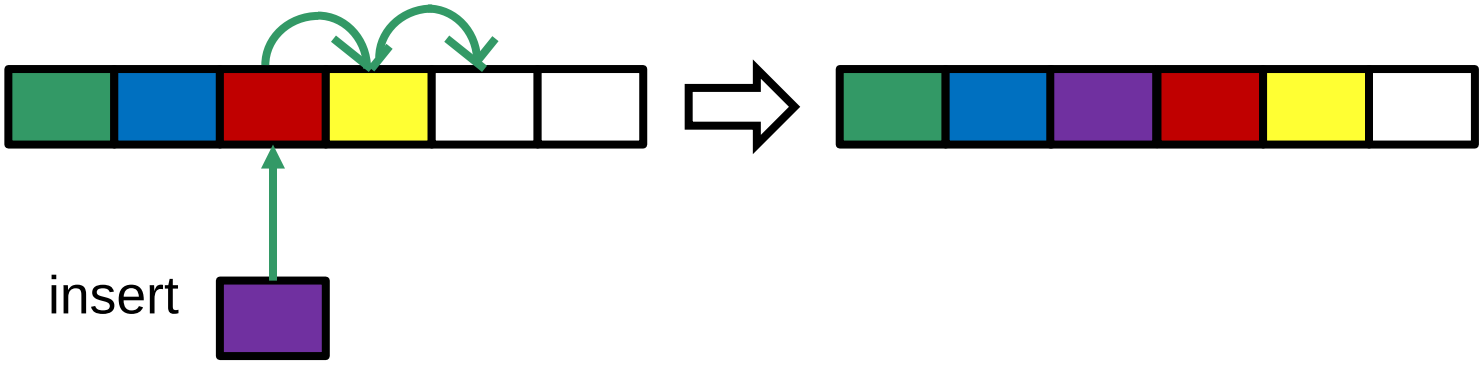
# Linked Data Structures

# Objectives

- Compare linked data structures to array-based structures
- Implement singly- and doubly- linked data structures
- Understand algorithms for managing a linked data structure
- Traverse linked data structures

# Array Limitations

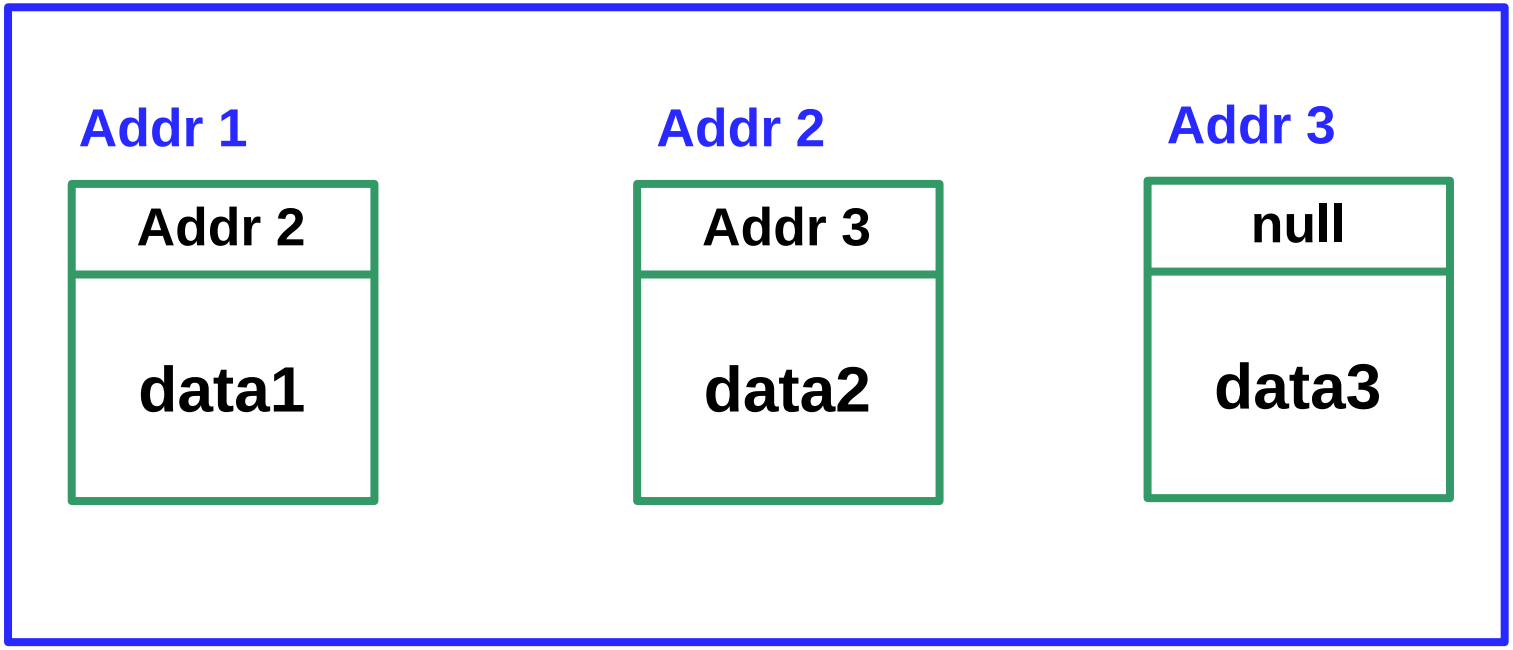
- Fixed size
- Physically stored in consecutive memory locations, so to insert or delete items, may need to shift data



# Linked Data Structures

- A linked data structure consists of items that are linked to other items
  - Each item points to another item

**Memory**



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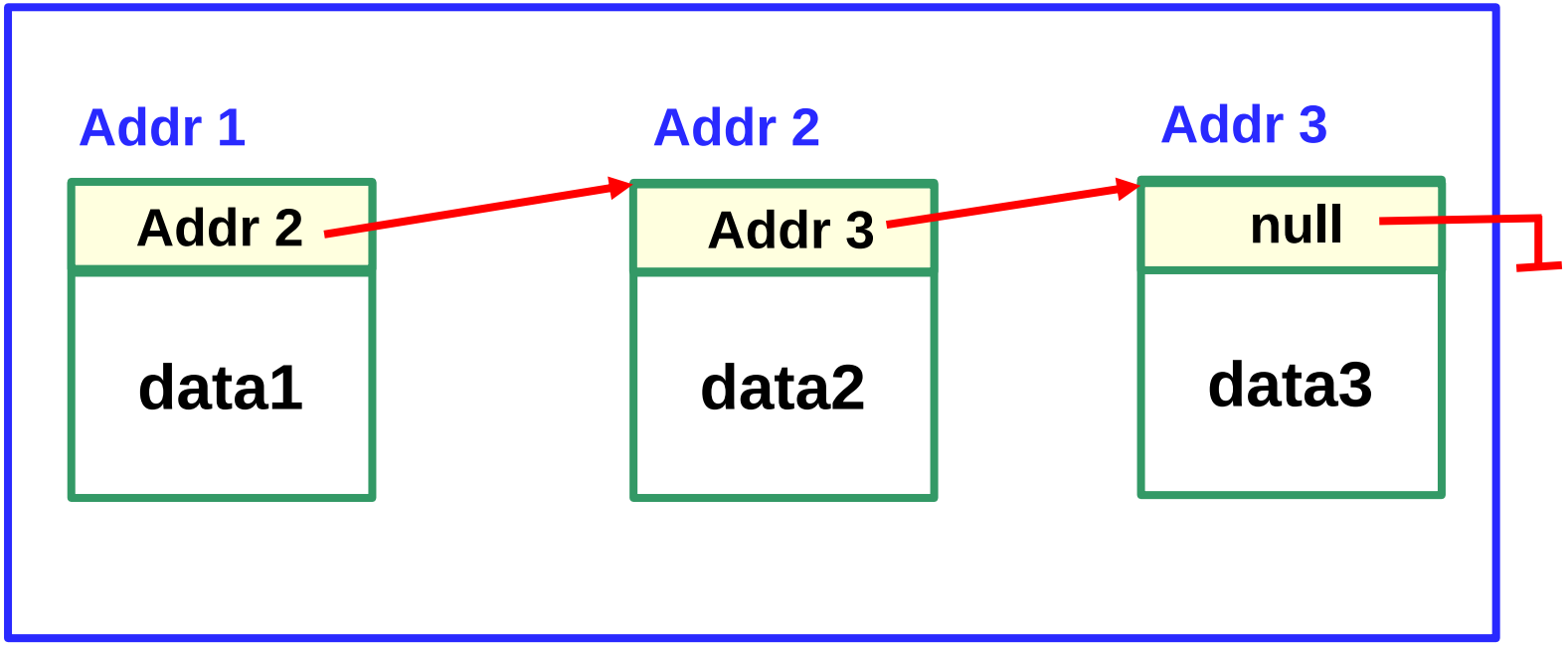
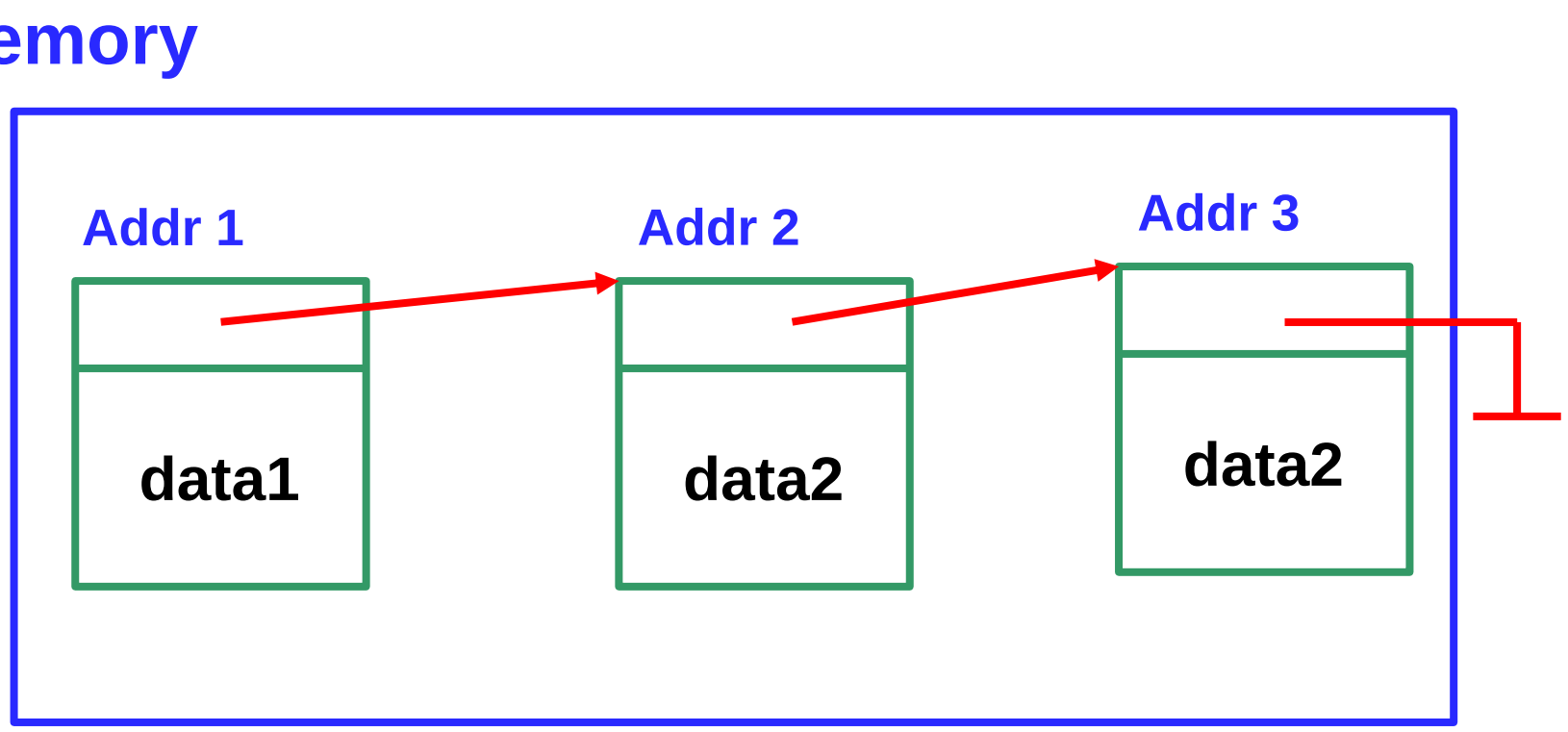


