ADT List

- 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

Topics

- Meaning of a List
- Insertion and Deletion of List Elements
- Selection Sort of List Elements
- Insertion and Deletion using a Sorted List

Topics

- Binary Search in a Sorted List
- Order of Magnitude of a Function
- Declaring and Using C Strings
- Using `typedef` with Arrays

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

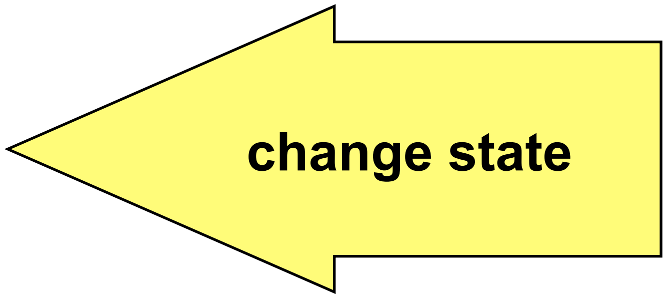
4 Basic Kinds of ADT Operations

- **Constructors** -- create a new instance (object) of an ADT
- **Mutators** -- change the state of one or more of the data values of an instance
- **Accessors**-- 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

ADT List Operations

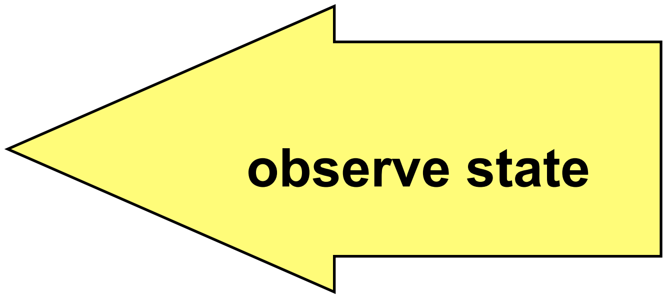
Mutators

- Insert
- Delete
- Sort



Accessors

- IsEmpty
- IsFull
- Length
- IsPresent



ADT List Operations

Iterator

- ■ Reset
- ■ GetNextItem

Access in Sequence

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

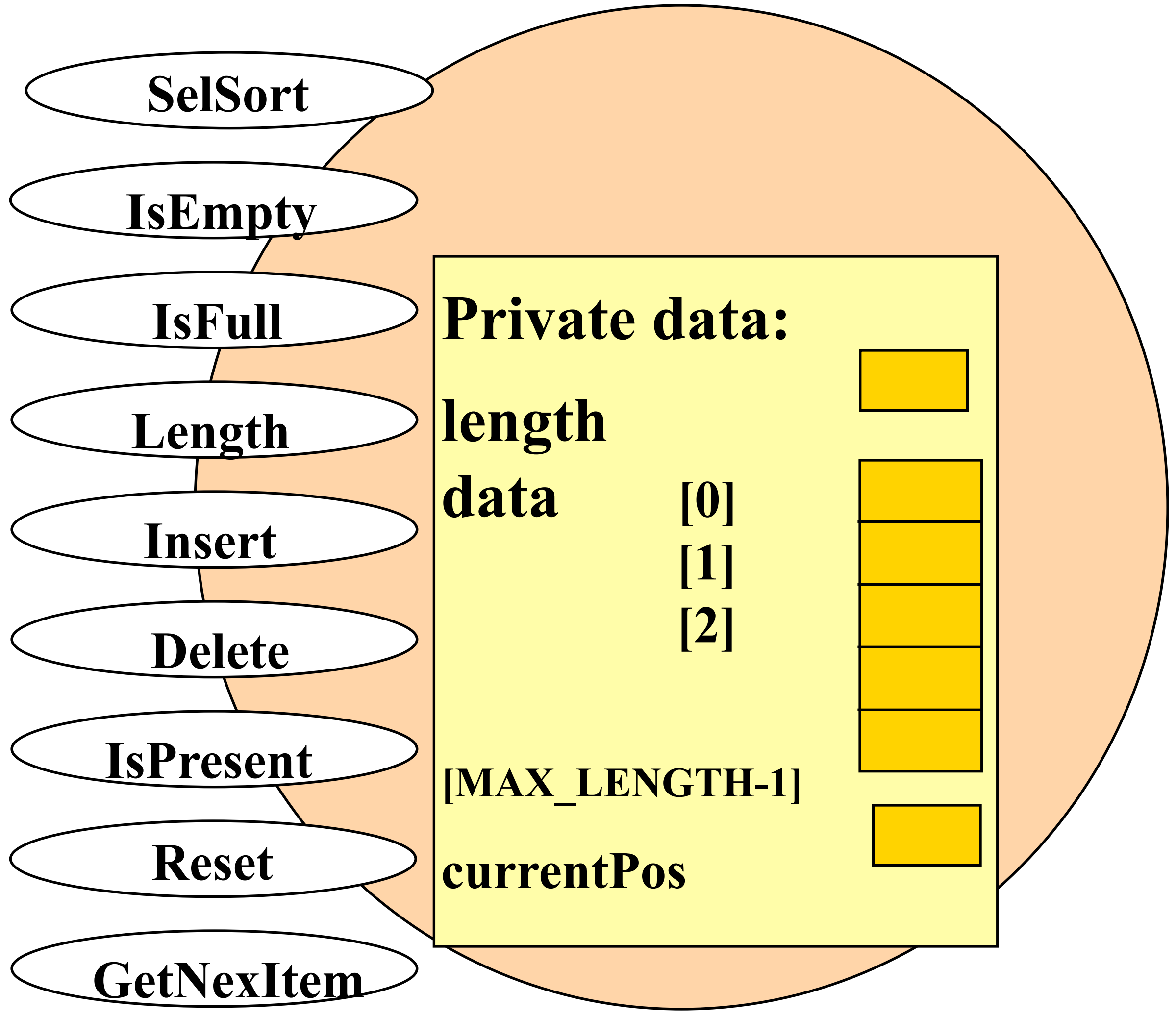
ADT Unsorted List Data Components

length — number of elements in list

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

`currentPos` — used in iteration

Array-based `class List`



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

Sorted and Unsorted Lists

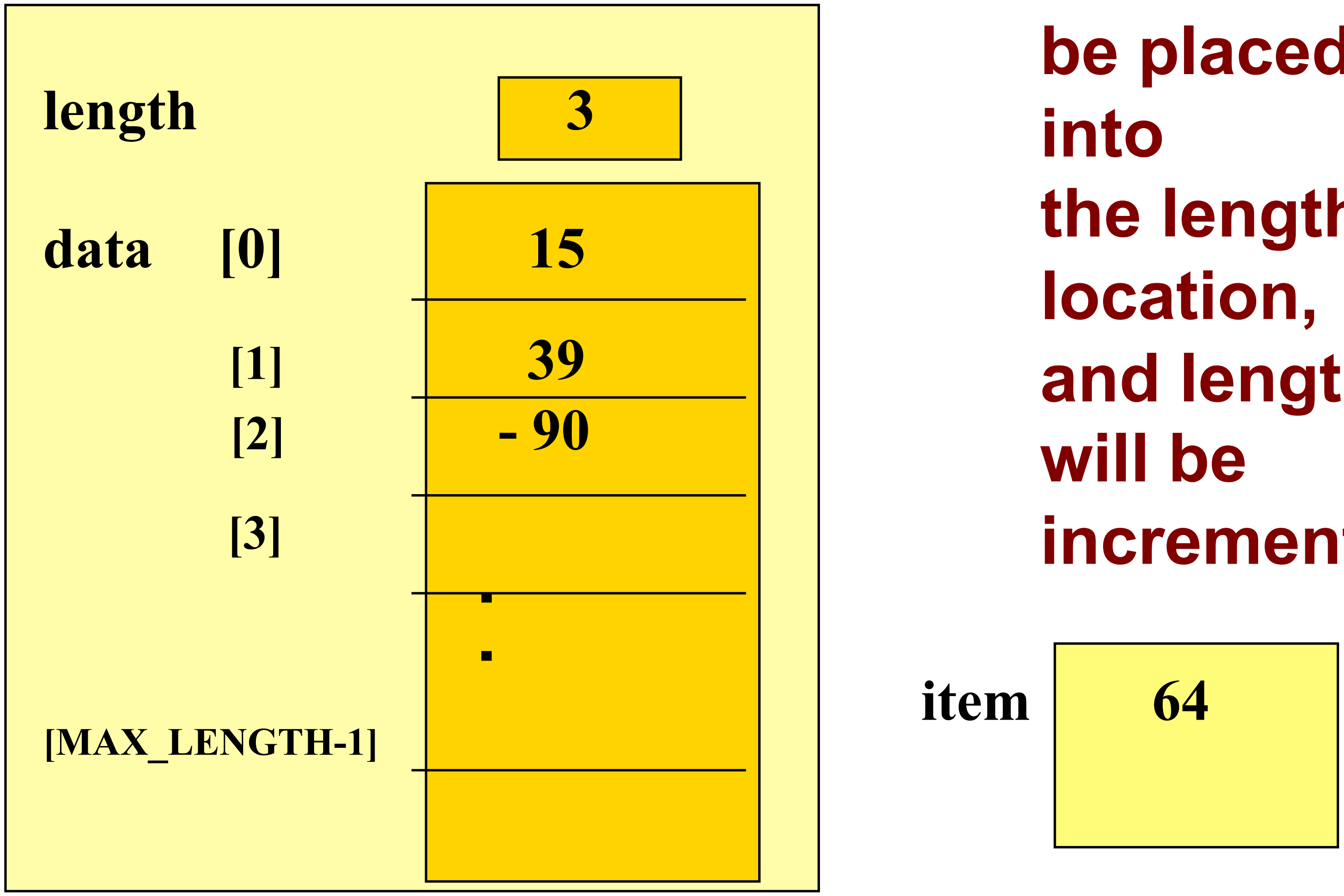
UNSORTED LIST	SORTED LIST
Elements are placed into the list in no particular order	List elements are sorted in some way -- either numerically or alphabetically

```
// 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;
}
```

