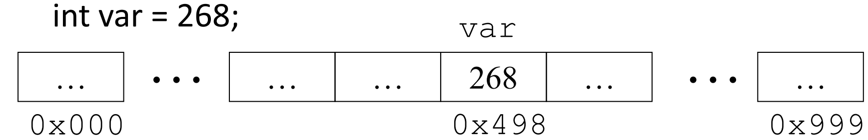
Chapter 4: (Pointers and) Linked Lists

- Pointer variables
- Operations on pointer variables
- Linked lists
- Operations on linked lists
- Variations on simple linked lists
  - doubly linked lists
  - circular linked lists

Pointer Variables

- Declaring a variable creates space for it
  - in a region of process memory called *stack*
  - each memory cell has an *address*
    - memory can be considered to be linearly addressed starting from 0 to MAX

int var = 268;



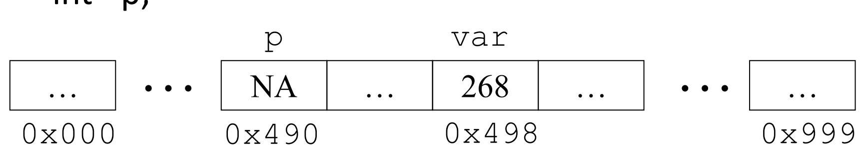
- Use pointers to refer to variables *indirectly* by *pointing at them*

Pointer Variable – Declaration

- A pointer contains the location, or address in memory, of a memory cell
- Declaration of an integer pointer variable p
  - static allocation; initially undefined, but not NULL

int var = 268;

int *p;

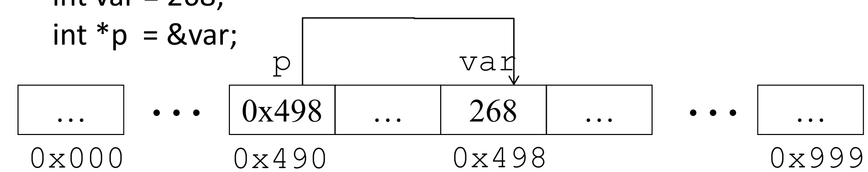


Pointer Variable – Assignment

- Can assign address of any variable (including another pointer variable) to the pointer variable

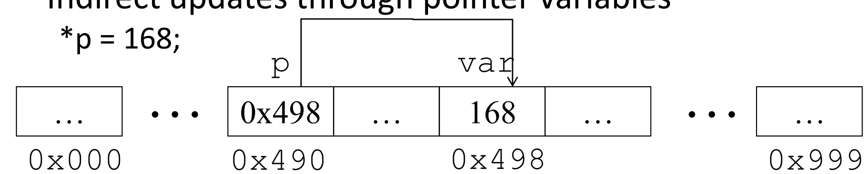
int var = 268;

int *p = &var;



- Indirect updates through pointer variables

*p = 168;



Pointer Variable – Assignment

- & : address-of operator
- * : used for "de-reference" a pointer
  - expression *p represents the memory cell to which p points
- Pointer variables are also variables!
  - need space in memory
  - can have pointer variables pointing to other pointer variables

```
int a, *p, **pp;
p = &a;
pp = &p;
```


Pointer Variable – Types

- All pointer variables hold integer addresses, but have types
  - very important during pointer arithmetic

```
int a, *ip = &a, **pp;
char c, *cp = &c;
ip ++; // increments value in 'ip' by 4/8
cp ++; // increments value in 'cp' by 1
pp = &a; // Is this valid ?
```

- Multiple/divide with pointer variables generally is not meaningful

see C4-pointers.cpp

New Operator

- All declared variables, arrays are statically assigned space (on the stack) by the compiler
- Can also allocate space dynamically at runtime
  - use the new operator

```
int *p = new int;
double *dp = new double(4.5);
my_class *instance = new my_class();
```

  - if the operator new cannot allocate memory, it throws the exception std::bad_alloc (in the <new> header)
    - very uncommon

