Lists

Chapter 6

Chapter Contents

Chapter Objectives

- To study list as an ADT
- Build a static-array-based implementation of lists and note strengths, weaknesses
- Build a dynamic-array-based implementation of lists, noting strengths and weaknesses
  - See need for destructor, copy constructor, assignment methods
- Take first look at linked lists, note strengths, weaknesses
- Study pointer-based implementation of linked lists
- (Optional) Study array-based implementation of linked lists

Consider Every Day Lists

- Groceries to be purchased
- Job to-do list
- List of assignments for a course
- Dean's list

- Can you name some others??

Properties of Lists

- Can have a single element
- Can have <u>no</u> elements
- There can be lists of lists

- We will look at the list as an abstract data type
  - Homogeneous
  - Finite length
  - Sequential elements

Basic Operations

- Construct an empty list
- Determine whether or not empty
- Insert an element into the list
- Delete an element from the list
- Traverse (iterate through) the list to
  - Modify
  - Output
  - Search for a specific value
  - Copy or save
  - Rearrange

Designing a `List` Class

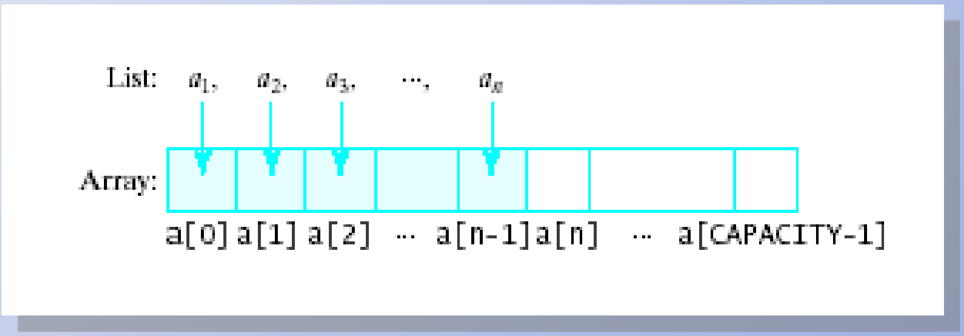
- Should contain at least the following function members
  - Constructor
  - `empty()`
  - `insert()`
  - `delete()`
  - `display()`
- Implementation involves
  - Defining data members
  - Defining function members from design phase

Designing a `List` Class

- Special note when implementing operations/functions
  - Always consider the characteristics (cases) of the list before performing an operations (inserting, deleting and so forth…). The about cases like the following when implementating:
    - Is the list empty?
    - Is operation being performed at the front?
    - Is operation being performed at the back?
    - Is operation being performed on list if one node?

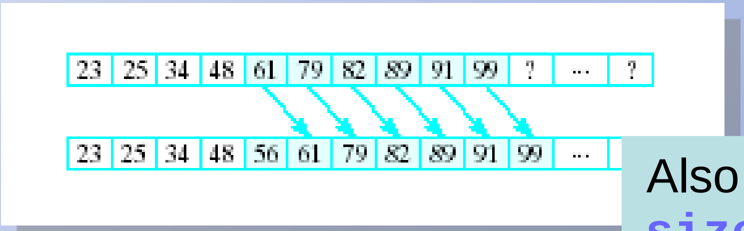
Array-Based Implementation of Lists

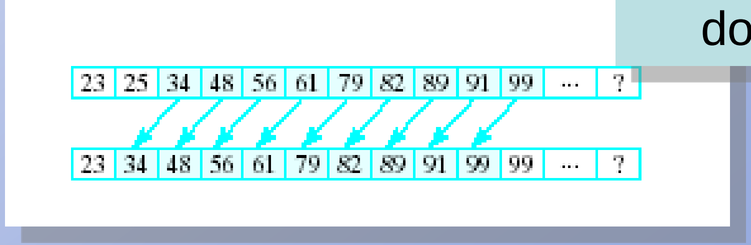
- An array is a viable choice for storing list elements
  - Element are sequential
  - It is a commonly available data type
  - Algorithm development is easy
- Normally sequential orderings of list elements match with array elements



Implementing Operations

- Constructor
  - Static array allocated at compile time
- Empty
  - Check if size == 1
- Traverse
  - Use a loop from 0th element to **`size – 1`**
- Insert
  - Shift elements to right of insertion point
- Delete
  - Shift elements back





Also adjust **`size`** up or down

`List` Class with Static Array

- Must deal with issue of declaration of CAPACITY
- Use `typedef` mechanism

```
typedef Some_Specific_Type ElementType
ElementType array[CAPACITY];
```

