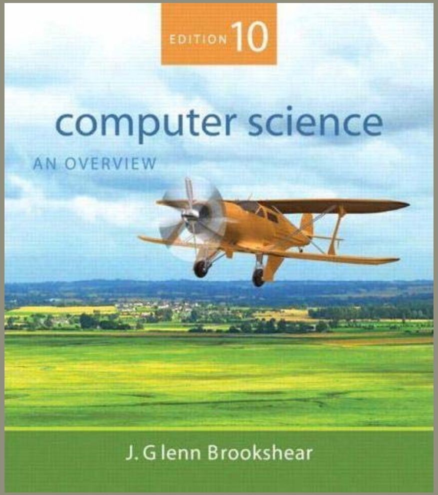
Chapter 8

Data Abstractions



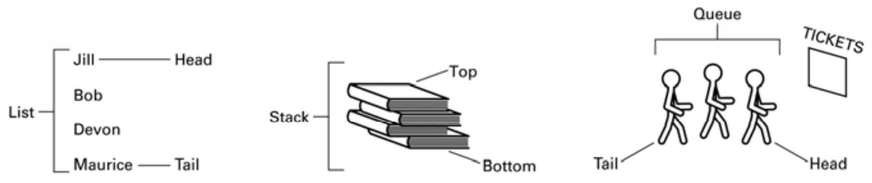
Chapter 8: Data Abstractions

- 8.1 Data Structure Fundamentals
- 8.2 Implementing Data Structures
- 8.3 A Short Case Study
- 8.4 Customized Data Types
- 8.5 Classes and Objects
- 8.6 Pointers in Machine Language

Basic Data Structures

- Homogeneous array
- Heterogeneous array
- 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

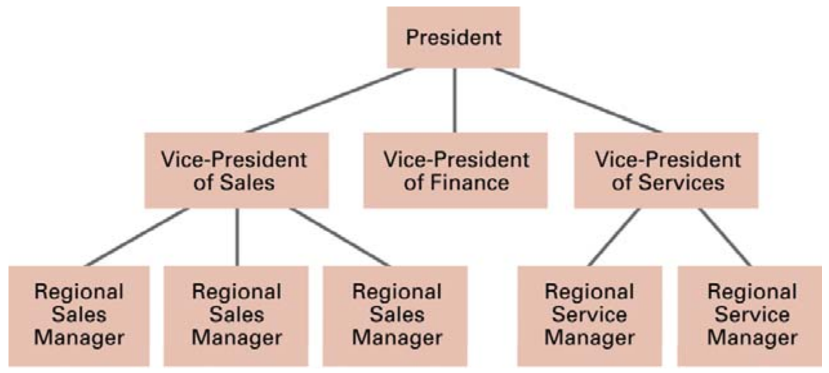
Terminology for Stacks

- **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

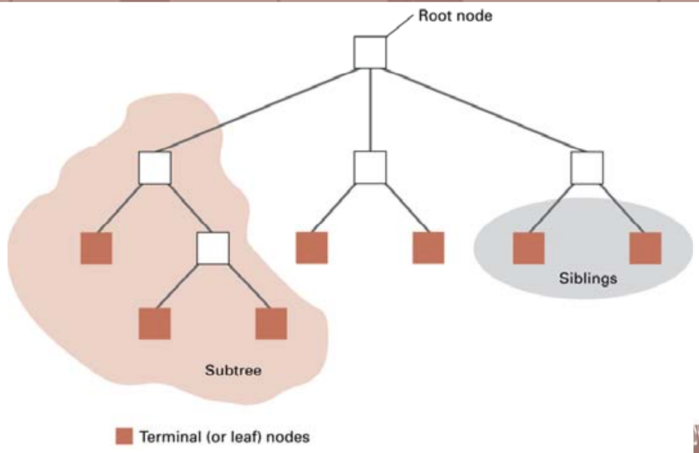
Terminology for a Tree (continued)

