Chapter 8: Data Abstractions

Computer Science: An Overview
Tenth Edition

by
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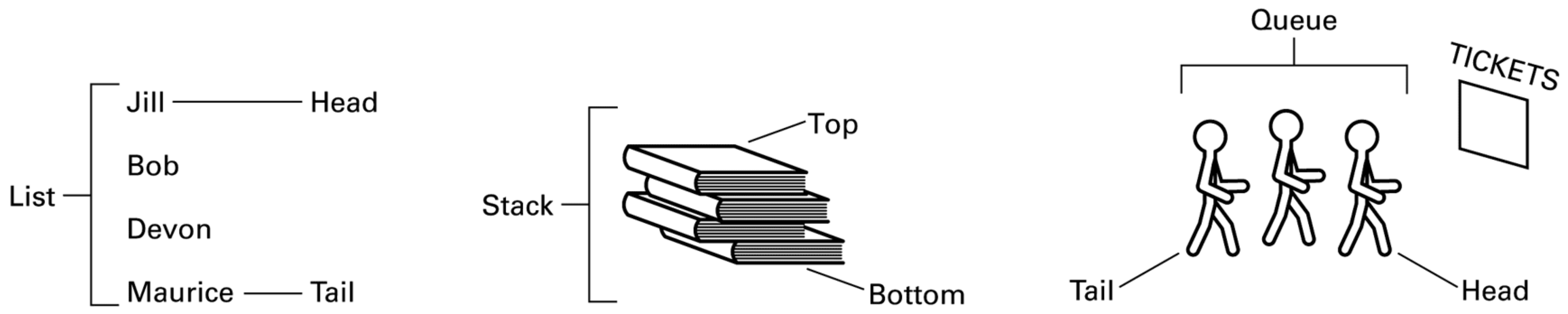
Basic Data Structures

- Homogeneous and Heterogeneous
- Static and Dynamic
- List
  - Stack
  - Queue
- Tree

Figure 8.1 **Lists, stacks, and queues**



a. A list of names

b. A stack of books

c. A queue of people

Terminology for Lists

- **List:** A collection of data whose entries are arranged sequentially
- **Head:** The beginning of the list
- **Tail:** The end of the list

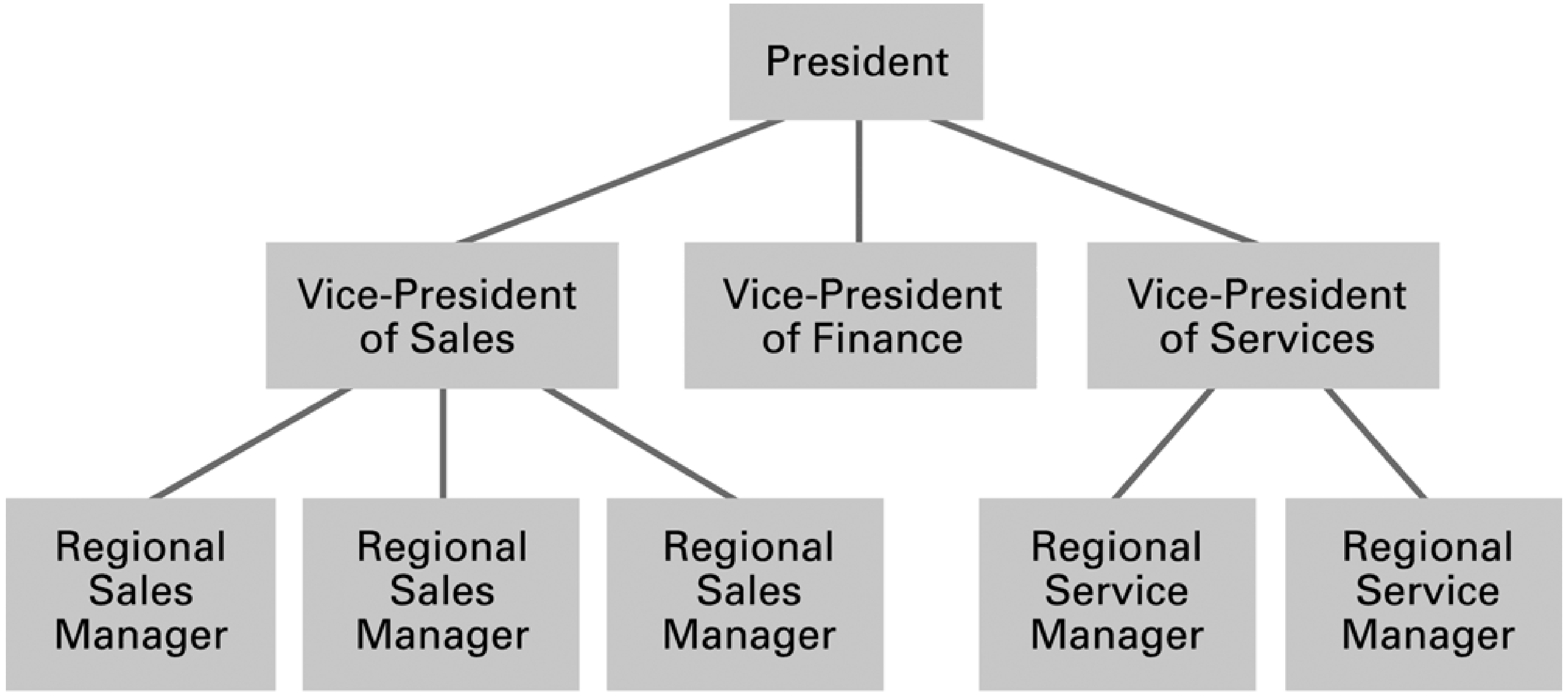
Terminology for Stacks

- **Stack:** A list in which entries are removed and inserted only at the head
- **LIFO:** Last-in-first-out
- **Top:** The head of list (stack)
- **Bottom** or **base:** The tail of list (stack)
- **Pop:** To remove the entry at the top
- **Push:** To insert an entry at the top

Terminology for Queues

- **Queue:** A list in which entries are removed at the head and are inserted at the tail
- **FIFO:** First-in-first-out

Figure 8.2 **An example of an organization chart**



Terminology for a Tree

- **Tree:** A collection of data whose entries have a hierarchical organization
- **Node:** An entry in a tree
- **Root node:** The node at the top
- **Terminal** or **leaf node:** A node at the bottom

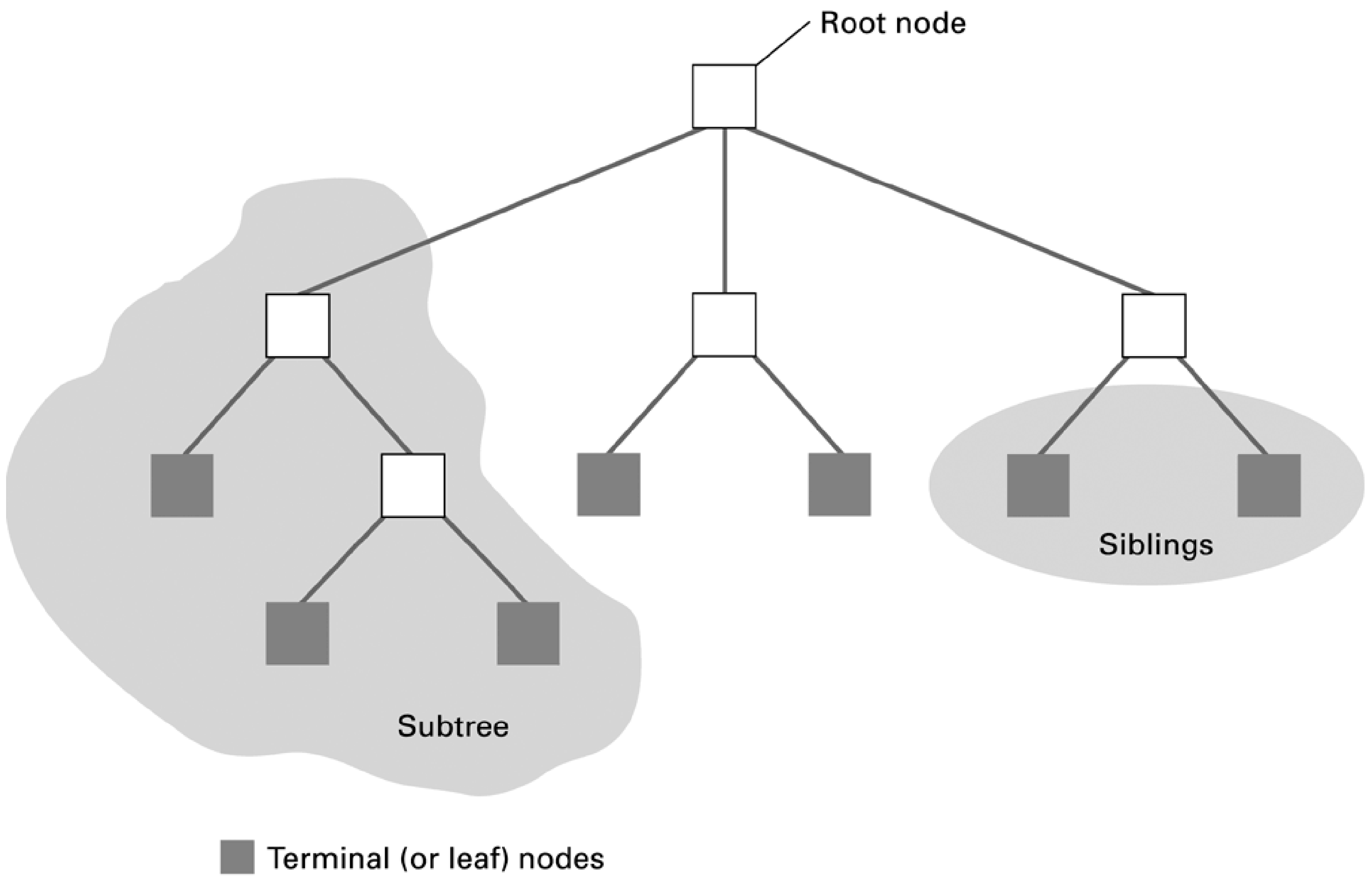
Terminology for a Tree (continued)

- **Parent:** The node immediately above a specified node
- **Child:** A node immediately below a specified node
- **Ancestor:** Parent, parent of parent, etc.
- **Descendent:** Child, child of child, etc.
- **Siblings:** Nodes sharing a common parent

Terminology for a Tree (continued)

- **Binary tree:** A tree in which every node has at most two children
- **Depth:** The number of nodes in longest path from root to leaf