Delete Operator

- Memory available to a program is limited
  - return dynamically allocated memory to the system if no longer needed
  - use the *delete* operator

```
int *p = new int(268);
cout << "Integer is: " << *p;
delete p;
```

see C4-funcarg.cpp

De-allocating Memory

- *delete* leaves the variable contents undefined
  - a pointer to a deallocated memory (*p) cell is possible and *dangerous*
  - deallocated memory can be reassigned after another call to *new*
  - so, indirect reference through 'p' after delete refers to undefined memory
  - called the *dangling pointer* error
  - p = NULL; // safeguard

see C4-dangling.cpp

Memory Leak

- A memory leak is another common problem when using pointers and dynamic memory
  - happens when allocated memory can no longer be reached
  - so, cannot be de-allocated!
  - wastes memory resources, eventually system will run out of memory

  int i, *ip;

  ip = new int(268);

  ip = &i; // memory leak!

Pointer Examples

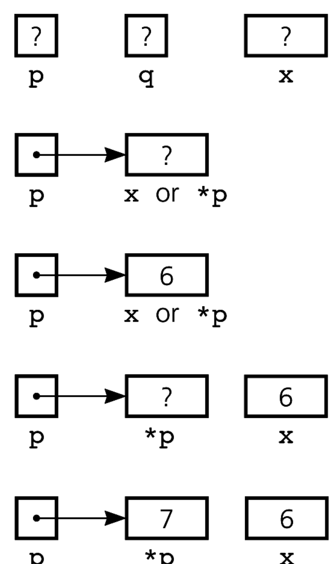
(a) `int *p, *q;`
    `int x;`

(b) `p = &x;`

(c) `*p = 6;`

(d) `p = new int;`

(e) `*p = 7;`



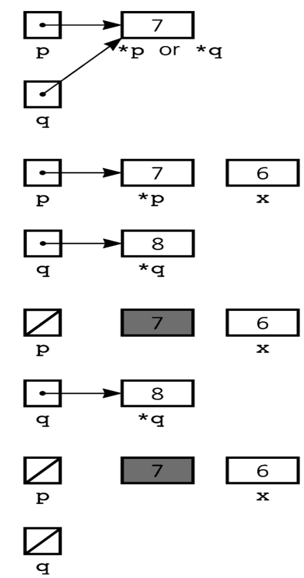
Pointers

(f) `q = p;`

(g) `q = new int;`
    `*q = 8;`

(h) `p = NULL;`

(i) `delete q;`
    `q = NULL;`



Best Practices

- Memory allocated using *new* should be deallocated using *delete*
  - destructor is a good place to deallocate memory
  - implicitly called once object goes *out of scope*
  - can also be called explicitly when object no longer needed
- Do not call *delete* again to de-allocate same memory
  - usually happened unintentionally!
- Do not call delete on a pointer
  - that is not initialized or is NULL,
  - that is pointing to a variable not allocated using *new*

Dynamic Allocation of Arrays

- Use "new" operator to allocate array dynamically

  int arraySize = 50;

  *double *anArray = new double[arraySize];*
- *delete[]* to release array memory

  delete[] anArray;
- The size of a dynamically allocated array can be increased

  *double *oldArray = anArray;*

  *anArray = new double[2*arraySize];*

Arrays and Pointers

- Array name is a pointer to array's first element
- Pointer variable assigned to an array name can be used just like an array

```
int arr[100], *ip;
ip = arr;
for(i=0 ; i<100 ; i++)
   ip[i] = arr[i]+1; // ip and arr are aliased
```

- ip[i], arr[i], *(ip+i) all point to the same location.

Linked List?

- Options for implementing an ADT List
  - Array has a fixed size
    - Data must be shifted during insertions and deletions
  - Linked list is able to grow in size as needed
    - Does not require the shifting of items during insertions and deletions

Linked List ?

