Linked List – first introduction

- **Meaning of a Linked List**
- **Meaning of a Dynamic Linked List**
- **Traversal, Insertion and Deletion of Elements in a Dynamic Linked List**
- **Specification of a Dynamic Linked Sorted List**
- **Insertion and Deletion of Elements in a Dynamic Linked Sorted List**

Linked List – first introduction (Continued)

- **Meaning of an Inaccessible Object**
- **Meaning of a Dangling Pointer**
- **Use of a Class Destructor**
- **Shallow Copy vs. Deep Copy of Class Objects**
- **Use of a Copy Constructor**

What is a List?

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

To implement the List ADT

The programmer must:

1) **choose a concrete data representation for the list, and**

2) **implement the list operations**

Recall:
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**

Recall: 4 Basic Kinds of ADT Operations

- **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**

List Operations

Transformers

- Insert
- Delete
- Sort

change state

Observers

- IsEmpty
- IsFull
- Length
- IsPresent

observe state

ADT List Operations

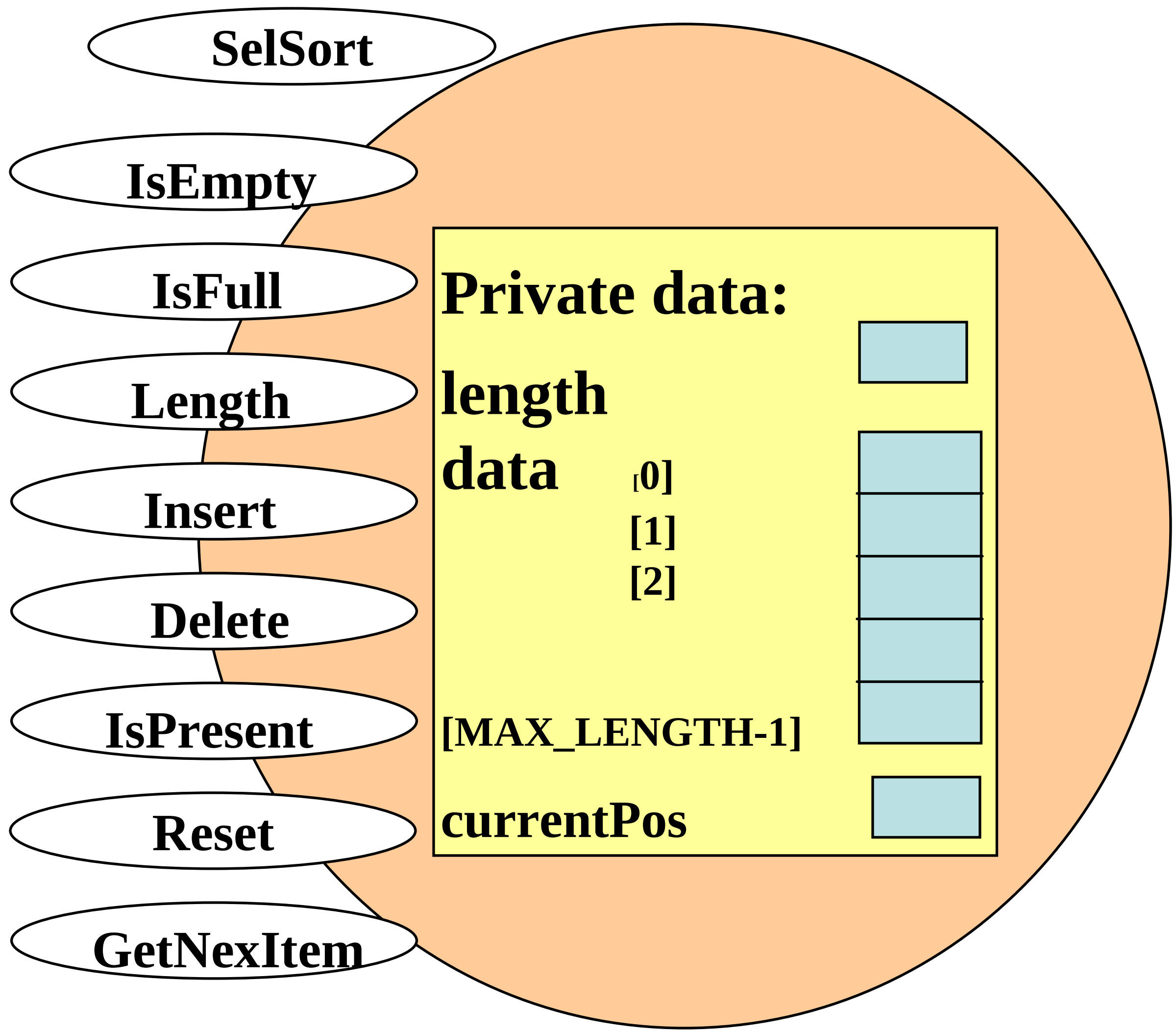
Iterator

- **Reset**
- **GetNextItem**

Iteration Pair

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

Array-based `class List`

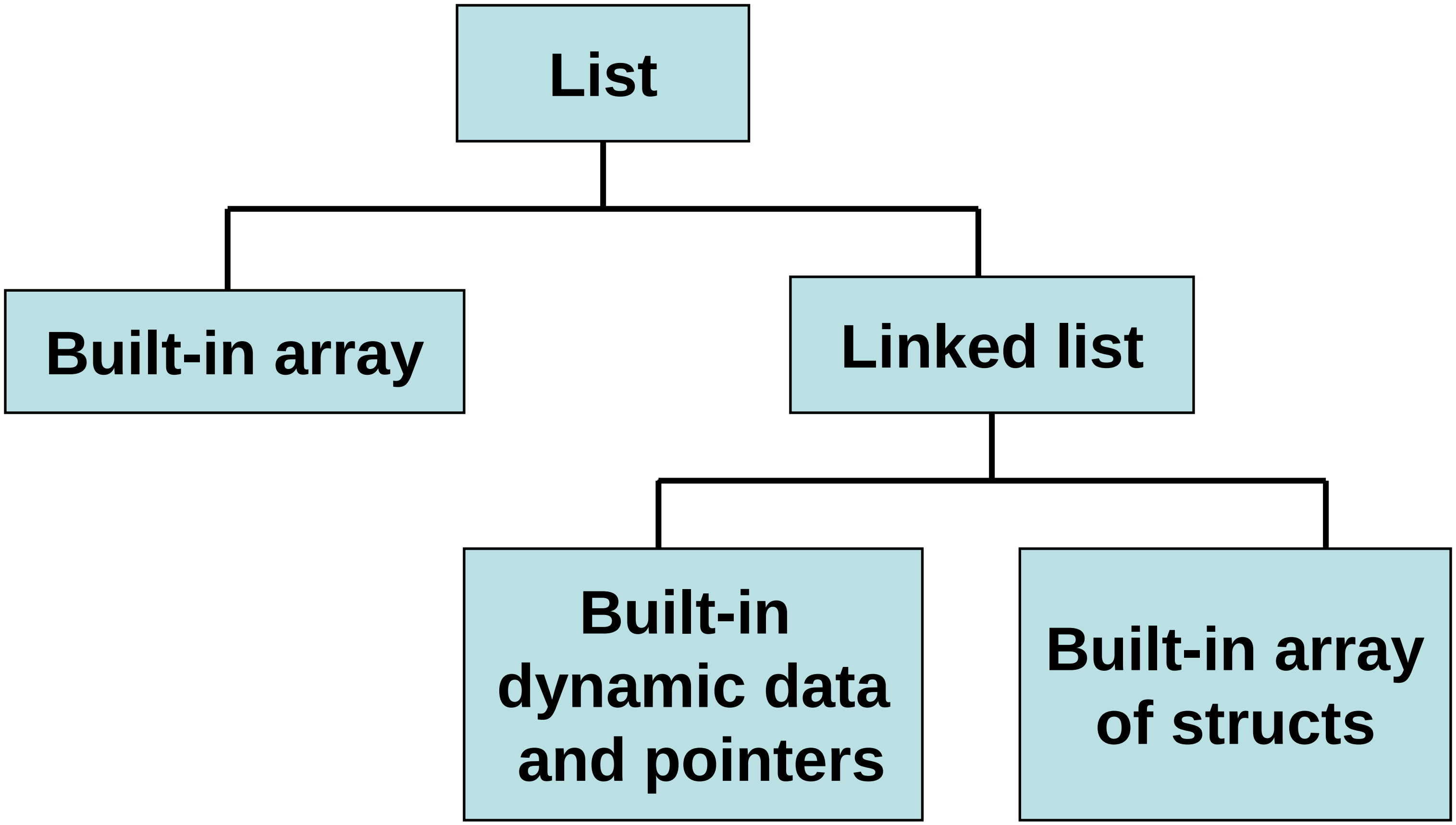


```
// Specification file array-based list ("list.h")
const  int  MAX_LENGTH  =  50;
typedef int   ItemType;

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
};
```

Implementation Structures

- **Use a built-in array stored in contiguous memory locations, implementing operations Insert and Delete by moving list items around in the array, as needed**
- **Use a linked list in which items are not necessarily stored in contiguous memory locations**
- **A linked list avoids excessive data movement from insertions and deletions**

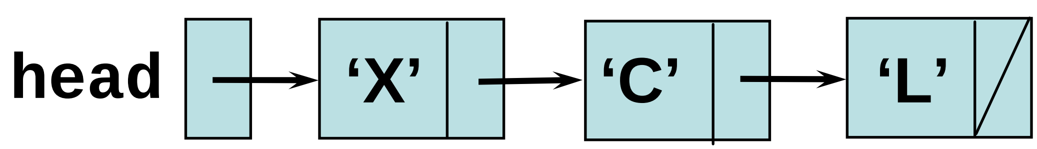
Implementation Possibilities for a List ADT



A Linked List

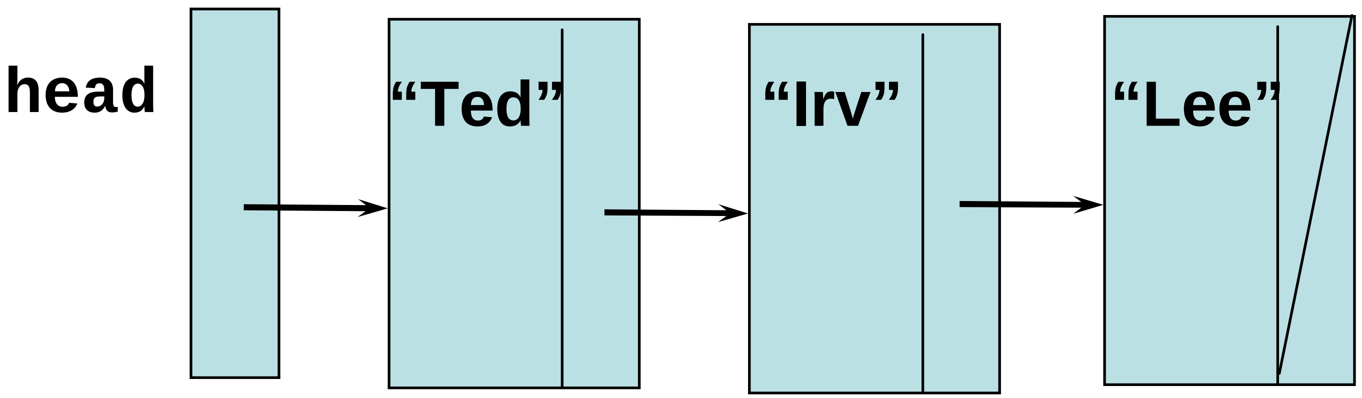
- **A linked list is a list in which the order of the components is determined by an explicit link member in each node**

- **Each node is a `struct` containing a data member and a link member that gives the location of the next node in the list**



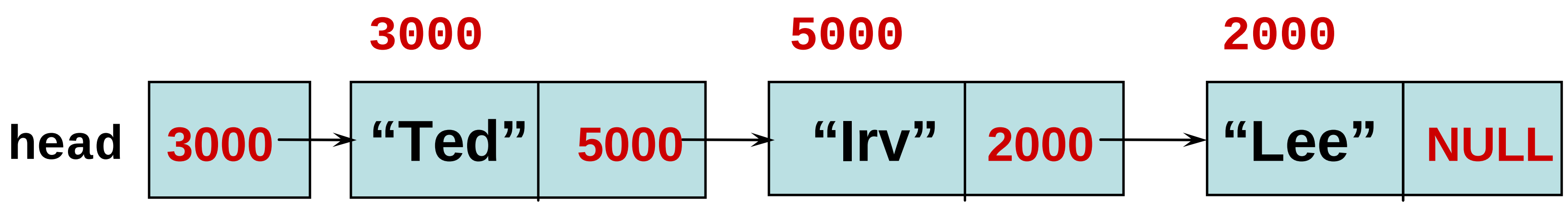
Dynamic Linked List

- **A dynamic linked list is one in which the nodes are linked together by pointers and an external pointer (or head pointer) points to the first node in the list**



Nodes can be located anywhere in memory

- **The link member holds the memory address of the next node in the list**



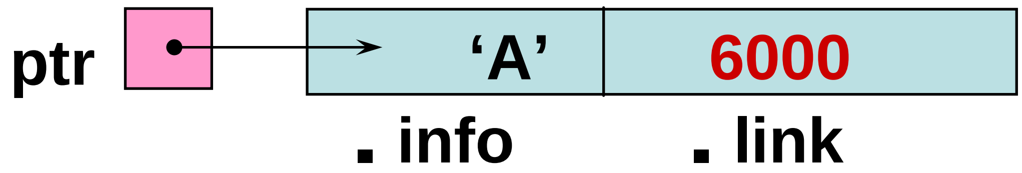
Declarations for a Dynamic Linked List

```
// Type declarations
struct NodeType
{
    char info;
    NodeType* link;
}

typedef  NodeType*  NodePtr;

// Variable DECLARATIONS
NodePtr  head;
NodePtr  ptr;
```