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

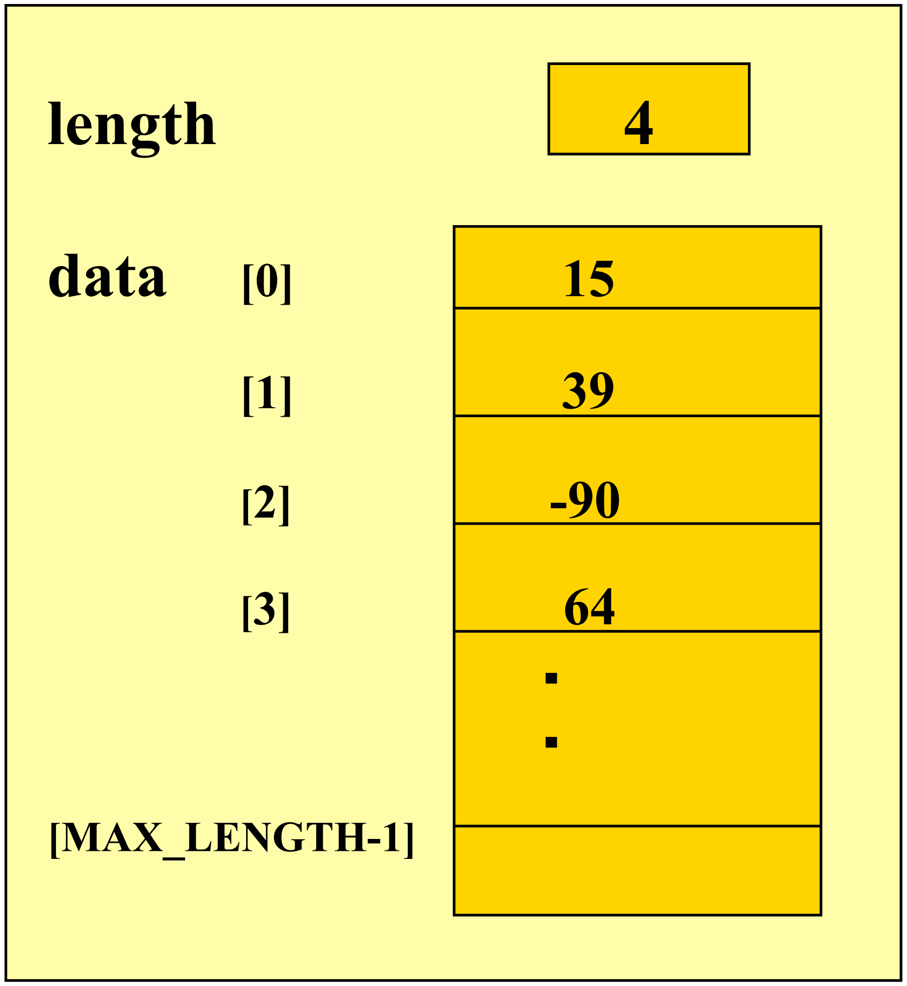
```
List::List ()
// Constructor
// Post: length == 0
{
     length = 0;
}

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++;
}
```

Before Inserting 64 into an Unsorted List

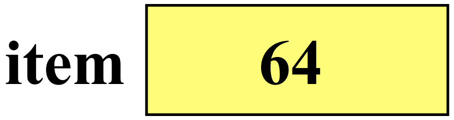


The item will be placed into the length location, and length will be incremented

After Inserting 64 into an Unsorted List



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



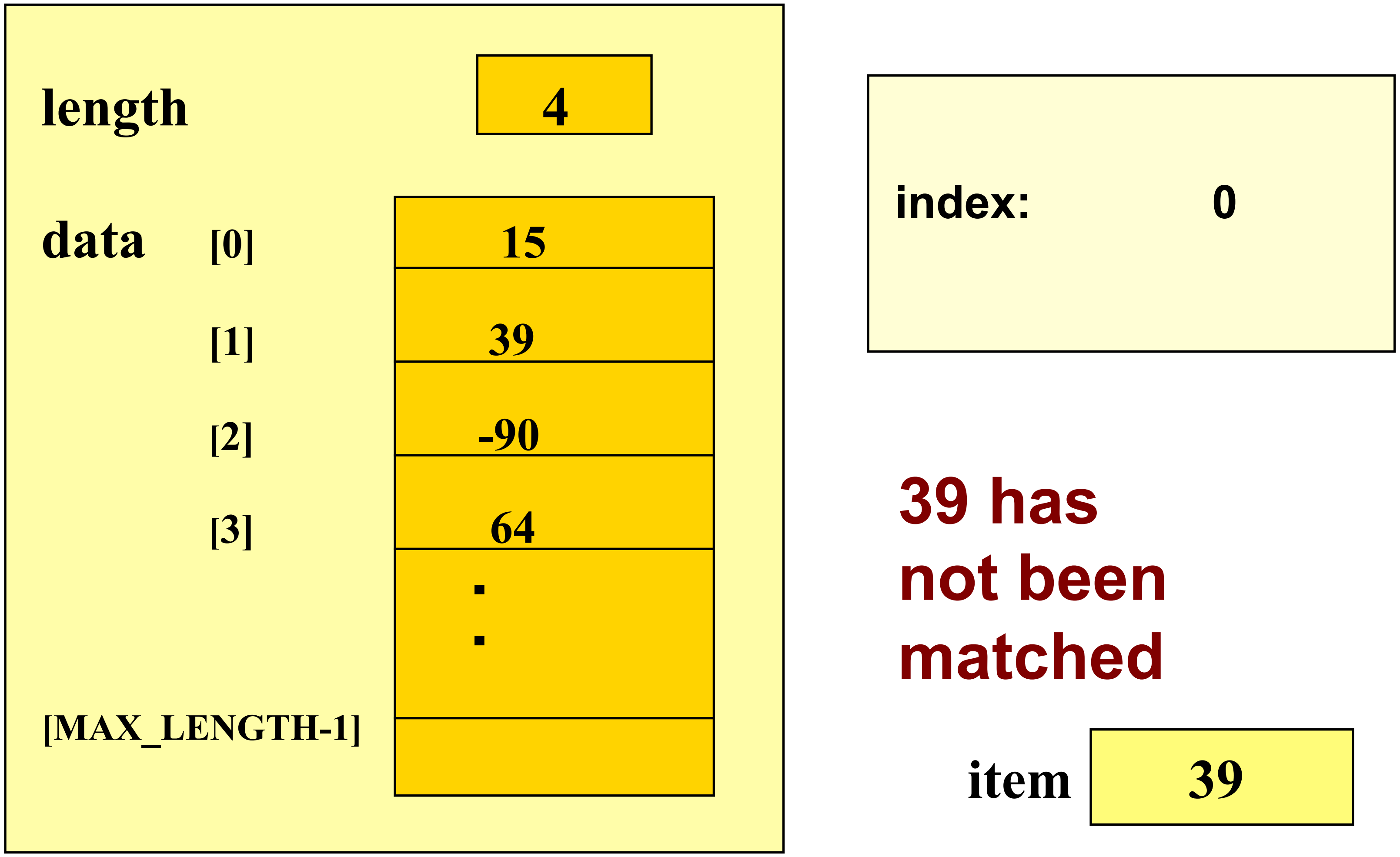
```
bool  List::IsEmpty ()  const
// Post: Return value is true if length is equal
//   to zero and false otherwise
{
    return (length == 0);
}
```

```
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);
}
```

```
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
```

