Chapter 12

Data Structures

Chapter 12 – Data Structures

Outline

Objectives

- In this chapter, you will learn:
  - To be able to allocate and free memory dynamically for data objects.
  - To be able to form linked data structures using pointers, self-referential structures and recursion.
  - To be able to create and manipulate linked lists, queues, stacks and binary trees.
  - To understand various important applications of linked data structures.

12.1 Introduction

- Dynamic data structures
  - Data structures that grow and shrink during execution
- Linked lists
  - Allow insertions and removals anywhere
- Stacks
  - Allow insertions and removals only at top of stack
- Queues
  - Allow insertions at the back and removals from the front
- Binary trees
  - High-speed searching and sorting of data and efficient elimination of duplicate data items

12.2 Self-Referential Structures

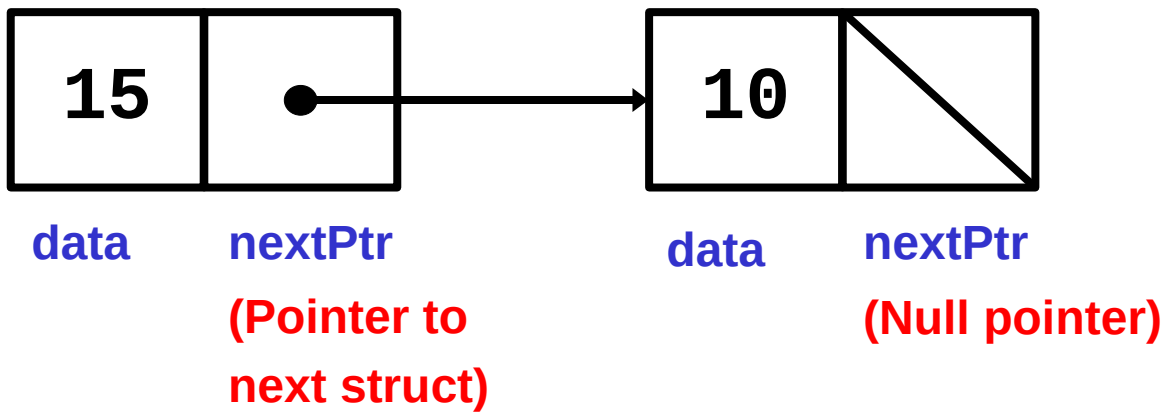
- Self-referential structures
  - Structure that contains a pointer to a structure of the same type
  - Can be linked together to form useful data structures such as lists, queues, stacks and trees
  - Terminated with a `NULL` pointer

```
struct node {
   int data;
   struct node * nextPtr;
}
```

- `nextPtr`
  - Points to an object of type node
  - Referred to as a link
    - Ties one node to another **node** (similar to a chain)

12.3 Dynamic Memory Allocation

Figure 12.1 Two self-referential structures linked together



12.3 Dynamic Memory Allocation

- Dynamic memory allocation
  - Obtain and release memory during execution
- `malloc`
  - Takes number of bytes to allocate
    - Use `sizeof` to determine the size of an object
  - Returns pointer of type `void *`
    - A `void *` pointer may be assigned to any pointer
    - If no memory available, returns `NULL`
  - Example

```
newPtr = malloc( sizeof( struct node ) );
```

- `free`
  - Deallocates memory allocated by `malloc`
  - Takes a pointer as an argument

```
free ( newPtr );
```

12.4 Linked Lists

- Linked list
  - Linear collection of self-referential class objects, called **nodes**
  - Connected by pointer links
  - Accessed via a pointer to the first node of the list
  - Subsequent nodes are accessed via the link-pointer member of the current node
  - Link pointer in the last node is set to `NULL` to mark the list's end
- Use a linked list instead of an array when
  - You have an unpredictable number of data elements
  - Your list needs to be sorted quickly

12.4 Linked Lists

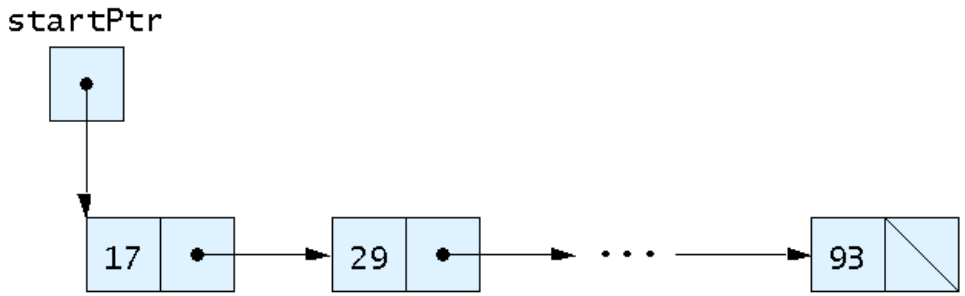
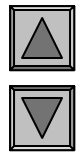


Fig. 12.2 A graphical representation of a linked list.

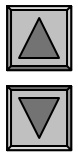


Outline

fig12_03.c (Part 1 of 8)

```
1  /* Fig. 12.3: fig12_03.c
2     Operating and maintaining a list */
3  #include <stdio.h>
4  #include <stdlib.h>
5
6  /* self-referential structure */
7  struct listNode {
8     char data;                /* define data as char */
9     struct listNode *nextPtr; /* listNode pointer */
10 }; /* end structure listNode */
11
12 typedef struct listNode ListNode;
13 typedef ListNode * ListNodePtr;
14
15 /* prototypes */
16 void insert( ListNodePtr *sPtr, char value );
17 char delete( ListNodePtr *sPtr, char value );
18 int isEmpty( ListNodePtr sPtr );
19 void printList( ListNodePtr currentPtr );
20 void instructions( void );
21
22 int main()
23 {
```

In insert() and delete() functions, sPtr is defined as a pointer to pointer, because its content may be changed during the operation.