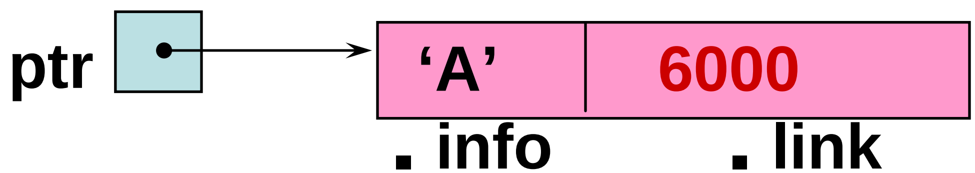
‘A’	6000
.info	.link

Pointer Dereferencing and Member Selection

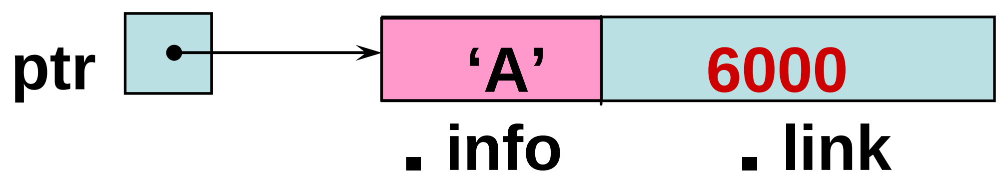
ptr



***ptr**

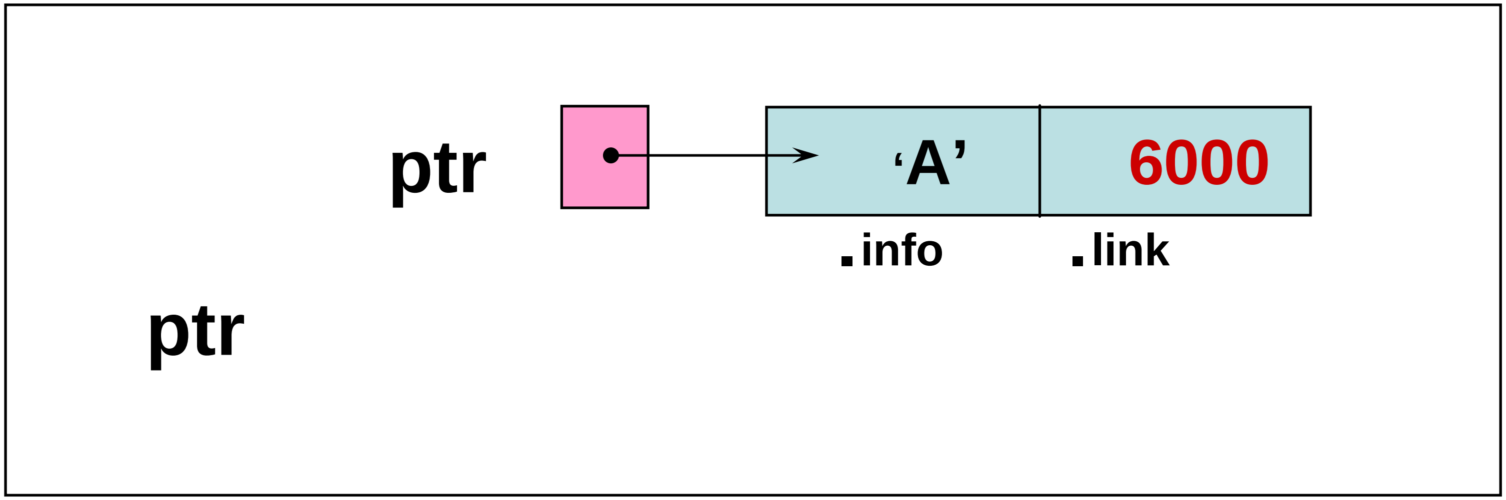


(*ptr).info

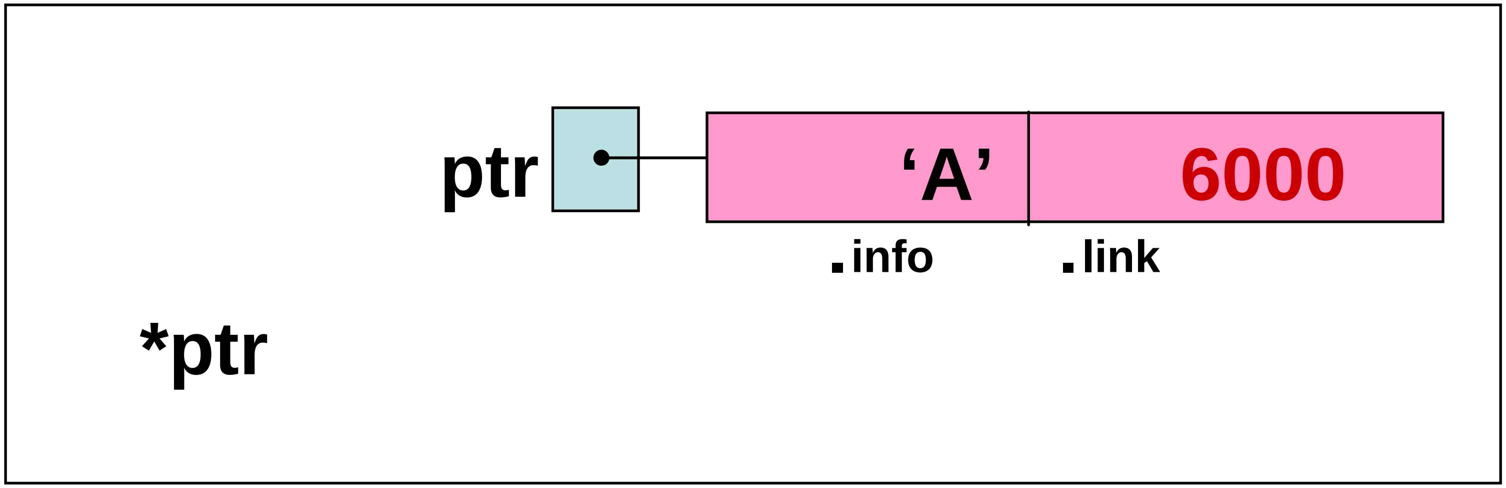


ptr->info

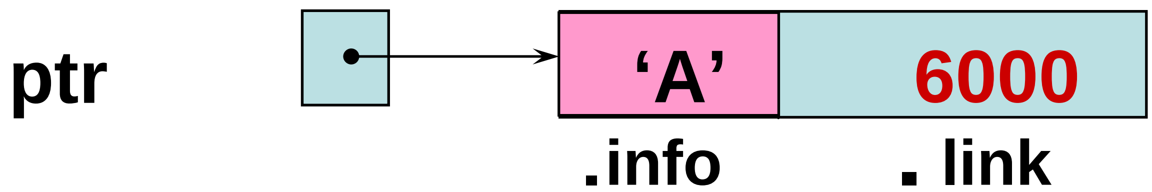
`ptr` is a pointer to a node



`*ptr` is the entire node pointed to by ptr



`ptr->info`
is a node member

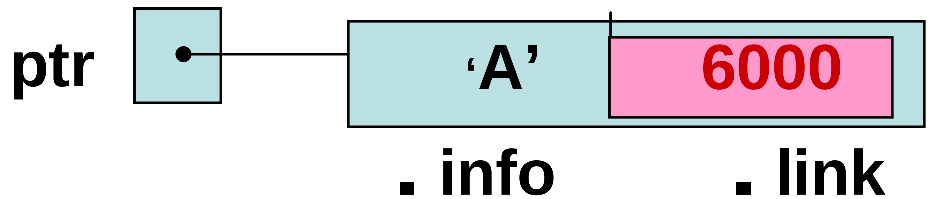


ptr->info **// it has info ‘A’**

(*ptr).info **// Equivalent**

`ptr->link`

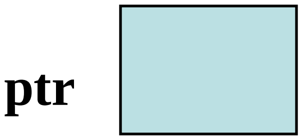
is a node member

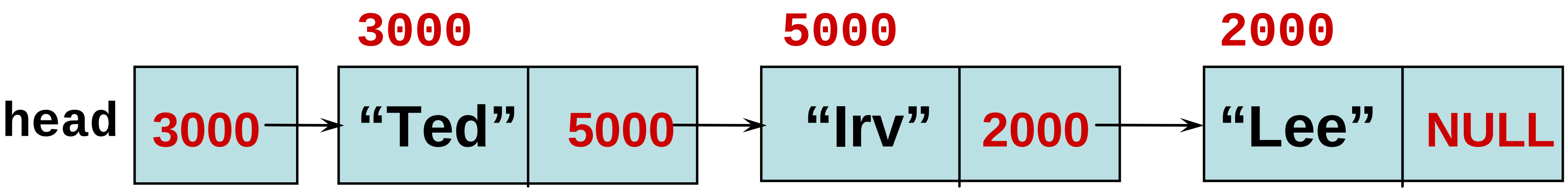


ptr->link **// it has an address 6000**

(*ptr).link **// Equivalent**

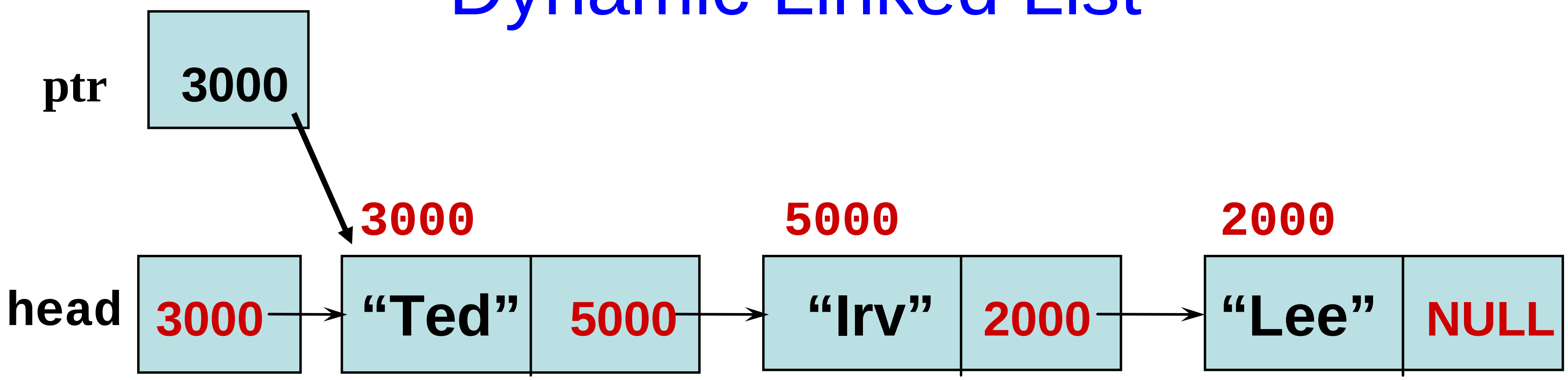
Traversing a Dynamic Linked List





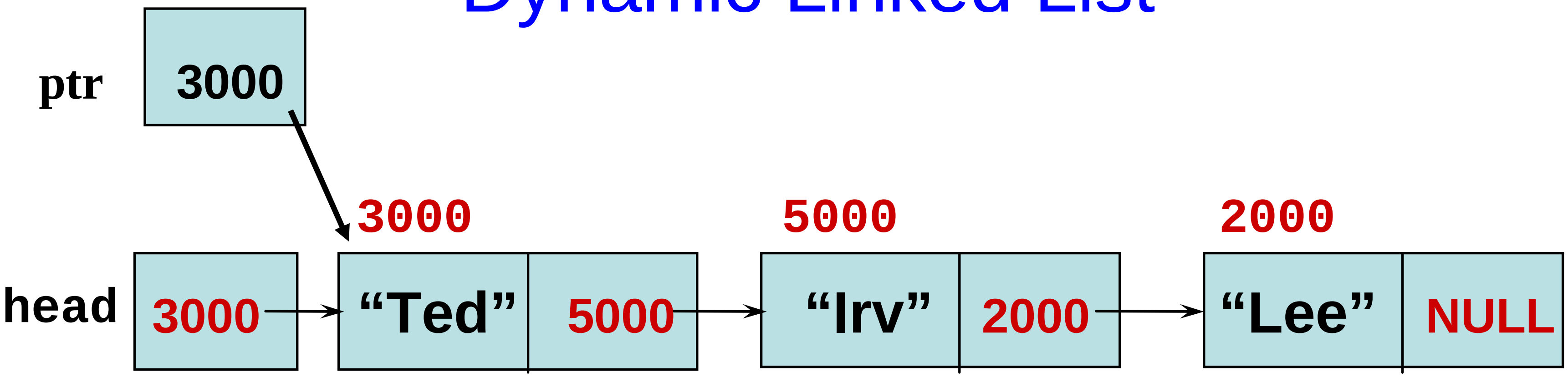

```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
    cout  <<  ptr->info;
    // Or, do something else with node *ptr
    ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List



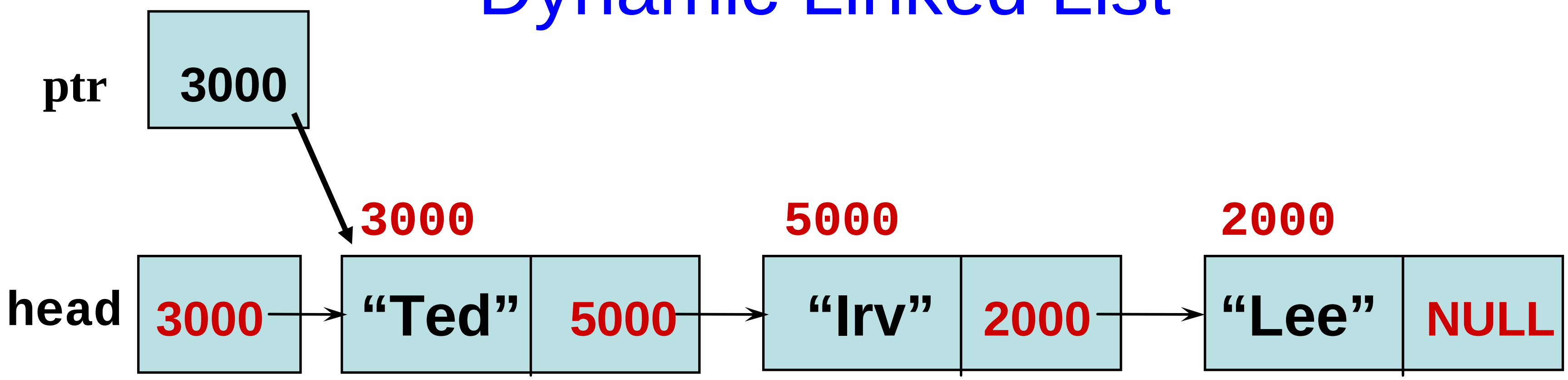

```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
     cout  <<  ptr->info;
    // Or, do something else with node *ptr
    ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List



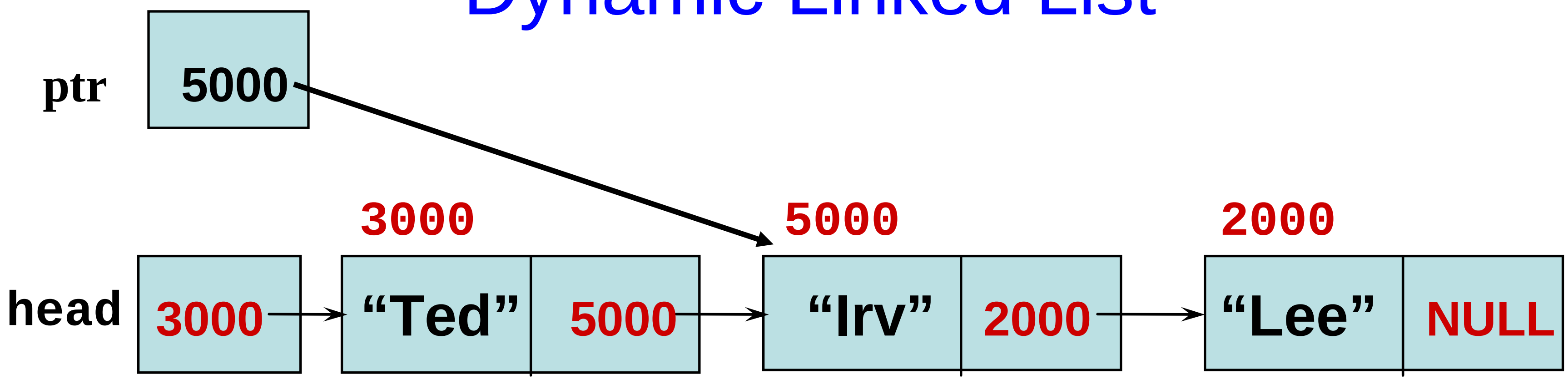

```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
  cout  <<  ptr->info;
 // Or, do something else with node *ptr
 ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List



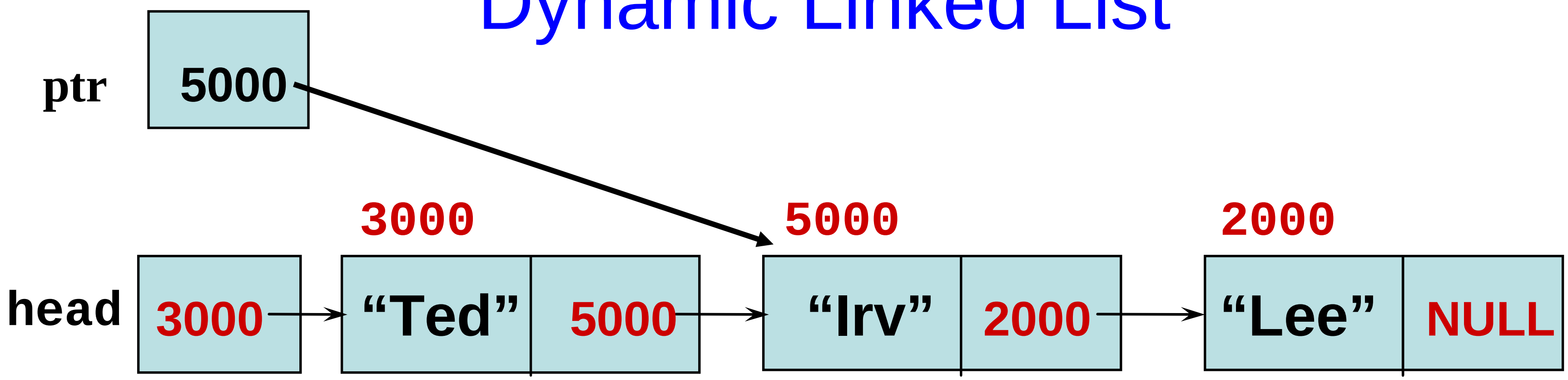

```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
    cout  <<  ptr->info;
    // Or, do something else with node *ptr
    ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List



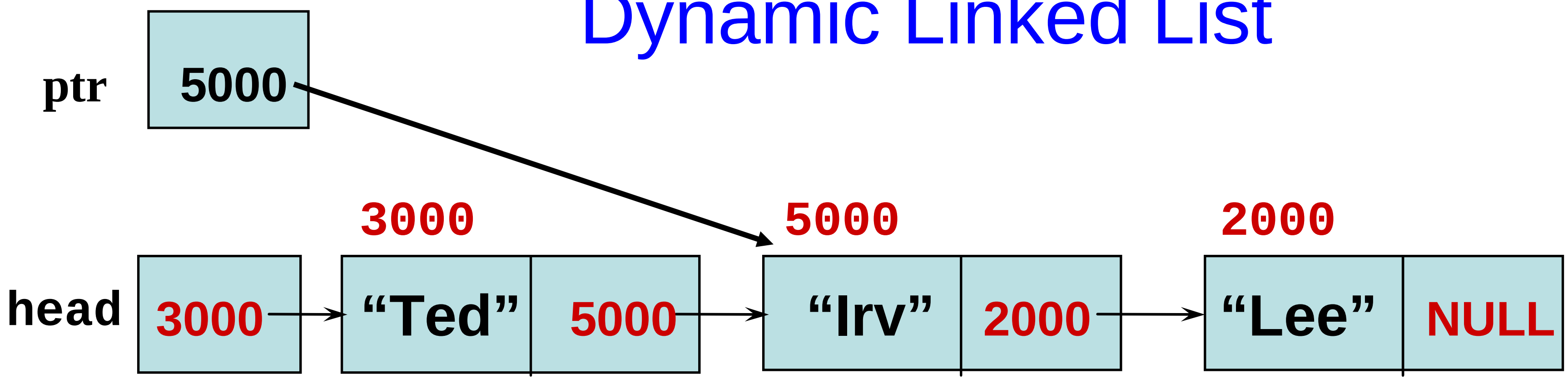

```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
     cout  <<  ptr->info;
    // Or, do something else with node *ptr
    ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List



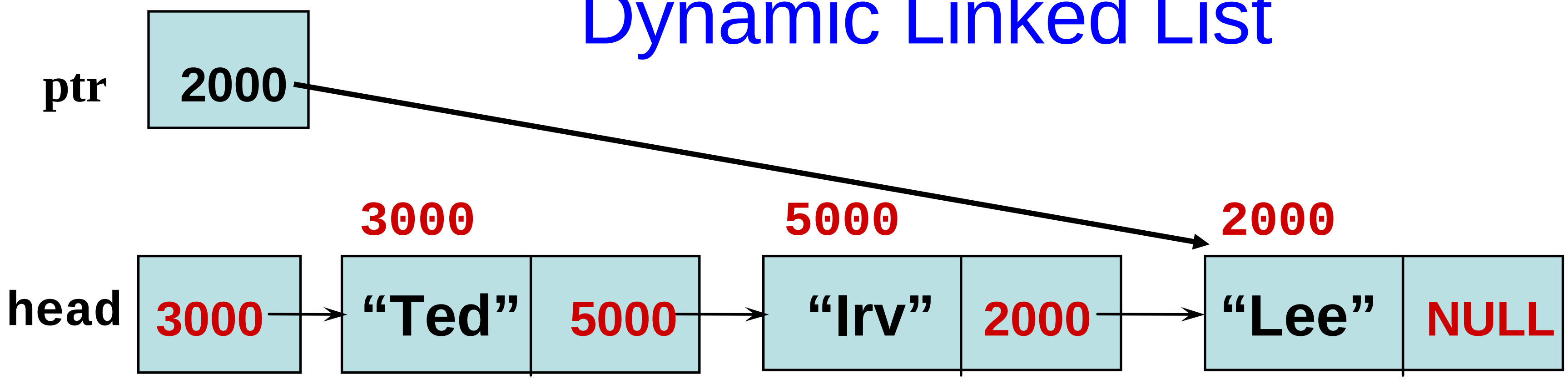

```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
      cout  <<  ptr->info;
     // Or, do something else with node *ptr
     ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List



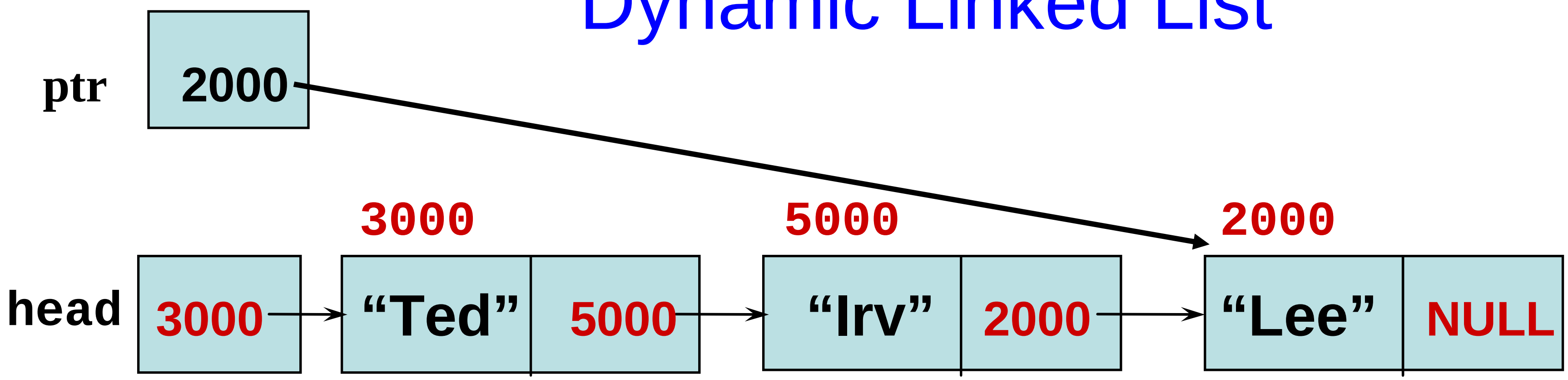

```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
     cout  <<  ptr->info;
     // Or, do something else with node *ptr
     ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List



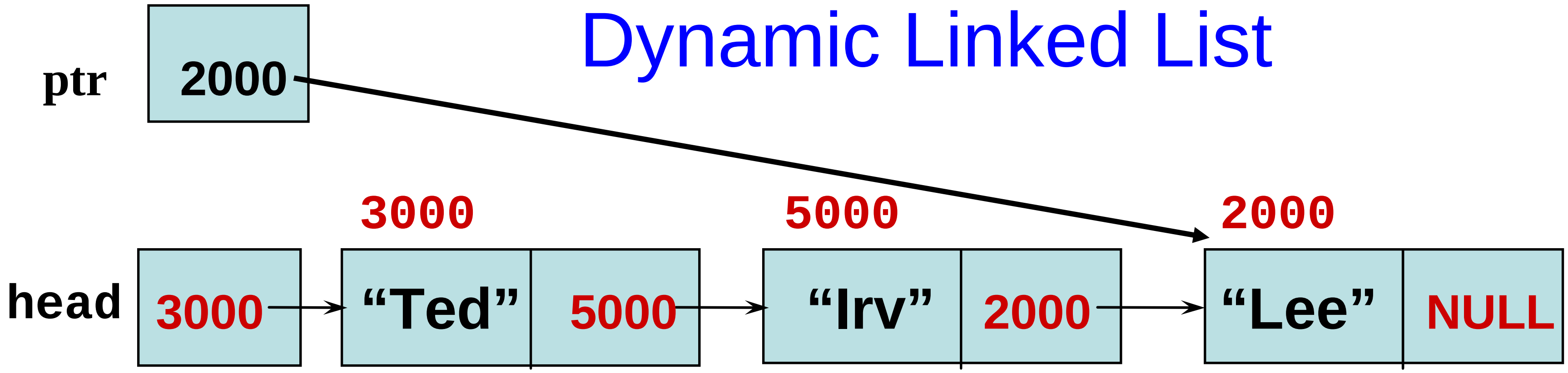