- **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

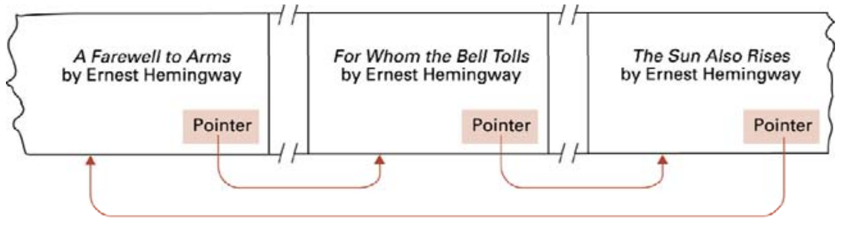
Figure 8.3 Tree terminology



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

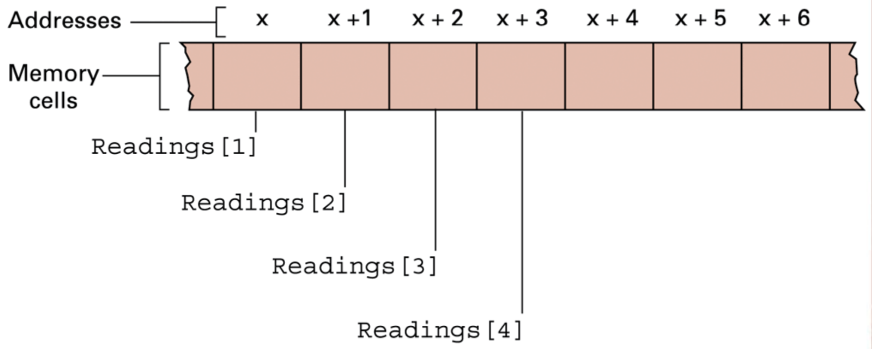


Figure 8.6 A two-dimensional array with four rows and five columns stored in row major order

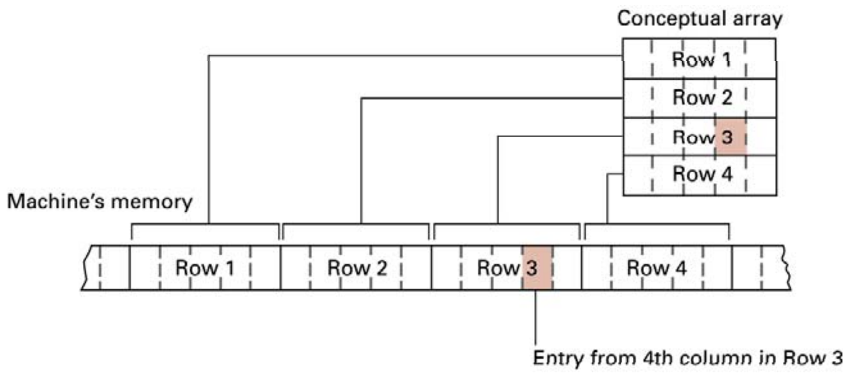
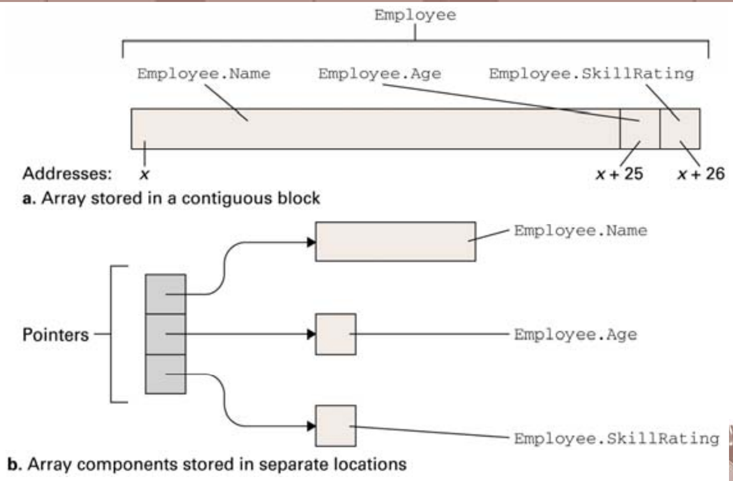