- For specific implementation of our class we simply fill in desired type for `Some_Specific_Type`

`List` Class with Static Array

- Can put `typedef` declaration inside or outside of class
  - Inside: must specify `List::ElementType` for reference to the type outside the class
  - Outside: now able to use the `template` mechanism (this will be our choice)
- Also specify the `CAPACITY` as a `const`
  - Also choose to declare outside class

`List` Class Example

- Declaration file (List.cpp), Fig. 6.1A. Look the code in the file "CodeSamplesChapter6" with the slides in this chapter.
  - Note use of **`typedef`** mechanism <u>outside</u> the class in statement "typedef int ElementType;".
  - This example good for a list of **`int`**

`List` Class Example

(code in file CodeSamplesChapter6)

- Definition, implementation Fig. 6.1B in List.cpp.
  - Note considerable steps required for **`insert()`**.
    - (mySize == CAPACITY) checks for a full array
    - (pos<0 || pos> mySize) checks to see if index/subscript is ok (0<=pos<mySize)
    - The “for” loop shifts the items to make room for the element to be stored at pos. Then the item is added and mySize is incremented.

`List` Class Example

- Note considerable steps required for `erase().`
  - (mySize ==) checks to see if the array is empty
  - (pos<0 || pos> mySize) checks to see if index/subscript is ok (0<=pos<mySize)
  - The “for” loop shifts the items left to close the space left the the erased item. Then mySize is decremented.

`List` Class Example

(code in file CodeSamplesChapter6)

- See the driver to test the functionality of your class in Fig 6.1C.

`List` Class with Static Array - Problems

- Stuck with "one size fits all"
  - Could be wasting space
  - Could run out of space
- Better to have instantiation of specific list specify what the capacity should be
- Thus we consider creating a `List` class with dynamically-allocated array

Dynamic-Allocation for `List` Class

- Changes required in data members
  - Eliminate const declaration for CAPACITY
  - Add variable data member to store capacity specified by client program
  - Change array data member to a pointer
  - Constructor requires considerable change
- Little or no changes required for
  - `empty()`
  - `display()`
  - `erase()`
  - `insert()`

Dynamic-Allocation for `List` Class

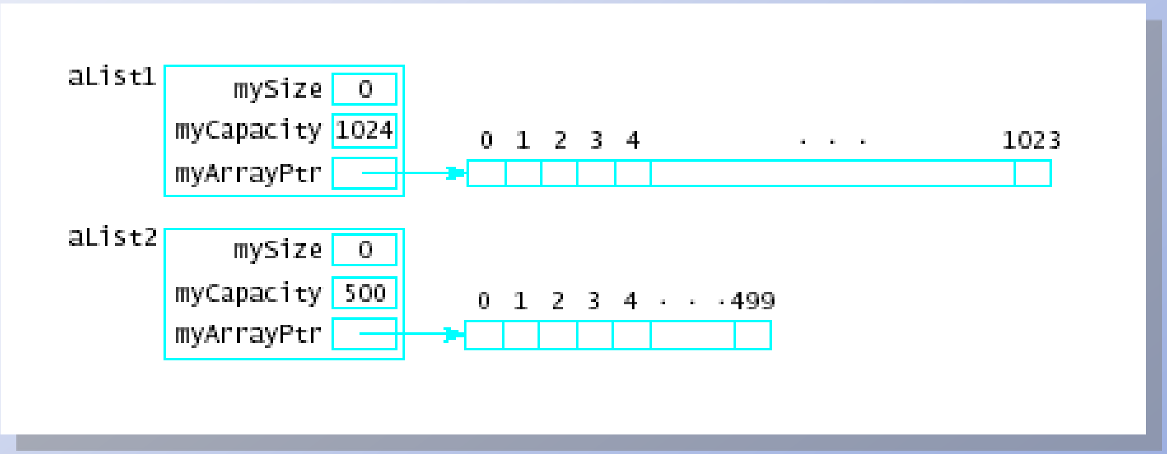
(code in file CodeSamplesChapter6)

- Note data changes in Fig. 6.2A from Fig. 6.1A in the private (state) area of your class in **`List.h.`**
- Note implementation file Fig. 6.2B,from Fig. 6.1B in **`List.cpp.`**
  - Changes to constructor
  - Addition of other functions to deal with dynamically allocated memory
- Note testing of various features (functionality of the class) in Fig. 6.2C, the demo program