```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
    cout  <<  ptr->info;
    // Or, do something else with node *ptr
    ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List



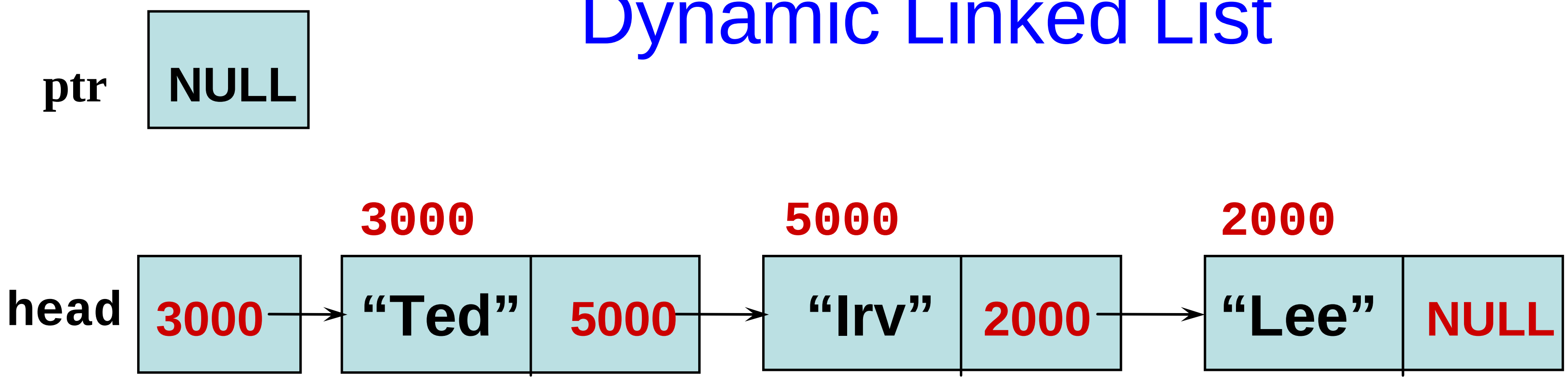

```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
     cout  <<  ptr->info;
    // Or, do something else with node *ptr
    ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List



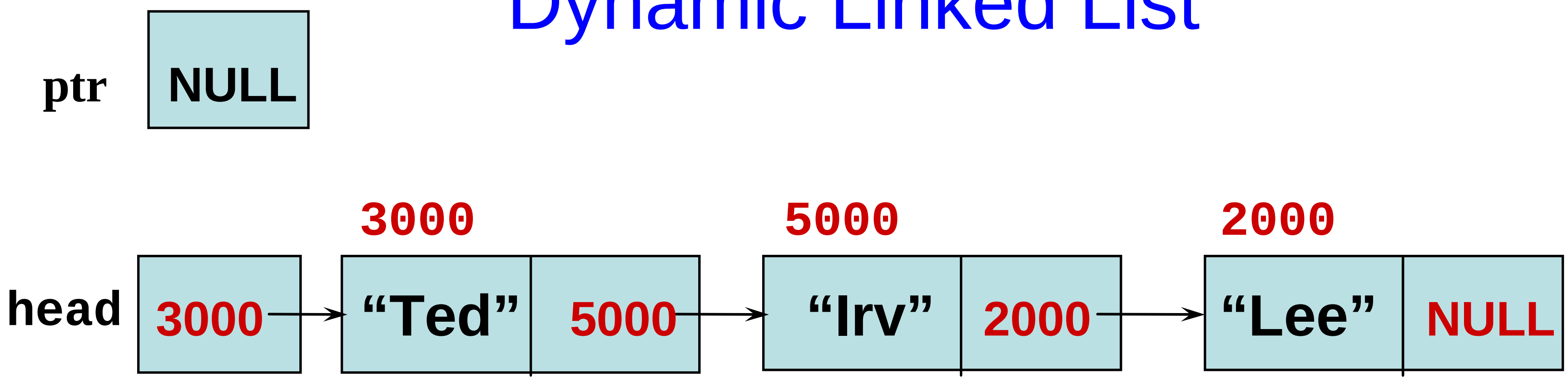

```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
    cout  <<  ptr->info;
    // Or, do something else with node *ptr
    ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List




```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
     cout  <<  ptr->info;
    // Or, do something else with node *ptr
    ptr  =  ptr->link;
}
```

Traversing a Dynamic Linked List




```
// Pre:  head points to a dynamic linked list
ptr  =  head;
while (ptr != NULL)
{
    cout  <<  ptr->info;
   // Or, do something else with node *ptr
   ptr  =  ptr->link;
}
```

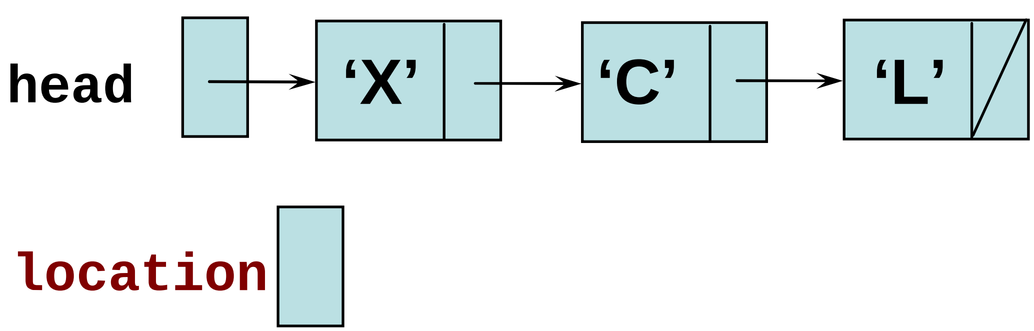
Using Operator new

Recall

- **If memory is available in the free store (or heap), operator new allocates the requested object, and**
- **it returns a pointer to the memory allocated**
- **The dynamically allocated object exists until the delete operator destroys it**

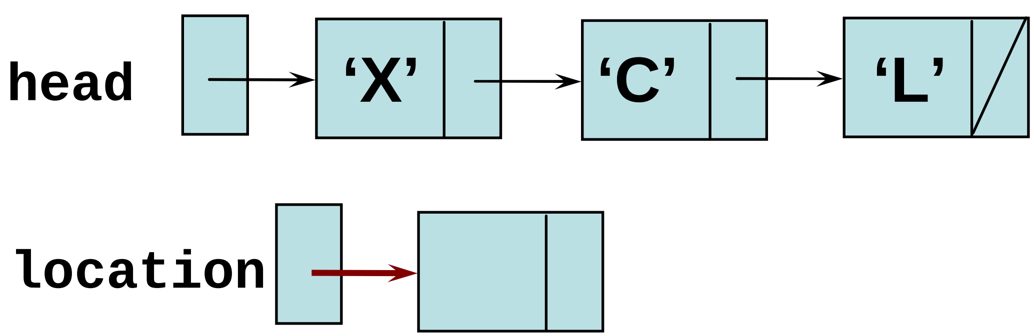
Inserting a Node at the Front of a List

```
char      item = 'B';
NodePtr   location;
location = new  NodeType;
location->info = item;
location->link = head;
head = location;
```

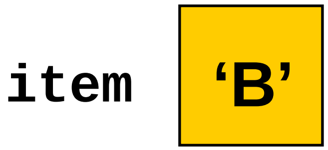


Inserting a Node at the Front of a List


```
char      item = ‘B’;
NodePtr   location;
location = new  NodeType;
location->info = item;
location->link = head;
head = location;
```

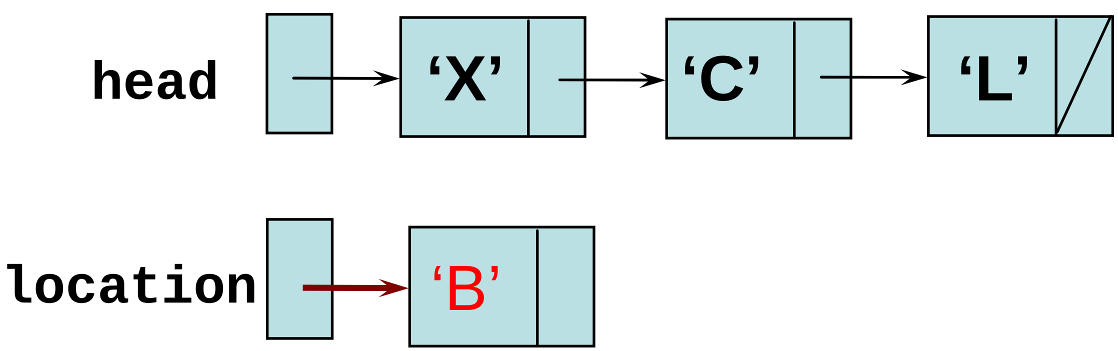


Inserting a Node at the Front of a List




```
char      item = 'B';
NodePtr   location;
location = new  NodeType;
location->info = item;
location->link = head;
head = location;
```

jg1



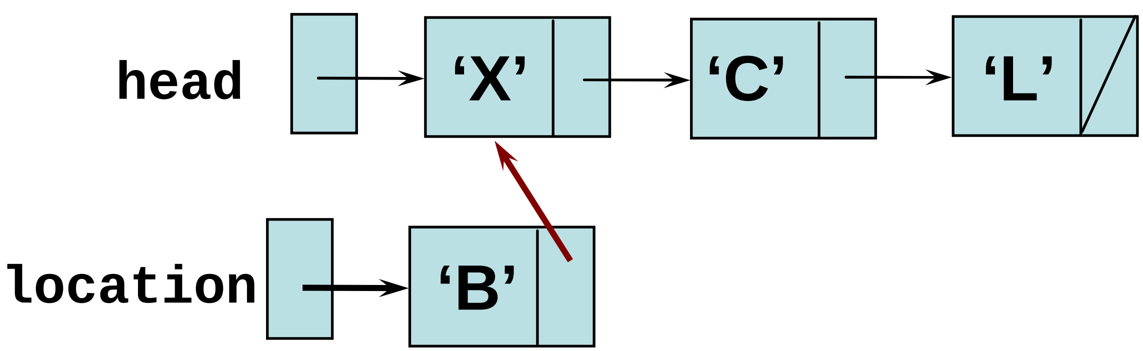
Slide 37

jg1 Again, although the fonts are less than 28", I don't believe it would make logical sense to split the content on slides 38-40 into different slides.
Jeffrey Goldings, 7/6/2009

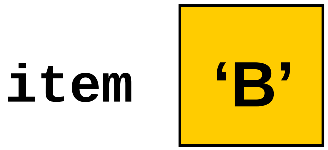
Inserting a Node at the Front of a List

item ‘B’

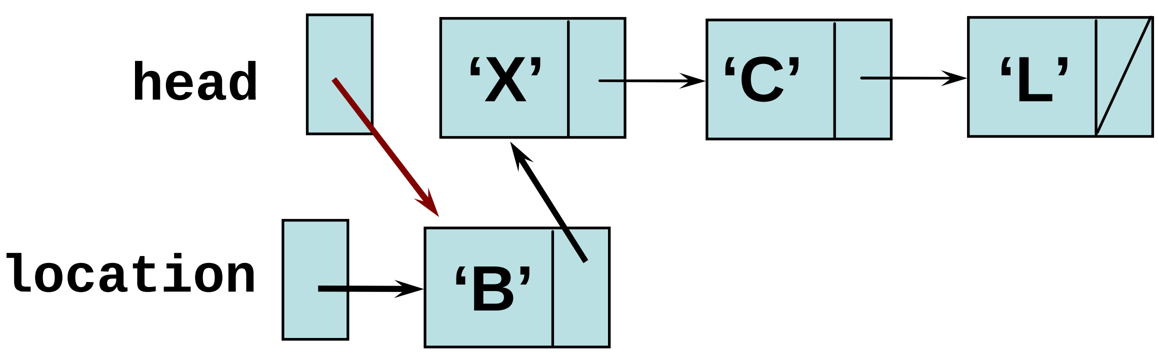
```
char      item = 'B';
NodePtr   location;
location = new  NodeType;
location->info = item;
location->link = head;
head = location;
```



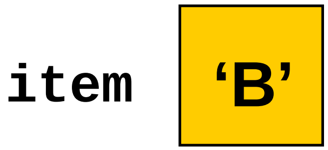
Inserting a Node at the Front of a List



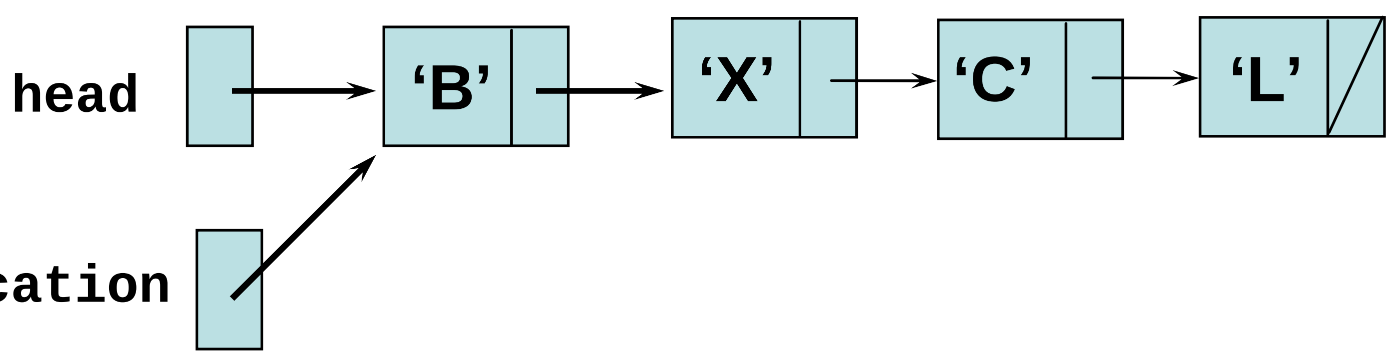

```
char     item = ‘B’;
NodePtr  location;
location = new  NodeType;
location->info = item;
location->link = head;
head = location;
```



Inserting a Node at the Front of a List




```
char      item = 'B';
NodePtr   location;
location = new  NodeType;
location->info = item;
location->link = head;
head = location;
```



Using Operator `delete`

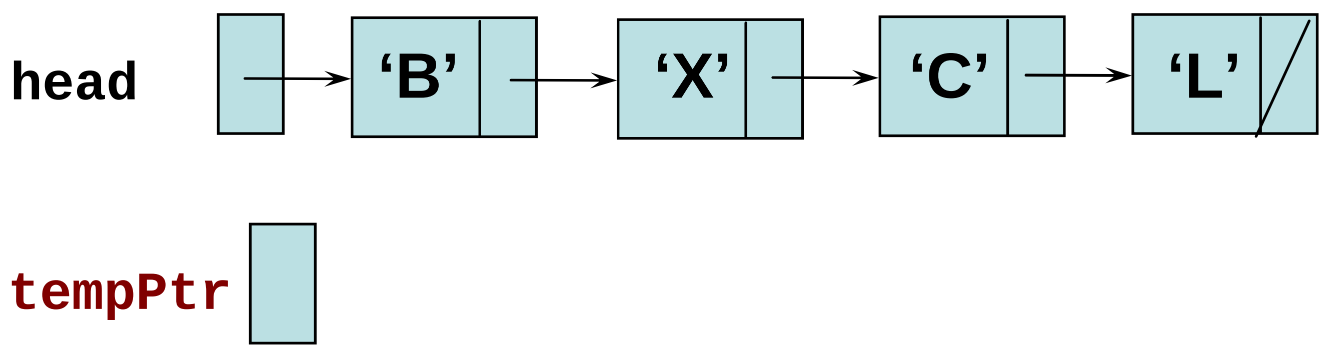
When you use the operator `delete`:

- **The object currently pointed to by the pointer is deallocated and the pointer is considered undefined**
- **The object's memory is returned to the free store**

item ‘B’

Deleting the First Node from the List

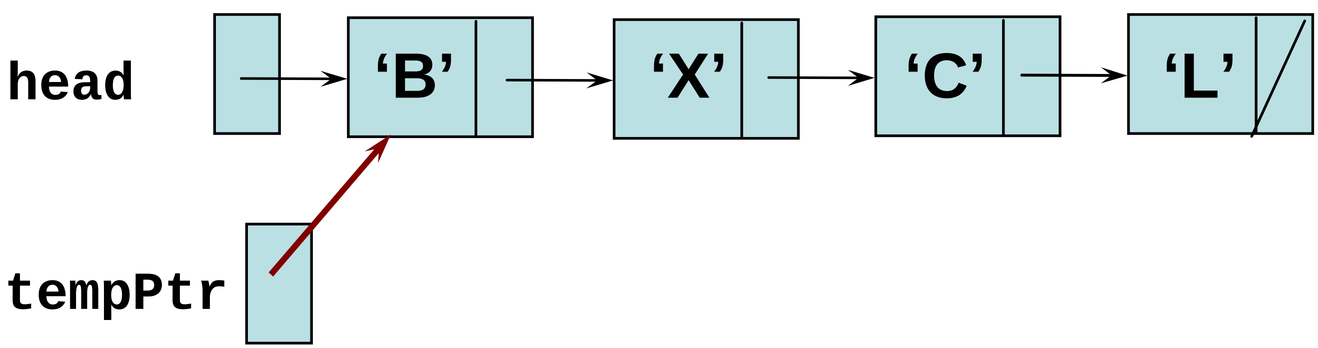
```
NodePtr  tempPtr;

item = head->info;
tempPtr = head;
head = head->link;
delete  tempPtr;
```



item ‘B’

Deleting the First Node from the List

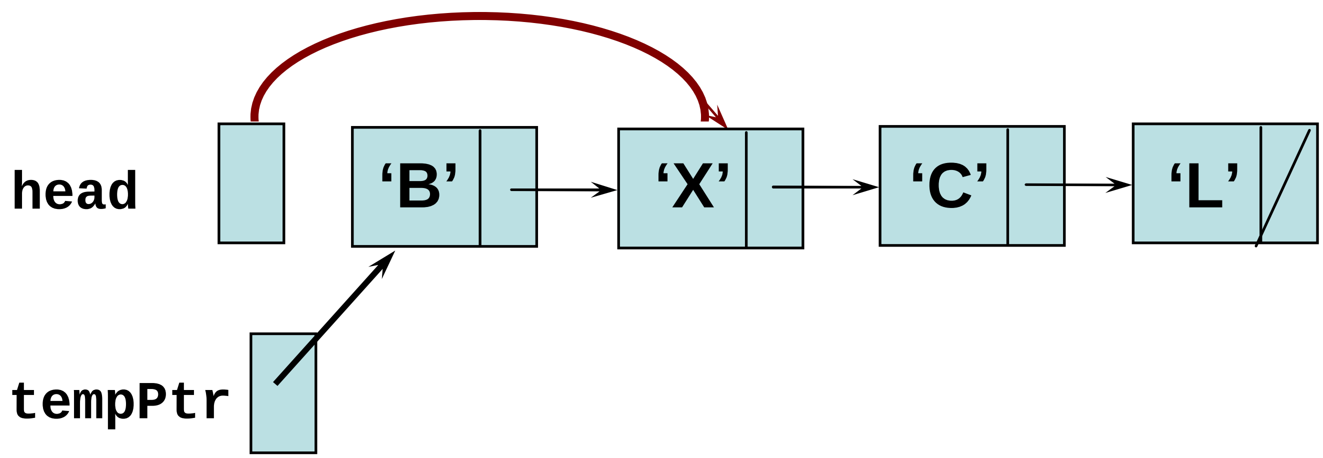
```
NodeType *  tempPtr;

item = head->info;
tempPtr = head;
head = head->link;
delete  tempPtr;
```



item 'B'

Deleting the First Node from the List

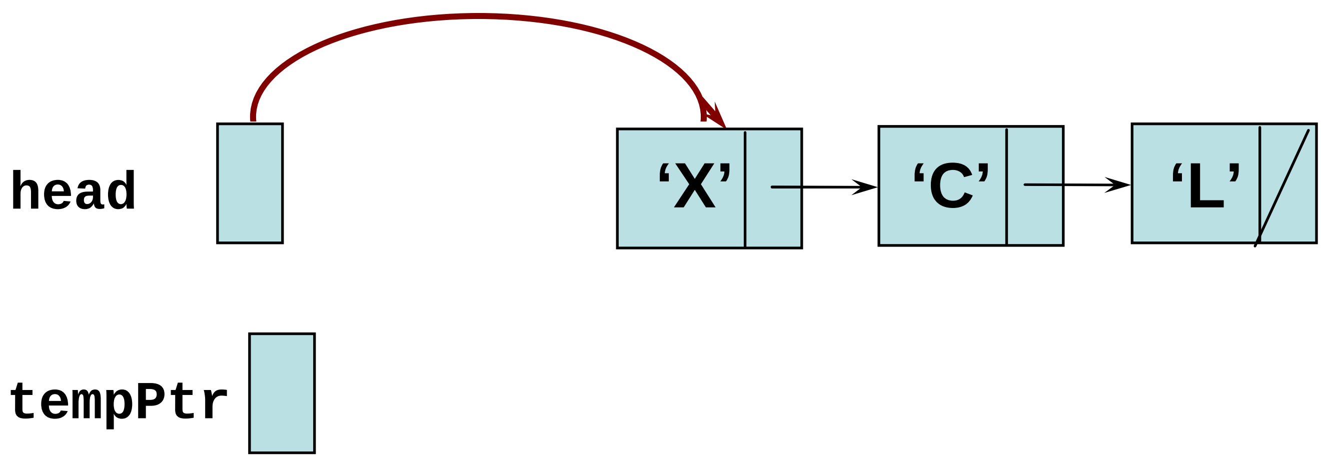
```
NodeType *  tempPtr;

item = head->info;
tempPtr = head;
head = head->link;
delete  tempPtr;
```



item 'B'

Deleting the First Node from the List

```
NodeType *  tempPtr;

item = head->info;
tempPtr = head;
head = head->link;
delete  tempPtr;
```



What is a Sorted List?