Figure 8.7 Storing the heterogeneous array Employee



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

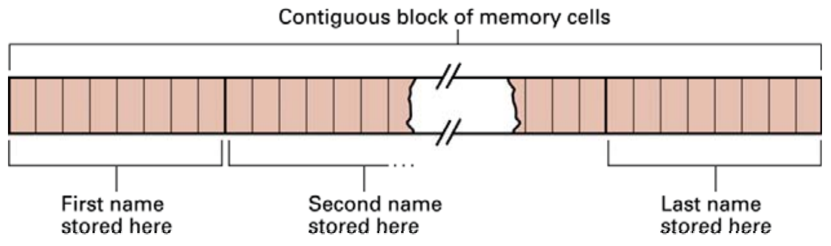


Figure 8.9 The structure of a linked list

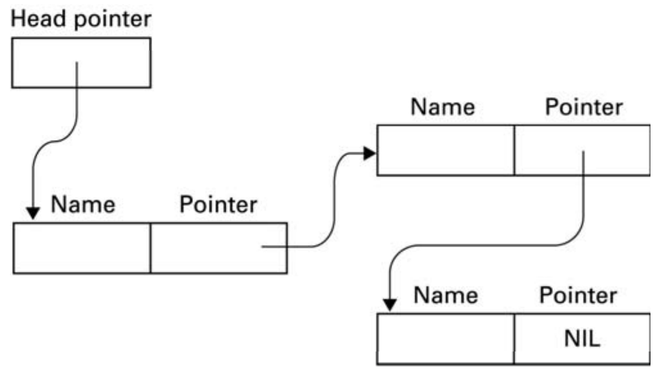


Figure 8.10 Deleting an entry from a linked list

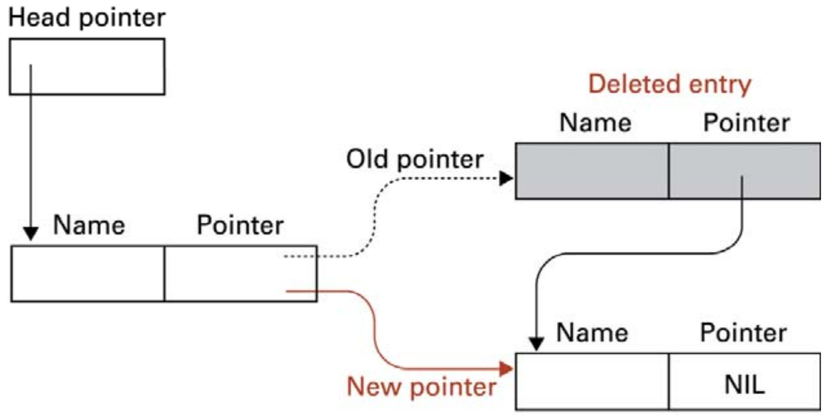
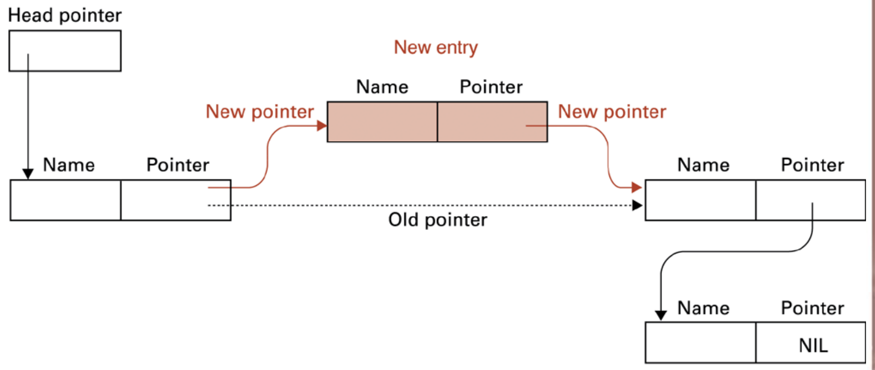


