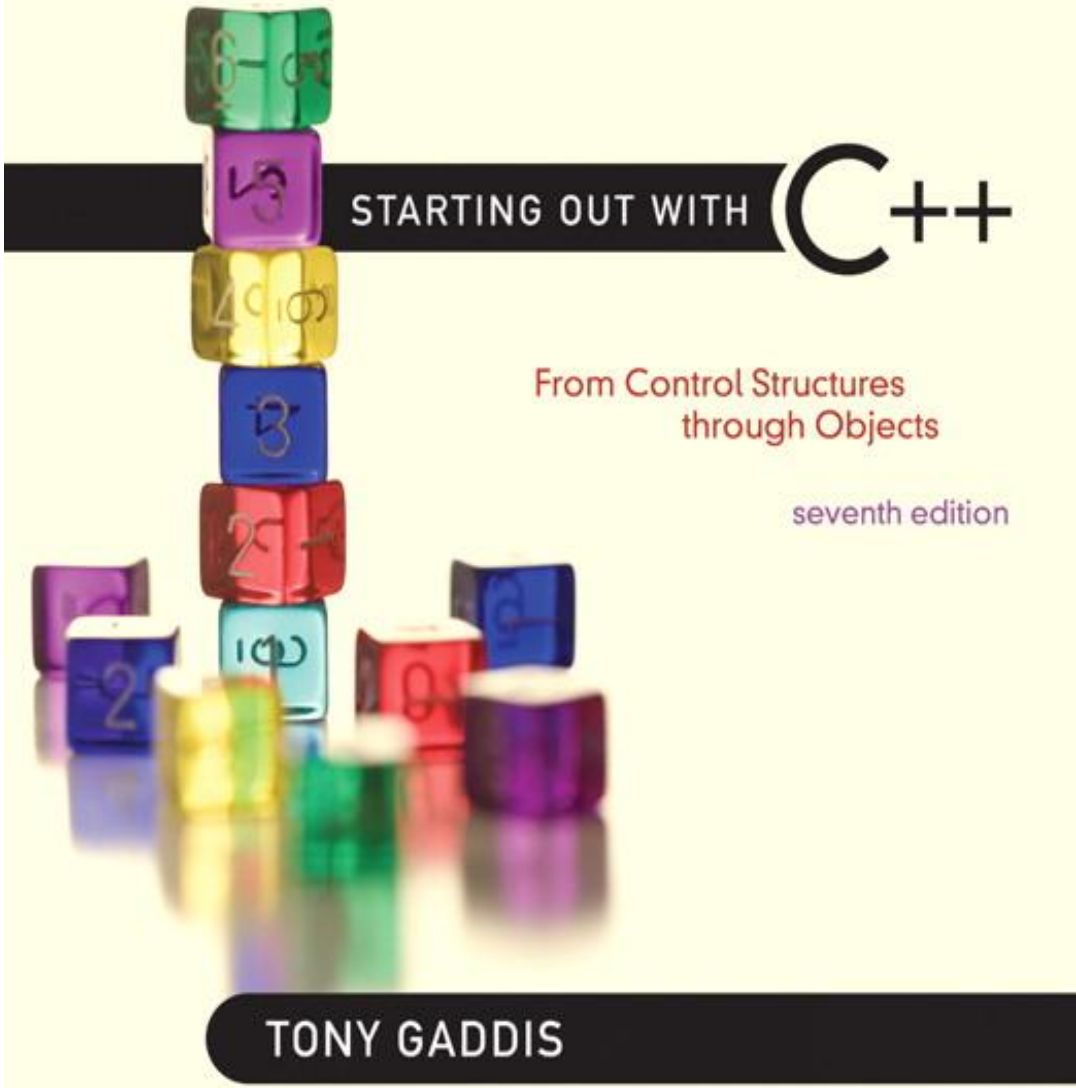
Chapter 17:

Linked Lists



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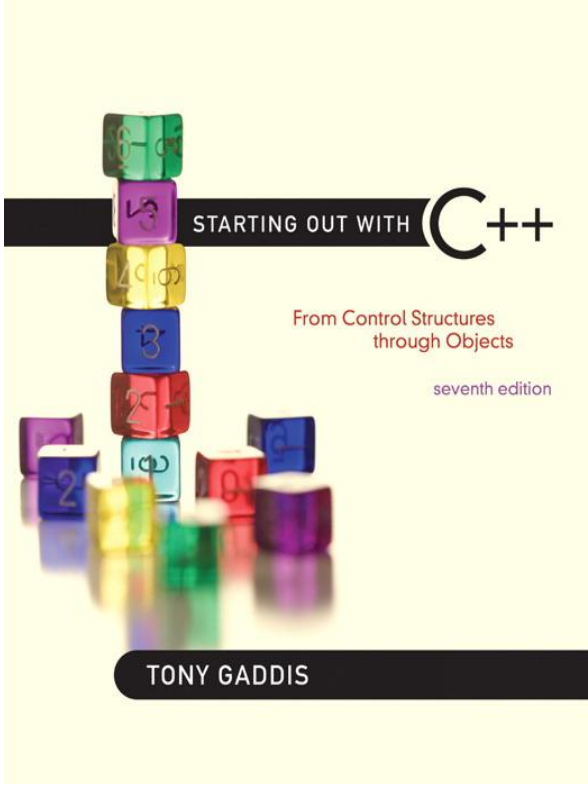
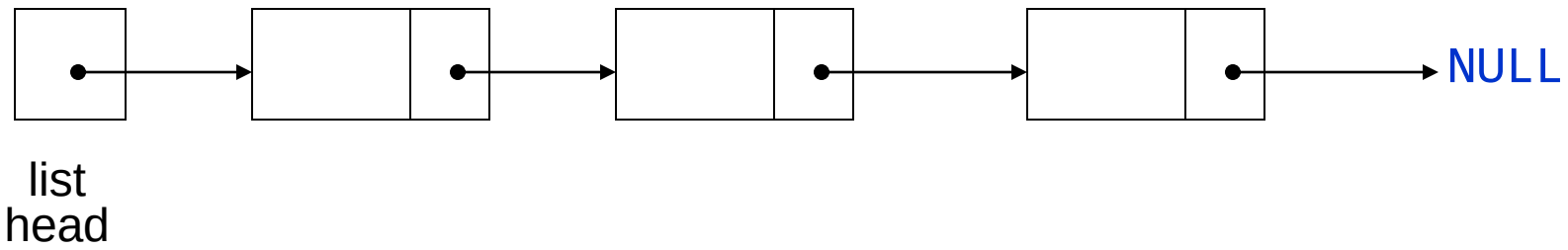