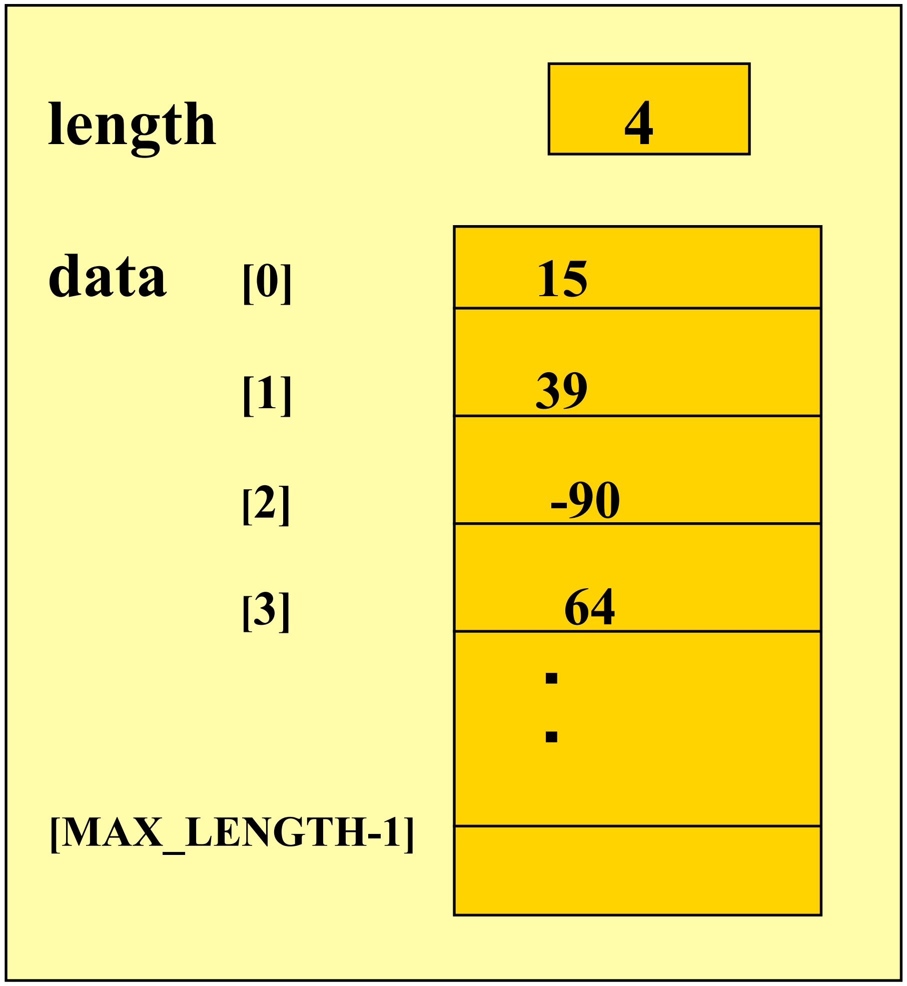
```
{
    int  index  =  0;

    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--;
    }
}
```