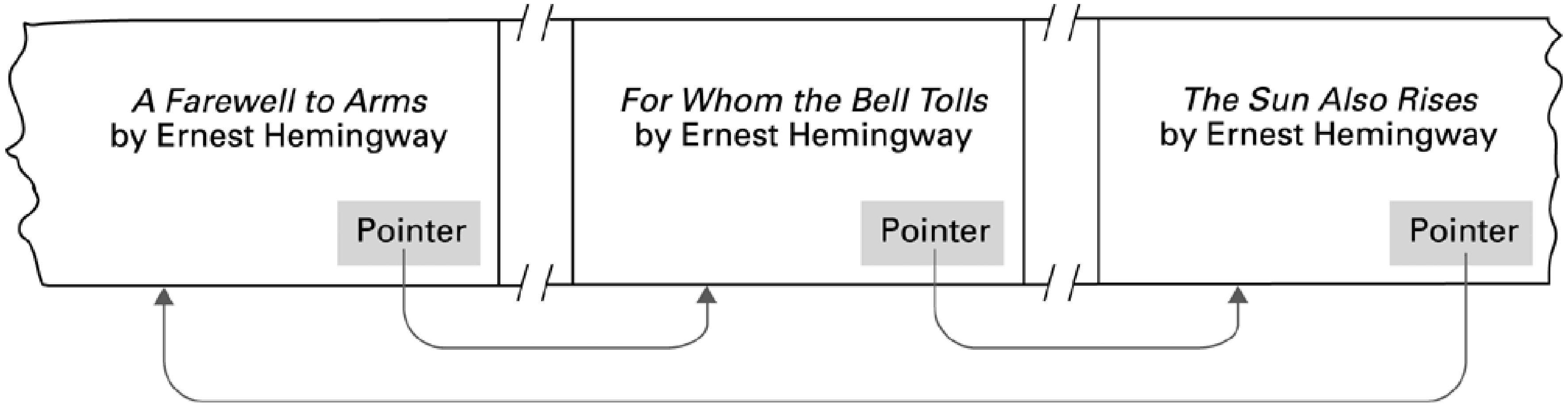
Figure 8.3 **Tree terminology**



Additional Concepts

- Static Data Structures: Size and shape of data structure does not change
- Dynamic Data Structures: Size and shape of data structure can change
- Pointers: Used to locate data

Figure 8.4 **Novels arranged by title but linked according to authorship**



Storing Arrays

- Homogeneous arrays
  - **Row-major order** versus **column major order**
  - Address polynomial
- Heterogeneous arrays
  - Components can be stored one after the other in a contiguous block
  - Components can be stored in separate locations identified by pointers

Figure 8.5 **The array of temperature readings stored in memory starting at address x**

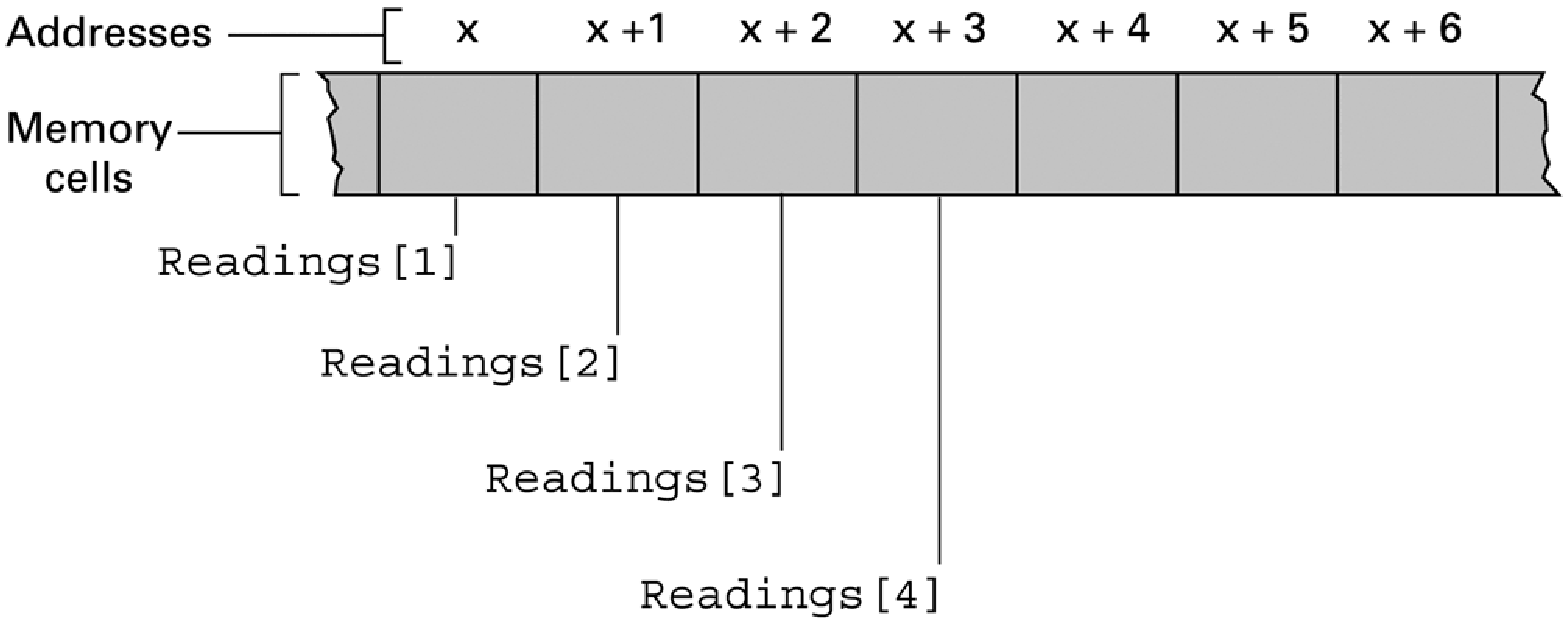
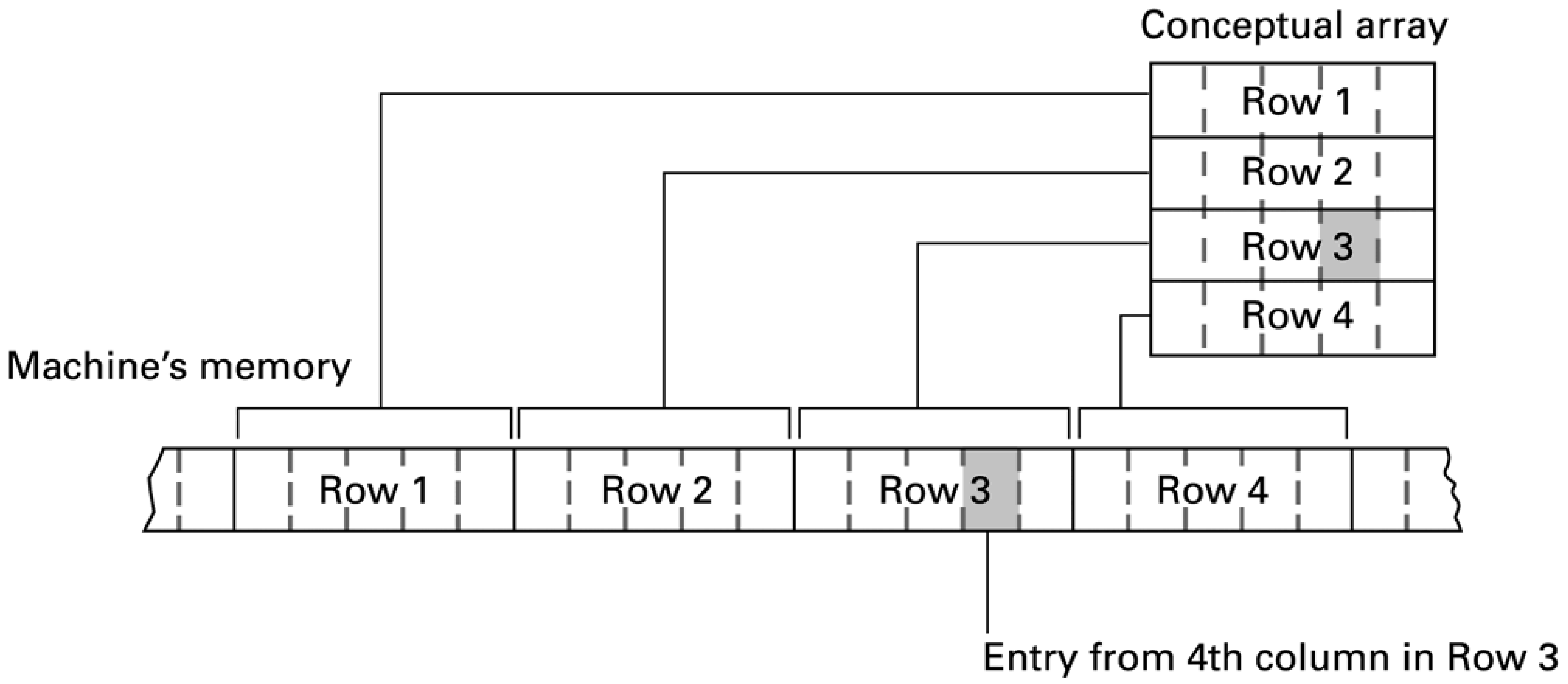
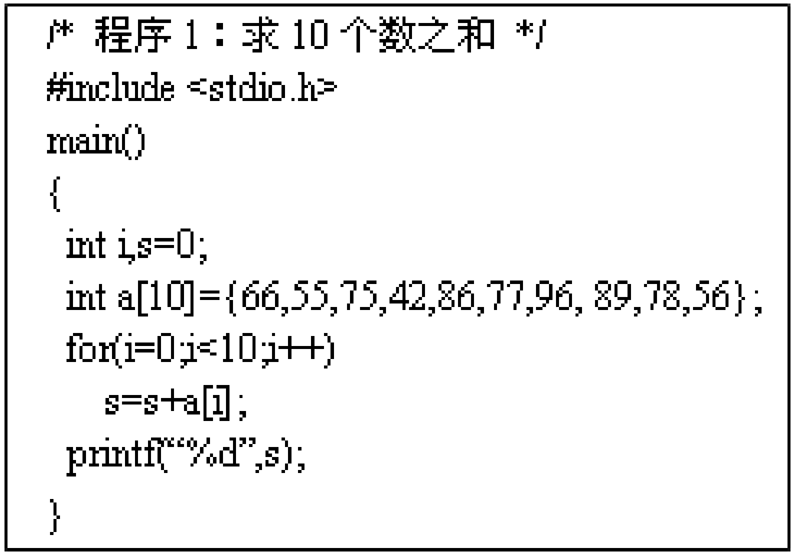


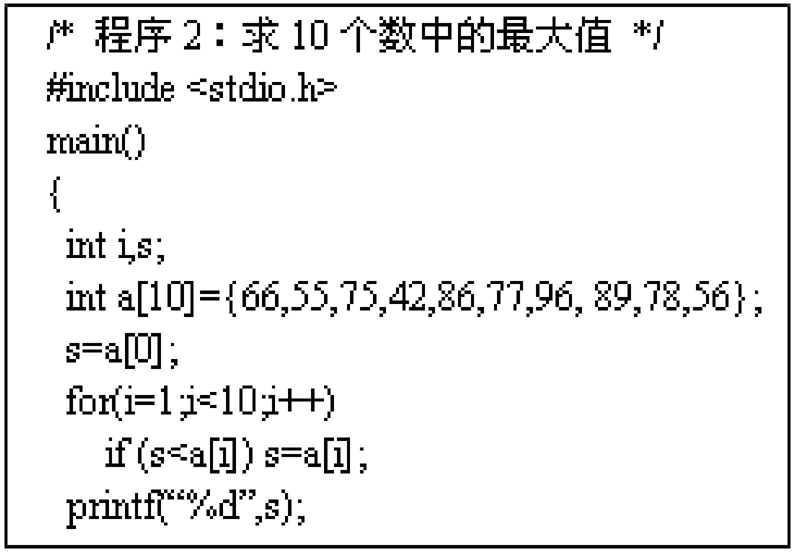
Figure 8.6 **A two-dimensional array with four rows and five columns stored in row major order**



