COMPREHENSIVE EDITION

PROGRAMMING AND PROBLEM SOLVING WITH C++

SIXTH EDITION

Nell Dale and Chip Weems

Chapter 13

Applied Arrays: Lists and Strings

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Chapter 13 Topics

- Meaning of a List
- Insertion and Deletion of List Elements
- Selection Sort of List Elements
- Insertion and Deletion using a Sorted List
- Binary Search in a Sorted List
- Order of Magnitude of a Function
- Declaring and Using C Strings
- Using `typedef` with Arrays

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What is a List?

- A **list** is a variable-length, linear collection of homogeneous elements
- **Linear** means that each list element (except the first) has a unique predecessor, and each element (except the last) has a unique successor

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4 Basic Kinds of ADT Operations

- **Constructors** -- create a new instance (object) of an ADT
- **Transformers** -- change the state of one or more of the data values of an instance
- **Observers** -- allow client to observe the state of one or more of the data values of an instance without changing them
- **Iterators** -- allow client to access the data values in sequence

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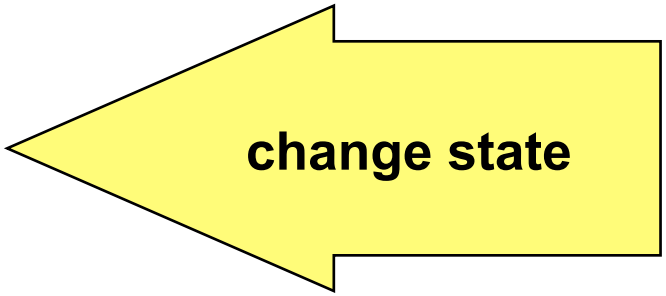
ADT List Operations

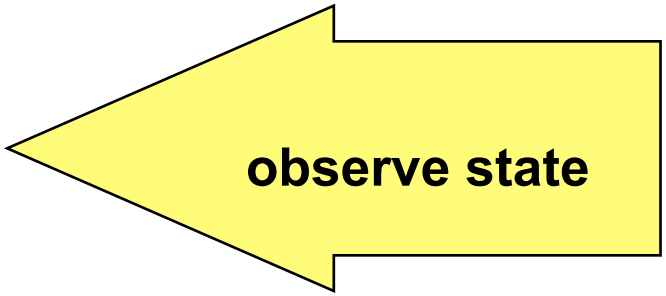
Transformers

- Insert
- Delete
- Sort



Observers

- IsEmpty
- IsFull
- Length
- IsPresent



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ADT List Operations

Iterator

- Reset
- GetNextItem

- Reset prepares for the iteration
- GetNextItem returns the next item in sequence
- No transformer can be called between calls to GetNextItem *(Why?)*

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ADT Unsorted List Data Components

length — number of elements in list

`data[0.. MAX_LENGTH -1]` — array of list elements

`currentPos` — used in iteration

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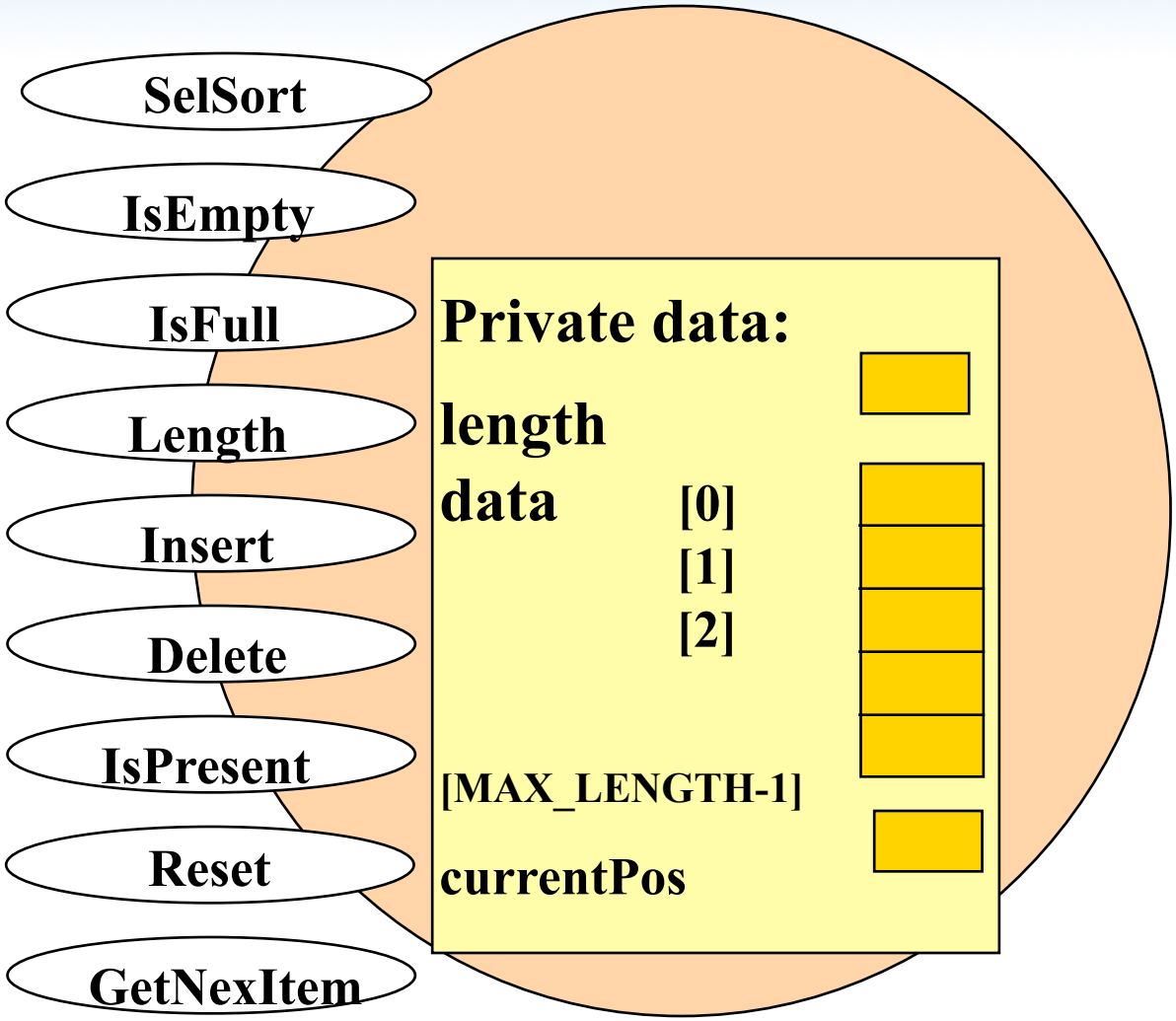
Array-based class List



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```
// Specification file array-based list ("list.h")
const  int  MAX_LENGTH  =  50;
typedef int   ItemType;

class  List                // Declares a class data type
{
public:                    // Public member functions

    List();                // constructor
    bool IsEmpty () const;
    bool IsFull ()  const;
    int  Length ()  const; // Returns length of list
    void Insert (ItemType  item);
    void Delete (ItemType  item);
    bool IsPresent(ItemType  item)  const;
    void SelSort ();
    void Reset ();
    ItemType GetNextItem ();
```

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```
private:            // Private data members
    int length; // Number of values currently stored
    ItemType data[MAX_LENGTH];
    int  CurrentPos;  // Used in iteration
};
```

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Sorted and Unsorted Lists

UNSORTED LIST	SORTED LIST
Elements are placed into the list in no particular order	List elements are in sorted in some way -- either numerically or alphabetically

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```
// Implementation file array-based list
// ("list.cpp")

#include  "list.h"
#include  <iostream>

using namespace std;

int  List::Length ()  const
// Post: Return value is length
{
    return  length;
}
```

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```
bool  List::IsFull ()  const
// Post: Return value is true
//       if length is equal
//  to MAX_LENGTH and false otherwise
{
    return (length == MAX_LENGTH);
}
```