Dynamic-Allocation for **`List`** Class

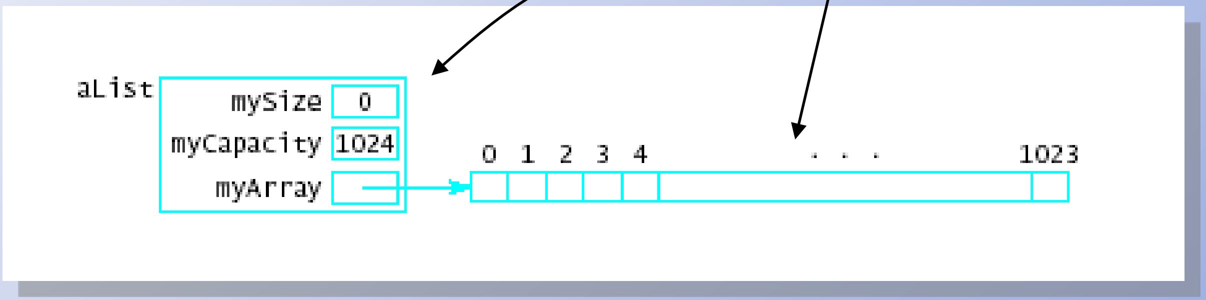
- Now possible to specify different sized lists

```
cin >> maxListSize;
List aList1 (maxListSize);
List aList2 (500);
```



New Functions Needed

- Destructor
  - When class object goes out of scope the pointer to the dynamically allocated memory is reclaimed automatically
  - The dynamically allocated memory is not

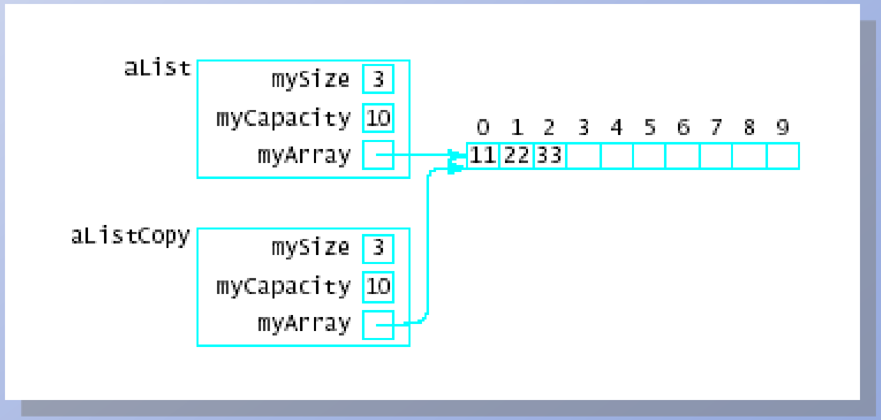


  - The destructor reclaims dynamically allocated memory

New Functions Needed

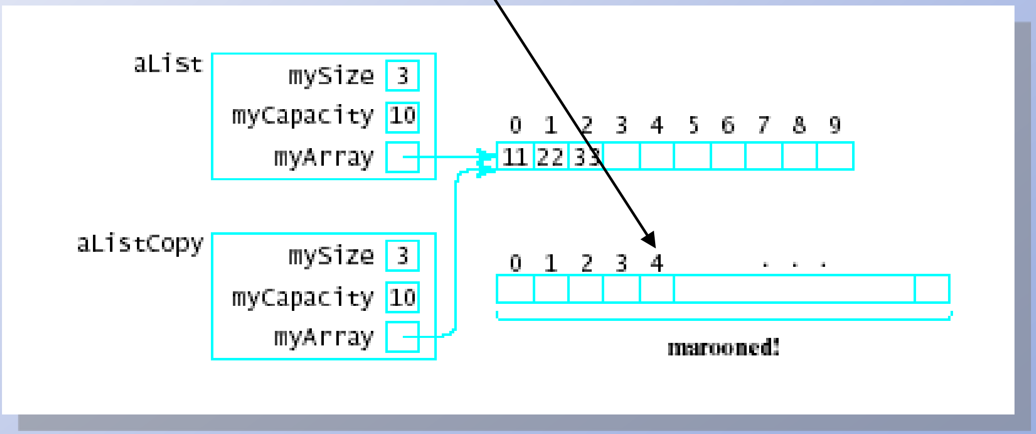
- Copy Constructor – makes a "deep copy" of an object
  - When argument passed as value parameter
  - When function returns a local object
  - When temporary storage of object needed
  - When object initialized by another in a declaration