Outline

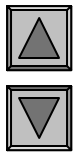
fig12_03.c (Part 2 of 8)

```
24    ListNodePtr startPtr = NULL; /* initialize startPtr */
25    int choice;                  /* user's choice */
26    char item;                   /* char entered by user */
27
28    instructions(); /* display the menu */
29    printf( "? " );
30    scanf( "%d", &choice );
31
32    /* loop while user does not choose 3 */
33    while ( choice != 3 ) {
34
35       switch ( choice ) {
36
37          case 1:
38             printf( "Enter a character: " );
39             scanf( "\n%c", &item );
40             insert( &startPtr, item );
41             printList( startPtr );
42             break;
43
44          case 2:
45
46             /* if list is not empty */
47             if ( !isEmpty( startPtr ) ) {
48                printf( "Enter character to be deleted: " );
49                scanf( "\n%c", &item );
50
```

Outline

fig12_03.c (Part 3 of 8)

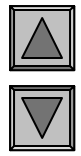
```
51                /* if character is found */
52                if ( delete( &startPtr, item ) ) {
53                   printf( "%c deleted.\n", item );
54                   printList( startPtr );
55                } /* end if */
56                else {
57                   printf( "%c not found.\n\n", item );
58                } /* end else */
59
60             } /* end if */
61             else {
62                printf( "List is empty.\n\n" );
63             } /* end else */
64
65             break;
66
67          default:
68             printf( "Invalid choice.\n\n" );
69             instructions();
70             break;
71
72       } /* end switch */
73
```



Outline

fig12_03.c (Part 4 of 8)

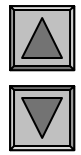
```
74       printf( "? " );
75       scanf( "%d", &choice );
76    } /* end while */
77
78    printf( "End of run.\n" );
79
80    return 0; /* indicates successful termination */
81
82 } /* end main */
83
84 /* display program instructions to user */
85 void instructions( void )
86 {
87    printf( "Enter your choice:\n"
88            "   1 to insert an element into the list.\n"
89            "   2 to delete an element from the list.\n"
90            "   3 to end.\n" );
91 } /* end function instructions */
92
93 /* Insert a new value into the list in sorted order */
94 void insert( ListNodePtr *sPtr, char value )
95 {
96    ListNodePtr newPtr;      /* pointer to new node */
97    ListNodePtr previousPtr; /* pointer to previous node in list */
98    ListNodePtr currentPtr;  /* pointer to current node in list */
99
```



Outline

fig12_03.c (Part 5 of 8)

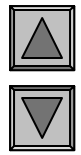
```
100    newPtr = malloc( sizeof( ListNode ) );
101
102    if ( newPtr != NULL ) {     /* is space available */
103       newPtr->data = value;
104       newPtr->nextPtr = NULL;
105
106       previousPtr = NULL;
107       currentPtr = *sPtr;
108
109       /* loop to find the correct location in the list (By Alphabetical Order)
*/
110       while ( currentPtr != NULL && value > currentPtr->data ) {
111          previousPtr = currentPtr;          /* walk to ...   */
112          currentPtr = currentPtr->nextPtr;  /* ... next node */
113       } /* end while */
114
115       /* Situation #1 : insert newPtr at beginning of list */
116       if ( previousPtr == NULL ) {
117          newPtr->nextPtr = *sPtr;
118          *sPtr = newPtr;
119       } /* end if */
120       else {/*Situation #2 : insert newPtr between previousPtr and currentPtr*/
121          previousPtr->nextPtr = newPtr;
122          newPtr->nextPtr = currentPtr;
123       } /* end else */
124
```



Outline

fig12_03.c (Part 6 of 8)

```
125    } /* end if */
126    else {
127       printf( "%c not inserted. No memory available.\n", value );
128    } /* end else */
129
130 } /* end function insert */
131
132 /* Delete a list element */
133 char delete( ListNodePtr *sPtr, char value )
134 {
135    ListNodePtr previousPtr; /* pointer to previous node in list */
136    ListNodePtr currentPtr;  /* pointer to current node in list */
137    ListNodePtr tempPtr;     /* temporary node pointer */
138
139    /* Situation #1 : delete first node */
140    if ( value == ( *sPtr )->data ) {
141       tempPtr = *sPtr;
142       *sPtr = ( *sPtr )->nextPtr;  /* de-thread the node */
143       free( tempPtr );             /* free the de-threaded node */
144       return value;
145    } /* end if */
146    else {
147       previousPtr = *sPtr;
148       currentPtr = ( *sPtr )->nextPtr;
149
```

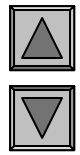


Outline

fig12_03.c (Part 7 of 8)

```
150       /* loop to find the correct location in the list */
151       while ( currentPtr != NULL && currentPtr->data != value ) {
152          previousPtr = currentPtr;          /* walk to ...   */
153          currentPtr = currentPtr->nextPtr;  /* ... next node */
154       } /* end while */
155
156       /* Situation #2 : delete node at currentPtr */
157       if ( currentPtr != NULL ) {
158          tempPtr = currentPtr;
159          previousPtr->nextPtr = currentPtr->nextPtr;
160          free( tempPtr );
161          return value;
162       } /* end if */
163
164    } /* end else */
165
166    return '\0';
167
168 } /* end function delete */
169
170 /* Return 1 if the list is empty, 0 otherwise */
171 int isEmpty( ListNodePtr sPtr )
172 {
173    return sPtr == NULL;
174
175 } /* end function isEmpty */
176
```

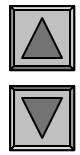
```
if (sPtr == NULL)
   return 1
else
   return 0;
```



Outline

fig12_03.c (Part 8 of 8)

```
177 /* Print the list */
178 void printList( ListNodePtr currentPtr )
179 {
180
181    /* if list is empty */
182    if ( currentPtr == NULL ) {
183       printf( "List is empty.\n\n" );
184    } /* end if */
185    else {
186       printf( "The list is:\n" );
187
188       /* while not the end of the list, visit nodes one by one */
189       while ( currentPtr != NULL ) {
190          printf( "%c --> ", currentPtr->data );
191          currentPtr = currentPtr->nextPtr;
192       } /* end while */
193
194       printf( "NULL\n\n" );
195    } /* end else */
196
197 } /* end function printList */
```



Outline

Program Output (Part 1 of 2)

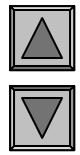
```
Enter your choice:
   1 to insert an element into the list.
   2 to delete an element from the list.
   3 to end.
? 1
Enter a character: B
The list is:
B --> NULL

? 1
Enter a character: A
The list is:
A --> B --> NULL

? 1
Enter a character: C
The list is:
A --> B --> C --> NULL

? 2
Enter character to be deleted: D
D not found.

? 2
Enter character to be deleted: B
B deleted.
The list is:
A --> C --> NULL
```