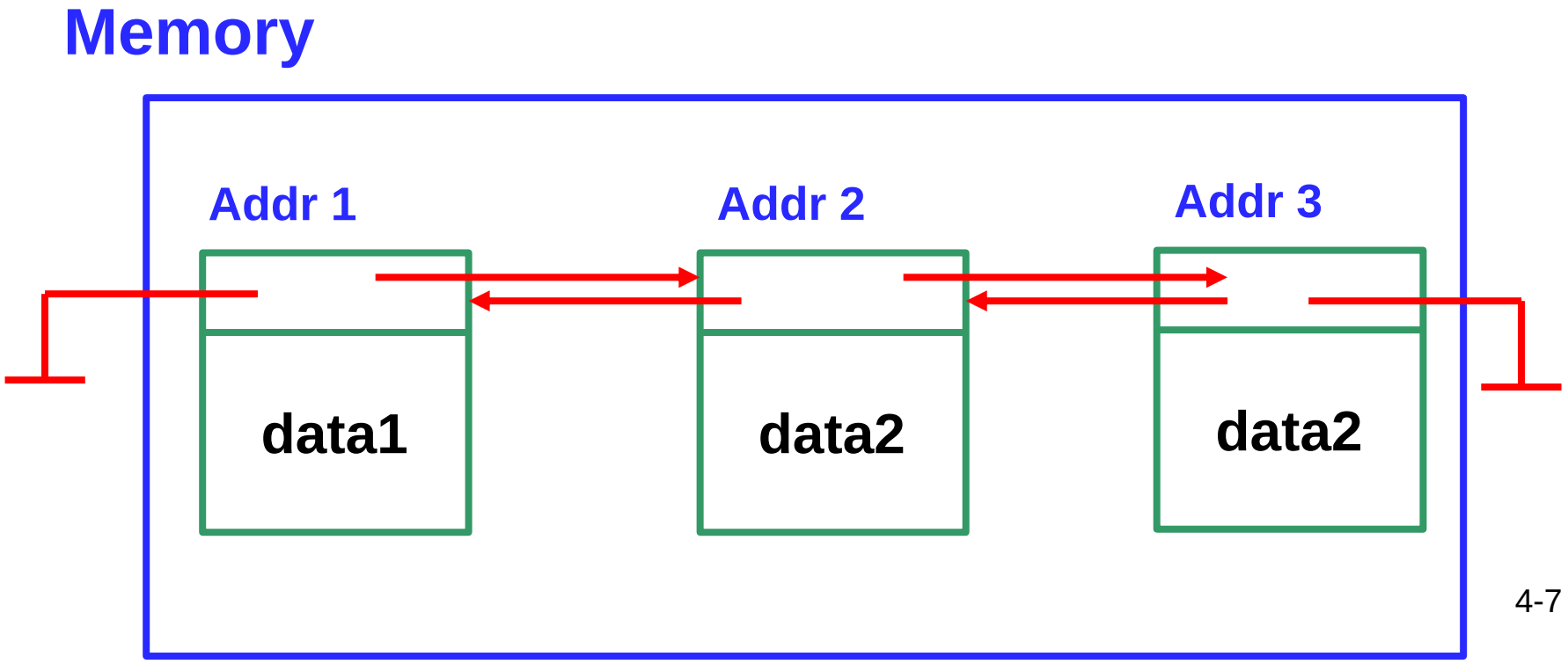
# Linear Linked Data Structures

- Singly linked list: each item points to the next item

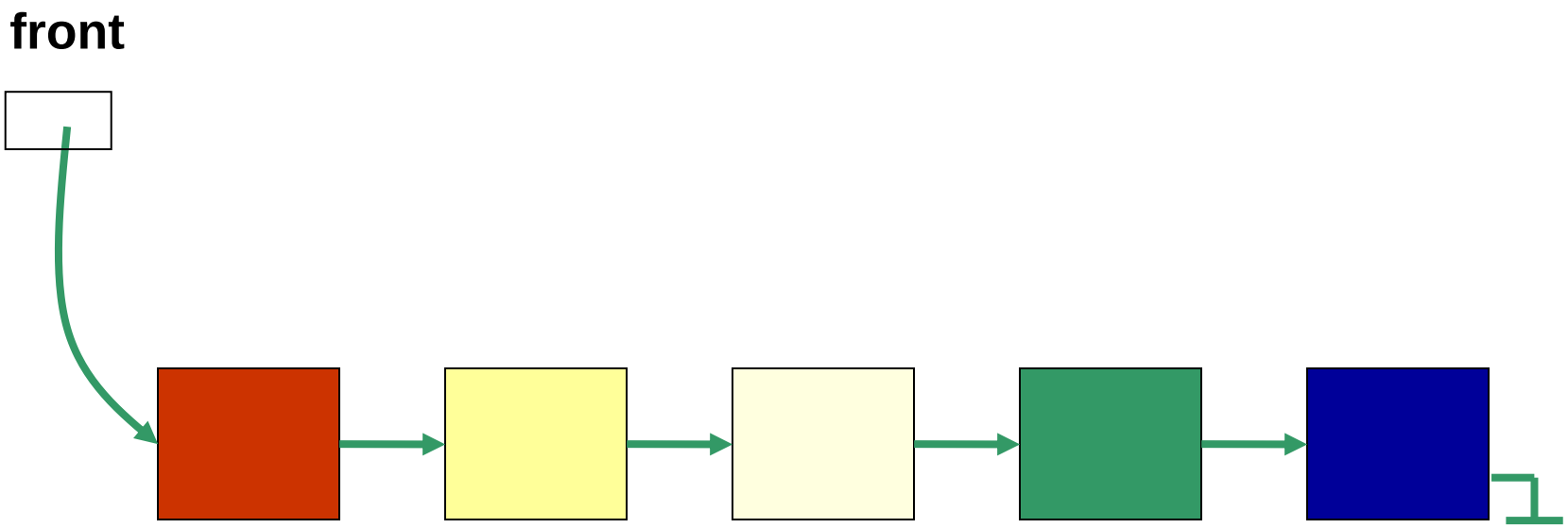


# Linked Data Structures

- Doubly linked list: each item points to the next item *and* to the previous item