17.1

Introduction to the Linked List ADT

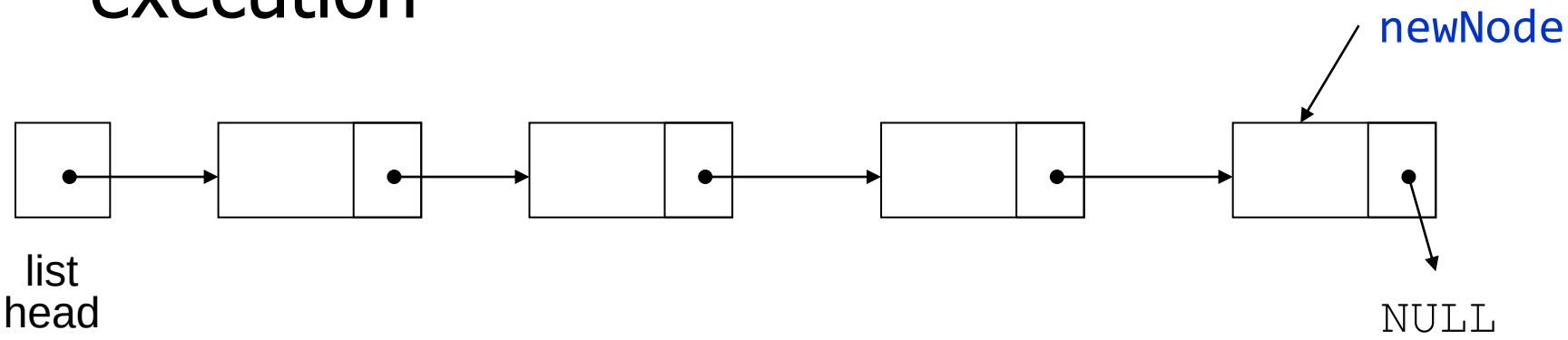
Introduction to the Linked List ADT

- Linked list: set of data structures (nodes) that contain references to other data structures



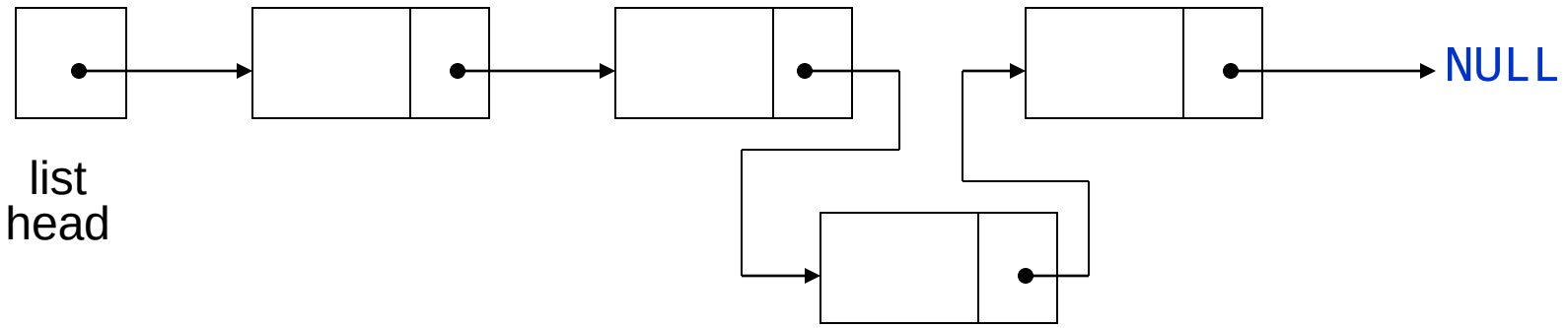
Introduction to the Linked List ADT

- References may be addresses or array indices
- Data structures can be added to or removed from the linked list during execution



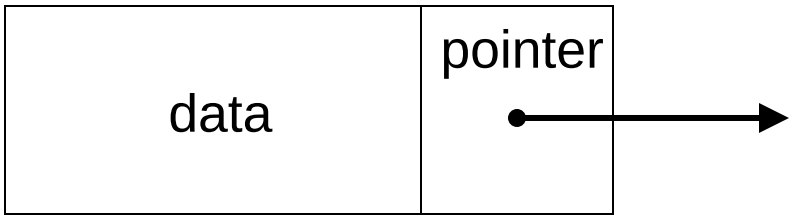
Linked Lists vs. Arrays and Vectors

- Linked lists can grow and shrink as needed, unlike arrays, which have a fixed size
- Linked lists can insert a node between other nodes easily (expensive operation in a vector)



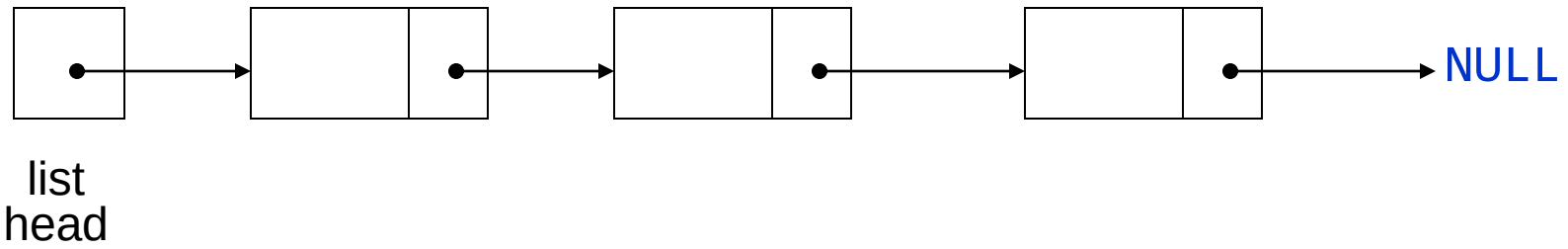
Node Organization

- A node contains:
  - data
    - one or more data fields that may be organized as a structure, object, etc.
  - pointer
    - points to next node in the list



Linked List Organization

- Linked list contains 0 or more nodes:

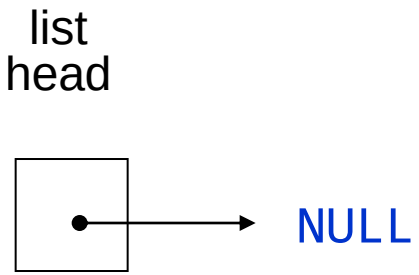


- Has a list head to point to first node
- Last node points to NULL

Empty List

- If a list currently contains 0 nodes, it is an empty list

- In this case the list head points to `NULL`



Declaring a Node

- Declare a node:

```
struct ListNode
{
   int data;          //data
   ListNode* next;    //pointer
};
```