A sorted list is:

- **a variable-length, linear collection of homogeneous elements,**
- **ordered according to the value of one or more data members**
- **The transformer operations must maintain the ordering**

What is a Sorted List?

In addition to Insert and Delete, let's add two new operations to our list:

InsertAsFirst* and *RemoveFirst

ADT HybridList Operations

Transformers

- **InsertAsFirst**
- **Insert**
- **RemoveFirst**
- **Delete**

change state

Same observers and iterators as ADT List

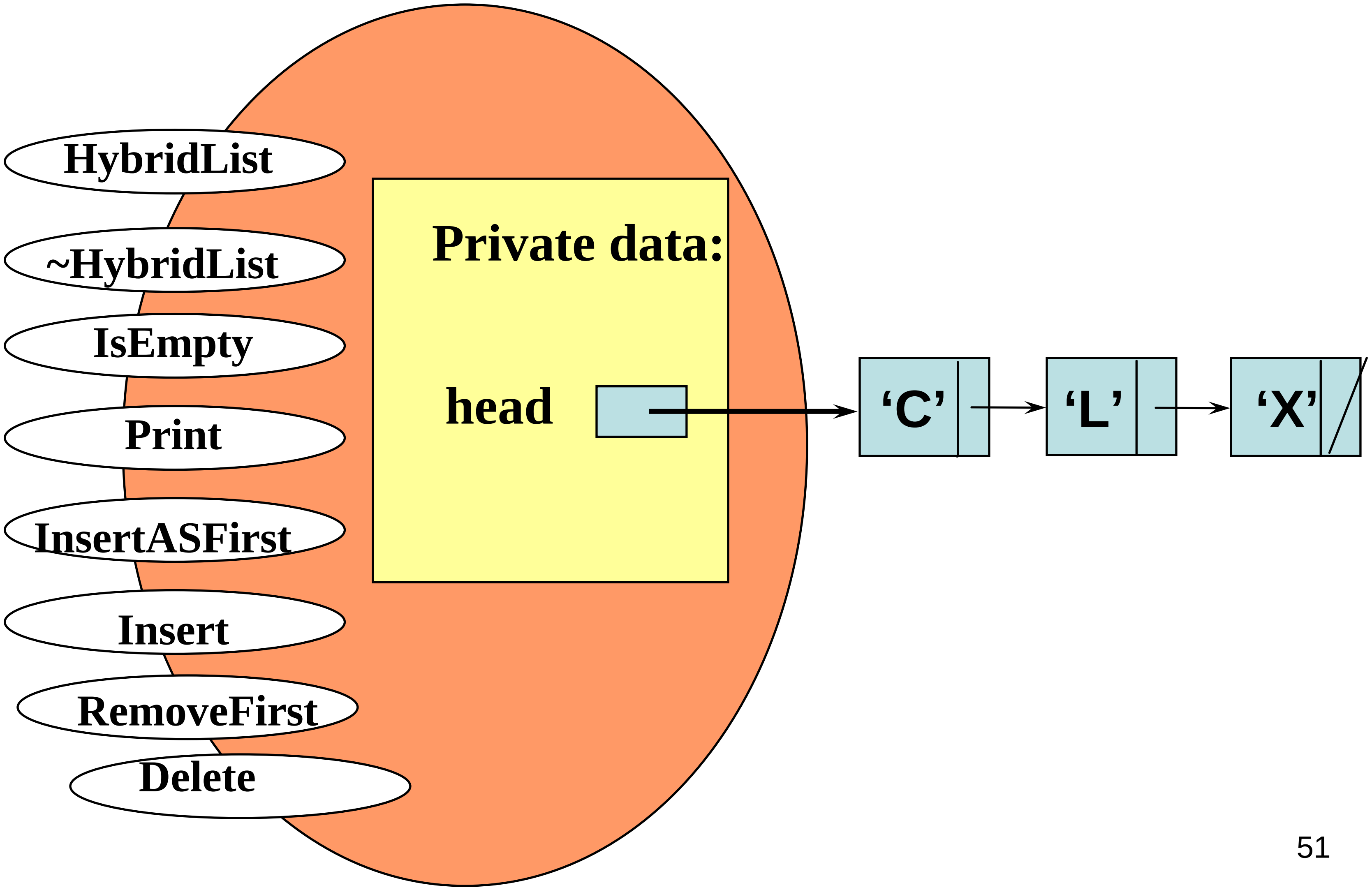
Since we have two insertion and two deletion operations, let’s call this a Hybrid List

struct NodeType

```
// Specification file sorted list (“slist2.h”)

typedef int ItemType;       // Type of each component is
                            // a simple type or a string
struct  NodeType
{
    ItemType item;          // Pointer to person’s name

    NodeType* link;         // Link to next node in list

};


typedef  NodeType*  NodePtr;
```

```
// Specification file  hybrid sorted list("slist2.h")
class  HybridList
{
public:
  bool IsEmpty () const;

  void InsertAsFirst(/* in */ ItemType  item);

    void Insert (/* in */  ItemType  item);

    void RemoveFirst(/* out */  ItemType&  item);

    void Delete (/* in */  ItemType  item);
    void Print () const;

   HybridList ();   // Constructor
    ~HybridList ();  // Destructor
    HybridList (const HybridList&  otherList);
                    // Copy-constructor

private:

    NodeType*  head;
};
```

class HybridList



Insert Algorithm

- ***What will be the algorithm to Insert an item into its proper place in a sorted linked list?***

- ***That is, for a linked list whose elements are maintained in ascending order?***

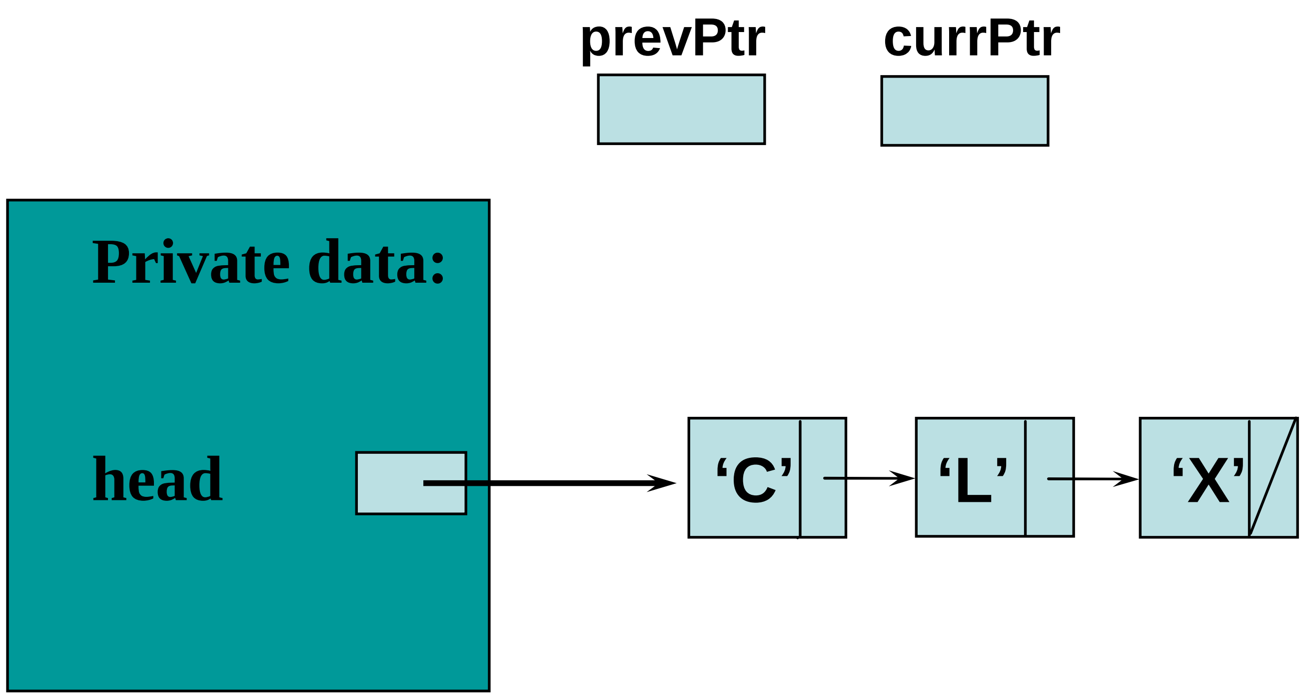
Insert algorithm for `HybridList`

- **Find proper position for the new element in the sorted list using two pointers prevPtr and currPtr, where prevPtr trails behind currPtr**
- **Obtain a new node and place item in it**
- **Insert the new node by adjusting pointers**

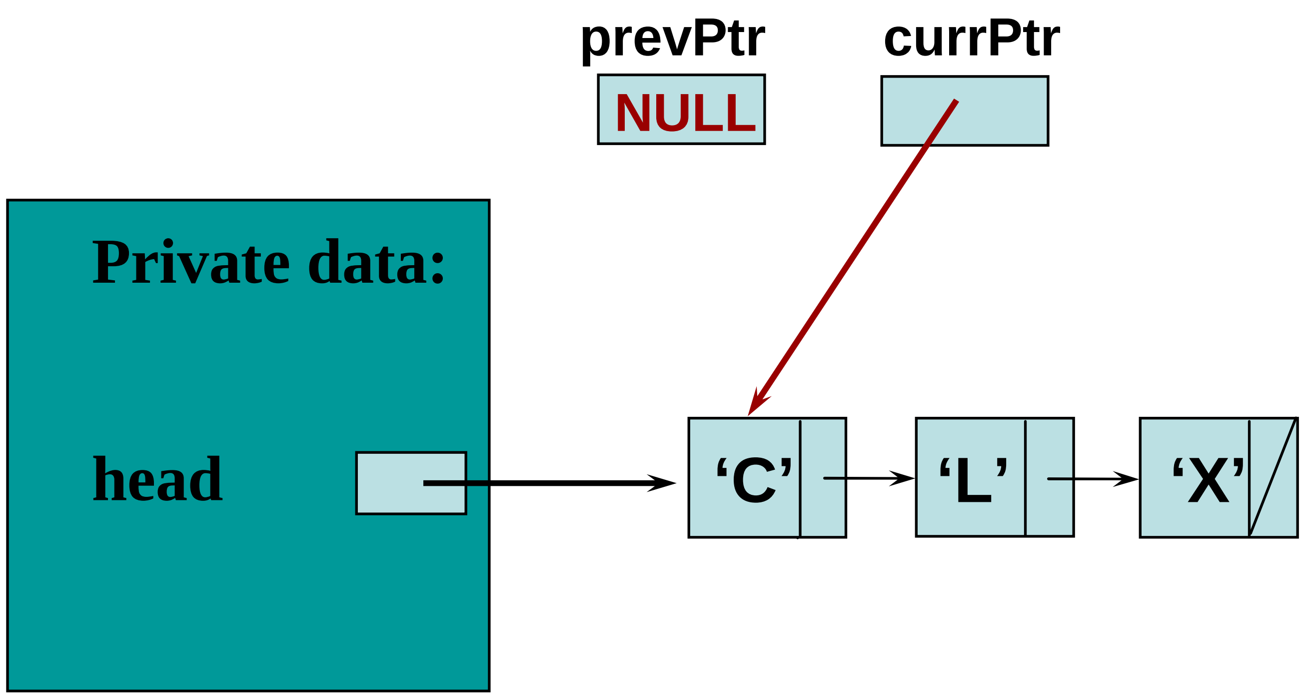
Implementing HybridList Member Function **Insert**

```
// Dynamic linked list implementation ("slist2.cpp")

void  HybridList::Insert (/* in */  ItemType  item)
// PRE:
//     item is assigned && components in ascending order
// POST:
//     item is in List && components in ascending order
{
            .
            .
            .

}
```

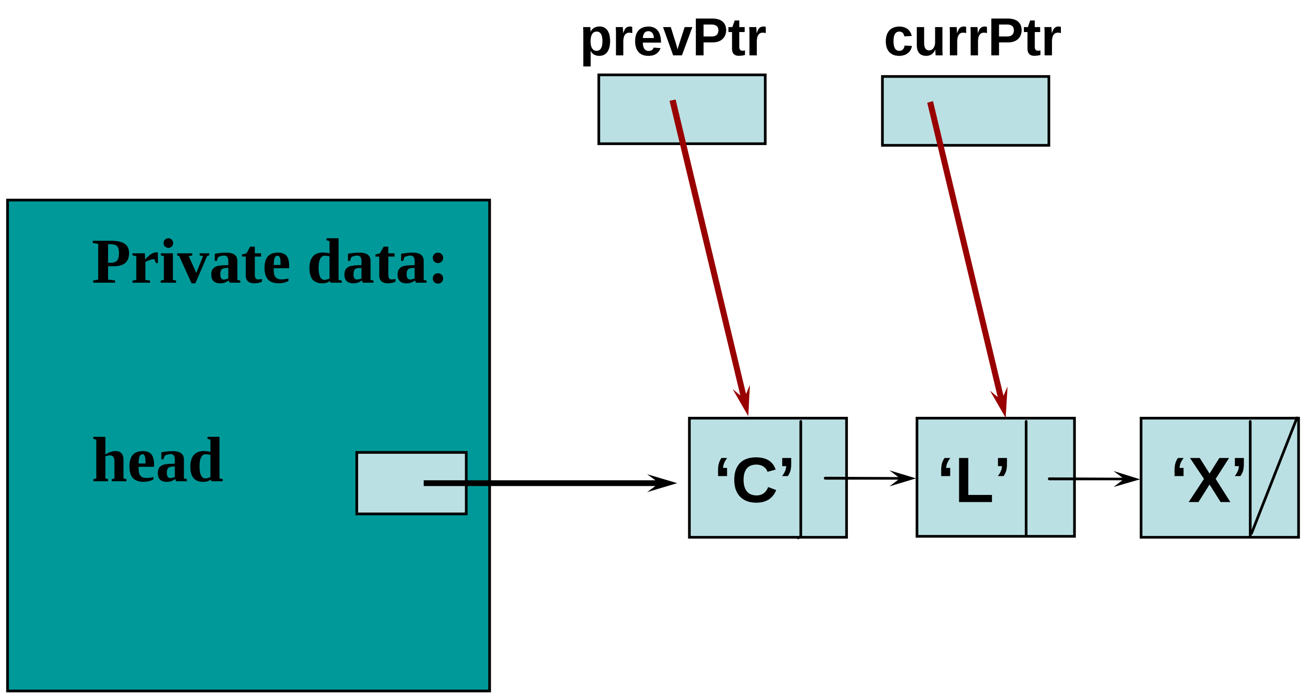
Inserting ‘S’ into a List



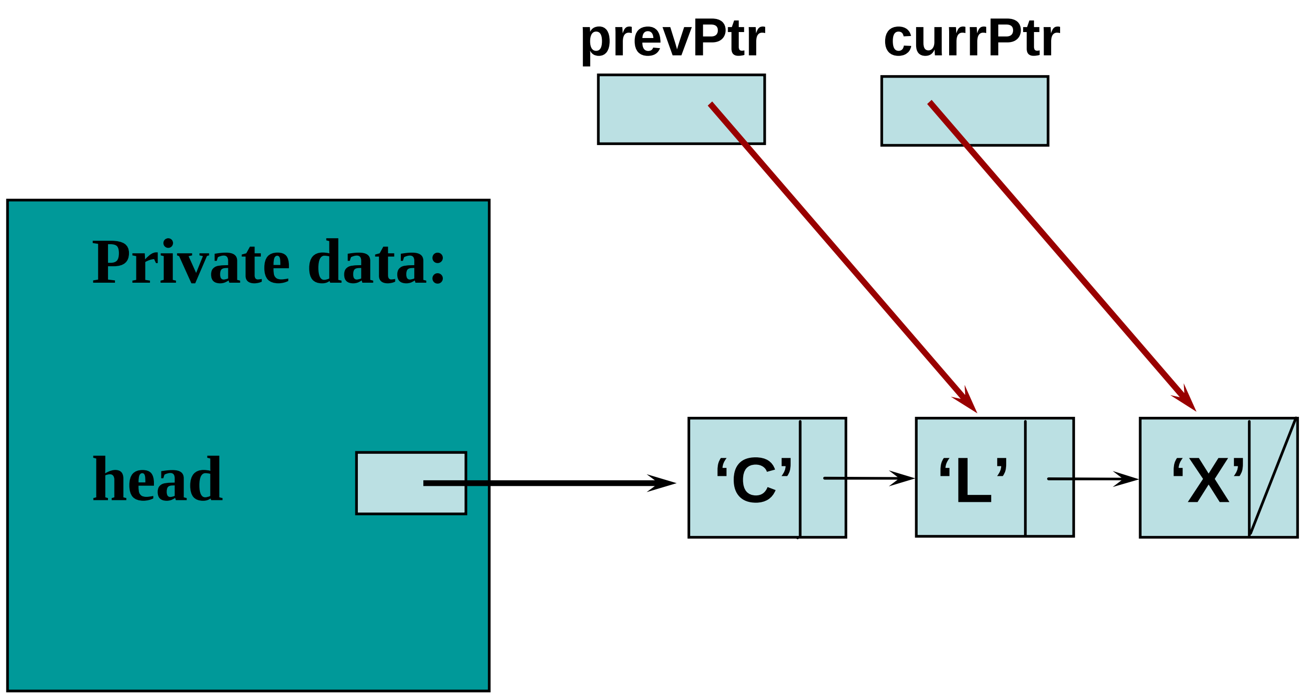
Finding Proper Position for ‘S’