Outline

Program Output (Part 2 of 2)

```
? 2
Enter character to be deleted: C
C deleted.
The list is:
A --> NULL

? 2
Enter character to be deleted: A
A deleted.
List is empty.

? 4
Invalid choice.

Enter your choice:
   1 to insert an element into the list.
   2 to delete an element from the list.
   3 to end.
? 3
End of run.
```

12.4 Linked Lists (Inserting a node)

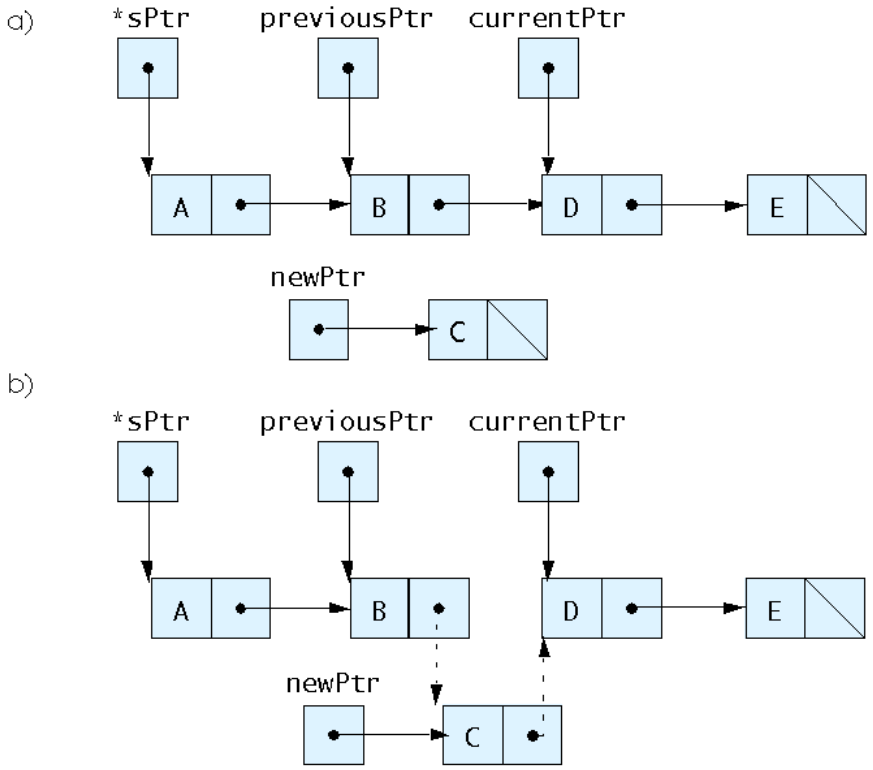


Fig. 12.5 Inserting a node in order in a list.

12.4 Linked Lists (Deleting a node)

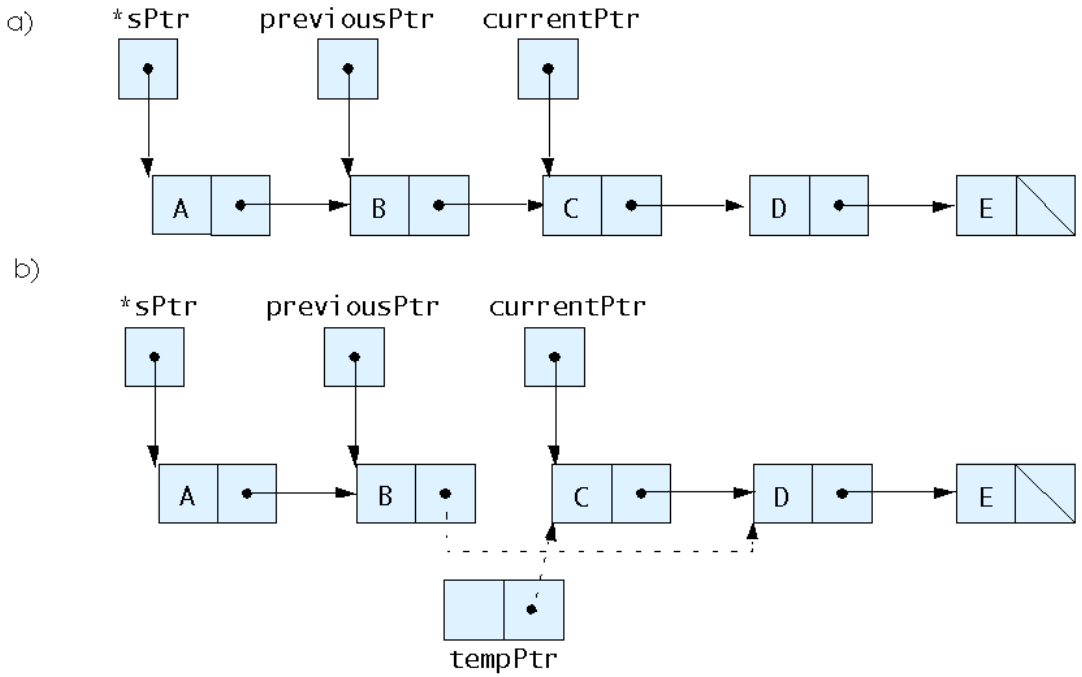


Fig. 12.6 Deleting a node from a list.

12.5 Stacks

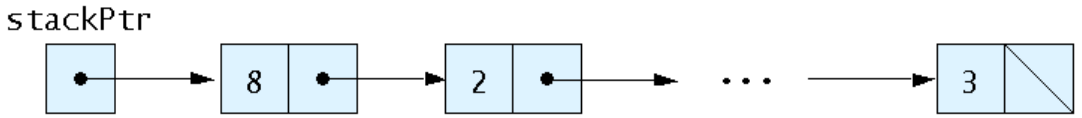
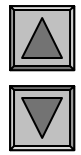


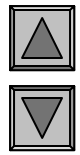
Fig. 12.7 Graphical representation of a stack.



