that list becomes circularly linked linear list or **Circular List**.
- **FIRST** is the address of first node of Circular List
- **LAST** is the address of the last node of Circular List
- **Advantages of Circular List**
  - In circular list, every node is accessible from given node
  - It saves time when we have to go to the first node from the last node. It can be done in single step because there is no need to traverse the in between nodes. But in double linked list, we will have to go through in between nodes



Circularly Linked Linear List Cont…

Disadvantages of Circular List

- It is not easy to reverse the linked list.
- If proper care is not taken, then the problem of infinite loop can occur.
- If we at a node and go back to the previous node, then we can not do it in single step. Instead we have to complete the entire circle by going through the in between nodes and then we will reach the required node.

Operations on Circular List

- Insert at First
- Insert at Last
- Insert in Ordered List
- Delete a node

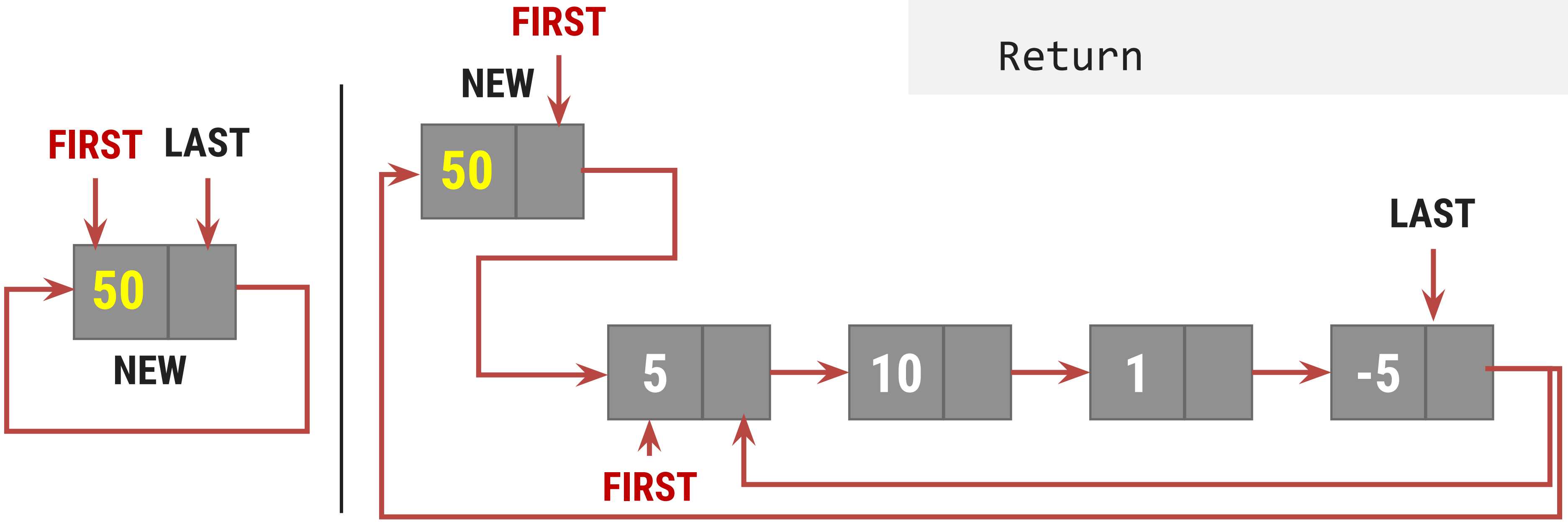
Procedure: CIR_INS_FIRST(X,FIRST,LAST)

- This procedure **inserts a new node at the first position** of Circular linked list.
- **X** is a new element to be inserted.
- **FIRST** and **LAST** are a **pointer to the first & last elements** of a Circular linked linear list, respectively.
- Typical node contains **INFO** and **LINK** fields.
- **NEW** is a temporary pointer variable.

Procedure: CIR_INS_FIRST(X,FIRST,LAST)

```
1. [Creates a new empty node]
     NEW ⇐ NODE
2. [Initialize fields of new node and
its link]
     INFO (NEW) ← X
```

```
IF    FIRST = NULL
THEN  LINK (NEW) ← NEW
      FIRST ← LAST ← NEW
ELSE  LINK (NEW) ← FIRST
      LINK (LAST) ← NEW
      FIRST ← NEW

Return
```



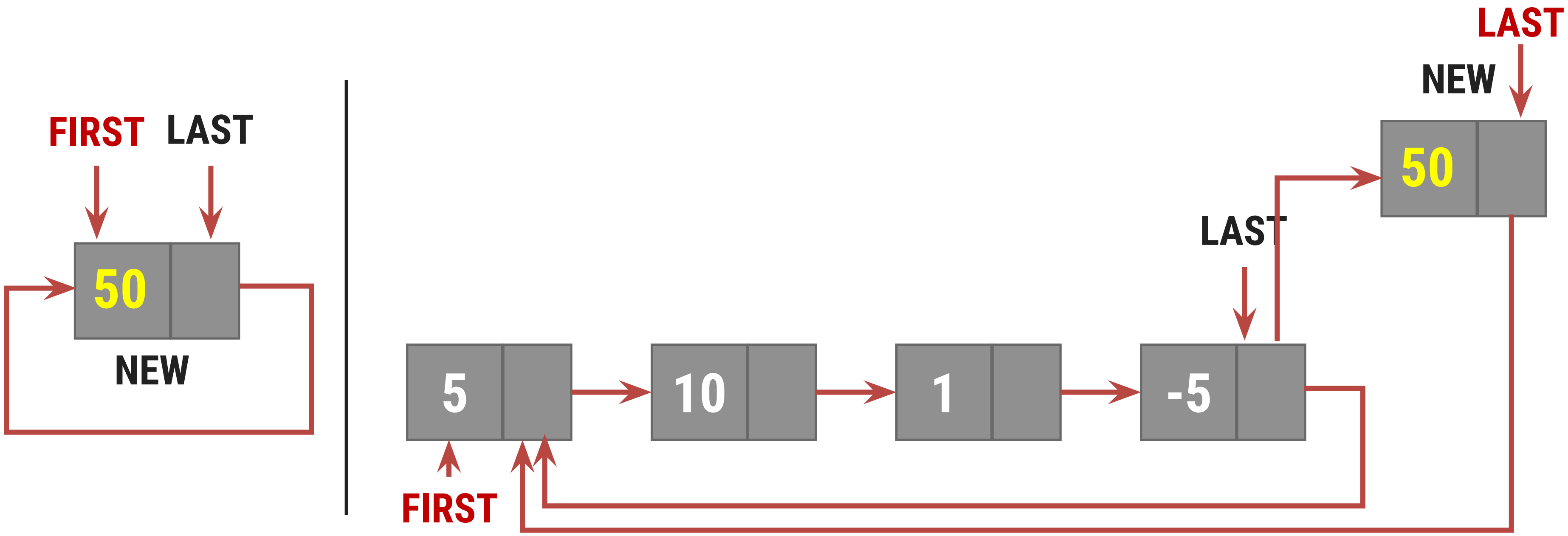
Procedure: CIR_INS_LAST(X,FIRST,LAST)