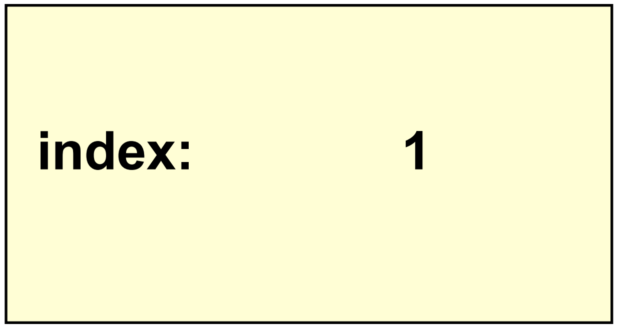
Deleting 39 from an Unsorted List



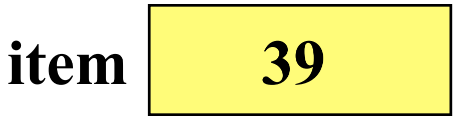
39 has not been matched

Deleting 39 from an Unsorted List

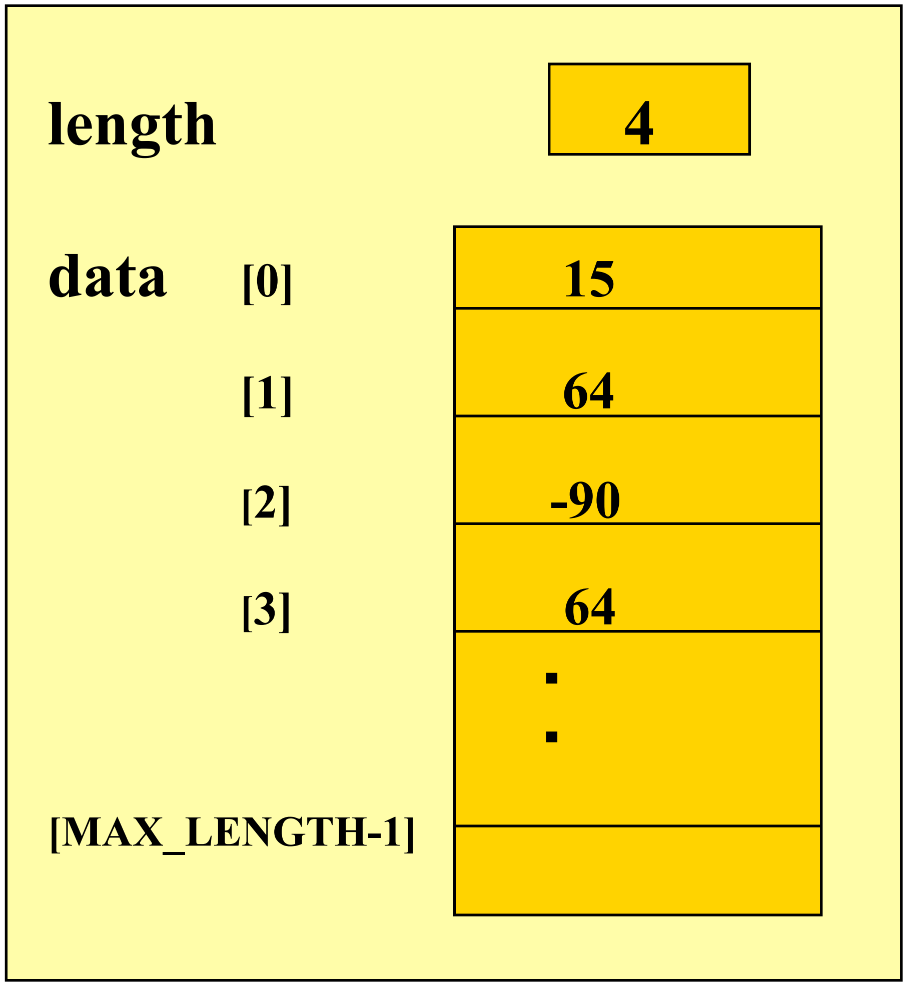


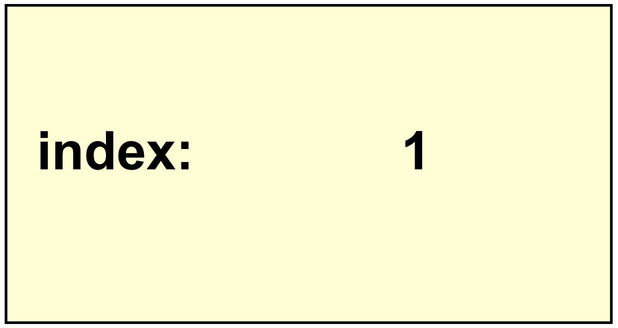


39 has been matched

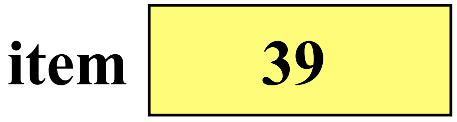


Deleting 39 from an Unsorted List

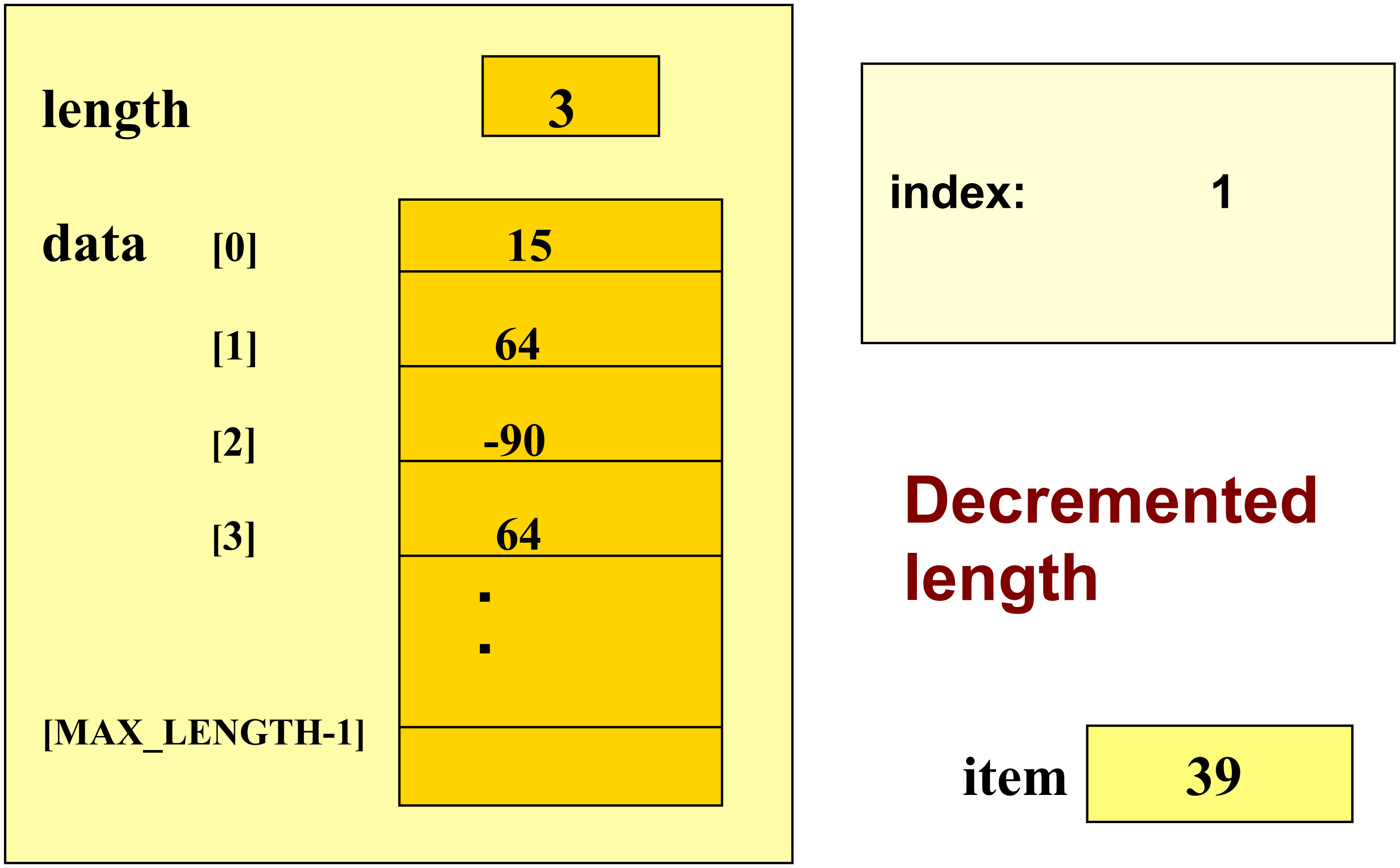




Placed copy of
last list element
into the position
where 39
was before



Deleting 39 from an Unsorted List



Decremented length

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;
 }
```

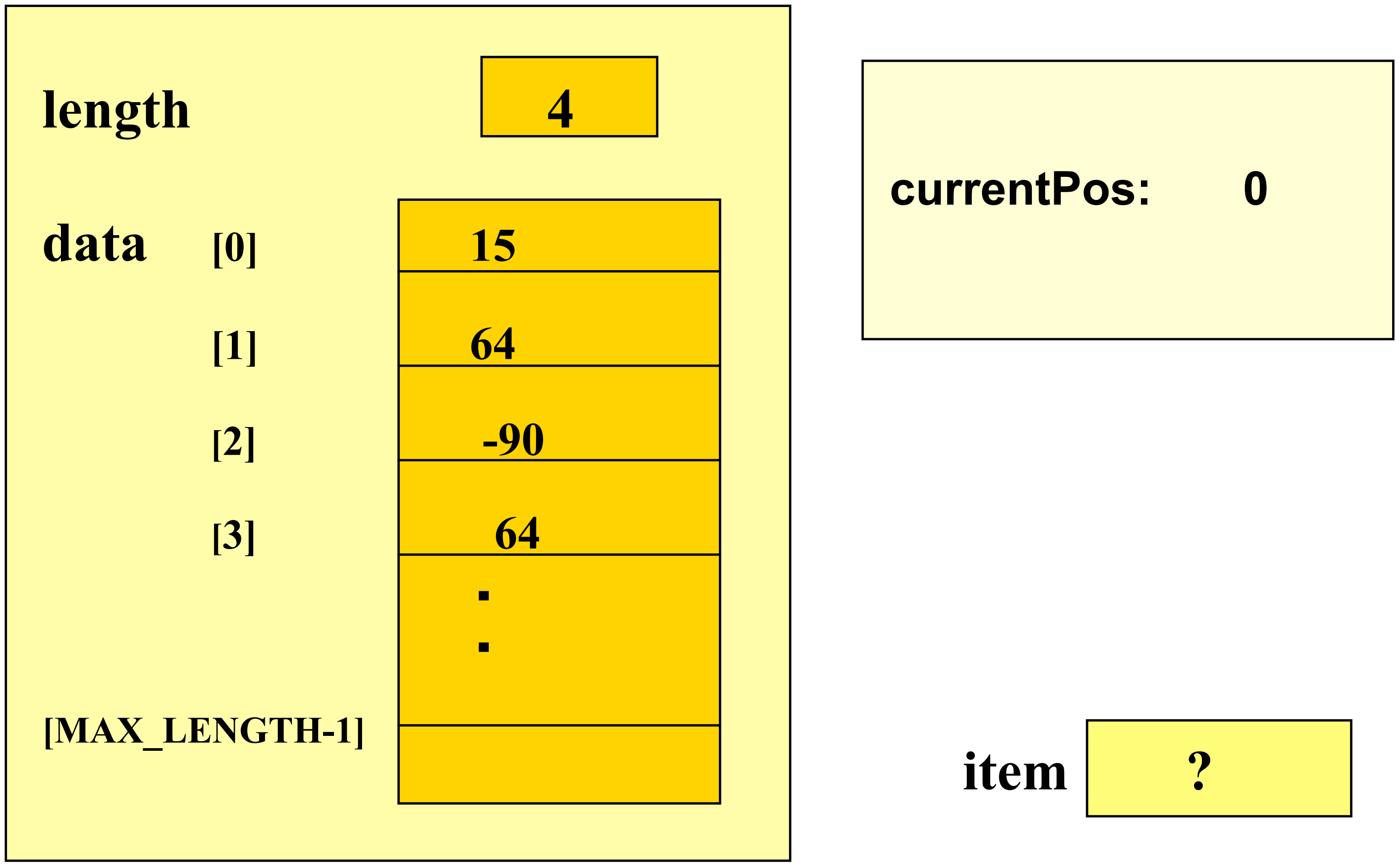
Iteration Operator