Homogeneous array

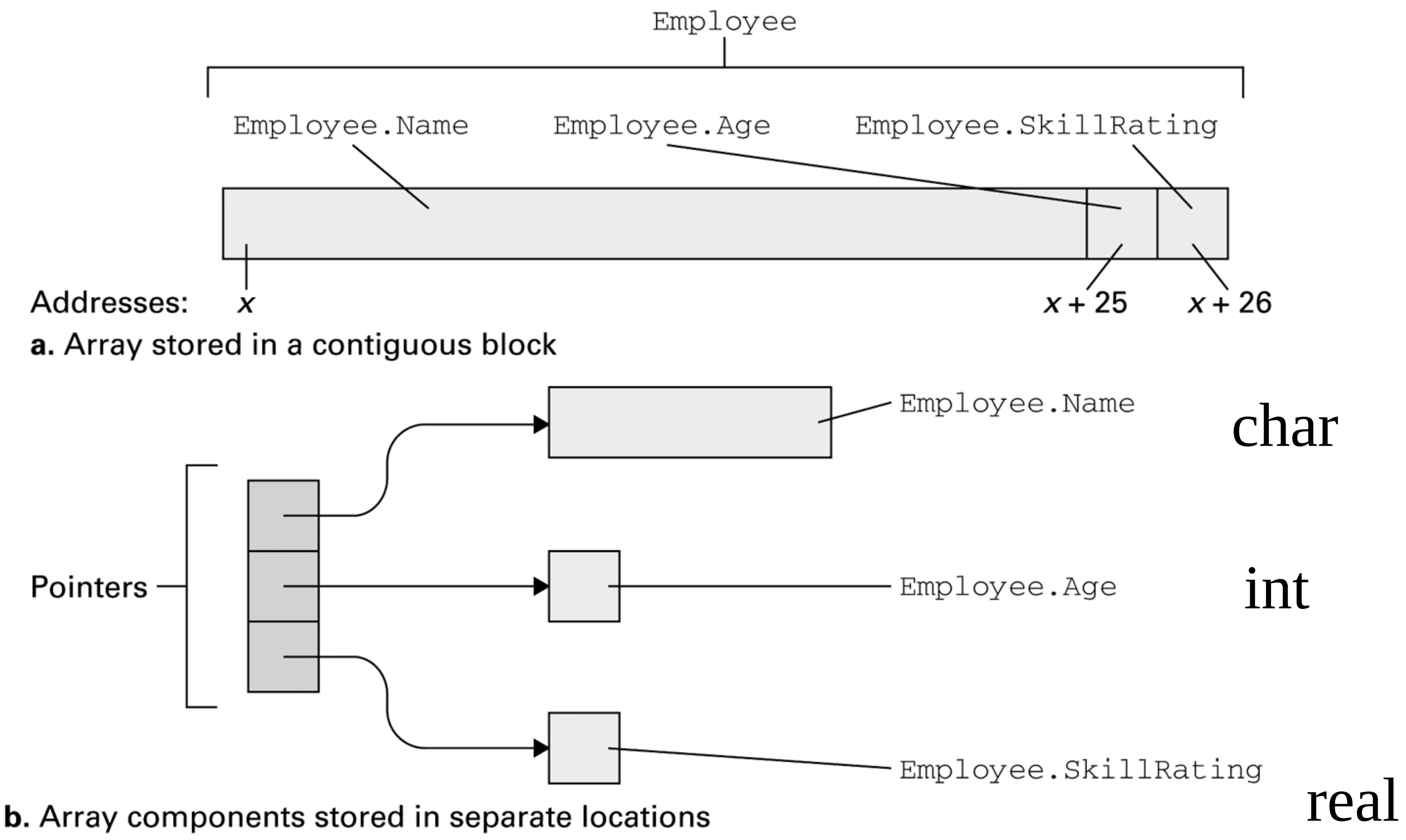


```
/* 程序 1：求 10 个数之和 */
#include <stdio.h>
main()
{
 int i,s=0;
 int a[10]={66,55,75,42,86,77,96, 89,78,56};
 for(i=0;i<10;i++)
     s=s+a[i];
 printf("%d",s);
}
```



```
/* 程序 2：求 10 个数中的最大值 */
#include <stdio.h>
main()
{
 int i,s;
 int a[10]={66,55,75,42,86,77,96, 89,78,56};
 s=a[0];
 for(i=1;i<10;i++)
     if (s<a[i]) s=a[i];
 printf("%d",s);
```

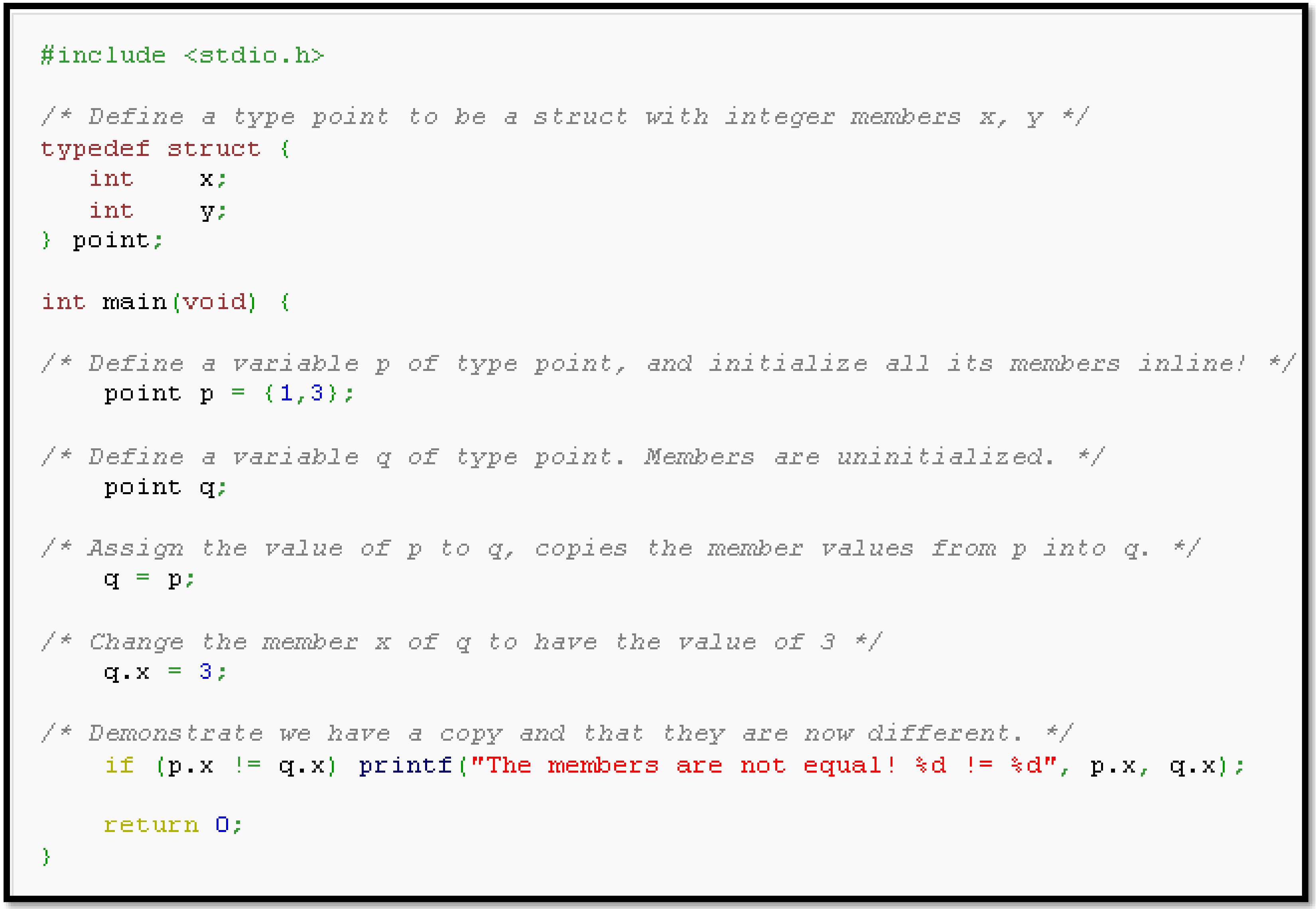
Figure 8.7 **Storing the heterogeneous array Employee**



a. Array stored in a contiguous block

b. Array components stored in separate locations

Heterogeneous array



```c
#include <stdio.h>

/* Define a type point to be a struct with integer members x, y */
typedef struct {
   int    x;
   int    y;
} point;

int main(void) {

/* Define a variable p of type point, and initialize all its members inline! */
    point p = {1,3};

/* Define a variable q of type point. Members are uninitialized. */
    point q;

/* Assign the value of p to q, copies the member values from p into q. */
    q = p;

/* Change the member x of q to have the value of 3 */
    q.x = 3;

/* Demonstrate we have a copy and that they are now different. */
    if (p.x != q.x) printf("The members are not equal! %d != %d", p.x, q.x);

    return 0;
}
```

Storing Lists

- **Contiguous list:** List stored in a homogeneous array
- **Linked list:** List in which each entries are linked by pointers
  - **Head pointer:** Pointer to first entry in list
  - **NIL pointer:** A “non-pointer” value used to indicate end of list

