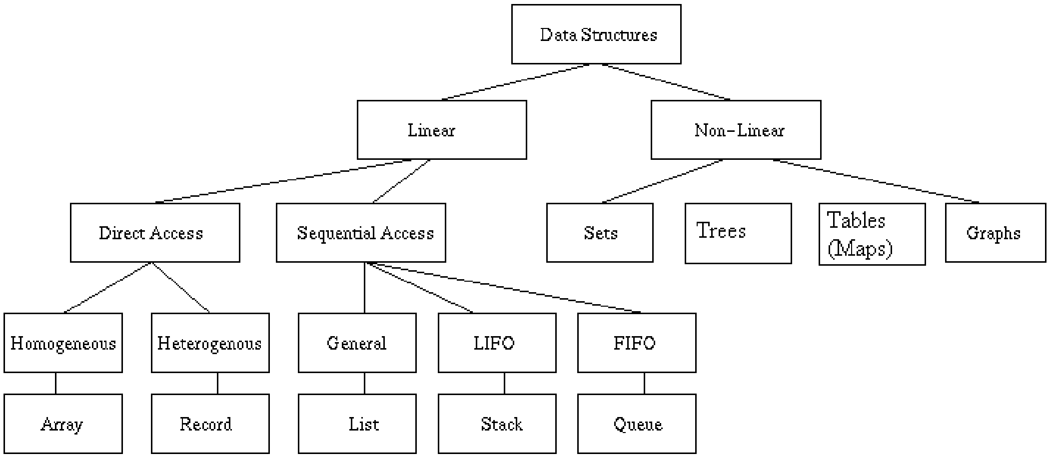
UNIT 3
Concrete Data Types

- Classification of Data Structures
- Concrete vs. Abstract Data Structures
- Most Important Concrete Data Structures
  - Arrays
  - Records
  - Linked Lists
  - Binary Trees

Overview of Data Structures

- There are two kinds of data types:
  - *simple* or *atomic*
  - *structured data types* or *data structures*
- An *atomic* data type represents a single data item.
- A *data structure* , on the other hand, has
  - a number of components
  - a structure
  - a set of operations
- Next slide shows a classification of the most important data structures (according to some specific properties)

Data Structure Classification



- Data Structures
  - Linear
    - Direct Access
      - Homogeneous
        - Array
      - Heterogenous
        - Record
    - Sequential Access
      - General
        - List
      - LIFO
        - Stack
      - FIFO
        - Queue
  - Non-Linear
    - Sets
    - Trees
    - Tables (Maps)
    - Graphs

Concrete Versus Abstract Types

- *Concrete data types* or *structures* (CDT's) are direct implementations of a relatively simple concept.
- *Abstract Data Types* (ADT's) offer a high level view (and use) of a concept independent of its implementation.
- Example: Implementing a student record:
  - CDT: Use a struct with public data and no functions to represent the record
    - does not hide anything
  - ADT: Use a class with private data and public functions to represent the record
    - hides structure of the data, etc.
- Concrete data structures are divided into:
  - *contiguous*
  - *linked*
  - *hybrid*
- Some fundamental concrete data structures:
  - arrays
  - records,
  - linked lists
  - trees
  - graphs.

C++ Arrays

- A C++ array has:
  - a collection of objects of the same type
  - a set of index values in the range [0,n]
- *Structure:*
  - objects are stored in consecutive locations
  - each object has a unique index
- *Operations:*
  - [i] accesses the (i+1)th object
- E.g. In

  char word[8];
  - word is declared to be an array of 8 characters
  - 8 is the *dimension* of the array
  - dimension must be known at compile time.

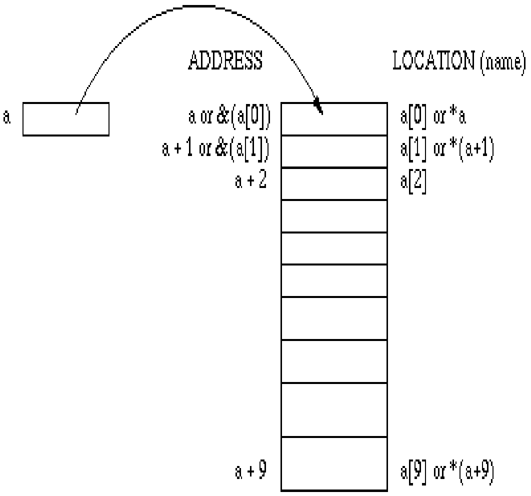
C++ Arrays (cont'd)

