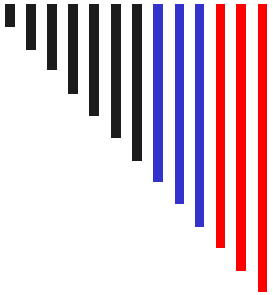


Chapter 15
Lists

Objectives

- To introduce the basic concepts of linked lists
- To introduce the basic concepts of stacks
- To introduce the basic concepts of queues
- To introduce the basic concepts of tree structures
- To introduce the basic concepts of graph structures

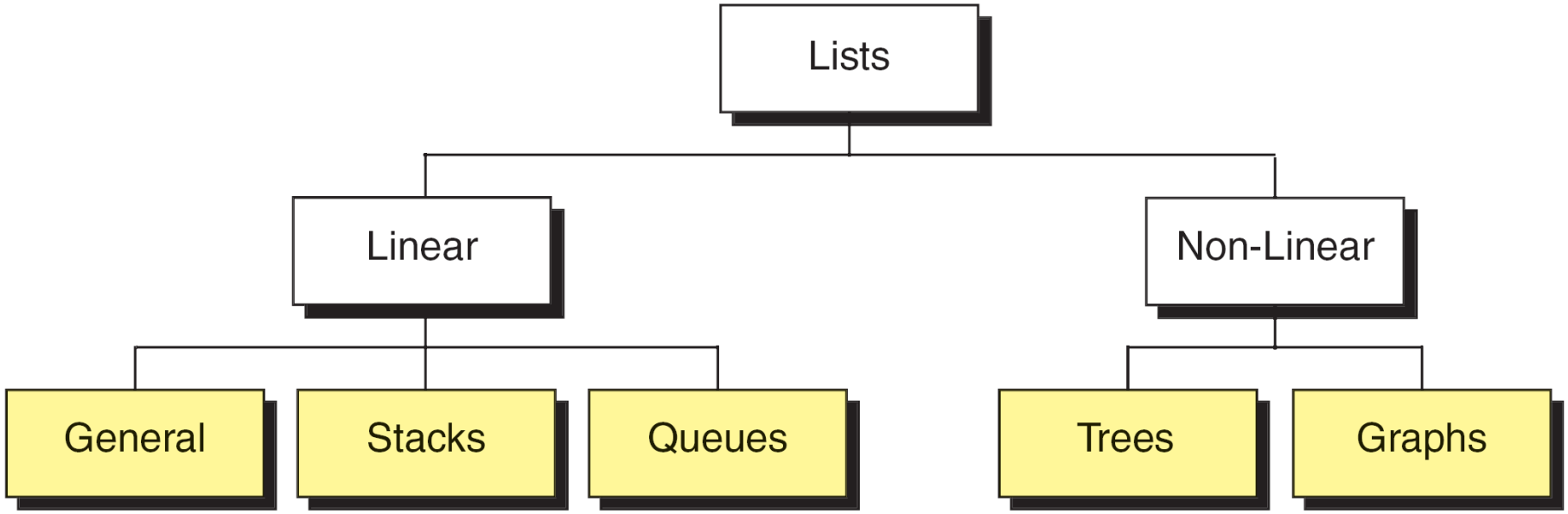


FIGURE 15-1 Lists

15-1 List Implementations

The C language does not provide any list structures or implementations. When we need them, we must provide the structures and functions for them. Traditionally, two data types, arrays and pointers, are used for their implementation.

Topics discussed in this section:

Array Implementation
Linked List Implementation
Pointers to Linked Lists

Array Implementation

- How?
- Pros and cons?

Linked List Implementation

- Linked list
  - An ordered collection of data in which each element contains the location of the next element or elements
- A node contains data and links
- Linear and non-linear structures
- Pros and cons over the array?

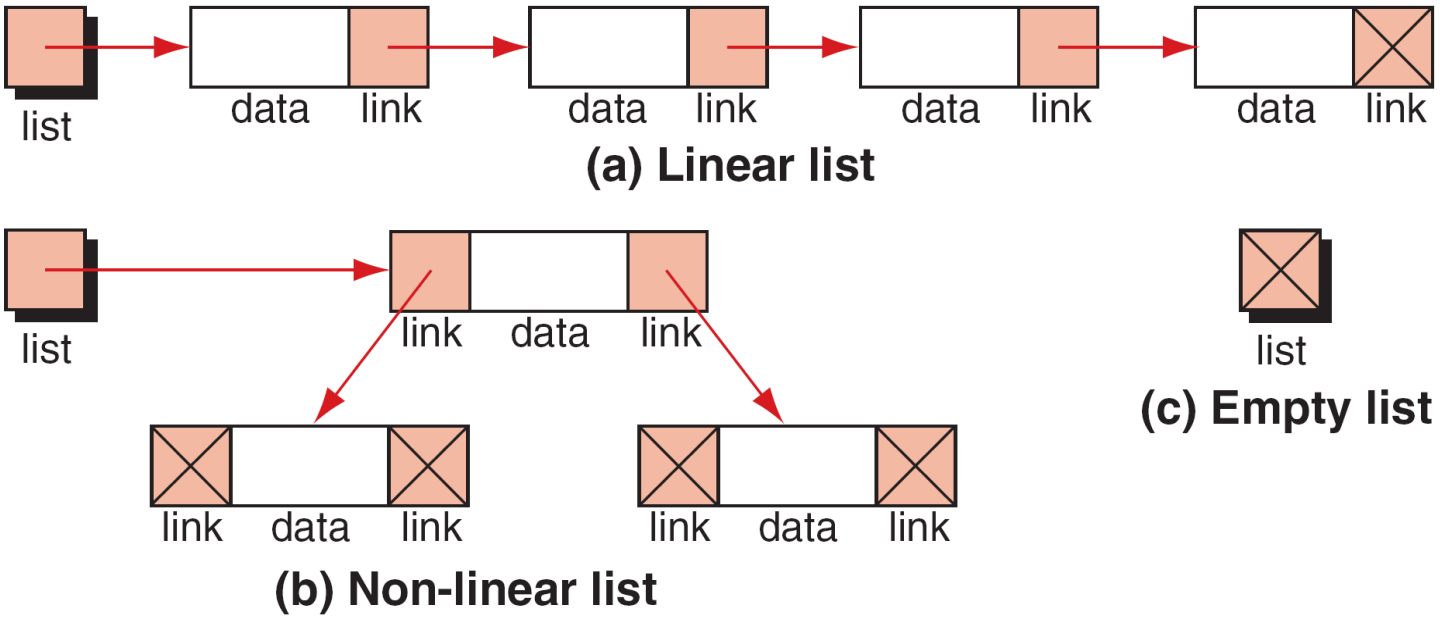


FIGURE 15-2 Linked Lists

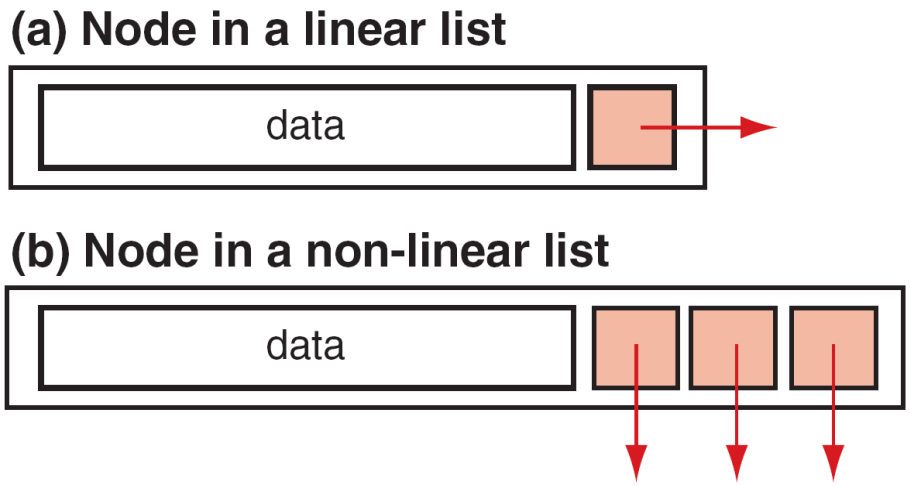


FIGURE 15-3 Nodes

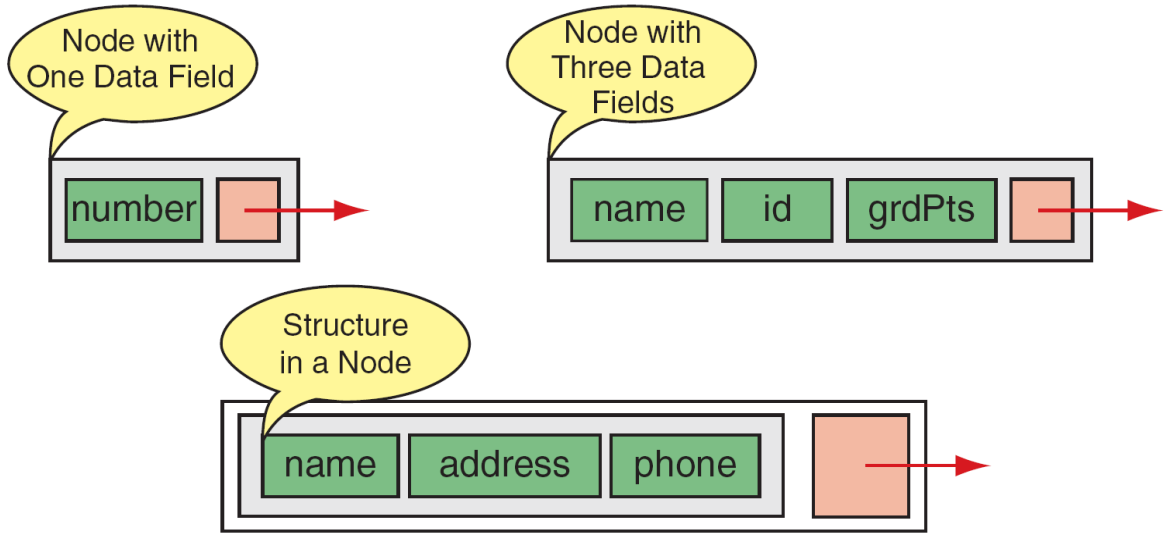


FIGURE 15-4 Linked List Node Structures

15-2 General Linear Lists

A general linear list is a list in which operations, such as retrievals, insertions, changes, and deletions, can be done anywhere in the list, that is, at the beginning, in the middle, or at the end of the list..

Topics discussed in this section:

Insert a Node
Delete a Node
Locating Data in Linear Lists
Traversing Linear Lists
Building a Linear List