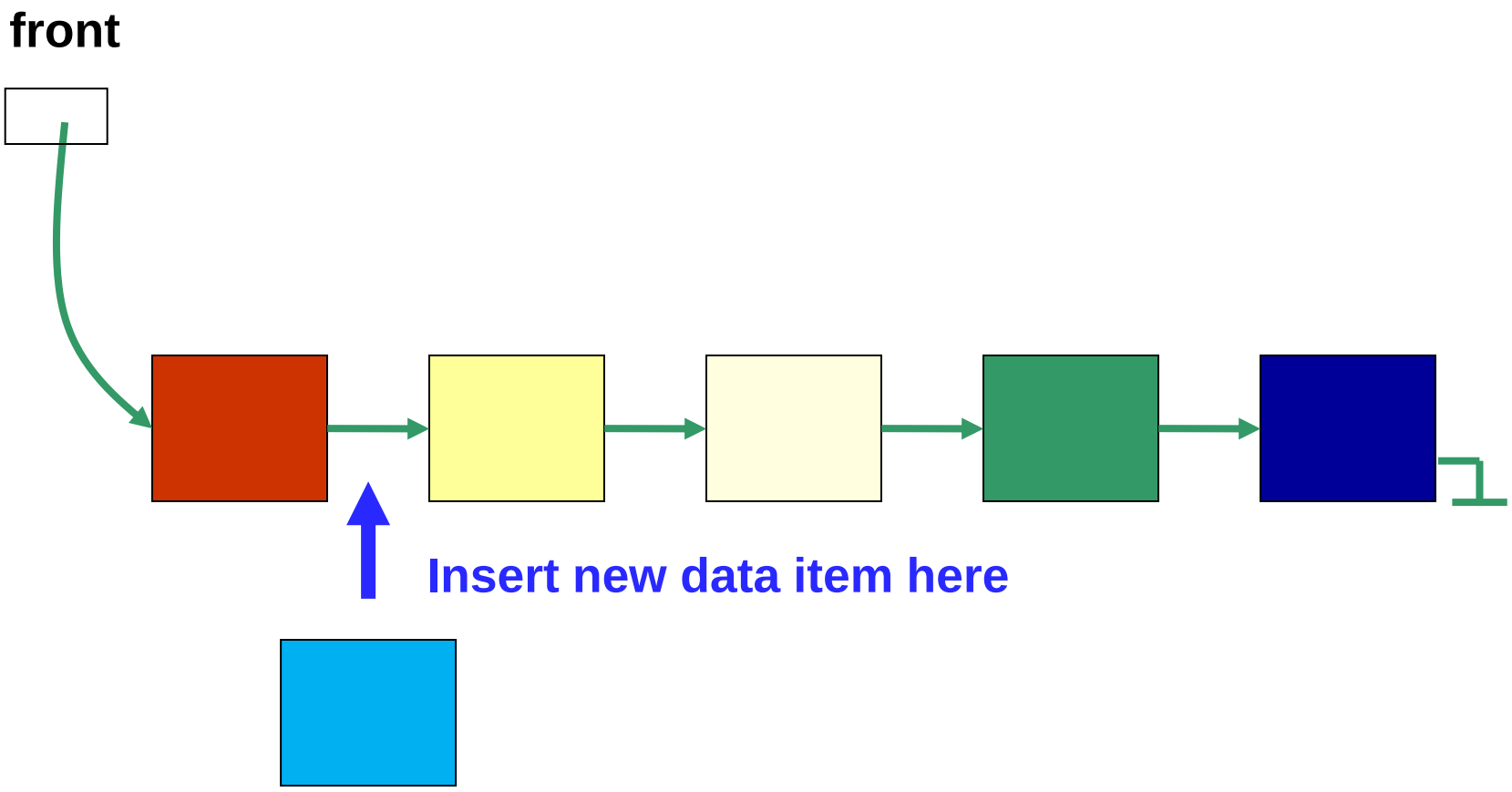
# Conceptual Diagram of a Singly-Linked List



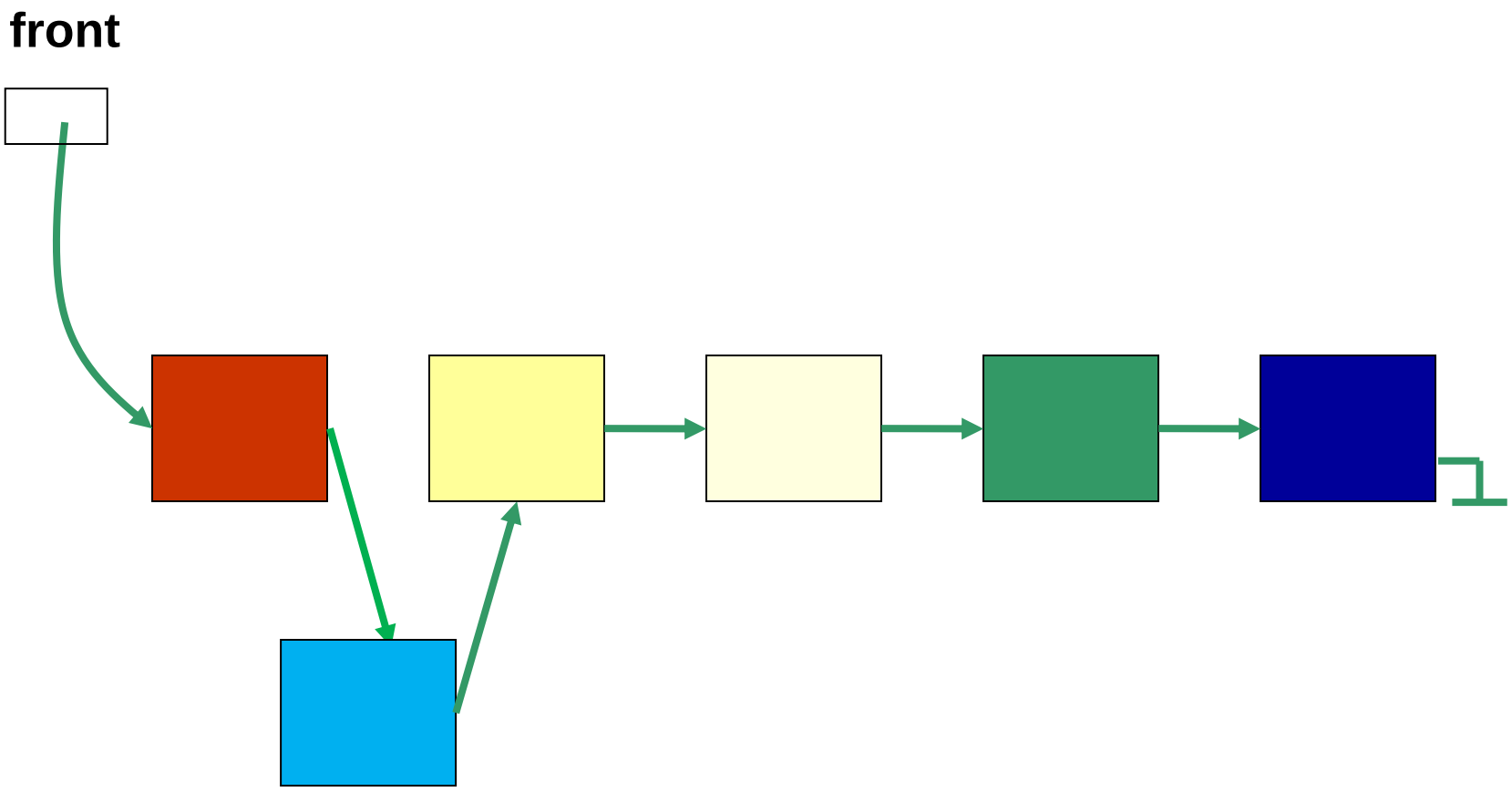
# Advantages of Linked Lists

- The items do not have to be stored in consecutive memory locations, so we can insert and delete items without shifting data.

# Advantages of Linked Lists

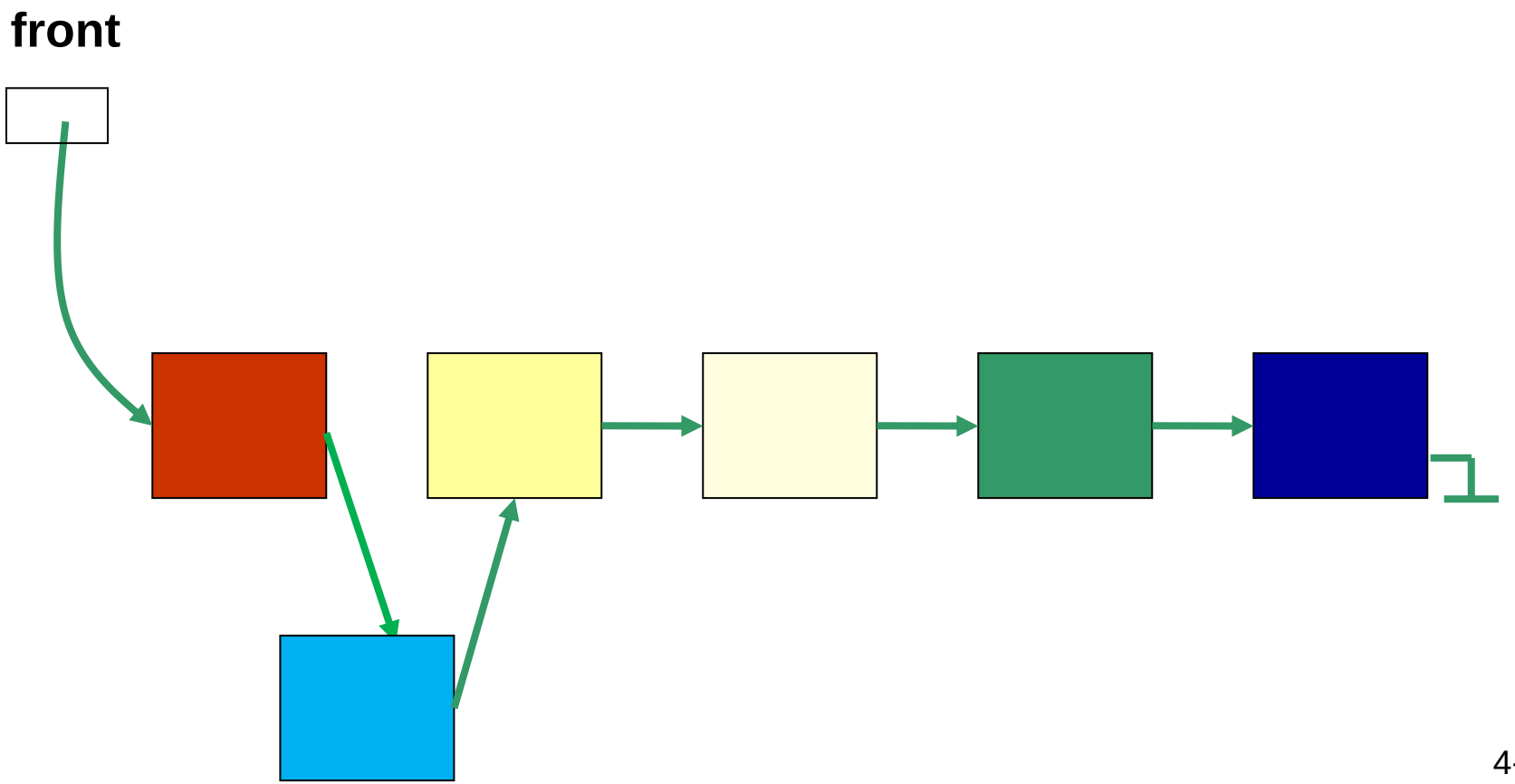


# Advantages of Linked Lists



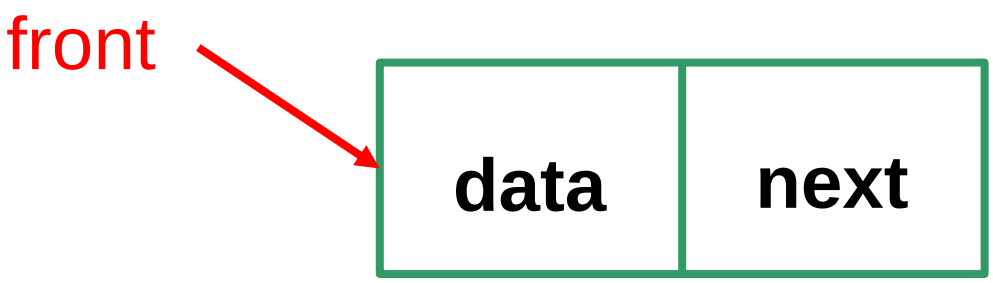
# Advantages of Linked Lists

Linked lists can grow and shrink dynamically (i.e. at run time).