- This procedure **inserts a new node at the last position** of Circular linked list.
- **X** is a new element to be inserted.
- **FIRST** and **LAST** are a **pointer to the first & last elements** of a Circular linked linear list, respectively.
- Typical node contains **INFO** and **LINK** fields.
- **NEW** is a temporary pointer variable.

Procedure: CIR_INS_LAST(X,FIRST,LAST)

```
1. [Creates a new empty node]
   NEW ⇐ NODE
2. [Initialize fields of new node
and its link]
   INFO (NEW) ⍰ X
```

```
IF   FIRST = NULL
THEN LINK (NEW) ⍰ NEW
     FIRST ⍰ LAST ⍰ NEW
ELSE LINK (NEW) ⍰ FIRST
     LINK (LAST) ⍰ NEW
     LAST ⍰ NEW
Return
```



Procedure: CIR_INS_ORD(X,FIRST,LAST)

- This function **inserts** a new node such that linked list preserves the ordering of the terms in **increasing order** of their **INFO** field.
- **X** is a new element to be inserted.
- **FIRST** and **LAST** are a **pointer to the first & last elements** of a Circular linked linear list, respectively.
- Typical node contains **INFO** and **LINK** fields.
- **NEW** is a temporary pointer variable.

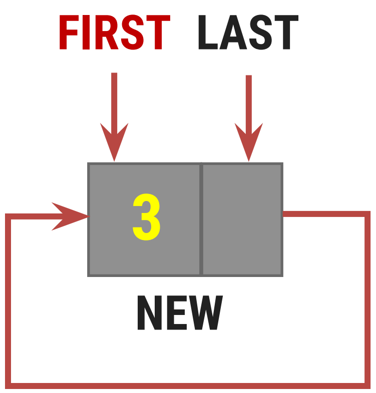
Procedure: CIR_INS_ORD(X,FIRST,LAST)

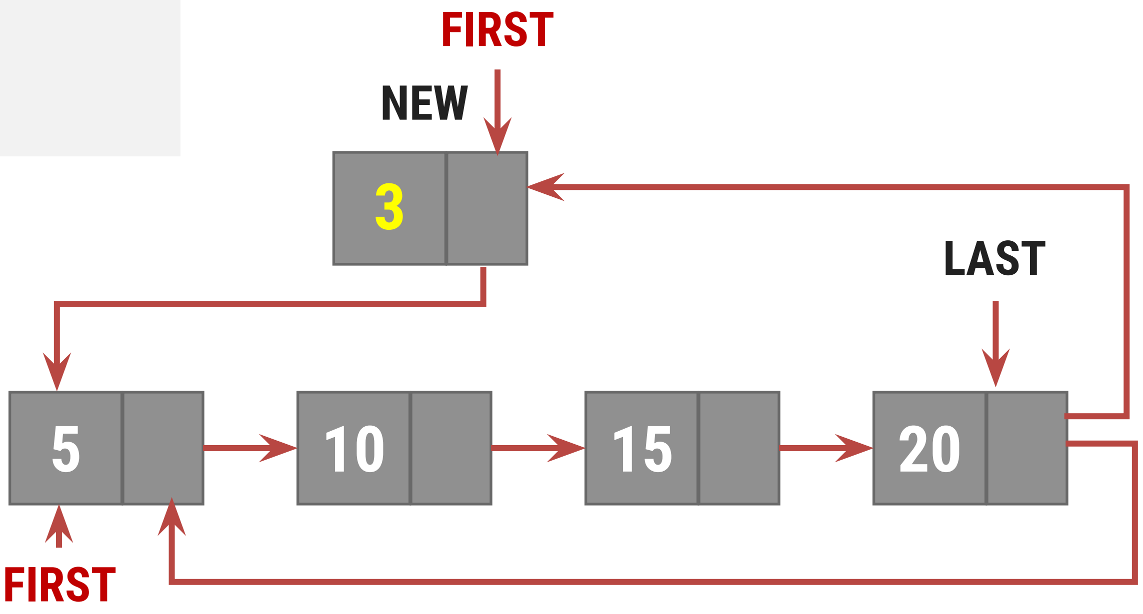
```
1. [Create New Empty Node]
   NEW ⇐ NODE
2. [Copy information content into new
   node]
   INFO(NEW) ← X
3. [Is Linked List Empty?]
   IF   FIRST = NULL
   THEN LINK(NEW) ← NEW
        FIRST ← LAST ← NEW
        Return
4. [Does new node precedes all other
   nodes in List?]
    IF     INFO(NEW)≤ INFO(FIRST)
    THEN   LINK(NEW) ← FIRST
           LINK(LAST) ← NEW
           FIRST ← NEW
           Return
5. [Initialize Temporary Pointer]
    SAVE ← FIRST
6. [Search for Predecessor of new node]
    Repeat while SAVE ≠ LAST &
      INFO(NEW) ≥ INFO(LINK(SAVE))
      SAVE←LINK(SAVE)
7. [Set link field of NEW node and its
   Predecessor]
    LINK(NEW) ← LINK(SAVE)
    LINK(SAVE) ← NEW
    IF   SAVE = LAST
    THEN LAST ← NEW
8. [Finished]
   Return
```