Figure 8.11 Inserting an entry into a linked list



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

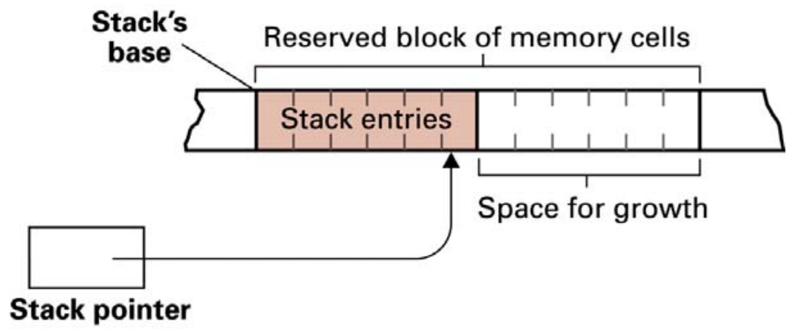
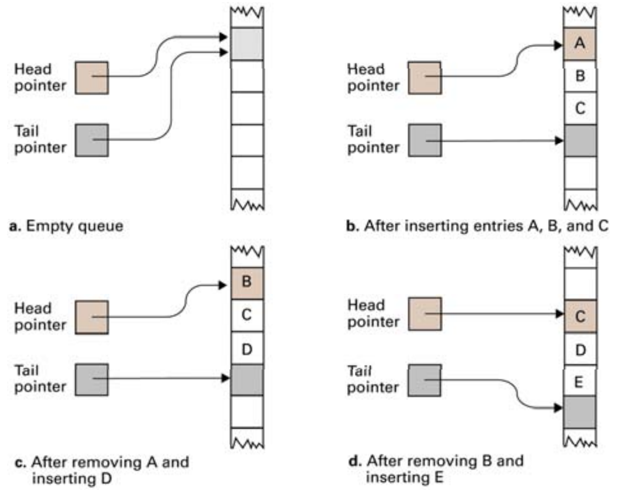


Figure 8.13 A queue implementation with head and tail pointers



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 8.14 A circular queue containing the letters P through V

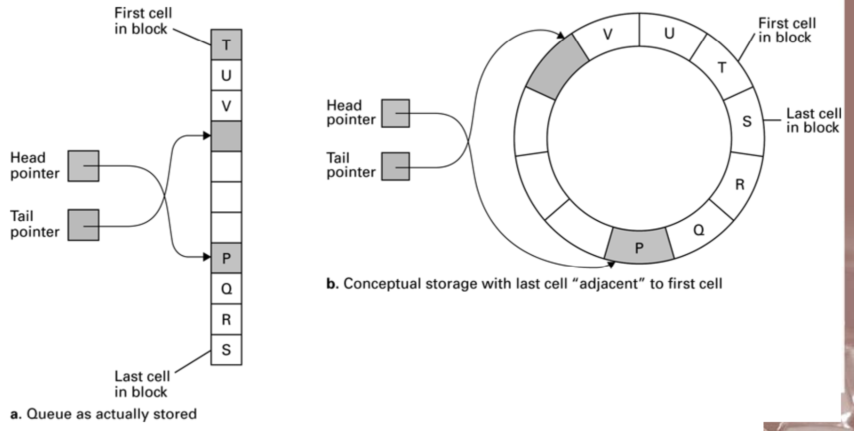


Figure 8.15 The structure of a node in a binary tree

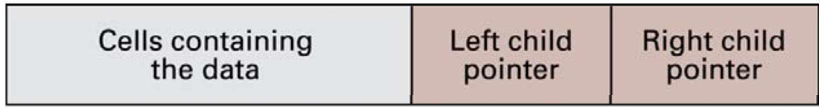


Figure 8.16 The conceptual and actual organization of a binary tree using a linked storage system