```
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;
}
```

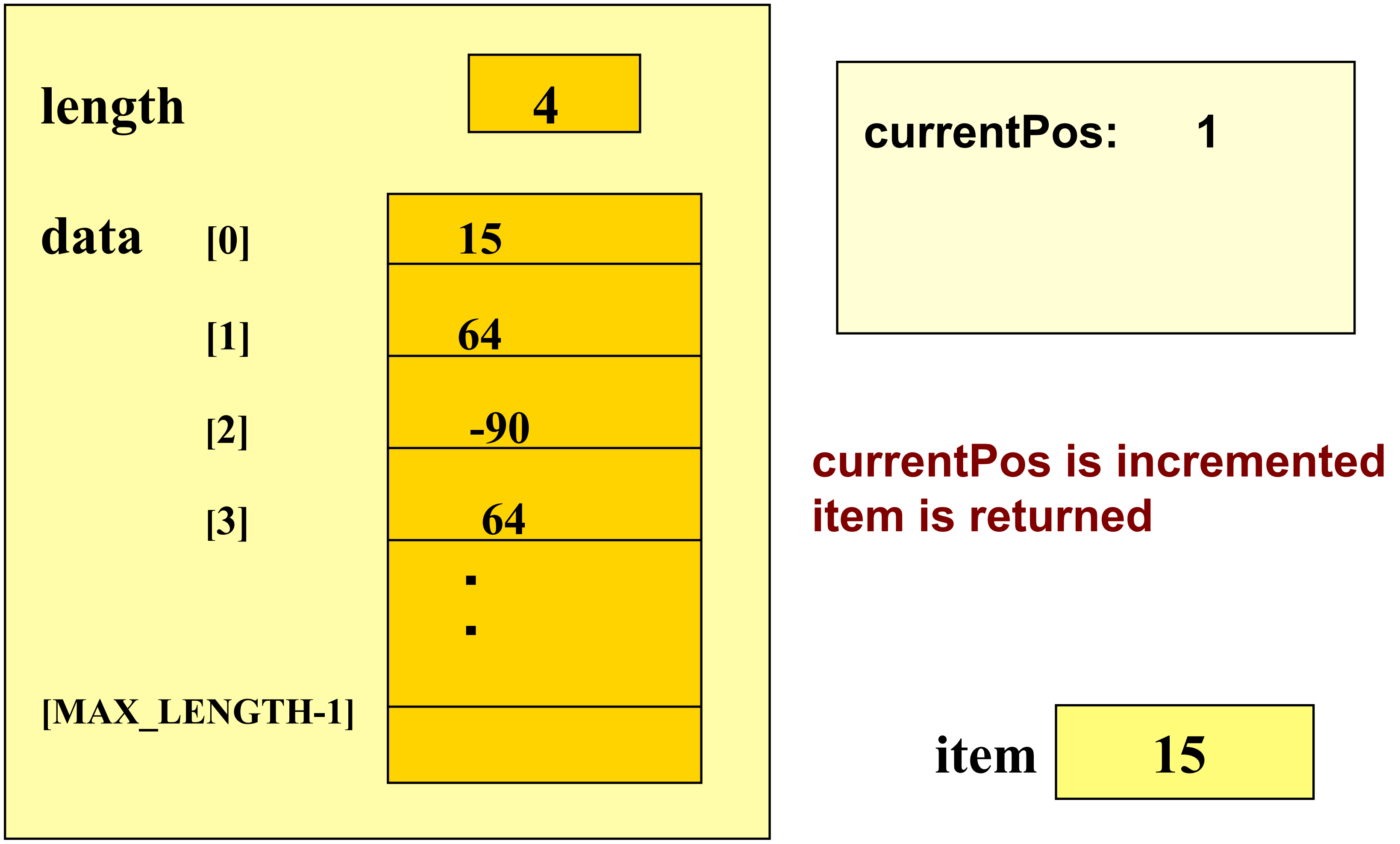
Iteration Operator

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

Reset



GetNextItem



currentPos is incremented
item is returned

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**

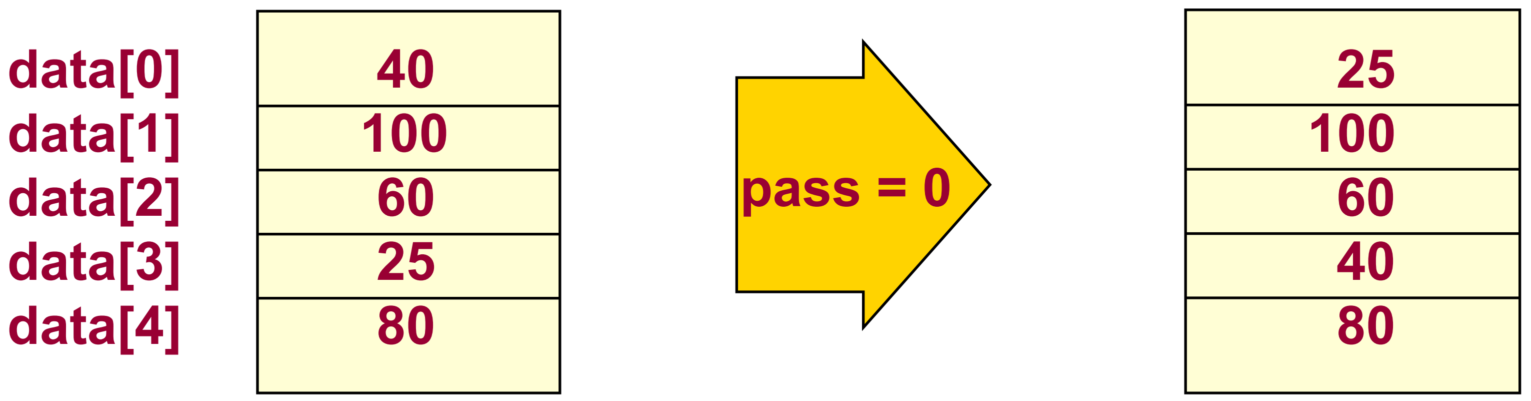
Selection Sort Process, cont...

- 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

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



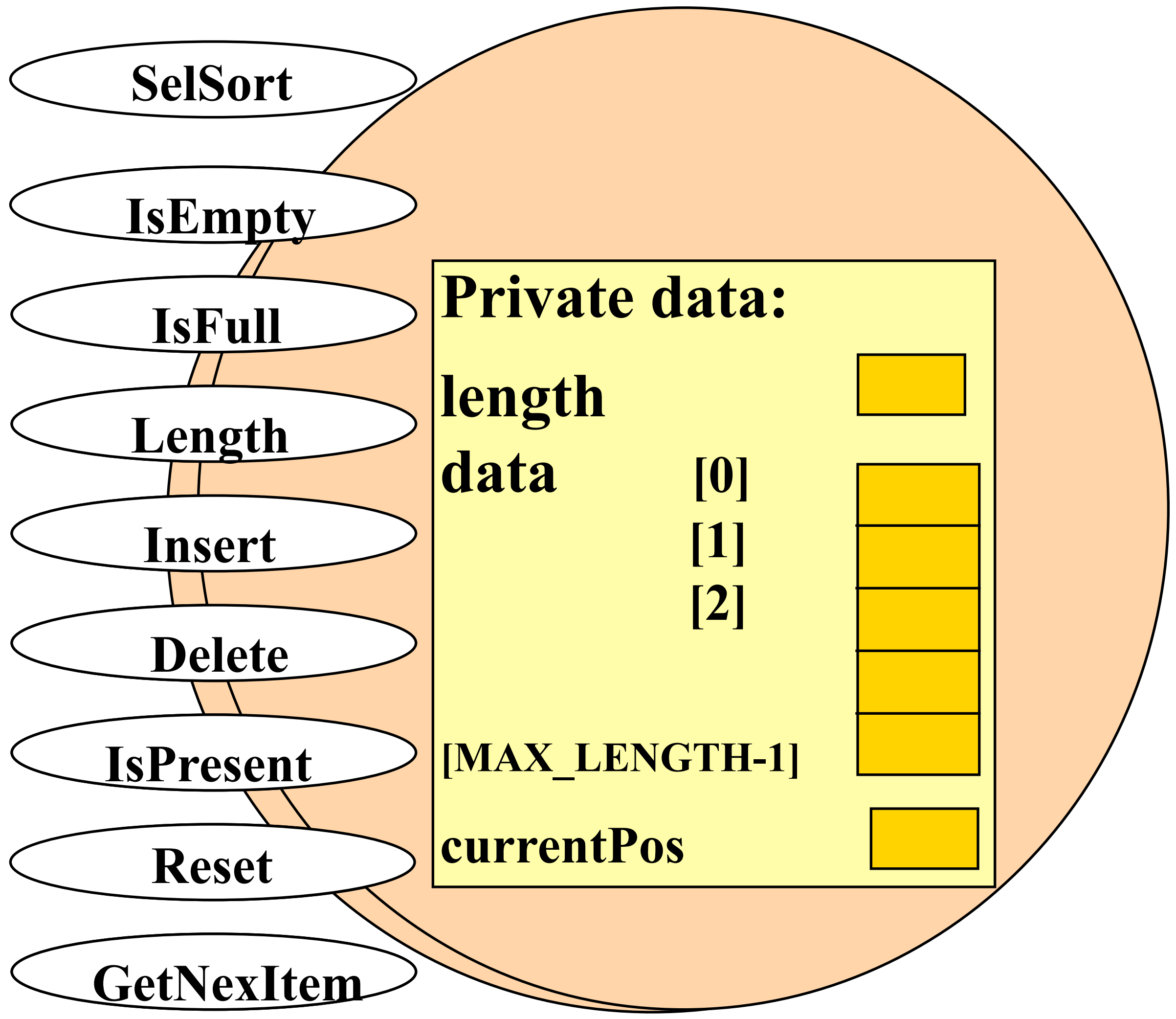
```
void  List::SelSort ()
// Sorts list into ascending order
{
    ItemType temp;
    int passCount;
    int sIndx;
    int minIndx; // Index of minimum so far
```

```
 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;
        }
        if (minIndex != passCount) {
            temp = data[minIndx];         // Swap
            data[minIndx] = data[passCount];
            data[passCount] = temp;
        }
  }  // end for
}
```

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

Array-based class SortedList



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

```
//  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 ();
private: //  private data members

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

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**

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

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
```

Implementing `SortedList` Member Function `Insert`

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

}
```

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

    // Insert item into array
    data[index] = item;
    length++;
}
```

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

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
{
            .
            .
            .
}
```

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
{
            .
            .
            .
}
```