Procedure: CIR_INS_ORD(3,FIRST,LAST)

```
1. [Create New Empty Node]
    NEW ⇐ NODE
2. [Copy information content into new
   node]
    INFO(NEW) ← X
3. [Is Linked List Empty?]
    IF   FIRST = NULL
    THEN LINK(NEW) ← NEW
         FIRST ← LAST ← NEW
         Return
```

```
4. [Does new node precedes all other
nodes in List?]
     IF    INFO(NEW)≤ INFO(FIRST)
     THEN  LINK(NEW) ← FIRST
           LINK(LAST) ← NEW
           FIRST ← NEW
           Return
```





Procedure: CIR_INS_ORD(18,FIRST,LAST)

5. [Initialize Temporary Pointer]

```
SAVE ← FIRST
```

6. [Search for Predecessor of new node]

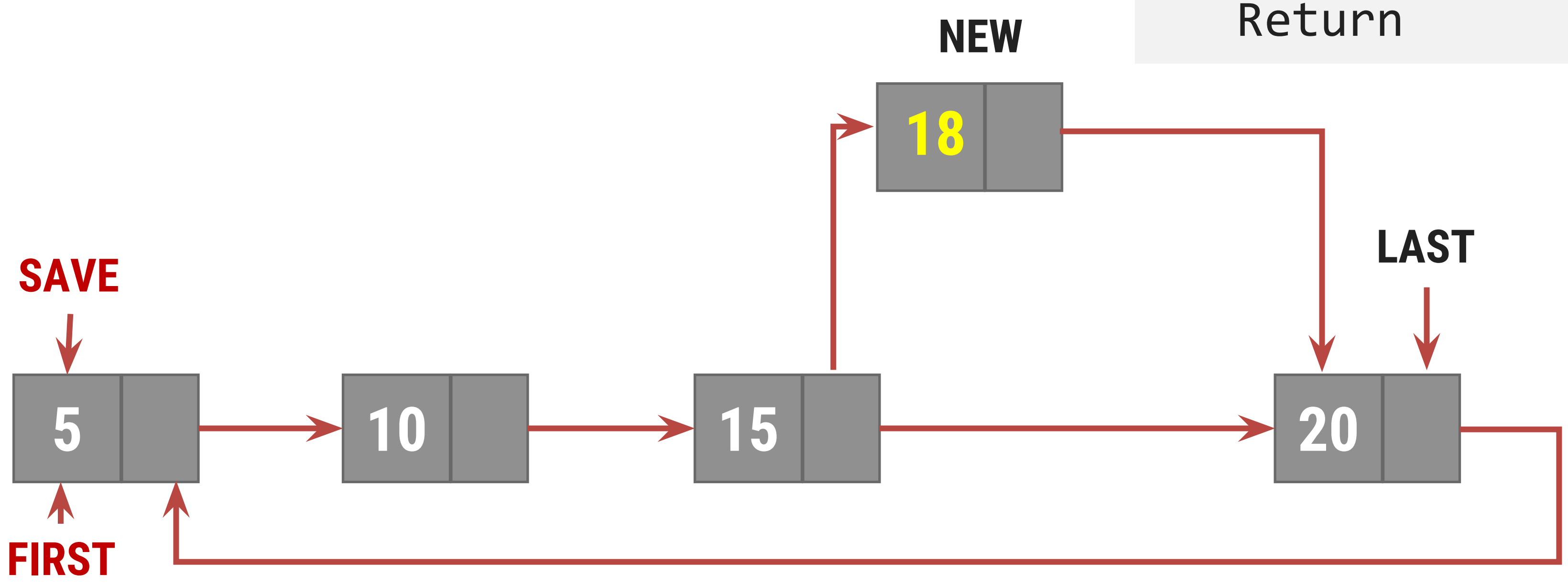
```
Repeat while SAVE ≠ LAST &
    INFO(NEW) ≥ INFO(LINK(SAVE))
   SAVE←LINK(SAVE)
```

7. [Set link field of NEW node and its Predecessor]

```
LINK(NEW) ← LINK(SAVE)
LINK(SAVE) ← NEW
IF    SAVE = LAST
THEN LAST ← NEW
```

8. [Finished]

```
Return
```



Procedure: CIR_DELETE(X,FIRST,LAST)

- This algorithm **delete** a node whose address is given by variable **X**.
- **FIRST** & **LAST** are **pointers to the First & Last elements** of a Circular linked list, respectively.
- Typical node contains **INFO** and **LINK** fields.
- **SAVE** & **PRED** are temporary pointer variable.