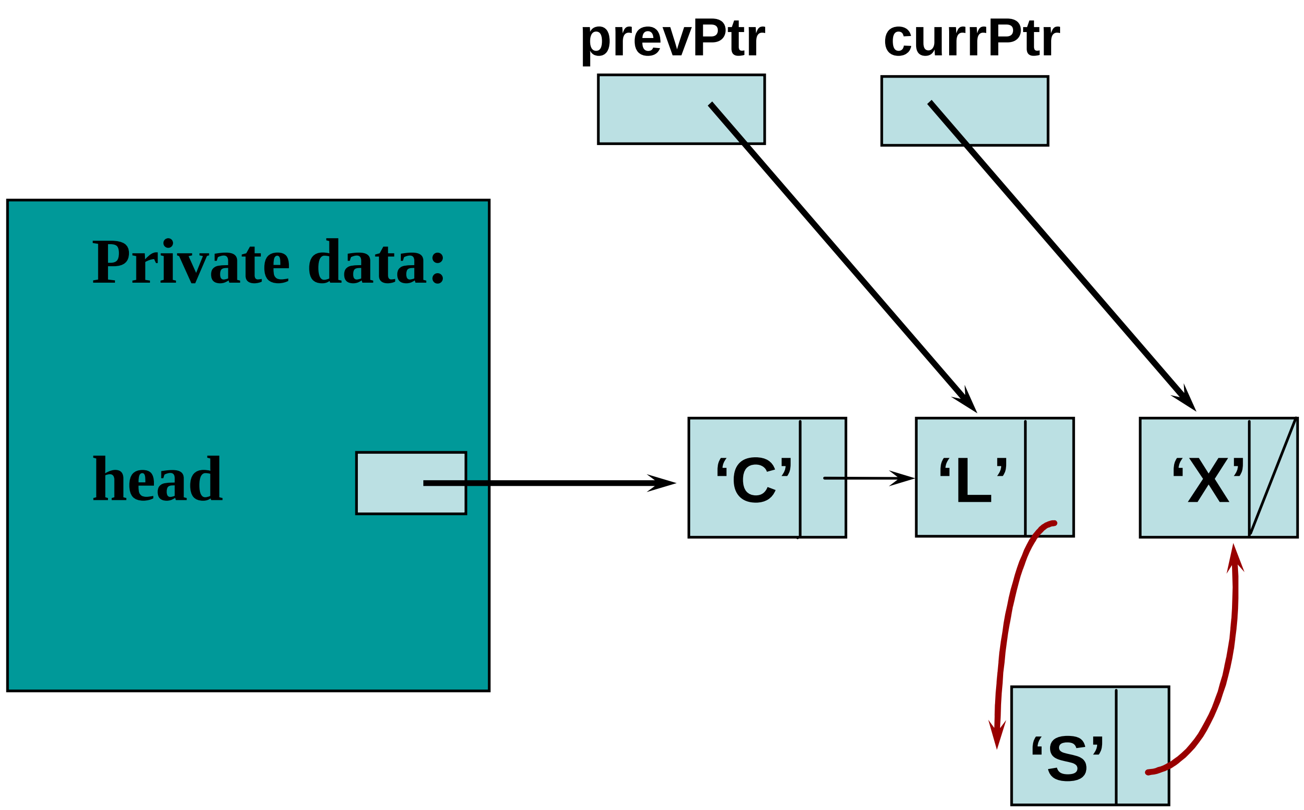
Finding Proper Position for ‘S’



Finding Proper Position for ‘S’



Inserting ‘S’ into Proper Position



```
// Implementation file for HybridList ("slist.cpp")
HybridList::HybridList ()  // Constructor
// Post: head == NULL
{
    head = NULL;
}

HybridList::~HybridList () // Destructor
// Post: All linked nodes deallocated
{
    ItemType  temp;
    // Keep deleting top node
    while (!IsEmpty)
        RemoveFirst (temp);
}
```

```
void  HybridList::Insert(/* in */  ItemType  item)
// Pre: item is assigned &&  components in ascending order
// Post: new node containing item is in its proper place
//      && components in ascending order
{
    NodePtr currPtr;
    NodePtr prevPtr;
    NodePtr location;
    location = new  NodeType;
    newNodePtr->link = item;
    prevPtr = NULL;
    currPtr = head;
    while (currPtr != NULL  &&  item > currPtr->info){
        prevPtr = currPtr;       // Advance both pointers
        currPtr = currPtr->link;
    }
    location->link = currPtr;// Insert new node here
    if (prevPtr == NULL)
        head = location;
    else
        prevPtr->link = location;
}
```

```
void HybridList::InsertAsFirst(/*in*/ ItemType item)
//Pre: item is assigned &&  components in ascending order
//Post: New node containing item is the first item in the list
//      && components in ascending order
{
    NodePtr newNodePtr = new NodeType;

    newNodePtr -> component = item;
    newNodePtr -> link = head;
    head = newNodePtr;
}
```

```
Void HybridList::Print() const
// Post: All values within nodes have been printed
{
    NodePtr currPtr = head; //Loop control pointer
    while (currPtr != NULL)
    {
        cout << currPtr->component << endl;
        currPtr = currPtr->link;
    }
}
```

```
void HybridList::RemoveFirst (/*out*/ ItemType& item)
// Pre: list is not empty && components in ascending
// order
// Post: item == element of first list node @ entry
//    &&  node containing item is no longer in list
//    &&  list components in ascending order
{
    NodePtr  tempPtr = head;

    // Obtain item and advance head
    item = head->info ;
    head = head->link;
    delete  tempPtr;
}
```

```
void  HybridList::Delete (/*in*/ ItemType item)
//  Pre: list is not empty && components in ascending order
//      &&  item == component member of some list node
// Post: item == element of first list node @ entry
//      &&  node containing first occurrence of item no longer
//      in list   &&  components in ascending order
{
    NodePtr   delPtr;
    NodePtr   currPtr; // Is item in first node?
    if (item == head->info)
    {  // If so, delete first node
        delPtr = head;
        head = head->link;
    }
    else {// Search for item in rest of list
    {
        currPtr = head;
        while (currPtr->link->info  !=  item)
            currPtr = currPtr->link;
        delPtr = currPtr->link;
        currPtr->link = currPtr->link->link;
     }
    delete  delPtr;
}
```

Recall that . . .

char str [8];

`str` is the base address of the array. We say `str` is a pointer because its value is an address. It is a pointer constant because the value of `str` itself cannot be changed by assignment. It "points" to the memory location of a `char`.

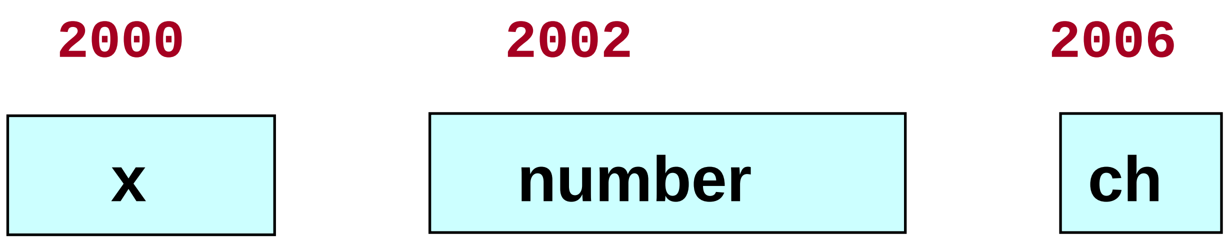
6000

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

Addresses in Memory

- **When a variable is declared, enough memory to hold a value of that type is allocated for it at an unused memory location. This is the address of the variable**

```
int      x;
float    number;
char     ch;
```



Obtaining Memory Addresses

- **the address of a non-array variable can be obtained by using the address-of operator &**

```
int     x;
float   number;
char    ch;

cout << “Address of x is “ << &x << endl;

cout << “Address of number is “ << &number << endl;

cout << “Address of ch is “ << &ch << endl;
```

What is a pointer variable?

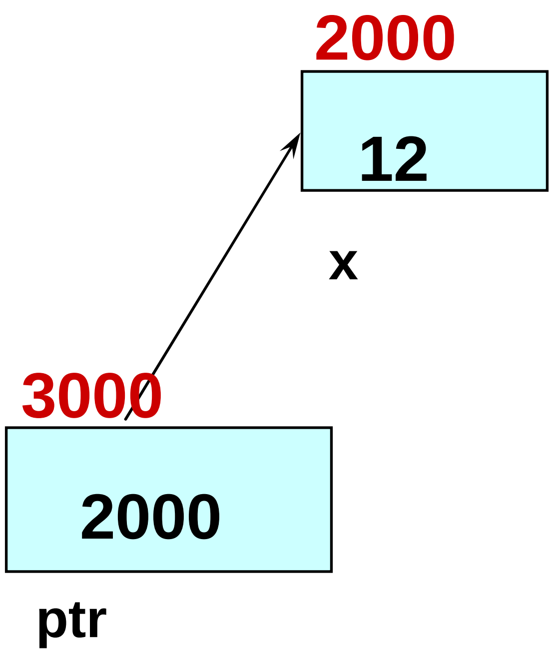
- **A pointer variable is a variable whose value is the address of a location in memory**

- **To declare a pointer variable, you specify the type of value that the pointer will point to, for example:**

```
int*   ptr; // ptr will hold the address of an int

char*  q;   // q will hold the address of a char
```

Using a Pointer Variable

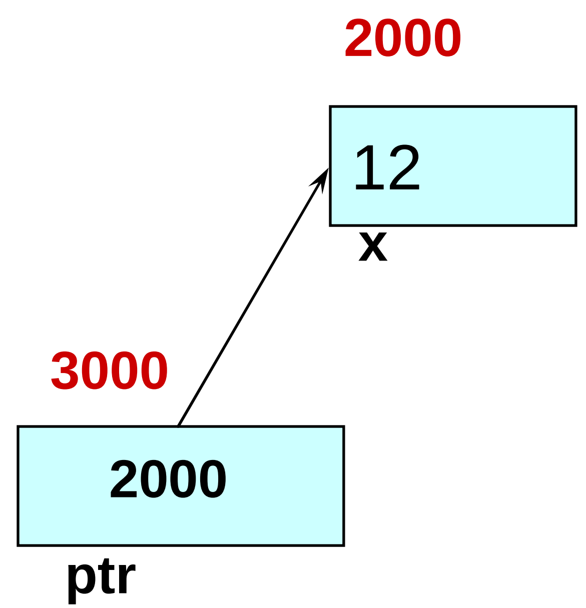
```
int  x;
x = 12;


int*  ptr;
ptr = &x;
```



NOTE: Because ptr holds the address of x, we say that ptr “points to” x

Unary operator * is the indirection (deference) operator

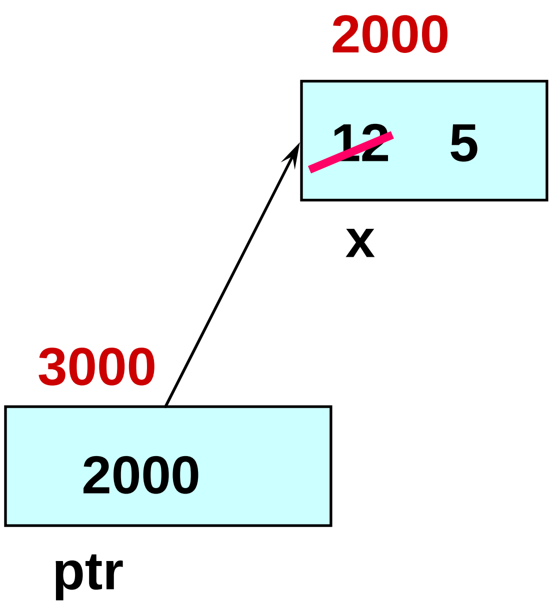
```
int  x;
x = 12;


int*  ptr;
ptr = &x;

cout  <<  *ptr;
```



NOTE: The value pointed to by ptr is denoted by *ptr

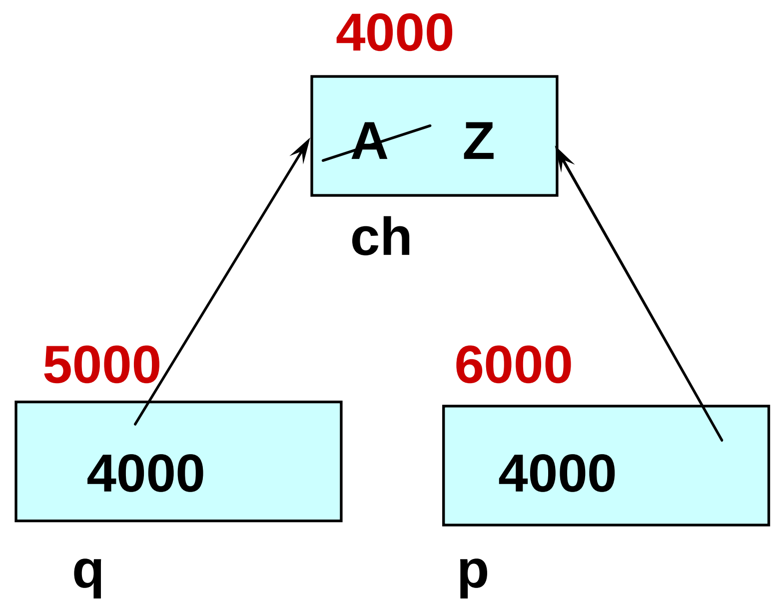
Using the Dereference Operator

```
int  x;
x = 12;

int*  ptr;
ptr = &x;

*ptr = 5;
// Changes the value
// at address ptr to 5
```



Another Example

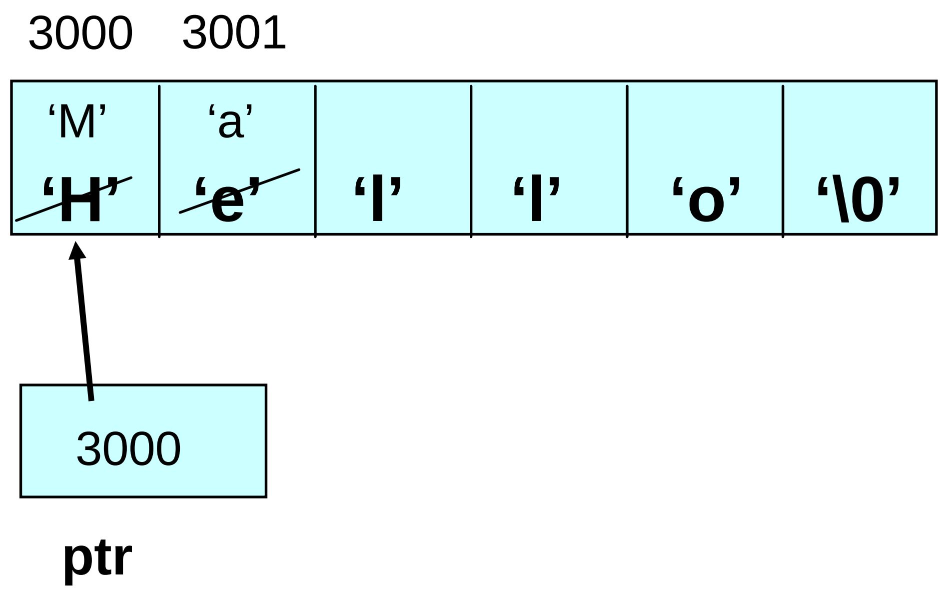
```
char  ch;
ch =  'A';

char*  q;
q  = &ch;

*q = 'Z';
char*  p;
p = q;
```




```
// The rhs has value 4000
// Now p and q both point to ch
```

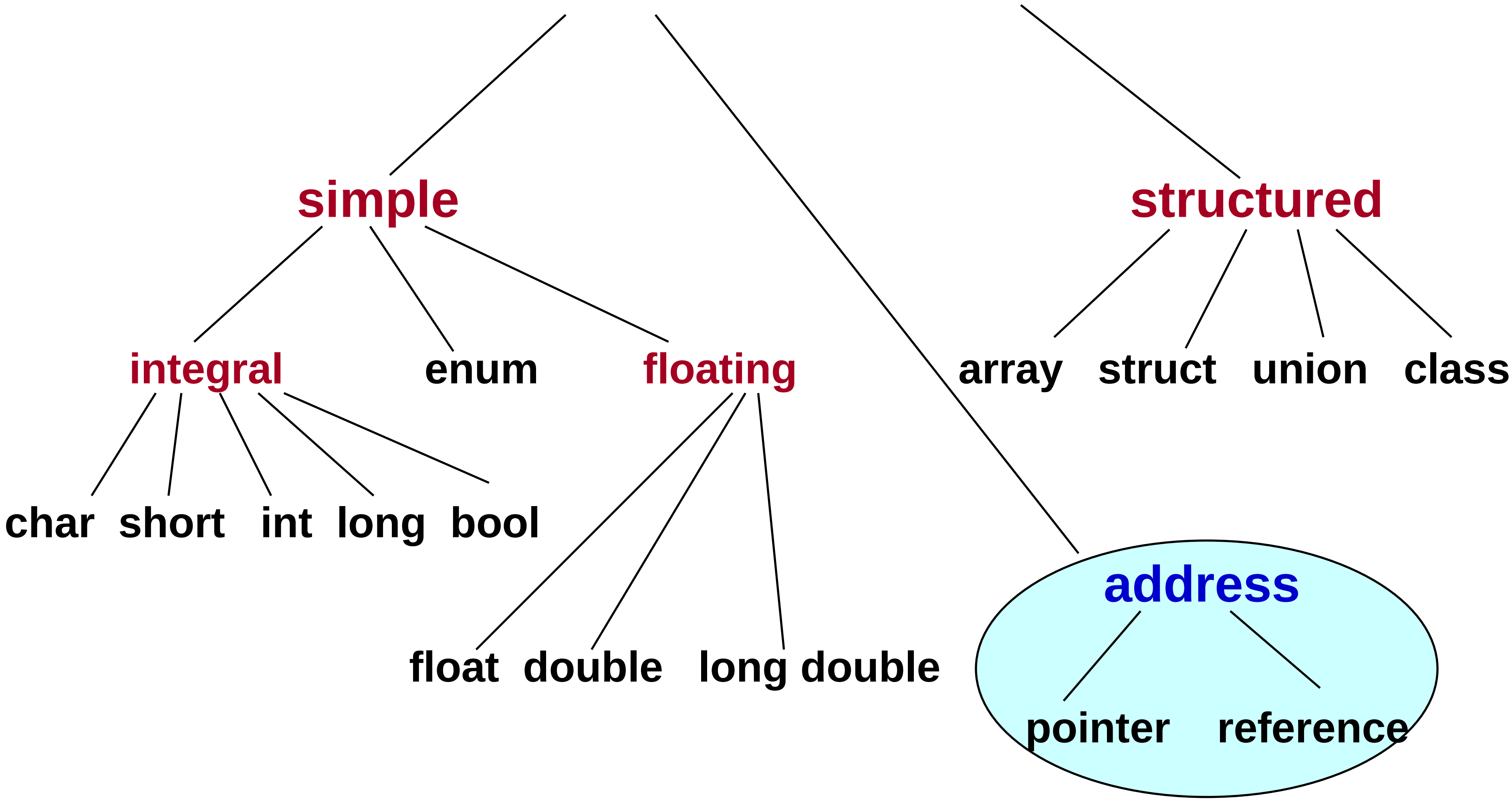
Using a Pointer to Access the Elements of a String

```
char msg[ ]="Hello";



char*  ptr;
ptr  =  msg;
// Recall that msg ==
//  &msg[ 0 ]
*ptr  = 'M';

ptr++;
// Increments the address

*ptr = 'a';
// in ptr
```



```
int StringLength (/* in */ const char str])
// Precondition: str  is a null-terminated string
// Postcondition:  Return value == length of str
//   (not counting '\0')

{
    char* p;
    int count = 0;

    p = str;

    while (*p != '\0')
    {
        count++;
        p++;
        // Increments the address p by sizeof char
    }

    return count;
}
```

C++ Data Types


simple
structured
integral
enum
floating
array
struct
union
class
char
short
int
long
bool
float
double
long double
address
pointer
reference

Some C++ Pointer Operations

Precedence

Higher	**->**	**Select member of class pointed to**
Unary:	++ -- ! * new delete **Increment, Decrement, NOT, Dereference, Allocate, Deallocate**	
Binary:	+ -	Add Subtract
	< <= > >=	Relational operators
	== !=	Tests for equality, inequality
Lower	=	Assignment

Operator new Syntax

```
new  DataType
```

```
new  DataType  [IntExpression]
```

If memory is available in an area called the heap (or free store), new allocates space for the requested object or array and returns a pointer to (address of) the memory allocated

Operator new Syntax, cont...

```
new   DataType
```

```
new   DataType  [IntExpression]
```

Otherwise, program terminates with error message

The dynamically allocated object exists until the delete operator destroys it

The **NULL** Pointer

NULL is a pointer constant 0, defined in header file cstddef, that means that the pointer points to nothing

It is an error to dereference a pointer whose value is NULL

Such an error may cause your program to crash, or behave erratically

```
while (ptr != NULL)
{
  . . . // Ok to use *ptr here
}
```

Three Kinds of Program Data

- **Static data:** **memory allocation exists throughout execution of program**

```
static long currentSeed;
```

- **Automatic data: automatically created at function entry, resides in activation frame of the function, and is destroyed when returning from function**