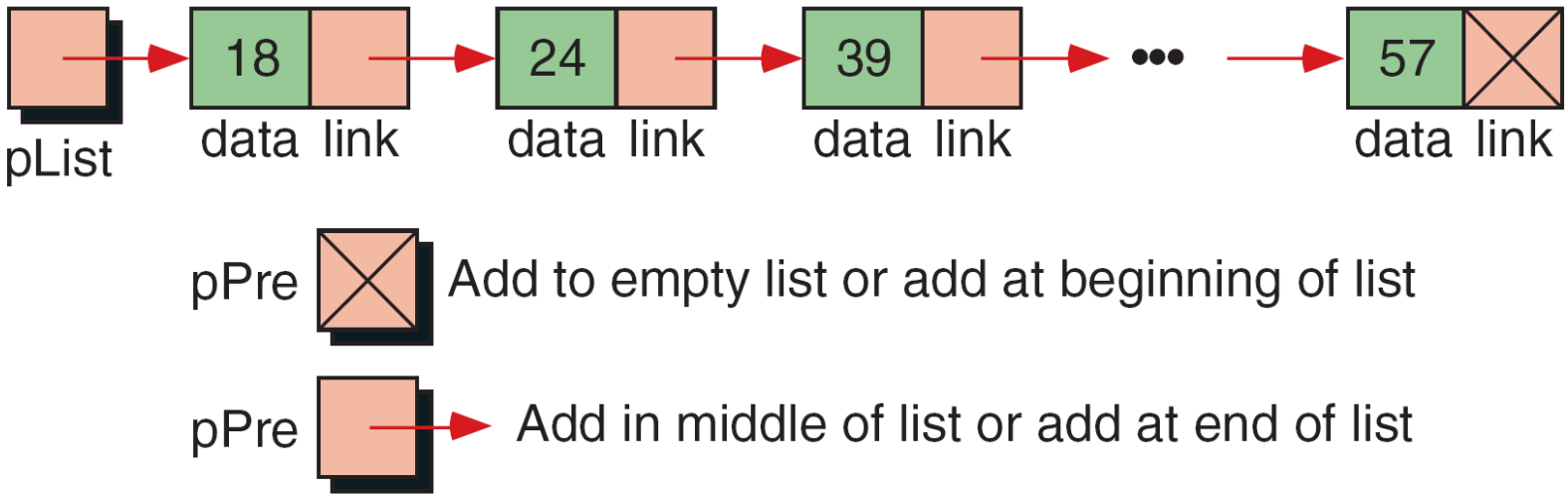


FIGURE 15-5 Pointer Combinations for Insert

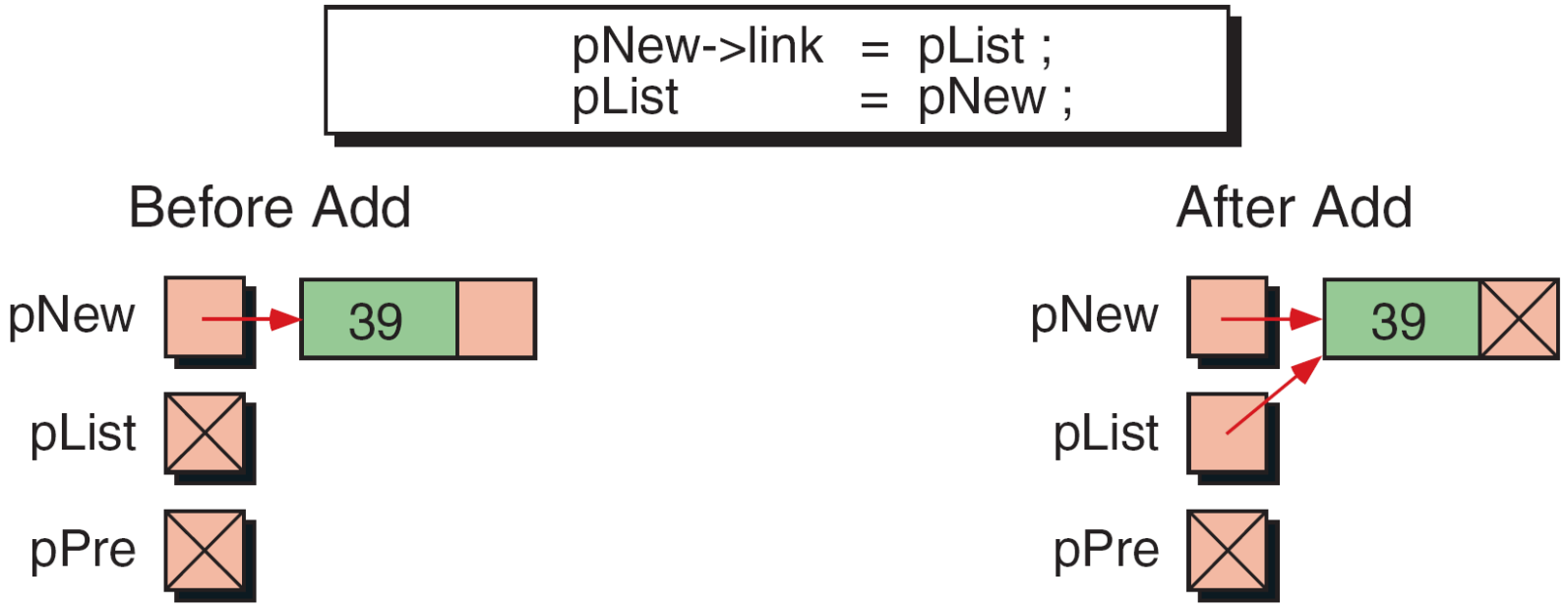


FIGURE 15-6 Insert Node to Empty List

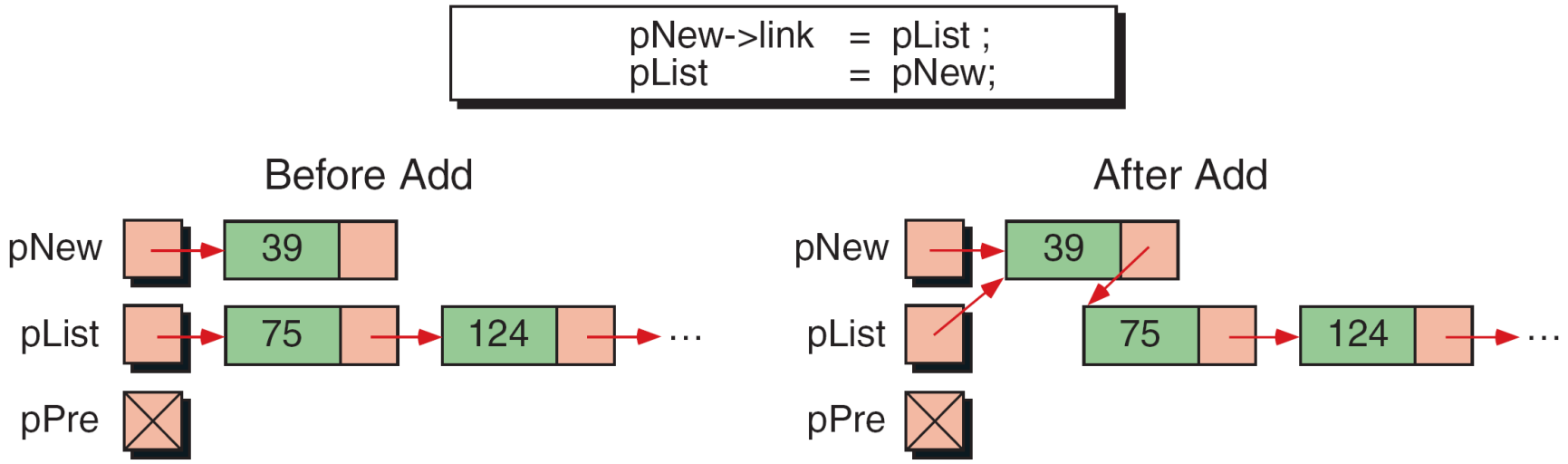


FIGURE 15-7 Insert Node at Beginning

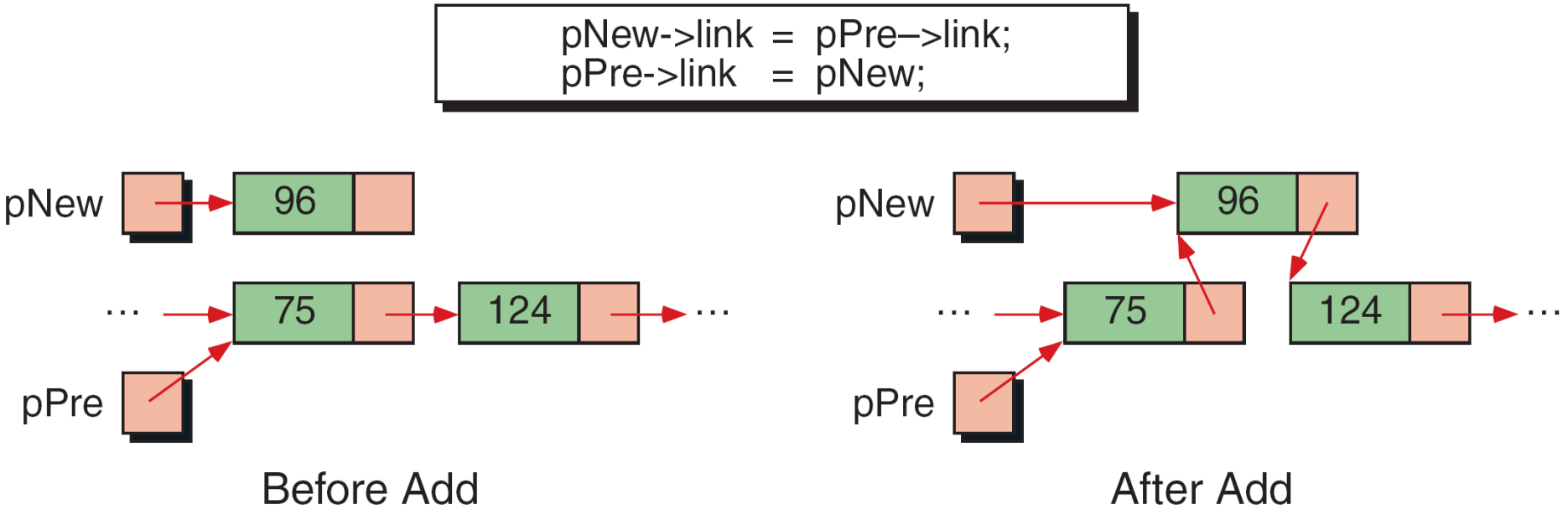


FIGURE 15-8 Insert Node in Middle

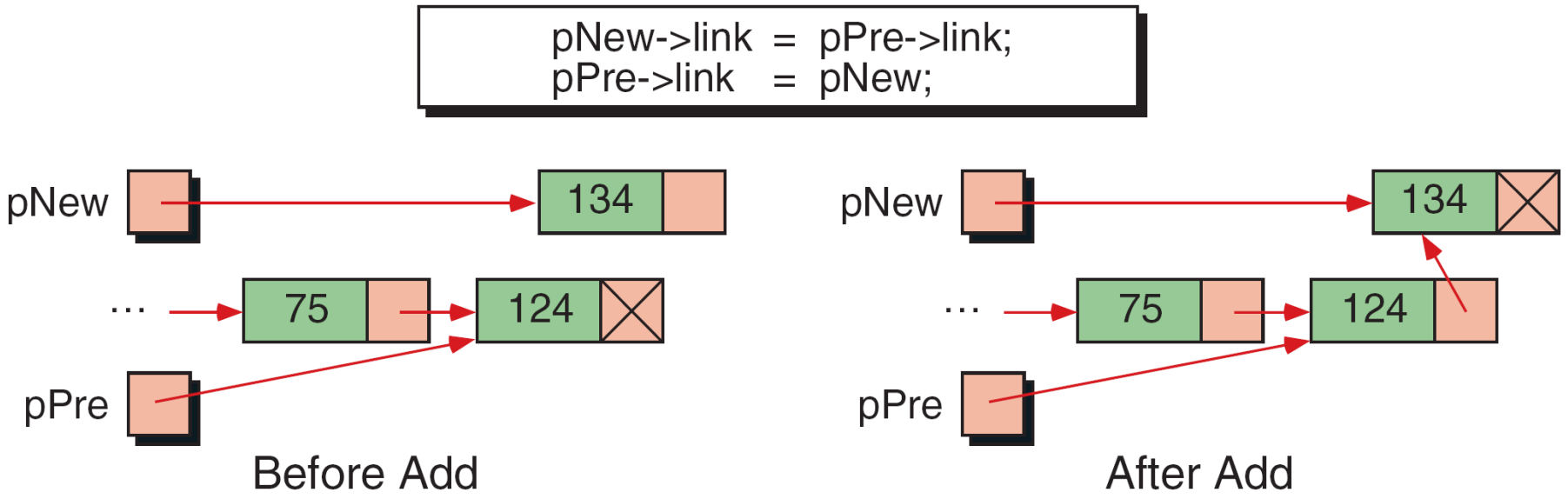


FIGURE 15-9 Insert Node at End

PROGRAM 15-1 Insert a Node

```
1  /* ==================== insertNode ====================
2     This function inserts a single node into a linear list.
3        Pre   pList is pointer to the list; may be null
4              pPre points to new node's predecessor
5              item contains data to be inserted
6        Post  returns the head pointer
7  */
8  NODE* insertNode (NODE* pList, NODE* pPre, DATA item)
9  {
10 // Local Declarations
11    NODE* pNew;
12
13 // Statements
14    if (!(pNew  = (NODE*)malloc(sizeof(NODE))))
15        printf("\aMemory overflow in insert\n"),
16              exit (100);
17
```

PROGRAM 15-1 Insert a Node

```
18      pNew->data = item;
19      if (pPre == NULL)
20         {
21          // Inserting before first node or to empty list
22          pNew->link  = pList;
23          pList       = pNew;
24         } // if pPre
25      else
26         {
27          // Inserting in middle or at end
28          pNew->link = pPre->link;
29          pPre->link = pNew;
30         } // else
31      return pList;
32  }  // insertNode
```

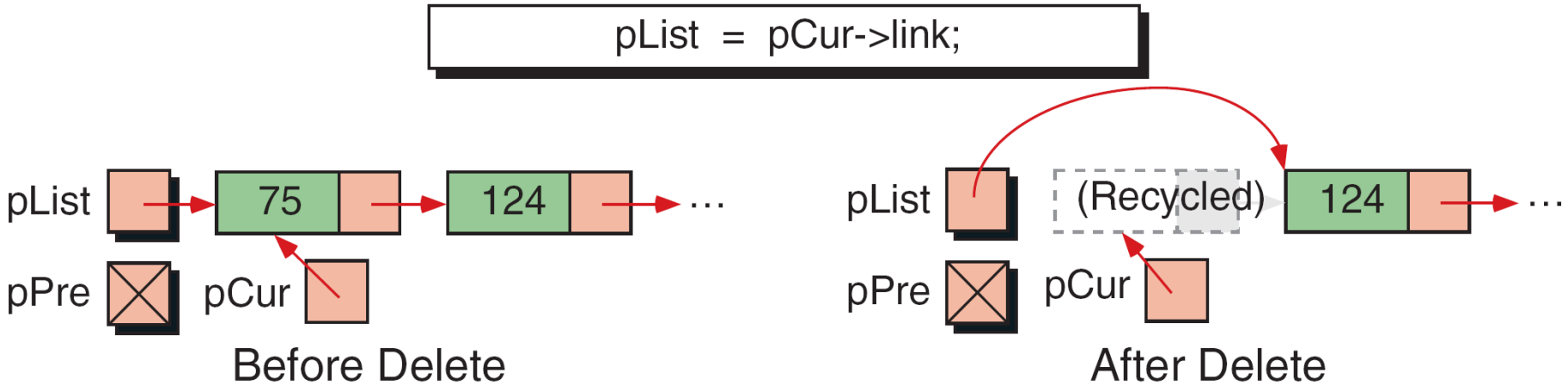


FIGURE 15-10 Delete First Node

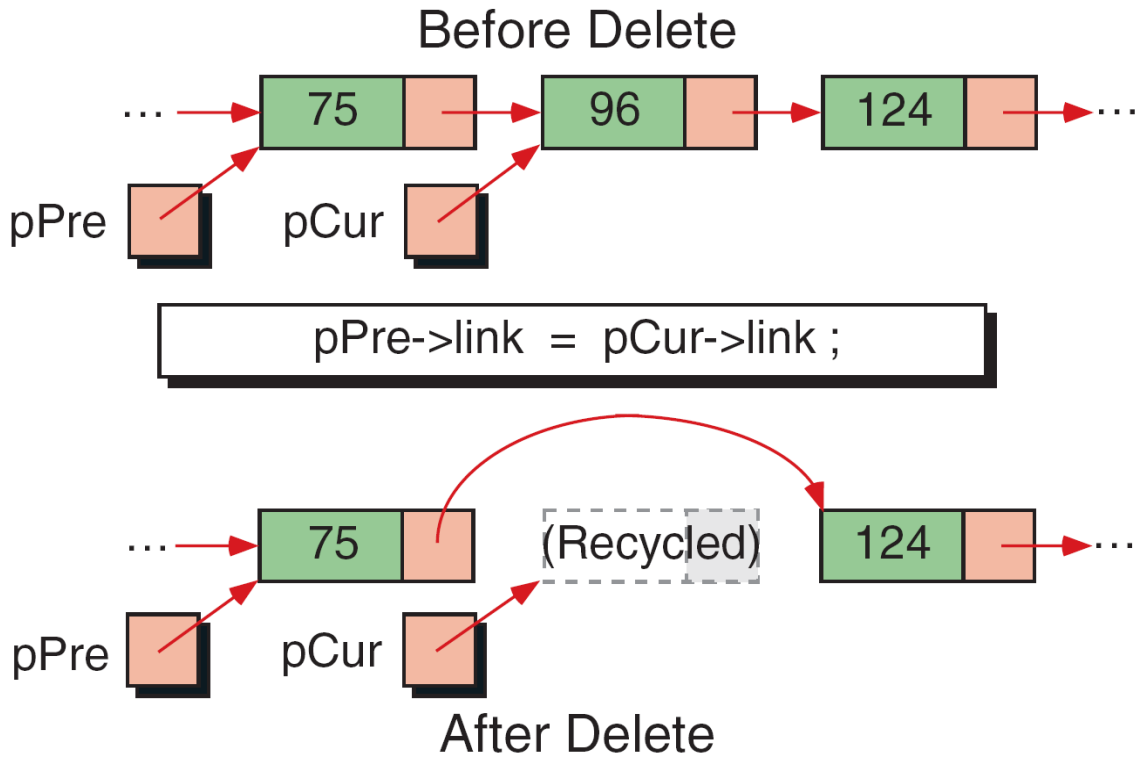


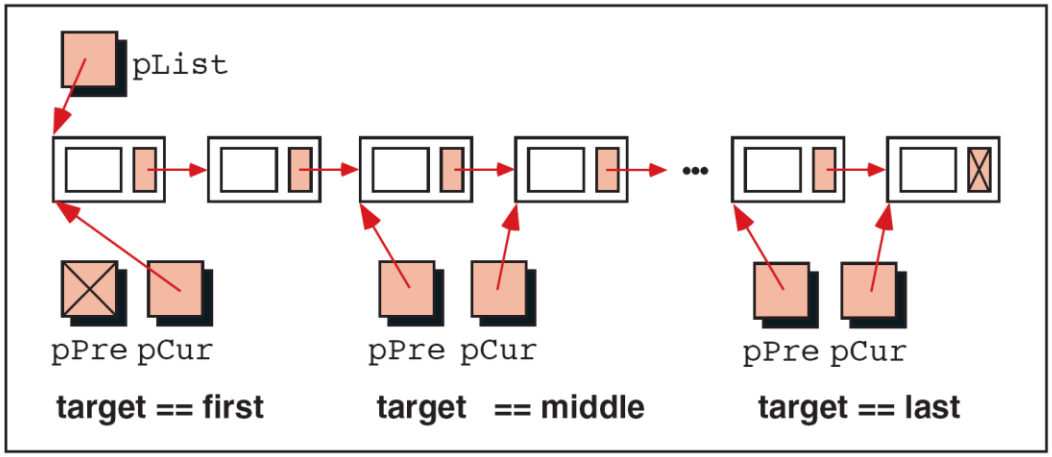
FIGURE 15-11 Delete—General Case

PROGRAM 15-2 Delete a Node

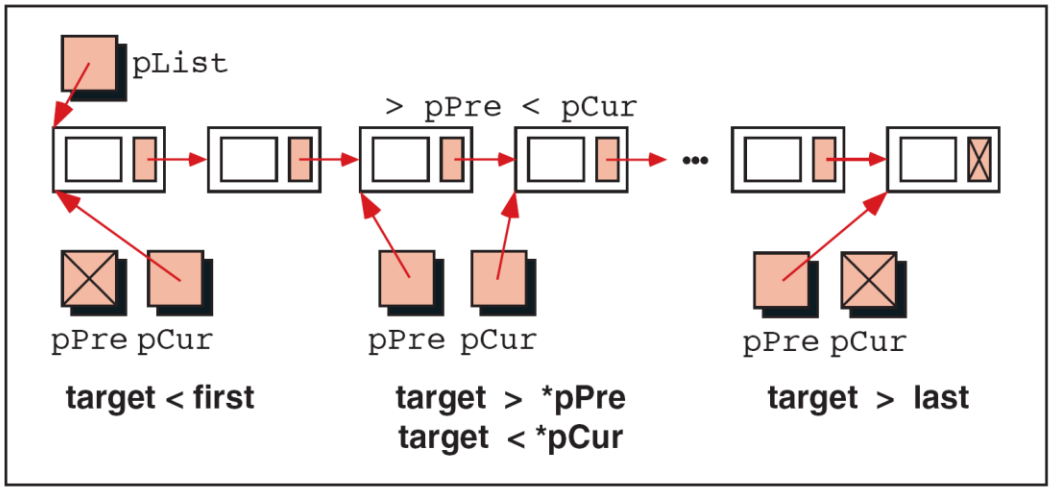
```
 1  /* ==================== deleteNode ====================
 2     This function deletes a single node from the link list.
 3        Pre   pList is a pointer to the head of the list
 4              pPre points to node before the delete node
 5              pCur points to the node to be deleted
 6        Post  deletes and recycles pCur
 7              returns the head pointer
 8  */
 9  NODE* deleteNode (NODE* pList, NODE* pPre, NODE* pCur)
10  {
11  // Statements
12     if (pPre == NULL)
13        // Deleting first node
14        pList = pCur->link;
15     else
16        // Deleting other nodes
17        pPre->link = pCur->link;
18     free  (pCur);
19     return pList;
20  }  // deleteNode
```

Condition	pPre	pCur	Return
target < first node	*NULL*	first node	0
target == first node	*NULL*	first node	1
first < target < last	largest node < target	first node > target	0
target == middle node	node's predecessor	equal node	1
target == last node	last's predecessor	last node	1
target > last node	last node	*NULL*	0

Table 15-1 Linear List Search Results



Successful Searches (Return *true*)



Unsuccessful Searches (Return *false*)

FIGURE 15-12 Search Results

PROGRAM 15-3 Search Linear List

```
 1  /* ==================== searchList ====================
 2     Given key value, finds the location of a node
 3        Pre   pList points to a head node
 4              pPre points to variable to receive pred
 5              pCur points to variable for current node
 6              target is key being sought
 7        Post  pCur points to first node with >= key
 8              -or- null if target > key of last node
 9              pPre points to largest node < key
10              -or- null if target < key of first node
11              function returns true if found
12                               false if not found
13  */
14  bool searchList (NODE*  pList, NODE**   pPre,
15                   NODE** pCur,  KEY_TYPE target)
16  {
17  // Local Declarations
18     bool found = false;
19
```

PROGRAM 15-3 Search Linear List

```
20  // Statements
21      *pPre = NULL;
22      *pCur = pList;
23
24      // start the search from beginning
25      while (*pCur != NULL && target > (*pCur)->data.key)
26          {
27           *pPre = *pCur;
28           *pCur = (*pCur)->link;
29          } // while
30
31      if (*pCur && target ==  (*pCur)->data.key)
32          found = true;
33      return found;
34  }   // searchList
```

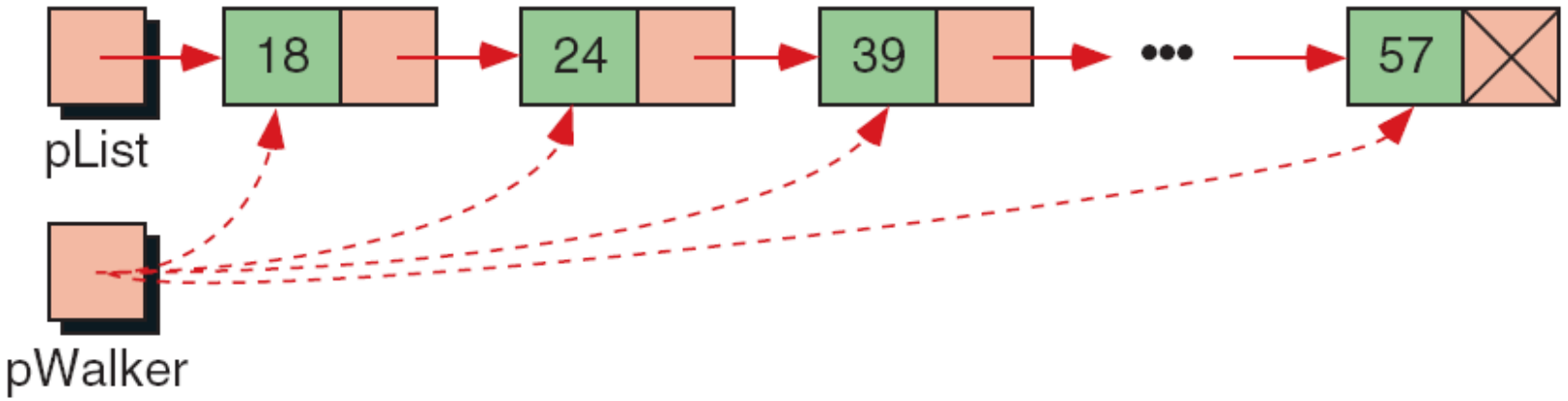


FIGURE 15-13 Linear List Traversal

PROGRAM 15-4 Print Linear List

```
 1  /* Traverse and print a linear list.
 2        Pre   pList is a valid linear list
 3        Post  List has been printed
 4  */
 5  void printList (NODE* pList)
 6  {
 7  // Local Declarations
 8     NODE* pWalker;
 9
10  // Statements
11     pWalker = pList;
12     printf("List contains:\n");
13
14     while (pWalker)
15        {
16         printf("%3d ", pWalker->data.key);
17         pWalker = pWalker->link;
18        } // while
19     printf("\n");
20     return;
21  } // printList
```

PROGRAM 15-5 Average Linear List

```
 1  /* This function averages the values in a linear list.
 2        Pre   pList is a pointer to a linear list
 3        Post  list average is returned
 4  */
 5  double averageList (NODE* pList)
 6  {
 7  // Local Declarations
 8     NODE* pWalker;
 9     int   total;
10     int   count;
11
12  // Statements
13     total   = count = 0;
14     pWalker = pList;
15     while (pWalker)
16        {
17         total += pWalker->data.key;
18         count++;
19         pWalker = pWalker->link;
20        } // while
21     return (double)total / count;
22  } // averageList
```

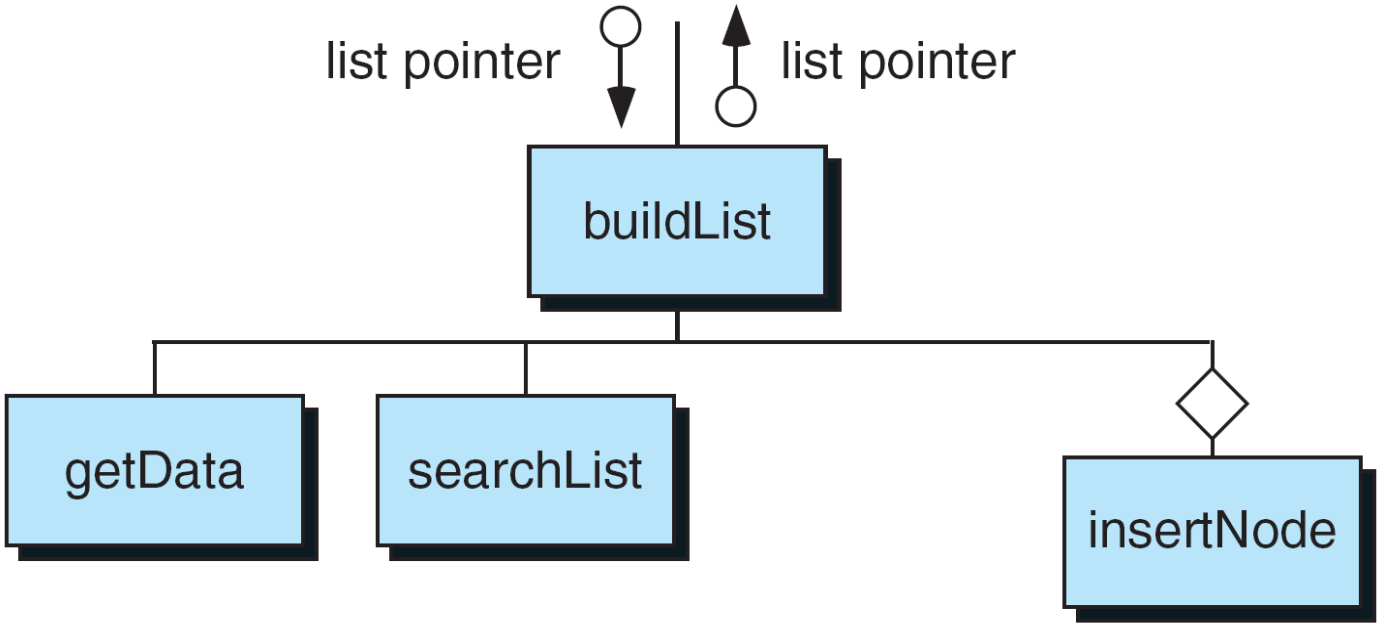


FIGURE 15-14 Design for Inserting a Node in a List

PROGRAM 15-6 Build List

```
 1  /* ==================== buildList ====================
 2     This program builds a key-sequenced linear list.
 3        Pre   fileID is file that contains data for list
 4        Post  list built
 5              returns pointer to head of list
 6  */
 7  NODE* buildList (char* fileID)
 8  {
 9  // Local Declarations
10     DATA  data;
11     NODE* pList;
12     NODE* pPre;
13     NODE* pCur;
14     FILE* fpData;
15
16  // Statements
17     pList = NULL;
18
```