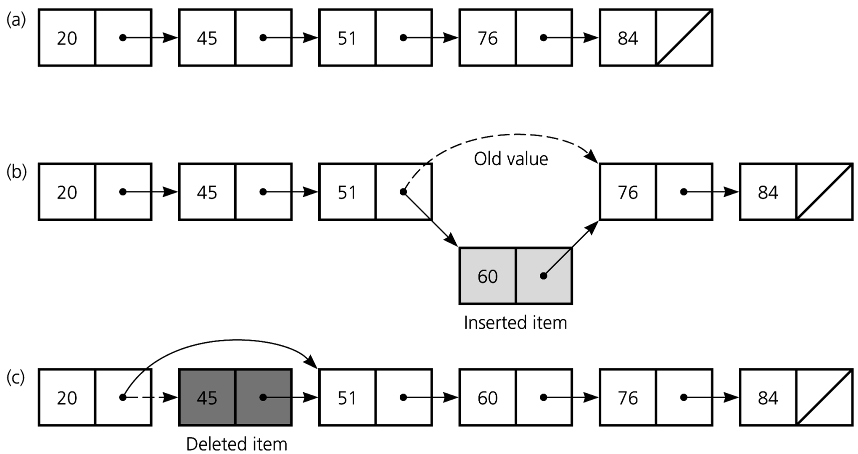
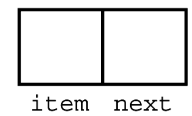


Figure 4-1 *(a) A linked list of integers; (b) insertion; (c) deletion*

Pointer-Based Linked Lists

- A node in a linked list is usually a `struct`

```
struct Node
{ int  item
  Node *next;
}; // end Node
```



- The head pointer points to the first node in a

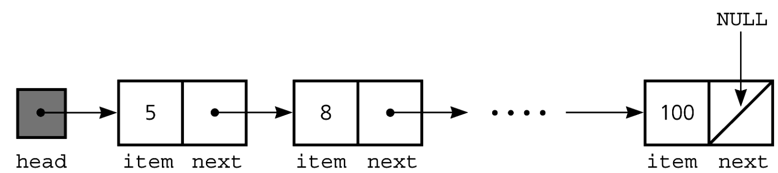


Figure 4-7 A head pointer to a list

Pointer-Based Linked Lists

- If head is *NULL*, the linked list is empty
- A node is dynamically allocated

```
Node *p;        // pointer to node
p = new Node;  // allocate node
```


Displaying the Contents of a Linked List

- Reference a node member with the -> operator
  `p->item`
- Visits each node in the linked list
  - pointer variable `cur` keeps track of current node

```
for (Node *cur = head; cur != NULL;
     cur = cur->next)
    cout << cur->item << endl;
```

Displaying the Contents of a Linked List

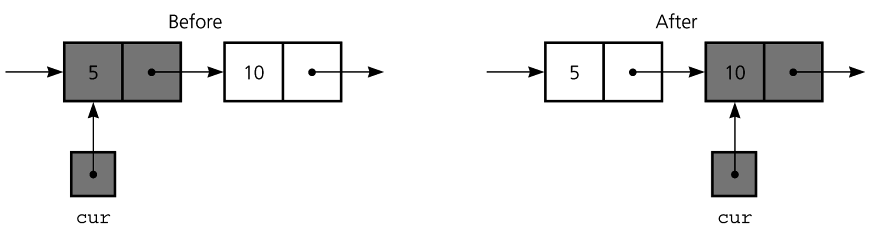


Figure 4-9

The effect of the assignment ***cur = cur->next***

Deleting a Specified Node from a Linked List

- Deleting an interior node

```
prev->next = cur->next;
```

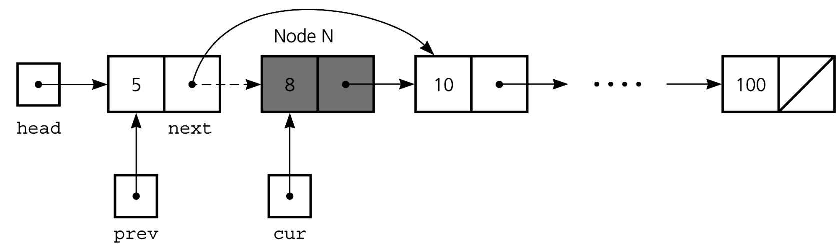


Figure 4-10 Deleting a node from a linked list

Deleting the First Node from a Linked List

- Deleting the first node

```
head = head->next;
```

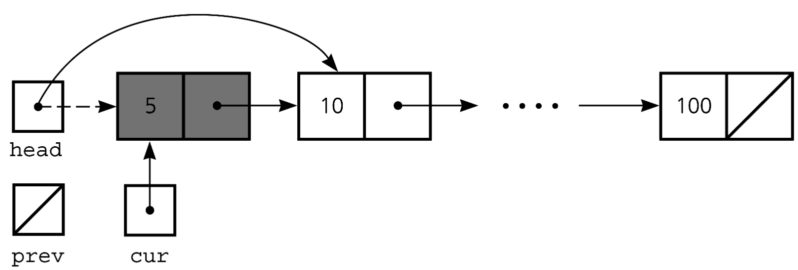


Figure 4-11 Deleting the first node

Inserting a Node into a Specified Position of a Linked List

- To insert a node between two nodes

```
newPtr->next = cur;
prev->next = newPtr;
```