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```
List::List ()
// Constructor
// Post: length == 0
{
    length = 0;
}

void  List::Insert (/* in */  ItemType  item)
// Pre: length < MAX_LENGTH && item is assigned
// Post: data[length@entry] == item &&
//       length == length@entry + 1
{
    data[length] = item;
    length++;
}
```

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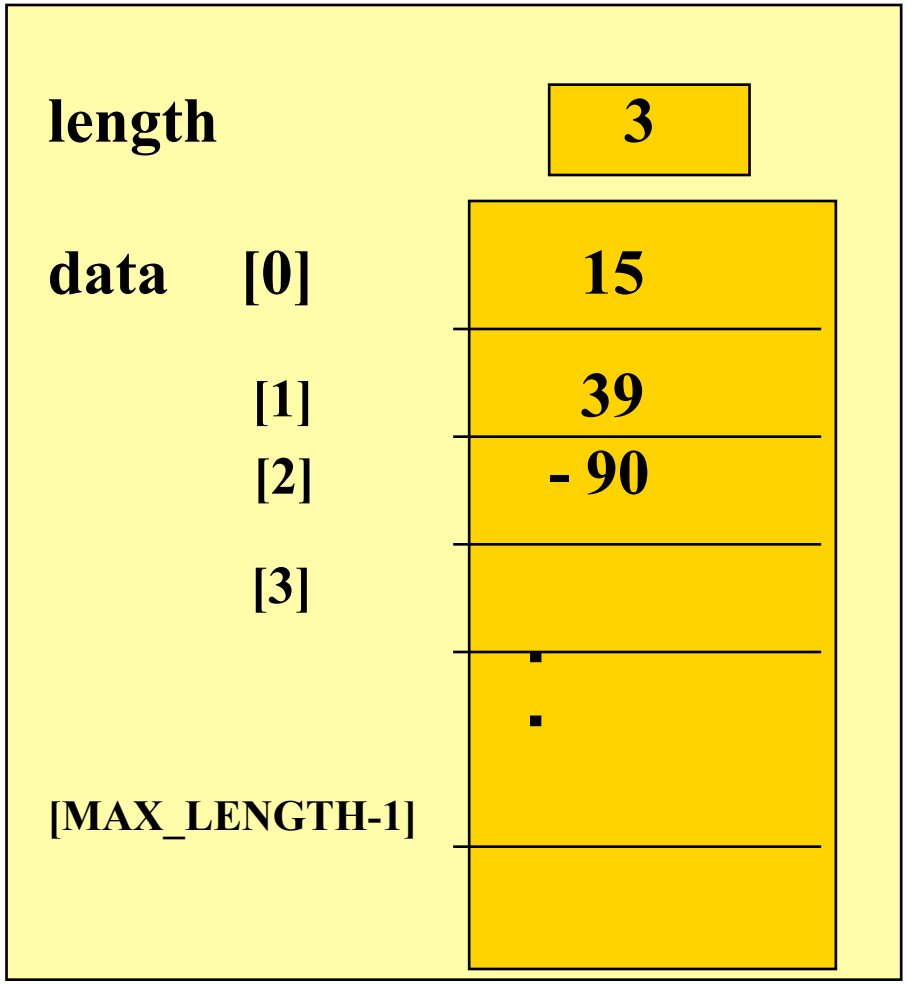
Before Inserting 64 into an Unsorted List



The item will be placed into the length location, and length will be incremented

item 64

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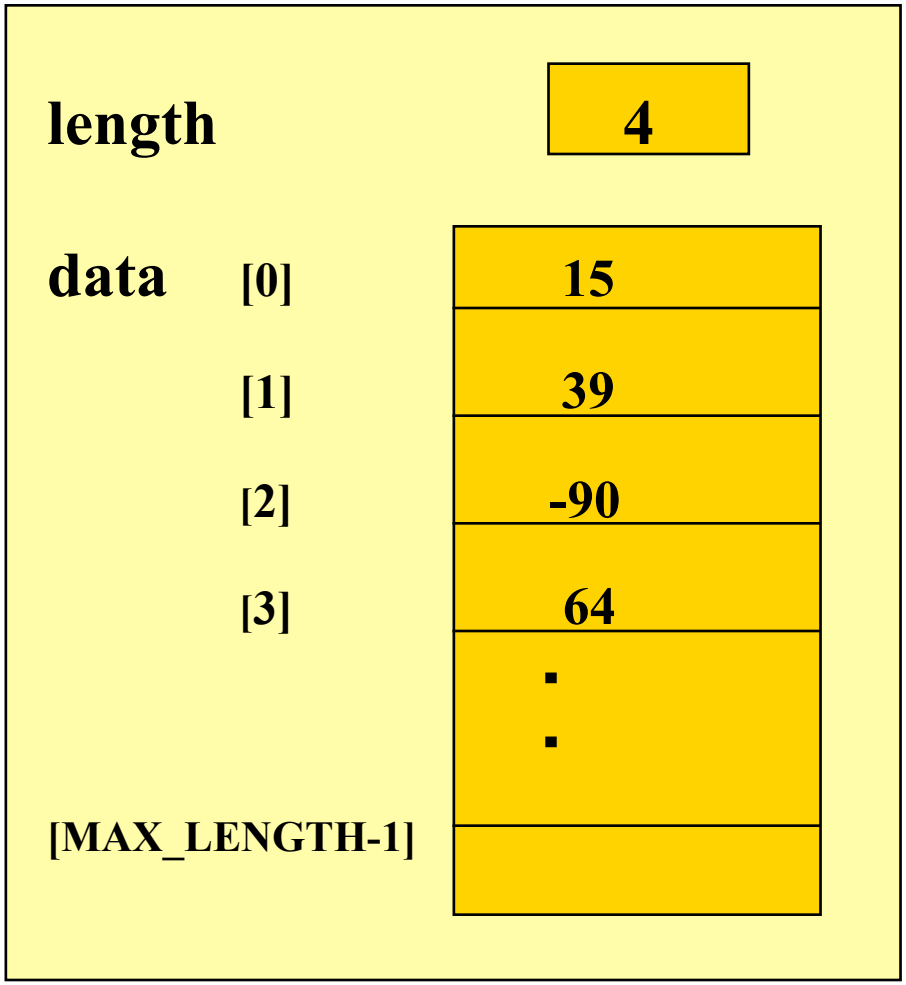
After Inserting 64 into an Unsorted List



The item will be placed into the length location, and length will be incremented

item 64

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```
bool  List::IsEmpty ()  const
// Post: Return value is true if length is equal
//  to zero and false otherwise
{
    return (length == 0);
}
```

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```
bool List::IsPresent( /* in */ ItemType item)
  const
// Searches the list for item, reporting
//   whether found
// Post: Function value is true, if item is in
//   data[0 . . length-1] and is false otherwise
{
    int index  =  0;
    while (index < length && item != data[index])
        Index++;
    return  (index < length);
}
```

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```
void  List::Delete ( /* in */  ItemType  item)
// Pre: length > 0  &&  item is assigned
// Post: IF item is in data array at entry
//    First occurrence of item is no longer
//    in array
//       && length == length@entry - 1
//    ELSE
//        length and data array are unchanged
```

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```
{
    int  index  =  0;