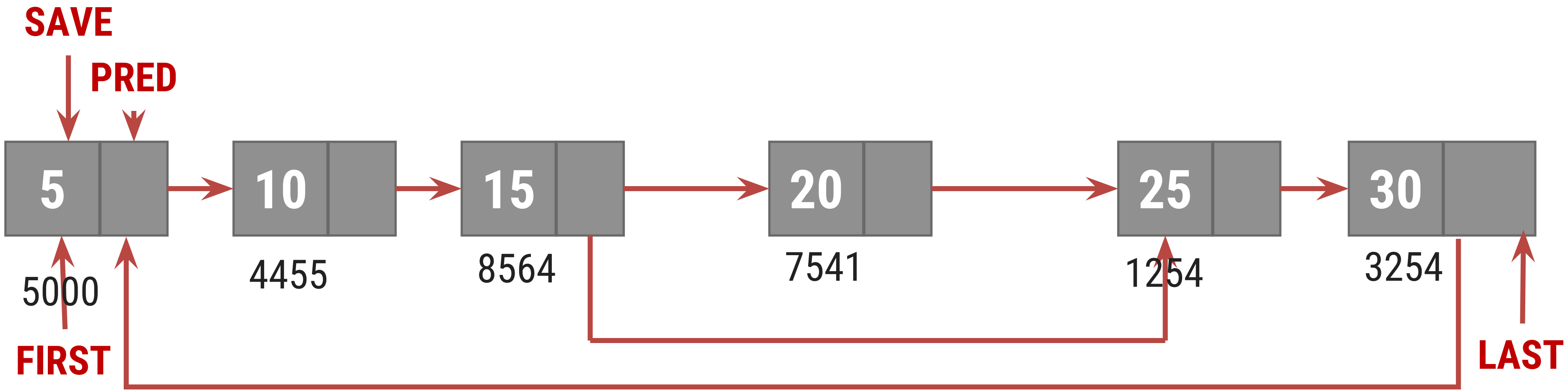
Procedure: CIR_DELETE(X,FIRST,LAST)

```
1. [Is Empty List?]
    IF   FIRST = NULL
    THEN write('Linked List is
             Empty')
             Return
2. [Initialize Search for X]
    SAVE ⍰ FIRST
3. [Find X]
    Repeat thru step 5
        while SAVE≠X & SAVE≠LAST
4. [Update predecessor marker]
    PRED ⍰ SAVE
5. [Move to next node]
    SAVE ⍰ LINK(SAVE)
6. [End of Linked List?]
    IF   SAVE ≠ X
    THEN    write('Node not found')
            Return
7. [Delete X]
    IF   X = FIRST
    THEN FIRST⍰LINK(FIRST)
      LINK(LAST)⍰FIRST
    ELSE LINK(PRED)⍰LINK(X)
      IF   X = LAST
      THEN LAST ⍰ PRED
8. [Free Deleted Node]
    Free (X)
```

Procedure: CIR_DELETE(7541,FIRST,LAST)

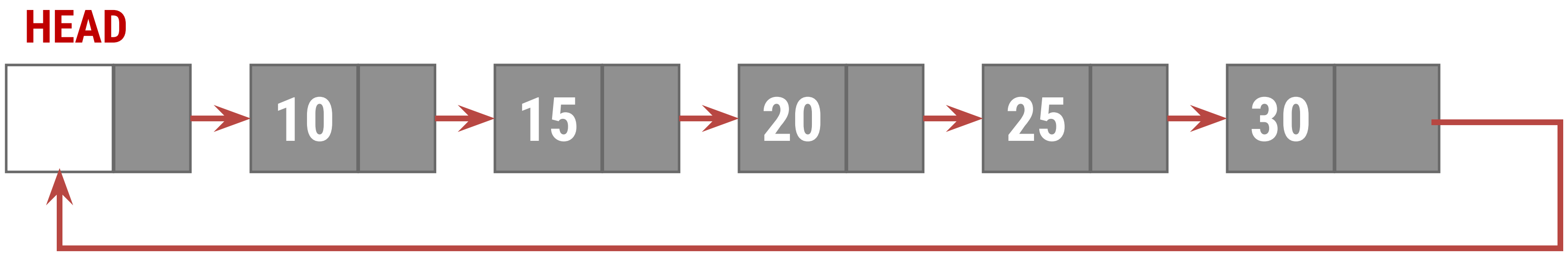
```
1. [Is Empty List?]
    IF   FIRST = NULL
    THEN write('Linked List is Empty')
    Return
2. [Initialize Search for X]
    SAVE ⍰ FIRST
3. [Find X]
    Repeat thru step5 while SAVE≠X & SAVE≠LAST
4. [Update predecessor marker]
    PRED ⍰ SAVE
5. [Move to next node]
    SAVE ⍰ LINK(SAVE)
```

```
6. [End of Linked List?]
    IF   SAVE ≠ X
    THEN write('Node not found')
     Return
7. [Delete X]
    IF   X = FIRST
    THEN FIRST⍰LINK(FIRST)
     LINK(LAST)⍰FIRST
    ELSE LINK(PRED)⍰LINK(X)
     IF X = LAST
     THEN   LAST ⍰ PRED
8. [Free Deleted Node]
    Free (X)
```



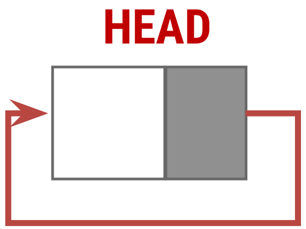
Circularly Linked List with Header Node

- We can have special node, often referred to as **Head node** of Circular Linked List.
- Head node does not have any value.
- Head node is always pointing to the first node if any of the linked list.
- One advantage of this technique is Linked list is never be empty.
- Pointer variable **HEAD** contains the address of head node.