Figure 8.8 **Names stored in memory as a contiguous list**

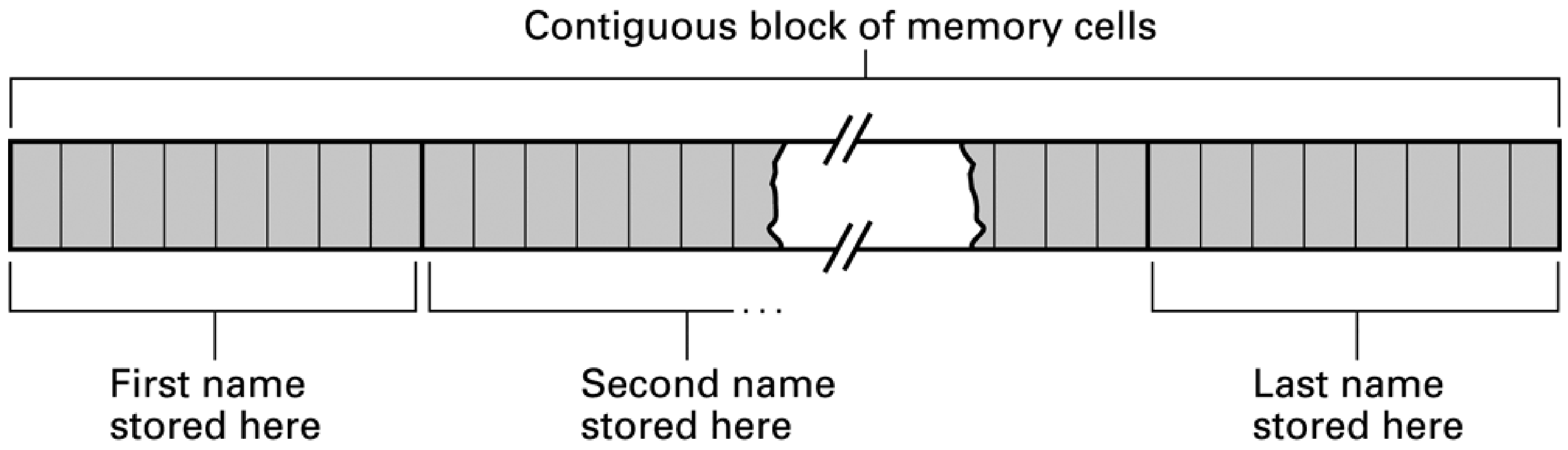


Figure 8.9 **The structure of a linked list**

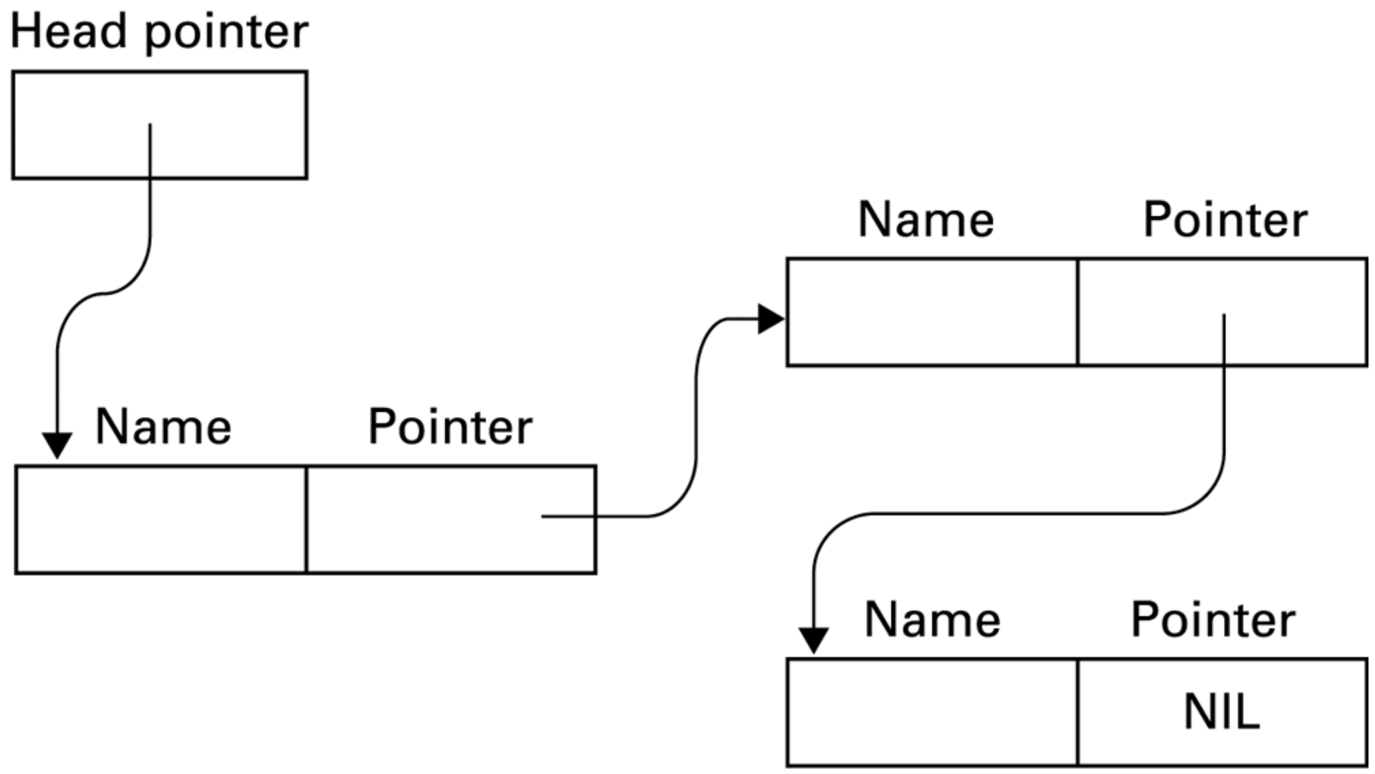


Figure 8.10 **Deleting an entry from a linked list**

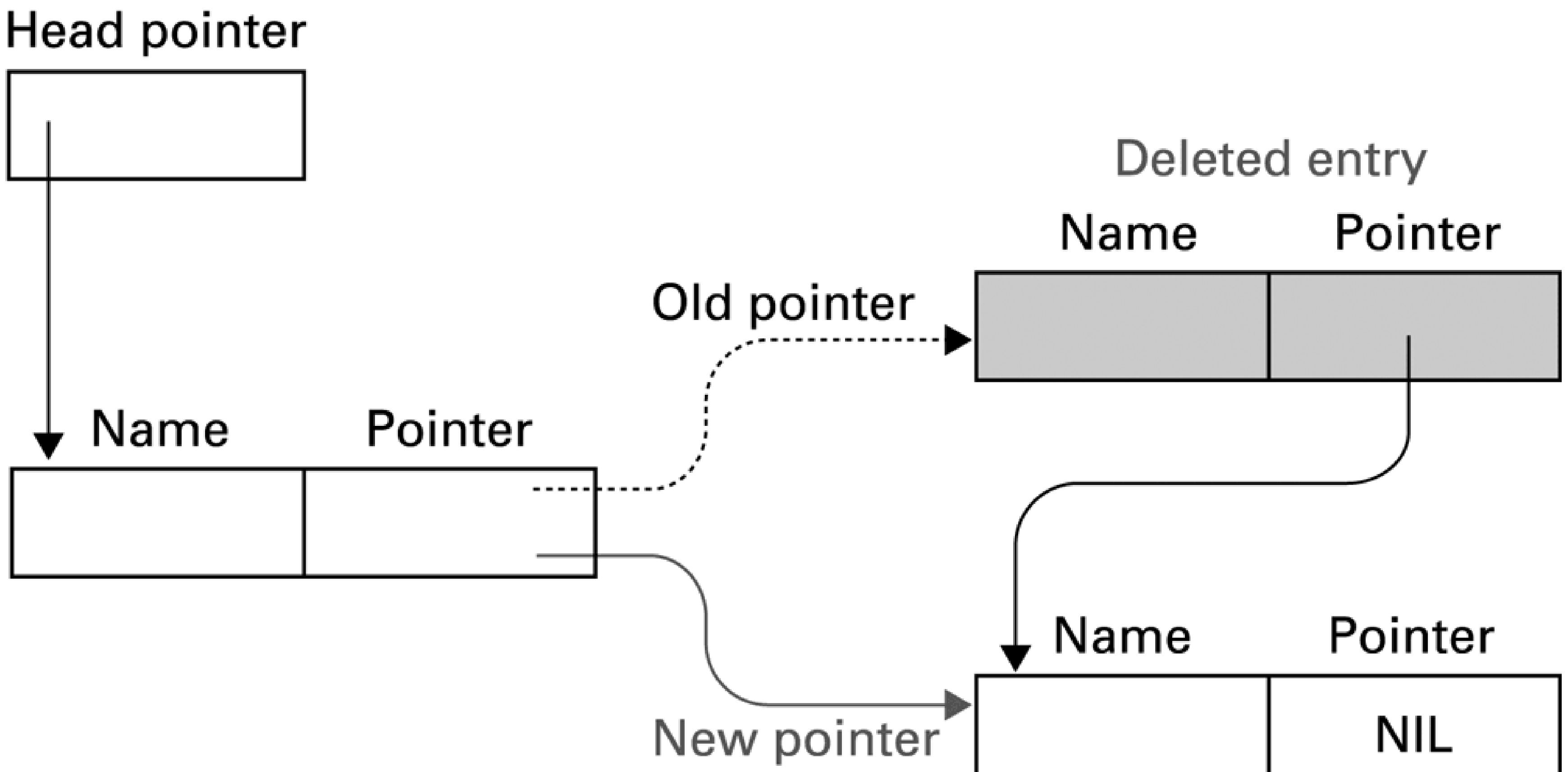
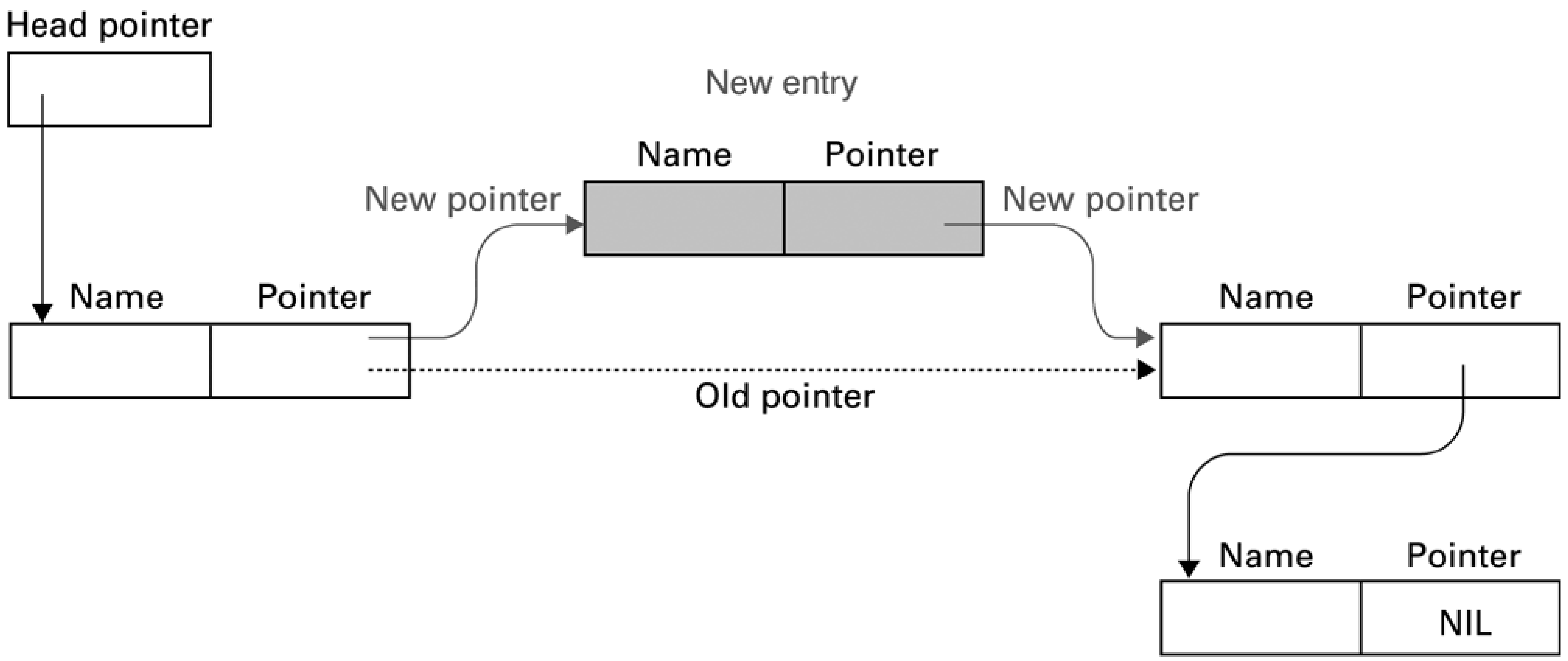