    while (index < length  &&
           item != data[index])
        index++;
    // IF item found, move last element into
    //  item's place
    if (index < length)
    {
        data[index] = data[length - 1];
        length--;
    }
}
```

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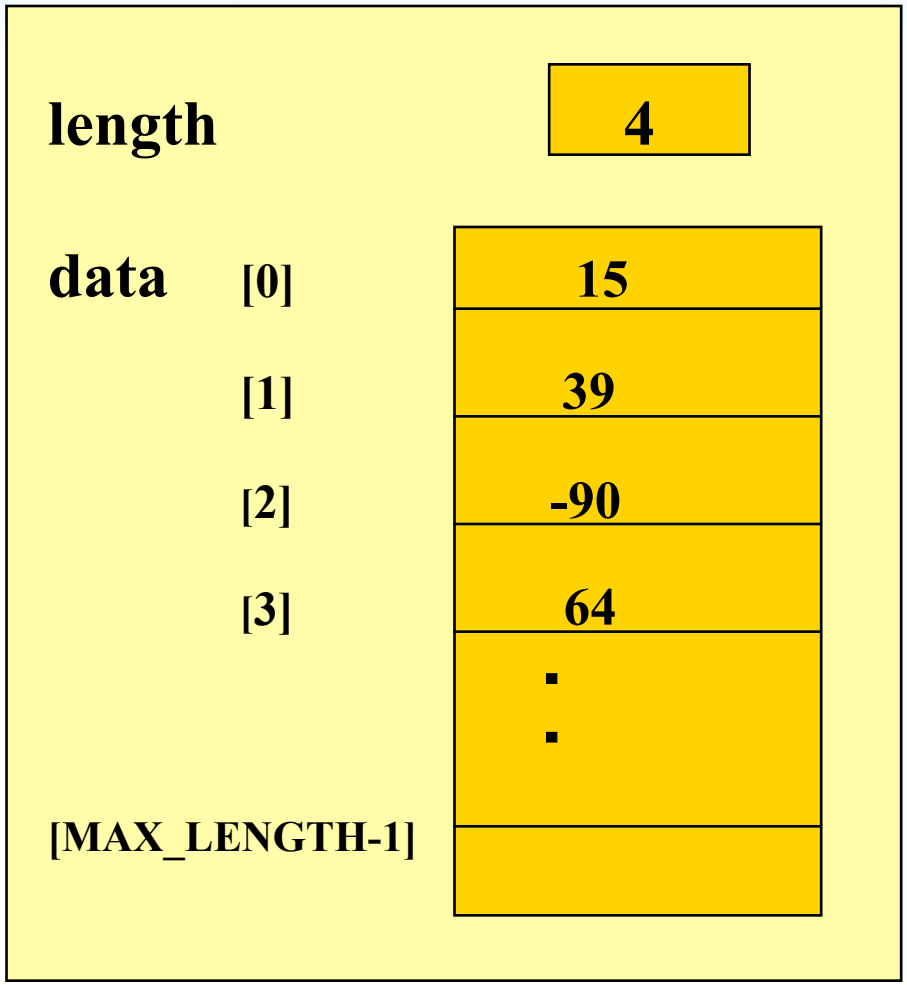
Deleting 39 from an Unsorted List



index: 0

39 has not been matched

item 39

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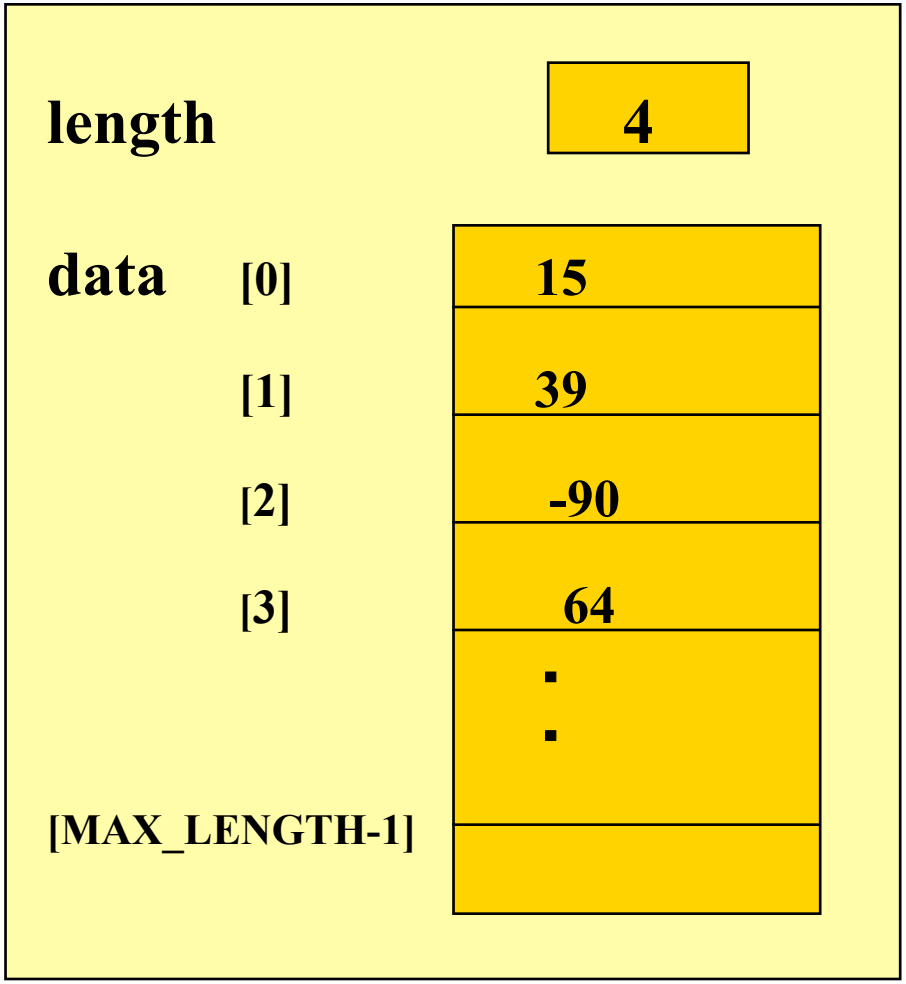
Deleting 39 from an Unsorted List



index: 1

39 has been matched

item 39

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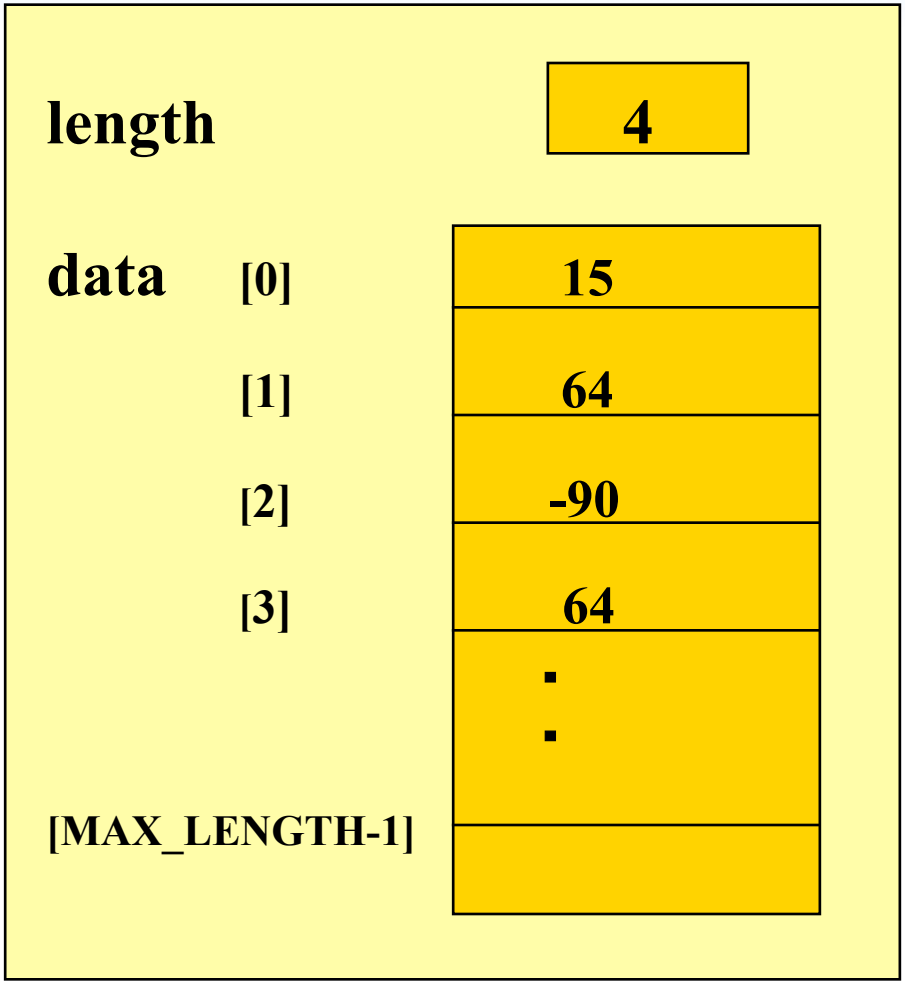
Deleting 39 from an Unsorted List



index: 1

Placed copy of last list element into the position where 39 was before

item 39

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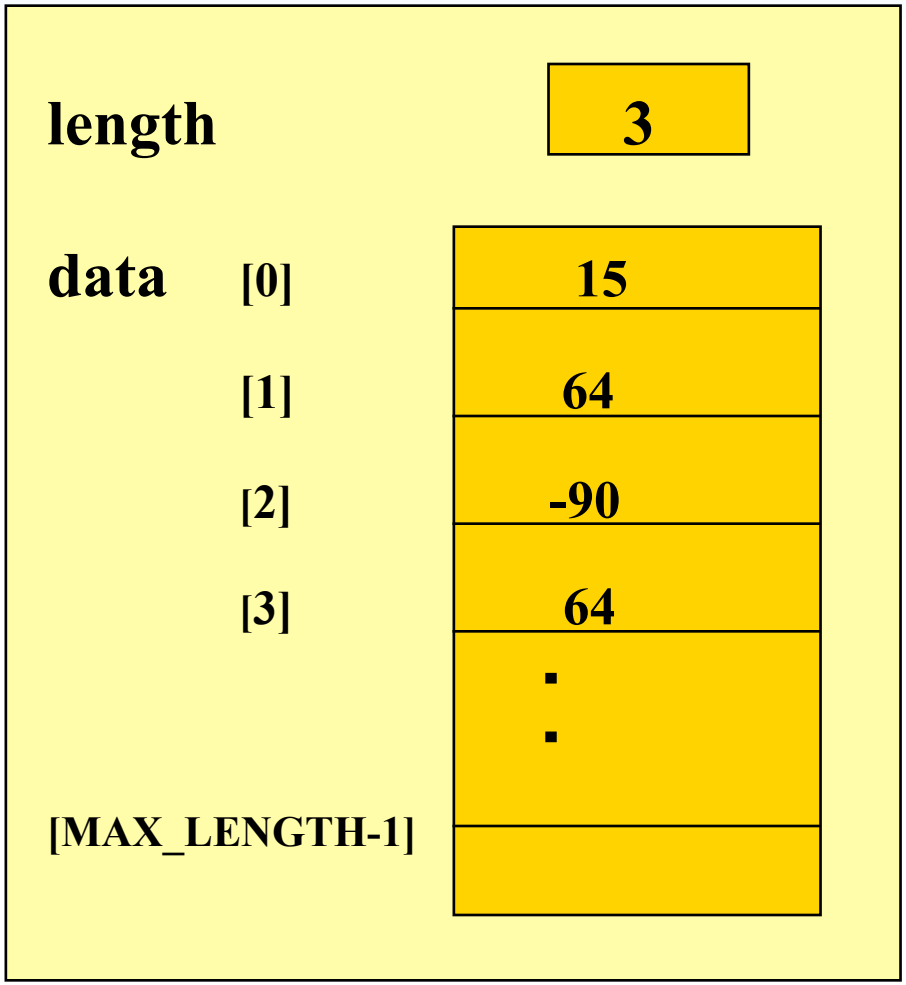
Deleting 39 from an Unsorted List



index: 1

Decremented length

item 39

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Preparing for Iteration

What should currentPos be initialized to in order to access the first item?