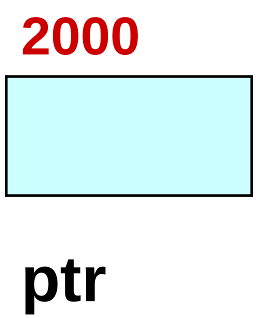
- **Dynamic data:** **explicitly allocated and deallocated during program execution by C++ instructions written by programmer using operators `new` and `delete`**

Allocation of Memory

STATIC ALLOCATION	DYNAMIC ALLOCATION
Static allocation is the allocation of memory space at compile time	**Dynamic allocation is the allocation of memory space at run time by using operator new**

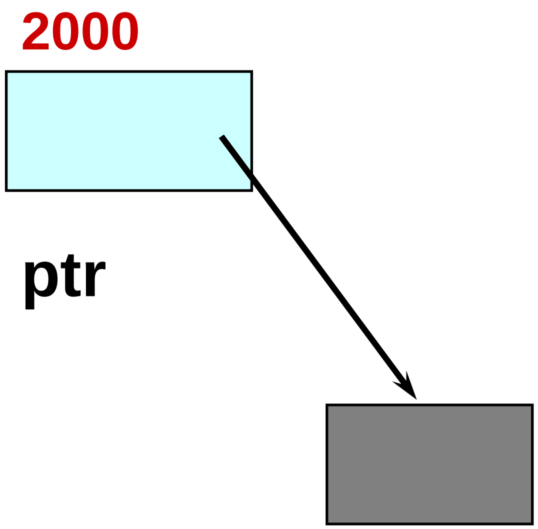
Dynamically Allocated Data

```
char*  ptr;

ptr = new char;

*ptr = ‘B’;

cout  <<  *ptr;
```



Dynamically Allocated Data

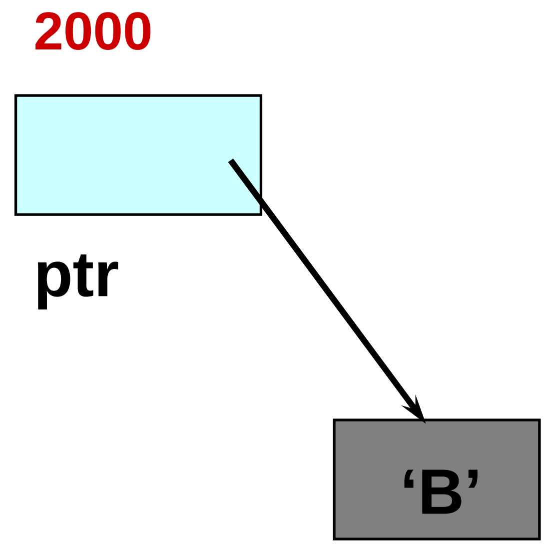
```
char*  ptr;

ptr = new char;
*ptr = ‘B’;

cout  <<  *ptr;
```



NOTE: Dynamic data has no variable name

Dynamically Allocated Data

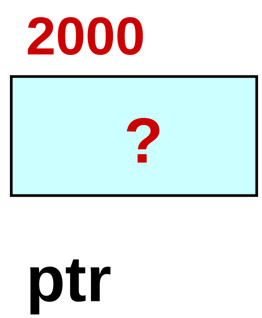
```
char*  ptr;


ptr = new char;
*ptr = ‘B’;
cout  <<  *ptr;
```



NOTE: Dynamic data has no variable name

Dynamically Allocated Data

```
char*  ptr;


ptr = new char;

*ptr = 'B';

cout  <<  *ptr;

delete  ptr;
```



NOTE: delete deallocates the memory pointed to by ptr

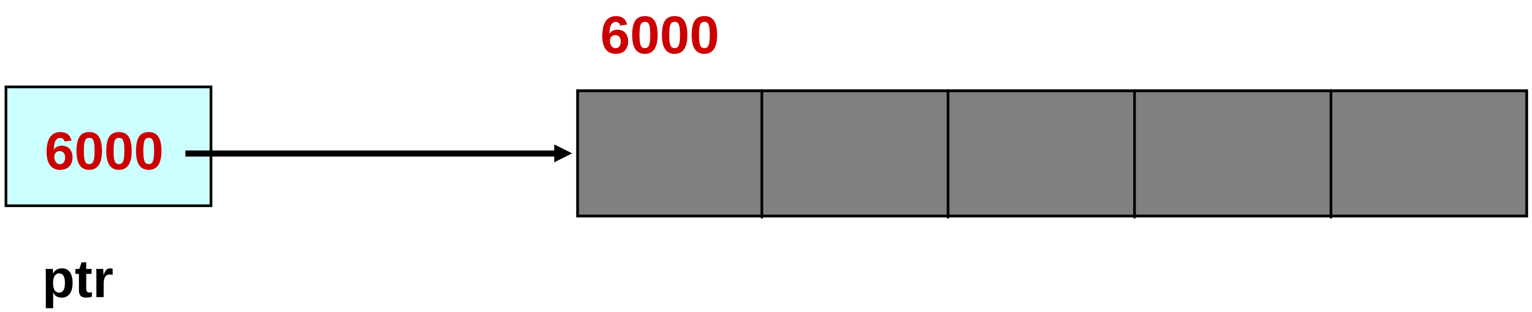
Using Operator `delete`

- **Operator delete returns memory to the free store, which was previously allocated at run-time by operator new**

- **The object or array currently pointed to by the pointer is de-allocated, and the pointer is considered unassigned**

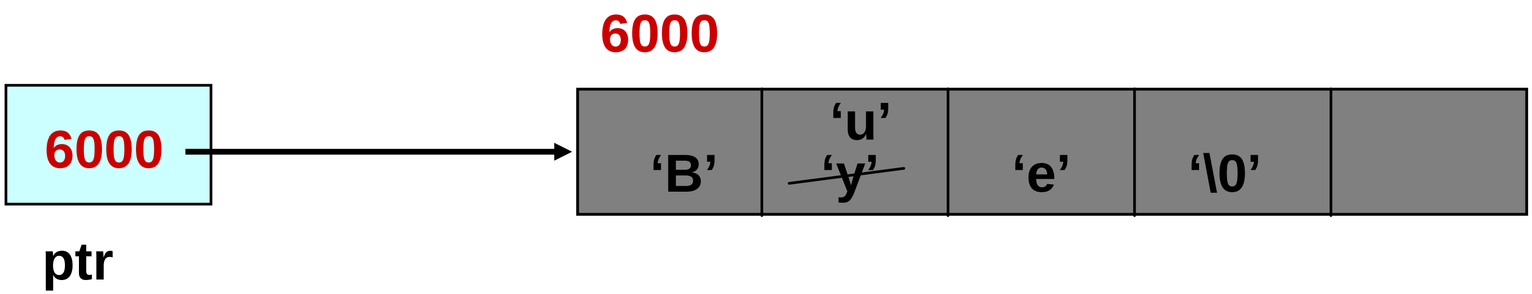
Dynamic Array Allocation

```
char *ptr;// ptr is a pointer variable that
          //  can hold the address of a char

ptr  =  new  char[ 5 ];
// Allocates memory for a 5-character array
//  dynamically at run time and stores the
//  base address into ptr
```



Dynamic Array Allocation

```
char  *ptr;

ptr  =  new  char[ 5 ];

strcpy(ptr, “Bye”);

ptr[ 1 ] = ‘u’;
// A pointer can be subscripted

cout  << ptr[ 2];
```



Operator `delete` Syntax

```
delete Pointer
```

```
delete [ ] Pointer
```

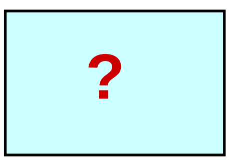
If the value of the pointer is NULL there is no effect.

Otherwise, the object or array currently pointed to by Pointer is de-allocated, and the value of Pointer is undefined.

The memory is returned to the free store Square brackets are used with delete to de-allocate a dynamically allocated array.

Dynamic Array Deallocation

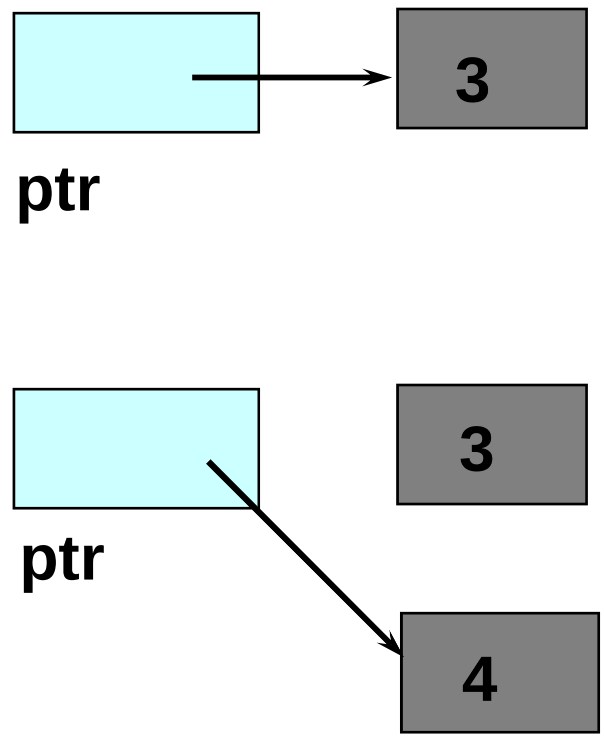
```
char *ptr;
ptr = new char[ 5 ];

strcpy(ptr, “Bye”);
ptr[ 1 ] = ‘u’;
delete  ptr;
// Deallocates array pointed to by ptr
// ptr itself is not deallocated
// The value of ptr is undefined
```



ptr

What happens here?

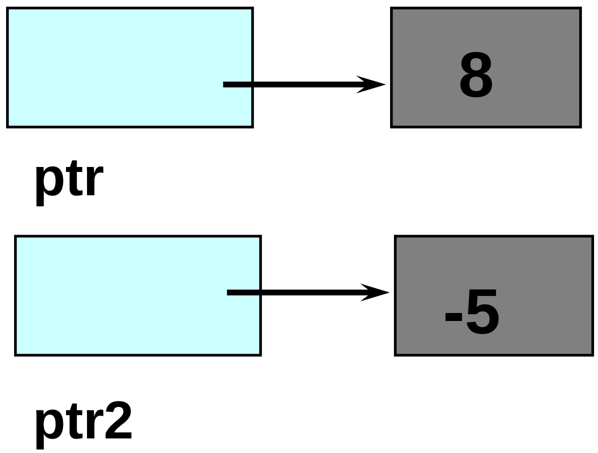
```
int* ptr = new int;
*ptr = 3;

ptr = new int;

//Changes value of ptr
*ptr = 4
```



Inaccessible Object

An inaccessible object is an unnamed object created by operator new that a programmer has left without a pointer to it.

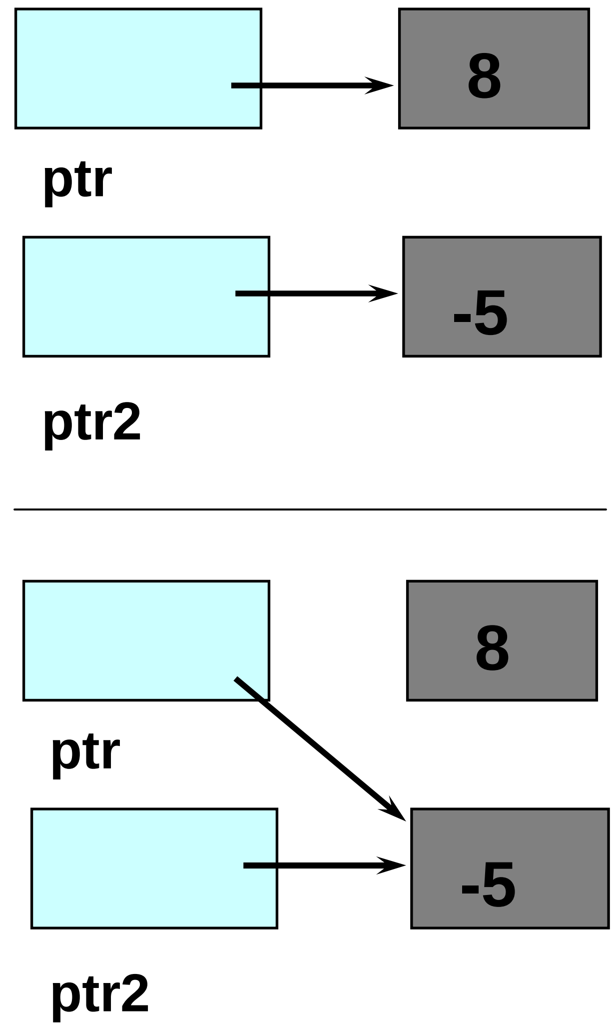
```
int* ptr = new int;
*ptr = 8;
int* ptr2 = new int;
*ptr2 = -5;
```



How else can an object become inaccessible?

Making an Object Inaccessible

```
int* ptr = new int;
*ptr = 8;
int* ptr2 = new int;
*ptr2 = -5;

ptr = ptr2;
//Here the 8 becomes
// inaccessible
```



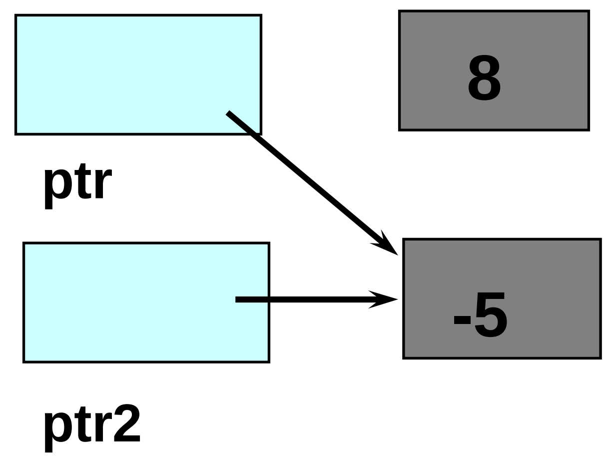
Memory Leak

A memory leak is the loss of available memory space that occurs when dynamic data is allocated but never de-allocated

A Dangling Pointer

- **A dangling pointer** **is a pointer that points to dynamic memory that has been de-allocated**

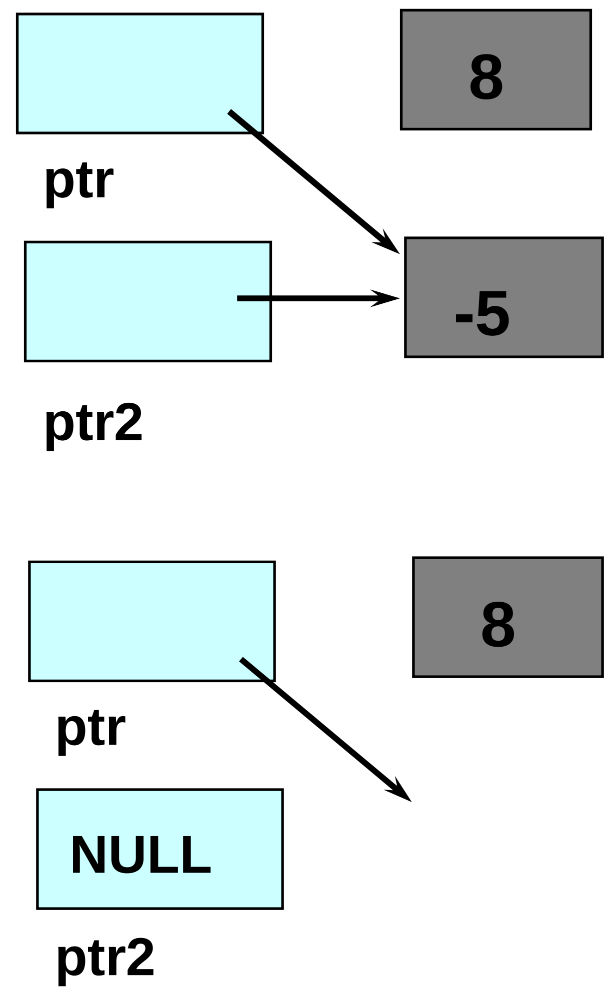
```
int* ptr = new int;
 *ptr = 8;
 int* ptr2 = new int;
 *ptr2 = -5;
 ptr = ptr2;
```



For example,

Leaving a Dangling Pointer

```
int* ptr = new int;
*ptr = 8;
int* ptr2 = new int;
*ptr2 = -5;
ptr = ptr2;




delete ptr2;
//ptr is left dangling
ptr2 = NULL;
```

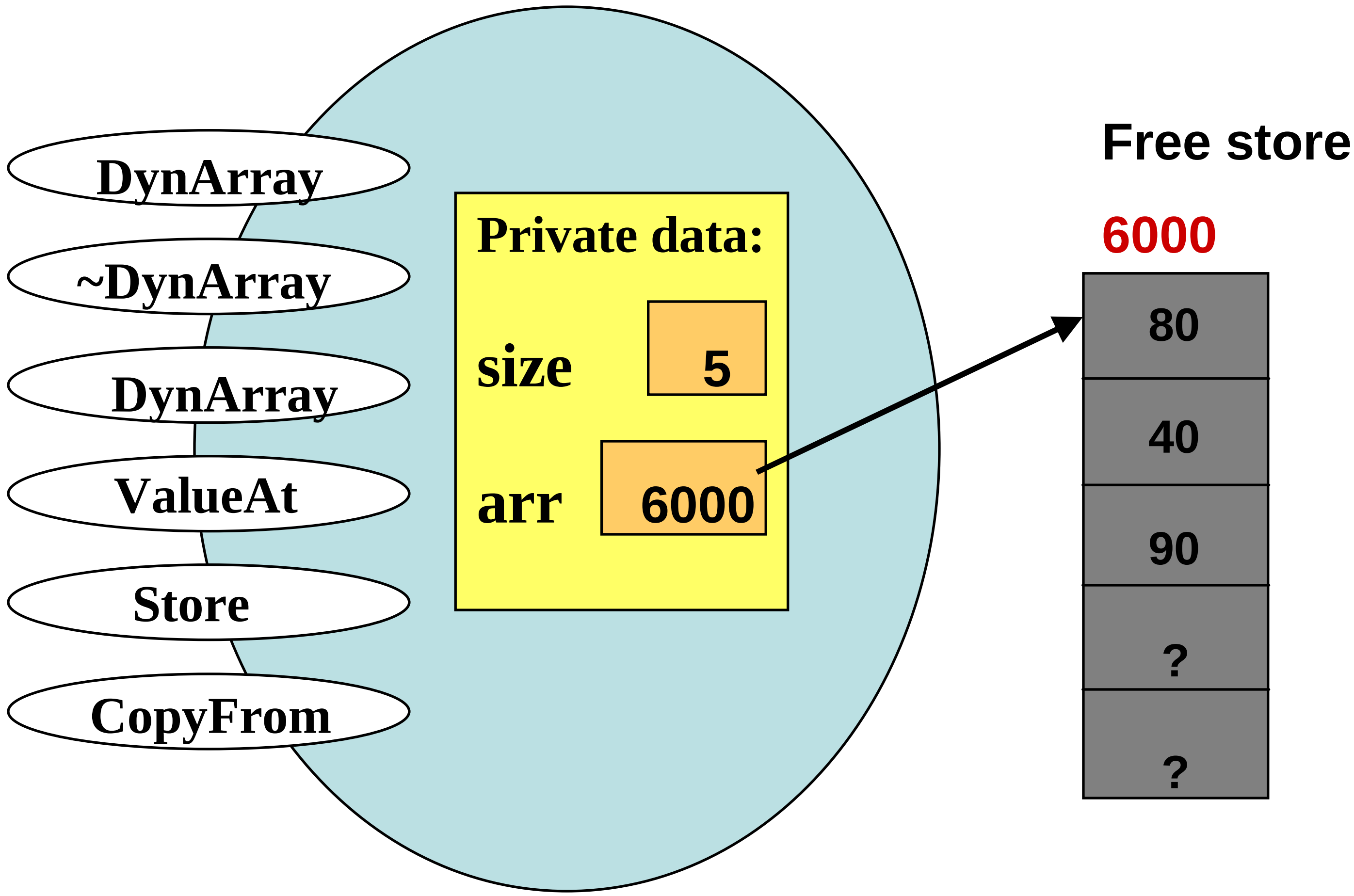


```
// Specification file (“dynarray.h”)
// Safe integer array class allows run-time specification
// of size, prevents indexes from going out of bounds,
// allows aggregate array copying and initialization
// Specification file continued

class DynArray
{
public:
    DynArray(/* in */  int arrSize);

       // Constructor
      // PRE:  arrSize is assigned
      // POST:  IF arrSize >= 1 && enough memory
      //  THEN
      //  Array of size arrSize is created with
      //  all elements == 0  ELSE error message
```