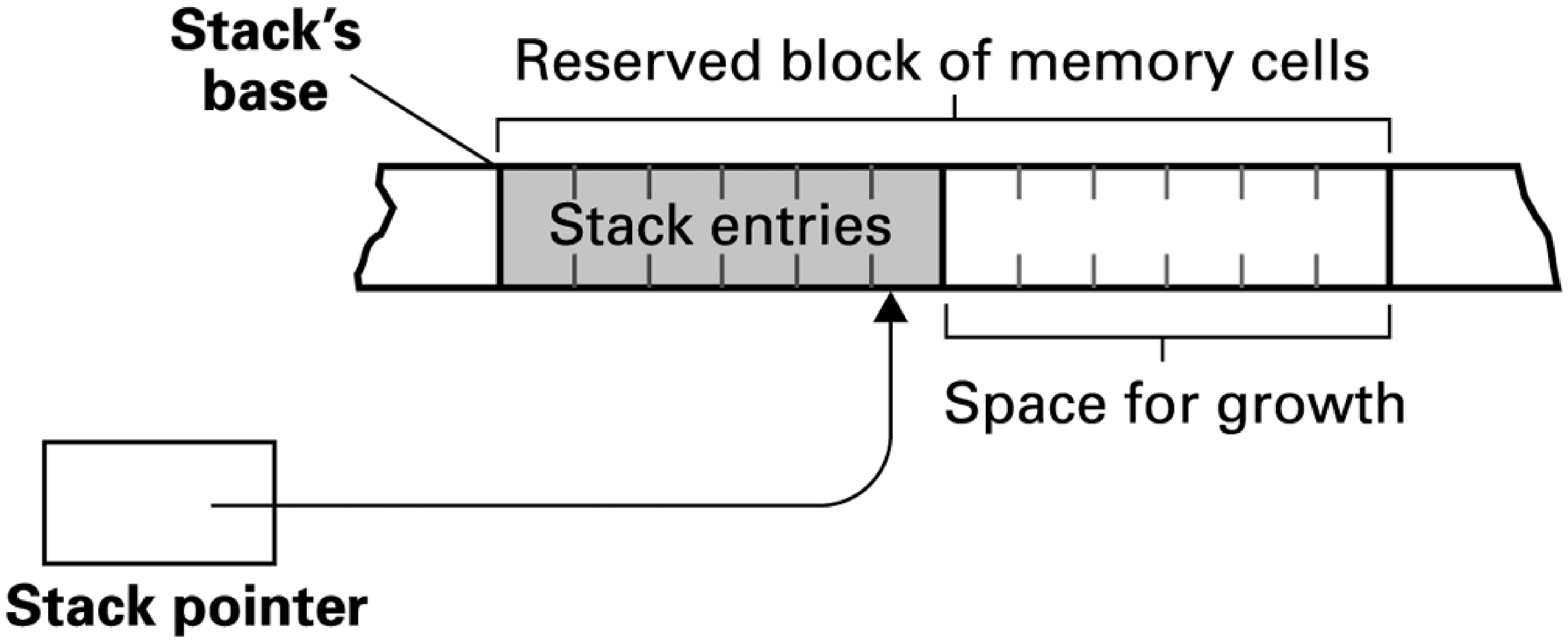
Figure 8.11 **Inserting an entry into a linked list**



Storing Stacks and Queues

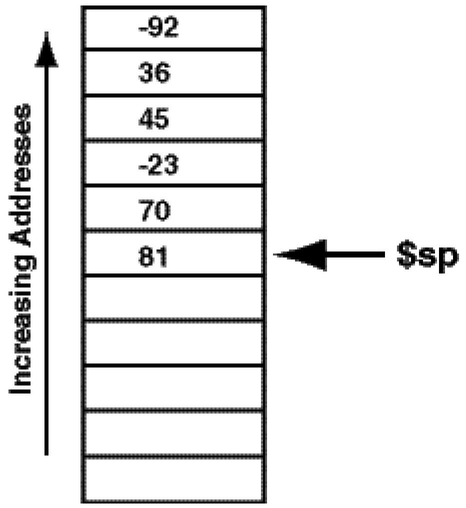
- Stacks usually stored as contiguous lists
- Queues usually stored as **Circular Queues**
  - Stored in a contiguous block in which the first entry is considered to follow the last entry
  - Prevents a queue from crawling out of its allotted storage space

Figure 8.12 **A stack in memory**

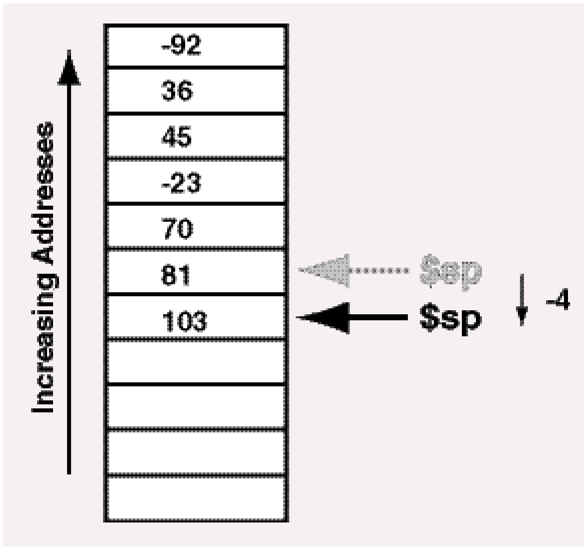


Stack

- Stack-like behavior is sometimes called "LIFO" for Last In First Out.
- The top item of the stack is 81. The bottom of the stack contains the integer -92
- Stack pointer $sp always points to the top of the stack.



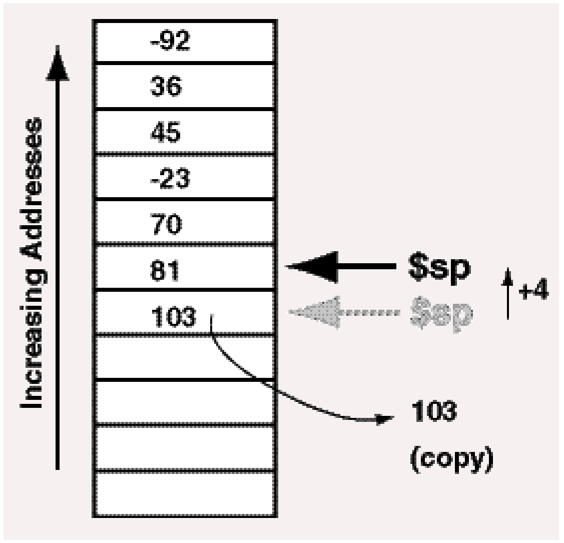
- To **push** an item onto the stack, first **subtract** 4 from the stack pointer, then store the item at the address in the stack pointer



MIPS (32-bit) example

```
                    # PUSH the item in $t0:
subu  $sp,$sp,4     #   point to the place for the new item,
sw    $t0,($sp)     #   store the contents of $t0 as the new top.
```

- To **pop** the top item from a stack, copy the item pointed at by the stack pointer, then **add** 4 to the stack pointer.



```
                          # POP the item into $t0:
lw    $t0,($sp)           #   Copy top the item to $t0.
addu  $sp,$sp,4           #   Point to the item beneath the old top.
```