Outline

fig12_08.c (Part 1 of 6)

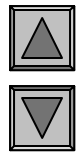
```
1  /* Fig. 12.8: fig12_08.c
2     dynamic stack program */
3  #include <stdio.h>
4  #include <stdlib.h>
5
6  /* self-referential structure */
7  struct stackNode {
8     int data;                 /* define data as an int */
9     struct stackNode *nextPtr; /* stackNode pointer */
10 }; /* end structure stackNode */
11
12 typedef struct stackNode StackNode;
13 typedef StackNode *StackNodePtr;
14
15 /* prototypes */
16 void push( StackNodePtr *topPtr, int info ); // Push means Insert a node
17 int pop( StackNodePtr *topPtr ); // Pop means Delete a node
18 int isEmpty( StackNodePtr topPtr );
19 void printStack( StackNodePtr currentPtr );
20 void instructions( void );
21
22 /* function main begins program execution */
23 int main()
24 {
25    StackNodePtr stackPtr = NULL;  /* points to stack top */
26    int choice;                    /* user's menu choice */
27    int value;                     /* int input by user */
28
```



Outline

fig12_08.c (Part 2 of 6)

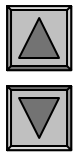
```
29    instructions(); /* display the menu */
30    printf( "? " );
31    scanf( "%d", &choice );
32
33    /* while user does not enter 3 */
34    while ( choice != 3 ) {
35
36       switch ( choice ) {
37
38          /* push value onto stack */
39          case 1:
40             printf( "Enter an integer: " );
41             scanf( "%d", &value );
42             push( &stackPtr, value );
43             printStack( stackPtr );
44             break;
45
46          /* pop value off stack */
47          case 2:
48
49             /* if stack is not empty */
50             if ( !isEmpty( stackPtr ) ) {
51                printf( "The popped value is %d.\n", pop( &stackPtr ) );
52             } /* end if */
53
```



Outline

fig12_08.c (Part 3 of 6)

```
54            printStack( stackPtr );
55            break;
56
57         default:
58            printf( "Invalid choice.\n\n" );
59            instructions();
60            break;
61
62      } /* end switch */
63
64      printf( "? " );
65      scanf( "%d", &choice );
66   } /* end while */
67
68   printf( "End of run.\n" );
69
70   return 0; /* indicates successful termination */
71
72 } /* end main */
73
74 /* display program instructions to user */
75 void instructions( void )
76 {
77    printf( "Enter choice:\n"
78            "1 to push a value on the stack\n"
79            "2 to pop a value off the stack\n"
80            "3 to end program\n" );
81 } /* end function instructions */
82
```



Outline

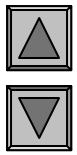
fig12_08.c (Part 4 of 6)

```
83 /* Insert a node at the stack top */
84 void push( StackNodePtr *topPtr, int info )
85 {
86    StackNodePtr newPtr; /* pointer to new node */
87
88    newPtr = malloc( sizeof( StackNode ) );
89
90    /* insert the node at stack top */
91    if ( newPtr != NULL ) {
92       newPtr->data = info;
93       newPtr->nextPtr = *topPtr;
94       *topPtr = newPtr;
95    } /* end if */
96    else { /* no space available */
97       printf( "%d not inserted. No memory available.\n", info );
98    } /* end else */
99
100 } /* end function push */
101
102 /* Remove a node from the stack top */
103 int pop( StackNodePtr *topPtr )
104 {
105    StackNodePtr tempPtr; /* temporary node pointer */
106    int popValue;         /* node value */
107
```

Outline

fig12_08.c (Part 5 of 6)

```
108    tempPtr = *topPtr;
109    popValue = ( *topPtr )->data;
110    *topPtr = ( *topPtr )->nextPtr;
111    free( tempPtr );
112
113    return popValue;
114
115 } /* end function pop */
116
117 /* Print the stack */
118 void printStack( StackNodePtr currentPtr )
119 {
120
121    /* if stack is empty */
122    if ( currentPtr == NULL ) {
123       printf( "The stack is empty.\n\n" );
124    } /* end if */
125    else {
126       printf( "The stack is:\n" );
127
128       /* while not the end of the stack */
129       while ( currentPtr != NULL ) {
130          printf( "%d --> ", currentPtr->data );
131          currentPtr = currentPtr->nextPtr;
132       } /* end while */
133
```



Outline

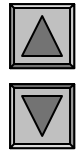
```
134       printf( "NULL\n\n" );
135    } /* end else */
136
137 } /* end function printList */
138
139 /* Return 1 if the stack is empty, 0 otherwise */
140 int isEmpty( StackNodePtr topPtr )
141 {
142    return topPtr == NULL;
143
144 } /* end function isEmpty */
```

fig12_08.c (Part 6 of 6)

Program Output (Part 1 of 2)

```
Enter choice:
1 to push a value on the stack
2 to pop a value off the stack
3 to end program
? 1
Enter an integer: 5
The stack is:
5 --> NULL

? 1
Enter an integer: 6
The stack is:
6 --> 5 --> NULL
```



Outline

Program Output (Part 2 of 2)

```
? 1
Enter an integer: 4
The stack is:
4 --> 6 --> 5 --> NULL

? 2
The popped value is 4.
The stack is:
6 --> 5 --> NULL

? 2
The popped value is 6.
The stack is:
5 --> NULL

? 2
The popped value is 5.
The stack is empty.

? 2
The stack is empty.

? 4
Invalid choice.

Enter choice:
1 to push a value on the stack
2 to pop a value off the stack
3 to end program
? 3
End of run.
```

12.5 Stacks

- Stack
  - New nodes can be added and removed only at the top
  - Similar to a pile of dishes
  - Last-in, first-out **(LIFO)**
  - Bottom of stack indicated by a link member to `NULL`
  - Constrained version of a linked list
- `push`
  - Adds a new node to the top of the stack
- `pop`
  - Removes a node from the top
  - Stores the popped value
  - Returns `true` if `pop` was successful

12.5 Stacks (push)

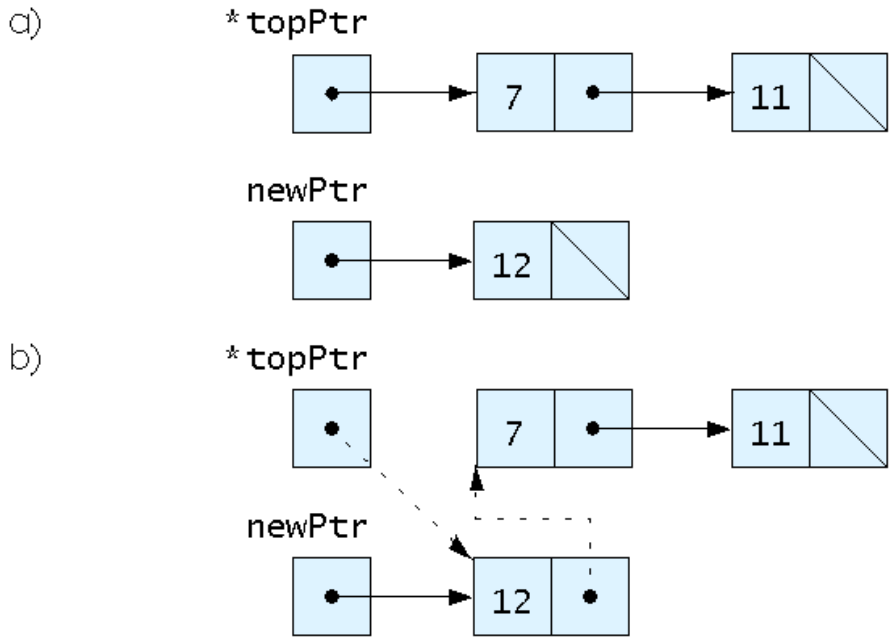


Fig. 12.10 push operation.