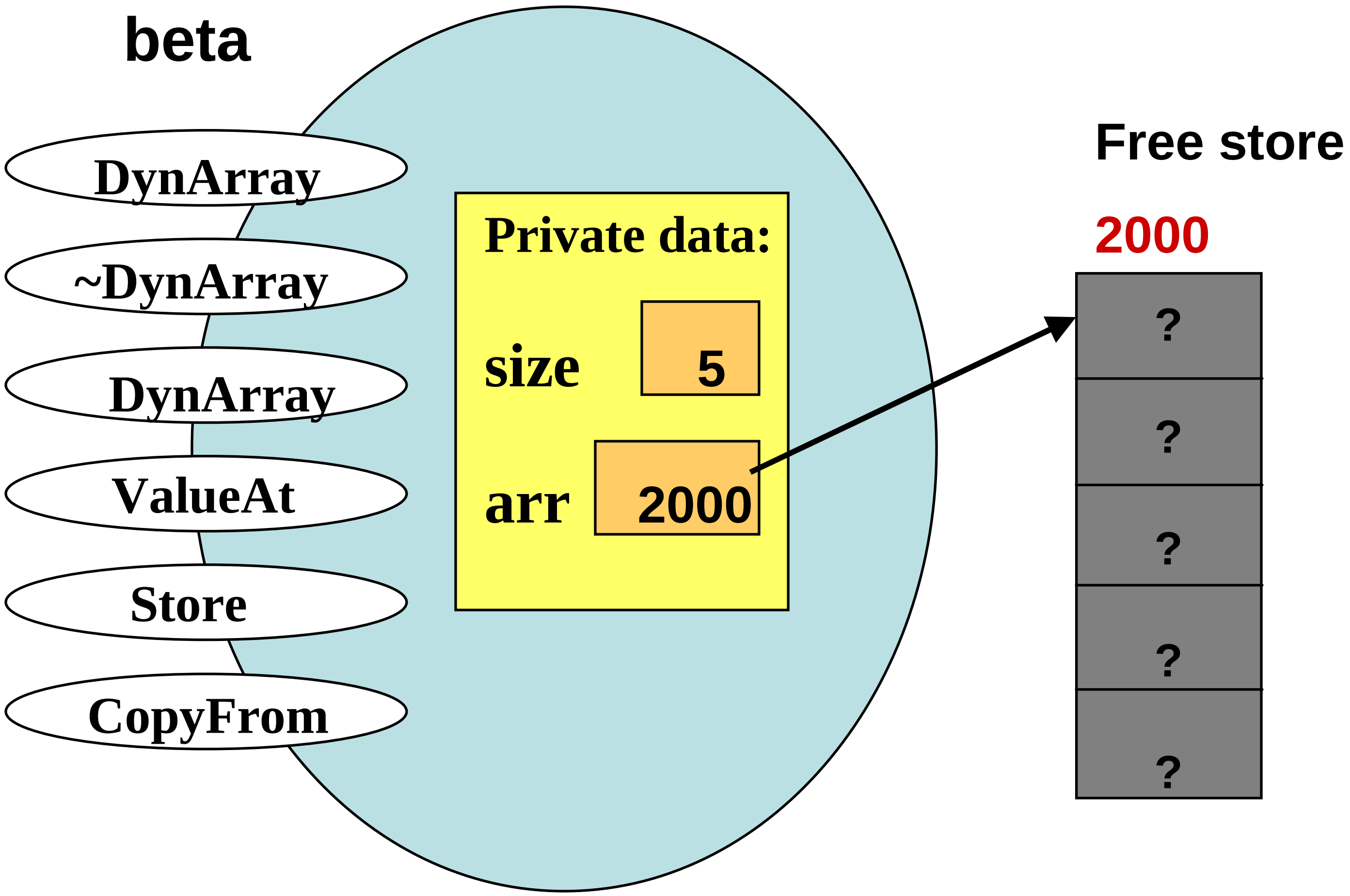
```
  DynArray(const DynArray& otherArr);
  // Copy constructor
  // POST: this DynArray is a deep copy of otherArr
  // Is implicitly called for initialization

// Specification file  continued

~DynArray();
  // Destructor
  // POST: Memory for dynamic array deallocated

int  ValueAt (/* in */ int i)  const;
  // PRE:  i is assigned
  // POST:
  // IF 0 <= i < size of this array THEN
  // FCTVAL == value of array element at index i
  // ELSE error message
```

```
// Specification file  continued
void  Store (/* in */ int val,  /* in */ int i);
    // PRE:  val and i are assigned
    // POST: IF 0 <= i < size of this array THEN
    //       val is stored in array element i
    //       ELSE error message

  void  CopyFrom (/* in */ DynArray otherArr);
    // POST:  IF enough memory THEN
     //            new array created (as deep copy)
     //            with size and contents
     //            same as otherArr
    //        ELSE error message.

private:
    int*  arr;
    int   size;
};
```

class DynArray

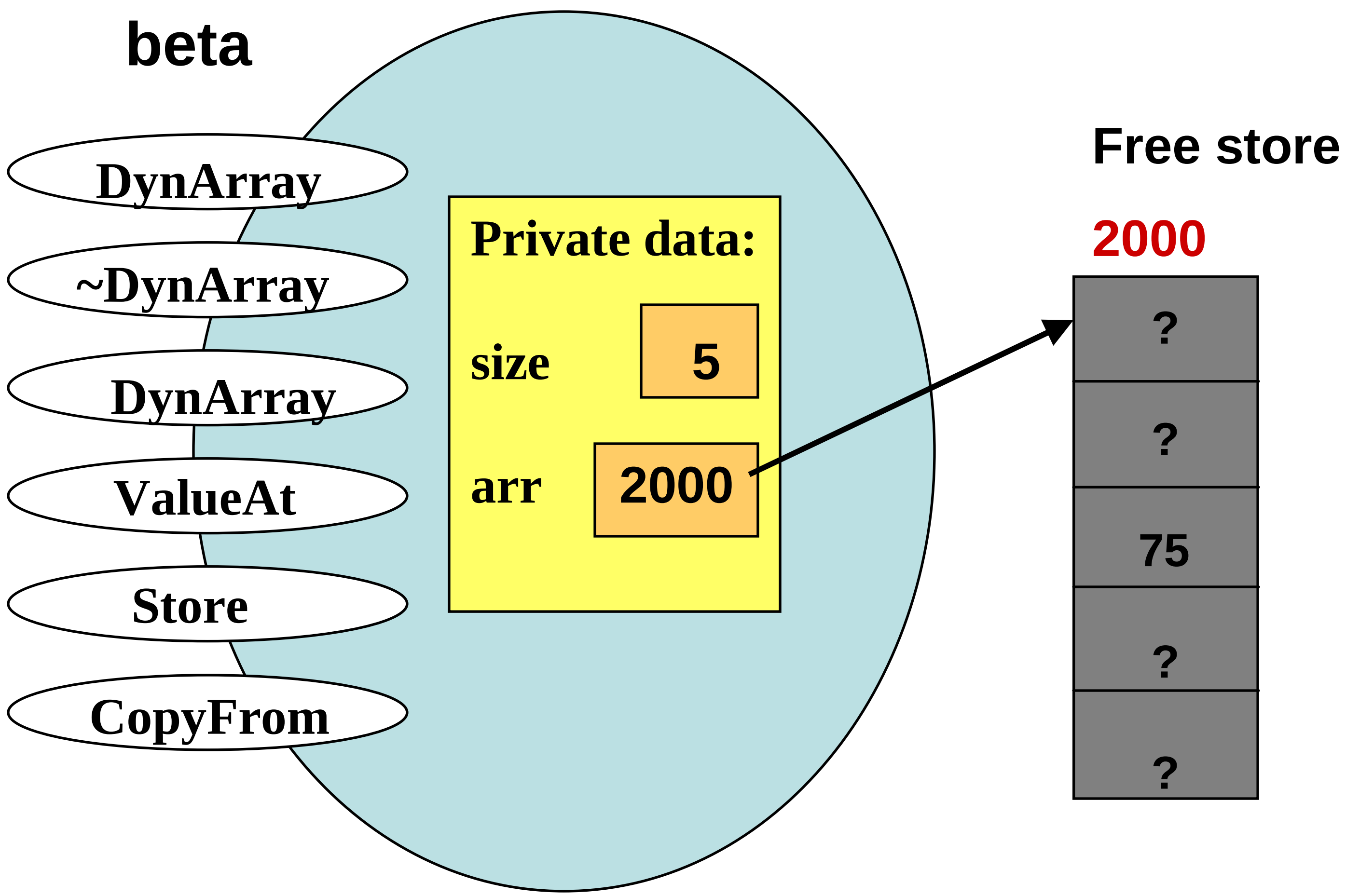


`DynArray beta(5); //constructor`



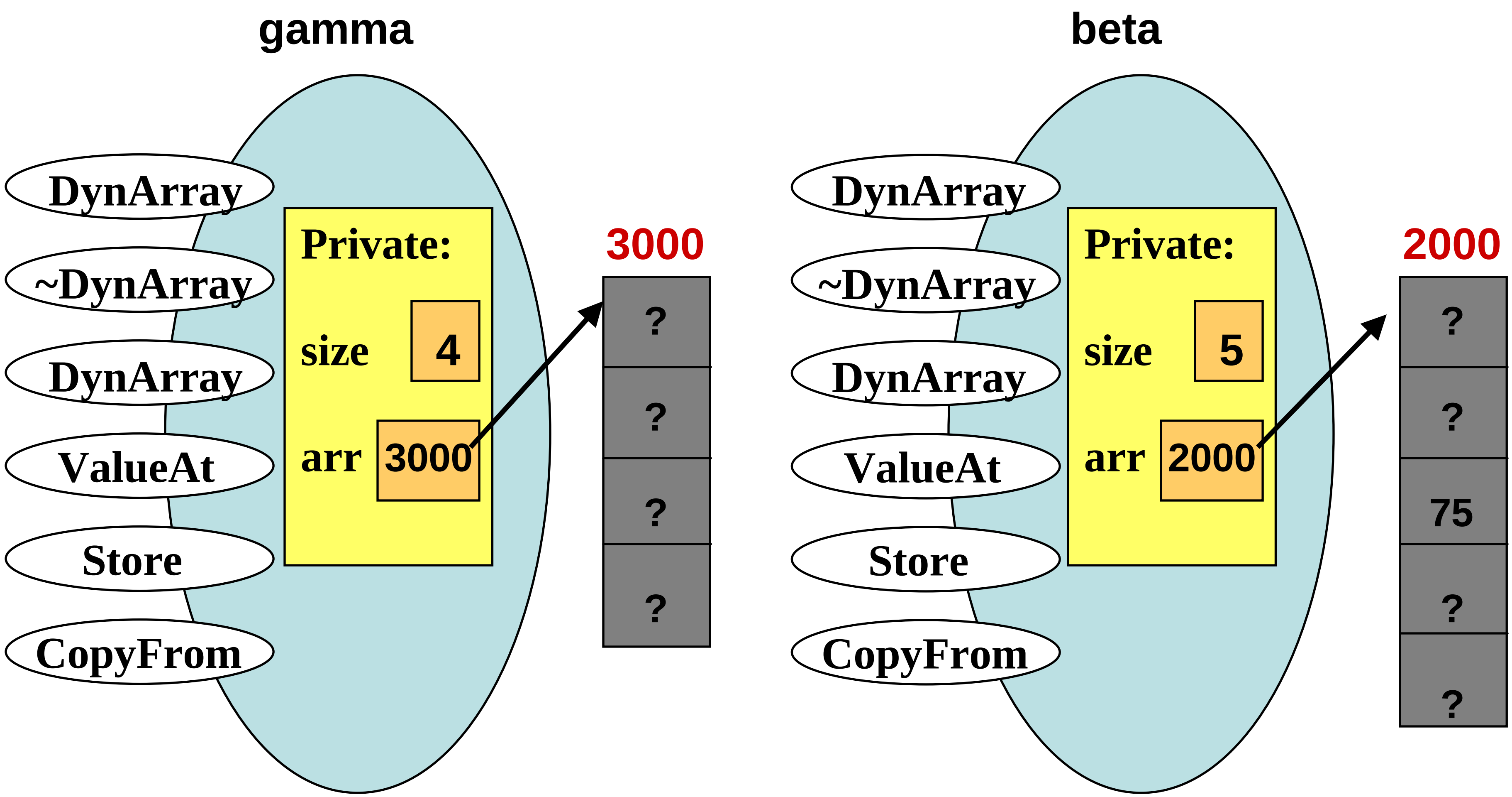
```
DynArray::DynArray(/* in */  int arrSize)
      // Constructor
      // PRE:  arrSize is assigned
      // POST:  IF arrSize >= 1 && enough memory THEN
      // Array of size arrSize is created with
      // all elements == 0  ELSE error message
{
    int i;
    if (arrSize < 1){
      cerr << "DynArray constructor - invalid size:"
             << arrSize << endl;
        exit(1);
    }
    arr = new  int[arrSize];    // Allocate memory
    size = arrSize;

    for (i = 0; i < size;  i++)
        arr[i] = 0;
}
```

beta.Store(75, 2);

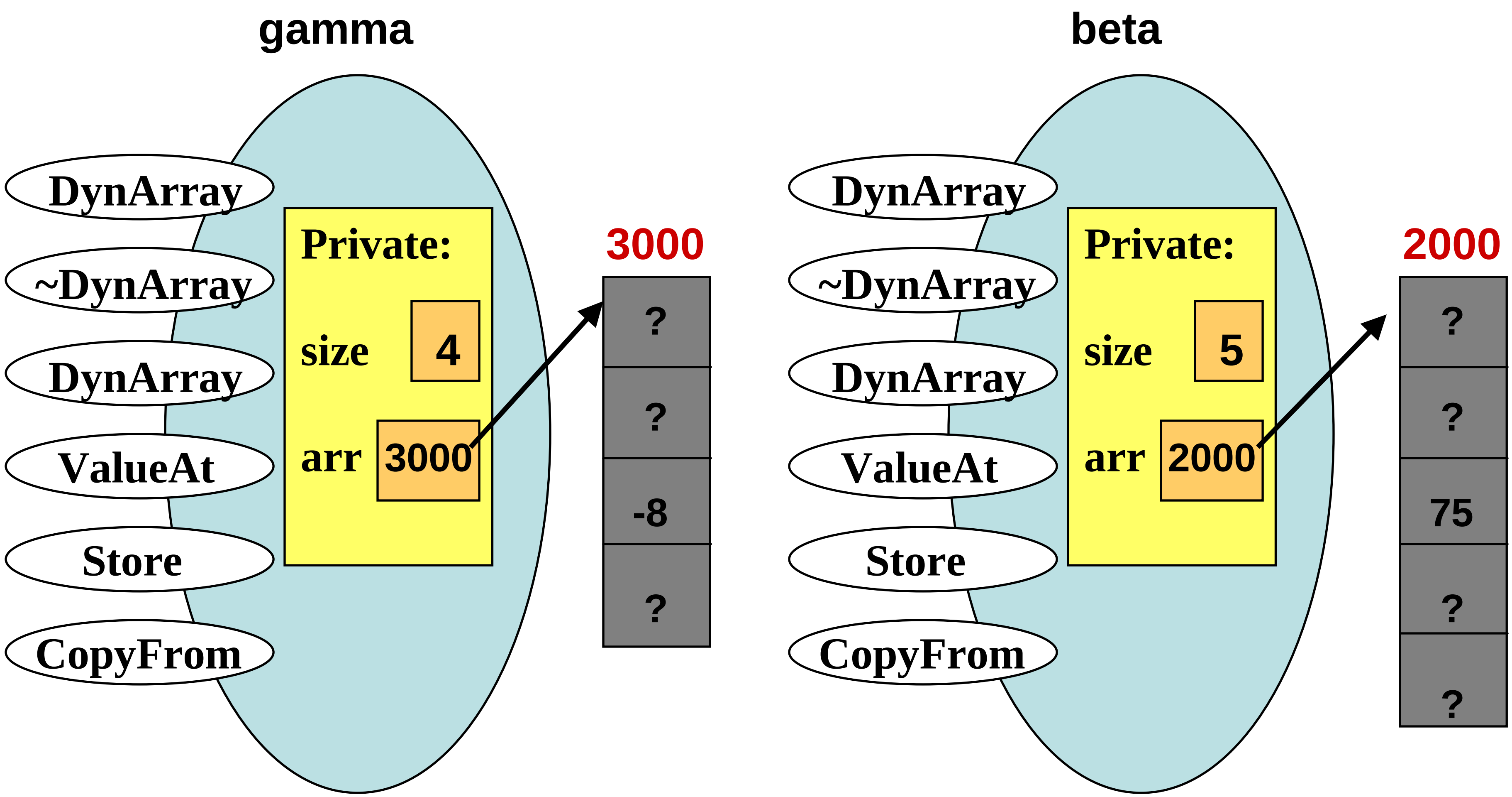


```
void  DynArray::Store (/*in*/ int val,  /*in*/ int i)
      // PRE:  val and i are assigned
      // POST: IF 0 <= i < size of this array THEN
      //       arr[i] == val
      //       ELSE error message
{

    if (i < 0 || i >= size)
    {
      cerr << "Store - invalid index : " << i << endl;
      exit(1);
    }
   arr[i] = val;

}
```

`DynArray gamma(4);//Constructor`



`gamma.Store(-8,2);`



```
int  DynArray::ValueAt (/* in */ int i)  const
      // PRE:  i is assigned
      // POST: IF 0 <= i < size THEN
      //       Return value == arr[i]
      //       ELSE halt with error message
{
    if (i < 0 || i >= size)
    {
        cerr << "ValueAt - invalid index : " << i
           << endl;
        exit(1);
    }
    return arr[i];
}
```

Why is a destructor needed?

When a DynArray class variable goes out of scope, the memory space for data members size and pointer `arr` is deallocated

But the dynamic array that `arr` points to is not automatically deallocated

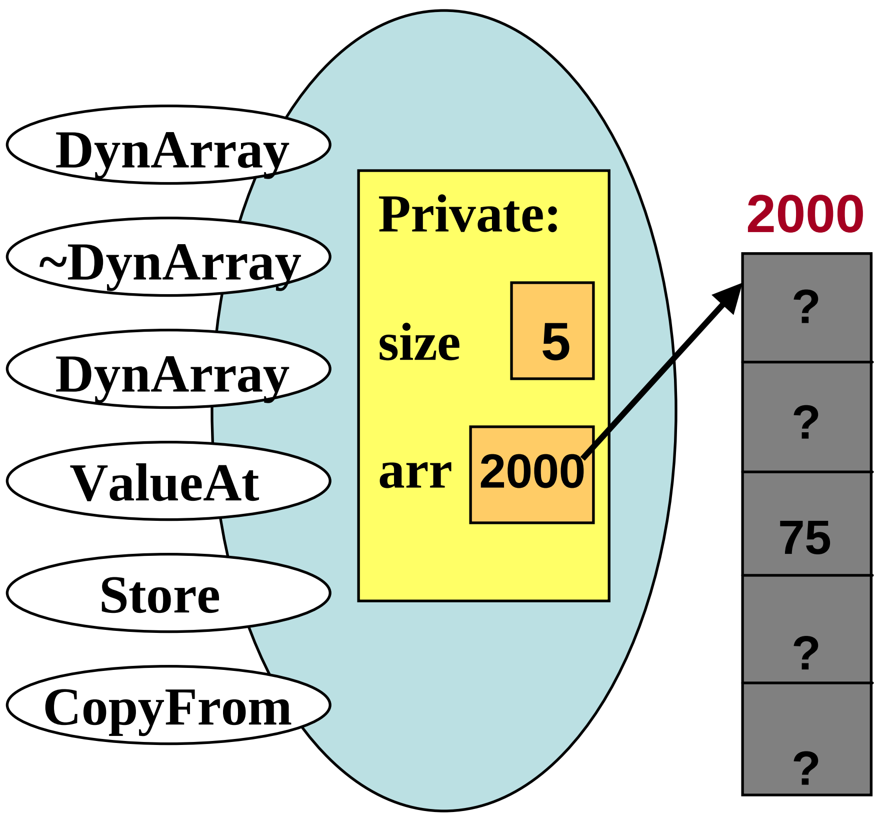
A class destructor is used to deallocate the dynamic memory pointed to by the data member

class DynArray Destructor

```
DynArray::~DynArray();
 // Destructor
 // POST: Memory for dynamic array
 deallocated
{
    delete [ ] arr;
 }
```

What happens . . .