# Nodes

- A linked list is a sequence of items called nodes
- A *node* in a singly linked list consists of two fields:
  - A *data* portion
  - A *link (pointer)* to the *next* node in the structure
- The first item (node) in the linked list is accessed via a *front* or *head* pointer



# Java LinearNode Class for Linked Lists

- We need to design a Java class called LinearNode for the nodes of a singly liked list
- Each node object stores data and a reference to another node of the linked list.
- Of which type should the data stored in a node?

# Java LinearNode Class for Linked Lists

- If a node stores data of a specific type, then if we need to create several linked lists storing each a different type of data, we will need to create several very similar implementations for the node class!
- This would be very inefficient.
- Instead we wish to design a node class able to store data of any type
  - We can accomplish this through the use of generic types.

# Generic Types

- Generic types (or just generics) allow us to make classes that work for any data type.
- To do this, the class definition needs a parameter. Class parameters are enclosed between angle brackets:

  <T>,  <E>, <MyType>, …

- It is conventional to use <T> as the name of a class parameter, but any name for the parameter is allowed in the < >.

# Generic Types

- Note that in generics we cannot use primitive types as class parameters.

  However, there are wrapper classes for the Java primitive types, i.e. Integer for int, Double for double, Boolean for boolean, etc.

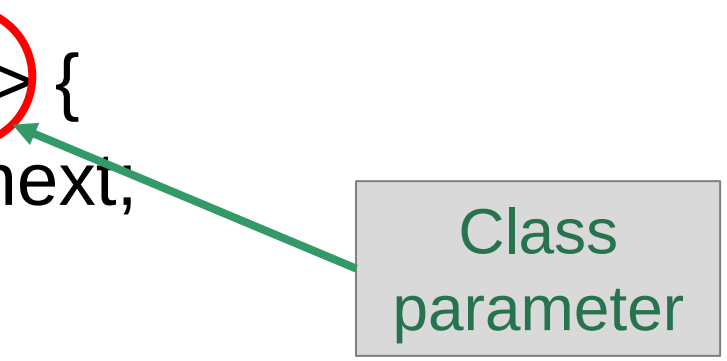
- The actual type of the data items is known only when an application program creates an object of that class
  - Example:
    - LinearNode<String> s = new …
    - LinearNode <Integer> n = new …
    - LinearNode <Double> d = new …
    - LinearNode <Person> p = new …
    - LinearNode <Rectangle> r = new …

# Java LinearNode Class for Linked Lists

```
public class LinearNode<T> {
    private LinearNode<T> next;
    private T dataItem;

    public LinearNode( ) {
       next = null;
       dataItem = null;
    }

    public LinearNode (T value) {
       next = null;
       dataItem = value;
    }
```



```
    public LinearNode<T> getNext( ) {
        return next;
    }
    public void setNext (LinearNode<T> node) {
        next = node;
    }
    public T getDataItem( ) {
        return dataItem;
    }
    public void setDataItem (T value) {
        dataItem = value;
    }
}
```

# Example: Create a LinearNode Object

- Example: create a node that contains the integer 7

Wrapper class

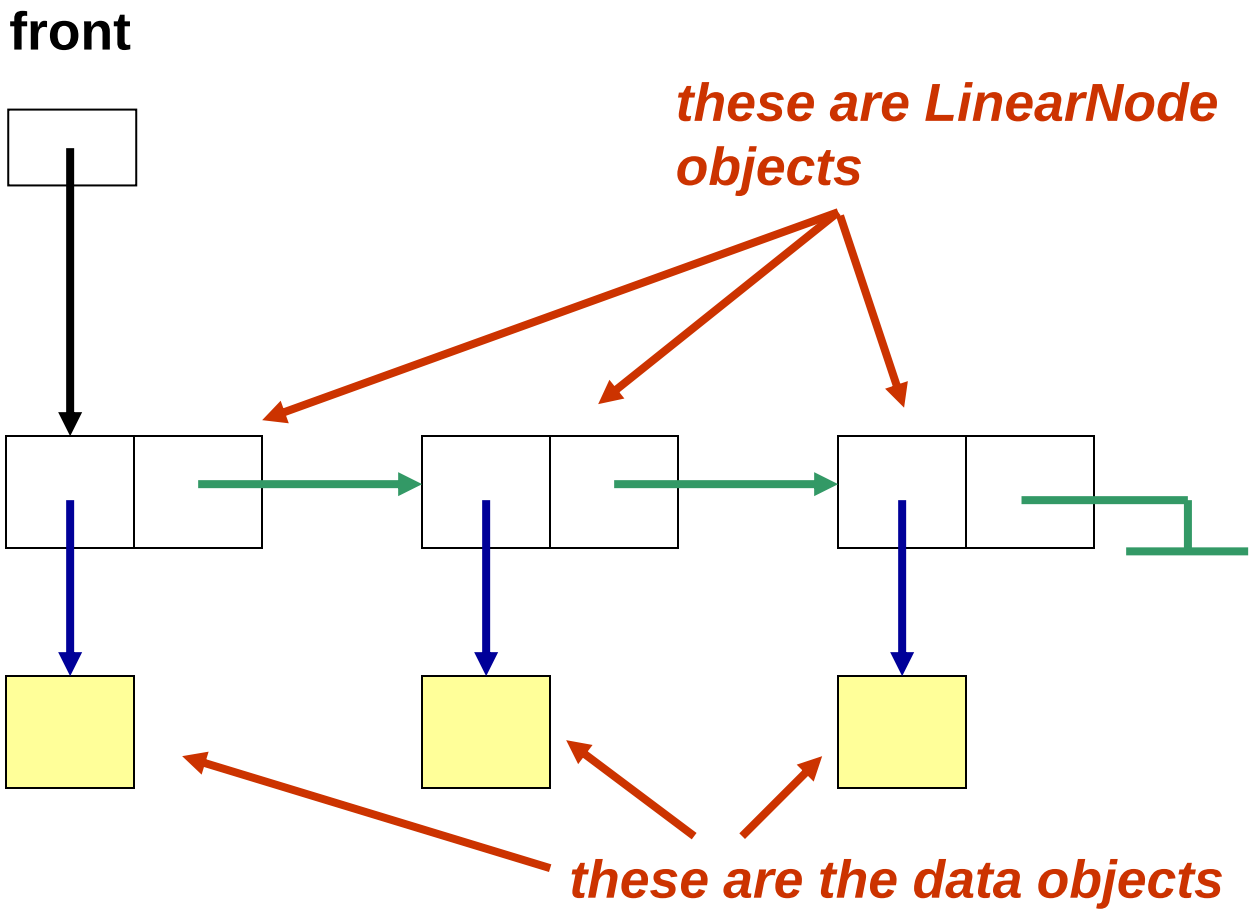
```
Integer intObj = new Integer(7);
LinearNode<Integer> inode =
                    new LinearNode<Integer> (intObj);
```

or

```
LinearNode<Integer> inode =
          new LinearNode<Integer> (new Integer(7));
```

Wrapper class needed because a generic type cannot be primitive

# Linked List of Node Objects



# Java Class for a Singly Linked List

```
public class SinglyLinkedList<T> {
    private LinearNode<T> front;

    public SinglyLinkedList( ) {
       front = null;
    }
```

# Linked List

Note*:* We will hereafter refer to a singly linked list just as a "linked list"

- Traversing a linked list
  - How is the first item accessed?
  - The second?
  - The last?
- What does the last item point to?
  - We call this the null link

# Discussion

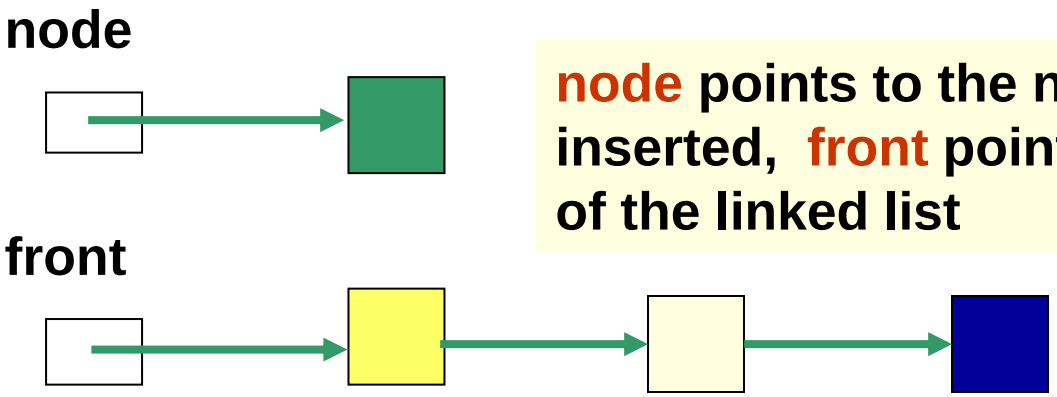
- How do we get to an item's successor?
- How do we get to an item's predecessor?
- How do we access, say, the 3rd item in the linked list?
- How does this differ from an array?