- If copy is not made, observe results (aliasing problem, "shallow" copy)



New Functions Needed

- Assignment operator
  - Default assignment operator makes shallow copy
  - Can cause memory leak, dynamically-allocated memory has nothing pointing to it



Notes on Class Design

(code in file CodeSamplesChapter6)

If a class allocates memory at run time using the **new**, then a it should provide …

- A destructor
- A copy constructor
- An assignment operator

- Note Fig. 6.3 which exercises constructors and destructor

Future Improvements to Our `List` Class

- Problem 1: Array used has fixed capacity
  Solution:
  - If larger array needed during program execution
  - Allocate, copy smaller array to the new one
- Problem 2: Class bound to one type at a time
  Solution:
  - Create multiple `List` classes with differing names
  - Use class template

Recall Inefficiency of Array-Implemented List

- `insert()` and `erase()` functions inefficient for dynamic lists
  - Those that change frequently
  - Those with many insertions and deletions

So ...

We look for an alternative implementation.

Linked List

For the array-based implementation:

1. First element is at location 0
2. Successor of item at location i is at location `i + 1`
3. End is at location `size – 1`

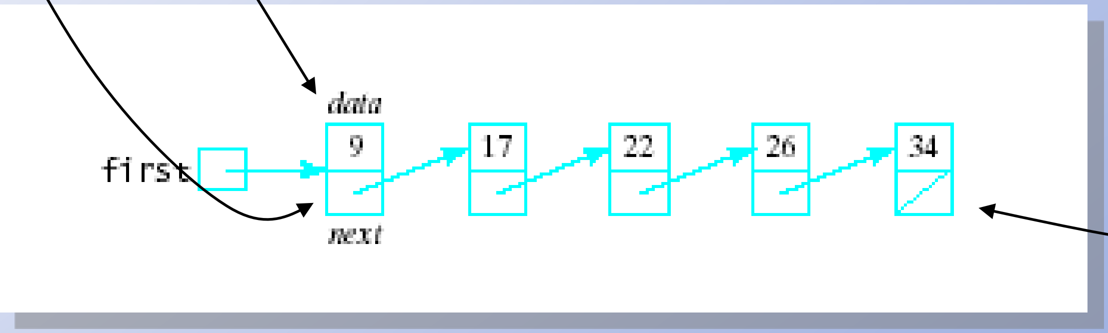
Fix:

1. Remove requirement that list elements be stored in consecutive location.
2. But then need a "link" that connects each element to its successor

Linked Lists !!

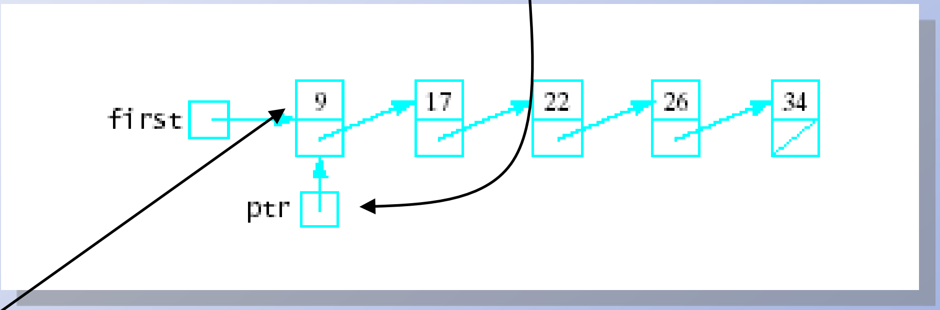
Linked List

- Linked list nodes contain
  - Data part – stores an element of the list
  - Next part – stores link/pointer to next element (when no next element, null value)



Linked Lists Operations

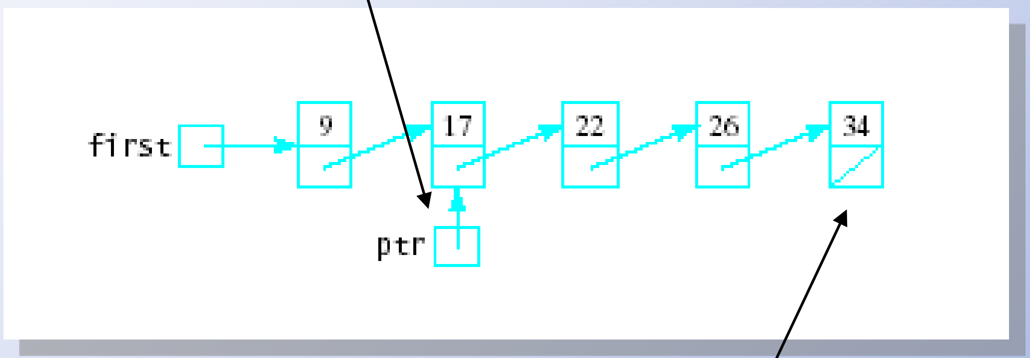
- Construction: `first = null_value;`
- Empty: `first == null_value?`
- Traverse
  - Initialize a variable `ptr` to point to first node