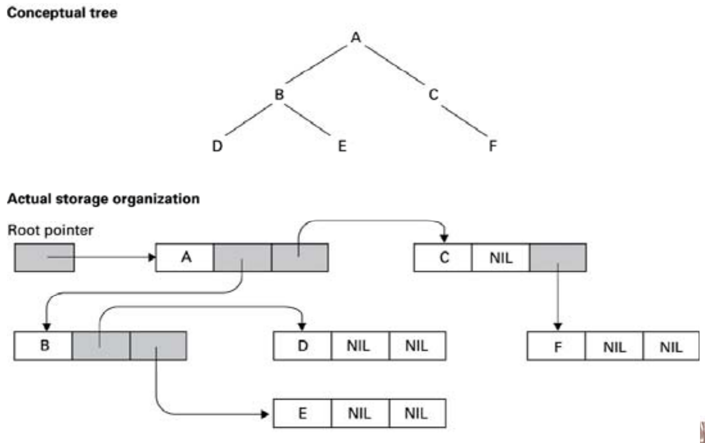


Figure 8.17 A tree stored without pointers

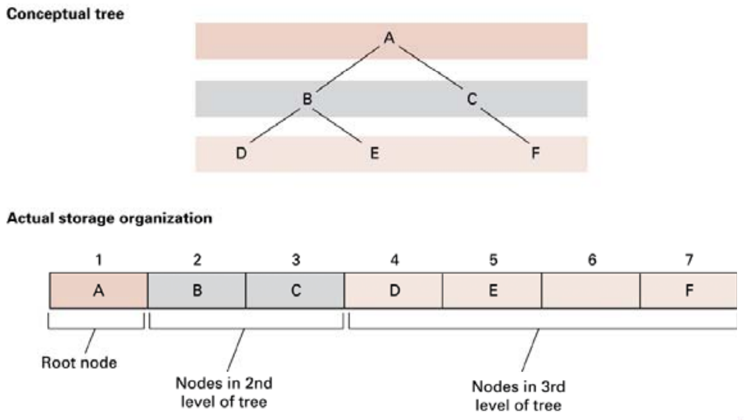
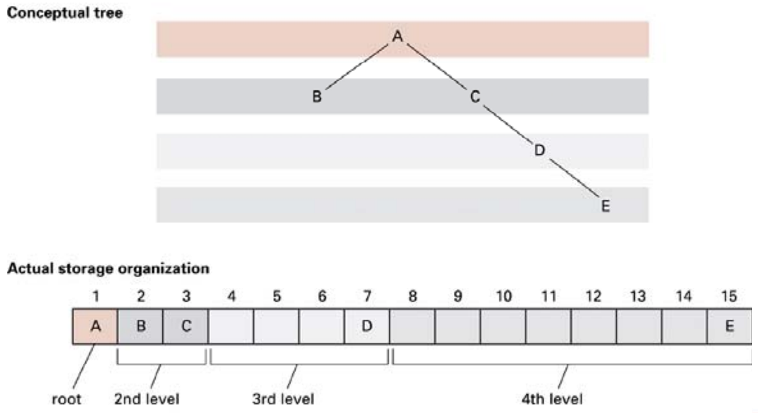

Conceptual tree
A
B
C
D
E
F
Actual storage organization
1
2
3
4
5
6
7
A
B
C
D
E
F
Root node
Nodes in 2nd level of tree
Nodes in 3rd level of tree

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

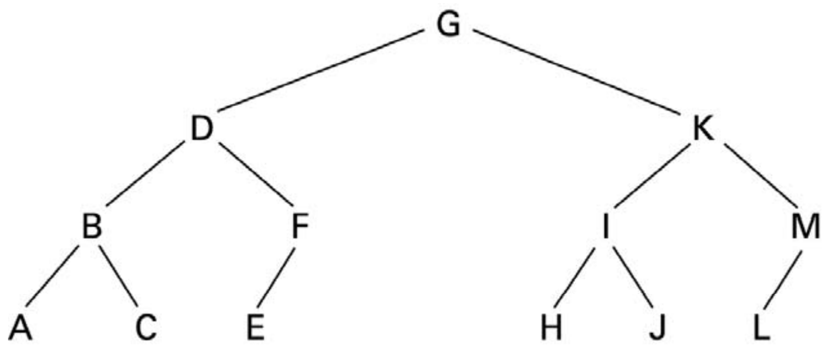
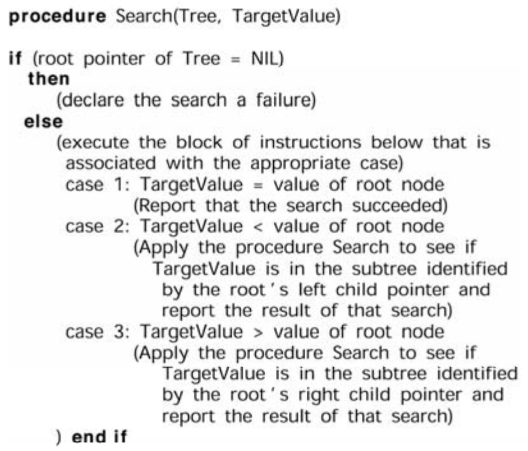