# Linked List Operations

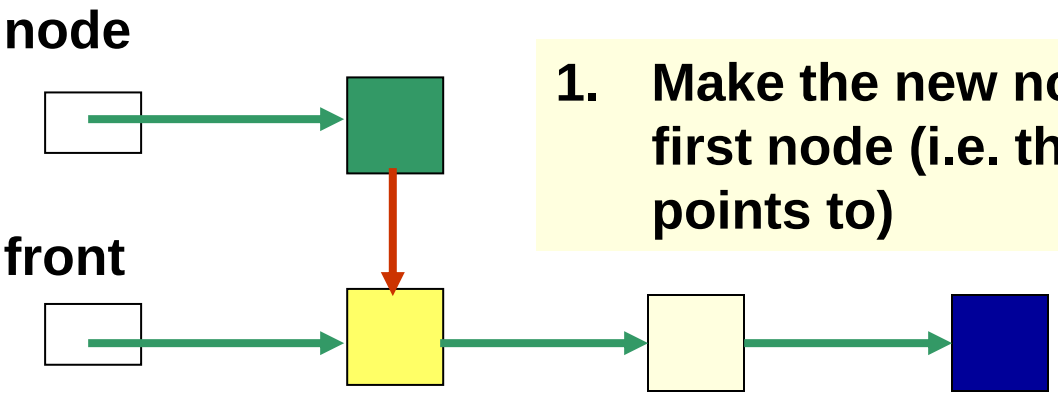
We will now examine linked list operations:

- Add an item to the linked list
  - We have 3 situations to consider:
    - insert a node at the front
    - insert a node in the middle
    - insert a node at the end

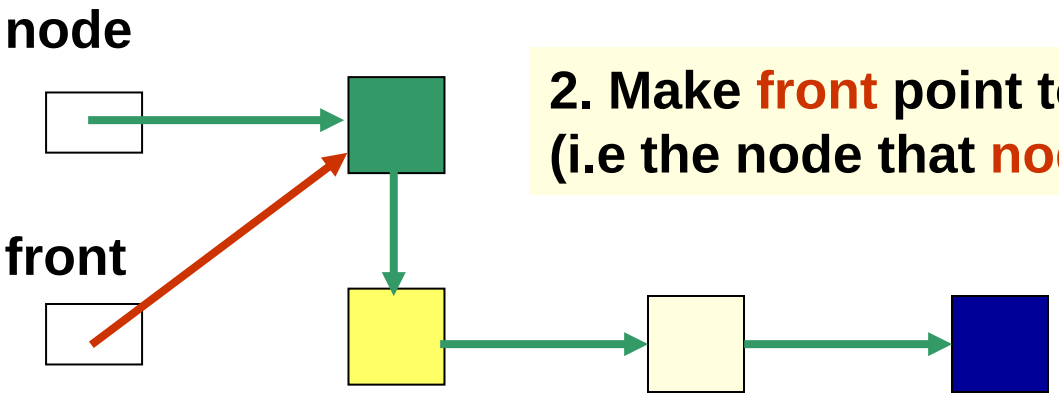
# Inserting a Node at the Front




**node** points to the new node to be inserted, **front** points to the first node of the linked list



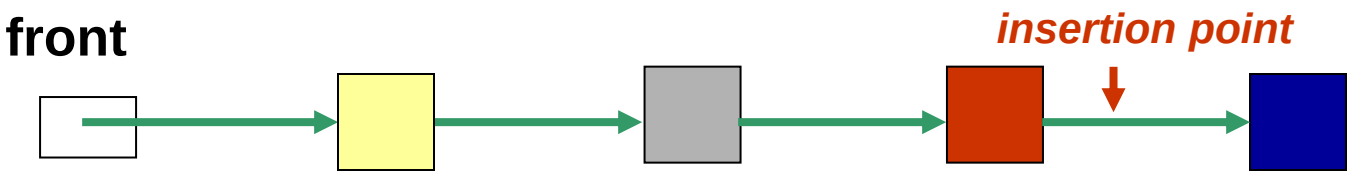

1. Make the new node point to the first node (i.e. the node that **front** points to)



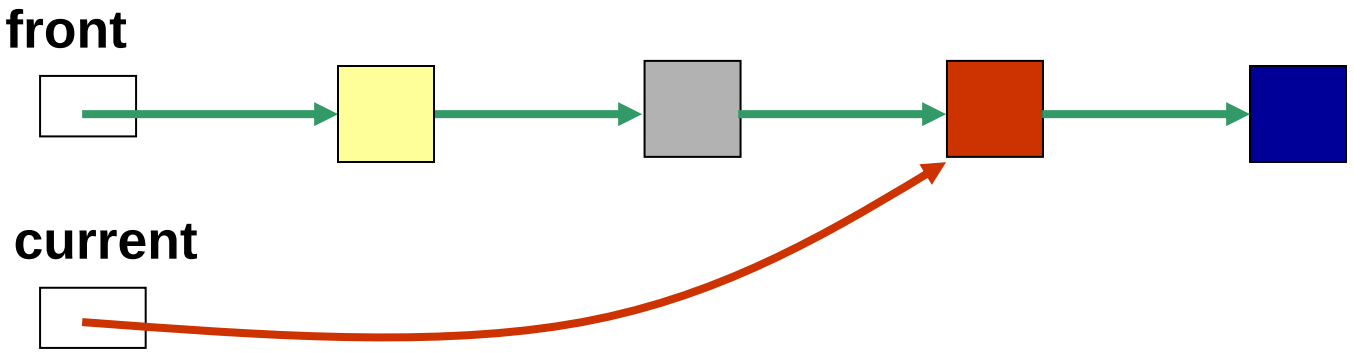

**2. Make front point to the new node (i.e the node that node points to)**

# Inserting a Node in the Middle

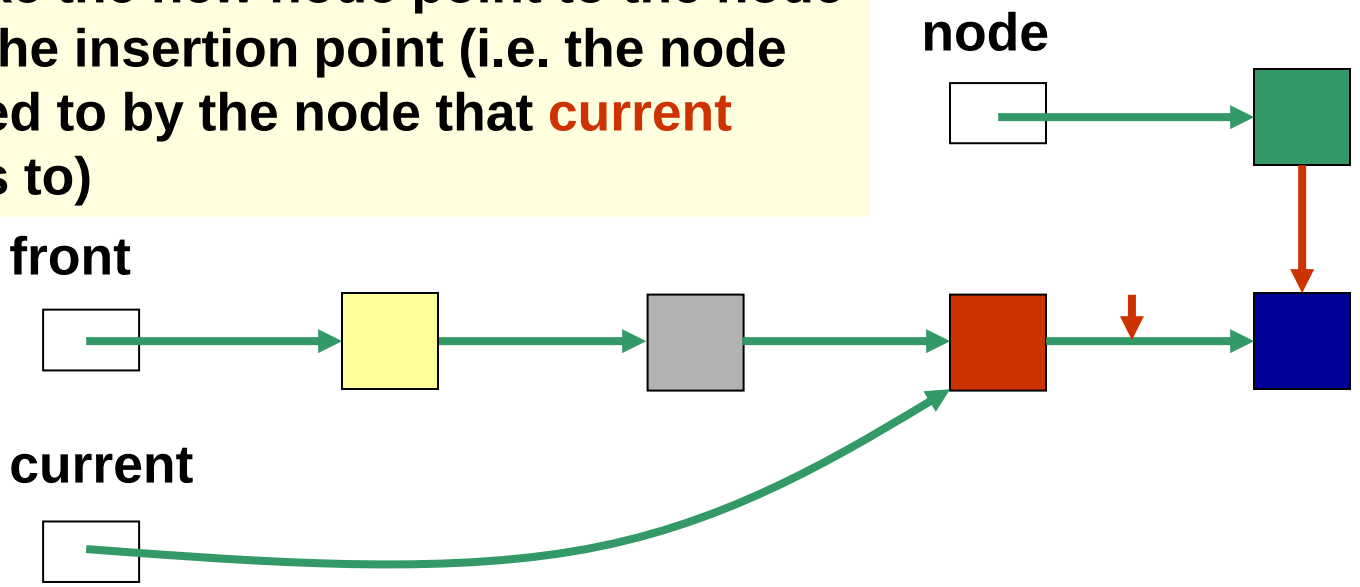
**Let's insert the new node after the *third* node in the linked list**

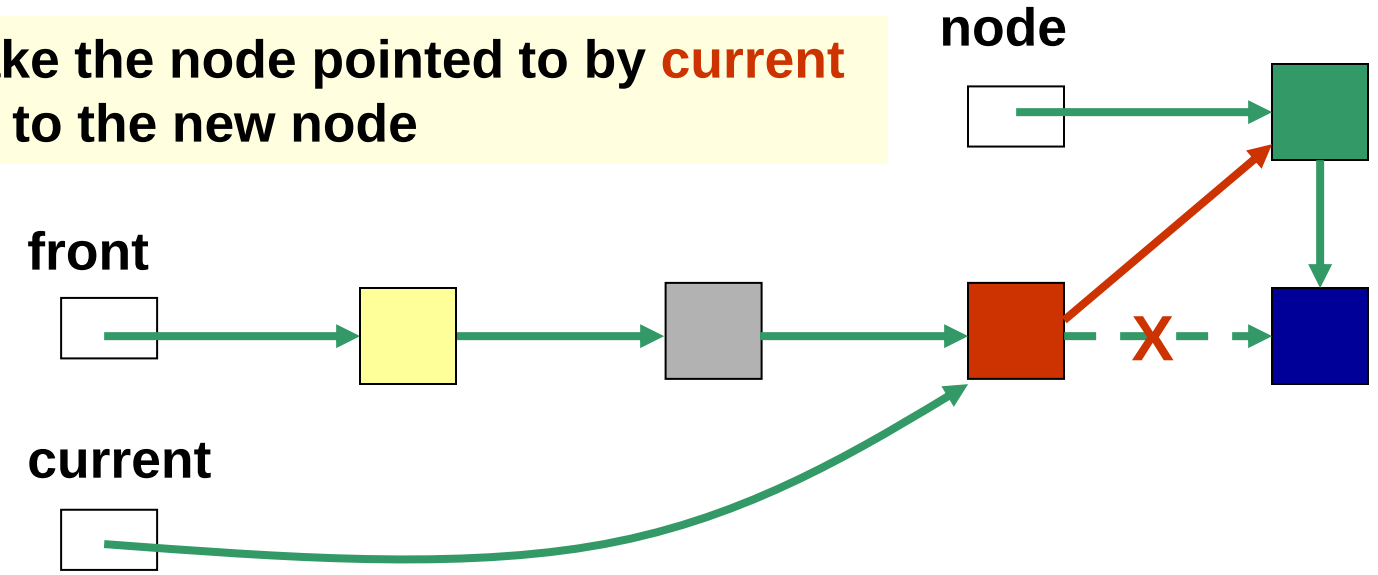

**1. Locate the node *preceding the insertion point* , since it will have to be modified (make current point to it)**

**2. Make the new node point to the node after the insertion point (i.e. the node pointed to by the node that current points to)**