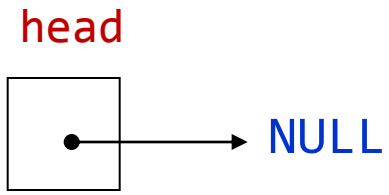
- No memory is allocated at this time

Defining a Linked List

- Define a pointer for the head of the list:

```
ListNode* head = NULL;
```

- Head pointer initialized to `NULL` to indicate an empty list



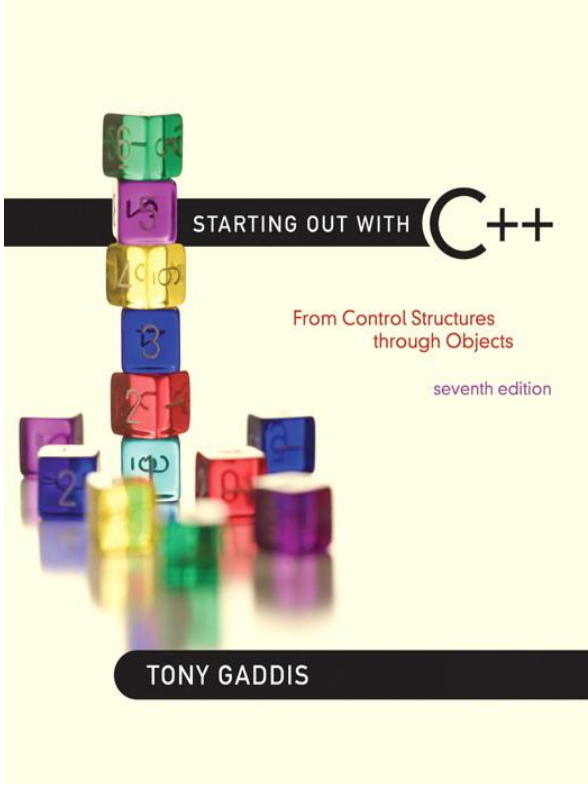
NULL Pointer

- Is used to indicate end-of-list
- Should always be tested for before using a pointer:

```
ListNode* p;
while (p != NULL) ...
```

- Can also test the pointer itself:

```
while (!p) ... //same meaning as above
```



17.2

Linked List Operations

Linked List Operations

- Basic operations:
  - append a node to the end of the list
  - insert a node within the list
  - traverse the linked list
  - delete a node
  - delete the list

Contents of NumberList.h

```
 1  // Specification file for the NumberList class
 2  #ifndef NUMBERLIST_H
 3  #define NUMBERLIST_H
 4
 5  class NumberList
 6  {
 7  private:
 8     // Declare a structure for the list
 9     struct ListNode
10     {
11        double value;           // The value in this node
12        struct ListNode *next;  // To point to the next node
13     };
14
15     ListNode *head;            // List head pointer
16
```

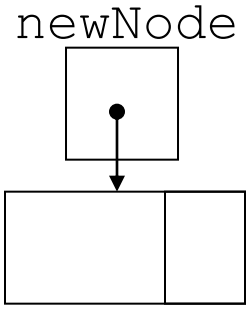
Contents of **`NumberList.h`** (Continued)

```
17  public:
18     // Constructor
19     NumberList()
20        { head = NULL; }
21
22     // Destructor
23     ~NumberList();
24
25     // Linked list operations
26     void appendNode(double);
27     void insertNode(double);
28     void deleteNode(double);
29     void displayList() const;
30  };
31  #endif
```

Create a New Node

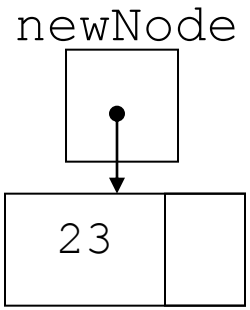
- Allocate memory for the new node:

```
newNode = new ListNode;
```



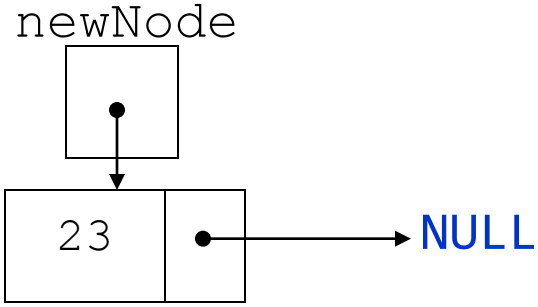
- Initialize the contents of the node:

```
newNode->value = num;
```



- Set the pointer field to `NULL`:

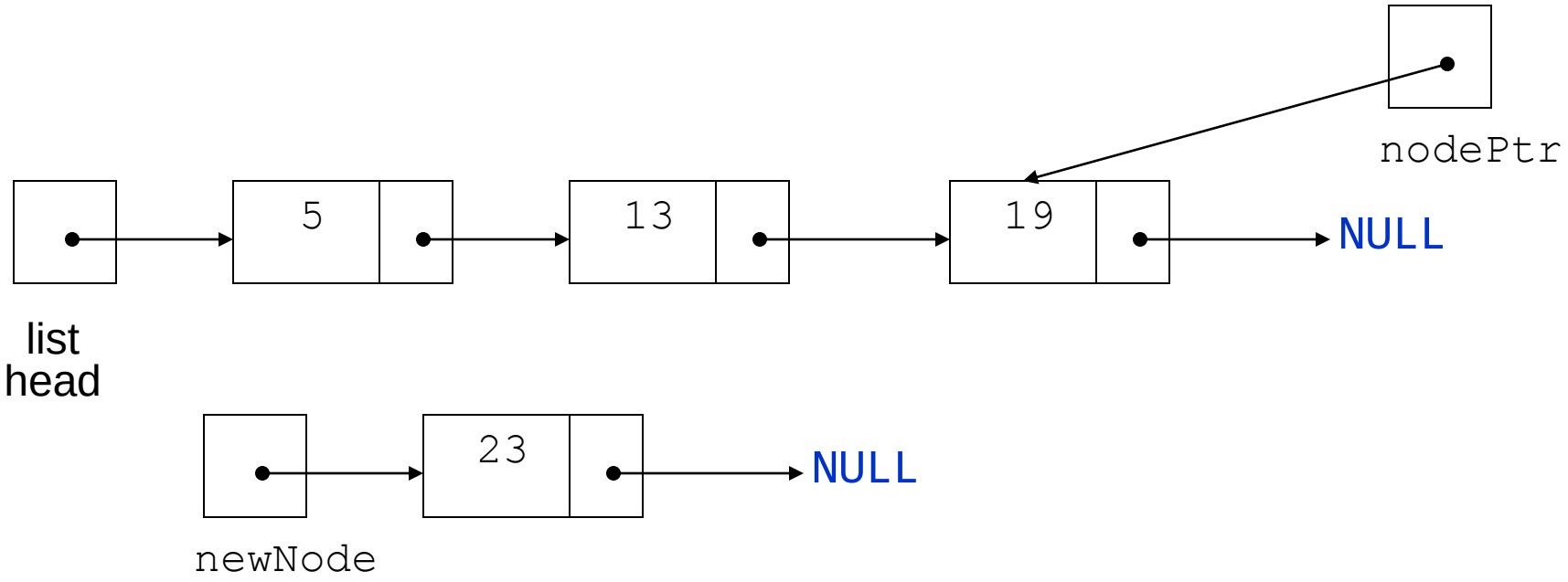
```
newNode->next = NULL;
```



Appending a Node

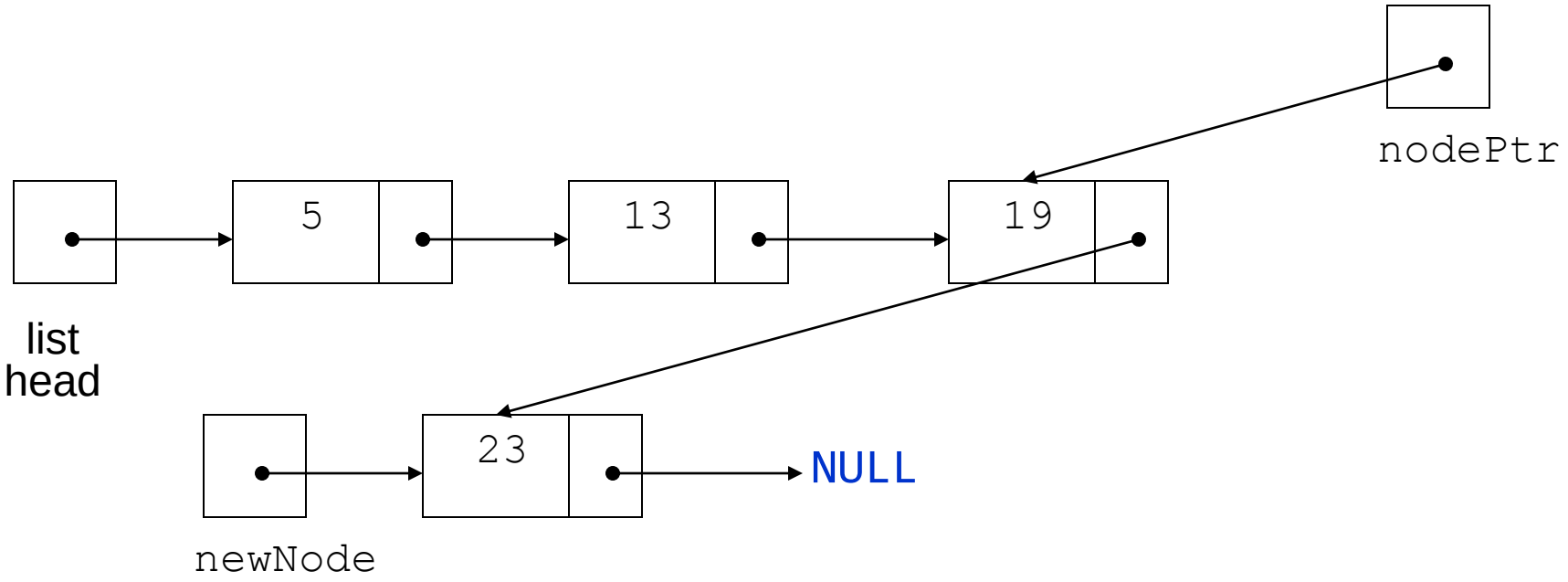
- Add a node to the end of the list
- Basic process:
  - Create the new node (as already described)
  - Add node to the end of the list:
    - If list is empty, set head pointer to this node
    - Else:
      - traverse the list to the end
      - set pointer of last node to point to new node

Appending a Node



New node created, end of list located

Appending a Node



New node added to end of list

C++ code for Appending a Node

```
11  void NumberList::appendNode(double num)
12  {
13     ListNode *newNode;  // To point to a new node
14     ListNode *nodePtr;  // To move through the list
15
16     // Allocate a new node and store num there.
17     newNode = new ListNode;
18     newNode->value = num;
19     newNode->next = NULL;
20
21     // If there are no nodes in the list
22     // make newNode the first node.
23     if (!head)
```

C++ code for Appending a Node (Continued)

```
24          head = newNode;
25       else  // Otherwise, insert newNode at end.
26       {
27          // Initialize nodePtr to head of list.
28          nodePtr = head;
29
30          // Find the last node in the list.
31          while (nodePtr->next)
32             nodePtr = nodePtr->next;
33
34          // Insert newNode as the last node.
35          nodePtr->next = newNode;
36       }
37    }
```

Program 17-1

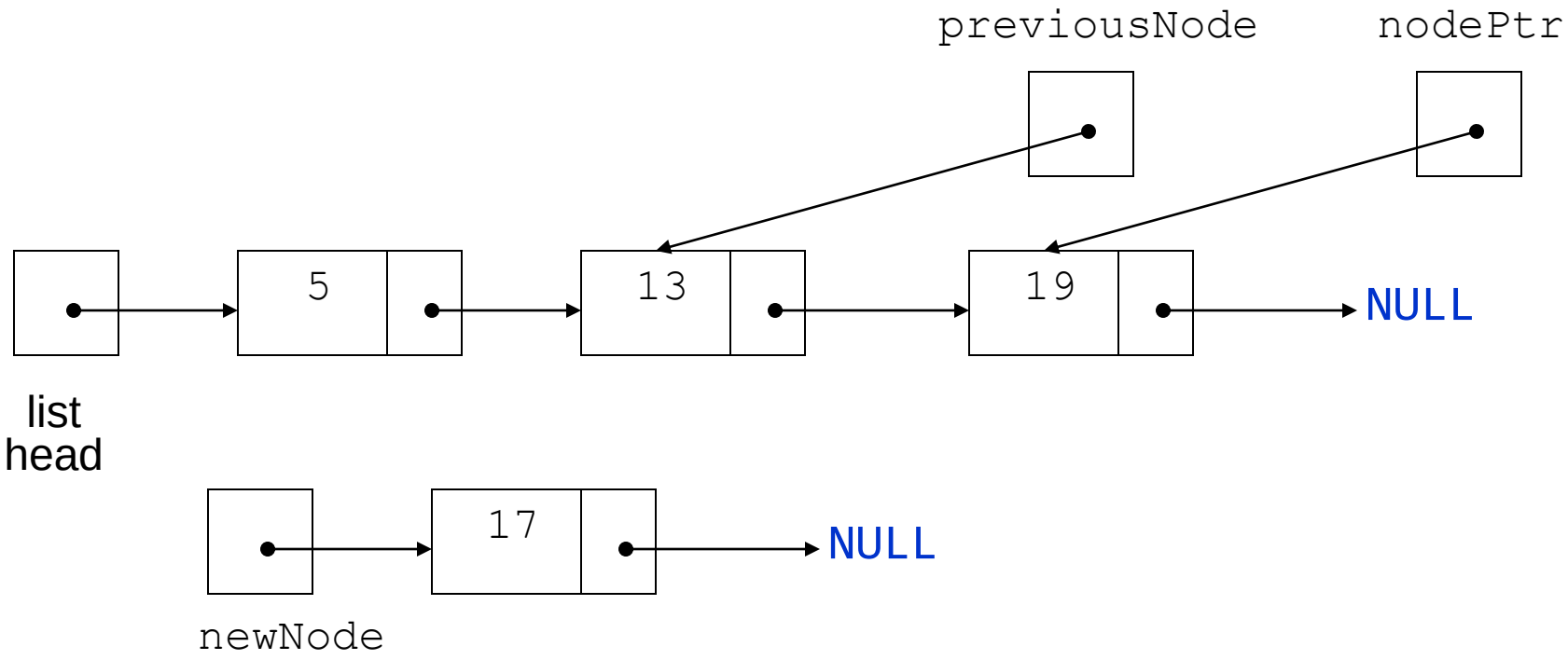
```
1  // This program demonstrates a simple append
2  // operation on a linked list.
3  #include <iostream>
4  #include "NumberList.h"
5  using namespace std;
6
7  int main()
8  {
9     // Define a NumberList object.
10    NumberList list;
11
12    // Append some values to the list.
13    list.appendNode(2.5);
14    list.appendNode(7.9);
15    list.appendNode(12.6);
16    return 0;
17 }
```

(This program displays no output.)