Empty List

LINK(HEAD) ← HEAD

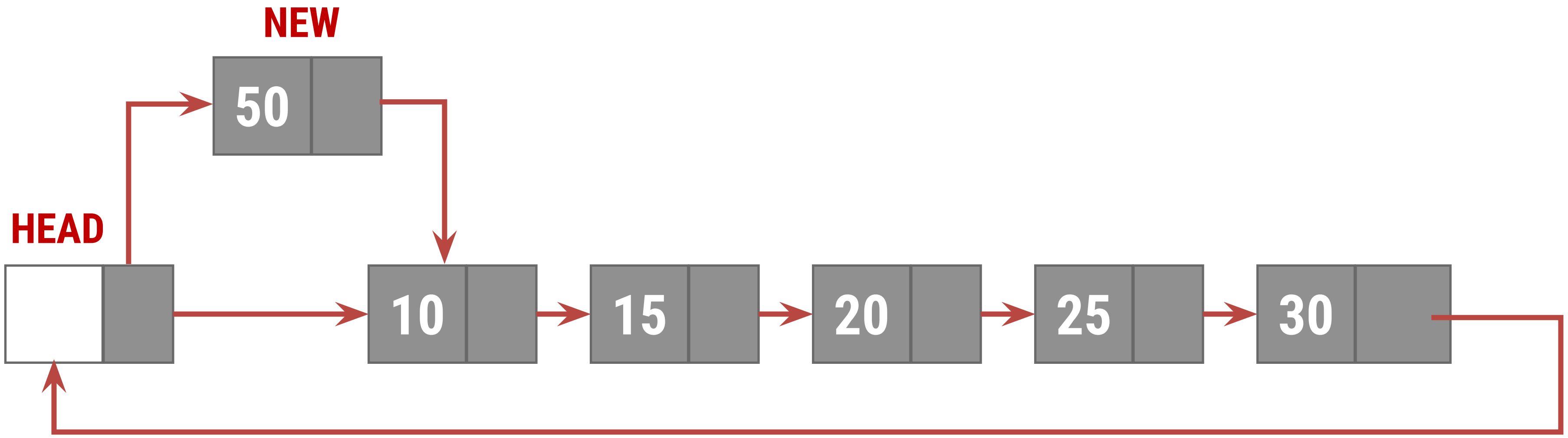


Procedure: CIR_HEAD_INS_FIRST(X,FIRST,LAST)

- This procedure **inserts a new node at the first position** of Circular linked list with Head node.
- **X** is a new element to be inserted.
- **FIRST** and **LAST** are a **pointer to the first & last elements** of a Circular linked linear list, respectively.
- Typical node contains **INFO** and **LINK** fields.
- **HEAD** is pointer variable pointing to Head node of Linked List.
- **NEW** is a temporary pointer variable.

Procedure: CIR_HEAD_INS_FIRST(X,FIRST,LAST)

```
1. [Create New Empty Node]
   NEW ⇐ NODE
2. [Initialize fields of new node and its link to the list]
   INFO(NEW) ⍰ X
   LINK(NEW) ⍰ LINK(HEAD)
   LINK(HEAD) ⍰ NEW
```

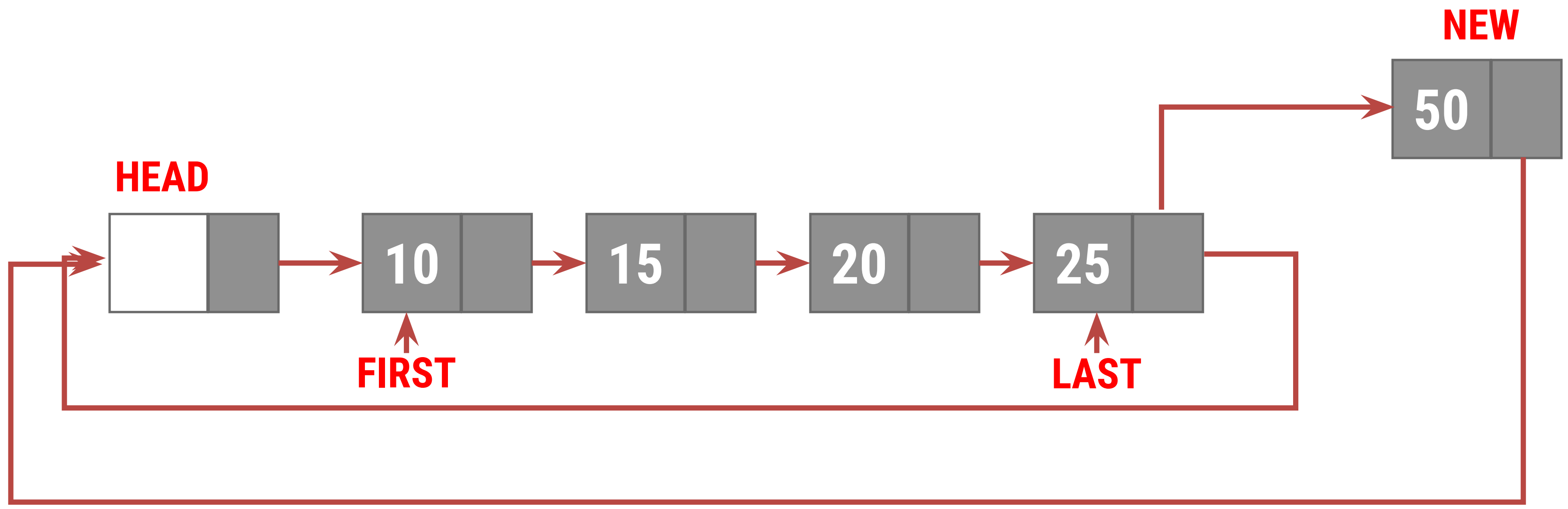


Procedure: CIR_HEAD_INS_LAST(X,FIRST,LAST)

- This procedure **inserts a new node at the last position** of Circular linked list with Head node.
- **X** is a new element to be inserted.
- **FIRST** and **LAST** are a **pointer to the first & last elements** of a Circular linked linear list, respectively.
- Typical node contains **INFO** and **LINK** fields.
- **HEAD** is pointer variable pointing to Head node of Linked List.
- **NEW** is a temporary pointer variable.