```
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
```

```
  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--;
   }
}\\
```

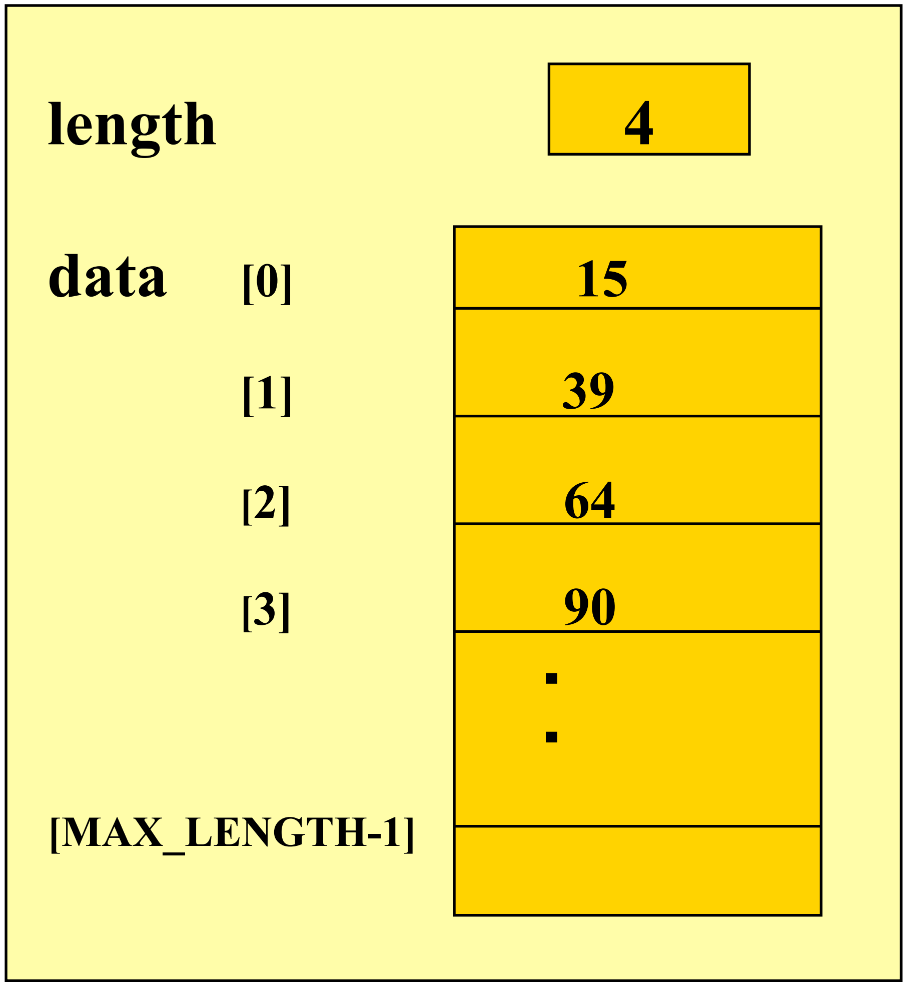
Improving Member Function `IsPresent`

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

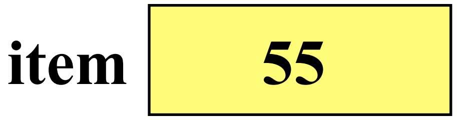
A match with item or we had examined all the elements in the unsorted List

How can the searching algorithm be improved for SortedList ADT?

Searching for 55 in a SortedList



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



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

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

```
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;
    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;
}
```

item = 84

Trace of Binary Search

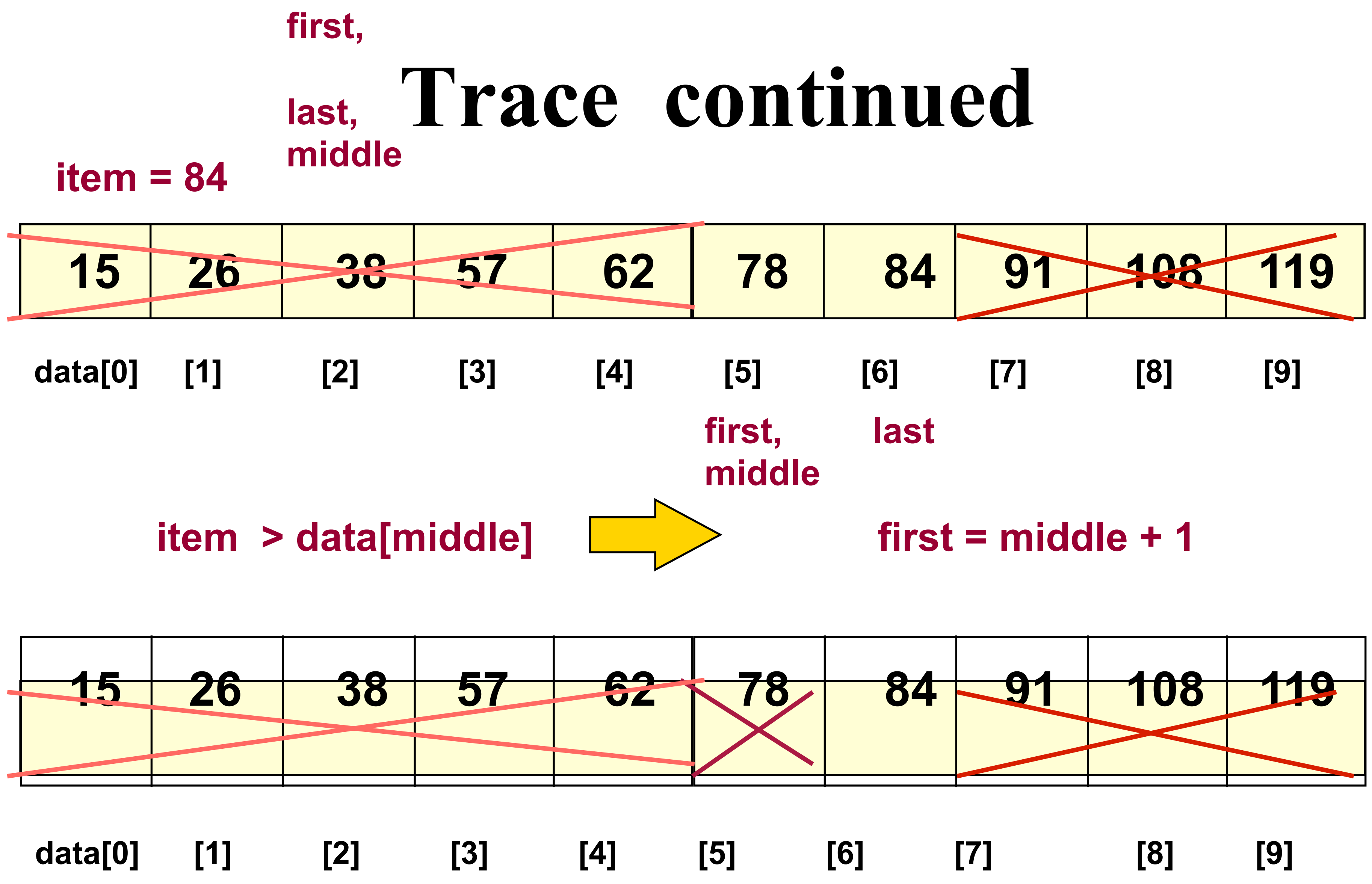
15	26	38	57	62	78	84	91	108	119
data[0]	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
first				middle					last

item > data[middle] $\Rightarrow$ 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] $\Rightarrow$ last = middle - 1

Trace continued



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

item == data[middle] ⇒ found = true

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 item = 45

Trace continued

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

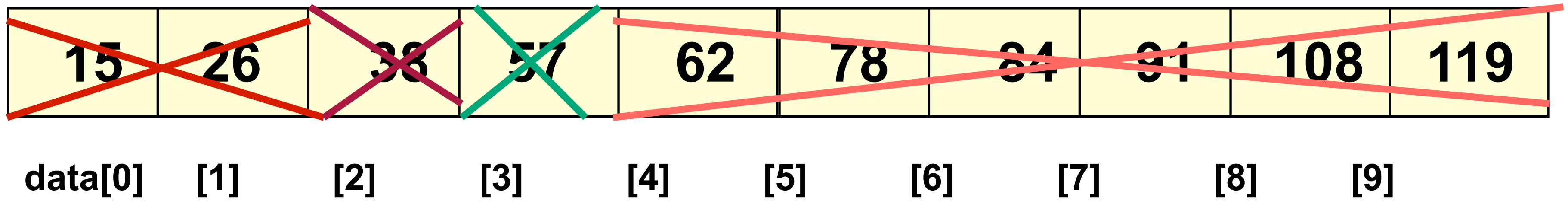
item > data[middle] $\Rightarrow$ first = middle + 1

~~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] $\Rightarrow$ last = middle - 1

Trace concludes

item = 45



last first

first > last → found = false

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
```

Still More Efficient `IsPresent`

```
{
    bool found;
    int  position;

    BinSearch (item, found, position);

    return  found;
}
```

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**

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

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

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

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	$O(N^2)$	

In Addition . . .

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

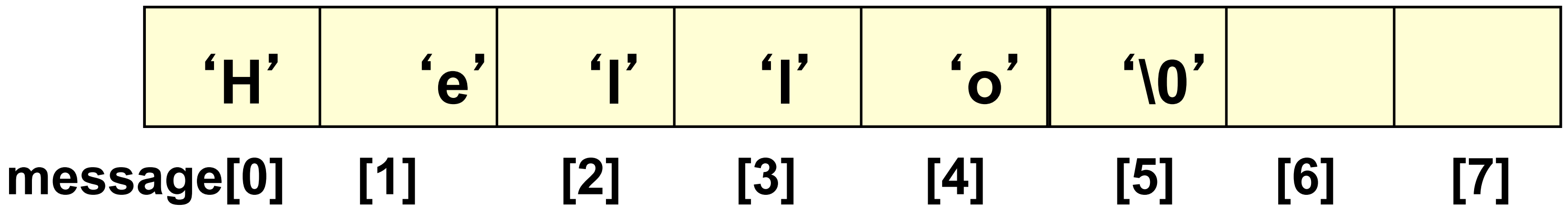
C++ also has another library of string functions for C strings that can be accessed by #include <cstring>

What is a C String?