12.5 Stacks (pop)

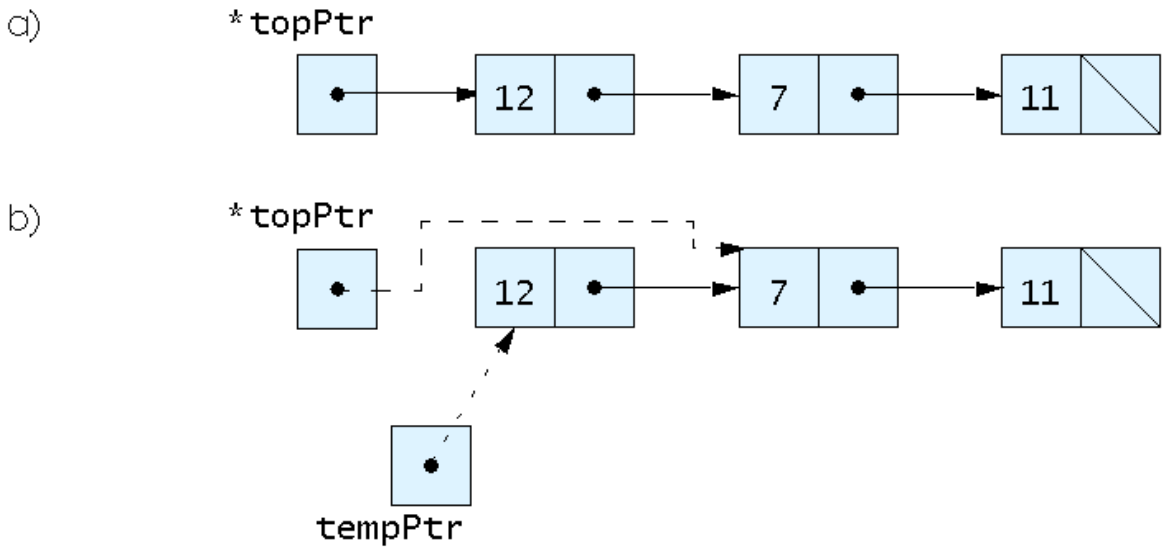


Fig. 12.11 pop operation.

12.6 Queues

- Queue
  - Similar to a supermarket checkout line
  - First-in, first-out **(FIFO)**
  - Nodes are removed only from the head
  - Nodes are inserted only at the tail
- Insert and remove operations
  - Enqueue (insert) and dequeue (remove)

12.6 Queues

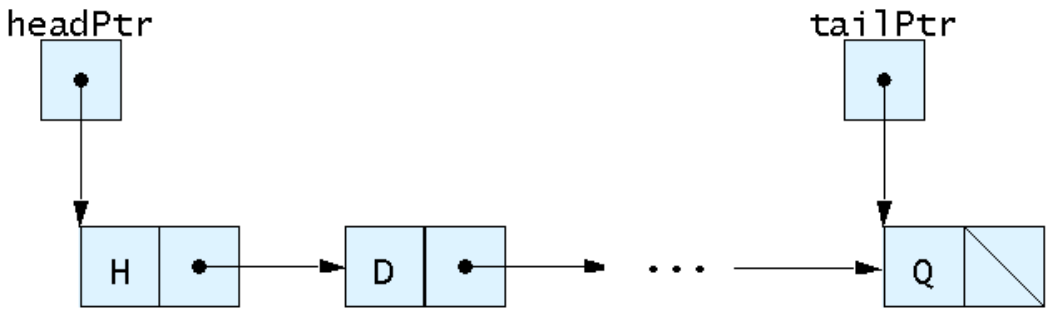
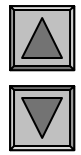


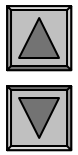
Fig. 12.12 A graphical representation of a queue.



Outline

fig12_13.c (Part 1 of 7)

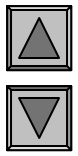
```
1  /* Fig. 12.13: fig12_13.c
2     Operating and maintaining a queue */
3
4  #include <stdio.h>
5  #include <stdlib.h>
6
7  /* self-referential structure */
8  struct queueNode {
9     char data;                  /* define data as a char */
10    struct queueNode *nextPtr; /* queueNode pointer */
11 }; /* end structure queueNode */
12
13 typedef struct queueNode QueueNode;
14 typedef QueueNode *QueueNodePtr;
15
16 /* function prototypes */
17 void printQueue( QueueNodePtr currentPtr );
18 int isEmpty( QueueNodePtr headPtr );
19 char dequeue( QueueNodePtr *headPtr, QueueNodePtr *tailPtr );
20 void enqueue( QueueNodePtr *headPtr, QueueNodePtr *tailPtr,
21               char value );
22 void instructions( void );
23
24 /* function main begins program execution */
25 int main()
26 {
```



Outline

fig12_13.c (Part 2 of 7)

```
27    QueueNodePtr headPtr = NULL; /* initialize headPtr */
28    QueueNodePtr tailPtr = NULL; /* initialize tailPtr */
29    int choice;                  /* user's menu choice */
30    char item;                   /* char input by user */
31
32    instructions(); /* display the menu */
33    printf( "? " );
34    scanf( "%d", &choice );
35
36    /* while user does not enter 3 */
37    while ( choice != 3 ) {
38
39       switch( choice ) {
40
41          /* enqueue value */
42          case 1:
43             printf( "Enter a character: " );
44             scanf( "\n%c", &item );
45             enqueue( &headPtr, &tailPtr, item );
46             printQueue( headPtr );
47             break;
48
49          /* dequeue value */
50          case 2:
51
```