```
void List::Reset()
// Post: currentPos has been initialized.
 {
     currentPos = 0;
 }
```

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Iteration Operator

```
ItemType GetNextItem ()
// Pre: No transformer has been executed since last call
// Post:Return value is currentPos@entry
//   Current position has been updated
//   If last item returned, next call returns first item
{
    ItemType item;
    item = data[currentPos];
    if (currentPos == length - 1)
        currentPos = 0;
    else
        currentPos++;
    return item;
}
```

Iteration Operator

```
{
    ItemType item;
    item = data[currentPos];
    if (currentPos == length - 1)
        currentPos = 0;
    else
        currentPos++;
    return item;
}
```

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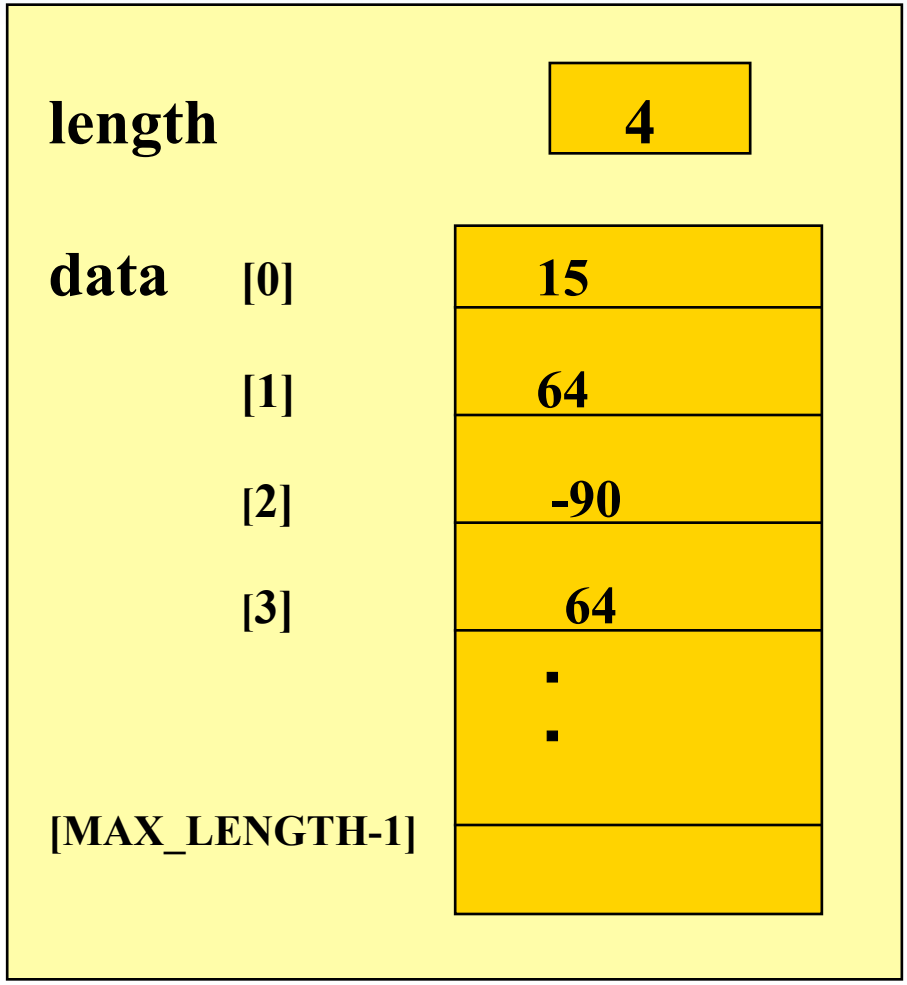
Reset



currentPos: 0

item ?

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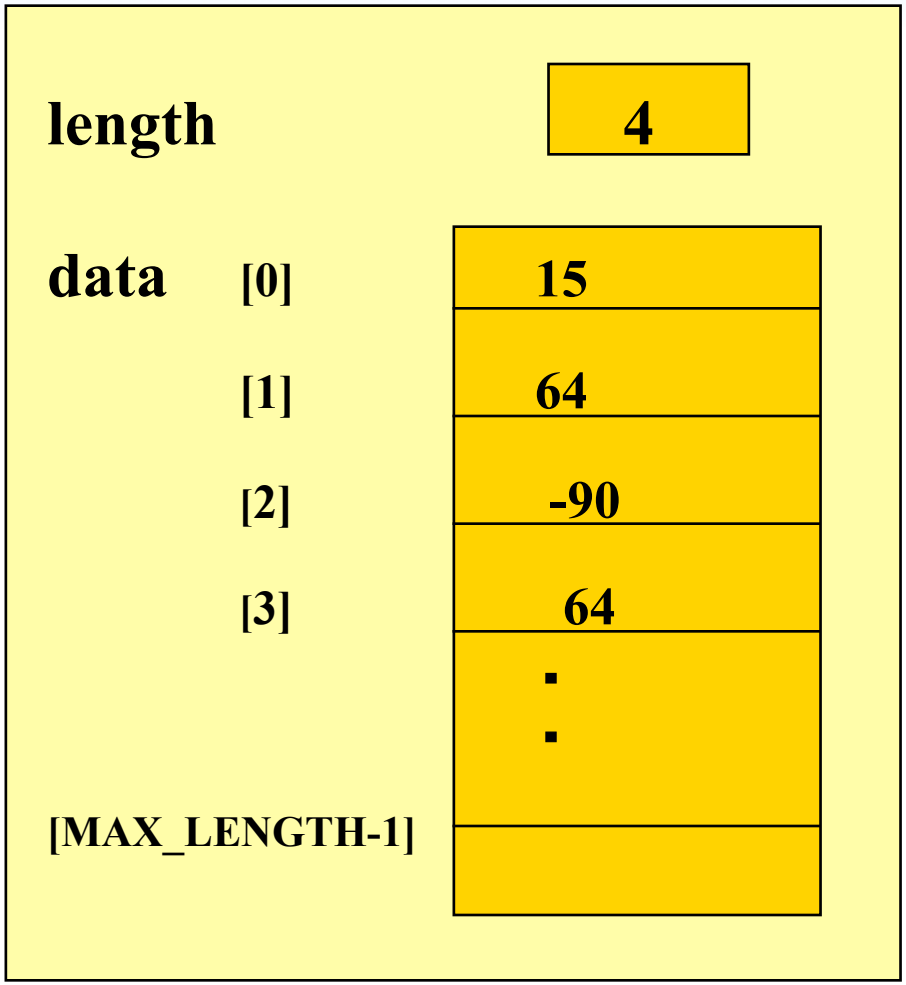
GetNextItem



currentPos: 1

currentPos is incremented
item is returned

item 15

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Selection Sort Process

Selection sort

- Examines the entire list to select the smallest element
- Places that element where it belongs (with array subscript 0)
- Examines the remaining list to select the smallest element from it

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Selection Sort Process, cont...

- Places that element where it belongs (with array subscript 1)
- Examines the last 2 remaining list elements to select the smallest one
- Places that element where it belongs in the array

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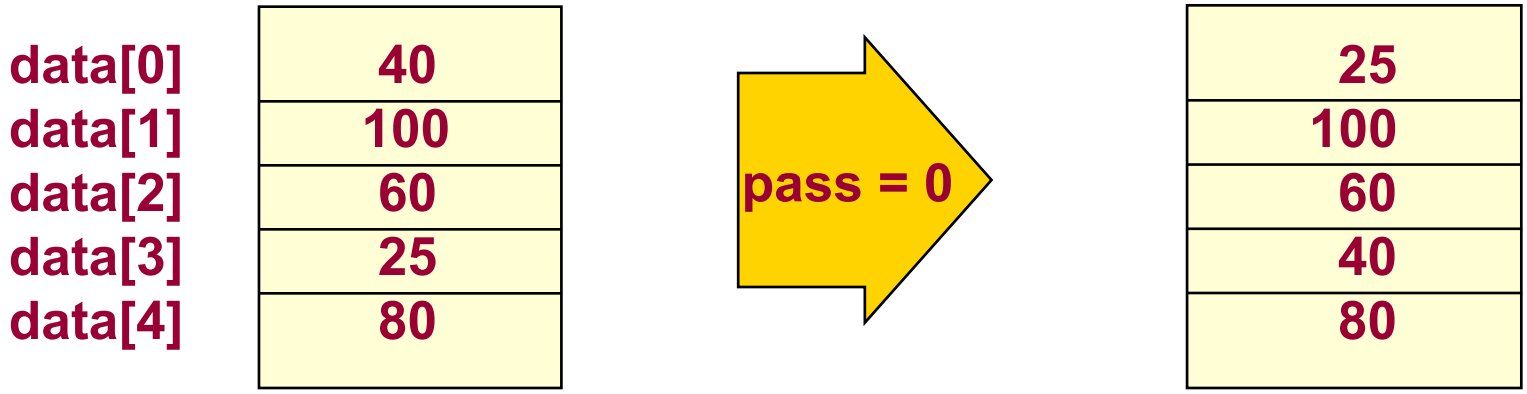
Selection Sort Algorithm

FOR passCount going from 0 through length - 2
Find minimum value in data[passCount . . length-1]
Swap minimum value with data[passCount]

length = 5



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```
void  List::SelSort ()
// Sorts list into ascending order
{
    ItemType temp;
    int passCount;
    int sIndx;
    int minIndx; // Index of minimum so far
```