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

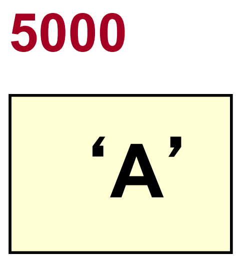
A C string variable can be initialized in its declaration in two equivalent ways.

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

char  message[8]  =  “Hello”;
```

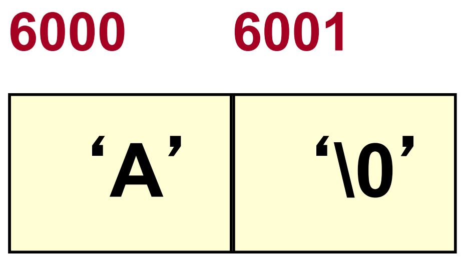


char vs. C string

‘A’ has data type char
and is stored in 1 byte



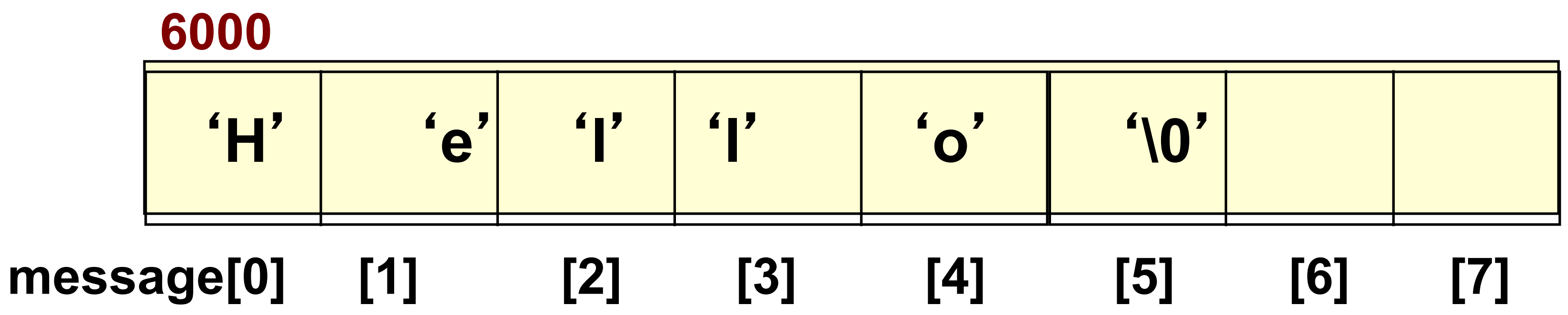
“A” is a C string of 2 characters
and is stored in 2 bytes



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.



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 . . .

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

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

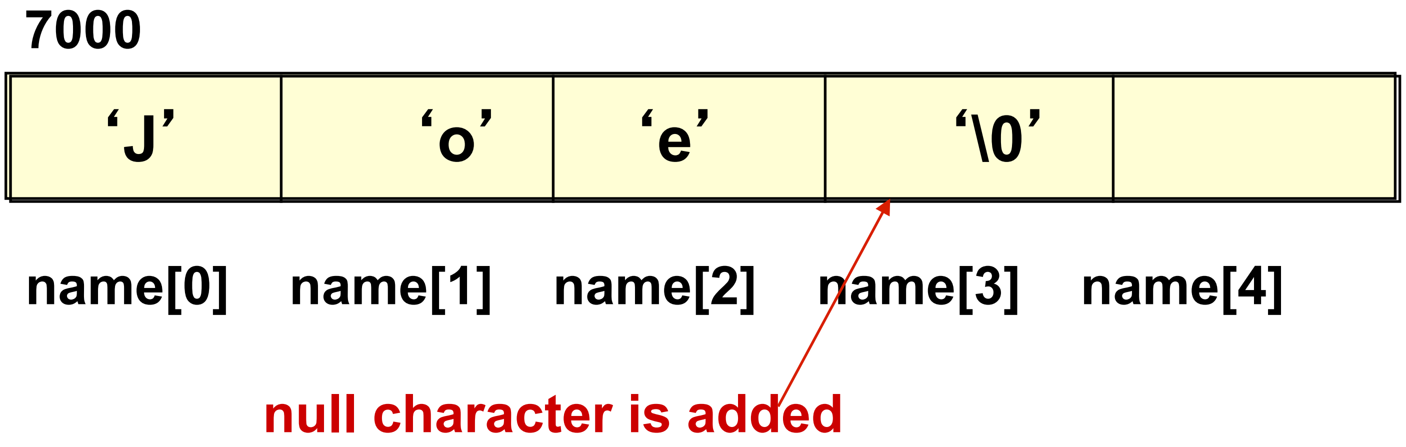
Example Using >>

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

total number of elements in the array

Suppose input stream looks like this:

□ □ J o e □



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

Example of Function `get()`

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

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

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

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);
```

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]

String Function Prototypes in <cstring >

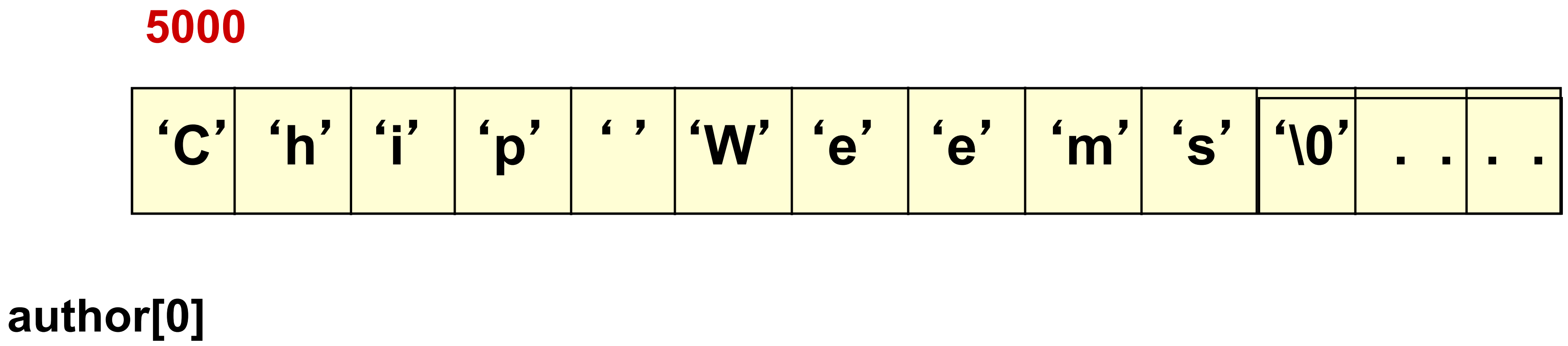
```
int   strlen (char  str[]);
//  FCTNVAL     ==  integer length of string str (not including  '\0')
```

```
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'
```

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
```

```
# include  <cstring >
 .
 .
 .
char author[21];
int  length;

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



```
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;
```

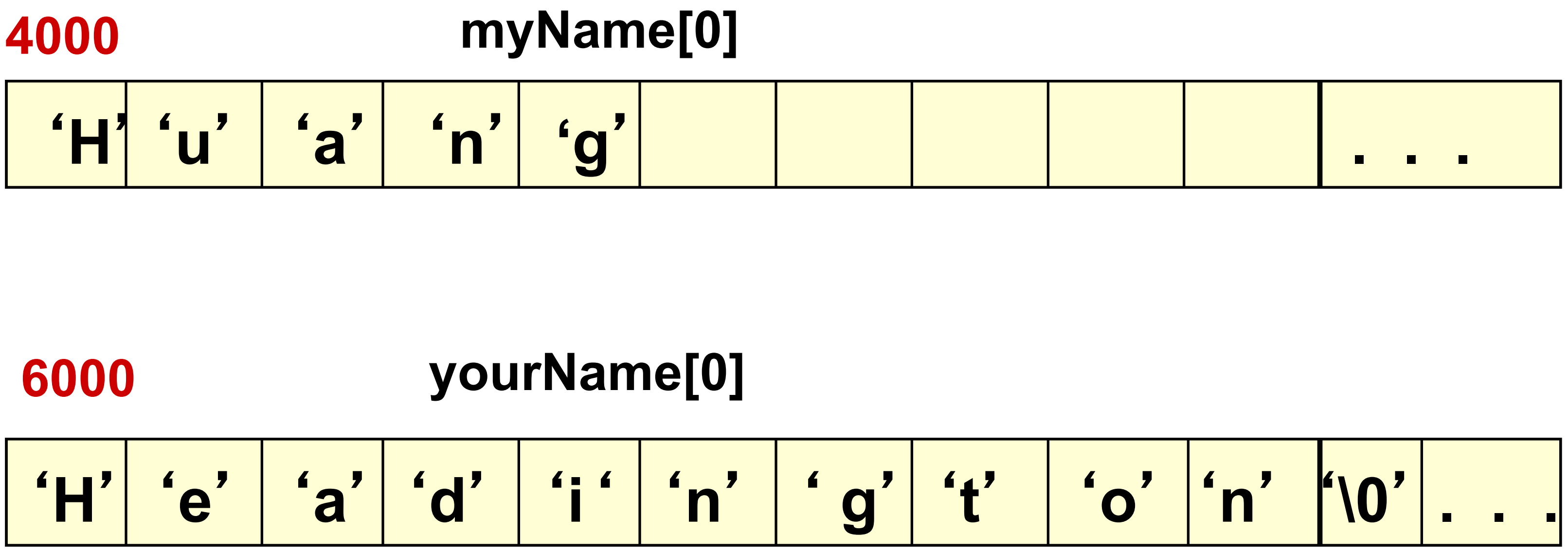
myName[0]