Inserting a Node into a Linked List

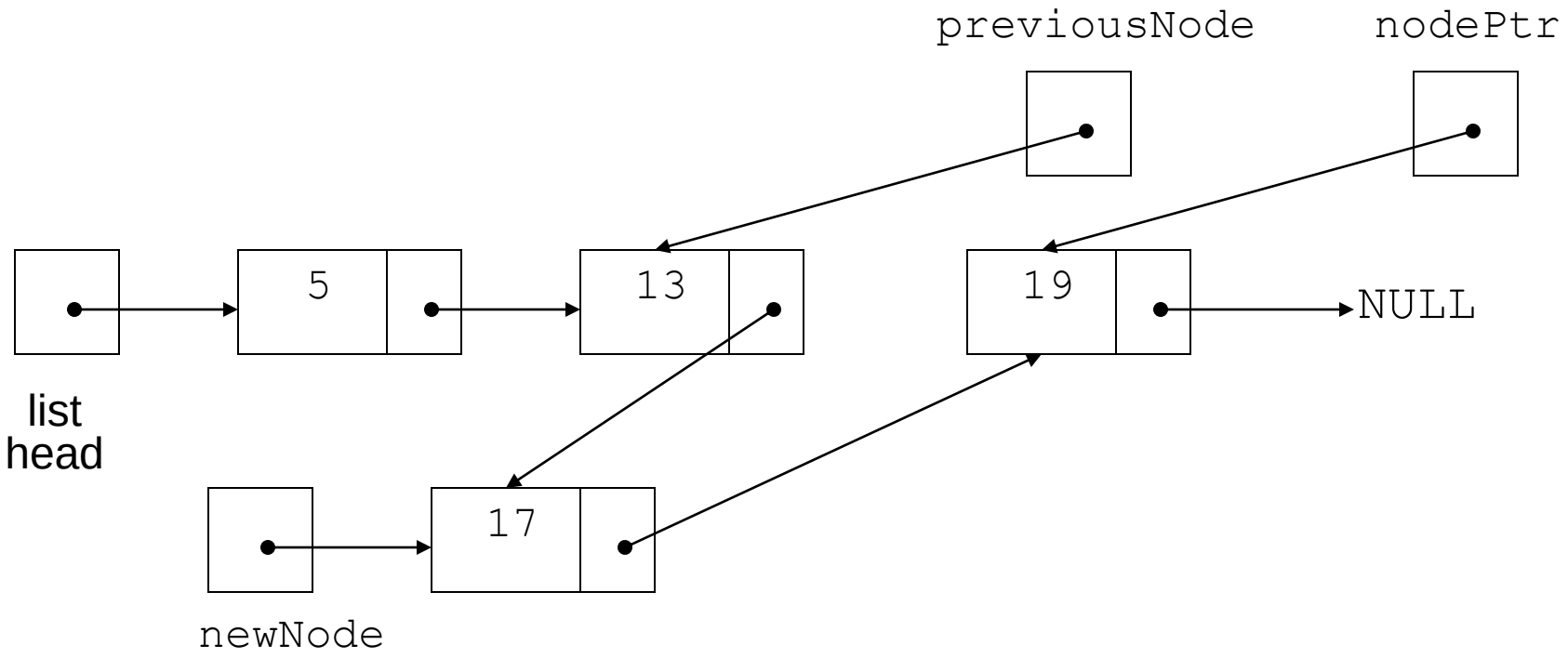
- Used to maintain a linked list in order
- Requires two pointers to traverse the list:
  - pointer to locate the node with data value greater than that of node to be inserted
  - pointer to 'trail behind' one node, to point to node before point of insertion
- New node is inserted between the nodes pointed at by these pointers

Inserting a Node into a Linked List



New node created, correct position located

Inserting a Node into a Linked List



New node inserted in order in the linked list

```
69  void NumberList::insertNode(double num)
70  {
71     ListNode *newNode;              // A new node
72     ListNode *nodePtr;              // To traverse the list
73     ListNode *previousNode = NULL; // The previous node
74
75     // Allocate a new node and store num there.
76     newNode = new ListNode;
77     newNode->value = num;
78
79     // If there are no nodes in the list
80     // make newNode the first node
81     if (!head)
82     {
83        head = newNode;
84        newNode->next = NULL;
85     }
86     else  // Otherwise, insert newNode
87     {
88        // Position nodePtr at the head of list.
89        nodePtr = head;
90
```

```
91          // Initialize previousNode to NULL.
92          previousNode = NULL;
93
94          // Skip all nodes whose value is less than num.
95          while (nodePtr != NULL && nodePtr->value < num)
96          {
97             previousNode = nodePtr;
98             nodePtr = nodePtr->next;
99          }
100
101         // If the new node is to be the 1st in the list,
102         // insert it before all other nodes.
103         if (previousNode == NULL)
104         {
```

```
105             head = newNode;
106             newNode->next = nodePtr;
107          }
108          else  // Otherwise insert after the previous node.
109          {
110             previousNode->next = newNode;
111             newNode->next = nodePtr;
112          }
113       }
114    }
```

Program 17-3

```
1  // This program demonstrates the insertNode member function.
2  #include <iostream>
3  #include "NumberList.h"
4  using namespace std;
5
6  int main()
7  {
8     // Define a NumberList object.
9     NumberList list;
10
11    // Build the list with some values.
12    list.appendNode(2.5);
13    list.appendNode(7.9);
14    list.appendNode(12.6);
15
16    // Insert a node in the middle of the list.
17    list.insertNode(10.5);
18
19    // Dispay the list
20    list.displayList();
21    return 0;
22 }
```

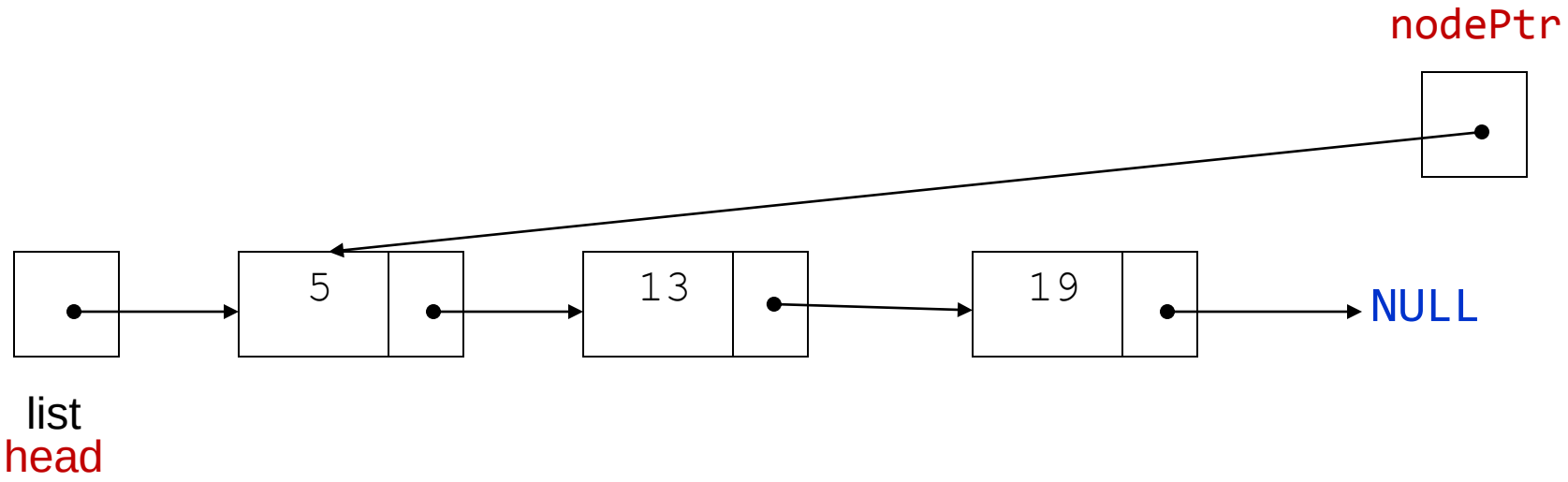
Program Output

```
2.5
7.9
10.5
12.6
```