PROGRAM 15-6 Build List

```
19      fpData = fopen(fileID, "r");
20      if (!fpData)
21         {
22          printf("Error opening file %s\a\n", fileID);
23          exit (210);
24         } // if open fail
25
26      while (getData (fpData, &data))
27         {
28          // Determine insert position
29          searchList (pList, &pPre, &pCur, data.key);
30          pList = insertNode(pList, pPre, data);
31         } // while
32      return pList;
33  } // buildList
```

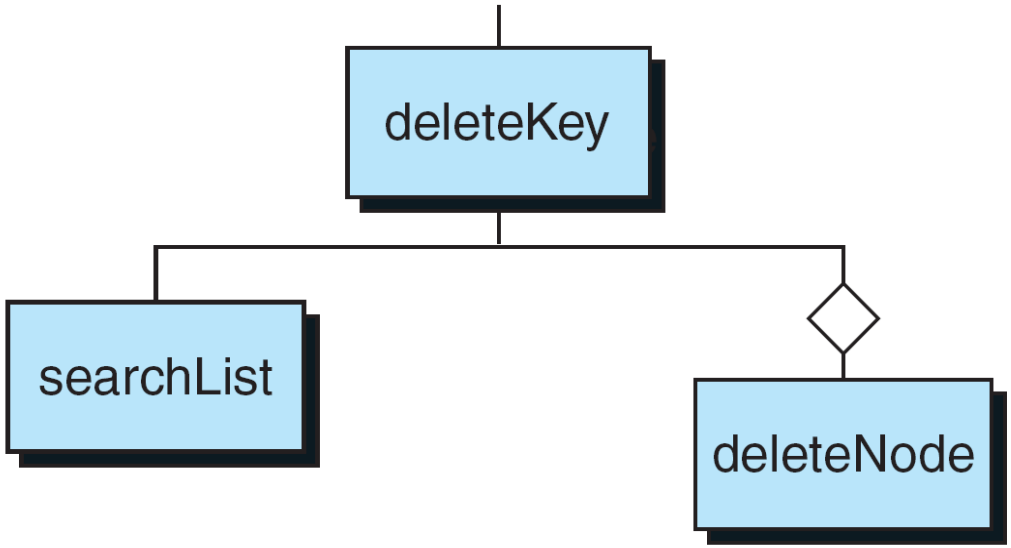


FIGURE 15-15 **Design for Remove Node**

PROGRAM 15-7 Delete Key

```
1  /* ==================== deleteKey ====================
2     Delete node from a linear list.
3        Pre   list is a pointer to the head of the list
4        Post  node has been deleted
5              -or- a warning message printed if not found
6              returns pointer to first node (pList)
7  */
8  NODE* deleteKey (NODE* pList)
9  {
10 // Local Declarations
11    int   key;
12    NODE* pHead;
13    NODE* pCur;
14    NODE* pPre;
15
16 // Statements
17    printf("Enter key of node to be deleted: ");
```

PROGRAM 15-7 Delete Key

```
18      scanf ("%d", &key);
19
20      if (!searchList(pList, &pPre, &pCur, key))
21          printf("%d is an invalid key\a\n", key);
22      else
23          pHead = deleteNode (pList, pPre, pCur);
24
25      return pHead;
26  } // deleteKey
```

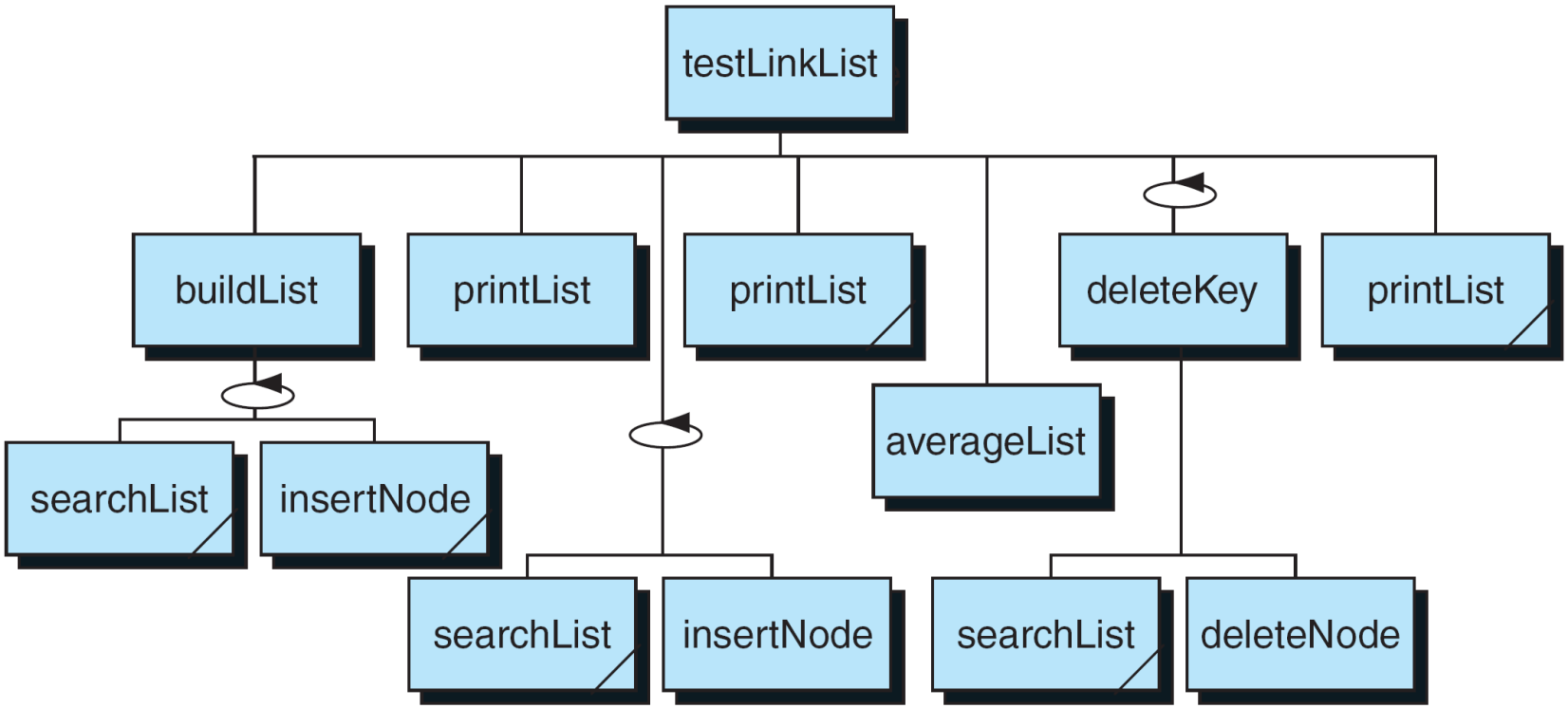


FIGURE 15-16 Link List Test Driver

PROGRAM 15-8 Test Driver for Link List

```
1  /* Test driver for list functions.
2        Written by:
3        Date:
4  */
5  #include <stdio.h>
6  #include <stdlib.h>
7  #include <stdbool.h>
8
9  // Global Declarations
10 typedef int KEY_TYPE;
11 typedef struct
12    {
13     KEY_TYPE key;
14    } DATA;
15 typedef struct nodeTag
16    {
17     DATA             data;
18     struct nodeTag* link;
19    } NODE;
20
```

PROGRAM 15-8 Test Driver for Link List

```
21 // Function Declarations
22 NODE* insertNode (NODE*  pList, NODE*  pPre, DATA  item);
23 NODE* deleteNode (NODE*  List,  NODE*  pPre, NODE* pCur);
24 bool  searchList (NODE*  pList, NODE**   pPre,
25                   NODE** pCur,  KEY_TYPE target);
26 void  printList  (NODE*  pList);
27 NODE* buildList  (char*  fileID);
28 NODE* deleteKey  (NODE*  pList);
29 bool  getData    (FILE*  fpData, DATA* pData);
30
31 double averageList (NODE* pList);
32
33 int main (void)
34 {
35 // Local Declarations
36    NODE*  pList;
37    NODE*  pPre;
38    NODE*  pCur;
39    DATA   data;
40    double avrg;
41    char   more;
42
43 // Statements
44    printf("Begin list test driver\n\n");
```

PROGRAM 15-8 Test Driver for Link List

```
45
46      // Build List
47      pList = buildList("P15-LIST.DAT");
48      if (!pList)
49         {
50          printf("Error building chron file\a\n");
51          exit  (100);
52         } // if
53      printList (pList);
54
55      printf("\nInsert data tests.\n");
56      printf("Enter key:                ");
57      scanf ("%d", &data.key);
58      do
59         {
60          if (searchList (pList, &pPre, &pCur, data.key))
61             printf("Key already in list. Not inserted\n");
62          else
63              pList = insertNode(pList, pPre, data);
64          printf("Enter key <-1> to stop: ");
65          scanf ("%d", &data.key);
66         } while (data.key != -1);
```

PROGRAM 15-8 Test Driver for Link List

```
67      printList (pList);
68
69      avrg = averageList(pList);
70      printf("\nData average: %.1f\n", avrg);
71
72      printf("\nDelete data tests.\n");
73      do
74         {
75          pList = deleteKey (pList);
76          printf("Delete another <Y/N>: ");
77          scanf (" %c", &more);
78         } while (more == 'Y' || more == 'y');
79
80      printList (pList);
81      printf("\nTests complete.\n");
82      return 0;
83  } // main
```

PROGRAM 15-8 Test Driver for Link List

```
Results:
Begin list test driver

List contains:
111 222 333 444 555 666 777

Insert data tests.
Enter key:                50
Enter key <-1> to stop: -1
List contains:
 50 111 222 333 444 555 666 777

Data average: 394.8

Delete data tests.
Enter key of node to be deleted: 50
Delete another <Y/N>: n
List contains:
111 222 333 444 555 666 777

Tests complete.
```

15-3 Stacks

A** stack **is a linear list in which all additions and deletions are restricted to one end, called the** top**. Stacks are known as the last in–first out (LIFO) data structure.

Topics discussed in this section:

Stack Structures
Stack Algorithms
Stack Demonstration

Note

A stack is a last in–first out (LIFO) data structure in which all insertions and deletions are restricted to one end, called the top.

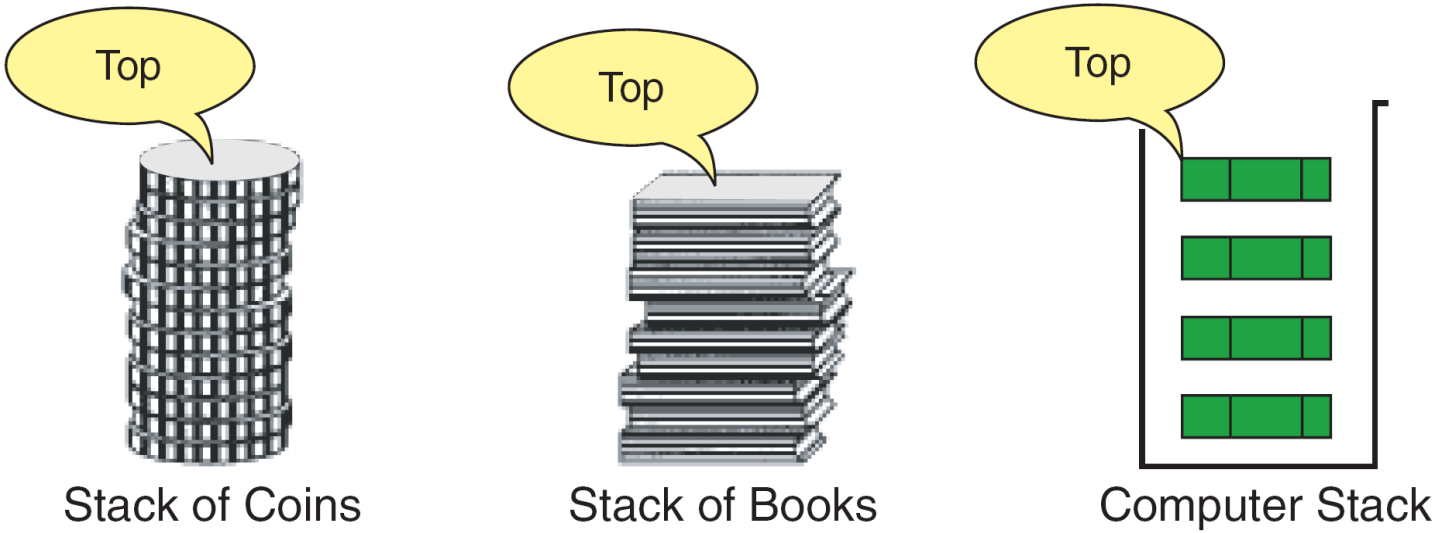


FIGURE 15-17 Stack

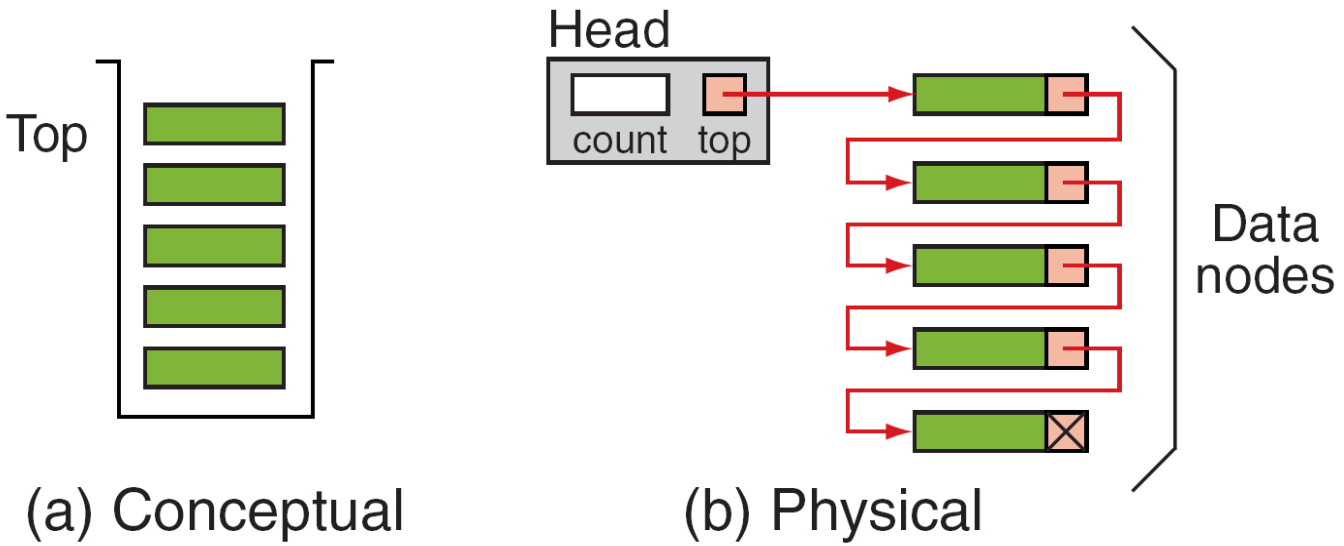
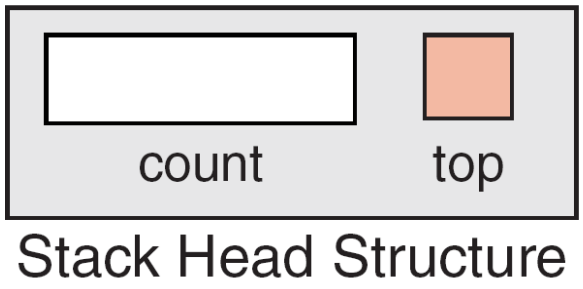


FIGURE 15-18 Conceptual and Physical Stack Implementations




```
typedef struct
   {
    int           count;
    struct node* top;
   } STACK;
typedef struct node
   {
    int           data;
    struct node* link;
   } STACK_NODE;
```

FIGURE 15-19 Stack Data Structure

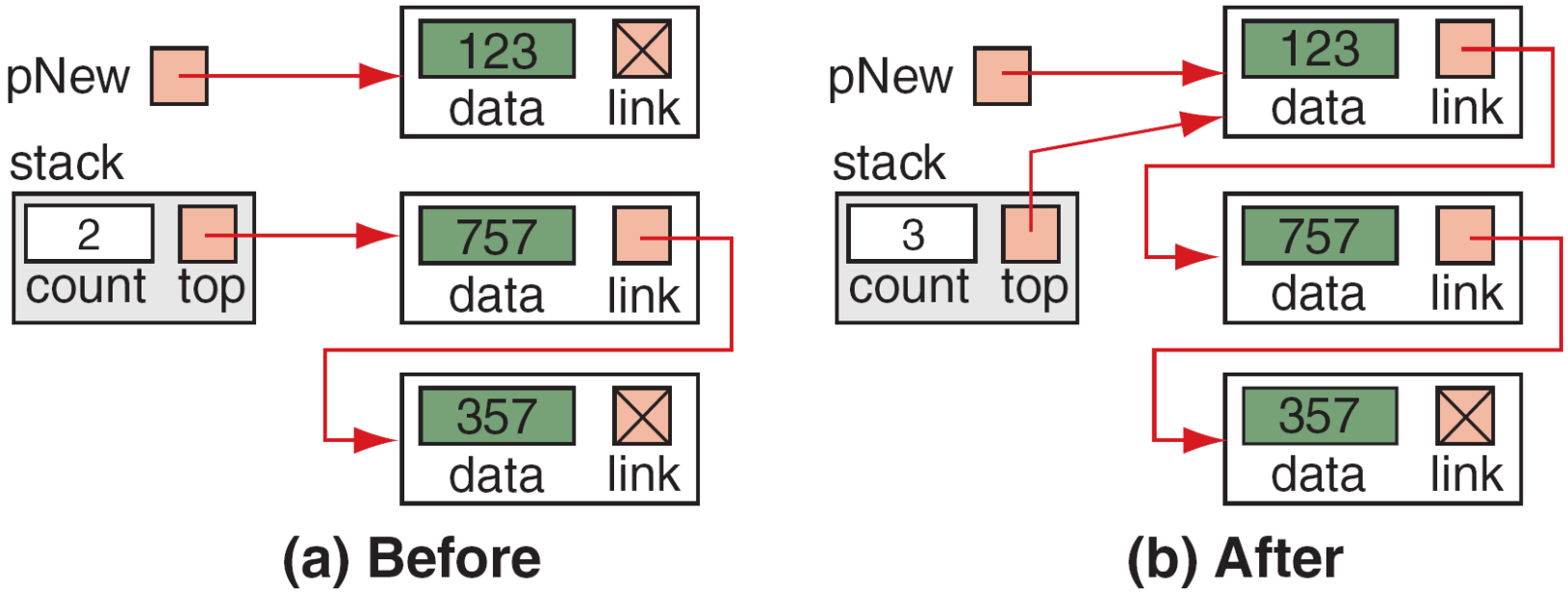


FIGURE 15-20 Streams

PROGRAM 15-9 Push Stack

```
1  /* ==================== push ====================
2     Inserts node into linked list stack.
3        Pre    pStack is pointer to valid stack header
4        Post   dataIn inserted
5        Return true  if successful
6               false if overflow
7  */
8  bool push (STACK* pStack, int dataIn)
9  {
10 // Local Declarations
11    STACK_NODE* pNew;
12    bool        success;
13
14 // Statements
15    pNew = (STACK_NODE*)malloc(sizeof (STACK_NODE));
16    if (!pNew)
17        success = false;
```

PROGRAM 15-9 Push Stack

```
18      else
19          {
20           pNew->data  = dataIn;
21           pNew->link  = pStack->top;
22           pStack->top = pNew;
23           pStack->count++;
24           success = true;
25          } // else
26      return success;
27  }   // push
```