  - Process data where `ptr` points

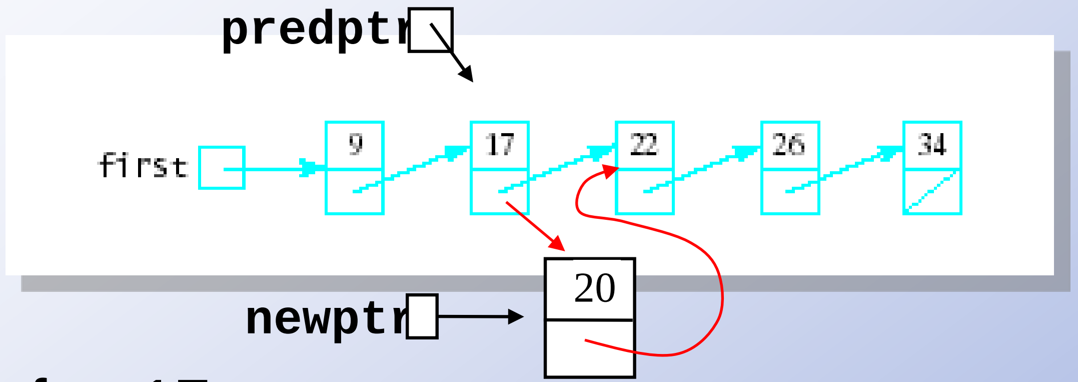
Linked Lists Operations

- Traverse (ctd)
  - set **`ptr = ptr->next`**, process **`ptr->data`**



  - Continue until **`ptr == null`**

Operations: Insertion



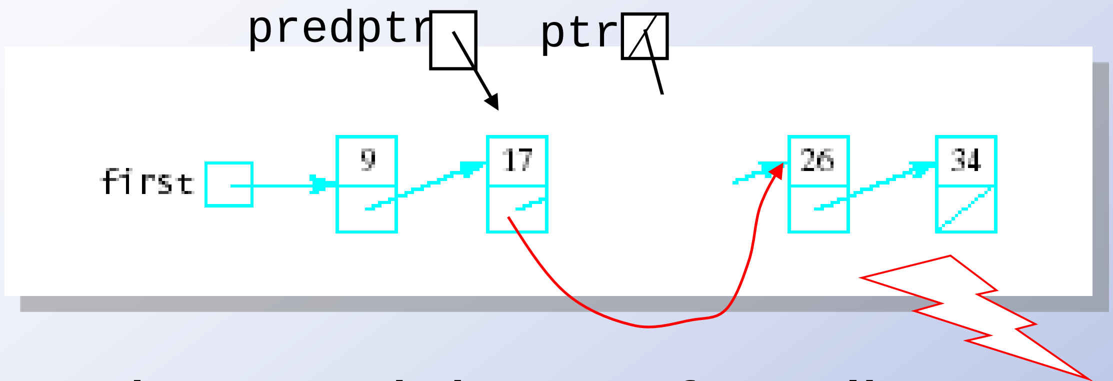
- Insertion
  - To insert 20 after 17
  - Need address of item before point of insertion
  - **`predptr`** points to the node containing 17
  - Get a new node pointed to by **`newptr`** and store 20 in it
  - Set the next pointer of this new node equal to the next pointer in its predecessor, thus making it point to its successor.
  - Reset the next pointer of its predecessor to point to this new node

Operations: Insertion

- Note: insertion also works at <u>end</u> of list
  - pointer member of new node set to **`null`**
- Insertion at the <u>beginning</u> of the list
  - **`predptr`** must be set to **`first`**
  - pointer member of **`newptr`** set to that value
  - **`first`** set to value of **`newptr`**

⌧ Note: In all cases, **no shifting of list elements is required !**

Operations: Deletion



To free space

- Delete node containing 22 from list.
  - Suppose **ptr** points to the node to be deleted
  - **predptr** points to its predecessor (the 20)
- Do a bypass operation:
  - Set the next pointer in the predecessor to point to the successor of the node to be deleted
  - Deallocate the node being deleted.