Procedure: CIR_HEAD_INS_LAST(X,FIRST,LAST)

```
1. [Create New Empty Node]
   NEW ⇐ NODE
2. [Initialize fields of new node and its link to the list]
   INFO(NEW) ⍰ X
   LINK(NEW) ⍰ HEAD
   LINK(LAST) ⍰ NEW
   LAST ⍰ NEW
```

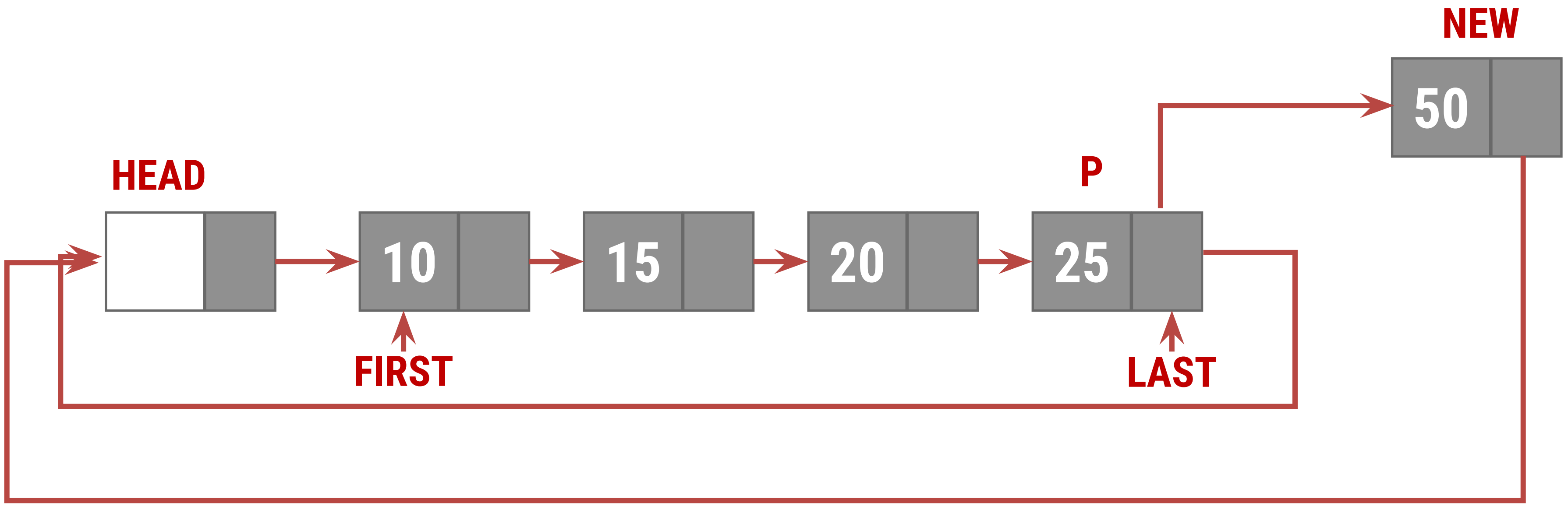


Procedure: CIR_HEAD_INS_AFTER-P (X,FIRST,LAST)

- This procedure **inserts a new node after a node whose address is given by P** of Circular linked list with Head node.
- **X** is a new element to be inserted.
- **FIRST** and **LAST** are a **pointer to the first & last elements** of a Circular linked linear list, respectively.
- Typical node contains **INFO** and **LINK** fields.
- **HEAD** is pointer variable pointing to Head node of Linked List.
- **NEW** is a temporary pointer variable.

Procedure: CIR_HEAD_INS_AFTER-P (X,FIRST,LAST)

```
1. [Create New Empty Node]
     NEW ⇐ NODE
2. [Initialize fields of new node and its link to the list]
     INFO(NEW) ⍰ X
     LINK(NEW) ⍰ LINK(P)
     LINK(P) ⍰ NEW
     IF   P = LAST
     THEN LAST ⍰ NEW
```



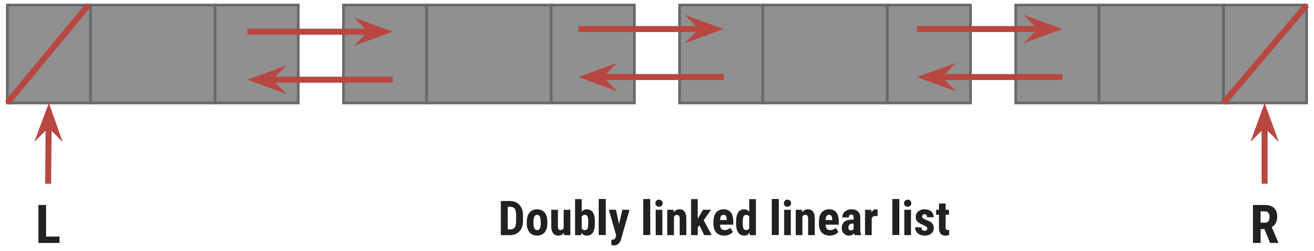
Doubly Linked Linear List

- In certain Applications, it is very desirable that a list be traversed in either forward or reverse direction.
- This property implies that each node must contain two link fields instead of usual one.
- The links are used to denote **Predecessor** and **Successor** of node.
- The link denoting its **predecessor** is called **Left Link.**
- The link denoting its **successor** is called **Right Link.**
- A list containing this type of node is called **doubly linked list** or **two way chain**.