- Array *indices* (or *subscripts*) start at 0.
  word 's elements are:
- word[0], word[1], ... , word[7]
- An array can also be initialized, but with constants only
- int ia[] = {1,2,0};
- Arrays cannot be assigned to one another; each element must be assigned in turn

Arrays & Pointers

- Are closely related.
  The declaration:
  `type a[10]`
  - allocates space for 10 items of type type
  - items are stored in consecutive memory locatic
- C++ treats consecutive elements in the array
  having consecutive addresses:
  &a[0] < &a[1] < ... < &a[9]
  and
  &a[1] = &a[0] + 1
  &a[i] = &a[i-1] + 1
- a is a variable of type pointer to `type,`
- &a[i] is the same as a+i
  a[i] is the same as *(a+i)
- There are two ways to access the elements c
  array. We can use either:
  - array subscripts, or
  - pointers

- Suppose we declare
  int a[10];
  then



Example

- Suppose we declare:
  int i, a[10]
  The following two statements output the elements of a

```
1.  for (i = 0; i < 10; i++)
        cout << a[i];          // using subscripts
2.  for (i = 0; i < 10; i++)
        cout << *(a + i);          // using pointers
```

- If
  int * p;
  then
  p = &a[i] or
  p = a + i
  makes p point to the i-th element of a .
- Straying beyond the range of an array results in a *segmentation fault*.
- Pointers are not integers
  - Exception: NULL (which is 0) can be assigned to a pointer.
  - NULL is the undefined pointer value

Dynamic arrays

- Are declared as pointers
- Space for these arrays is allocated later, when the size is known
- **Example:** Consider the declarations:

```
int b[10];
int * a;
a = new int[10];
```

Then:

- a and b are both arrays
- b is a ***fixed array*** ; a is a ***dynamic array***
- [] can also be used on a
- a[2] is the third element of a

BUT

- b has space for ten integers
- a has space for one pointer
  - space for its elements must be allocated by new
- b is a constant pointer; a can be changed

- A dynamic array can be expanded
  - I.e. to expand a we can write:

```
int* temp = new int[10 + n];
for (int i = 0; i<10; i++)
        temp[i] = a[i];
delete a;
a = temp;
```

Example Using Dynamic Arrays:

Implementation of EmployeeDB using dynamic arrays:

EmployeeDB (Dynamic Array)

Passing Array Parameters

- Arrays are always passed by reference
- Suppose we declare,

```
int a[10];
```

To pass array a to a function f, f may be declared as:

```
type f( int d[], int size ) or
type f( int* d , int size)
```

- In any case, f is called by f(a, sizeof a) .

Multi-dimensional Arrays

- To store the temperature measured at each hour of each day for a week, we can declare :
  `int temp[7][24];`
  - temp is a 2-dimensional array.
  - to get the temperature at noon on Monday, we can do:
    `temp[1][11];`
- To pass a multi-dimensional array to a function, the first subscript can be free.
- i.e. To pass temp to f, f may been declared as

```
... f(int t[][24], int size1); or
... f(int (*t)[24], int size1);  or
... f(int** t, int size1, int size2)
```

- In the last declaration, t is a pointer to a pointer, while in the other two t is a pointer to an array of 24 integers

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Multi-dimensional Arrays vs. Pointers

- Given the declarations:

```
int t[7][24];
int* s[7];
int** r;
```

  we can allocate adequate space to s and r so that t, s and r behave as 2d arrays
  - i.e   t[3][4]   s[3][4]   r[3][4]   all work fine
- But
  - t is a true 2-dimensional array (has space allocated)
  - s is an array of 7 pointers (each pointing to an array of 24 integers)
  - r is a pointer to a pointer
- A use of *semi-dynamic* arrays:
  arrays with different row length
- i.e.
  `char* day[8] = {"Illegal day name", "Sunday", ..., "Friday"}`

Features of Arrays

- Simple structures.
- Their size is fixed;
  - dynamic arrays can be expanded, but expansion is expensive.
- Insertion and deletion in the middle is difficult.
- Algorithms are simple.
- Accessing the i-th element is very efficient

C++ Records (struct's)

- Records allow us to group data and use them together as a unit
- The record type has:
  - a collection of objects of same or different type
  - each object has a unique name
  - .obname accesses the object with name obname.
- C++ uses "struct" for records. They are also called "structures" in C++.
- For instance, after declaring

```
struct date {
        int day;
        char* month;
        int year;
};
```

  date is now a new type; it can be used as:

```
date today = {20, "jun" , 1993};
```

- We can access the components of a structure using the *select member* operator ".“

  E.g. today.month[2] // 'n'

A C++ struct may also have function members.