Traversing a Linked List

- Visit each node in a linked list:
  - display contents, validate data, etc.
- Basic process:
  - set a pointer to the contents of the head pointer
  - while pointer is not `NULL`
    - process data
    - go to the next node by setting the pointer to the pointer field of the current node in the list
  - end while

Traversing a Linked List

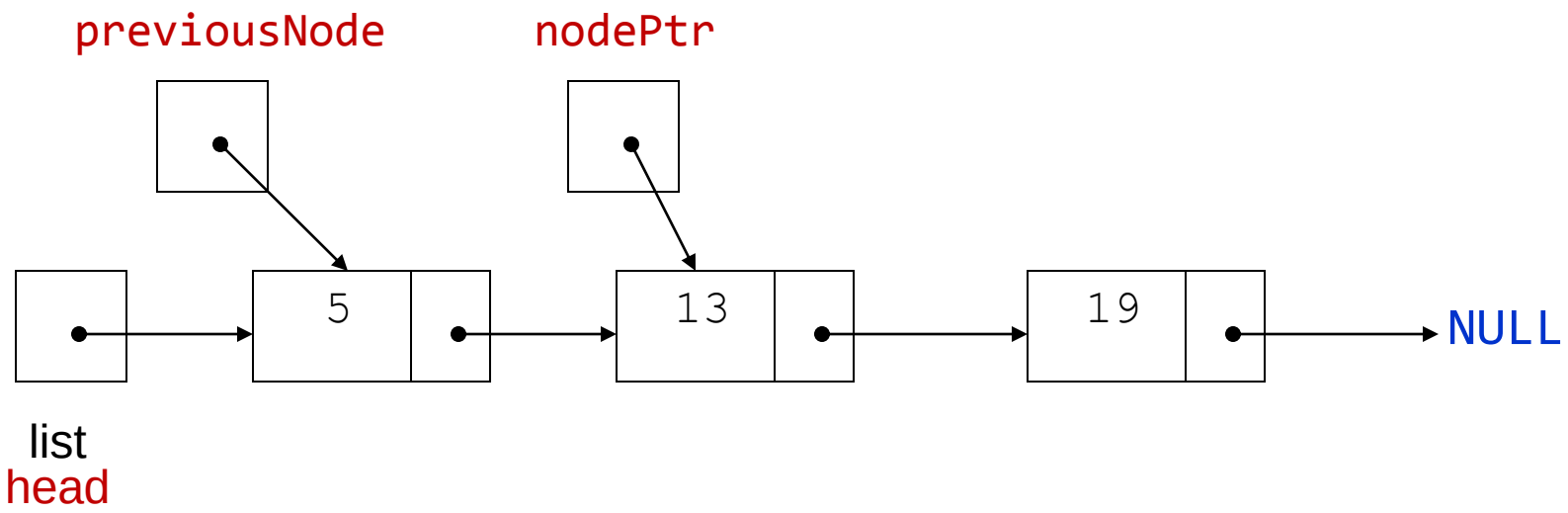


nodePtr points to the node containing **5**, then the node containing **13**, then the node containing **19**, then points to NULL, and the list traversal stops

Deleting a Node

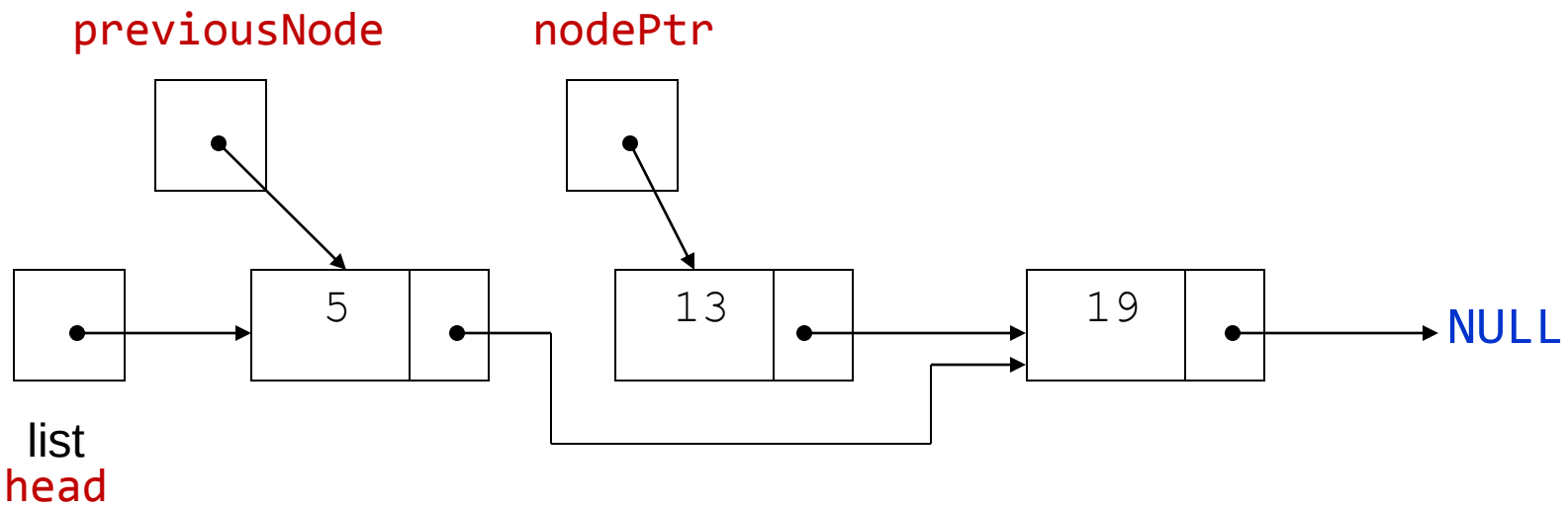
- Used to remove a node from a linked list
- If list uses dynamic memory, then delete node from memory `delete ptr;`
- Requires two pointers
  - one to locate the node to be deleted
  - one to point to the node before the node to be deleted