Figure 8.13 **A queue implementation with head and tail pointers**

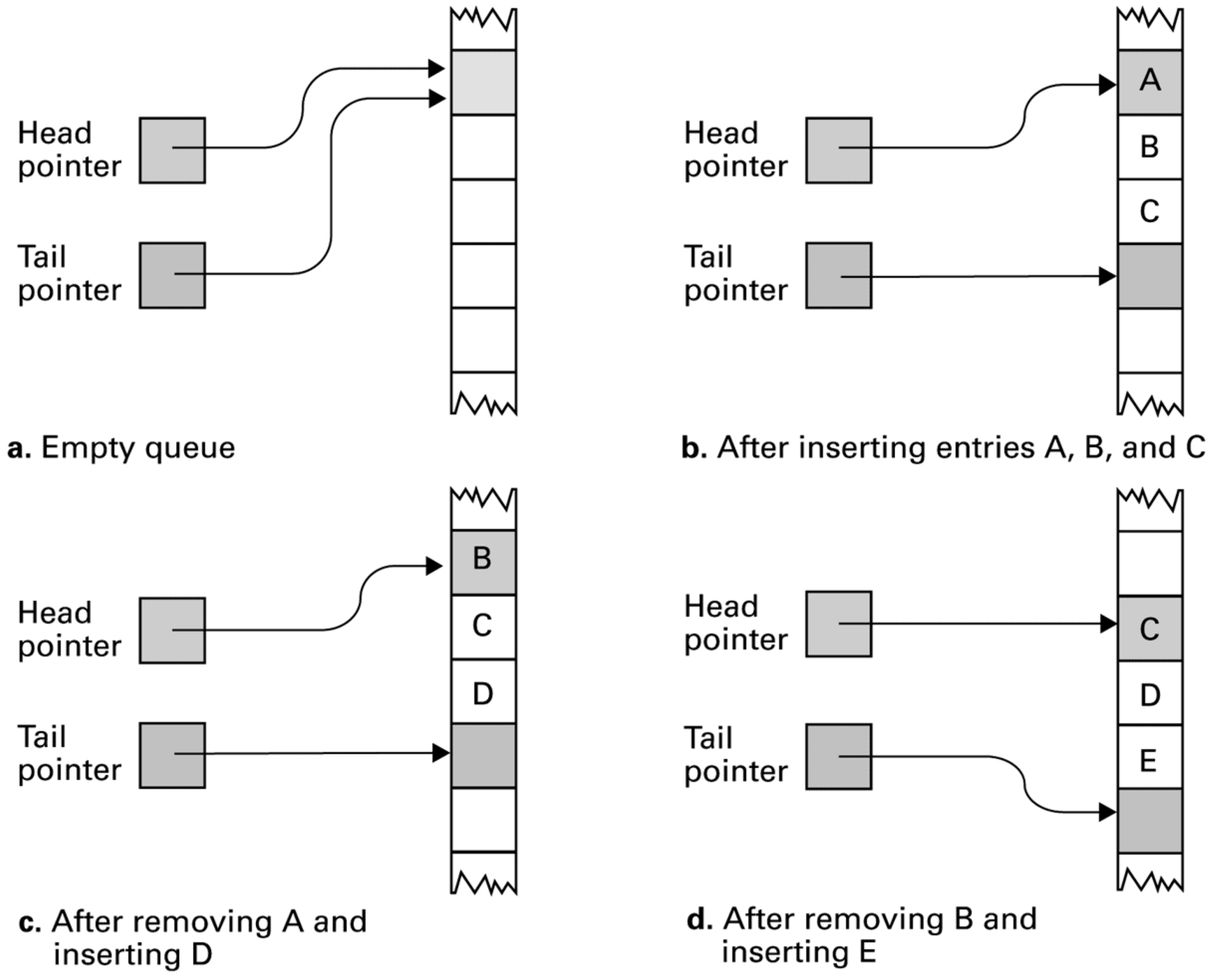
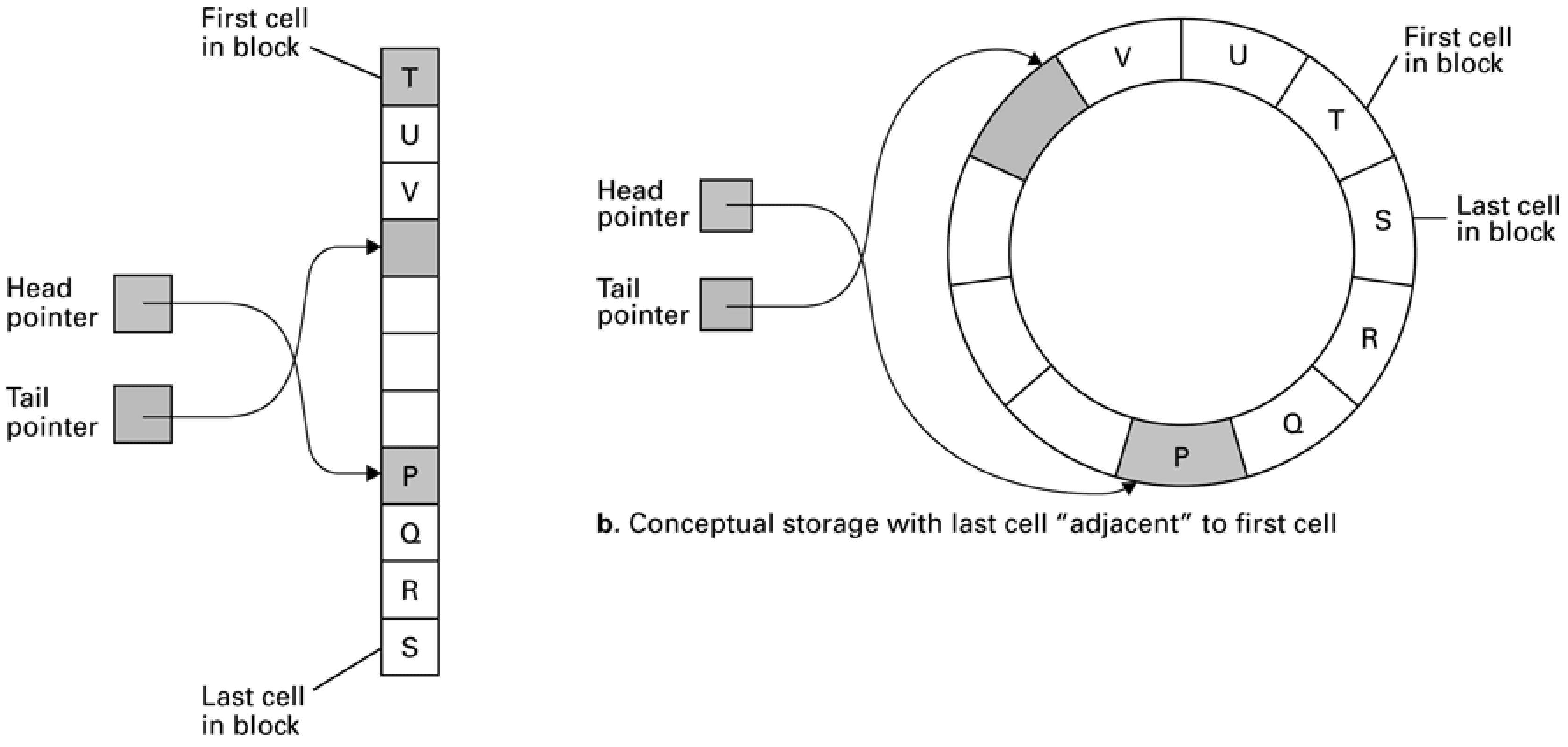


Figure 8.14 **A circular queue containing the letters P through V**



a. Queue as actually stored

b. Conceptual storage with last cell "adjacent" to first cell

Storing Binary Trees

- Linked structure
  - Each node = data cells + two child pointers
  - Accessed via a pointer to root node
- Contiguous array structure
  - A[1] = root node
  - A[2],A[3] = children of A[1]
  - A[4],A[5],A[6],A[7] = children of A[2] and A[3]

Figure 8.15 **The structure of a node in a binary tree**

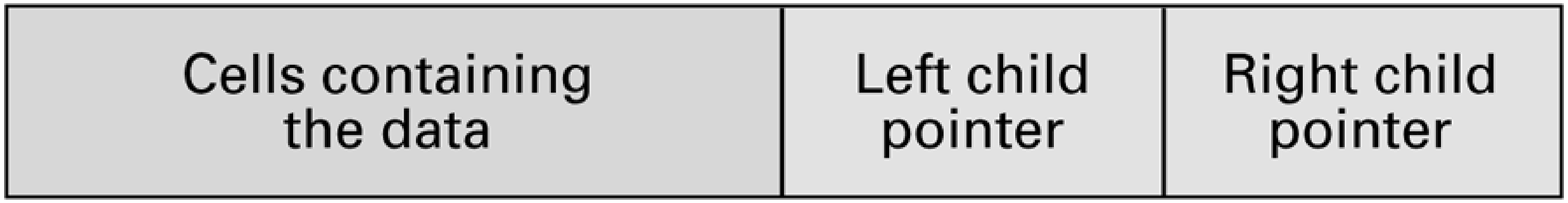


Figure 8.16 The conceptual and actual organization of a binary tree using a linked storage system