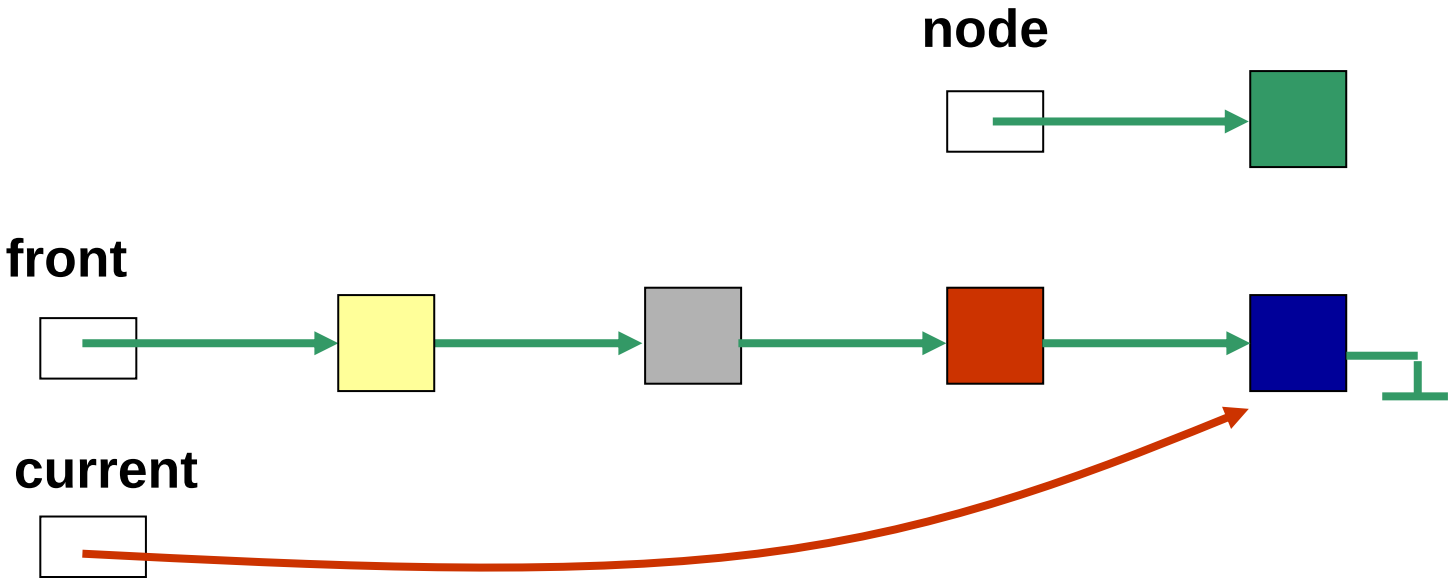



**3. Make the node pointed to by current point to the new node**



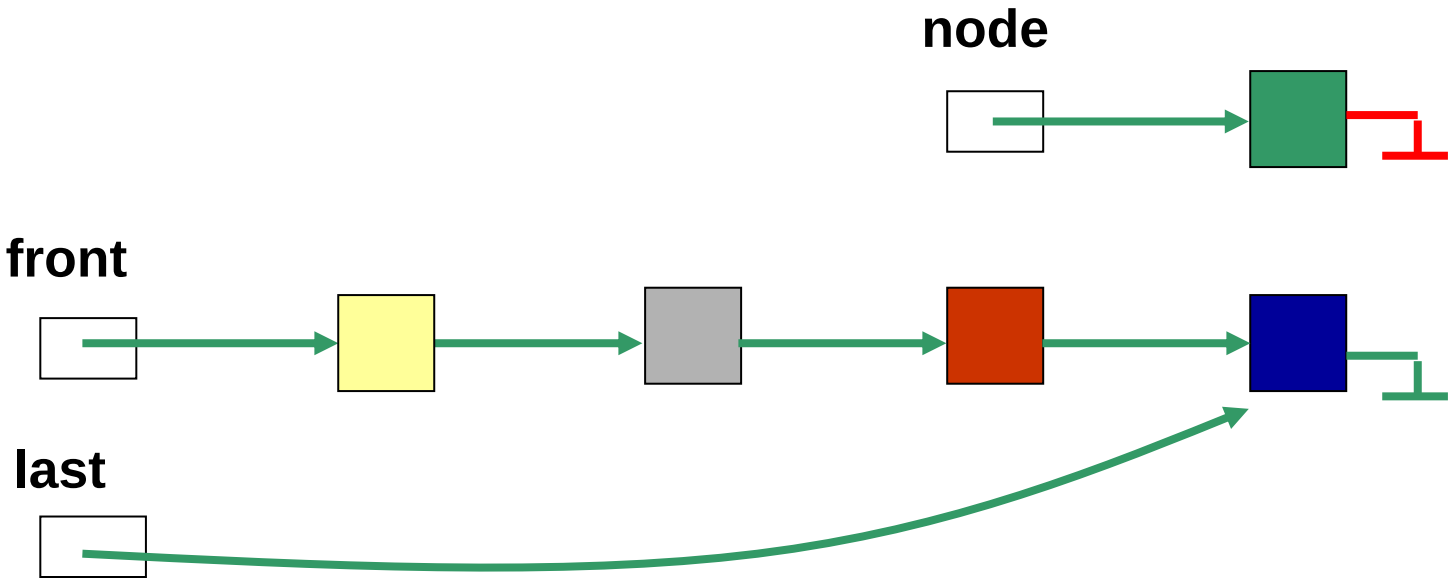
# Inserting a Node at the End

**1. Locate the last node**



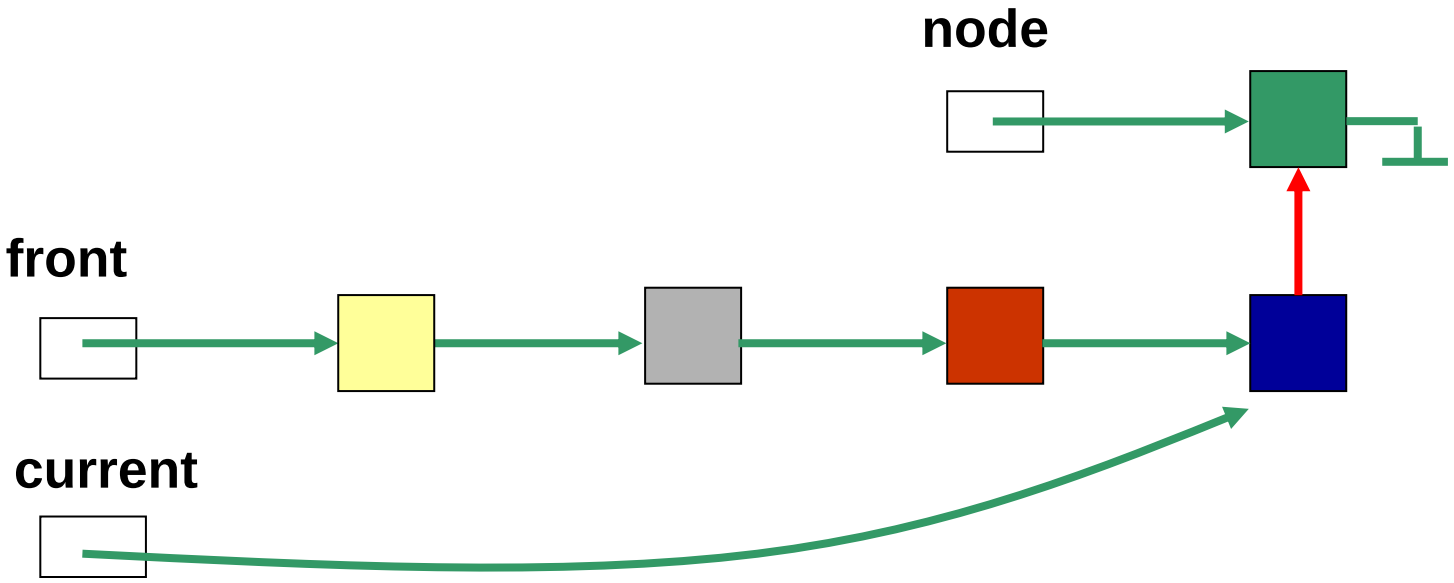
# Inserting a Node at the End

**2. Make new node point to null**



# Inserting a Node at the End

**3. Make last point to new node**



# Algorithm for Inserting a Node in a Singly Linked List

**Algorithm** insert (*newNode*, *predecessor*)
**In**: New node to be inserted after *predecessor*.
**Out**: {Insert *newNode* in linked list after *predecessor*; *newNode* must be inserted at the front of the list if predecessor is null.}

```
if predecessor is null then {
        make newNode point to front
        front = newNode
}
else {
        succ = node that predecessor points to
        make newNode point to succ
        make predecessor point to newNode
}
```