Figure 8.21 The binary search as it would appear if the list were implemented as a linked binary tree



```
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

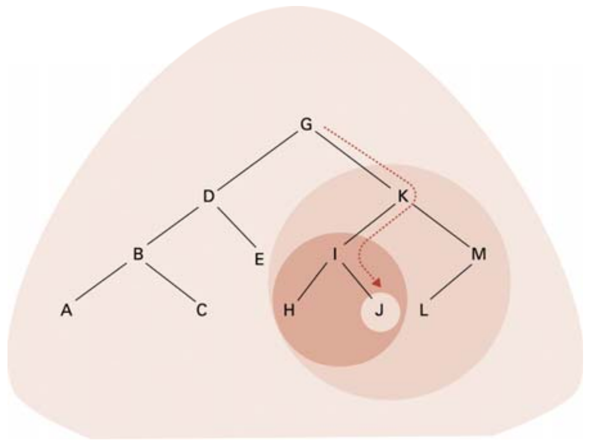


Figure 8.23 Printing a search tree in alphabetical order

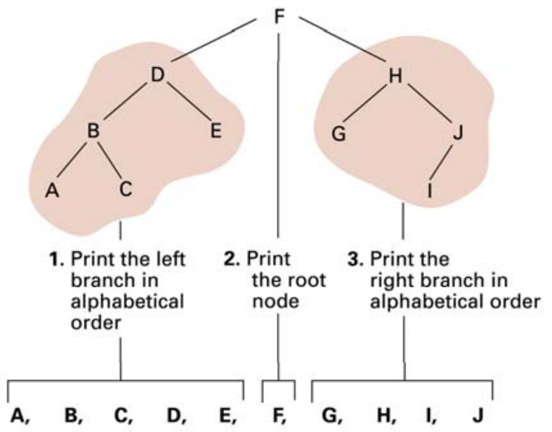
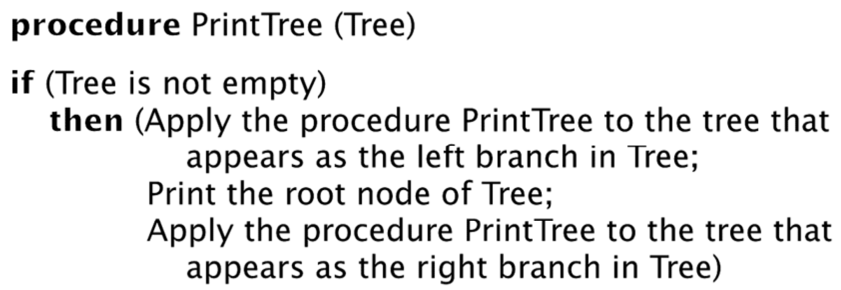

F
D
H
B
E
G
J
A
C
I
1. Print the left branch in alphabetical order
2. Print the root node
3. Print the right branch in alphabetical order
A, B, C, D, E, F, G, H, I, J

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

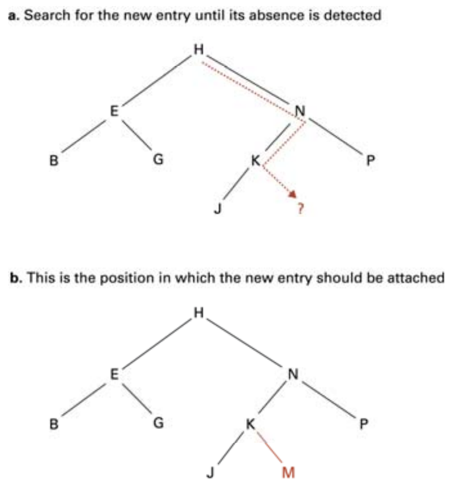
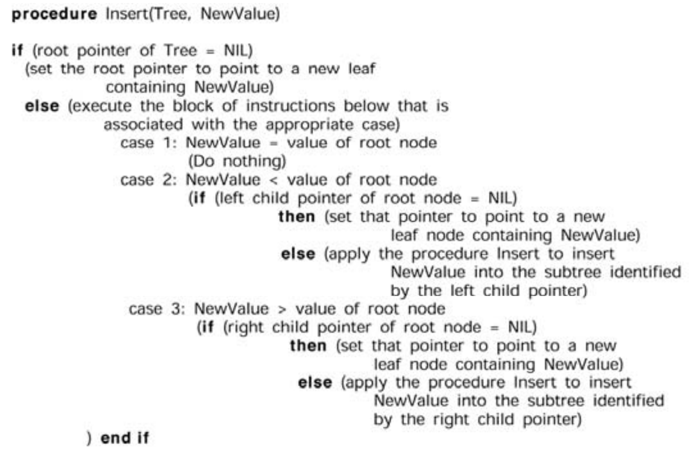

a. Search for the new entry until its absence is detected
H
E
N
B
G
K
P
J
?
b. This is the position in which the new entry should be attached
H
E
N
B
G
K
P
J
M

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;
 }
}
```