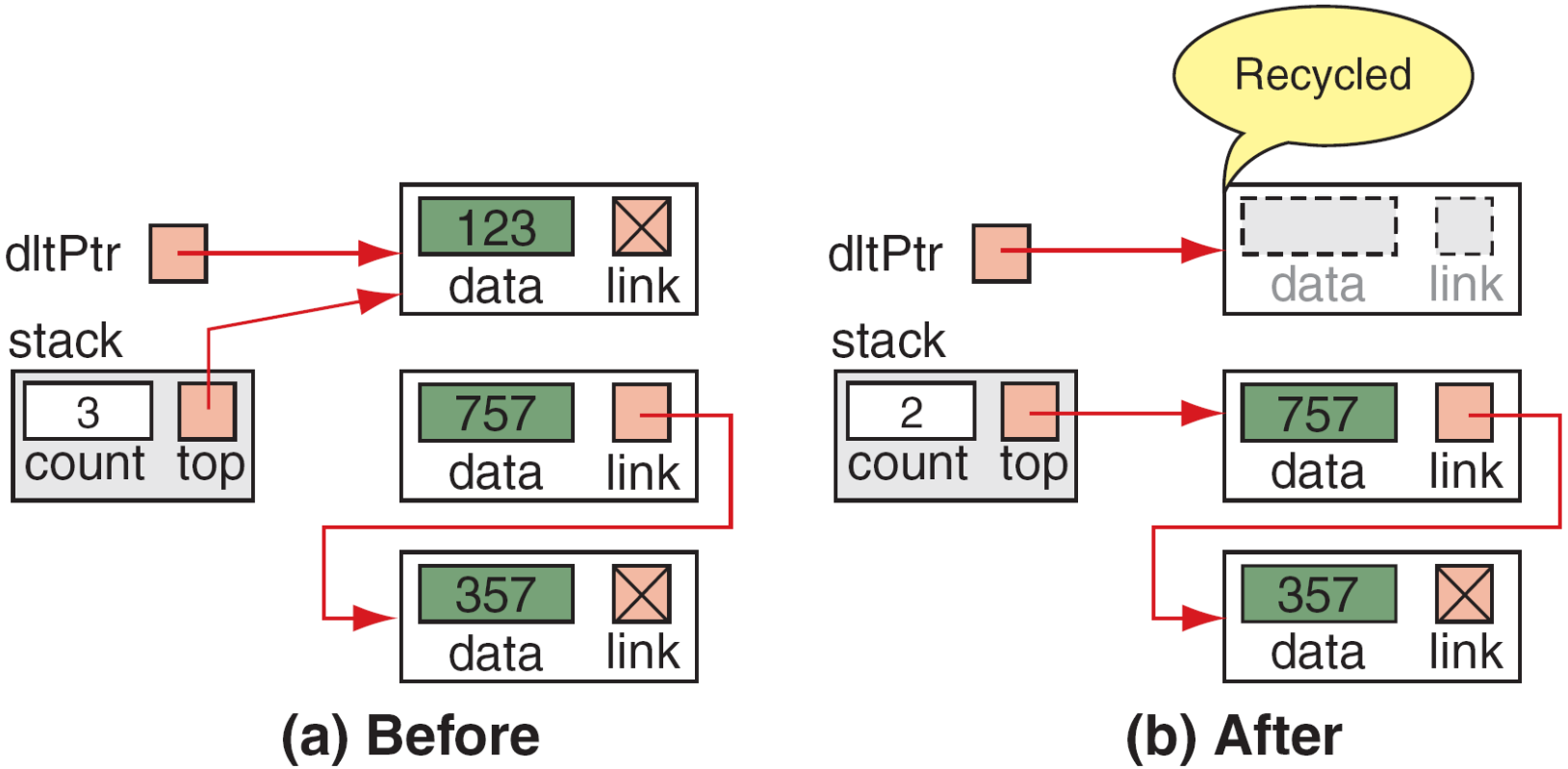


FIGURE 15-21 Pop Stack Example

PROGRAM 15-10 Pop Stack

```
1  /* ==================== pop ====================
2     Delete node from linked list stack.
3        Pre     pStackTop is pointer to valid stack
4        Post    dataOut contains deleted data
5        Return  true  if successful
6                false if underflow
7  */
8  bool pop (STACK* pStack, int* dataOut)
9  {
10 // Local Declarations
11    STACK_NODE* pDlt;
12    bool        success;
13
14 // Statements
15    if (pStack->top)              // Test for Empty Stack
16       {
17        success  = true;
18        *dataOut = pStack->top->data;
```

PROGRAM 15-10 Pop Stack

```
20          pStack->top = (pStack->top)->link;
21          pStack->count--;
22          free (pDlt);
23        } // else
24     else
25        success = false;
26     return success;
27  }  // pop
```

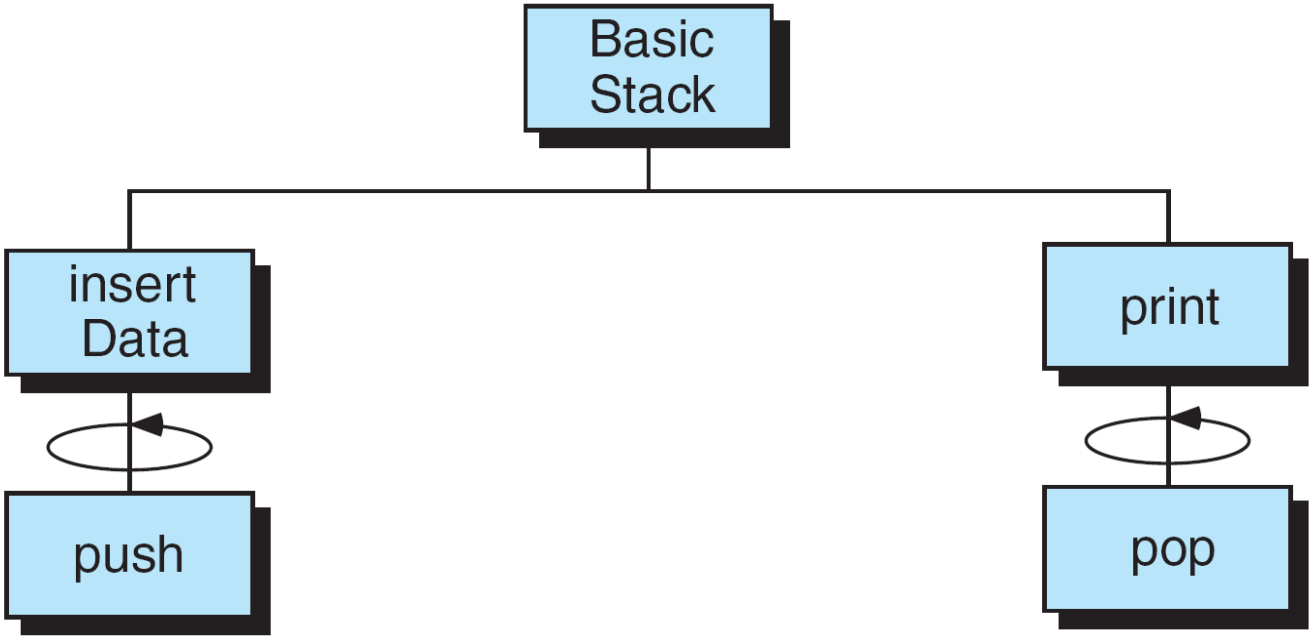


FIGURE 15-22 Design for Basic Stack Program

PROGRAM 15-11 Simple Stack Application Program

```
1  /* This program is a test driver to demonstrate the
2     basic operation of the stack push and pop functions.
3        Written by:
4        Date:
5  */
6  #include <stdio.h>
7  #include <stdlib.h>
8  #include <stdbool.h>
9
10 // Global Declarations
11 typedef struct node
12    {
13     int          data;
14     struct node* link;
15    } STACK_NODE;
16
17 typedef struct
```

PROGRAM 15-11 Simple Stack Application Program

```
18      {
19       int          count;
20       STACK_NODE* top;
21      } STACK;
22
23  // Function Declarations
24  void insertData (STACK* pStack);
25  void print      (STACK* pStack);
26  bool push       (STACK* pList, int  dataIn);
27  bool pop        (STACK* pList, int* dataOut);
28
29  int main (void)
30  {
31  // Local Declarations
32  STACK* pStack;
33
34  // Statements
35     printf("Beginning Simple Stack Program\n");
36
```

PROGRAM 15-11 Simple Stack Application Program

```
37      pStack = malloc(sizeof(STACK));
38      if (!pStack)
39         printf("Error allocating stack"), exit(100);
40
41      pStack->top   = NULL;
42      pStack->count = 0;
43      insertData (pStack);
44      print      (pStack);
45
46      printf("\nEnd Simple Stack Program\n");
47      return 0;
48  }  // main
```

```
Results:
Beginning Simple Stack Program
Creating numbers:  854 763 123 532  82 632  33 426 228  90
Stack contained:    90 228 426  33 632  82 532 123 763 854
End Simple Stack Program
```

PROGRAM 15-12 Insert Data

```
/* ================= insertData =================
   This program creates random numbers and
   inserts them into a linked list stack.
      Pre  pStack is a pointer to first node
      Post Stack has been created
*/
void insertData (STACK* pStack)
{
// Local Declarations
   int  numIn;
   bool success;

// Statements
   printf("Creating numbers: ");
   for (int nodeCount = 0; nodeCount < 10; nodeCount++)
       {
        // Generate random number
        numIn   = rand() % 999;
        printf("%4d", numIn);
        success = push(pStack, numIn);
```

PROGRAM 15-12 Insert Data

```
21            if (!success)
22               {
23                printf("Error 101: Out of Memory\n");
24                exit (101);
25               } // if
26            } // for
27      printf("\n");
28      return;
29   }  // insertData
```

PROGRAM 15-13 Print Stack

```
 1  /* ====================== print ====================
 2     This function prints a singly linked stack.
 3        Pre     pStack is pointer to valid stack
 4        Post    data in stack printed
 5  */
 6  void print (STACK* pStack)
 7  {
 8  // Local Declarations
 9     int printData;
10
11  // Statements
12     printf("Stack contained:  ");
13     while (pop(pStack, &printData))
14         printf("%4d", printData);
15     return;
16  }  // print
```

15-4 Queues

A queue is a linear list in which data can be inserted only at one end, called the rear, and deleted from the other end, called the front.

Topics discussed in this section:

Queue Operations
Queue Linked List Design
Queue Functions
Queue Demonstration

Note

A queue is a linear list in which data can be inserted at one end, called the rear, and deleted from the other end, called the front. It is a first in–first out (FIFO) restricted data structure.

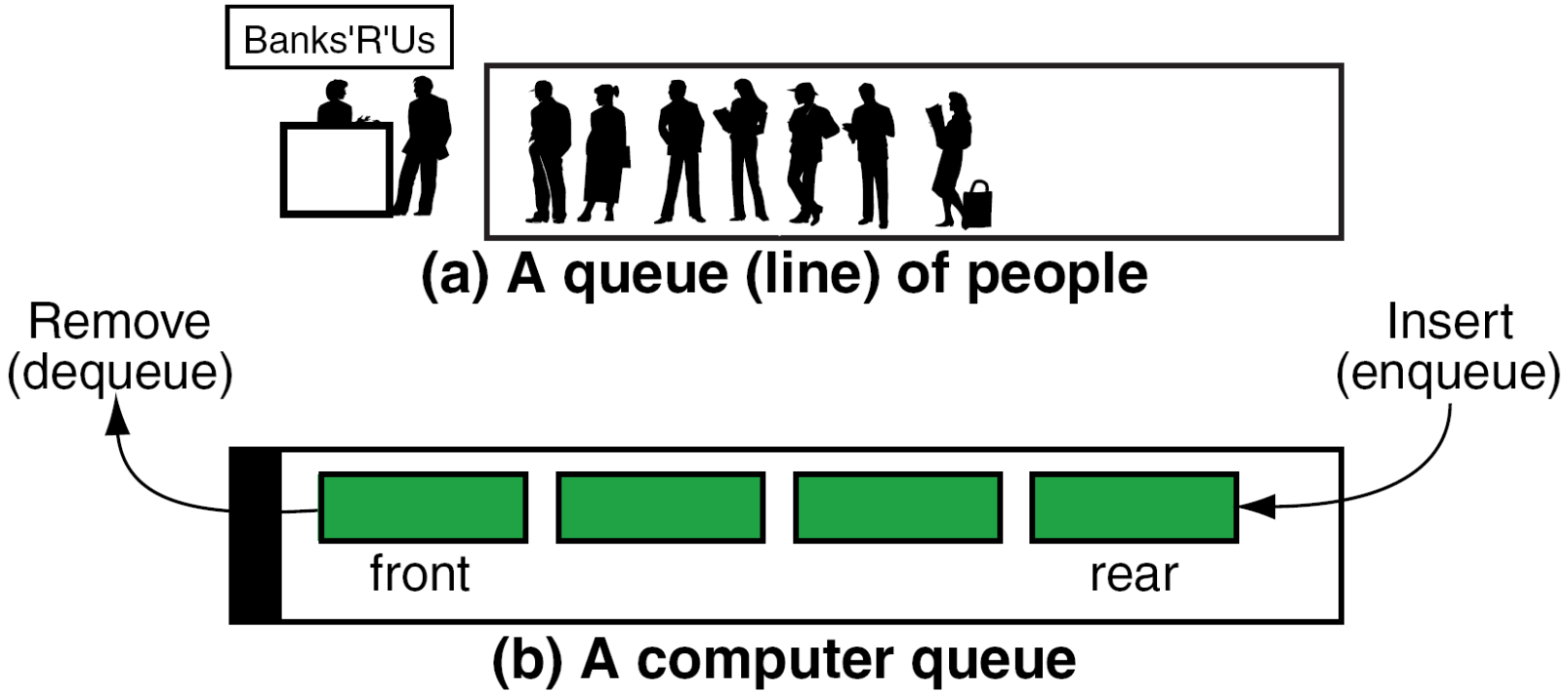


FIGURE 15-23 Queue Concept

Note

Enqueue inserts an element at the rear of the queue.

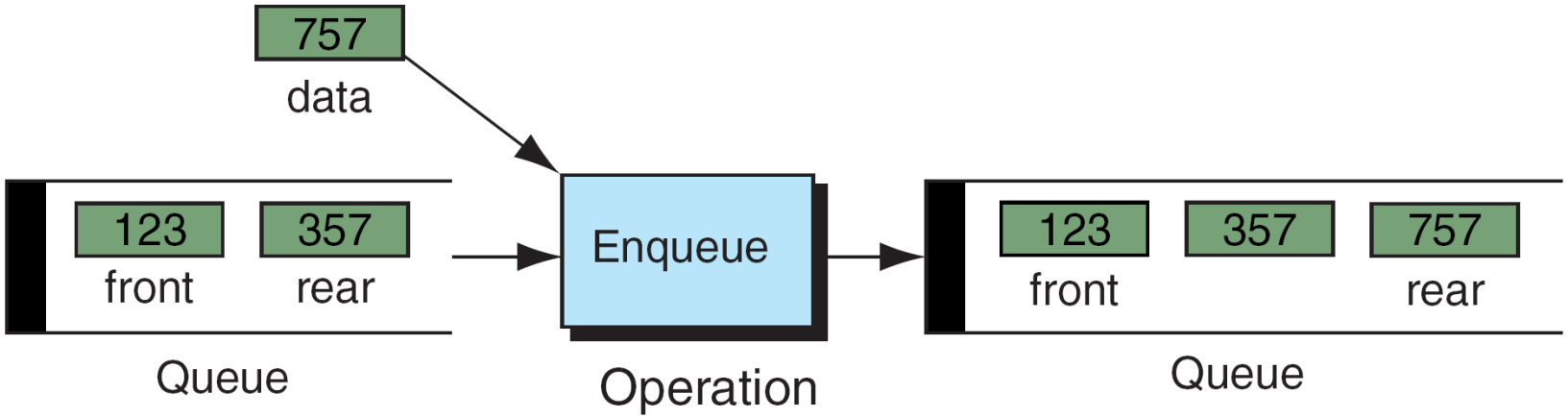


FIGURE 15-24 Enqueue

Note

Dequeue deletes an element at the front of the queue.

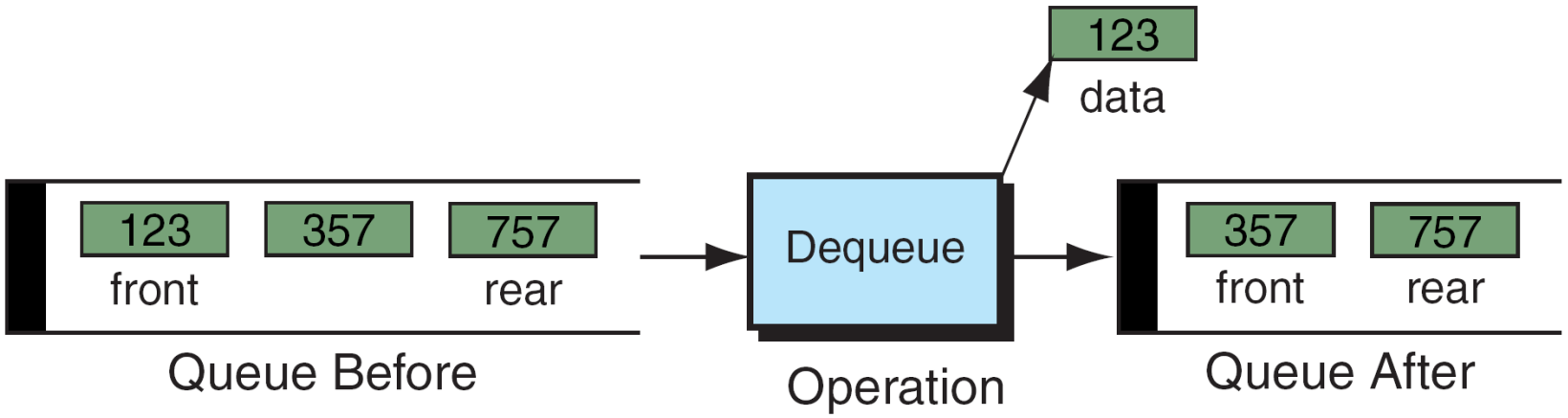


FIGURE 15-25 Dequeue

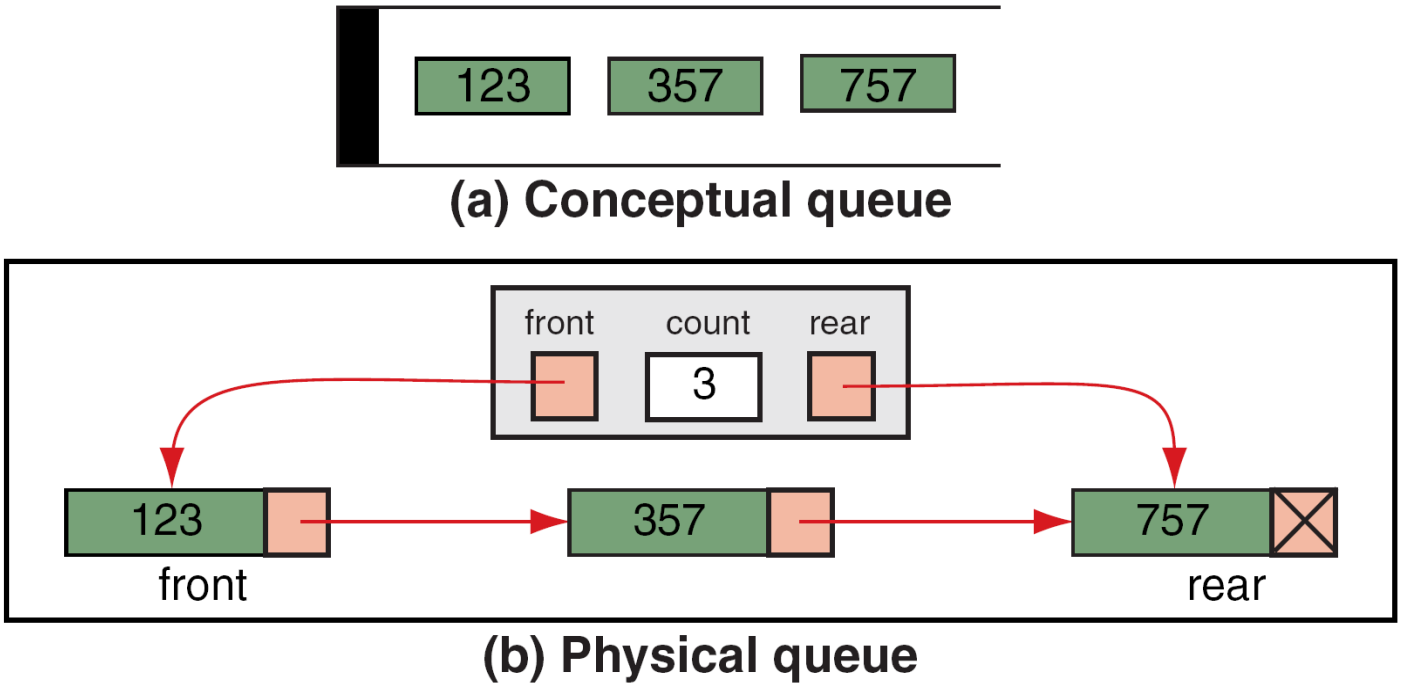
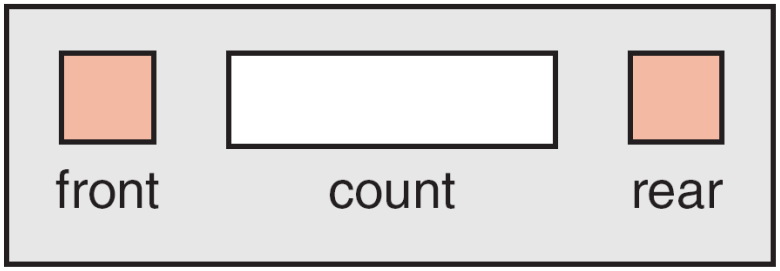