Deleting a Node



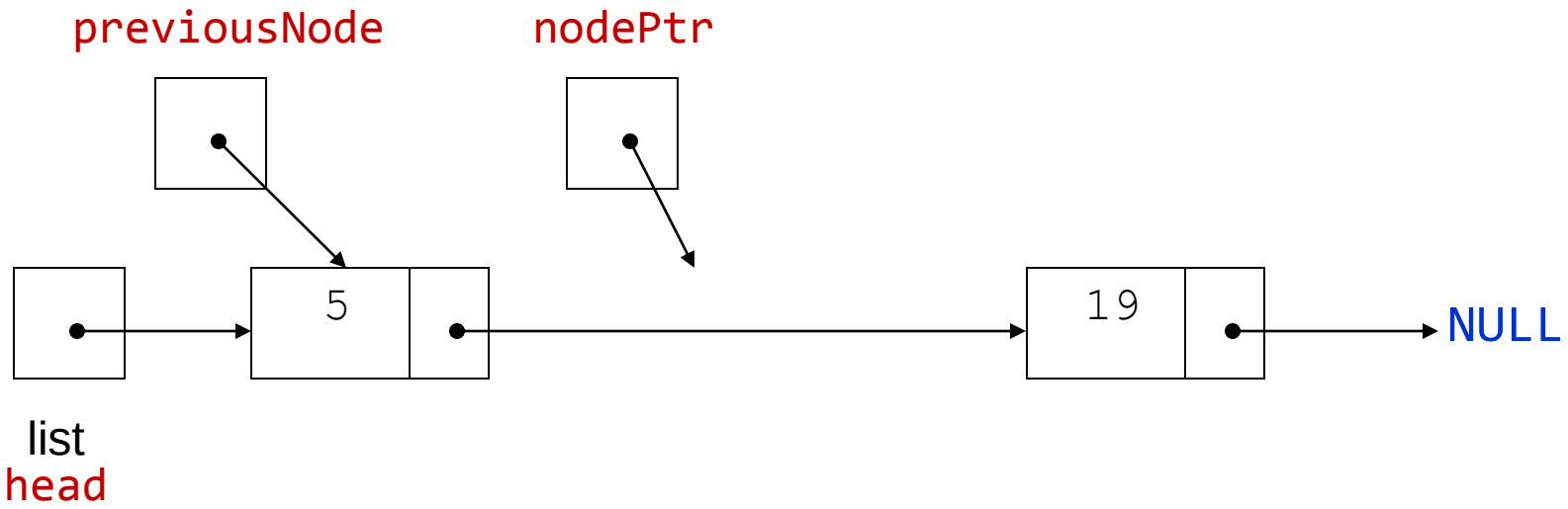
Locating the node containing `13` and `delete it`

Deleting a Node



Adjusting pointer around the node to be deleted

Deleting a Node



Linked list after deleting the node containing `13`

```
122 void NumberList::deleteNode(double num)
123 {
124    ListNode *nodePtr;       // To traverse the list
125    ListNode *previousNode;  // To point to the previous node
126
127    // If the list is empty, do nothing.
128    if (!head)
129       return;
130
131    // Determine if the first node is the one.
132    if (head->value == num)
133    {
134       nodePtr = head->next;
135       delete head;
136       head = nodePtr;
137    }
138    else
139    {
```

```
139     {
140        // Initialize nodePtr to head of list
141        nodePtr = head;
142
143        // Skip all nodes whose value member is
144        // not equal to num.
145        while (nodePtr != NULL && nodePtr->value != num)
146        {
147           previousNode = nodePtr;
148           nodePtr = nodePtr->next;
149        }
150
151        // If nodePtr is not at the end of the list,
152        // link the previous node to the node after
153        // nodePtr, then delete nodePtr.
154        if (nodePtr)
155        {
156           previousNode->next = nodePtr->next;
157           delete nodePtr;
158        }
159     }
160  }
```

Program 17-4

```
1  // This program demonstrates the deleteNode member function.
2  #include <iostream>
3  #include "NumberList.h"
4  using namespace std;
5
6  int main()
7  {
8     // Define a NumberList object.
9     NumberList list;
10
11    // Build the list with some values.
12    list.appendNode(2.5);
13    list.appendNode(7.9);
14    list.appendNode(12.6);
15
16    // Display the list.
17    cout << "Here are the initial values:\n";
18    list.displayList();
19    cout << endl;
20
```

```
21      // Delete the middle node.
22      cout << "Now deleting the node in the middle.\n";
23      list.deleteNode(7.9);
24
25      // Display the list.
26      cout << "Here are the nodes left.\n";
27      list.displayList();
28      cout << endl;
29
30      // Delete the last node.
31      cout << "Now deleting the last node.\n";
32      list.deleteNode(12.6);
33
34      // Display the list.
35      cout << "Here are the nodes left.\n";
36      list.displayList();
37      cout << endl;
38
```

```
39      // Delete the only node left in the list.
40      cout << "Now deleting the only remaining node.\n";
41      list.deleteNode(2.5);
42
43      // Display the list.
44      cout << "Here are the nodes left.\n";
45      list.displayList();
46      return 0;
47  }
```

Program 17-4 *(continued)*

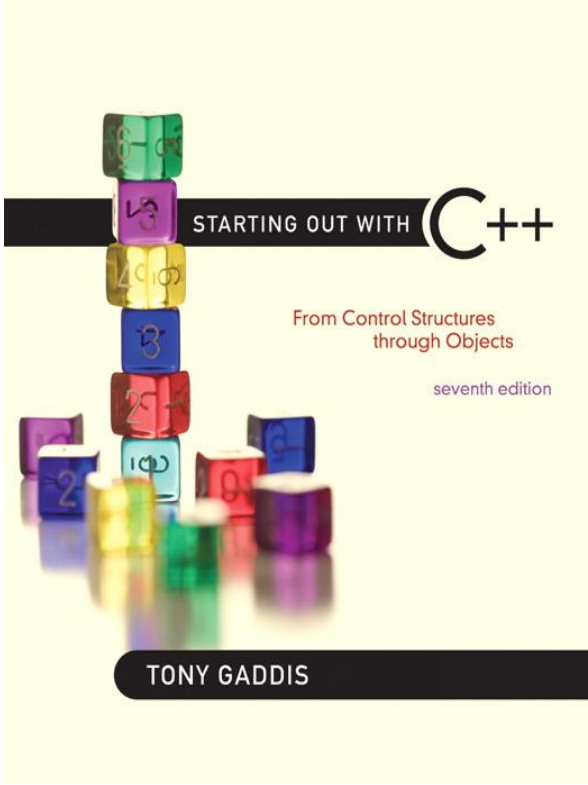
Program Output

```
Here are the initial values:
2.5
7.9
12.6

Now deleting the node in the middle.
Here are the nodes left.
2.5
12.6

Now deleting the last node.
Here are the nodes left.
2.5

Now deleting the only remaining node.
Here are the nodes left.
```

Destroying (deleting) a Linked List

- Must remove all nodes used in the list
- To do this, use list traversal to visit each node
- For each node,
  - Unlink the node from the list
  - If the list uses dynamic memory, then free the node's memory
- Set the list head to `NULL`

```
167 NumberList::~NumberList()
168 {
169    ListNode *nodePtr;   // To traverse the list
170    ListNode *nextNode;  // To point to the next node
171
172    // Position nodePtr at the head of the list.
173    nodePtr = head;
174
175    // While nodePtr is not at the end of the list...
176    while (nodePtr != NULL)
177    {
178       // Save a pointer to the next node.
179       nextNode = nodePtr->next;
180
181       // Delete the current node.
182       delete nodePtr;
183
184       // Position nodePtr at the next node.
185       nodePtr = nextNode;
186    }
187 }
```