Linked Lists - Advantages

- Access any item as long as external link to first item maintained
- Insert new item without shifting
- Delete existing item without shifting
- Can expand/contract as necessary

Linked Lists - Disadvantages

- Overhead of links:
  - used only internally, pure overhead
- If dynamic, must provide
  - destructor
  - copy constructor
- No longer have direct access to each element of the list
  - Many sorting algorithms need direct access
  - Binary search needs direct access
- Access of n^{th} item now less efficient
  - must go through first element, and then second, and then third, etc.

Linked Lists - Disadvantages

- List-processing algorithms that require fast access to each element cannot be done as efficiently with linked lists.
- Consider adding an element at the end of the list

Array	Linked List
`a[size++] = value;`	Get a new node; set data part = value next part = *null_value* If list is empty Set first to point to new node. Else Traverse list to find last node Set next part of last node to point to new node.

This is the inefficient part

Using C++ Pointers and Classes

- To Implement Nodes

```
class Node
  {
   public:
   DataType data;
   Node * next;
  };
```

- Note: The definition of a Node is <u>recursive</u>
  - (or self-referential)
- It uses the name Node in its definition
- The `next` member is defined as a pointer to a Node

Working with Nodes

- Declaring pointers

  `Node * ptr;` or

  ```
  typedef Node * NodePointer;
     NodePointer ptr;
  ```

- Allocate and deallocate

  `ptr = new Node;` `delete ptr;`

- Access the data and next part of node

  `(*ptr).data` and `(*ptr).next`

  or

  `ptr->data` and `ptr->next`

Working with Nodes

- Note data members are public

```
class Node
{    public:
     DataType data;
     Node * next;          };
```

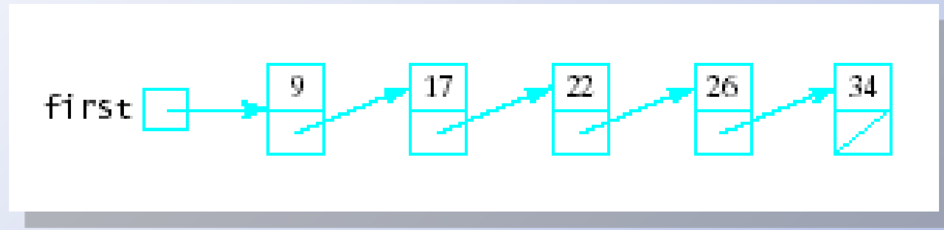
- This class declaration will be placed inside another class declaration for `List`
- The data members `data` and `next` of struct `Node` will be public inside the class
  - will accessible to the member and friend functions
  - will be private outside the class

Class `List`

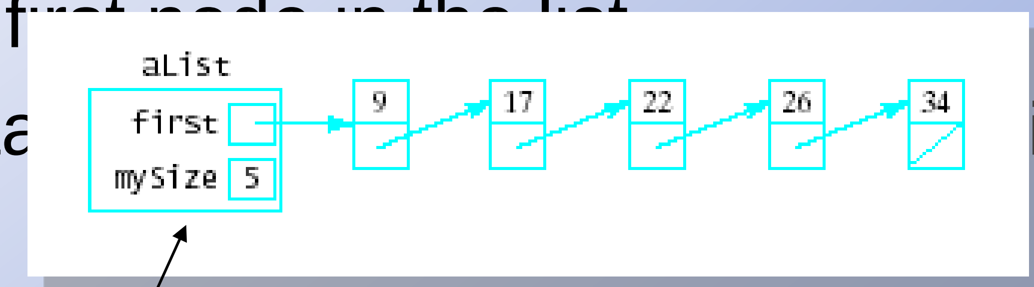
```
typedef int ElementType;
class List
{
 private:
 class Node
 {
 public:
  ElementType data;
  Node * next;
 };
 typedef Node * NodePointer;
  . . .
```