FIGURE 15-26 Conceptual and Physical Queue Implementations

Node Structure



Head Structure

```
typedef struct node
    {
     int           data;
     struct node*  next;
    } QUEUE_NODE;

typedef struct
    {
     QUEUE_NODE*  front;
     int          count;
     QUEUE_NODE*  rear;
    } QUEUE;
```

FIGURE 15-27 Queue Data Structure

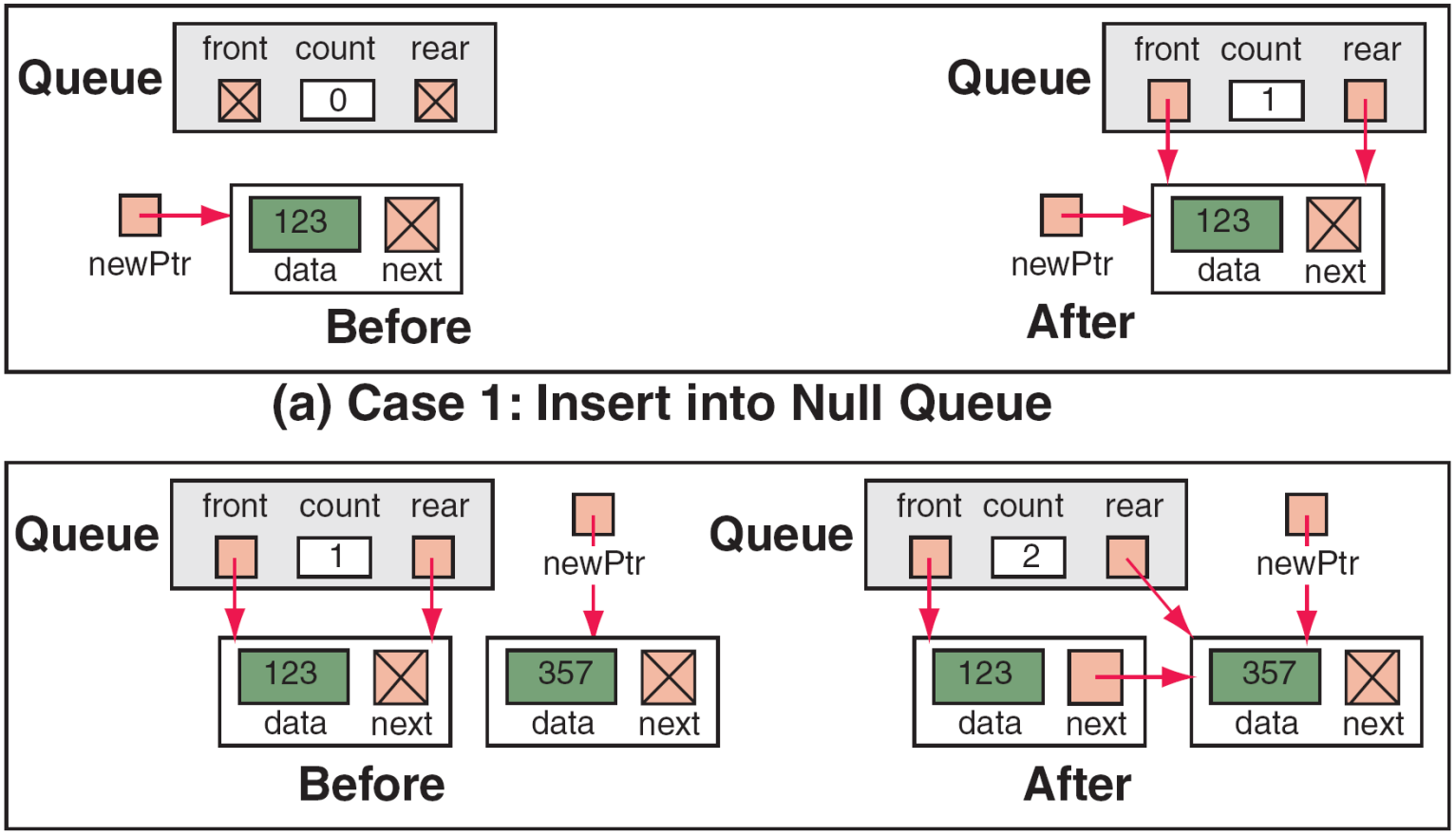


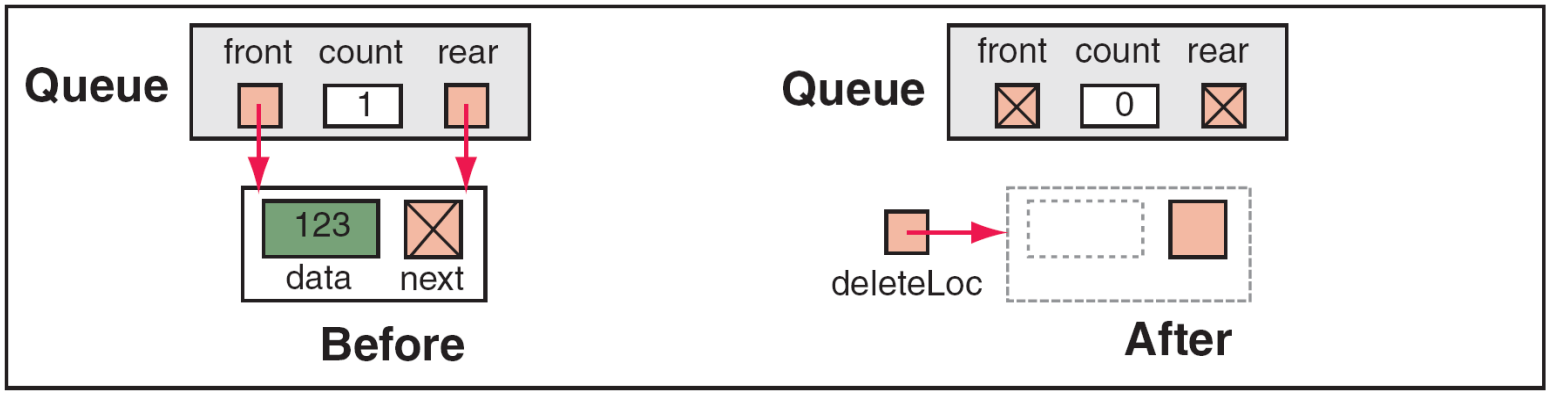
FIGURE 15-28 Enqueue Example

PROGRAM 15-14 Enqueue

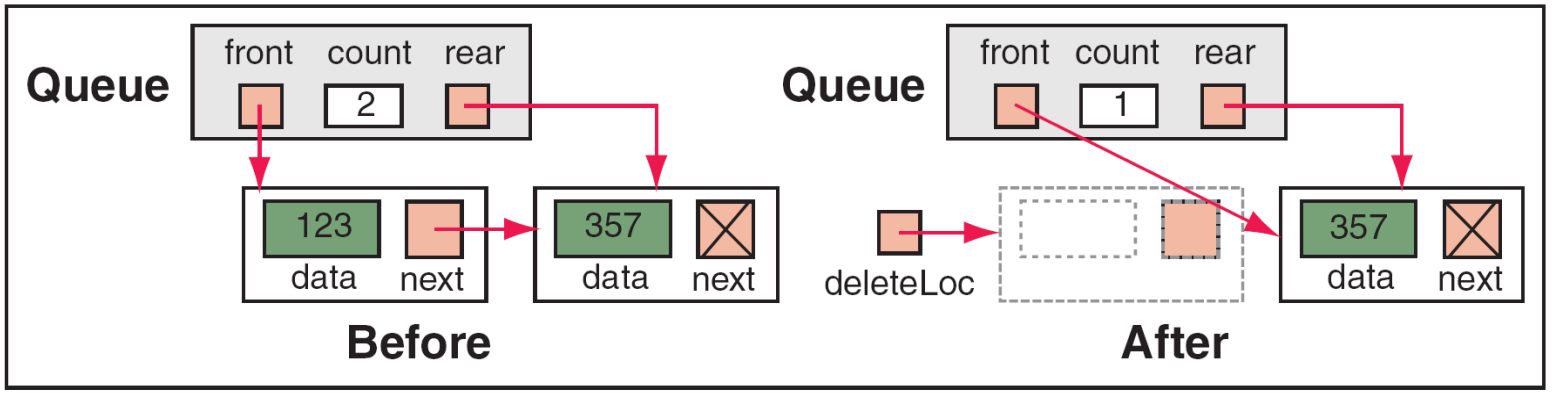
```
 1  /* ================ enqueue ================
 2     This algorithm inserts data into a queue.
 3        Pre    queue is valid
 4        Post   data have been inserted
 5        Return true if successful, false if overflow
 6  */
 7  bool enqueue (QUEUE* queue, int dataIn)
 8  {
 9  // Local Declarations
10     QUEUE_NODE* newPtr;
11
12  // Statements
13     if (!(newPtr = malloc(sizeof(QUEUE_NODE))))
14        return false;
15
16     newPtr->data = dataIn;
17     newPtr->next = NULL;
18
```

PROGRAM 15-14 Enqueue

```
19      if (queue->count == 0)
20         // Inserting into null queue
21         queue->front  = newPtr;
22      else
23         queue->rear->next = newPtr;
24      (queue->count)++;
25      queue->rear = newPtr;
26      return true;
27   }  // enqueue
```



(a) Case 1: Delete only item in queue



(b) Case 2: Delete item at front of queue

FIGURE 15-29 Dequeue Examples

PROGRAM 15-15 Dequeue

```
/* ================= dequeue ================
   This algorithm deletes a node from the queue.
      Pre    queue is pointer to queue head structure
             dataOut is pointer to data being deleted
      Post   Data pointer to queue front returned and
             front element deleted and recycled.
      Return true if successful; false if underflow
*/
bool dequeue (QUEUE* queue, int* dataOut)
{
// Local Declarations
   QUEUE_NODE* deleteLoc;

// Statements
   if (!queue->count)
       return false;

```

PROGRAM 15-15 Dequeue

```
18      *dataOut = queue->front->data;
19      deleteLoc = queue->front;
20      if (queue->count == 1)
21          // Deleting only item in queue
22          queue->rear  = queue->front = NULL;
23      else
24          queue->front = queue->front->next;
25      (queue->count)--;
26      free (deleteLoc);
27
28      return true;
29  }   // dequeue
```

PROGRAM 15-16 Simple Queue Demonstration

```
 1  /* This program is a test driver to demonstrate the
 2     basic operation of the enqueue and dequeue functions.
 3        Written by:
 4        Date:
 5  */
 6  #include <stdio.h>
 7  #include <stdlib.h>
 8  #include <string.h>
 9  #include <stdbool.h>
10
11  // Global Declarations
12  typedef struct node
13     {
14      int           data;
15      struct node* next;
16     } QUEUE_NODE;
17
18  typedef struct
19     {
20      QUEUE_NODE* front;
```

PROGRAM 15-16 Simple Queue Demonstration

```
21       int          count;
22       QUEUE_NODE* rear;
23     } QUEUE;
24
25  // Function Declarations
26  void insertData (QUEUE* pQueue);
27  void print      (QUEUE* pQueue);
28  bool enqueue    (QUEUE* pList, int  dataIn);
29  bool dequeue    (QUEUE* pList, int* dataOut);
30
31  int main (void)
32  {
33  // Local Declarations
34  QUEUE* pQueue;
35
36  // Statements
37     printf("Beginning Simple Queue Program\n");
38
39     pQueue = malloc(sizeof(QUEUE));
40     if (!pQueue)
41        printf("Error allocating queue"), exit(100);
42
```

PROGRAM 15-16 Simple Queue Demonstration

```
43      pQueue->front = NULL;
44      pQueue->count = 0;
45      pQueue->rear  = NULL;
46
47      insertData (pQueue);
48      print      (pQueue);
49
50      printf("\nEnd Simple Queue Program\n");
51      return 0;
52  }   // main
```

```
Results:
Beginning Simple Queue Program
Creating numbers:  854 763 123 532  82
Queue contained:   854 763 123 532  82
End Simple Queue Program
```

PROGRAM 15-17 Insert Data

```
/* ================== insertData ==================
   This program creates random number data and
   inserts them into a linked list queue.
      Pre  pQueue is a pointer to first node
      Post Queue created and filled
*/
void insertData (QUEUE* pQueue)
{
// Local Declarations
   int  numIn;
   bool success;

// Statements
   printf("Creating numbers: ");
   for (int nodeCount = 0; nodeCount < 5; nodeCount++)
       {
        // Generate random number
        numIn  = rand() % 999;
        printf("%4d", numIn);
```

PROGRAM 15-17 Insert Data

```
20            success = enqueue(pQueue, numIn);
21            if (!success)
22               {
23                printf("Error 101: Out of Memory\n");
24                exit (101);
25               } // if
26           } // for
27       printf("\n");
28       return;
29   }  // insertData
```

PROGRAM 15-18 Print Queue

```
1  /* ====================== print ====================
2     This function prints a singly linked queue.
3        Pre     pQueue is pointer to valid queue
4        Post    data in queue printed
5  */
6  void print (QUEUE* pQueue)
7  {
8  // Local Declarations
9     int printData;
10
11 // Statements
12    printf("Queue contained:  ");
13    while (dequeue(pQueue, &printData))
14        printf("%4d", printData);
15    return;
16 }  // print
```

15-5 Trees

Trees are used extensively in computer science to represent algebraic formulas; as an efficient method for searching large, dynamic lists; and for such diverse applications as artificial intelligence systems and encoding algorithms.

Topics discussed in this section:

Basic Tree Concepts
Terminology
Binary Trees
Binary Search Trees
Binary Tree Example

Note

A tree consists of a finite set of elements, called nodes, and a finite set of directed lines, called branches, that connect the nodes.

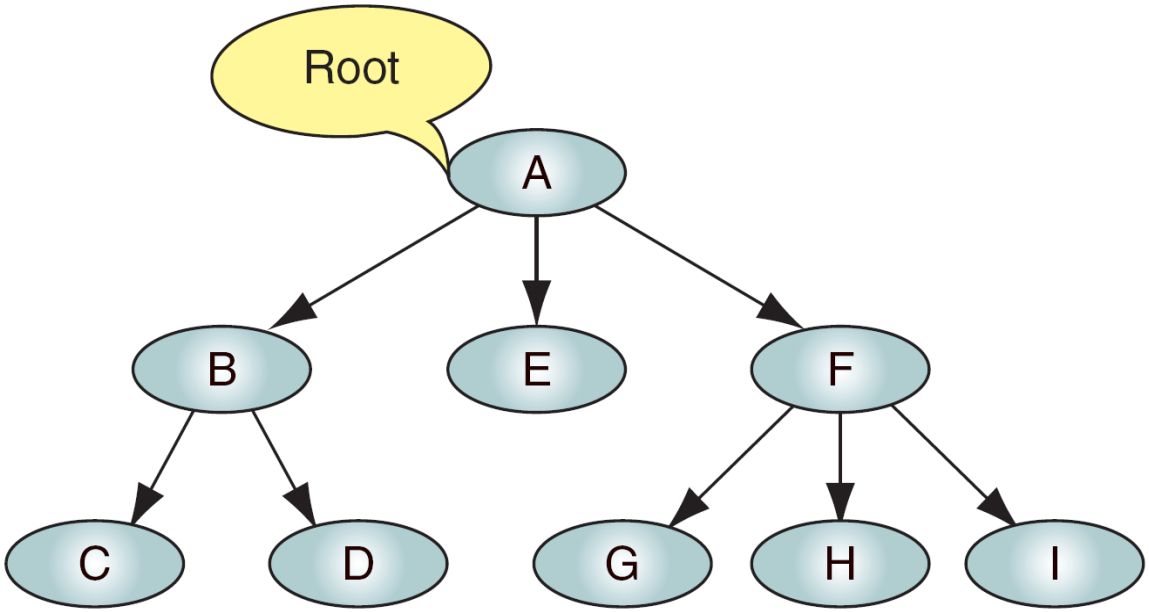
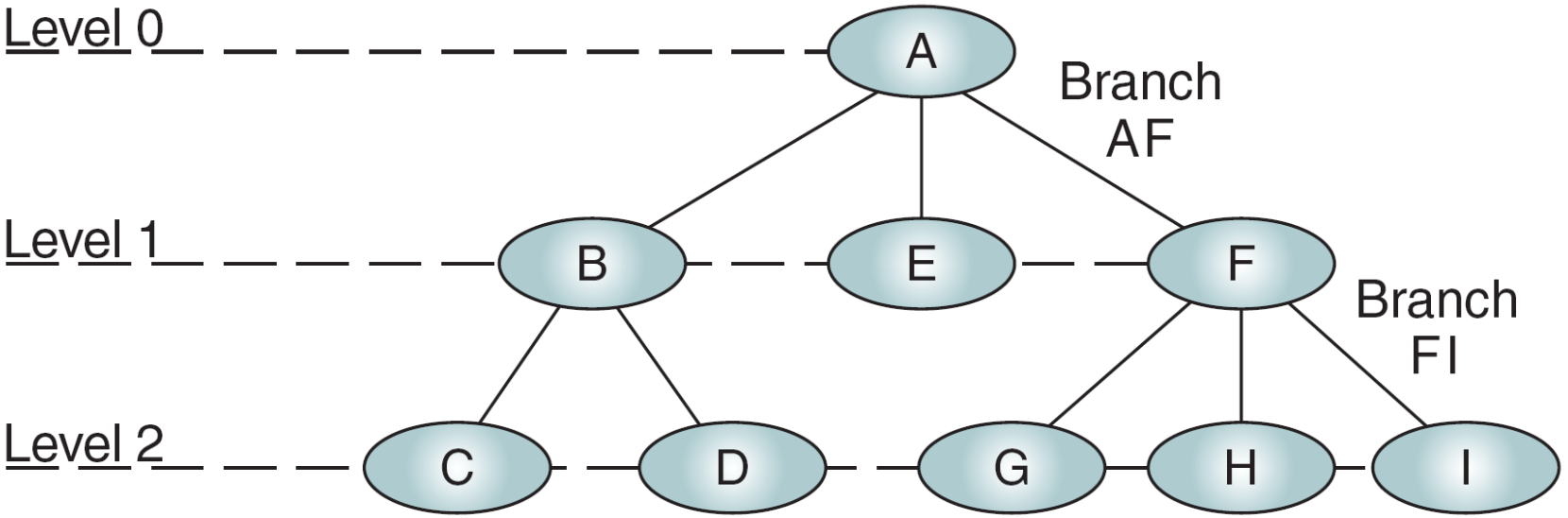


FIGURE 15-30 Tree



Root: A	Siblings: {B, E, F}, {C, D}, {G, H, I}
Parents: A, B, F	Leaves: C, D, E, G, H, I
Children: B, E, F, C, D, G, H, I	Internal nodes: B, F

FIGURE 15-31 Tree Nomenclature

Note

The level of a node is its distance from the root. The height of a tree is the level of the leaf in the longest path from the root plus 1.