Outline

```
52             /* if queue is not empty */
53             if ( !isEmpty( headPtr ) ) {
54                item = dequeue( &headPtr, &tailPtr );
55                printf( "%c has been dequeued.\n", item );
56             } /* end if */
57
58             printQueue( headPtr );
59             break;
60
61          default:
62             printf( "Invalid choice.\n\n" );
63             instructions();
64             break;
65
66       } /* end switch */
67
68       printf( "? " );
69       scanf( "%d", &choice );
70    } /* end while */
71
72    printf( "End of run.\n" );
73
74    return 0; /* indicates successful termination */
75
76 } /* end main */
77
```

fig12_13.c (Part 3 of 7)

Outline

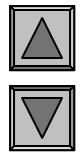
fig12_13.c (Part 4 of 7)

```
78 /* display program instructions to user */
79 void instructions( void )
80 {
81    printf ( "Enter your choice:\n"
82             "   1 to add an item to the queue\n"
83             "   2 to remove an item from the queue\n"
84             "   3 to end\n" );
85 } /* end function instructions */
86
87 /* insert a node a queue tail */
88 void enqueue( QueueNodePtr *headPtr, QueueNodePtr *tailPtr,
89               char value )
90 {
91    QueueNodePtr newPtr; /* pointer to new node */
92
93    newPtr = malloc( sizeof( QueueNode ) );
94
95    if ( newPtr != NULL ) { /* is space available */
96       newPtr->data = value;
97       newPtr->nextPtr = NULL;
98
99       /* if empty, insert node at head */
100      if ( isEmpty( *headPtr ) ) {
101         *headPtr = newPtr;
102      } /* end if */
```

Outline

fig12_13.c (Part 5 of 7)

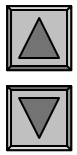
```
103       else {
104          ( *tailPtr )->nextPtr = newPtr;
105       } /* end else */
106
107       *tailPtr = newPtr;
108    } /* end if */
109    else {
110       printf( "%c not inserted. No memory available.\n", value );
111    } /* end else */
112
113 } /* end function enqueue */
114
115 /* remove node from queue head */
116 char dequeue( QueueNodePtr *headPtr, QueueNodePtr *tailPtr )
117 {
118    char value;           /* node value */
119    QueueNodePtr tempPtr; /* temporary node pointer */
120
121    value = ( *headPtr )->data;
122    tempPtr = *headPtr;
123    *headPtr = ( *headPtr )->nextPtr;
124
125    /* if queue is empty */
126    if ( *headPtr == NULL ) {
127       *tailPtr = NULL;
128    } /* end if */
129
```



Outline

fig12_13.c (Part 6 of 7)

```
130    free( tempPtr );
131
132    return value;
133
134 } /* end function dequeue */
135
136 /* Return 1 if the list is empty, 0 otherwise */
137 int isEmpty( QueueNodePtr headPtr )
138 {
139    return headPtr == NULL;
140
141 } /* end function isEmpty */
142
143 /* Print the queue */
144 void printQueue( QueueNodePtr currentPtr )
145 {
146
147    /* if queue is empty */
148    if ( currentPtr == NULL ) {
149       printf( "Queue is empty.\n\n" );
150    } /* end if */
151    else {
152       printf( "The queue is:\n" );
153
```



Outline

```
154       /* while not end of queue */
155       while ( currentPtr != NULL ) {
156          printf( "%c --> ", currentPtr->data );
157          currentPtr = currentPtr->nextPtr;
158       } /* end while */
159
160       printf( "NULL\n\n" );
161    } /* end else */
162
163 } /* end function printQueue */
```

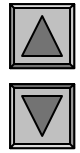
fig12_13.c (Part 7 of 7)

Program Output (Part 1 of 2)

```
Enter your choice:
   1 to add an item to the queue
   2 to remove an item from the queue
   3 to end
? 1
Enter a character: A
The queue is:
A --> NULL

? 1
Enter a character: B
The queue is:
A --> B --> NULL

? 1
Enter a character: C
The queue is:
A --> B --> C --> NULL
```



Outline

Program Output (Part 2 of 2)

```
? 2
A has been dequeued.
The queue is:
B --> C --> NULL

? 2
B has been dequeued.
The queue is:
C --> NULL

? 2
C has been dequeued.
Queue is empty.

? 2
Queue is empty.

? 4
Invalid choice.

Enter your choice:
   1 to add an item to the queue
   2 to remove an item from the queue
   3 to end
? 3
End of run.
```