- `data` is public inside class `Node`
- class `Node` is private inside `List`

Data Members for Linked-List Implementation



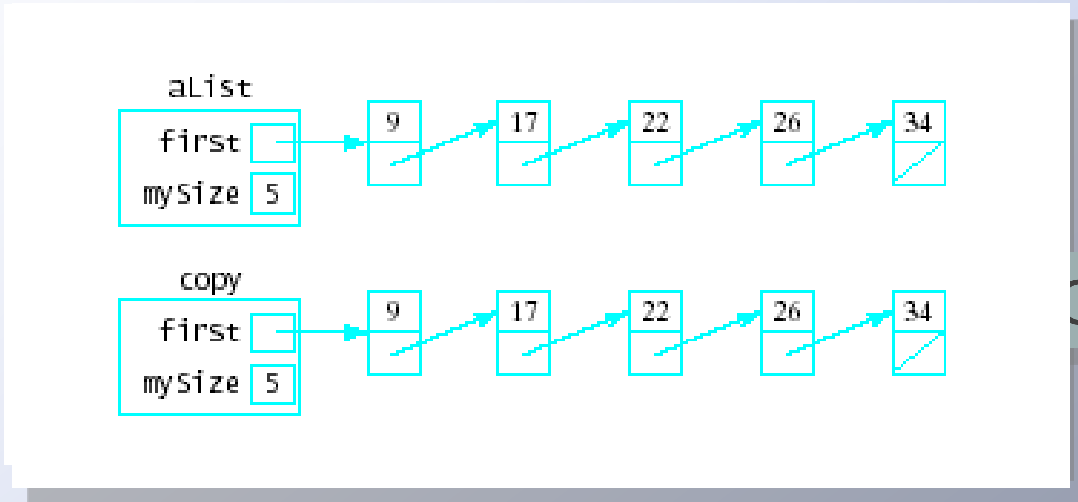
- A linked list will be characterized by:
  - A pointer to the f
  - Each node conta in the list
  - The last node contains a null pointer
- As a variation **`first`** may
  - be a structure
  - also contain a count of the elements in the list



Function Members for Linked-List Implementation

- Constructor
  - Make `first` a null pointer and
  - set `mySize` to 0
- Destructor
  - Nodes are dynamically allocated by **`new`**
  - Default destructor will not specify the **`delete`**
  - All the nodes from that point on would be "marooned memory"
  - A destructor must be explicitly implemented to do the `delete`

Function Members for Linked-List Implementation



- Copy constructor for deep copy
  - By default, when a copy is made of a **List** object, it only gets the head pointer
  - Copy constructor will make a new linked list of nodes to which **copy** will point

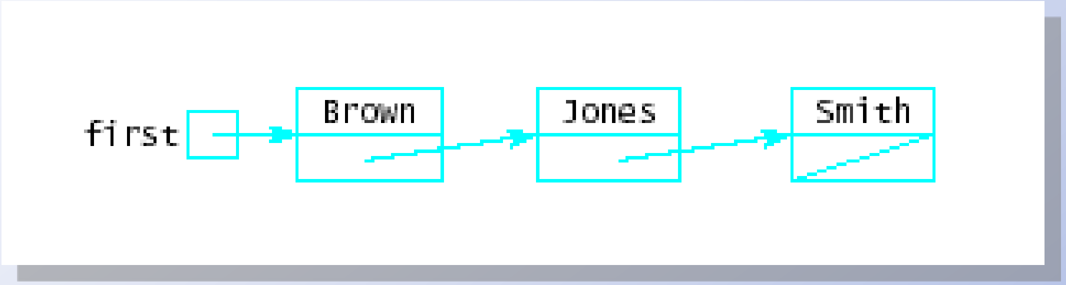
Array-Based Implementation of Linked Lists (optional)

- Node structure

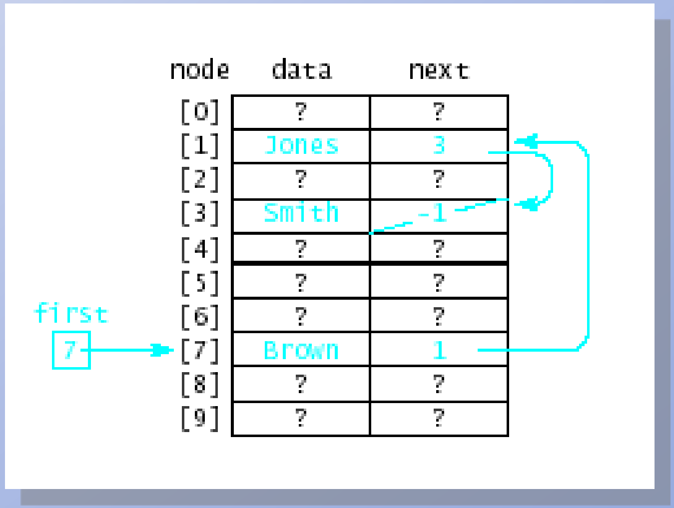
```
struct NodeType
{
   DataType data;
   int next;
};
const int NULL_VALUE = -1;
// Storage Pool
const int NUMNODES = 2048;
NodeType node [NUMNODES];
int free;
```