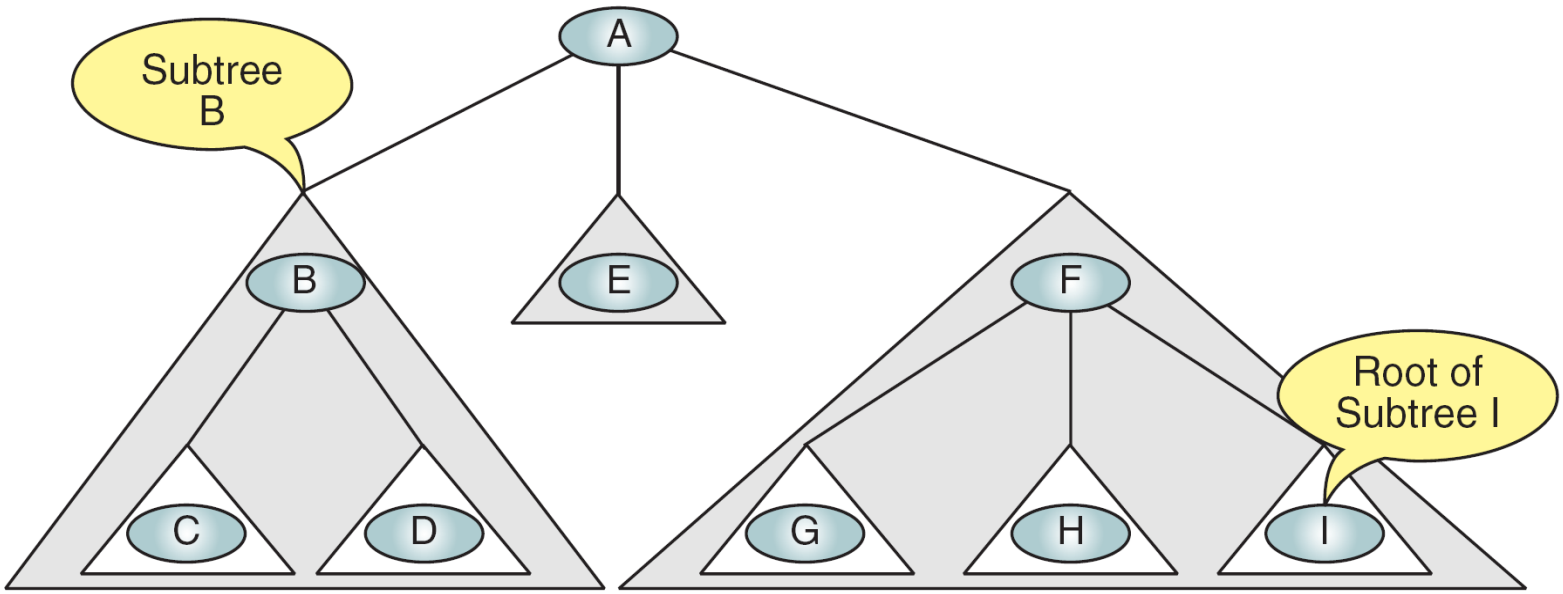


FIGURE 15-32 Subtrees

Note

A tree is a set of nodes that either:

1. Is empty, or

2. Has a designated node, called the root, from which hierarchically descend zero or more subtrees, which are also trees

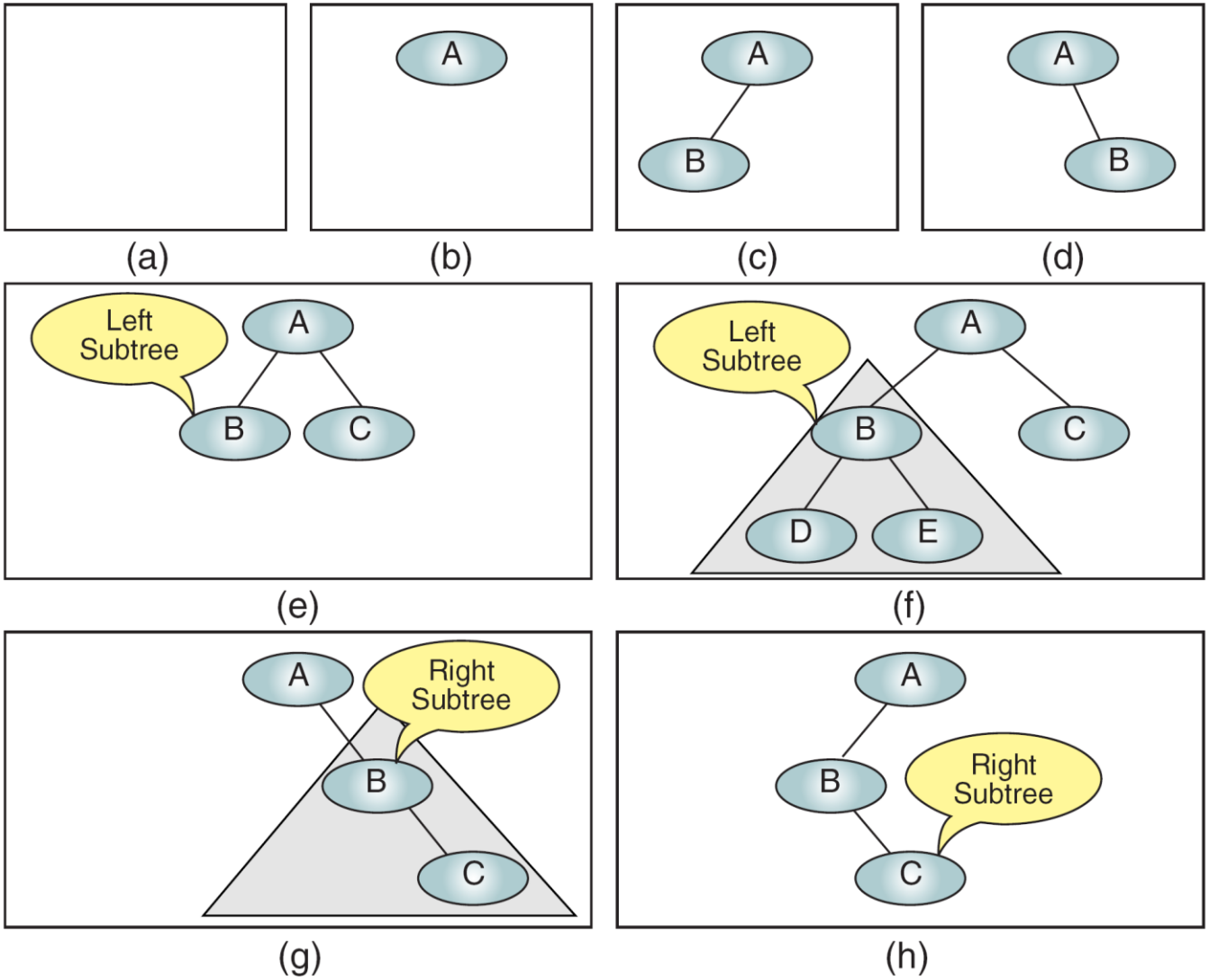
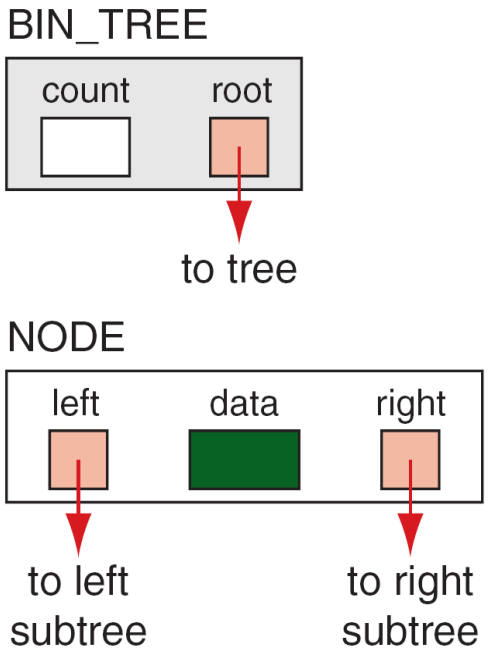


FIGURE 15-33 Collection of Binary Trees




```
typedef struct
  {
   int    count;
   NODE* root;
  } BIN_TREE;

typedef struct node
  {
   int           data;
   struct node* left;
   struct node* right;
  } NODE;
```

FIGURE 15-34 Binary Tree Data Structure

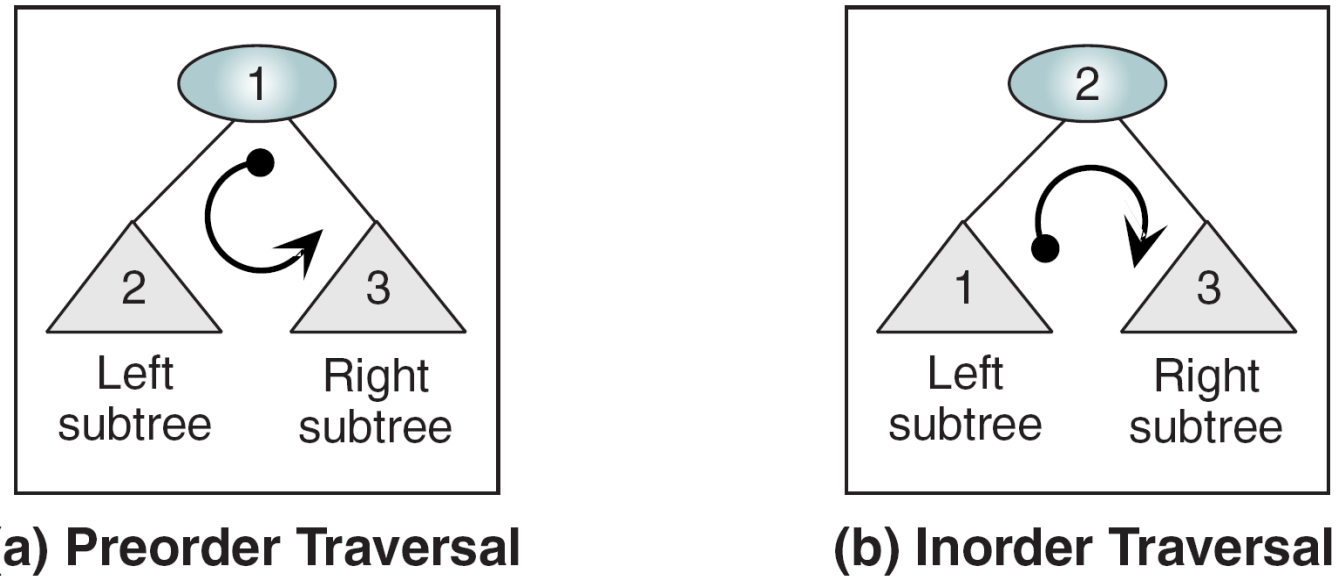


FIGURE 15-35 Binary Tree Traversals

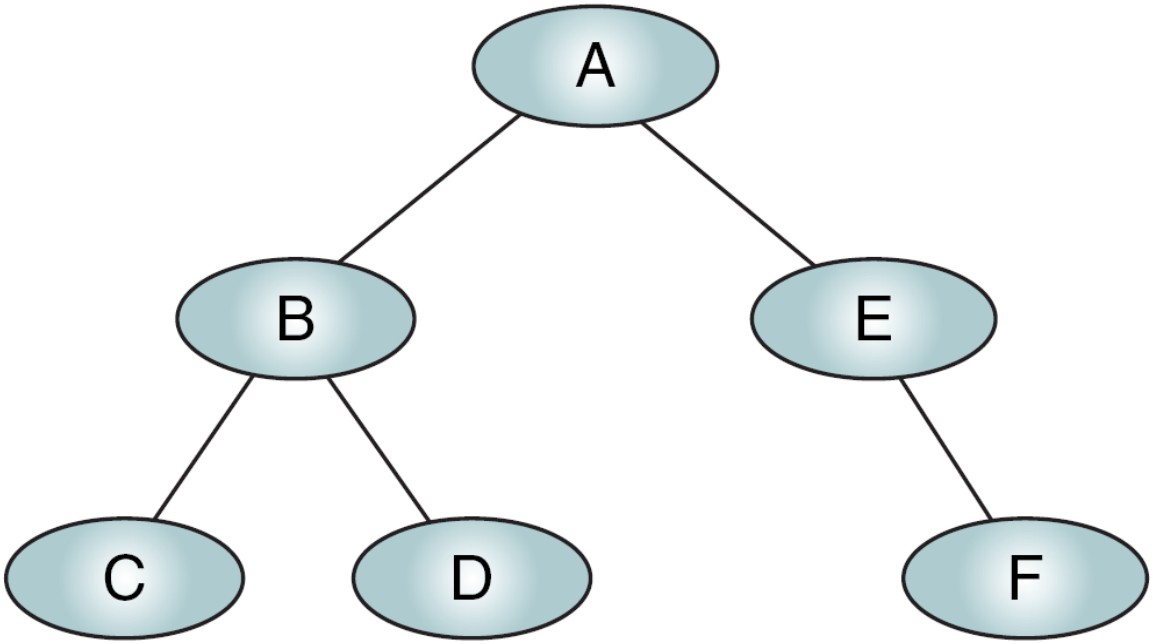


FIGURE 15-36 Binary Tree for Traversals

Note

In the preorder traversal, the root is processed first, before its subtrees.

PROGRAM 15-19 Preorder Traversal of a Binary Tree

```
1  /* Traverse a binary tree and print its data (integers)
2        Pre  root is entry node of a tree or subtree
3        Post each node has been printed
4  */
5  void preOrder (NODE* root)
6  {
7  // Statements
8     if (root)
9        {
10        printf("%4d", root->data);
11        preOrder (root->left);
12        preOrder (root->right);
13       } // if
14    return;
15 }  // preOrder
```

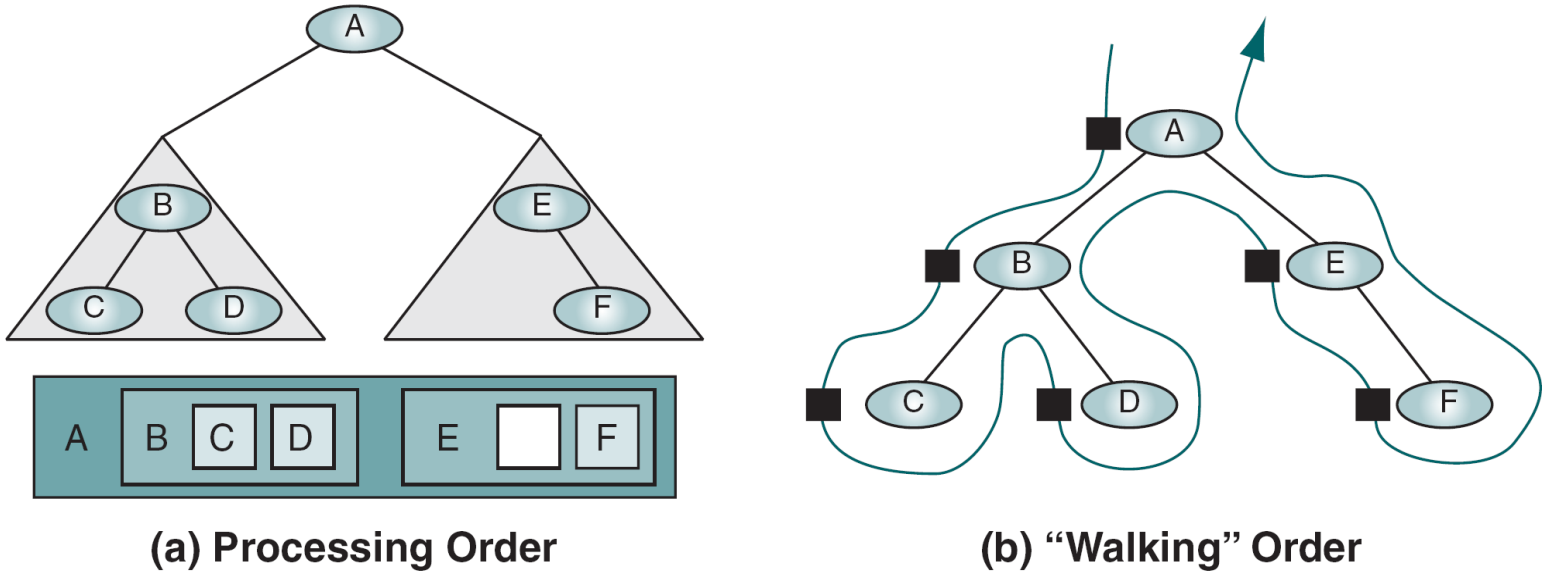


FIGURE 15-37 Preorder Traversal—A B C D E F

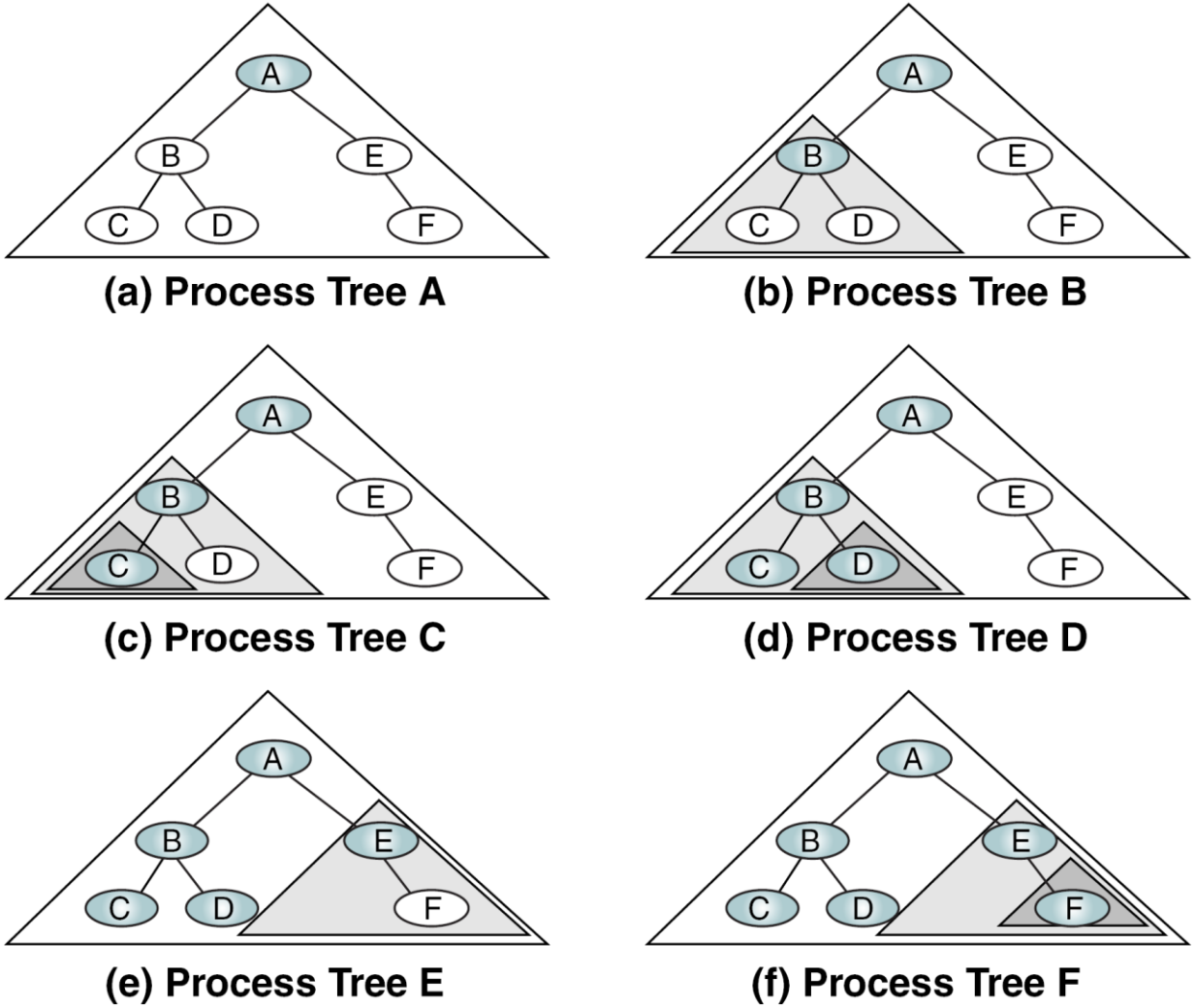


FIGURE 15-38 Algorithmic Traversal of Binary Tree

PROGRAM 15-20 Inorder Traversal of a Binary Tree

```
1  /* Traverse a binary tree and print its data (integers)
2        Pre  root is entry node of a tree or subtree
3        Post each node has been printed
4  */
5  void inOrder (NODE* root)
6  {
7  // Statements
8     if (root)
9        {
10        inOrder (root->left);
11        printf("%4d", root->data);
12        inOrder (root->right);
13       } // if
14    return;
15 }  // inOrder
```