12.6 Queues (Enqueue)

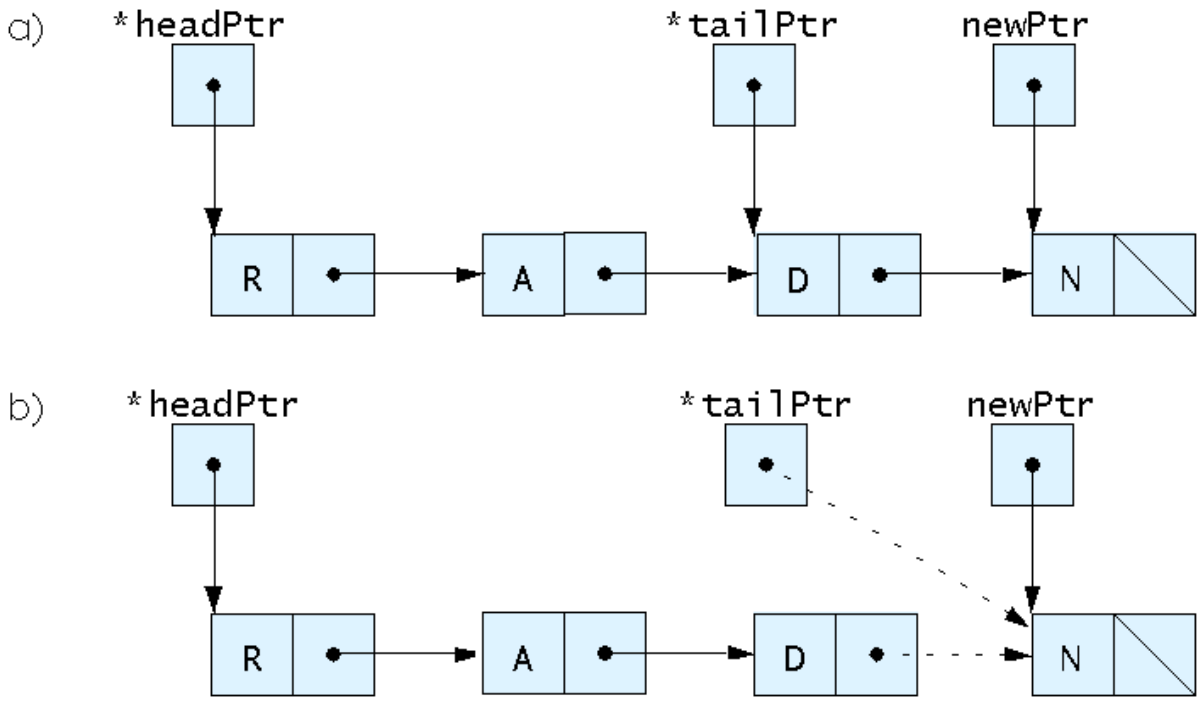


Fig. 12.15 A graphical representation of the enqueue operation

12.6 Queues (Dequeue)

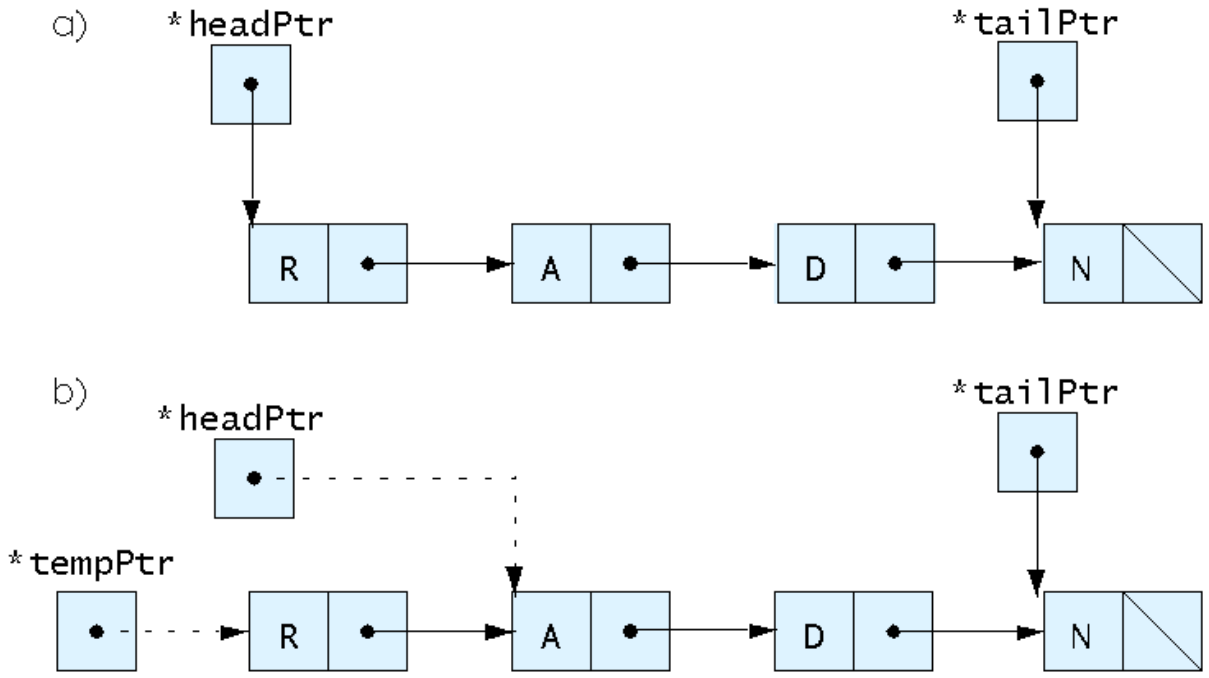


Fig. 12.16 A graphical representation of the dequeue operation.

12.7 Trees

- Tree nodes contain two or more links
  - All other data structures we have discussed only contain one
- Binary trees
  - All nodes contain two links
    - None, one, or both of which may be NULL
  - The root node is the first node in a tree.
  - Each link in the root node refers to a child
  - A node with no children is called a leaf node

12.7 Trees

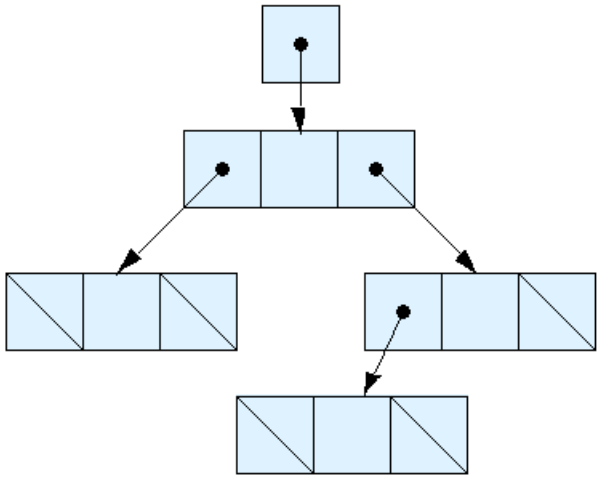


Fig. 12.17 A graphical representation of a binary tree.

12.7 Trees

- Binary search tree
  - Values in left subtree less than parent
  - Values in right subtree greater than parent
  - Facilitates duplicate elimination
  - Fast searches - for a balanced tree, maximum of $\log_2 n$ comparisons

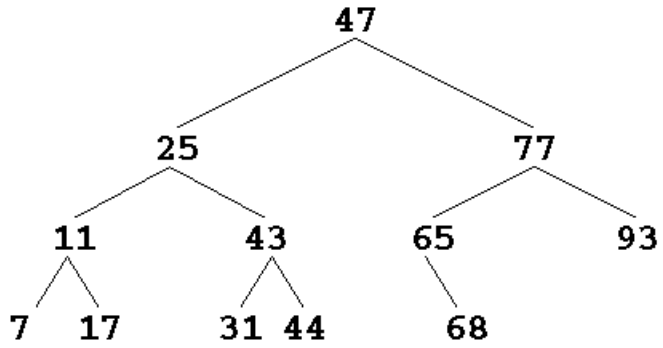
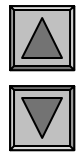


Fig. 12.18 A binary search tree.