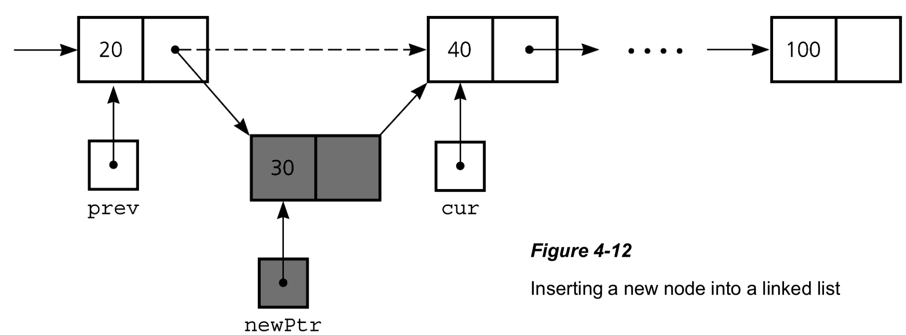


Figure 4-12

Inserting a new node into a linked list

Inserting a Node at the Beginning of a Linked List

- To insert a node at the beginning of a linked list

```
newPtr->next = head;
head = newPtr;
```

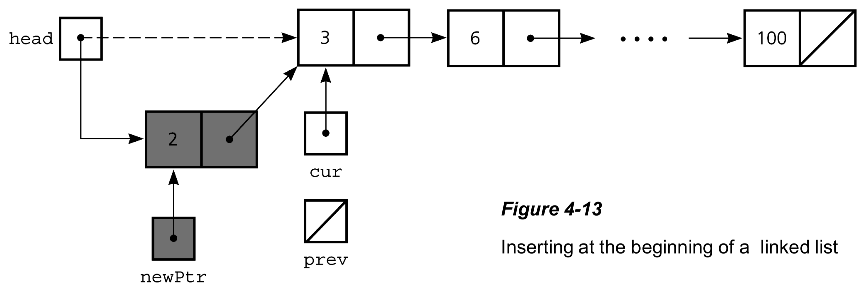


Figure 4-13

Inserting at the beginning of a linked list

Inserting a Node into a Specified Position of a Linked List

- Finding the point of insertion or deletion for a sorted linked list of objects

```
 Node *prev, *cur;
for (prev = NULL, cur = head;
     (cur != NULL)&&(newValue > cur->item);
      prev = cur, cur = cur->next);
```


A Pointer-Based Implementation of the ADT List

- Public methods
  - `isEmpty`
  - `getLength`
  - `insert`
  - `remove`
  - `retrieve`
- Private method
  - `find`
- Private data members
  - `head`
  - `size`
- Local variables to methods
  - `cur`
  - `prev`

see C4-ListP.cpp

Constructors and Destructors

- Default constructor initializes `size` and `head`
- A destructor is required for de-allocating dynamically allocated memory
  - else, we will have a memory leak!

```
List::~List()
{
    while (!isEmpty())
        remove(1);
}   // end destructor
```

Constructors and Destructors

- Copy constructor creates a deep copy
  - copies size, head, and the linked list
  - the copy of head points to the copied linked list
- In contrast, a shallow copy
  - copies size and head
  - the copy of head points to the original linked list
- If you omit a copy constructor, the compiler generates one
  - but it is only sufficient for implementations that use statically allocated arrays