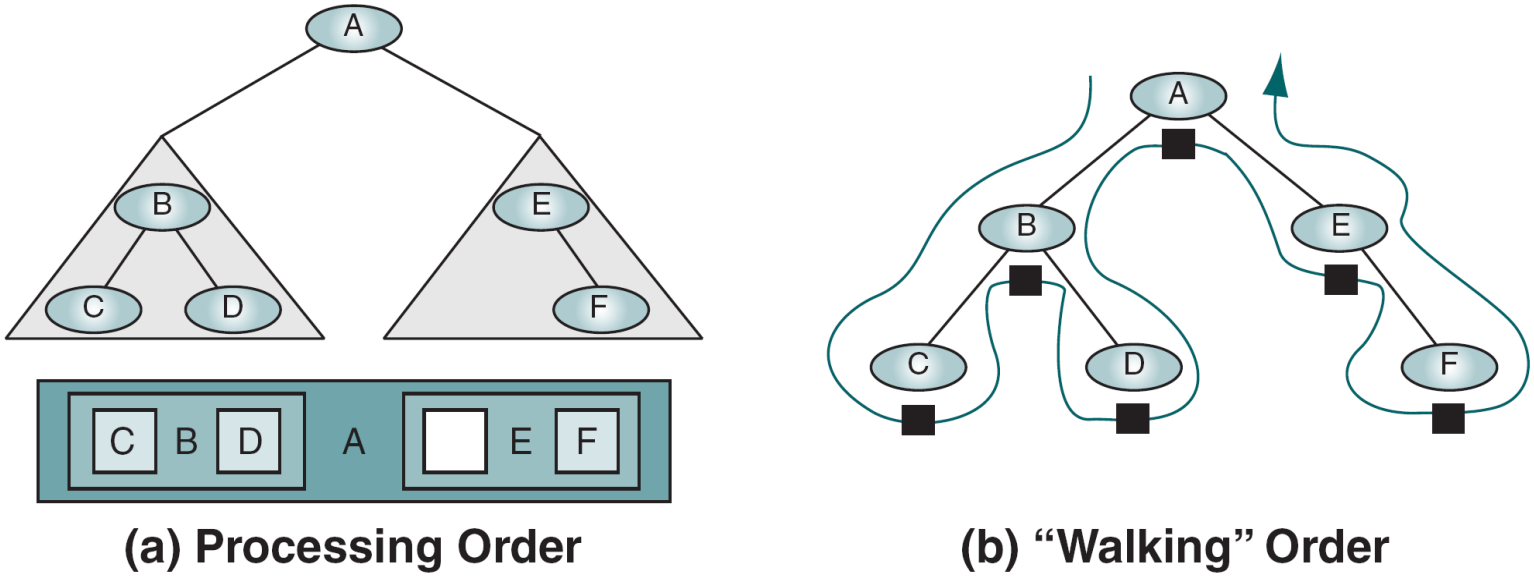


FIGURE 15-39 Inorder Traversal—C B D A E F

Note

In the inorder traversal, the root is processed between its subtrees.

Note

In a binary search tree, the left subtree contains key values less than the root, and the right subtree contains key values greater than or equal to the root.

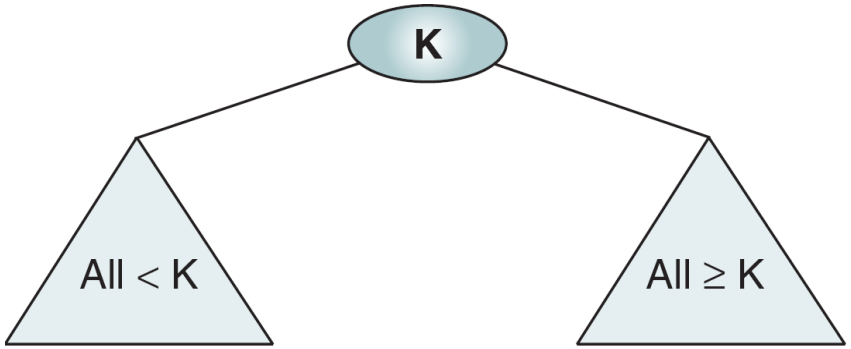


FIGURE 15-40 Binary Search Tree

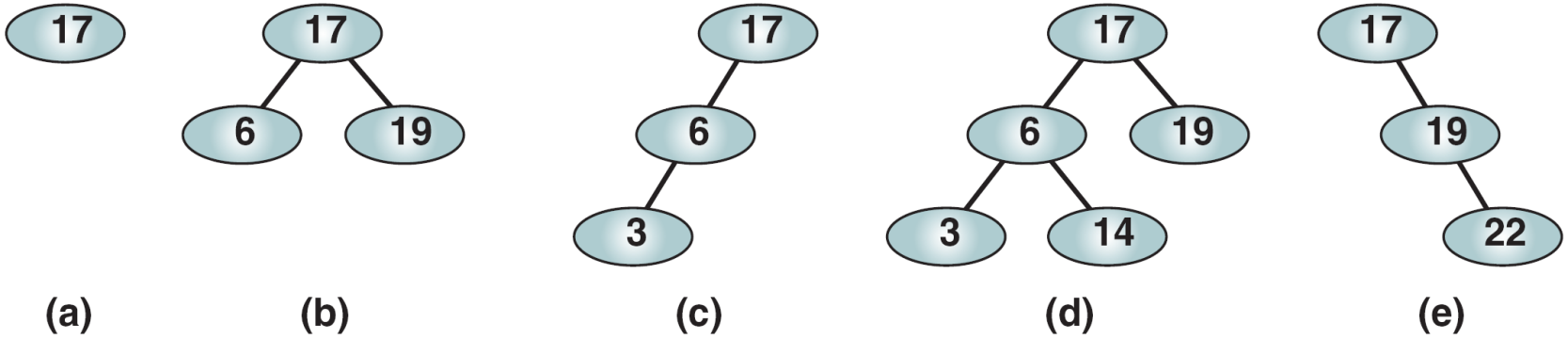


FIGURE 15-41 **Valid Binary Search Trees**

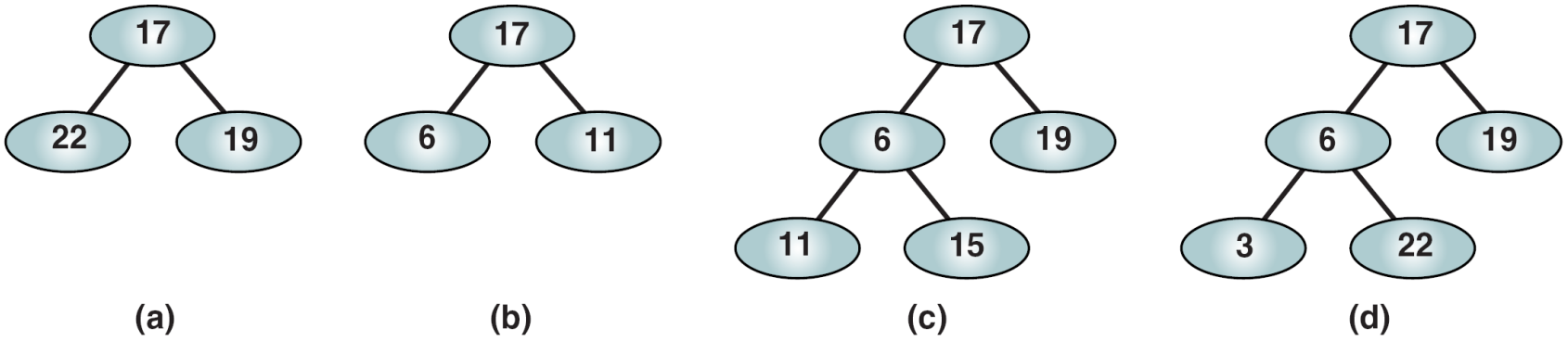


FIGURE 15-42 Invalid Binary Search Trees

Note

All BST insertions take place at a leaf or a leaflike node.

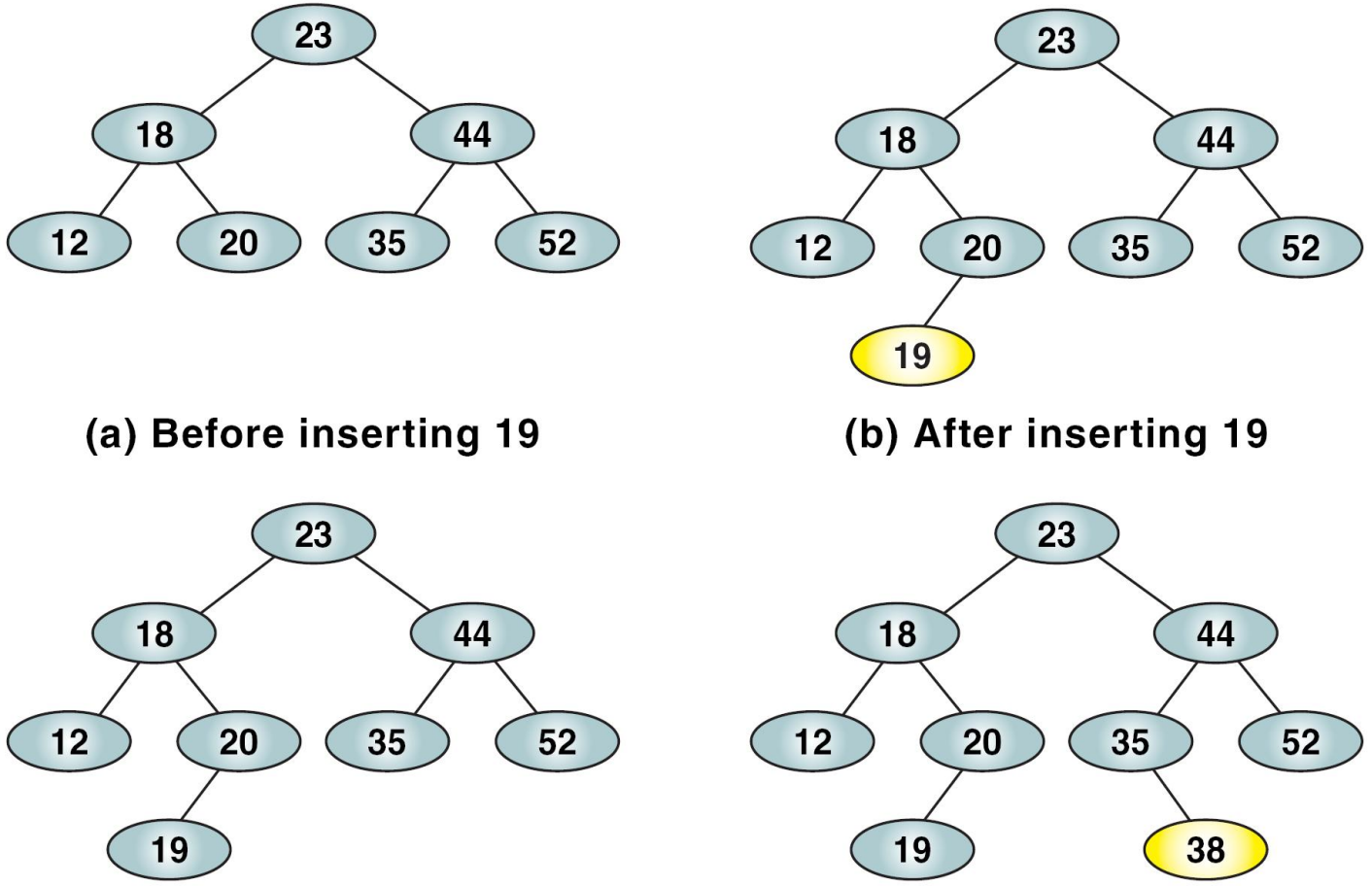


FIGURE 15-43 BST Insertion

PROGRAM 15-21 Binary Tree Insert Function

```
 1  /* ==================== BST_Insert ====================
 2     This function uses recursion to insert the new data
 3     into a leaf node in the BST tree.
 4        Pre    Application has called BST_Insert, which
 5               passes root and data pointer
 6        Post   Data have been inserted
 7        Return pointer to [potentially] new root
 8  */
 9  NODE* BST_Insert (BST_TREE* tree,
10                    NODE* root,     int dataIn)
11  {
12  // Local Declarations
13     NODE* newPtr;
14
15  // Statements
16
17     if (!root)
18        {
19         // NULL tree -- create new node
20         newPtr = malloc(sizeof (NODE));
```

PROGRAM 15-21 Binary Tree Insert Function

```
21          if (!newPtr)
22             printf("Overflow in Insert\n"), exit (100);
23          newPtr->data = dataIn;
24          newPtr->left = newPtr->right = NULL;
25          return newPtr;
26         } // if
27
28      // Locate null subtree for insertion
29      if (dataIn < root->data)
30          root->left = BST_Insert(tree, root->left,
31                                  dataIn);
32      else
33         // new data >= root data
34          root->right = BST_Insert(tree, root->right,
35                                   dataIn);
36      return root;
37  }   // BST_Insert
```

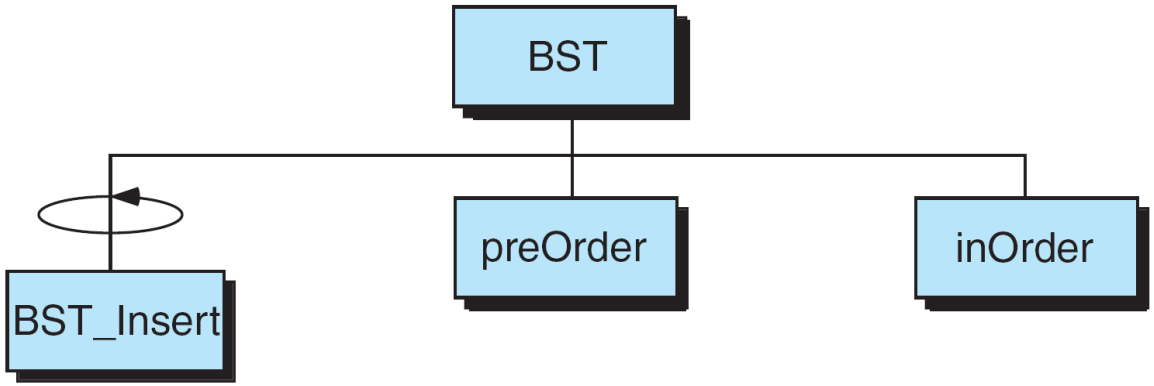


FIGURE 15-44 Binary Tree Example

PROGRAM 15-22 Binary Tree Example

```
1  /* Demonstrate the binary search tree insert and
2     traversals.
3        Written by:
4        Date:
5  */
6  #include <stdio.h>
7  #include <stdlib.h>
8
9  // Global Declarations
10 typedef struct node
11   {
12    int          data;
13    struct node* left;
14    struct node* right;
15   } NODE;
16
17 typedef struct
18   {
19    int   count;
20    NODE* root;
```

PROGRAM 15-22 Binary Tree Example

```
21    } BST_TREE;
22
23 // Function Declarations
24 void  preOrder   (NODE* root);
25 void  inOrder    (NODE* root);
26 NODE* BST_Insert (BST_TREE* tree,
27                   NODE* root,     int data);
28
29 int main (void)
30 {
31 // Local Declarations
32    int       numIn;
33    BST_TREE tree;
34
35 // Statements
36    printf("Please enter a series of integers."
37           "\nEnter a negative number to stop\n");
38
39    tree.count = 0;
40    tree.root  = NULL;
```

PROGRAM 15-22 Binary Tree Example

```
41      do
42         {
43          printf("Enter a number: ");
44          scanf("%d", &numIn);
45          if (numIn > 0)
46             {
47              tree.root = BST_Insert
48                  (&tree, tree.root, numIn);
49              tree.count++;
50             } // if
51         } while (numIn > 0);
52
53      printf("\nData in preOrder: ");
54      preOrder (tree.root);
55
56      printf("\n\nData in inOrder:  ");
57      inOrder (tree.root);
58
59      printf("\n\nEnd of BST Demonstration\n");
60      return 0;
61   }  // main
```

PROGRAM 15-22 Binary Tree Example

```
Results
Please enter a series of integers.
Enter a negative number to stop
Enter a number: 45
Enter a number: 54
Enter a number: 23
Enter a number: 32
Enter a number: 3
Enter a number: -1

Data in preOrder:    45   23    3   32   54

Data in inOrder:      3   23   32   45   54

End of BST Demonstration
```

15-6 Graphs

A graph is a collection of nodes, called vertices, and a collection of segments, called lines, connecting pairs of vertices. In other words, a graph consists of two sets, a set of vertices and a set of lines.

Topics discussed in this section:

Graph Traversal

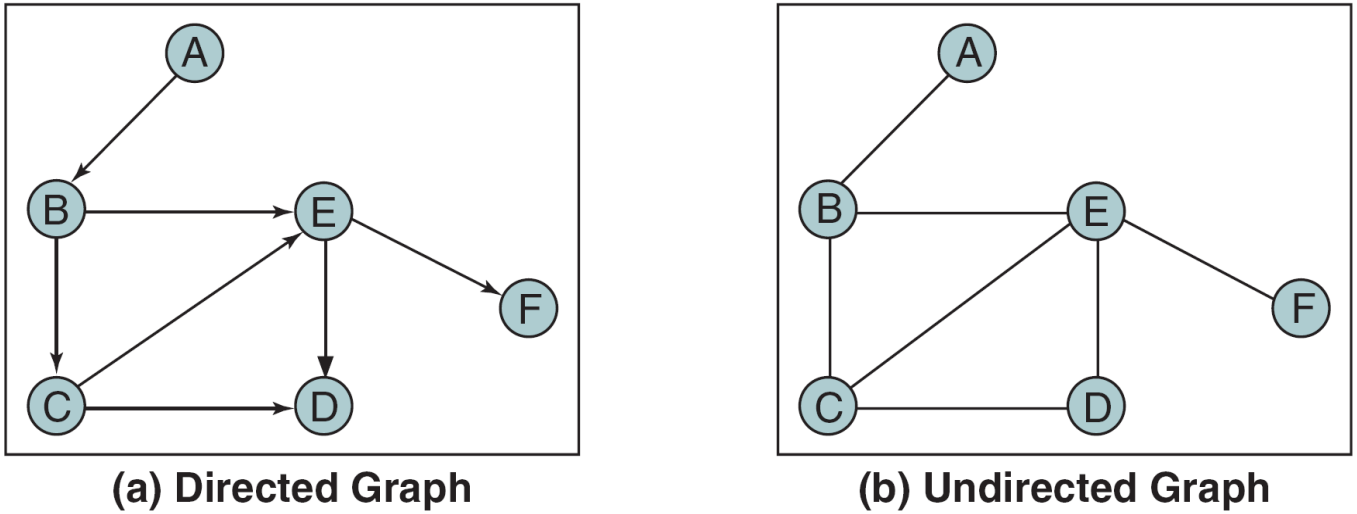


FIGURE 15-45 Directed and Undirected Graphs

Note

Graphs may be directed or undirected. In a directed graph, each line, called an arc, has a direction indicating how it may be traversed. In an undirected graph, the line is known as an edge, and it may be traversed in either direction.

Note

A file is an external collection of related data treated as a unit.