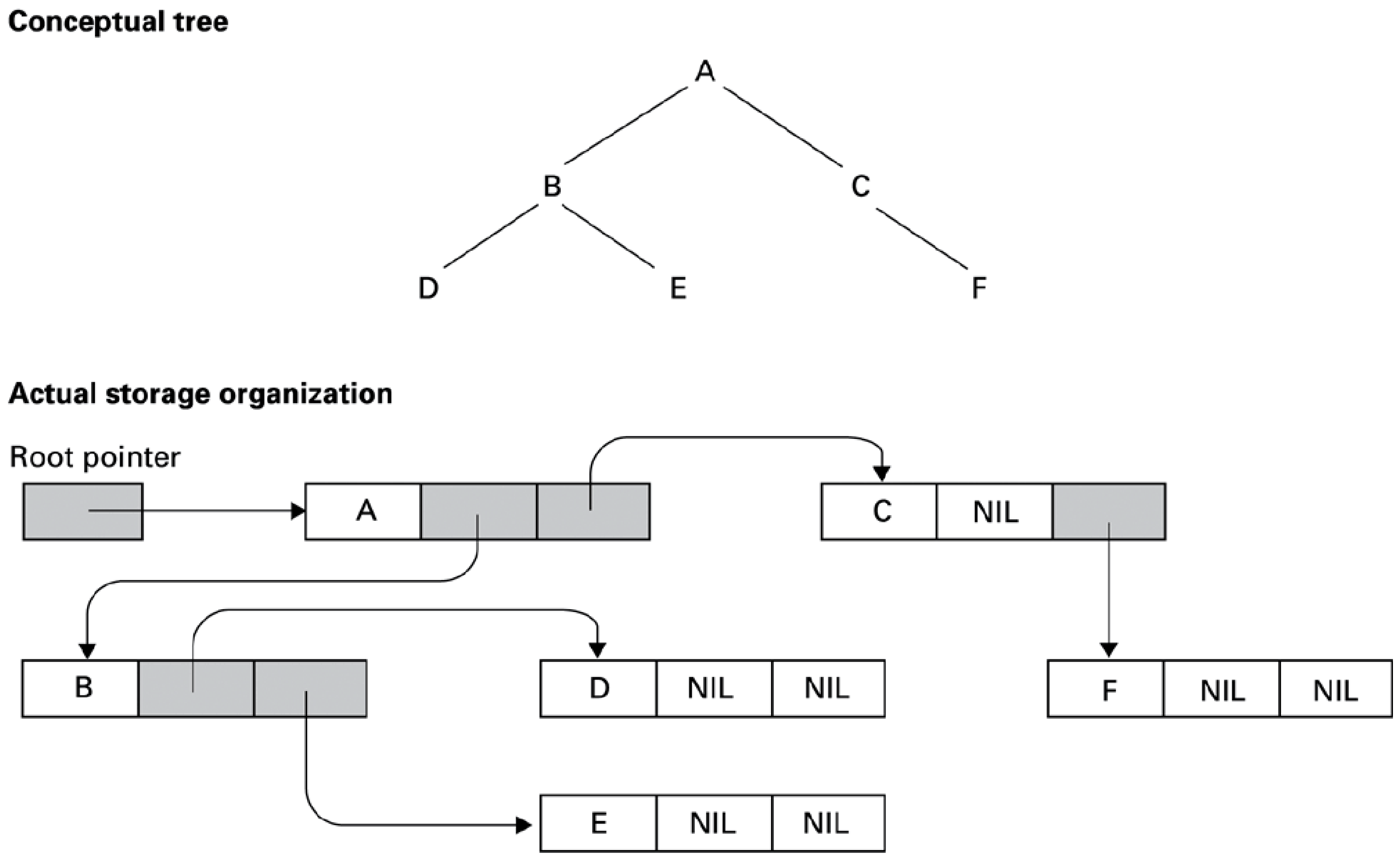


Figure 8.17 **A tree stored without pointers**

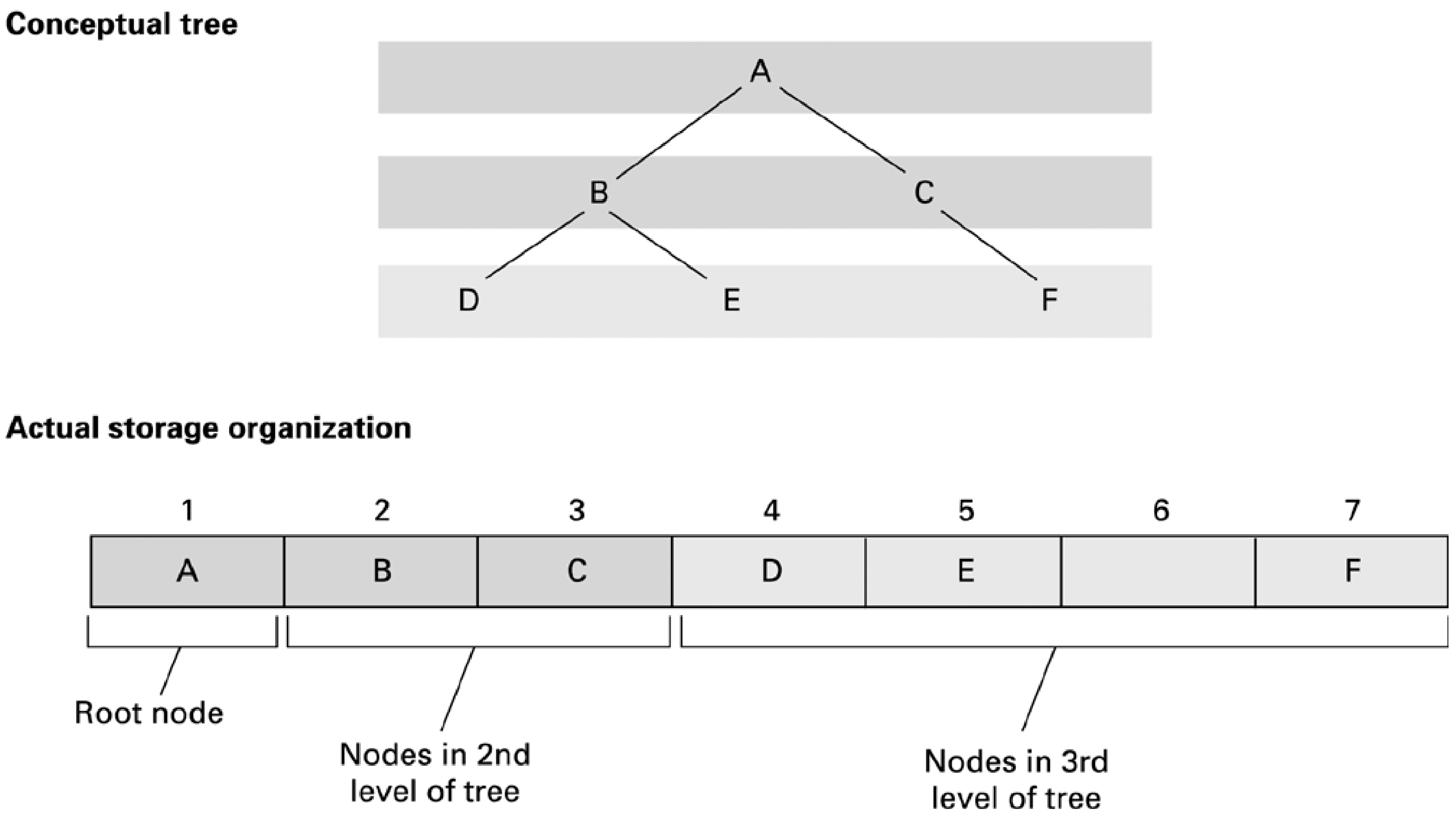
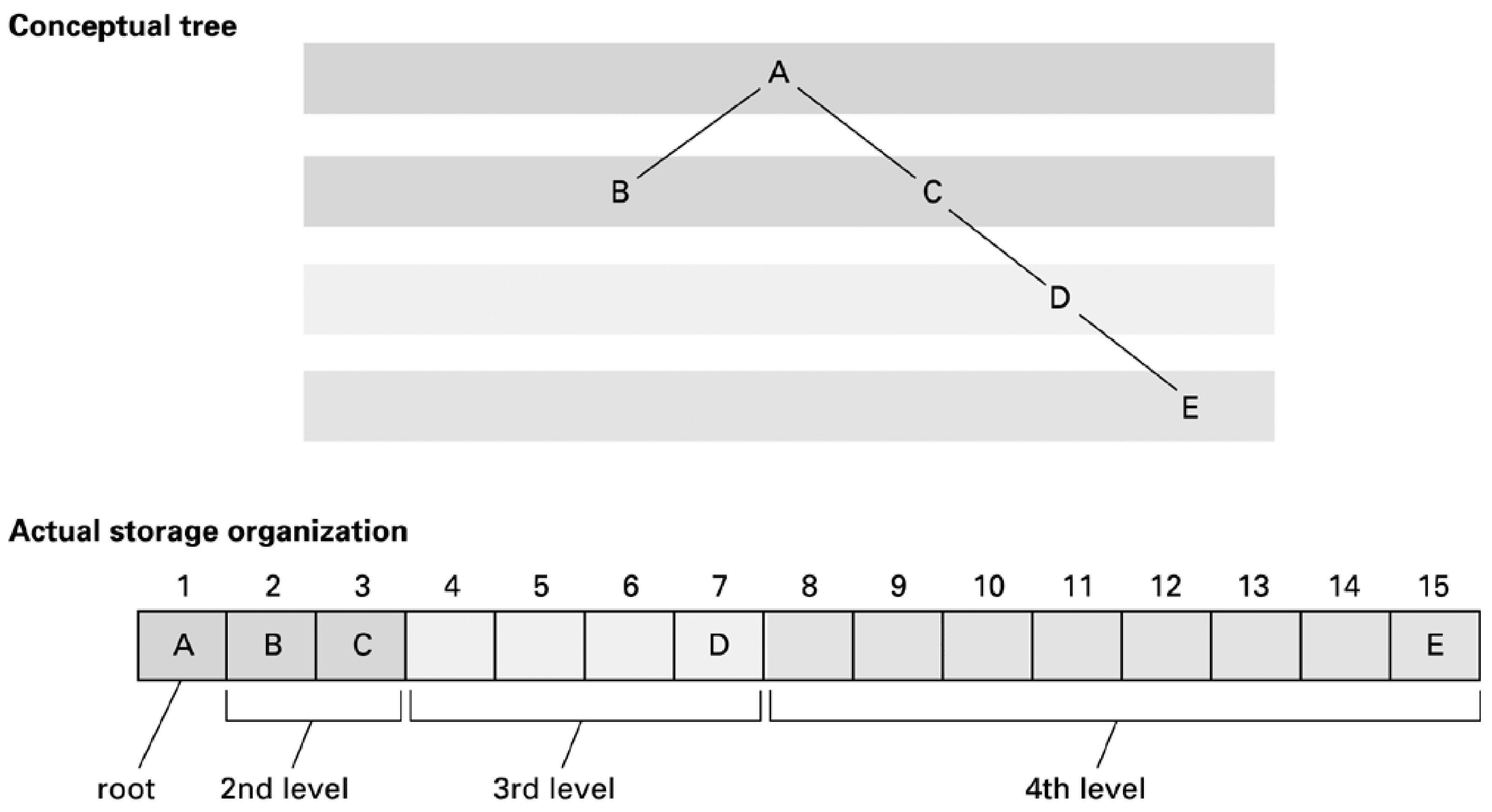

Conceptual tree
A
B
C
D
E
F
Actual storage organization
1
2
3
4
5
6
7
A
B
C
D
E
F
Root node
Nodes in 2nd level of tree
Nodes in 3rd level of tree

Figure 8.18 **A sparse, unbalanced tree shown in its conceptual form and as it would be stored without pointers**



Manipulating Data Structures

- Ideally, a data structure should be manipulated solely by pre-defined procedures.
  - Example: A stack typically needs at least `push` and `pop` procedures.
  - The data structure along with these procedures constitutes a complete abstract tool.

Figure 8.19 **A procedure for printing a linked list**

```
procedure PrintList (List)
CurrentPointer ← head pointer of List.
while (CurrentPointer is not NIL) do
    (Print the name in the entry pointed to by CurrentPointer;
     Observe the value in the pointer cell of the List entry
      pointed to by CurrentPointer, and reassign CurrentPointer
      to be that value.)
```

Case Study

Problem: Construct an abstract tool consisting of a list of names in alphabetical order along with the operations search, print, and insert.

Figure 8.20 **The letters A through M arranged in an ordered tree**

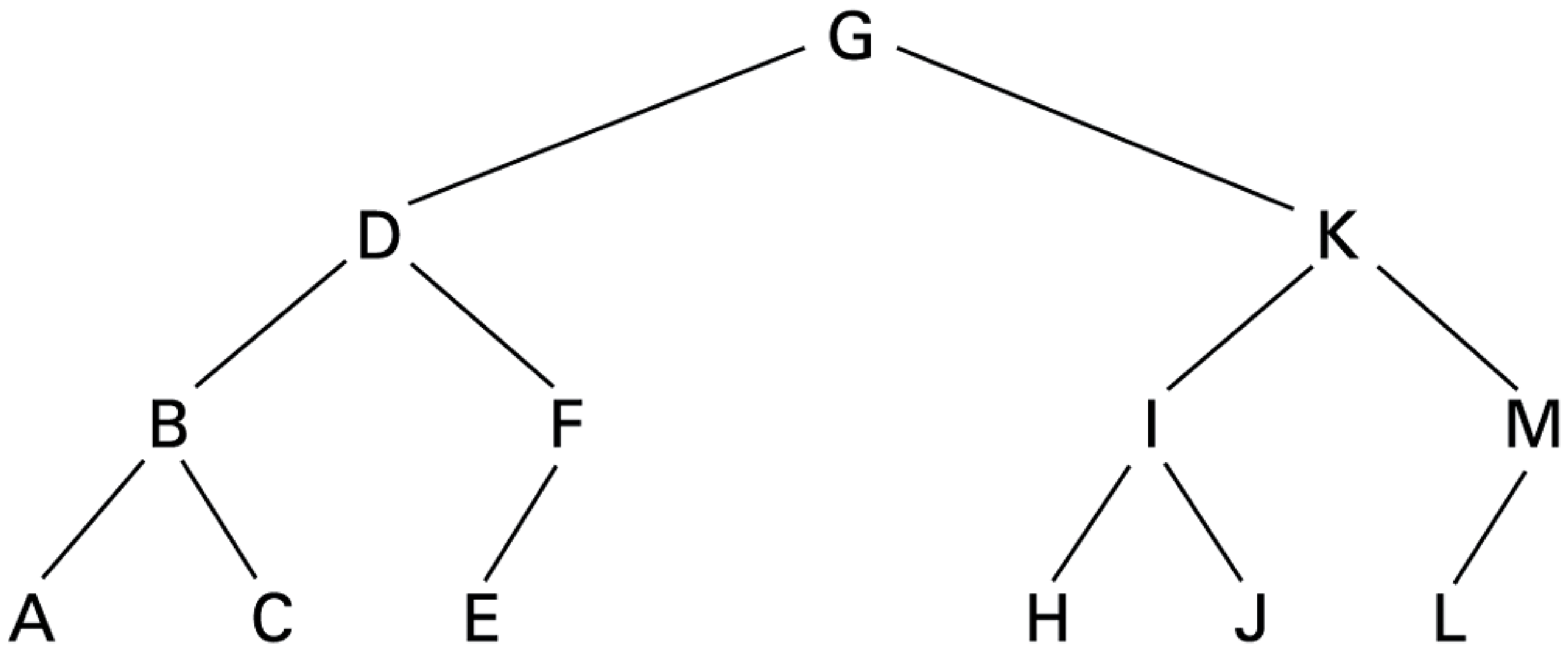


Figure 8.21 **The binary search as it would appear if the list were implemented as a linked binary tree**

```
procedure Search(Tree, TargetValue)

if (root pointer of Tree = NIL)
   then
       (declare the search a failure)
  else
       (execute the block of instructions below that is
        associated with the appropriate case)
        case 1: TargetValue = value of root node
                  (Report that the search succeeded)
        case 2: TargetValue < value of root node
                  (Apply the procedure Search to see if
                     TargetValue is in the subtree identified
                      by the root's left child pointer and
                      report the result of that search)
        case 3: TargetValue > value of root node
                  (Apply the procedure Search to see if
                      TargetValue is in the subtree identified
                      by the root's right child pointer and
                      report the result of that search)
       ) end if
```

Figure 8.22 **The successively smaller trees considered by the procedure in Figure 8.18 when searching for the letter J**