‘H’	‘u’	‘a’	‘n’	‘g’	‘\0’					. . .

yourName[0]

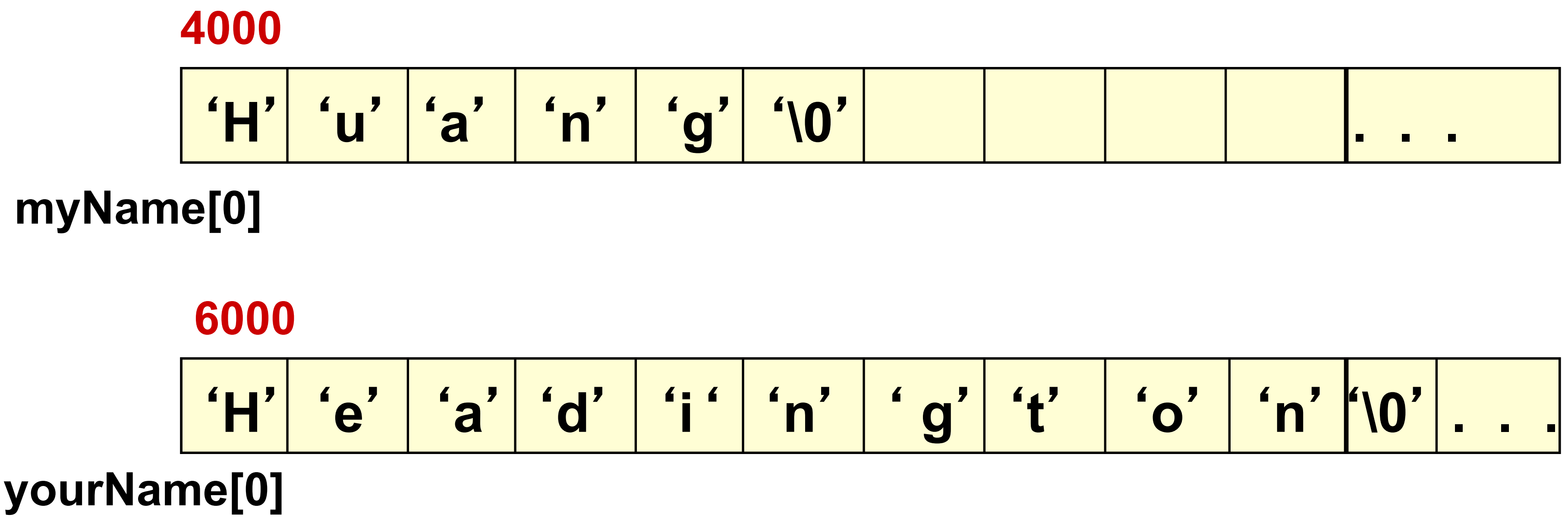
‘H’	‘e’	‘a’	‘d’	‘i ‘	‘n’	‘ g’	‘t’	‘o’	‘n’	‘\0’	. . .

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

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



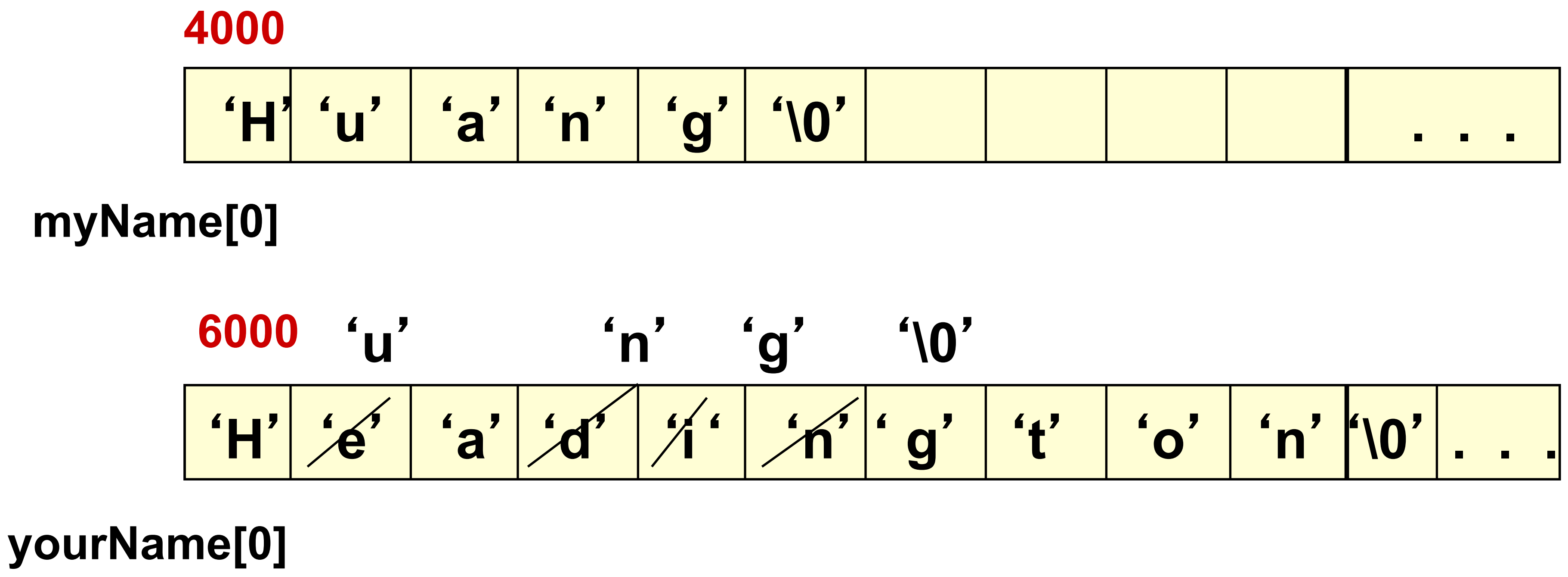
```
char  myName[21] = "Huang";
char  yourName[21];


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

What happens?



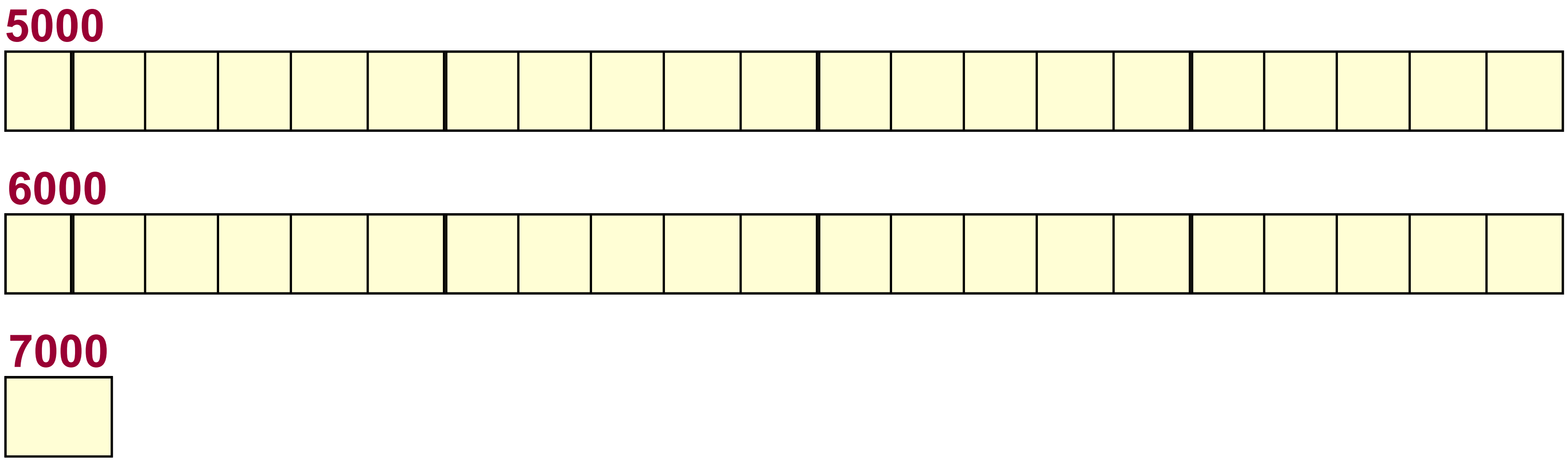
```
char  myName[21]  = “Huang”;
char  yourName[21];

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

What happens?



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