# Java Implementation of Algorithm for Inserting a Node in a Singly Linked List

```
public void insert (LinearNode<T> newNode,
                    LinearNode<T> predecessor) {
    if (predecessor == null) {
        newNode.setNext(front);
        front = newNode;
    }
    else {
        LinearNode<T> succ = predecessor.getNext();
        newNode.setNext(succ);
        predecessor.setNext(newNode);
    }
}
```

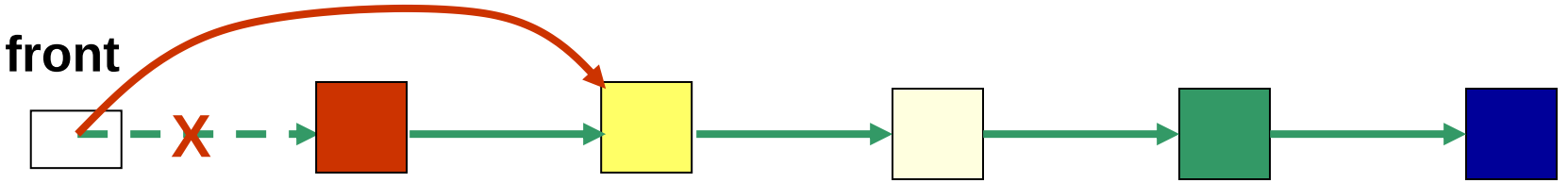
# Linked List Operations

- Delete an item from the linked list
  - We have 3 situations to consider:
    - delete the node at the front
    - delete an interior node
    - delete the last node

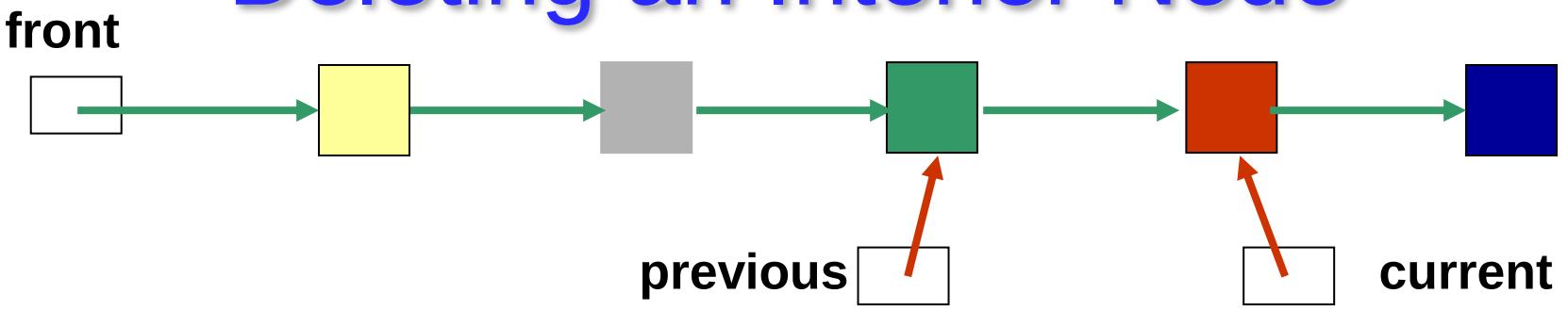
# Deleting the First Node

**front points to the first node in the linked list, which points to the second node**

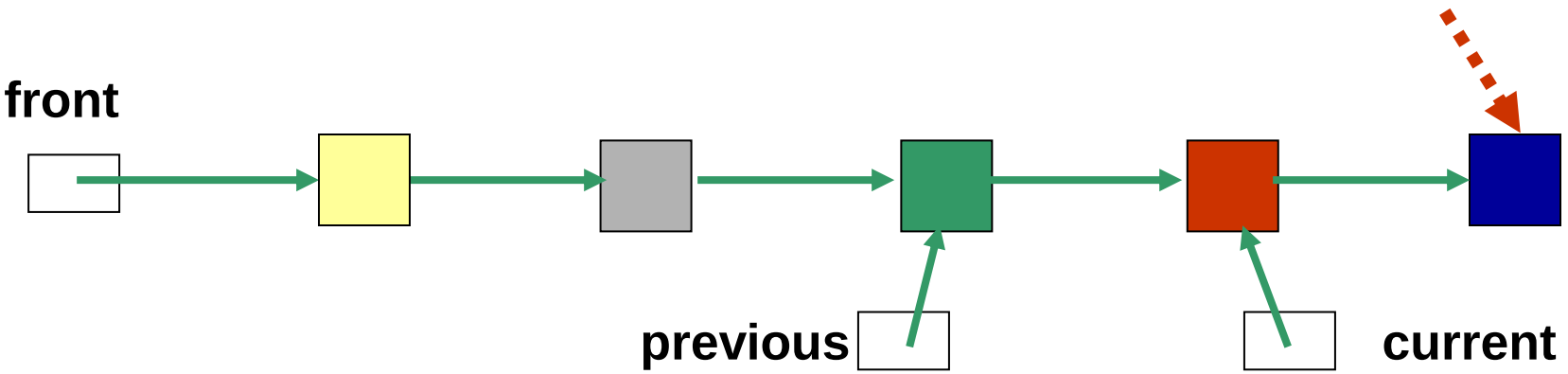

**Make front point to the second node (i.e. the node pointed to by the first node)**



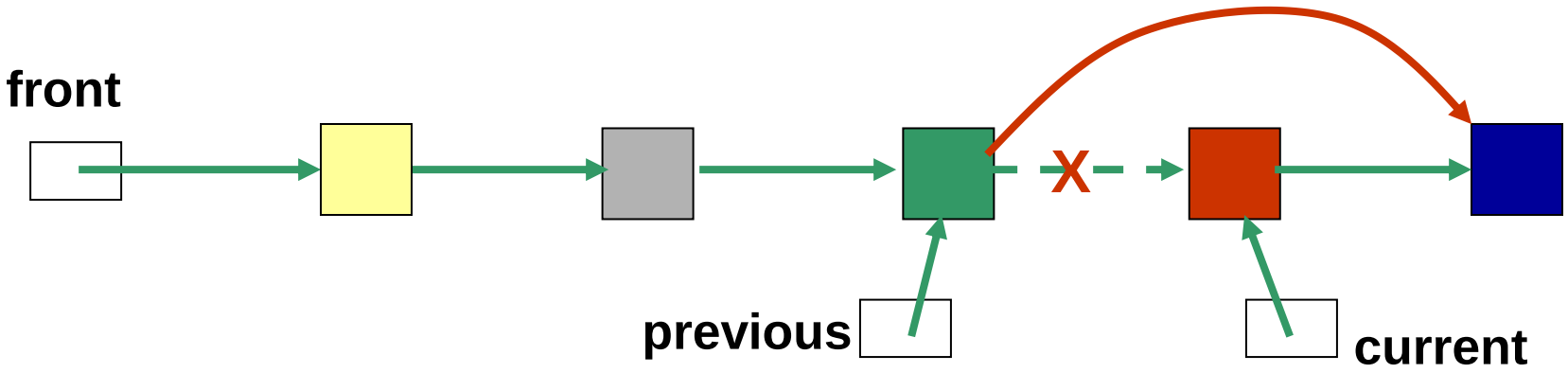
# Deleting an Interior Node




1. Traverse the linked list so that current points to the node to be deleted and previous points to the node prior to the one to be deleted



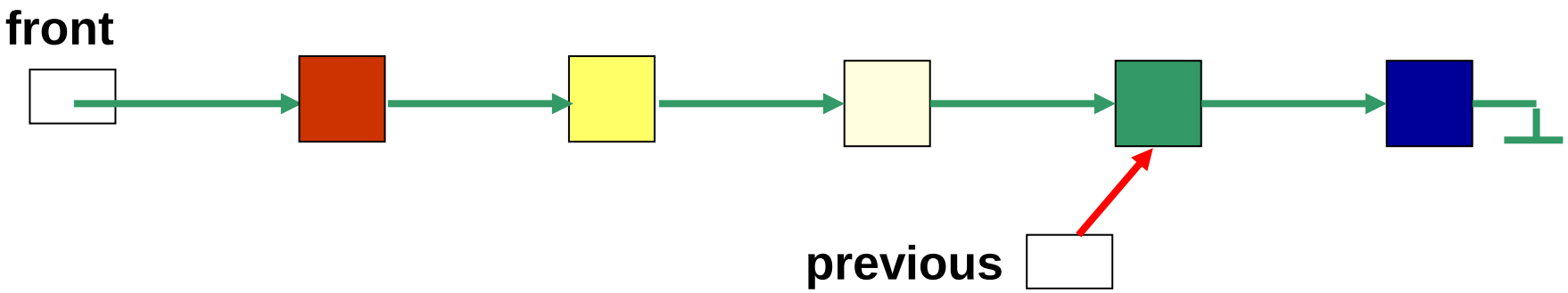

2. We need to get at the node *following the one to be deleted* (i.e. the node pointed to by the node that current points to)