12.7 Trees

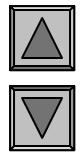
- Tree traversals:
  - Inorder traversal – prints the node values in ascending order
    1. Traverse the left subtree with an inorder traversal
    2. Process the value in the node (i.e., print the node value)
    3. Traverse the right subtree with an inorder traversal
  - Preorder traversal
    1. Process the value in the node
    2. Traverse the left subtree with a preorder traversal
    3. Traverse the right subtree with a preorder traversal
  - Postorder traversal
    1. Traverse the left subtree with a postorder traversal
    2. Traverse the right subtree with a postorder traversal
    3. Process the value in the node



Outline

fig12_19.c (Part 1 of 6)

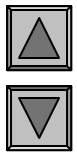
```
1  /* Fig. 12.19: fig12_19.c
2     Create a binary tree and traverse it
3     preorder, inorder, and postorder */
4  #include <stdio.h>
5  #include <stdlib.h>
6  #include <time.h>
7
8  /* self-referential structure */
9  struct treeNode {
10    struct treeNode *leftPtr;  /* treeNode pointer */
11    int data;                  /* define data as an int */
12    struct treeNode *rightPtr; /* treeNode pointer */
13 }; /* end structure treeNode */
14
15 typedef struct treeNode TreeNode;
16 typedef TreeNode *TreeNodePtr;
17
18 /* prototypes */
19 void insertNode( TreeNodePtr *treePtr, int value );
20 void inOrder( TreeNodePtr treePtr );
21 void preOrder( TreeNodePtr treePtr );
22 void postOrder( TreeNodePtr treePtr );
23
24 /* function main begins program execution */
25 int main()
26 {
```



Outline

fig12_19.c (Part 2 of 6)

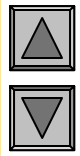
```
27    int i;                        /* counter */
28    int item;                     /* variable to hold random values */
29    TreeNodePtr rootPtr = NULL; /* initialize rootPtr */
30
31    srand( time( NULL ) );
32    printf( "The numbers being placed in the tree are:\n" );
33
34    /* insert random values between 1 and 15 in the tree */
35    for ( i = 1; i <= 10; i++ ) {
36       item = rand() % 15;
37       printf( "%3d", item );
38       insertNode( &rootPtr, item );
39    } /* end for */
40
41    /* traverse the tree preOrder */
42    printf( "\n\nThe preOrder traversal is:\n" );
43    preOrder( rootPtr );
44
45    /* traverse the tree inOrder */
46    printf( "\n\nThe inOrder traversal is:\n" );
47    inOrder( rootPtr );
48
49    /* traverse the tree postOrder */
50    printf( "\n\nThe postOrder traversal is:\n" );
51    postOrder( rootPtr );
52
```



Outline

```
53    return 0; /* indicates successful termination */
54
55 } /* end main */
56
57 /* insert node into tree */
58 void insertNode( TreeNodePtr *treePtr, int value )
59 {
60
61    /* if tree is empty */
62    if ( *treePtr == NULL ) {
63       *treePtr = malloc( sizeof( TreeNode ) );
64
65       /* if memory was allocated then assign data */
66       if ( *treePtr != NULL ) {
67          ( *treePtr )->data = value;
68          ( *treePtr )->leftPtr = NULL;
69          ( *treePtr )->rightPtr = NULL;
70       } /* end if */
71       else {
72          printf( "%d not inserted. No memory available.\n", value );
73       } /* end else */
74
75    } /* end if */
```

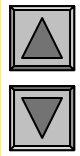
fig12_19.c (Part 3 of 6)



Outline

fig12_19.c (Part 4 of 6)

```
76    else { /* tree is not empty */
77
78       /* data to insert is less than data in current node */
79       if ( value < ( *treePtr )->data ) {
80          insertNode( &( ( *treePtr )->leftPtr ), value );
81       } /* end if */
82
83       /* data to insert is greater than data in current node */
84       else if ( value > ( *treePtr )->data ) {
85          insertNode( &( ( *treePtr )->rightPtr ), value );
86       } /* end else if */
87       else { /* duplicate data value ignored */
88          printf( "dup" );
89       } /* end else */
90
91    } /* end else */
92
93 } /* end function insertNode */
94
95 /* begin inorder traversal of tree */
96 void inOrder( TreeNodePtr treePtr )
97 {
98
```



Outline

```
99    /* if tree is not empty then traverse */
100   if ( treePtr != NULL ) {
101      inOrder( treePtr->leftPtr );
102      printf( "%3d", treePtr->data );
103      inOrder( treePtr->rightPtr );
104   } /* end if */
105
106 } /* end function inOrder */
107
108 /* begin preorder traversal of tree */
109 void preOrder( TreeNodePtr treePtr )
110 {
111
112   /* if tree is not empty then traverse */
113   if ( treePtr != NULL ) {
114      printf( "%3d", treePtr->data );
115      preOrder( treePtr->leftPtr );
116      preOrder( treePtr->rightPtr );
117   } /* end if */
118
119 } /* end function preOrder */
120
```

fig12_19.c (Part 5 of 6)

Outline

fig12_19.c (Part 6 of 6)

```
121 /* begin postorder traversal of tree */
122 void postOrder( TreeNodePtr treePtr )
123 {
124
125    /* if tree is not empty then traverse */
126    if ( treePtr != NULL ) {
127       postOrder( treePtr->leftPtr );
128       postOrder( treePtr->rightPtr );
129       printf( "%3d", treePtr->data );
130    } /* end if */
131
132 } /* end function postOrder */
```

Program Output

```
The numbers being placed in the tree are:
  6   7   4 12   7dup   2   2dup   5   7dup 11

The preOrder traversal is:
  6   4   2   5   7 12 11

The inOrder traversal is:
  2   4   5   6   7 11 12

The postOrder traversal is:
  2   5   4 11 12   7   6
```

12.7 Trees (In Order Traversal)

```
6 13 17 27 33 42 48
```

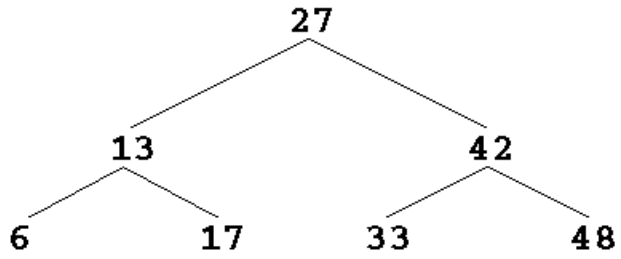


Fig. 12.21 A binary search tree.