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```
for (passCount = 0; passCount < length - 1;
        passCount++)
    {
        minIndx = passCount;
        // Find index of smallest value left
        for (sIndx = passCount + 1;
              sIndx <  length; sIndx++)
            if (data[sIndx] = data[minIndx])
                minIndx = sIndx;
        temp = data[minIndx];       // Swap
        data[minIndx] = data[passCount];
        data[passCount] = temp;
    }
}
```

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Recall:
Sorted and Unsorted Lists

UNSORTED LIST	SORTED LIST
Elements are placed into the list in no particular order	List elements are ordered in some way -- either numerically or alphabetically

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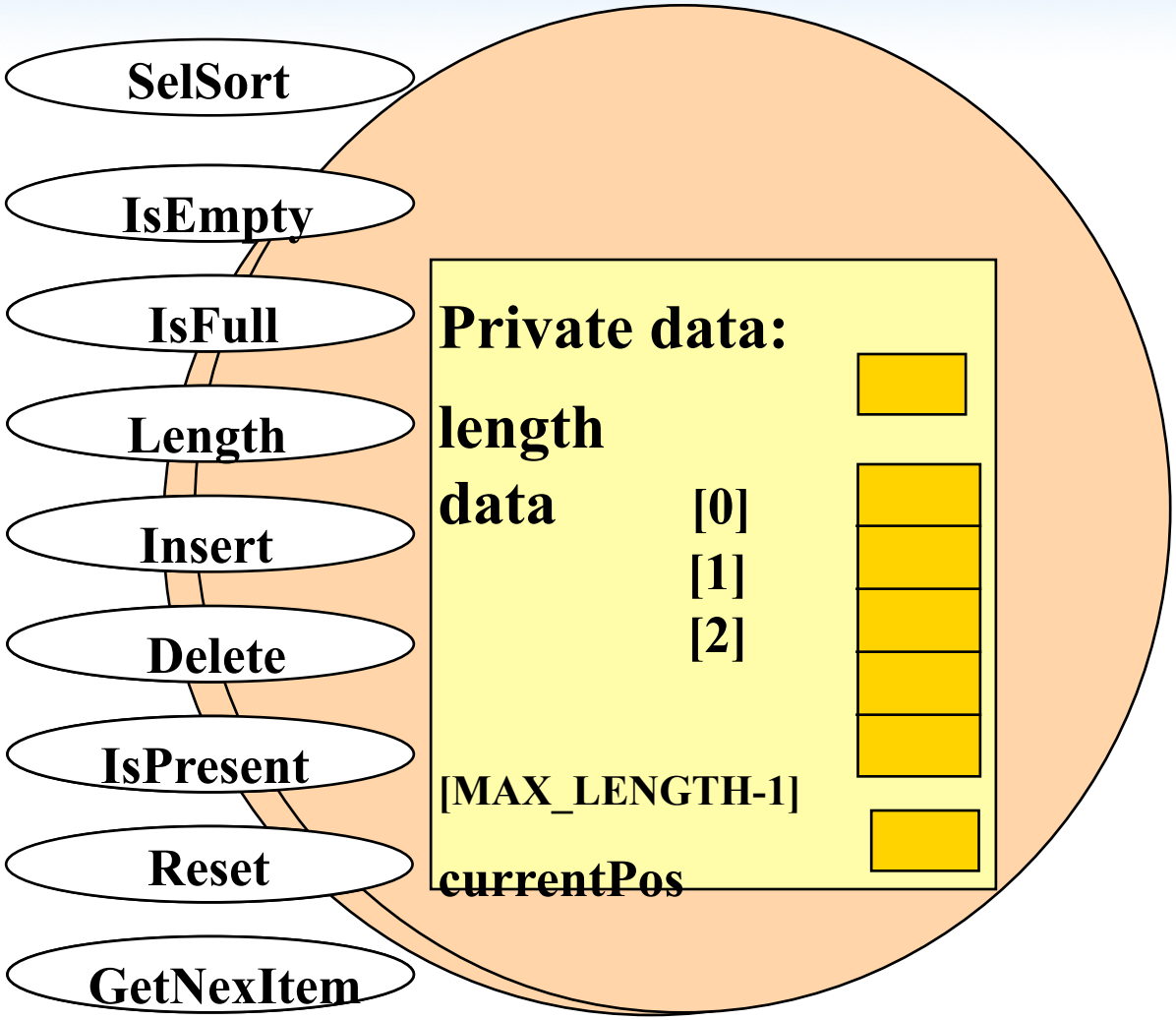
Array-based class SortedList



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```
// Specification file sorted list (“slist.h”)
const  int  MAX_LENGTH  =  50;
typedef int   ItemType;

class SortedList       // Declares a class data type
{
public:                // Public member functions

    List();            // constructor
    bool IsEmpty () const;
    bool IsFull ()  const;
    int  Length ()  const; // Returns length of list
    void Insert (ItemType  item);
    void Delete (ItemType  item);
    bool IsPresent(ItemType  item)  const;
    void SelSort ();
    void Reset ();
    ItemType GetNextItem ();
```