Doubly Linked Linear List

- Typical node of doubly linked linear list contains INFO, LPTR RPTR Fields
- **LPTR** is pointer variable pointing to Predecessor of a node
- **RPTR** is pointer variable pointing to Successor of a node
- Left most node of doubly linked linear list is called **L**, **LPTR** of node **L is always NULL**
- Right most node of doubly linked linear list is called **R**, **RPTR** of node **R is always NULL**

Typical node of Doubly Linked List

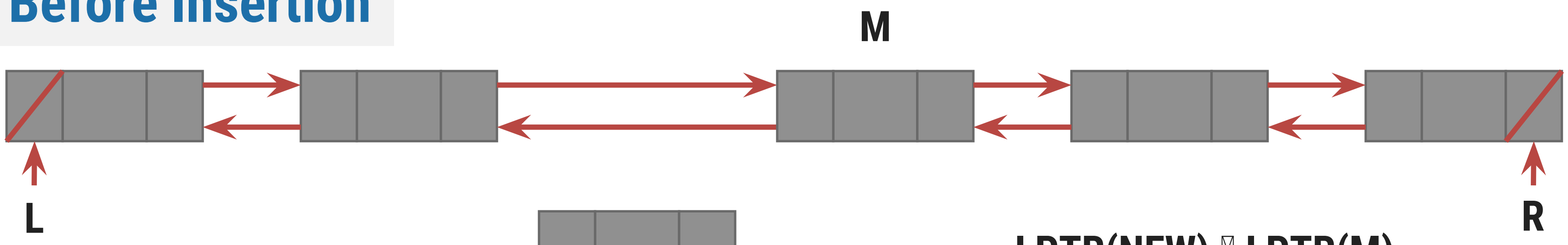


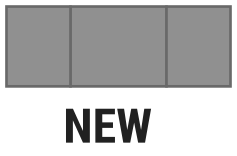
Doubly linked linear list

Insert node in Doubly Linked List

Insertion in the middle of Doubly Linked Linear List

Before Insertion





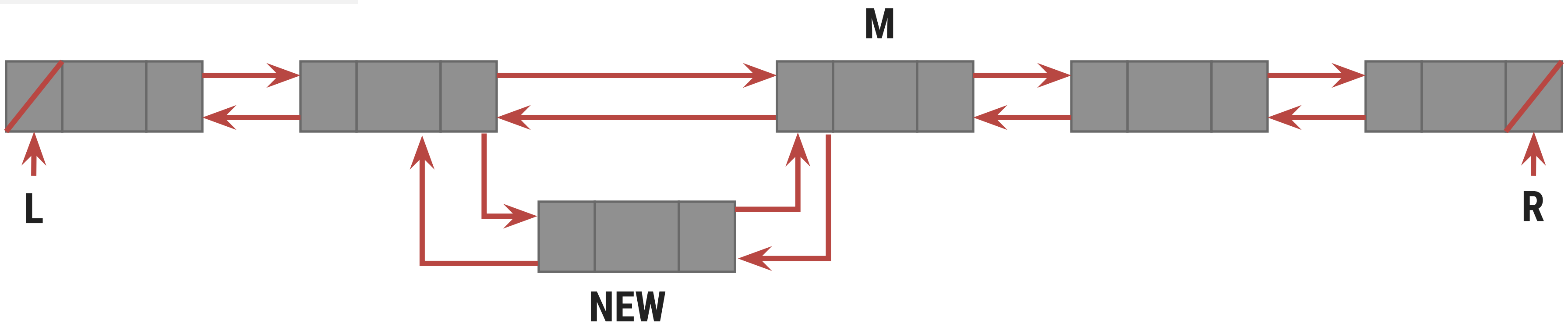
LPTR(NEW) ← LPTR(M)