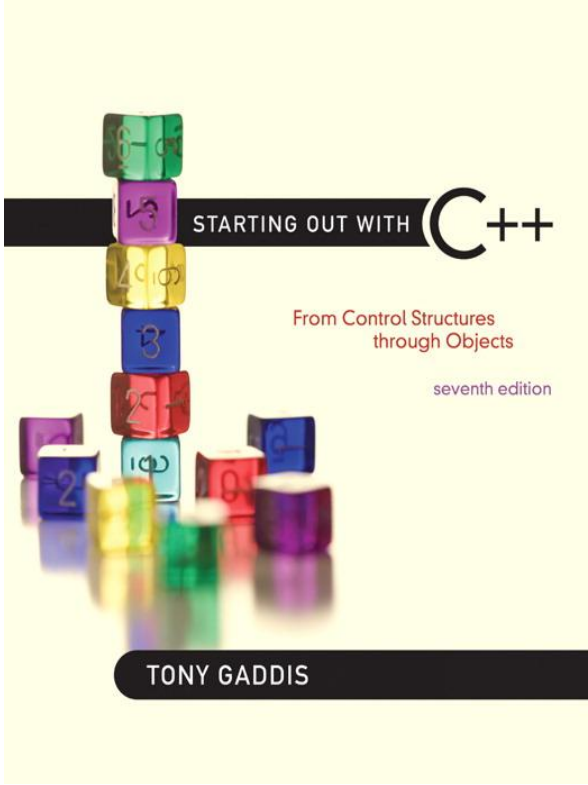


17.3

A Linked List Template

A Linked List Template

- When declaring a linked list, you must specify the type of data to be held in each node
- Using templates, you can declare a linked list that can hold the data type determined at list definition time
- See `LinkedList.h` (versions 1 and 2) and Program 17-5



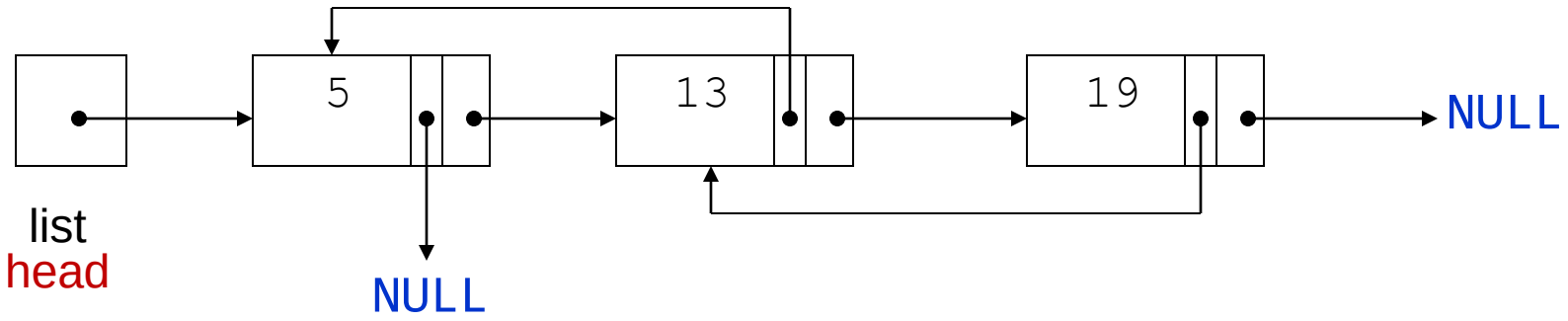
17.4

Variations of the Linked List

Variations of the Linked List

Other linked list organizations:

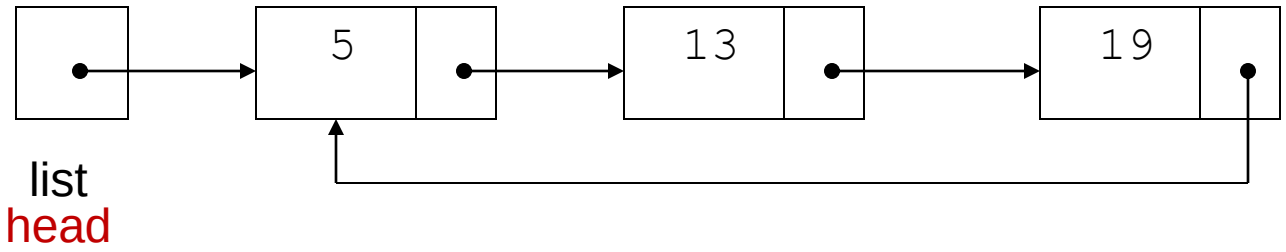
- doubly-linked list
  - each node contains two pointers: one to the next node in the list, one to the previous node in the list

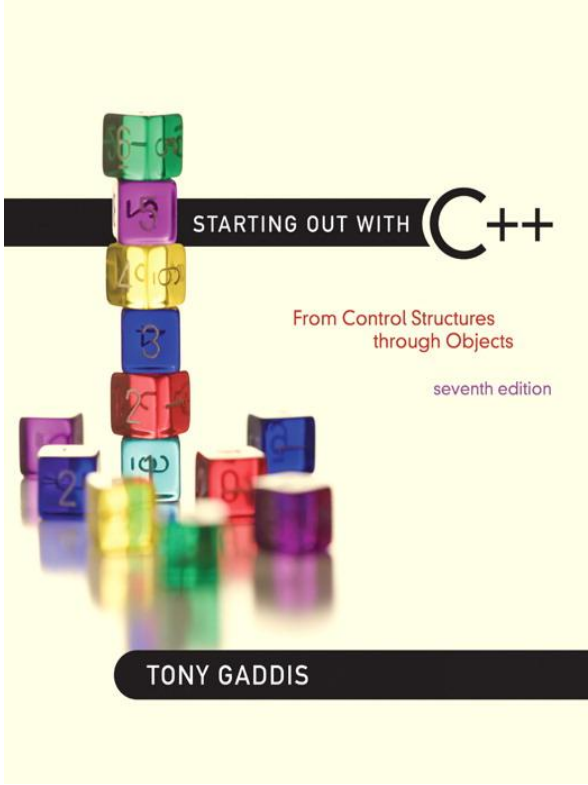


Variations of the Linked List

Other linked list organizations

- circular linked list:
  - the last node in the list points back to the first node in the list, not to `NULL`





17.5

The STL `list` Container

The STL `list` Container

```
#include <list>
#include <algorithm>
```

- Template for a doubly-linked list
- Member functions for
  - locating beginning, end of list:
    - `front, back //references`
    - `begin, end  //iterators`
  - adding elements to the list:
    - `insert, merge, push_back, push_front`
  - removing elements from the list:
    - `erase, pop_back, pop_front, unique`
- See Table 17-1 for a list of member functions