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```
private: // Private data members
    // Number of values currently stored
    int length;
    ItemType data[MAX_LENGTH];
    int  CurrentPos;  // Used in iteration
};
```

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```
//  SPECIFICATION FILE     ARRAY-BASED SORTED LIST
      (slist.h)
const  int  MAX_LENGTH  =  50;
typedef   int   ItemType;

class  SortedList
{
public: // public member functions
   SortedList ();  // constructor
   bool IsEmpty () const;
   bool IsFull ()  const;
   int  Length ()  const; // returns length of list
   void Insert (ItemType  item);
   void Delete (ItemType  item);
   bool IsPresent(ItemType  item)  const;
   void Print ();
```

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```
private: //  private data members

  int length; // number of values currently stored
  ItemType  data[MAX_LENGTH];
  void   BinSearch ( ItemType item, bool& found, int&
  position) const;
};
```

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Member Functions

Which member function specifications and implementations must change to ensure that any instance of the SortedList ADT remains sorted at all times?

- **Insert**
- **Delete**

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Insert Algorithm for SortedList ADT

- **Create space** for the new item by shifting down all the larger list elements
- **Put** the new item in the list
- **Increment** length

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Implementing `SortedList` Member Function `Insert`

```
// Implementation file ("slist.cpp")

void SortedList::Insert (/* in */  ItemType  item)
// Pre: length < MAX_LENGTH && item is assigned
//     && data[0 . . length-1] are in
//     ascending order
```

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Implementing `SortedList` Member Function `Insert`

```
// Post: item is in the list && length ==
//    length@entry + 1 && data[0 . . length-1] are
//    in ascending order
{
            .
            .
            .

}
```

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```
void  SortedList::Insert (ItemType  item)
{
    int index;
    // Find proper location for new element
    index  =  length - 1;
    // Starting at bottom of array shift down
    //  values larger than item to make room for
    //  new item
```

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```
while (index >= 0  &&  item < data[index] )
    {
        data[index + 1]  =  data[index];
        index--;
     }
    // Insert item into array
    data[index] = item;
    length++;
}
```

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Delete Algorithm for SortedList ADT

- **Find** the position of the element to be deleted from the sorted list
- **Eliminate** space occupied by the item being deleted by shifting up all the larger list elements
- **Decrement** length

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Implementing `SortedList` Member Function `Delete`

```
void  SortedList::Delete (/* in */  ItemType  item)
//  Deletes item from list, if it is there
//  Pre: 0 < length <= INT_MAX/2 && item is assigned
//      && data[0 . . length-1] are in ascending order
// Post: IF item is in data array at entry
//      First occurrence of item is no longer in array
//      && length == length@entry-1
//      && data[0 . . Length-1] are in ascending order
//        ELSE
//      length and data array are unchanged
{
              .
              .
              .
}
```

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Implementing `SortedList` Member Function `Delete`

```
// Post: IF item is in data array at entry
//       First occurrence of item is no longer
//       in array
//       && length == length@entry-1
//       && data[0 . . Length-1] are in
//       ascending order
//         ELSE
//       length and data array are unchanged
{
              .
              .
              .
}
```

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```
void SortedList::Delete (/* in */  ItemType  item)
{
    bool found;    // true, if item is found
    int  position; // Position of item, if found
    int  index;
    // Find location of element to be deleted
```

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```
BinSearch (item, found, position);
    if (found)
    {
      // Shift elements that follow in sorted list

        for (index = position; index < length + 1;
             index++)
            data[index ] = data[index  + 1];
         length--;
    }
}
```

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Improving Member Function `IsPresent`

Recall that with the unsorted List ADT we examined each list element beginning with data[0], until we either found:

A match with item or we had examined all the elements in the unsorted List

How can the searching algorithm be improved for SortedList ADT?

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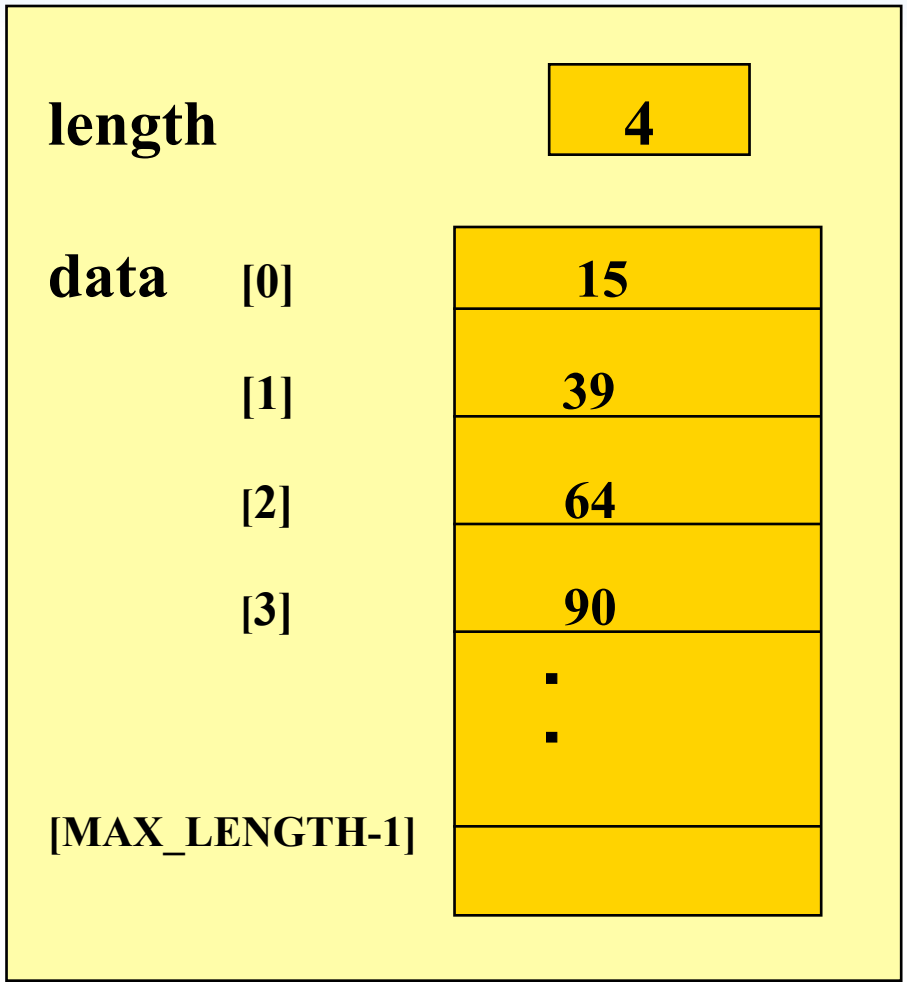
Searching for 55 in a SortedList



A sequential search for 55 can stop when 64 has been examined.

item 55

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Binary Search in SortedList

- Examines the element in the middle of the array
  - Is it the sought item? If so, stop searching
  - Is the middle element too small? Then start looking in second half of array
  - Is the middle element too large? Then begin looking in first half of the array

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Binary Search in SortedList

- Repeat the process in the half of the data that should be examined next
- Stop when item is found or when there is nowhere else to look

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```
void  SortedList::BinSearch (ItemType  item,   bool&  found,
   int&  position)
// Searches sorted list for item, returning position of item,
//  if item was found
{
    int middle;
    int first  =  0;
    int last  = length - 1;
    found = false;
```