The difference between classes and records:
by default, a class components are private, while a struct's components are public

C++ Records (cont')

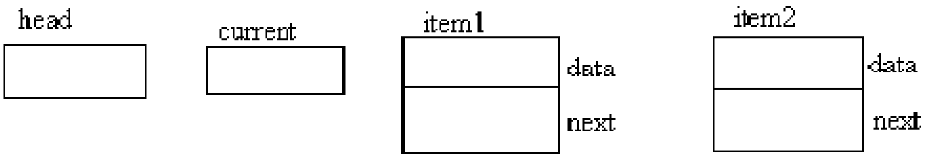
- Structures are commonly used to implement lists, trees, etc. An item of these types of structures usually looks like:

```
struct item {
     int data;
     item* next;
} ;
```

- We can then declare:

```
item item1, item2, *head, *current;
```

  - The physical structure of this would look like the following:



The operator ->

- Structure components can be accessed by pointers using the *point at member* operator "->".
- E.g. If we set

  head = &item1

  then

  head -> data

  is the data field of item1 .
- Structures can be *copied member-wise* :

  item2 = *head

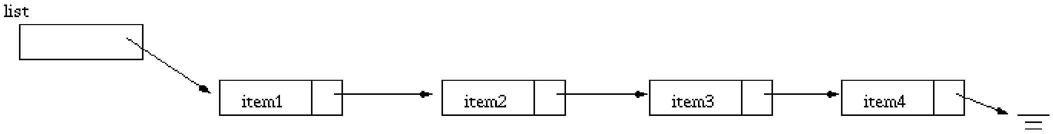
- We can also pass a structure as a parameter to a function. However, it is usually more efficient to pass a structure by reference, or to pass a pointer to the structure instead.
- i.e.

  void f(const date& d) or

  void f(const date* d)

Linked Lists

- A (*singly*) *linked list* is a sequence of nodes linked together:



- They represent sequences of data items.
- Each node in the list contains the item and a pointer to the next element.
- The last pointer is set to 0 (or NULL) to denote the end of the list.
- The whole list is defined by a pointer to the first item (called list here).
- In C++ the node and the list are defined as:

```
// TYPE is the type of our items
typedef int TYPE;
struct node {
            TYPE item;
            node* next;
};
```

or

```
typedef int TYPE;
class node {
     public:
            TYPE item;
            node* next;
};
```

Common Operations on Linked List

- **Insert an item in the list**. Many types of insertion:
  - **insert_first**: insert item at the front of list
  - **insert_last**: insert item at the end of the list
  - **insert_after**: insert item in list after a certain node
- **find**: finds the node in the list with a given item
- **delete_item:** removes an item from the list
- **printNode:** prints the contents of a node

- **A Singly Linked List Toolkit**

  The following files contain an implementation of a module (or toolkit) for the singly linked list structure:

  Singly Linked List

- **Example Using Linked Lists**

  Implementation of EmployeeDB using singly linked lists:

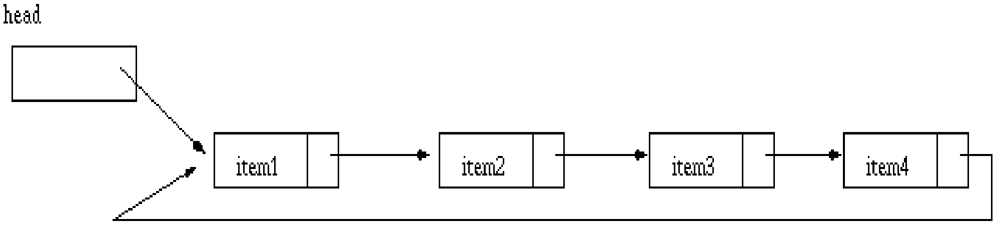
  EmployeeDB (Linked List)

Head Nodes

- Processing of this first node is different from processing of the other nodes.
- A *head node* is a dummy node at the beginning of the list.
  - It is similar to the other nodes, except that it has a special value
  - It is never deleted.
  - Processing every actual node is the same.
- Usually, it is more confusing and it is not used.