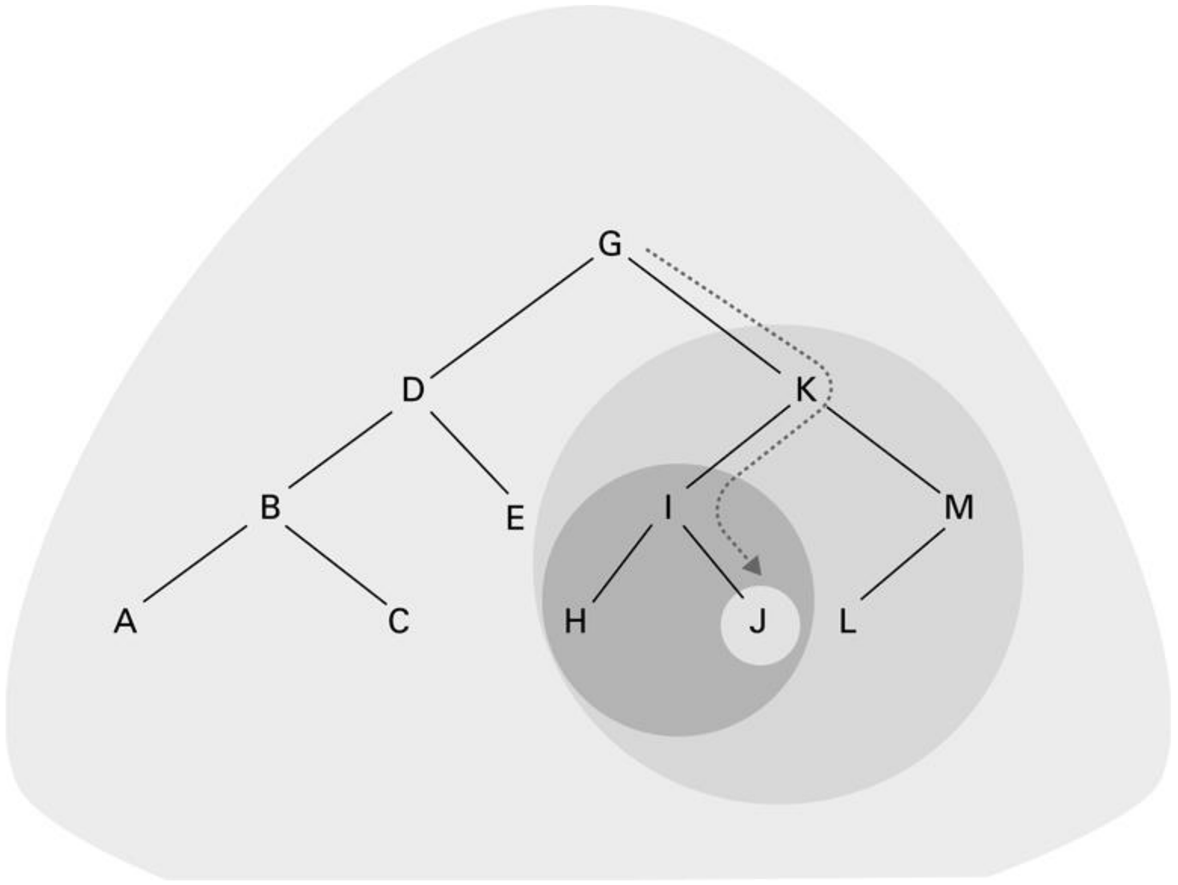


Figure 8.23 **Printing a search tree in alphabetical order**

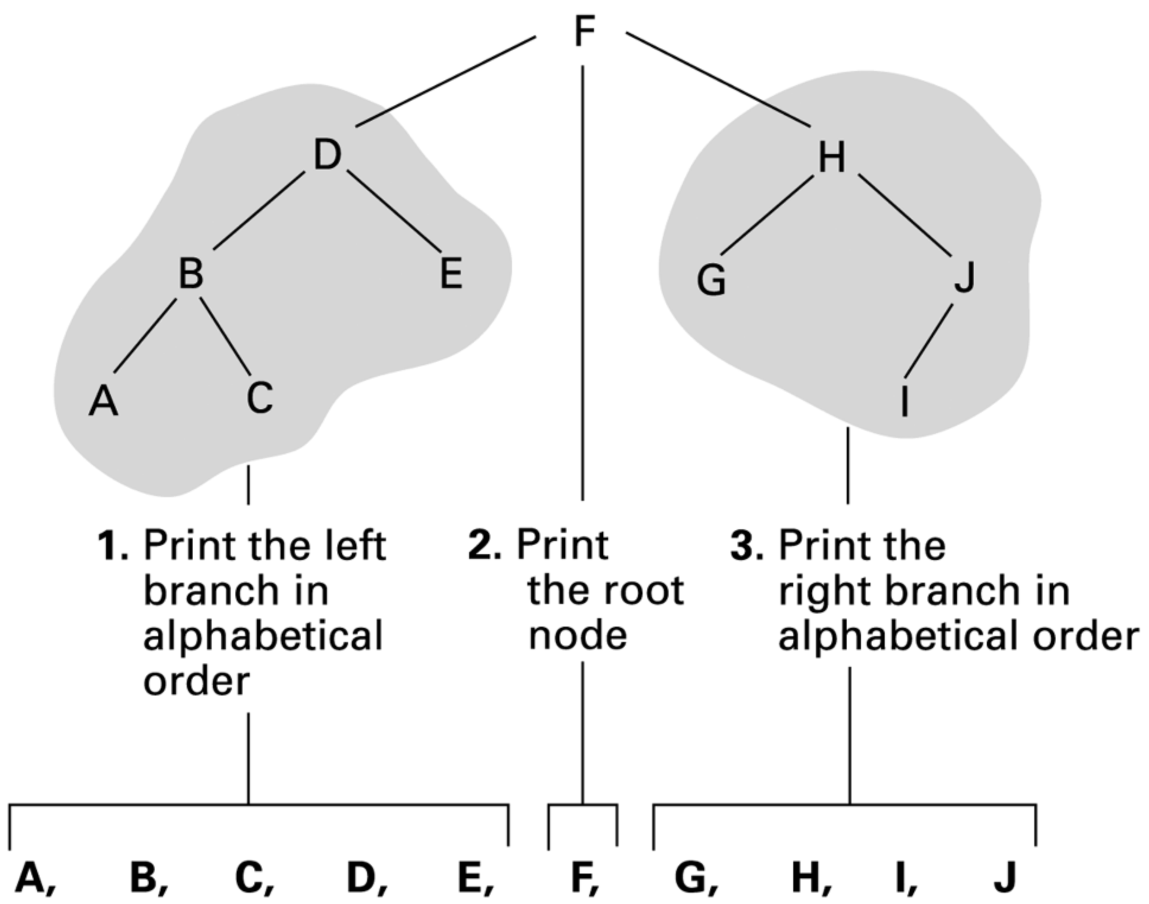

F
D
H
B
E
G
J
A
C
I
1. Print the left branch in alphabetical order
2. Print the root node
3. Print the right branch in alphabetical order
A, B, C, D, E, F, G, H, I, J

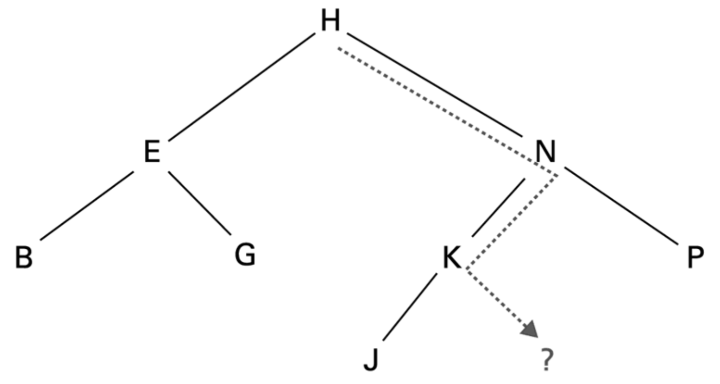
Figure 8.24 **A procedure for printing the data in a binary tree**

```
procedure PrintTree (Tree)

if (Tree is not empty)
    then (Apply the procedure PrintTree to the tree that
                    appears as the left branch in Tree;
                Print the root node of Tree;
                Apply the procedure PrintTree to the tree that
                    appears as the right branch in Tree)
```

Figure 8.25 **Inserting the entry M into the list B, E, G, H, J, K, N, P stored as a tree**

a. Search for the new entry until its absence is detected



b. This is the position in which the new entry should be attached

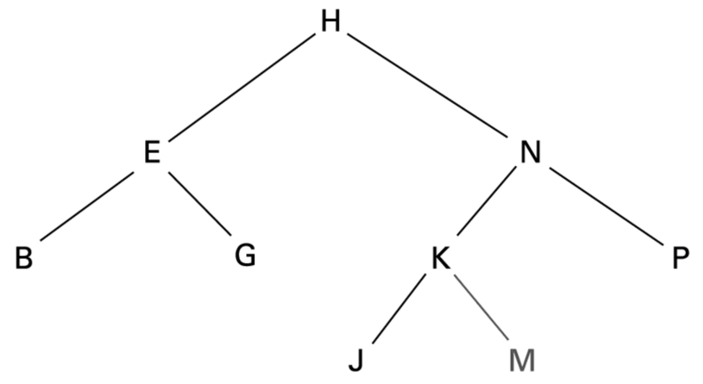


Figure 8.26 **A procedure for inserting a new entry in a list stored as a binary tree**

```
procedure Insert(Tree, NewValue)

if (root pointer of Tree = NIL)
  (set the root pointer to point to a new leaf
             containing NewValue)
  else (execute the block of instructions below that is
             associated with the appropriate case)
               case 1: NewValue = value of root node
                          (Do nothing)
               case 2: NewValue < value of root node
                          (if (left child pointer of root node = NIL)
                                  then (set that pointer to point to a new
                                                 leaf node containing NewValue)
                                  else (apply the procedure Insert to insert
                                                 NewValue into the subtree identified
                                                 by the left child pointer)
                case 3: NewValue > value of root node
                           (if (right child pointer of root node = NIL)
                                   then (set that pointer to point to a new
                                               leaf node containing NewValue)
                                    else (apply the procedure Insert to insert
                                               NewValue into the subtree identified
                                               by the right child pointer)
          ) end if
```

User-defined Data Type

- A template for a heterogeneous structure
- Example:

```
define type EmployeeType to be
{char      Name[25];
 int       Age;
 real      SkillRating;
}
```

Abstract Data Type

- A user-defined data type with procedures for access and manipulation
- Example:

```
define type StackType to be
{int StackEntries[20];
 int StackPointer = 0;
 procedure push(value)
    {StackEntries[StackPointer] ← value;
     StackPointer ¬ StackPointer + 1;
    }
 procedure pop . . .
}
```

Class

- An abstract data type with extra features
  - Characteristics can be inherited
  - Contents can be encapsulated
  - Constructor methods to initialize new objects

Figure 8.27 **A stack of integers implemented in Java and C#**

```
class StackOfIntegers
{private int[] StackEntries = new int[20];
 private int StackPointer = 0;


 public void push(int NewEntry)
 {if (StackPointer < 20)
    StackEntries[StackPointer++] = NewEntry;
 }

 public int pop()
 {if (StackPointer > 0) return StackEntries[--StackPointer];
  else return 0;
 }
}
```