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```
while (last >= first  &&   !found)
     {  middle = (first + last)/2; // Index of middle element

        if (item  <  data[middle])
            last = middle - 1;     // Look in first half next
        else if (item  >  data[middle])
           first = middle + 1;     // Look in second half next
        else
           found = true;           // Item  has been found
     }
     if  (found)
       position = middle;
}
```

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Trace of Binary Search

item = 84

15	26	38	57	62	78	84	91	108	119
data[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
first				middle					last

item > data[middle] → first = middle + 1

~~15~~	~~26~~	~~38~~	~~57~~	~~62~~	78	84	91	108	119
data[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
					first		middle		last

item < data[middle] → last = middle - 1

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Trace continued

item = 84

~~15~~	~~26~~	~~38~~	~~57~~	~~62~~	78	84	~~91~~	~~108~~	~~119~~
data[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]

first, middle

last

item > data[middle] → first = middle + 1

~~15~~	~~26~~	~~38~~	~~57~~	~~62~~	~~78~~	84	~~91~~	~~108~~	~~119~~
data[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]

first, last, middle

item == data[middle] → found = true

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Another Binary Search Trace

item = 45

15	26	38	57	62	78	84	91	108	119
data[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
first				middle					last

item < data[middle] → last = middle - 1

15	26	38	57	~~62~~	~~78~~	~~84~~	~~91~~	~~108~~	~~119~~
data[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
first	middle		last						

item > data[middle] → first = middle + 1

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Trace continued

item = 45

~~15~~	~~26~~	38	57	~~62~~	~~78~~	~~84~~	~~91~~	~~108~~	~~119~~
data[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]

first, middle

last

item > data[middle] → first = middle + 1

~~15~~	~~26~~	~~38~~	57	~~62~~	~~78~~	~~84~~	~~91~~	~~108~~	~~119~~
data[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]

first, middle, last

item < data[middle] → last = middle - 1

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item = 45

Trace concludes

~~15~~	~~26~~	~~38~~	~~57~~	62	78	~~84~~	~~91~~	108	119
data[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
		last	first						

first > last ⇒ found = false

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Still More Efficient `IsPresent`

```
bool  SortedList::IsPresent
  (/* in */  ItemType  item)  const
// Searches list for item, reporting whether found
// Pre: length <= INT_MAX/2 && item is assigned
//    &&  data[0 . . length-1] are in ascending order
// Post: Return value == true, if item is in
//   data[0 . . length-1] == false, otherwise
```

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Still More Efficient `IsPresent`

```
{
    bool found;
    int  position;

    BinSearch (item, found, position);

    return  found;
}
```

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Comparison of Sequential and Binary Searches

	Average Number of Iterations to Find `item`	
Length	***Sequential Search***	***Binary Search***
10	**5.5**	**2.9**
100	**50.5**	**5.8**
1,000	**500.5**	**9.0**
10,000	**5000.5**	**12.4**

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Order of Magnitude of a Function

The order of magnitude, or Big-O notation, of an expression describes the complexity of an algorithm according to the highest order of N that appears in its complexity expression

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Names of Orders of Magnitude

$O(1)$	constant time
$O(\log_2 N)$	logarithmic time
$O(N)$	linear time
$O(N^2)$	quadratic time
$O(N^3)$	cubic time

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N	$\log_2 N$	$N*\log_2 N$	N^2
1	0	0	1
2	1	2	4
4	2	8	16
8	3	24	64
16	4	64	256
32	5	160	1024
64	6	384	4096
128	7	896	16,384

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Big-O Comparison of List Operations

OPERATION	UnsortedList	SortedList
IsPresent	O(N)	O(N) sequential search $O(\log_2 N)$ binary search
Insert	O(1)	O(N)
Delete	O(N)	O(N)
SelSort	$O(N^2)$	

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In Addition . . .

To the string class from the standard library accessed by #include <string>

C++ also has another library of string functions for C strings that can be accessed by #include <cstring>

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What is a C String?

A C string is a char array terminated by the null character '\0' (with ASCII value 0)

A C string variable can be initialized in its declaration in two equivalent ways.

```
char message[8] = { 'H', 'e', 'l', 'l', 'o', '\0' };

char  message[8]  =  "Hello";
```

'H'	'e'	'l'	'l'	'o'	'\0'		
message[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]

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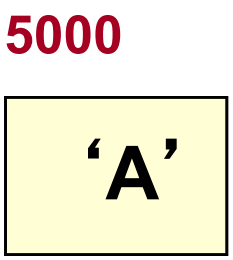
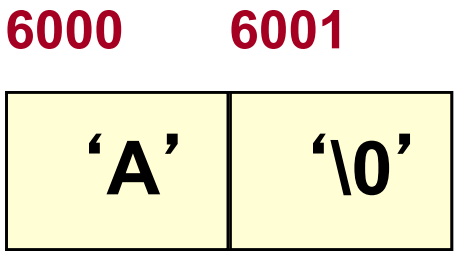
`char` vs. C string

'A' has data type `char`
and is stored in 1 byte



"A" is a C string of 2 characters
and is stored in 2 bytes



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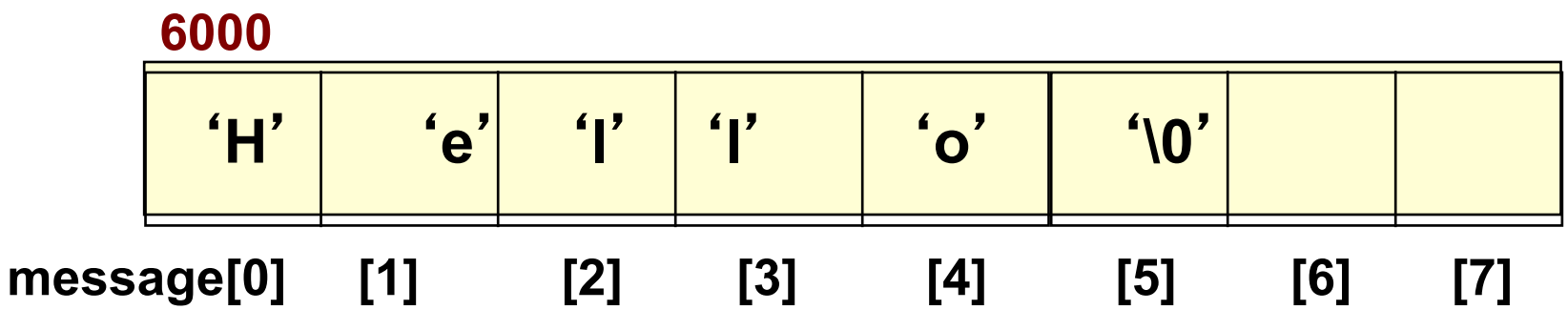
Recall that . . .

```
char message[8];
 // Declaration allocates memory
```

To the compiler, the value of the identifier message is the base address of the array. We say `message` is a pointer (because its value is an address). It "points" to a memory location.



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Aggregate C String I/O in C++

I/O of an entire C string is possible using the array identifier with no subscripts and no looping.

EXAMPLE

```
char   message[8];
cin  >>  message;
cout  <<  message;
```

However . . .

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Extraction operator >>

When using the extraction operator (>>) to read input characters into a string variable, the following things happen:

- The >> operator skips any leading whitespace characters such as blanks and newlines
- It then reads successive characters into the array

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Extraction Operator >>

- And the >> operator stops at the first trailing whitespace character (which is not consumed, but remains waiting in the input stream)
- The >> operator adds the null character to the end of the string

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Example Using >>

```
char  name[5];
cin  >>  name;
```

total number of elements in the array

Suppose input stream looks like this:

□ □ J o e □

7000

'J'	'o'	'e'	'\0'	
name[0]	name[1]	name[2]	name[3]	name[4]

null character is added

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Function `get()`

- Because the extraction operator stops reading at the first trailing whitespace, >> cannot be used to input a string with blanks in it
- If your string's declared size is not large enough to hold the input characters and add the '\0', the extraction operator stores characters into memory beyond the end of the array
- Use `get` function with two parameters to overcome these obstacles

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Example of Function `get()`