**3. Make the node that previous points to, point to the node following the one to be deleted**

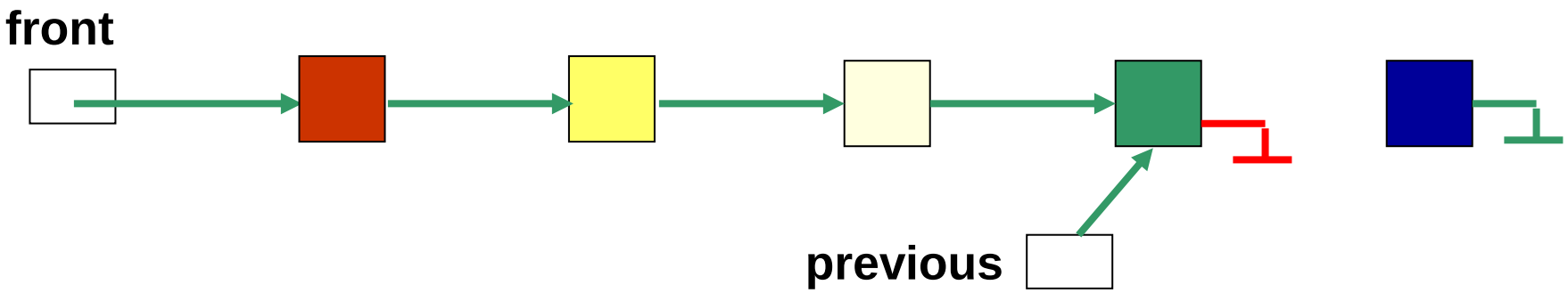
# Deleting the Last Node

**1. Find the previous to the last node in the linked list**



# Deleting the Last Node

**1. Make previous point to null**

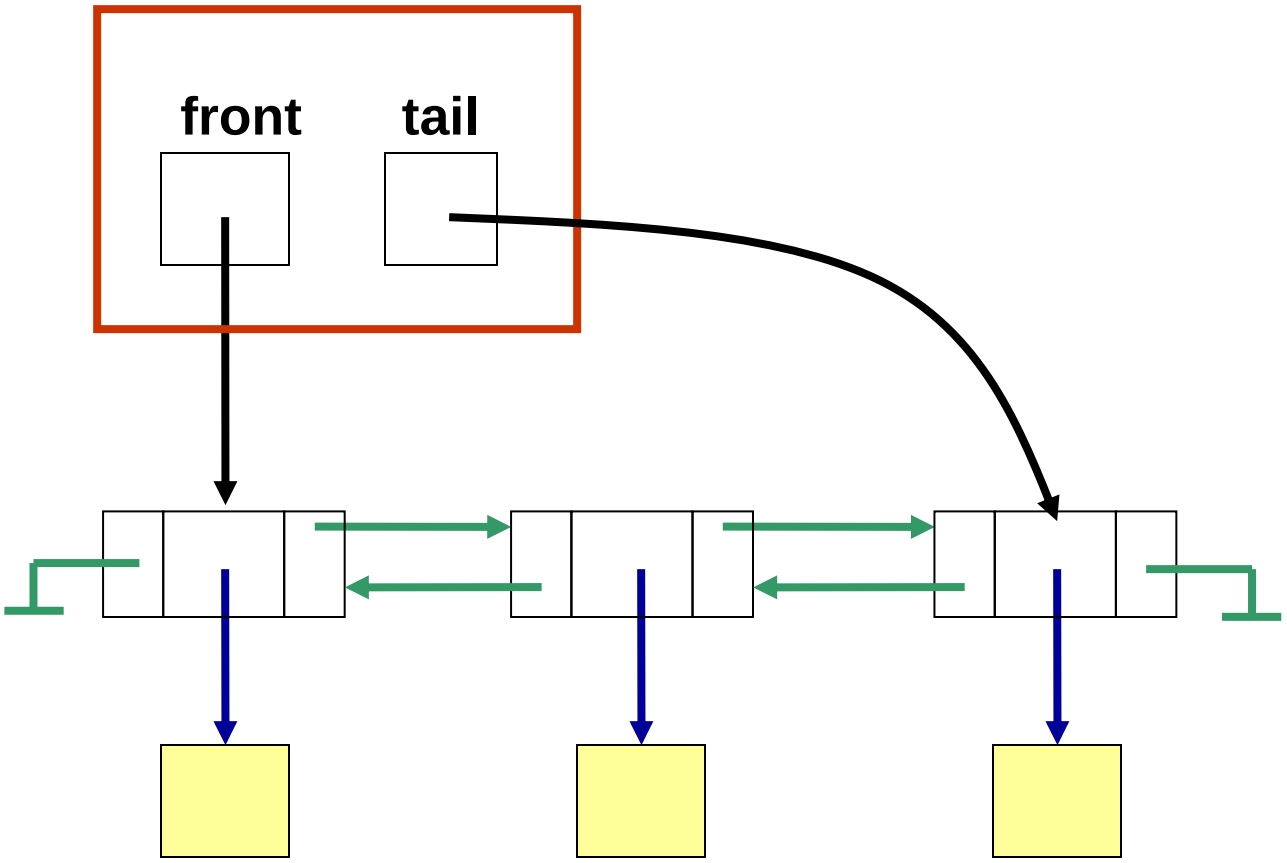


**Algorithm** delete (*nodeToDelete*)
**In**: node to delete
**Out**: *true* if the node was deleted, *false* otherwise
current = front
predecessor = null
**while** (current ≠ null) **and** (current ≠ *nodeToDelete*) do {
    predecessor = current
    current = current.getNext()
}
**if** current is null **then return** *false*
**else** {
    **if** predecessor ≠ null **then**
        make predecessor point to current.getNext()
    **else** front = front.getNext()
    **return** *true*
}

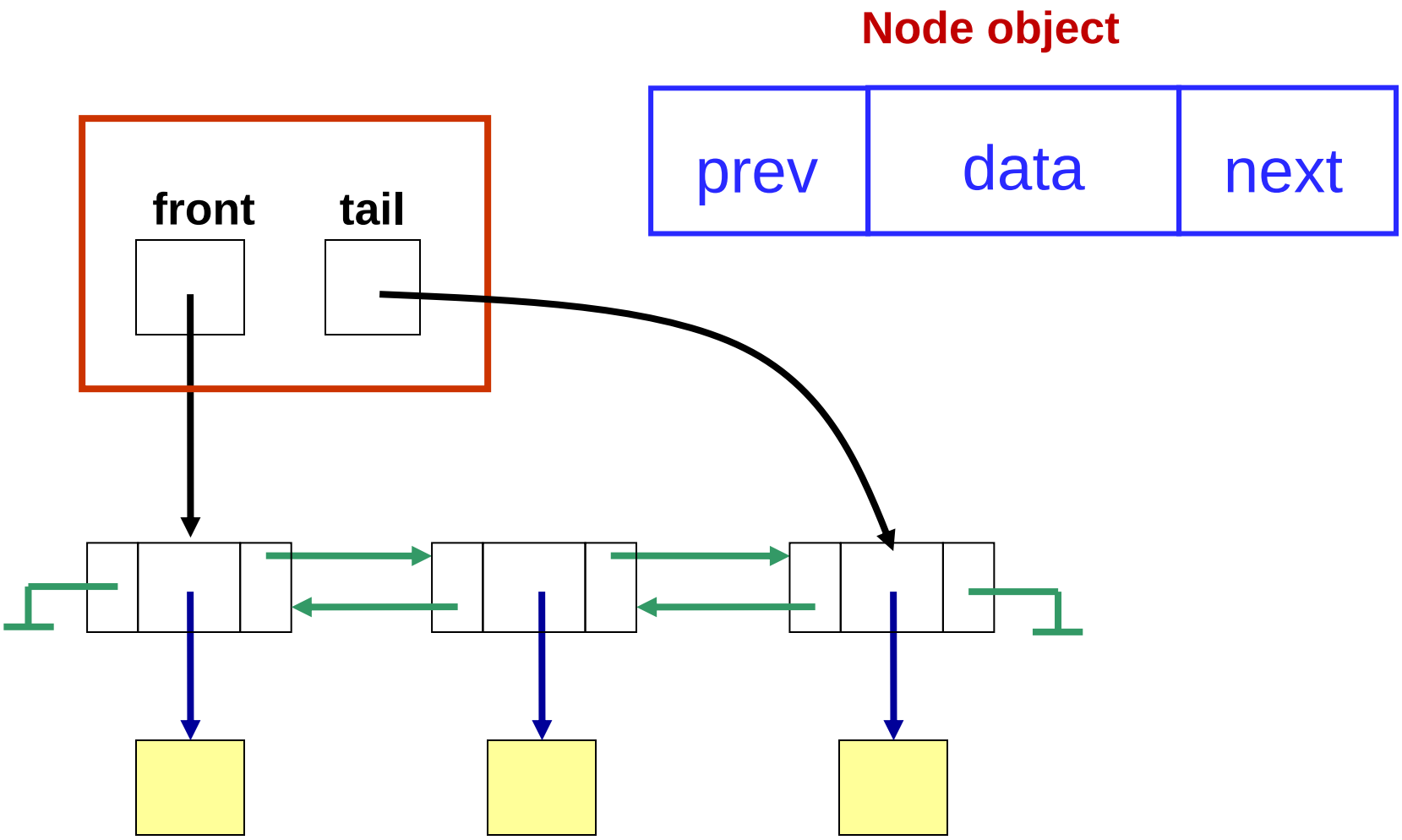
# Java Implementation of Algorithm *delete*

```
public boolean delete (LinearNode<T> nodeToDelete) {
    LinearNode<T> current, predecessor;
    current = front;
    predecessor = null;
    while ((current != null) && (current != nodeToDelete)) {
        predecessor = current;
        current = current.getNext();
    }
    if (current == null) return false;
    else {
        if (predecessor != null)
            predecessor.setNext(current.getNext());
        else front = front.getNext();
        return true;
    }
}
```

# Doubly Linked List



# Doubly Linked List



# Java Class for a Node of a Doubly Linked List

```
public class LinearNodeDLL<T> {
    private LinearNodeDLL<T> next;
    private LinearNodeDLL<T> prev;
    private T dataItem;

    public LinearNodeDLL( ) {
      next = null;
      prev = null;
      dataItem = null;
    }

    public LinearNodeDLL (T value) {
      next = null;
      prev = null;
      dataItem = value;
    }
```

```
    public LinearNodeDLL<T> getNext( ) {
      return next;
    }
     public void setNext (LinearNodeDLL<T> node) {
      next = node;
    }
 public LinearNodeDLL<T> getPrev( ) {
      return prev;
    }
     public void setPrev (LinearNodeDLL<T> node) {
      prev = node;
    }
     public T getDataItem( ) {
      return dataItem;
    }
     public void setDataItem (T value) {
      dataItem = value;
    }
}
```

# Java Class for a Doubly Linked List

```
public class DoublyLinkedList<T> {
    private LinearNodeDLL<T> front;
    private LinearNodeDLL<T> tail;

    public DoublyLinkedList( ) {
       front = null;
       tail = null;
    }
   …
}
```

Write algorithms to add a new node to a doubly linked list and to remove a node from a doubly linked list.