Shallow Copy vs. Deep Copy

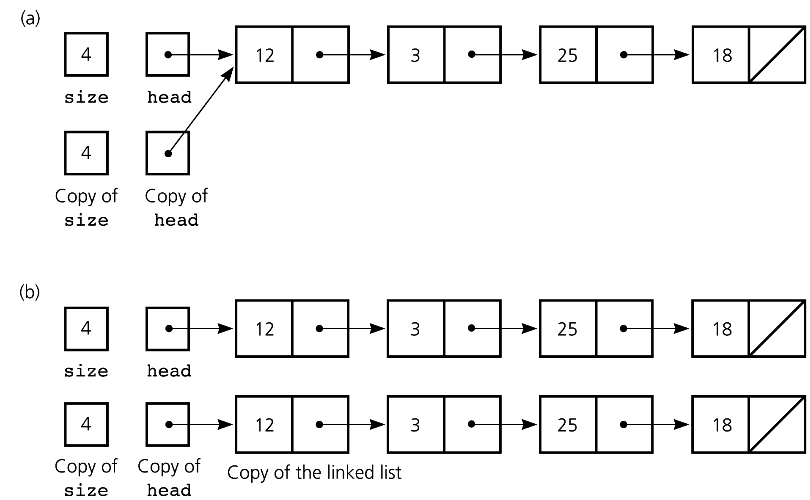


Figure 4-18 Copies of the linked list in Figure 4-17; (a) a shallow copy; (b) a deep copy

Comparing Array-Based and Pointer-Based Implementations

- Size
  - increasing the size of a resizable array can waste storage and time
  - linked list grows and shrinks as necessary
- Storage requirements
  - array-based implementation requires less memory than a pointer-based one for each item in the ADT

Comparing Array-Based and Pointer-Based Implementations

- Retrieval
  - the time to access the ith item
    - Array-based: Constant (independent of i)
    - Pointer-based: Depends on i
- Insertion and deletion
  - Array-based: Requires shifting of data
  - Pointer-based: Requires a traversal

Passing a Linked List to a Method

- A method with access to a linked list's head pointer has access to the entire list
- Pass the head pointer to a method as a reference argument
  - Enables method to change value of the head

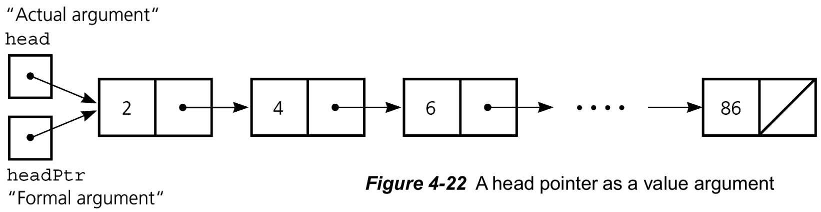


Figure 4-22 A head pointer as a value argument

Processing Linked Lists Recursively

- Recursive strategy to display a list
  - write the first item in the list
  - write the rest of the list (a smaller problem)
- Recursive strategies to display a list backward
  - write the list minus its first item backward
  - write the first item in the list
- Recursive view of a sorted linked list
  - The linked list to which `head` points is a sorted list if
    - `head` is *NULL or*
    - `head->next` is *NULL or*
    - `head->item < head->next->item`, and `head->next` points to a sorted linked list

see C4-ListP.cpp

Objects as Linked List Data

- Data in a node of a linked list can be an instance of a class

```
typedef ClassName ItemType;
struct Node
{  ItemType item;
   Node *next;
}; //end struct
Node *head;
```


Consts and References

- "Const" keyword is often used in C++
  - const int val = 100;
  - const int *ptr = &val;
  - const int * const ptr = &val;
  - void List::method() const;
- Reference variables
  - used for passing arguments to methods by *reference*
  - changes made within the method reflected in caller

see C4-RefVar.cpp

Variations: Circular Linked Lists

- Last node points to the first node
- Every node has a successor
- No node in a circular linked list contains NULL

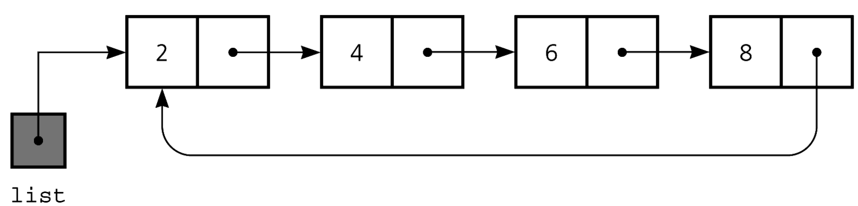


Figure 4-25 A circular linked list

Variations: Circular Linked Lists

- Access to last node requires a traversal
- Make external pointer point to last instead of first node
  – to access both first and last nodes without a traversal