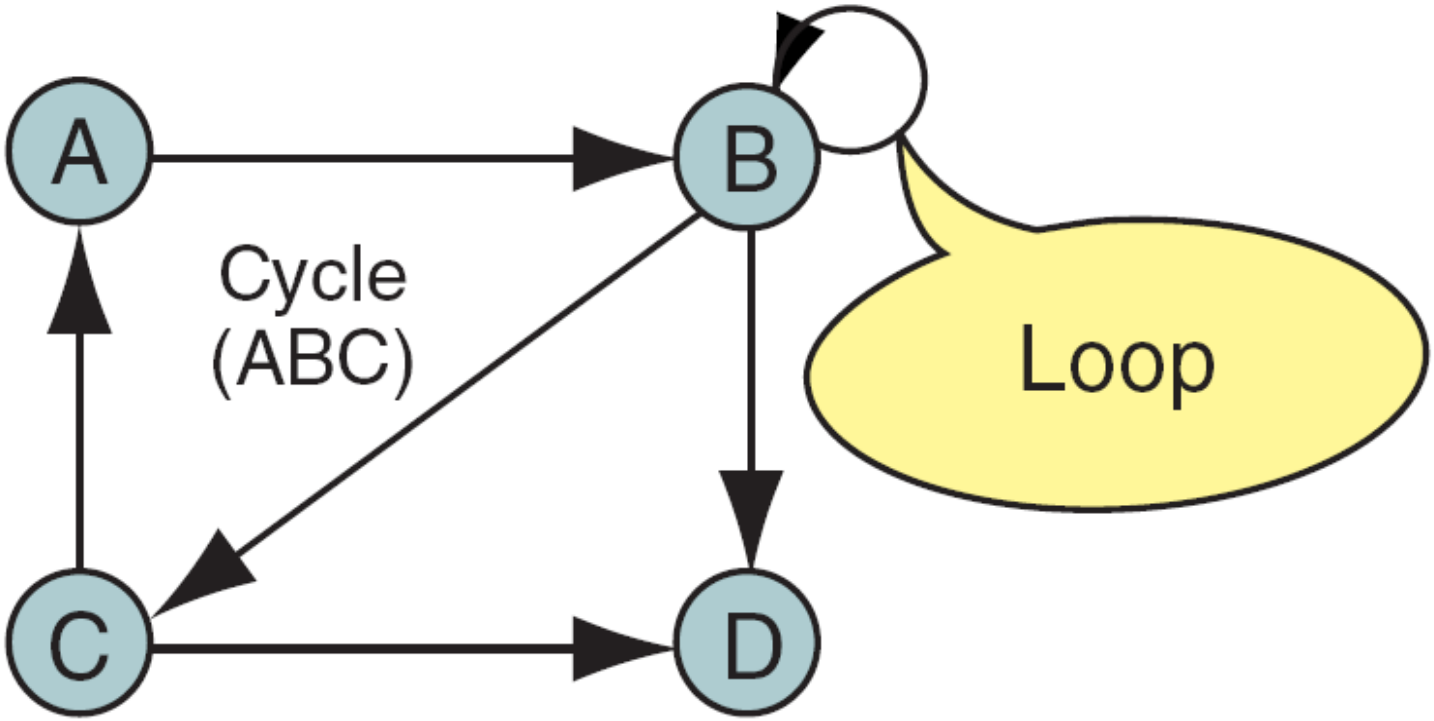


FIGURE 15-46 **Cycles and Loops**

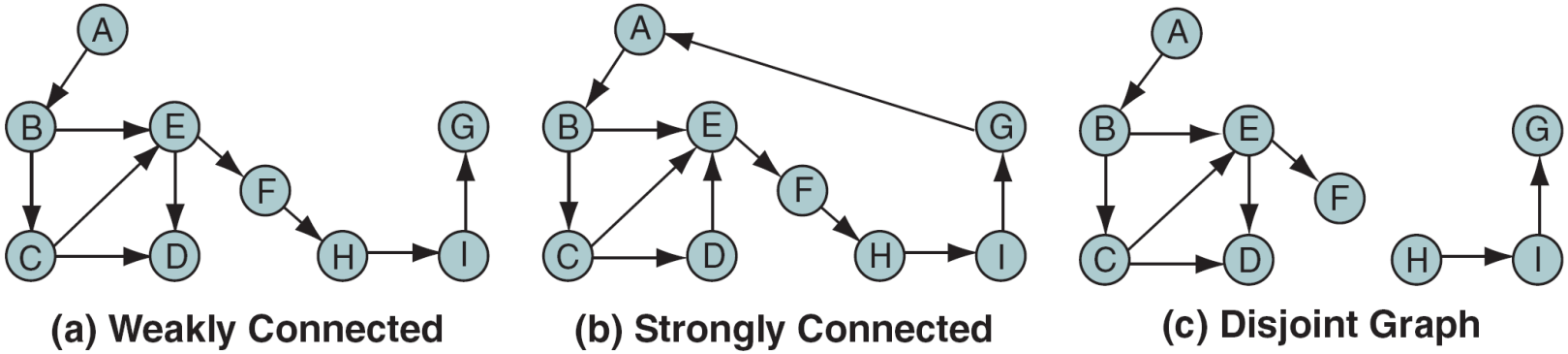


FIGURE 15-47 Connected and Disjoint Graphs

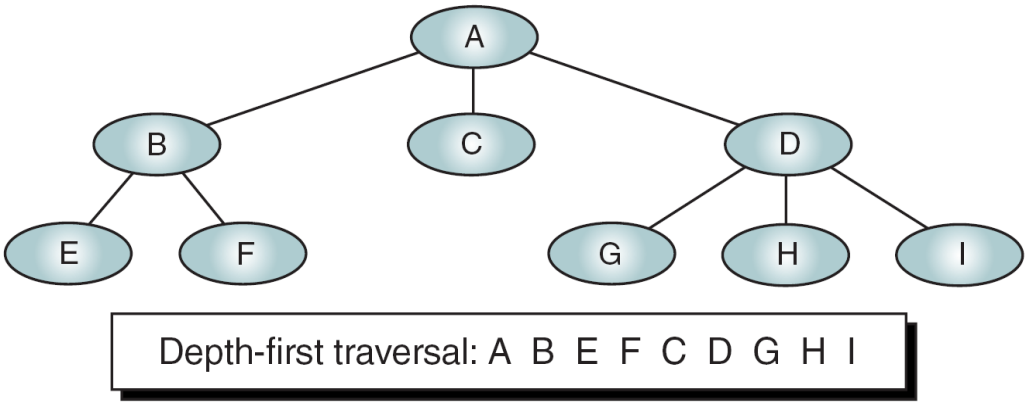


FIGURE 15-48 Depth-first Traversal of a Tree

Note

In the depth-first traversal, all of a node's descendents are processed before moving to an adjacent node.

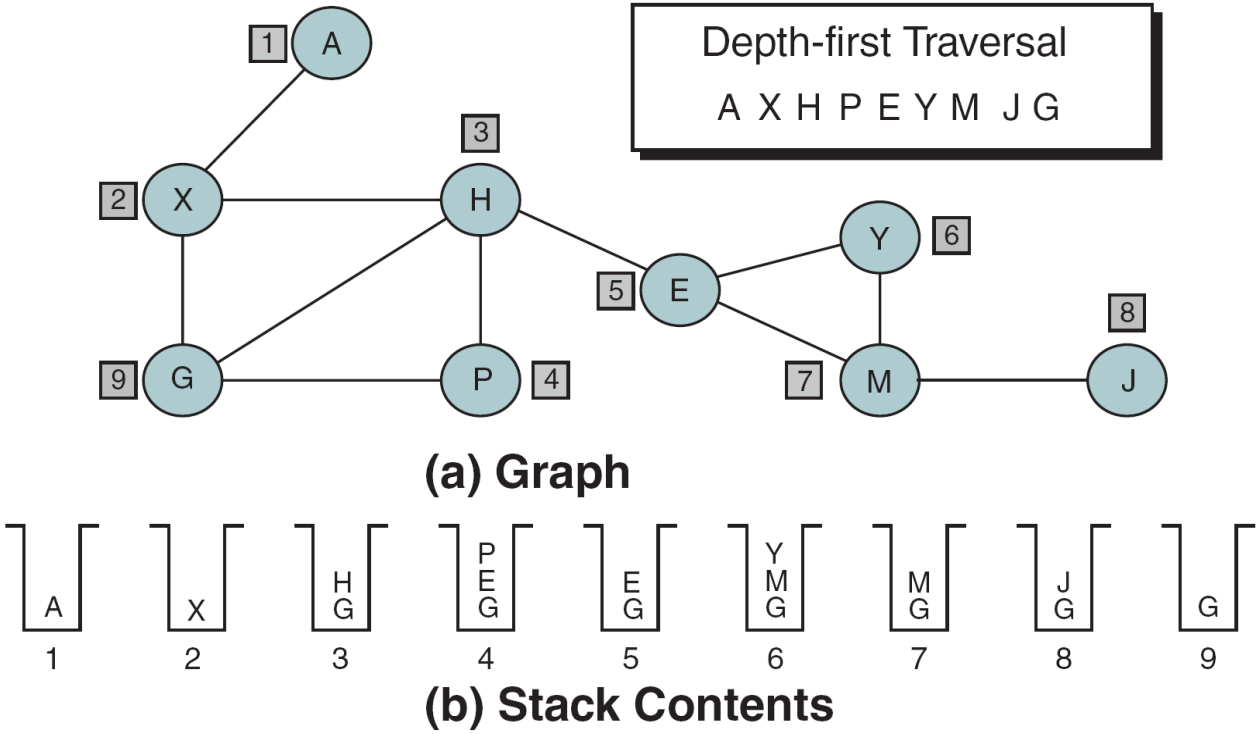


FIGURE 15-49 Depth-first Traversal of a Graph

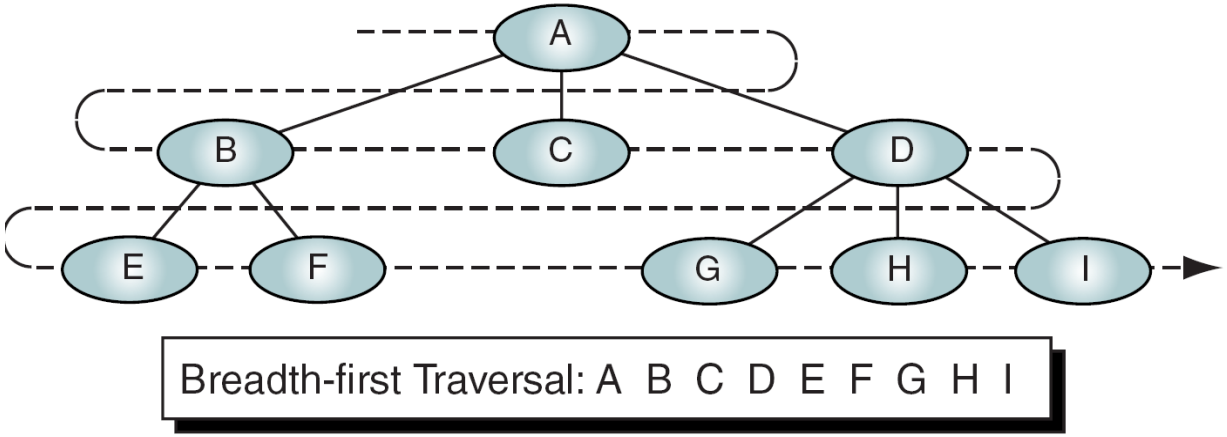


FIGURE 15-50 Breadth-first Traversal of a Tree

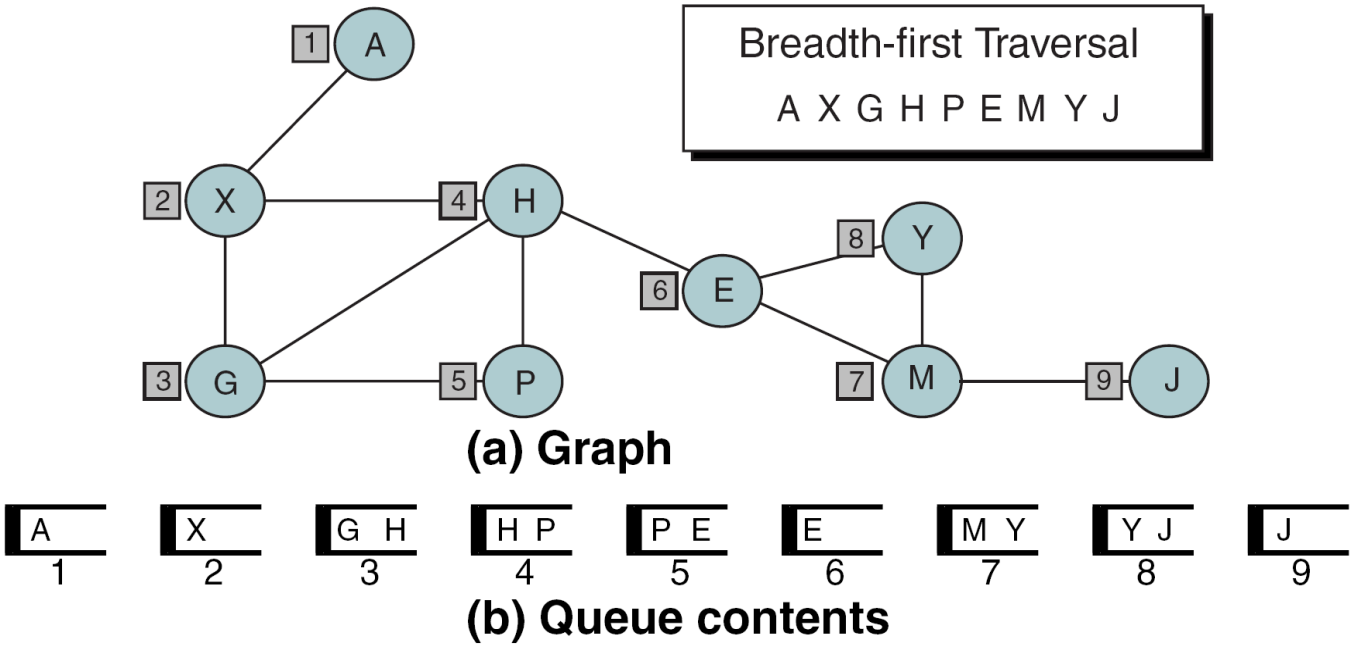


FIGURE 15-51 Breadth-first Traversal of a Graph

Note

In the breadth-first traversal, all adjacent vertices are processed before processing the descendents of a vertex.

15-7 Software Engineering

Because lists are useful structures, programmers use them in many applications. Rather than rewrite their functions each time we need them, we can write functions once and put them in a library. The name given to a complete set of these functions is abstract data type (ADT).

Topics discussed in this section:

Atomic and Composite Data
Data Structure and Abstract Data Type
A Model for an Abstract Data Type
ADT Data Structure

Note

Atomic Data Type

1. A set of values.

2. A set of operations on the values.

Note

Data Structure

1. **A combination of elements, each of which is either a data type or another data structure.**
2. **A set of associations or relationships (structure) involving the combined elements.**

array	struct
A homogeneous combination of data structures. Position association.	A heterogeneous combination of data structures. No association.

Table 15-2 Two Structures

Note

In the concept of abstraction
We know what a data type can do.
How it is done is hidden.

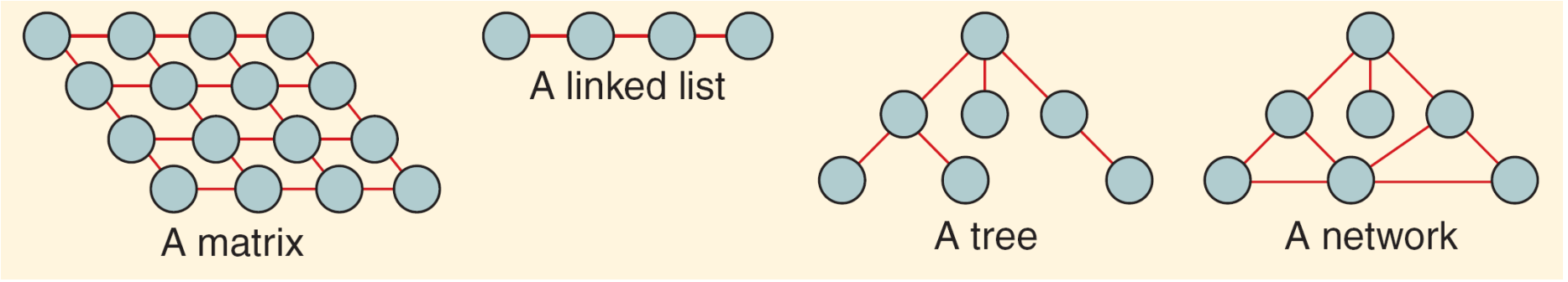


FIGURE 15-52 Structures for Holding a List

Note

Abstract Data Type

1. Declaration of data.

2. Declaration of operations.

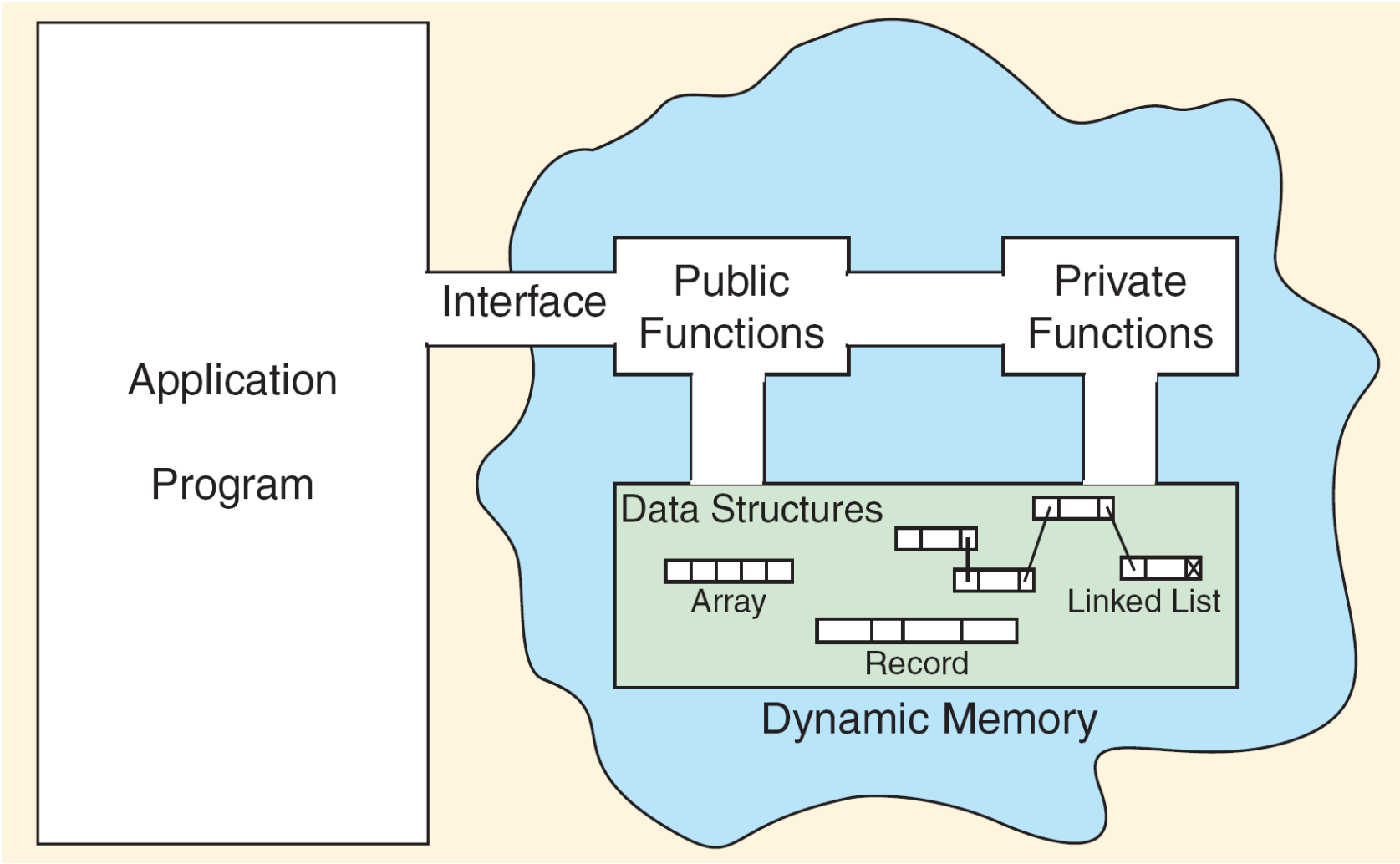


FIGURE 15-53 Abstract Data Type Model