Pointers in Machine Language

- **Immediate addressing**: Instruction contains the data to be accessed
- **Direct addressing**: Instruction contains the address of the data to be accessed
- **Indirect addressing**: Instruction contains the location of the address of the data to be accessed

Figure 8.28 Our first attempt at expanding the machine language in Appendix C to take advantage of pointers

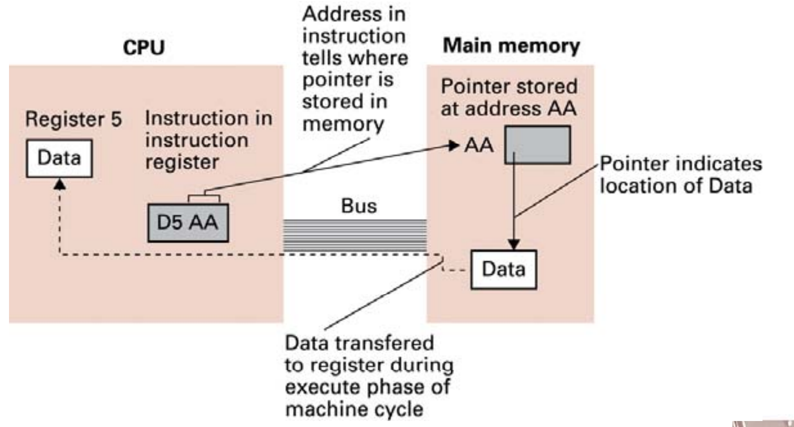
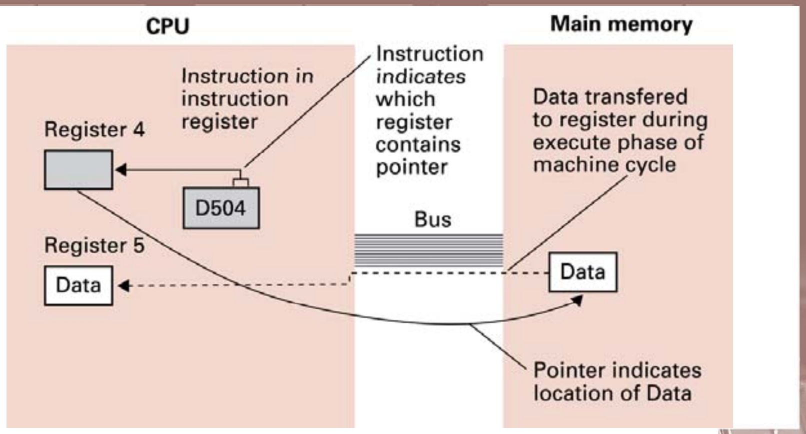

CPU
Address in instruction tells where pointer is stored in memory
Main memory
Pointer stored at address AA
Register 5
Data
Instruction in instruction register
AA
Pointer indicates location of Data
Bus
D5 AA
Data
Data transfered to register during execute phase of machine cycle

Figure 8.29 Loading a register from a memory cell that is located by means of a pointer stored in a register



CPU
Main memory
Instruction in instruction register
Instruction *indicates* which register contains pointer
Register 4
D504
Data transfered to register during execute phase of machine cycle
Bus
Register 5
Data
Data
Pointer indicates location of Data