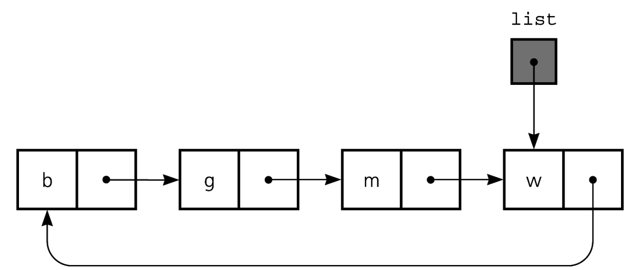


Figure 4-26 A circular linked list with an external pointer to the last node

Variations: Dummy Head Nodes

- Dummy head node
  – always present, even when the linked list is empty
  – insertion and deletion algorithms initialize prev to point to the dummy head node, rather than to NULL
    - eliminates special case for head node

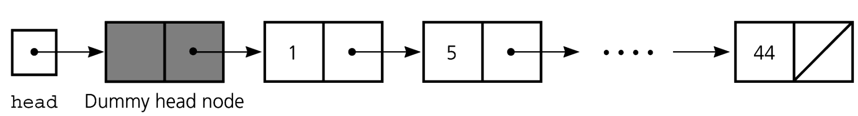


Figure 4-27 A dummy head node

Variations: Doubly Linked Lists

- Each node points to both its predecessor and its successor
- Circular doubly linked list with dummy head node
  – precede pointer of the dummy head node points to the last node
  – next pointer of the last node points to the dummy head node

Variations: Doubly Linked Lists

- To delete the node to which `cur` points

```
(cur->precede)->next = cur->next;
(cur->next)->precede = cur->precede;
```

- To insert a new node pointed to by `newPtr` before the node pointed to by `cur`

```
newPtr->next = cur;
newPtr->precede = cur->precede;
cur->precede = newPtr;
newPtr->precede->next = newPtr;
```


Variations: Doubly Linked Lists

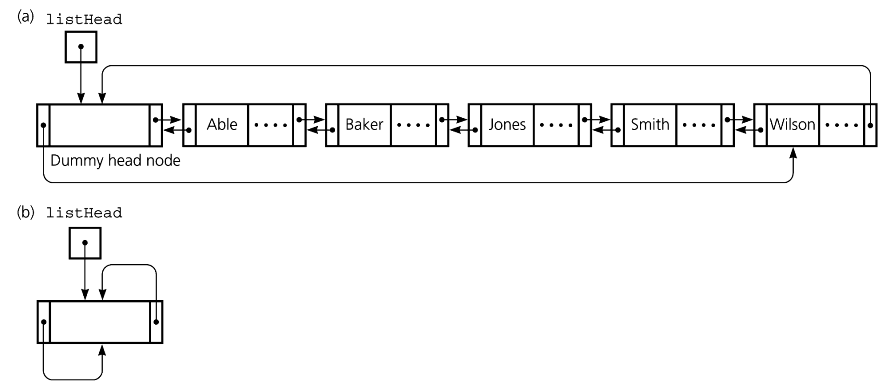


Figure 4-29 (a) A circular doubly linked list with a dummy head node
(b) An empty list with a dummy head node

The C++ Standard Template Library

- The STL contains class templates for some common ADTs, including the list class
- The STL provides support for predefined ADTs through three basic items
  - Containers
    - Objects that hold other objects
  - Algorithms
    - That act on containers
  - Iterators
    - Provide a way to cycle through the contents of a container

Summary

- The C++ new and delete operators enable memory to be dynamically allocated and recycled
- Using static ‘arrays’ Vs dynamic ‘lists’
- A class that allocates memory dynamically needs an explicit copy constructor and destructor
  - compiler provides shallow copy constructor by default
- In a doubly linked list, each node points to both its successor and predecessor