RPTR(NEW) ← M

LPTR(M) ← NEW

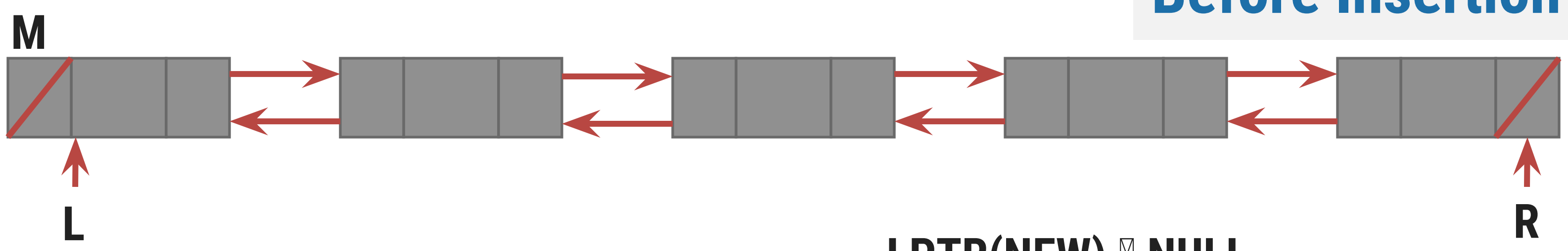
RPTR(LPTR(NEW)) ← NEW

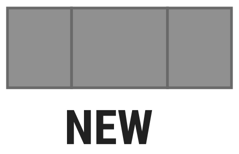
After Insertion



Left most insertion in Doubly Linked Linear List

Before Insertion





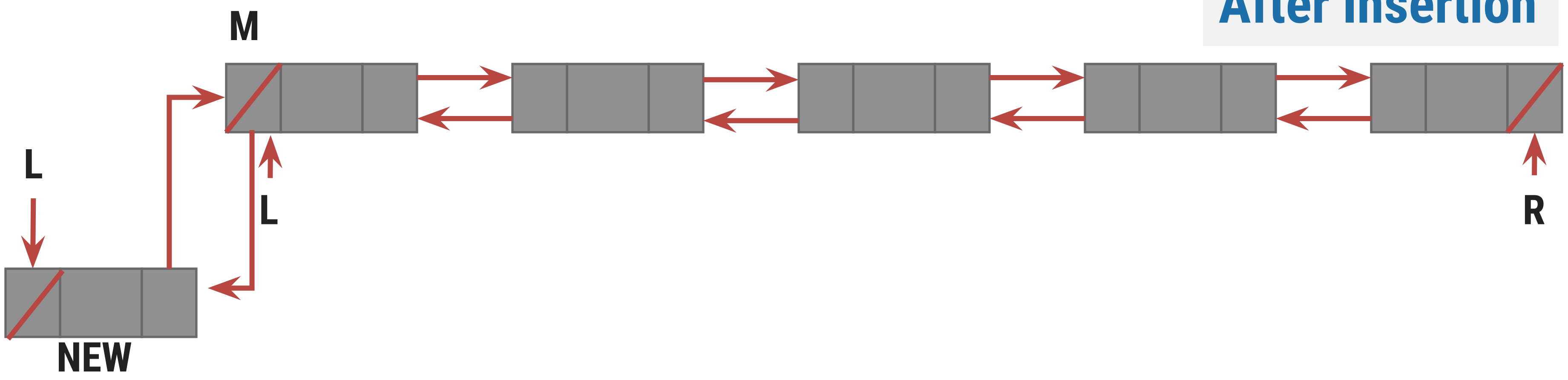
LPTR(NEW) ← NULL

RPTR(NEW) ← M

LPTR(M) ← NEW

L ← NEW

After Insertion



Procedure: DOU_INS (L,R,M,X)

- This algorithm inserts a new node in doubly linked linear list.
- The **insertion** is to be **performed** to the **left of a specific node with** its **address** given by the pointer variable **M.**
- Typical node of doubly linked list contains following fields **LPTR**, **RPTR** and **INFO.**
- **LPTR** is pointer variable pointing to Predecessor of a node.
- **RPTR** is pointer variable pointing to Successor of a node.
- **L** & **R** are pointer variables pointing for Leftmost and Rightmost node of Linked List.
- **NEW** is the address of New Node.
- **X** is value to be inserted.

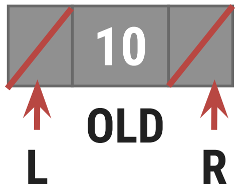
Procedure: DOU_INS (L,R,M,X)

```
1. [Create New Empty Node]
     NEW ← NODE
2. [Copy information field]
     INFO(NEW) ← X
3. [Insert into an empty list]
     IF    R = NULL
     THEN LPTR(NEW) ← NULL
          RPTR(NEW) ← NULL
          L ← R ← NEW
          Return
4. [Is left most insertion ?]
     IF  M = L
     THEN LPTR(NEW) ← NULL
          RPTR(NEW) ← M
          LPTR(M)← NEW
          L ← NEW
          Return
5. [Insert in middle]
     LPTR(NEW) ← LPTR(M)
     RPTR(NEW) ← M
     LPTR(M) ← NEW
     RPTR(LPTR(NEW)) ← NEW
     Return
```

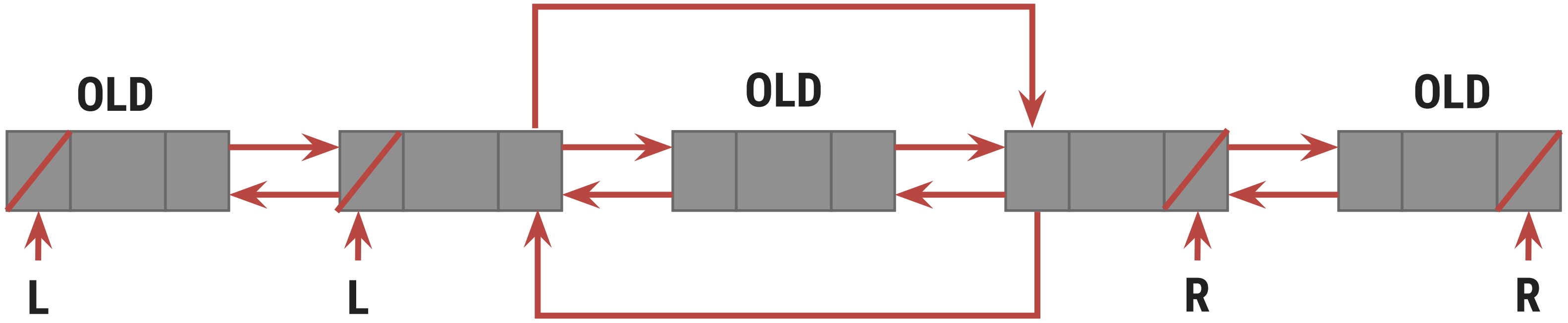
PROCEDURE: DOU _DEL (L, R, OLD)

- This algorithm **deletes the node** whose **address** is contained in the variable **OLD.**
- Typical node of doubly linked list contains following fields **LPTR**, **RPTR** and **INFO.**
- **LPTR** is pointer variable pointing to Predecessor of a node.
- **RPTR** is pointer variable pointing to Successor of a node.
- **L** & **R** are pointer variables pointing for Leftmost and Rightmost node of Linked List.

Delete from Doubly Linked List



L ← R ← NULL



L ← RPTR(L)
LPTR (L) ← NULL

RPTR(LTRP(OLD)) ← RPTR(OLD)
LPTR(RTRP(OLD)) ← LPTR(OLD)

R ← LPTR(R)
RPTR (R) ← NULL

PROCEDURE: DOU _DEL (L, R, OLD)

```
1. [Is underflow ?]
     IF    R=NULL
     THEN write (‘UNDERFLOW’)
           Return
2. [Delete node]
    IF L = R (single node in list)
    THEN L ⍰ R ⍰ NULL
    ELSE IF OLD = L (left most node)
           THEN   L ⍰ RPTR(L)
                  LPTR (L) ⍰ NULL
           ELSE IF OLD = R (right most)
                THEN   R ⍰ LPTR (R)
                       RPTR (R) ⍰ NULL
                ELSE   RPTR(LPTR (OLD)) ⍰ RPTR (OLD)
                       LPTR(RPTR (OLD)) ⍰ LPTR (OLD)
3. [FREE deleted node ?]
     FREE(OLD)
```

Thank You