Array-Based Implementation of Linked Lists (optional)

- Given a list with names



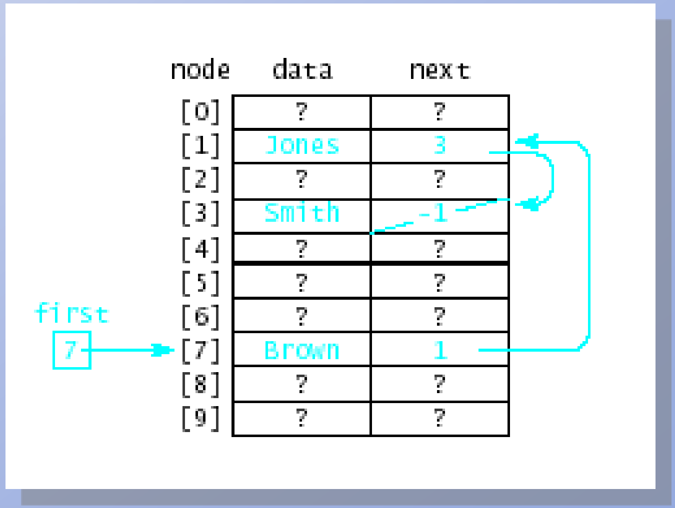
- Implementation would look like this



Array-Based Implementation of Linked Lists (optional)

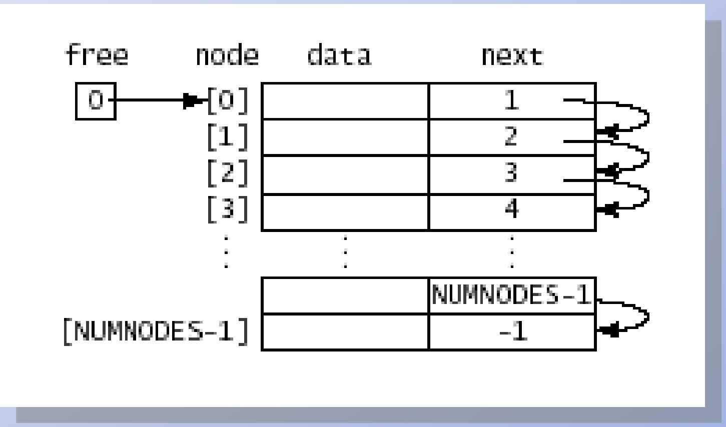
- To traverse

```
ptr = first;
while (ptr != NULL_VALUE)
{
// process data at node[ptr].data
ptr = node[ptr].next;
}
```



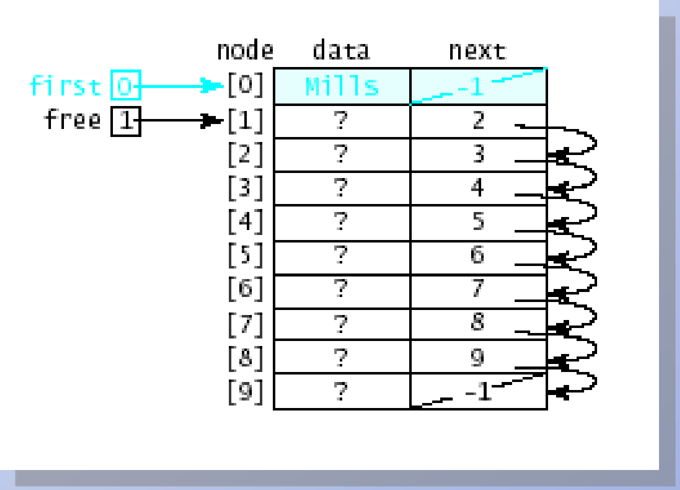
Organizing Storage Pool (optional)

- In the array
  - Some locations are storing nodes of the list
  - Others are free nodes, available for new data
- Could initially link all nodes as free



Organizing Storage Pool (optional)

- Then use nodes as required for adds and inserts
  - Variable free points to beginning of linked nodes of storage pool



Organizing Storage Pool (optional)

- Links to actual list and storage pool maintained as new data nodes are added and deleted