Circular Linked Lists (or rings)

- A circular linked list looks like:



- A circular linked list is appropriate when there is no distinct first and last item.
- The algorithms for circular linked lists are similar to those for singly linked lists, except that
  - none of the links is null
  - the end of the list is reached when **curr->next == head**

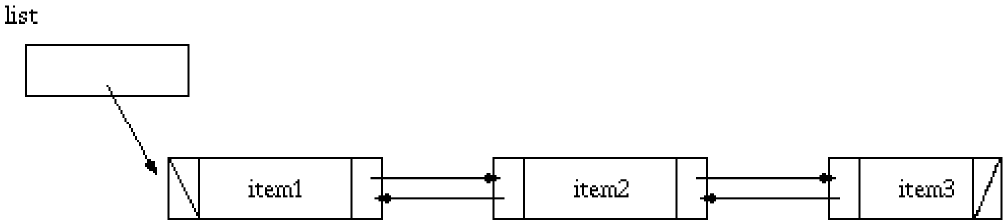
Doubly-linked Lists

- Similar to singly linked lists except that each node also has a pointer to the *previous* node.
- Doubly linked list node definition:

```
        struct dnode {
                TYPE item;
                dnode* next;
                dnode* prev;
        } ;
```

- Operations are defined similarly

A Doubly Linked List Toolkit :
Can be found in
Doubly Linked List



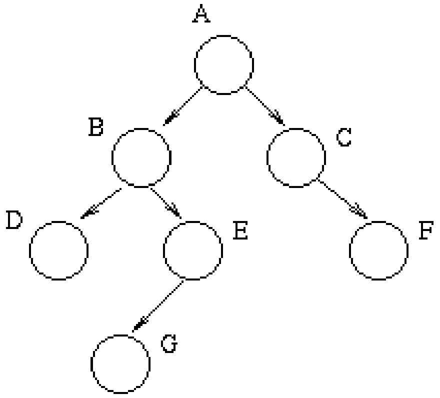
Features of Linked Lists

Compared to arrays, linked lists have the following advantages/disadvantages:

- *Advantages*
  - Are dynamic structures; space is allocated as required.
  - Their size is not fixed; it grows as needed.
  - Insertion and deletion in the middle is easy.
- *Disadvantages*
  - More space is needed for the links.
  - Algorithms are more complex.
  - Impossible to directly access a node of the list.

Binary Trees

- A binary tree is a structure that
  - is either empty, or
  - it consists of a node called a *root* and two binary trees called the *left subtree* and the *right subtree* .
- Pictorially a binary tree looks like the following:



Parents, Children & Paths

- *Parents & Children:*
  - If there is a link from node N to M then N is the *parent* of M and M is a *child* of N.
  - The *root* has no parent.
  - A *leaf* is a node on the bottom level of the tree without any children.
  - A node can have a maximum of 2 children.
  - A tree cannot have cycles.
- *Grandparents, grand children, ancestors, descendants* are defined similarly.
- Path from N1 to Nk
  - a sequence of nodes N1, N2,..., Nk, where Ni is a parent of Ni+1.
  - *path length* : # of nodes in the path from N1 to Nk (some authors use # of edges).

- *Depth* or *level* of a node N
  - length of the unique path from the root to N
  - the level of the root is 1.
- *Height* of a node N:
  - length of the longest path from N to a leaf
  - a leaf's height is 1.
- *Height* of the tree:
  - height of its root
- The number of nodes in a binary tree of height h is >= h and <= 2h -1 nodes.

Implementation of Trees

- Implementation of a binary tree in C++:
  - a node in the tree contains the item and two pointers to the subtrees:

```
typedef int TYPE ;
struct bnode {
      TYPE item;
      bnode* left;
      bnode* right;
};
```

- A C++ binary search tree is just a pointer to the root.

Common Operations for Binary Trees

- **Insert an item in the tree**: To the left or right of a node:
  - **insert_left**: insert item on the left of a given node
  - **insert_right**: insert item on the right of a given node
- **find**: finds the node in the tree with a given item
- **find_parent**: finds the parent of a given node in the tree
- **delete_node:** removes the node with the given item from the tree
- **print:** prints the whole tree (sideways)

A Binary Tree Toolkit

- An implementation of a module (or toolkit) for the binary tree structure can be found in the Examples:
  - Binary Tree

Traversing a binary tree

- There are three types of traversal.
  - *preorder* : node then left subtree then right subtree
  - *inorder* : left subtree then node then right subtree
  - *postorder* : left subtree then right subtree then node
- **Inorder traversal**: The following code applies a function visit to every node in the tree inorder:

```
void inorder( bnode* root ) {
// apply the function visit to every node in the tree, inorder
        if( root != NULL ) {
                inorder( root->left);
                visit ( root );    // apply visit to the root of the tree
                inorder( root->right);
        }
}
```

- Tree traversal is not usually implemented by a function. What is shown here is just an example.

Higher trees and Graphs

N-ary Trees

- Like binary trees except that a node may have up to n subtrees.

Graphs

- More general than trees. They can have cycles and are usually hybrid structures.