```
char  message[8];
cin.get (message, 8);
// Inputs at most 7 characters plus '\0'
```

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inFileStream.get (str, count + 1)

- `get` does not skip leading whitespace characters such as blanks and newlines

- `get` reads successive characters (including blanks) into the array

- get stops when it either has read count characters, or it reaches the newline character '\n', whichever comes first

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inFileStream.get (str, count + 1)

- `get` appends the null character to str
- If newline is reached, it is not consumed by `get`, but remains waiting in the input stream

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Function `ignore()`

- `ignore` can be used to consume any remaining characters up to and including the newline '\n' left in the input stream by `get`

```
cin.get(string1, 81);
  // Inputs at most 80 characters
  cin.ignore(30, '\n');
  // Skips at most 30 characters
  //  but stops if '\n' is read
  cin.get(string2, 81);
```

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Another Example Using `get()`

```
char  ch;
char  fullName[31];
char  address[31];
cout << "Enter your full name: ";
cin.get (fullName, 31);
cin.get (ch);  // To consume the newline
cout << "Enter your address: ";
cin.get (address, 31);
```

'N'	'e'	'l'	'l'	' '	'D'	'a'	'l'	'e'	'\0'	. . .

fullName[0]

'A'	'u'	's'	't'	'i'	'n'	' '	'T'	'X'	'\0'	. . .

address[0]

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String Function Prototypes in <cstring >

```
int   strlen (char  str[]);
//  FCTNVAL     ==  integer length of string str (not including '\0')
```

```
int   strcmp (char  str1[], char  str2[]);
//  FCTNVAL     ==  negative, if str1 precedes str2 lexicographically
//                  ==  positive, if str1 follows str2 lexicographically
//                  ==  0, if str1 and str2 characters same through '\0'
```

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String Function Prototypes in <cstring >, cont...

```
char * strcpy (char  toStr[],  char  fromStr[]);
//  FCTNVAL     ==  base address of toStr (usually ignored)
// POSTCONDITION:     characters in string fromStr are copied to
//                    string toStr, up to and including '\0',
//                    overwriting contents of string toStr
```

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```
# include  <cstring >
  .
  .
  .

 char author[21];
 int  length;

 cin.get (author, 21);
 length = strlen (author);
 // What is the value of length ?
```

5000

‘C’	‘h’	‘i’	‘p’	‘ ’	‘W’	‘e’	‘e’	‘m’	‘s’	‘\0’	. .	. .

author[0]

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```
char  myName[21] = "Huang";    // What is output?
char  yourName[21];

cout << "Enter your last name: ";
cin.get (yourName, 21);

if  (strcmp (myName, yourName) == 0)
    cout  <<  "We have the same name! ";
else if  (strcmp (myName, yourName) < 0)
    cout  <<  myName   << " comes before "
          <<  yourName;
else if  (strcmp (myName, yourName) > 0)
    cout  <<  yourName  << "comes before "
          <<  myName;
```

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myName[0]

‘H’	‘u’	‘a’	‘n’	‘g’	‘\0’					. . .

yourName[0]

‘H’	‘e’	‘a’	‘d’	‘i ‘	‘n’	‘ g’	‘t’	‘o’	‘n’	‘\0’	. . .

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```
char  myName[21] = "Huang";
char  yourName[21];

if (myName  ==  yourName)
// Compares addresses only!
//   That is, 4000 and 6000 here.
//   == does not compare contents!
{
    .
}
```

4000 myName[0]

'H'	'u'	'a'	'n'	'g'						. . .

6000 yourName[0]

'H'	'e'	'a'	'd'	'i'	'n'	'g'	't'	'o'	'n'	'\0'	. . .

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```
char  myName[21] = "Huang";
char  yourName[21];
```

```
cin.get (yourName, 21);
yourName  =  myName;
```

What happens?

4000

'H'	'u'	'a'	'n'	'g'	'\0'					. . .

myName[0]

6000

'H'	'e'	'a'	'd'	'i'	'n'	'g'	't'	'o'	'n'	'\0'	. . .

yourName[0]

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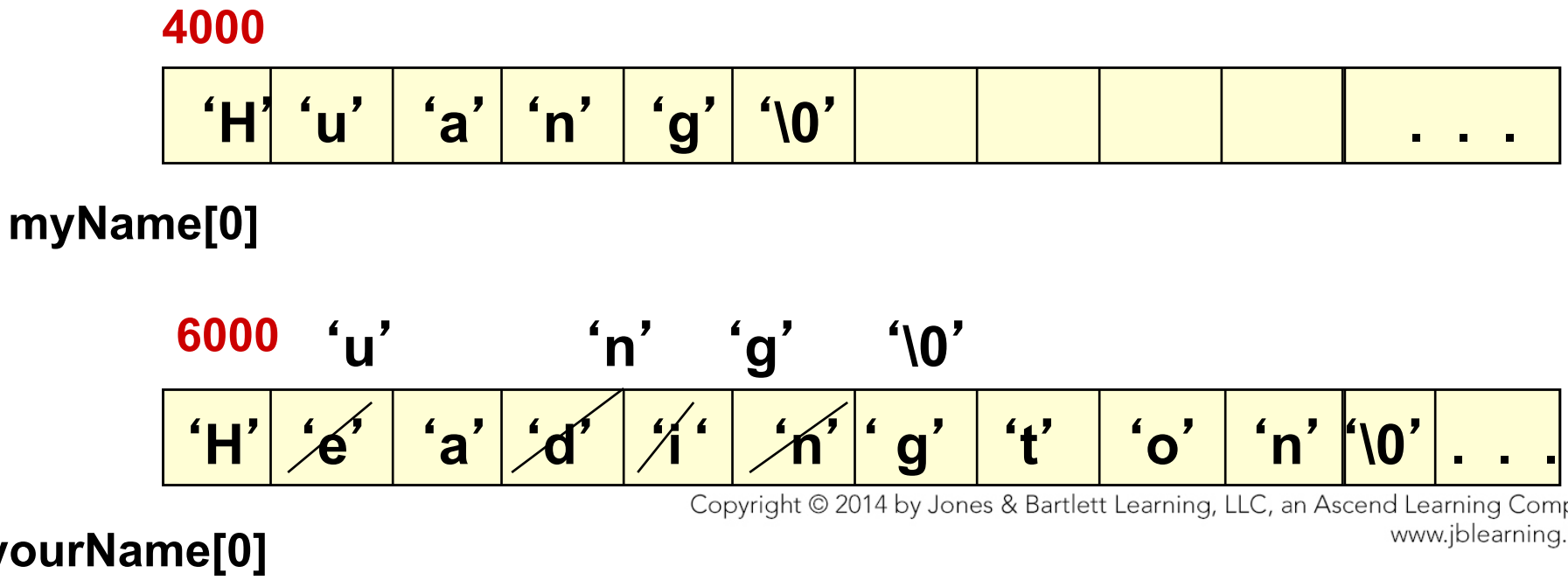
```
char  myName[21]  = "Huang";
char  yourName[21];

cin.get (yourName, 21);
strcpy (yourName, myName);
```

What happens?



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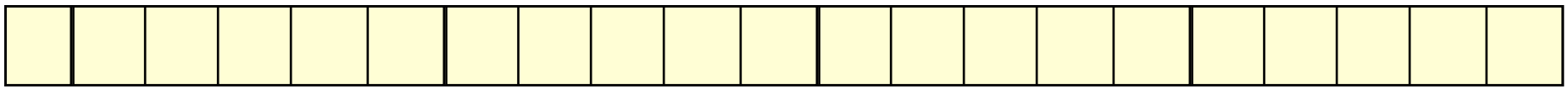
Using `typedef` with Arrays

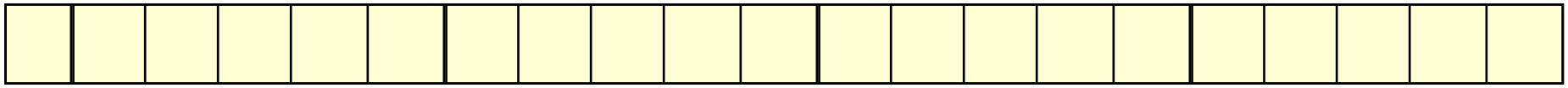
```
typedef char String20[21];
// Names String20 as an array type

String20   myName;   // These declarations allocate
String20   yourName; //  memory for three  variables
bool isSeniorCitizen;
```

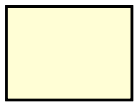
5000



6000



7000



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