- ***When a function is called that passes a DynArray object by value, what happens?***

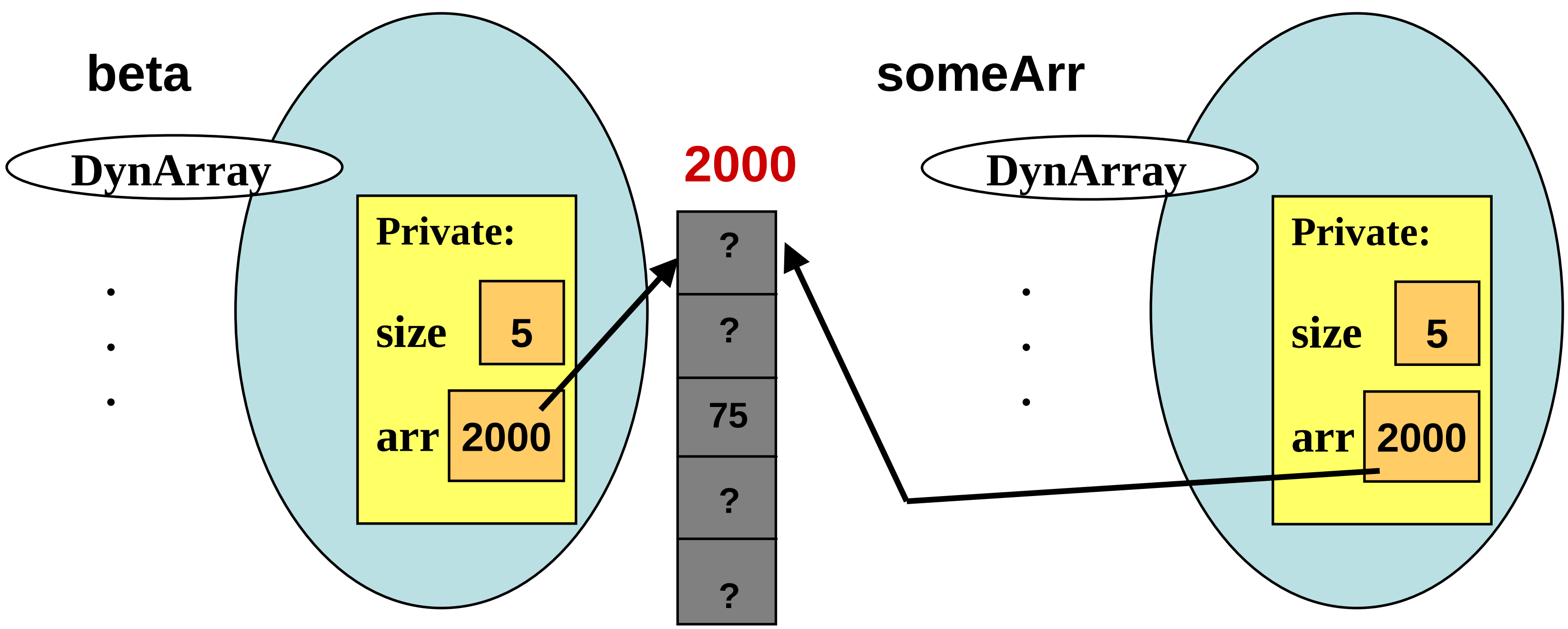


Passing a Class Object by Value

```
 // Function code

void  SomeFunc(DynArray  someArr)
 // Uses pass by value
{
        .
                .
        .
        .
 }
```

By default, Pass-by-value makes a shallow copy

```
DynArray  beta(5);          // Client code
     .
     .
SomeFunc(beta);            //  Function call
```



shallow copy

Shallow Copy vs. Deep Copy

- ***A shallow copy*** **copies only the class data members, and does not make a copy of any pointed-to data**

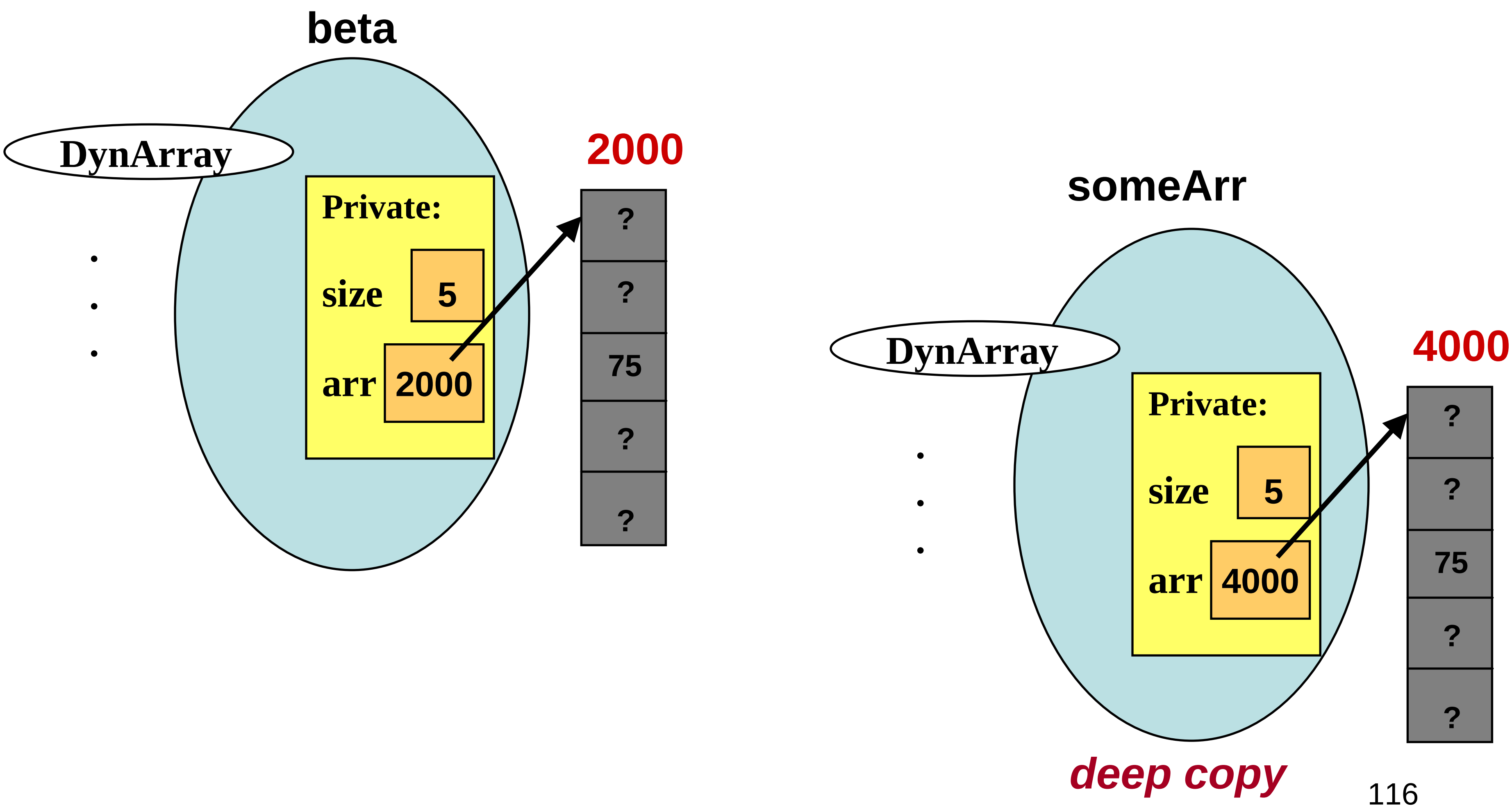
- ***A deep copy*** **copies not only the class data members, but also makes a separate stored copy of any pointed-to data**

What's the difference?

- ***A shallow copy*** **shares the pointed to dynamic data with the original class object**

- ***A deep copy*** **makes its own copy of the pointed to dynamic data at different locations than the original class object**

Making a (Separate) Deep Copy



Initialization of Class Objects

- **C++ defines initialization to mean**
  - **initialization in a variable declaration**
  - **passing an object argument by value**
  - **returning an object as the return value of a function**
- **By default, C++ uses shallow copies for these initializations**

As a result . . .

- **When a class has a data member that points to dynamically allocated data, you must write what is called a copy constructor**

- **The copy constructor is implicitly called in initialization situations and makes a deep copy of the dynamic data in a different memory location**

Copy Constructor

Most difficult algorithm so far:

- **If the original is empty, the copy is empty**
- **Otherwise, make a copy of the head with pointer to it**
- **Loop through original, copying each node and adding it to the copy until you reach the end**

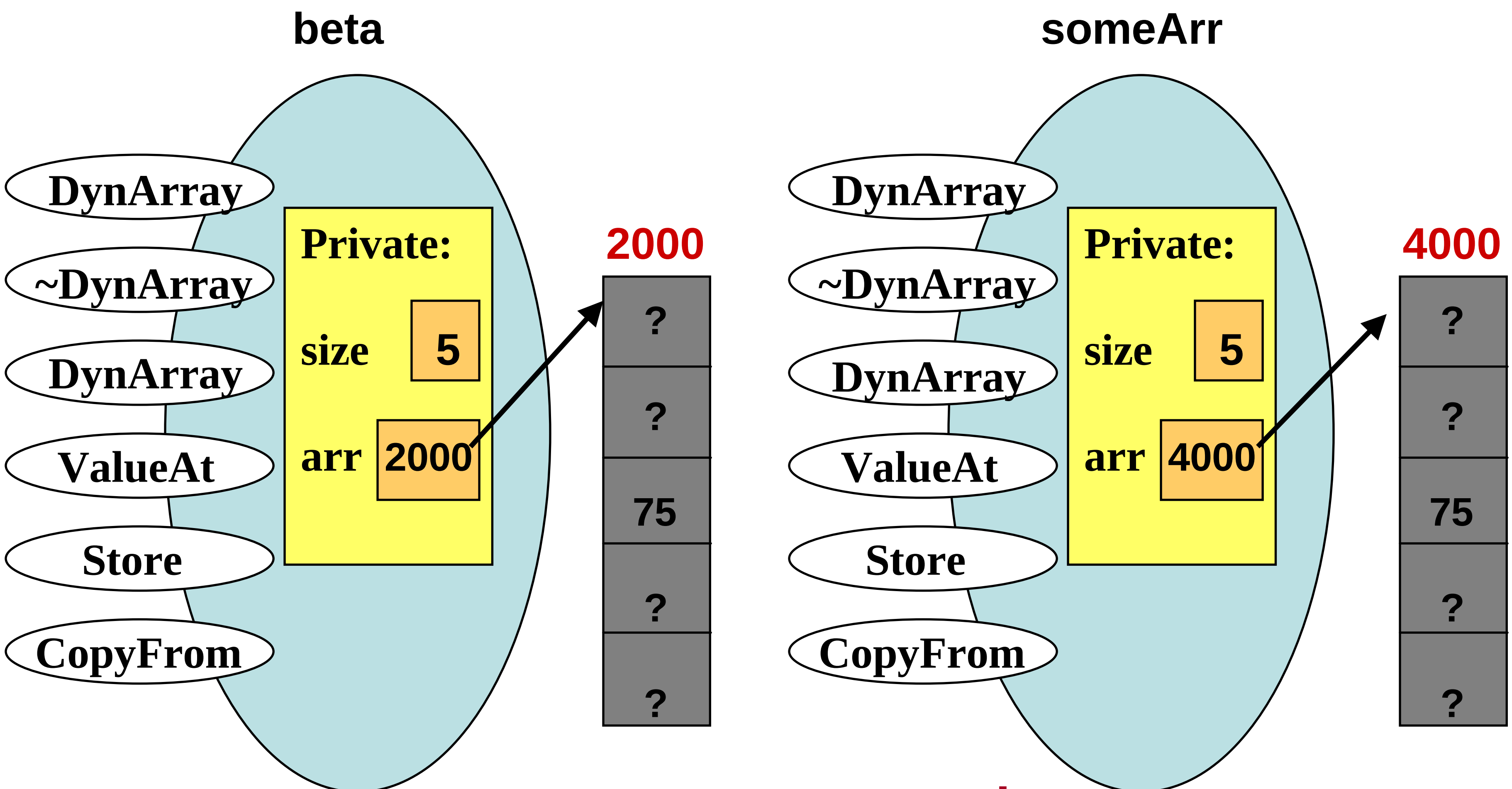
Copy Constructor

- **Copy constructor is a special member function of a class that is implicitly called in these three situations:**
  - **Passing object parameters by value**
  - **Initializing an object variable in its declaration**
  - **Returning an object as the return value of a function**

More about Copy Constructors

- **When you provide (write) a copy constructor for a class, the copy constructor is used to make copies for pass by value**
- **You do not explicitly call the copy constructor**
- **Like other constructors, it has no return type**
- **Because the copy constructor properly defines pass by value for your class, it must use pass by reference in its definition**

```
SomeFunc(beta); // copy-constructor
                // beta passed by value
```



deep copy

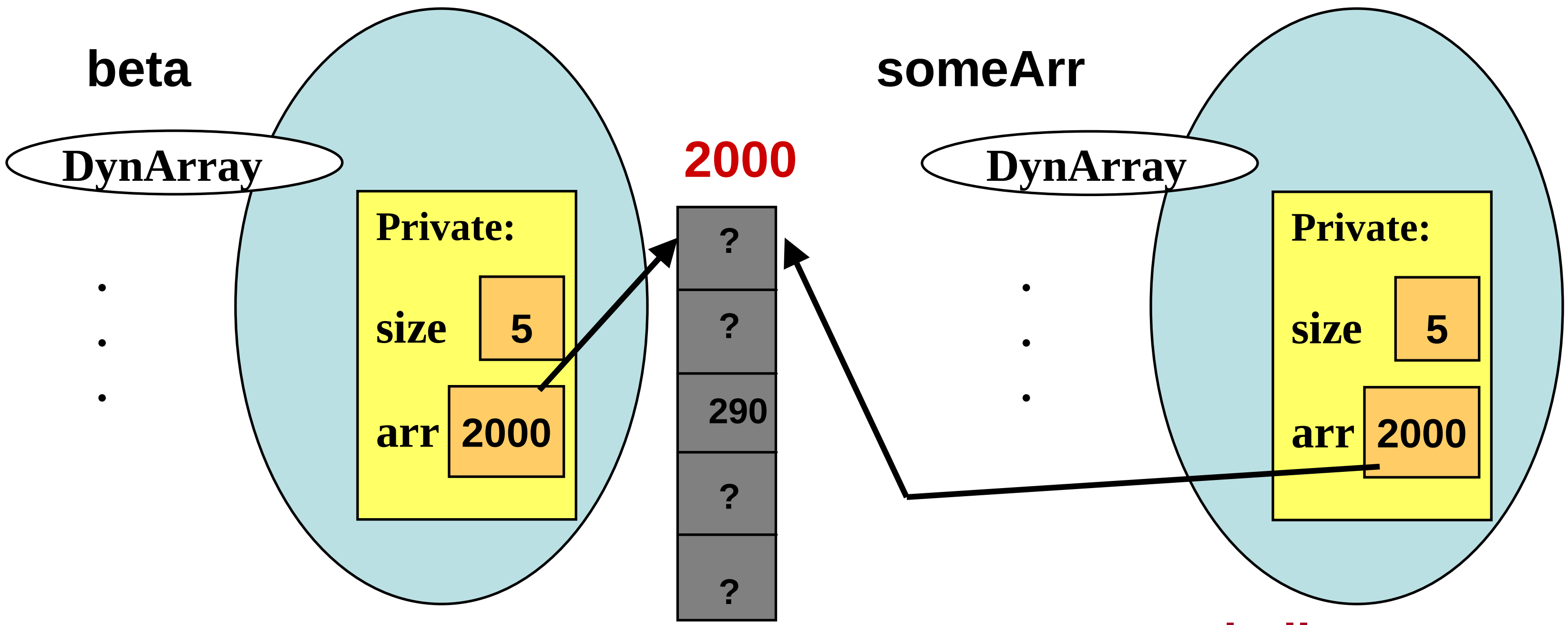
Suppose **SomeFunc** calls Store

```
void  SomeFunc(DynArray  someArr)
// Uses pass by value
{
   someArr.Store(290, 2);
        .
   .
   .

}
```

What happens in the shallow copy scenario?

`beta.arr[2]` has changed

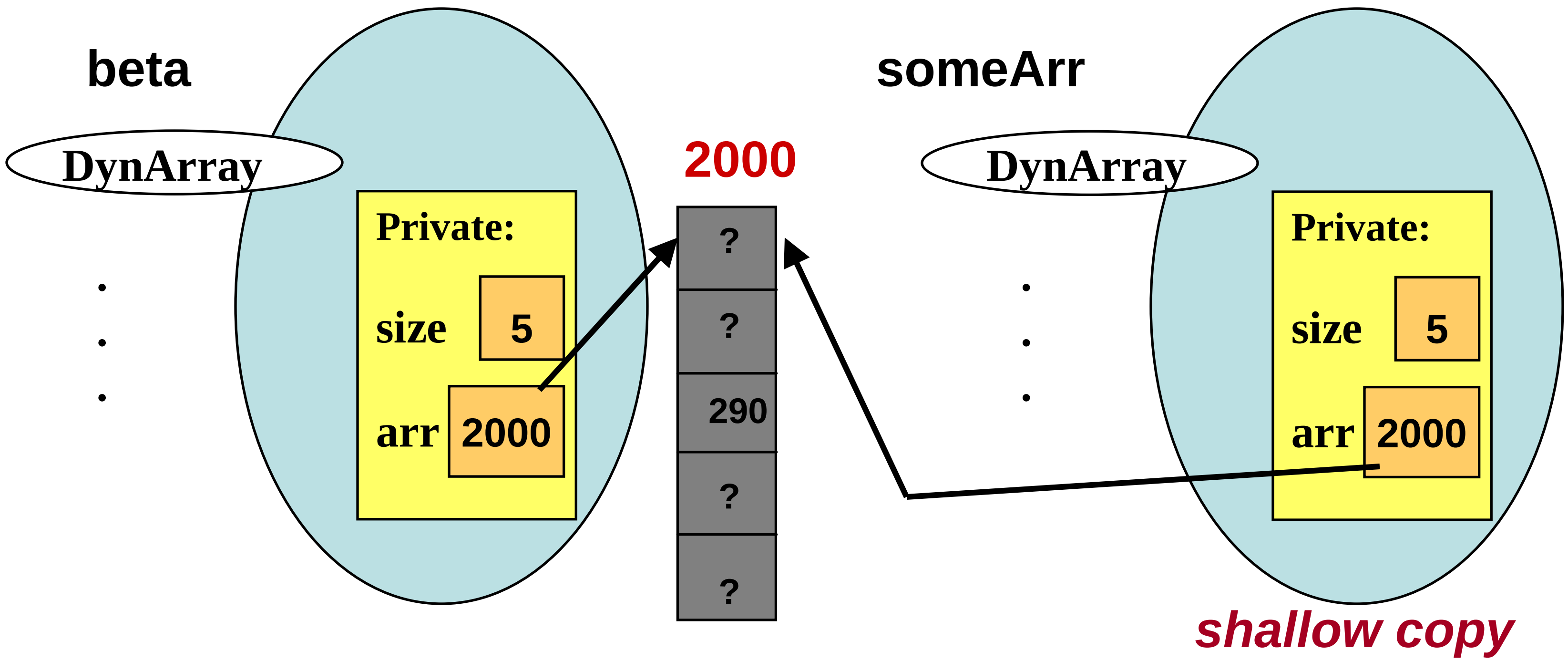
```
DynArray  beta(5);          // Client code
     .
     .
     .
SomeFunc(beta);
```



shallow copy

`beta.arr[2]` has changed

Although beta is passed by value, its dynamic data has changed!



Classes with Data Member Pointers Need

CONSTRUCTOR

COPY CONSTRUCTOR

DESTRUCTOR

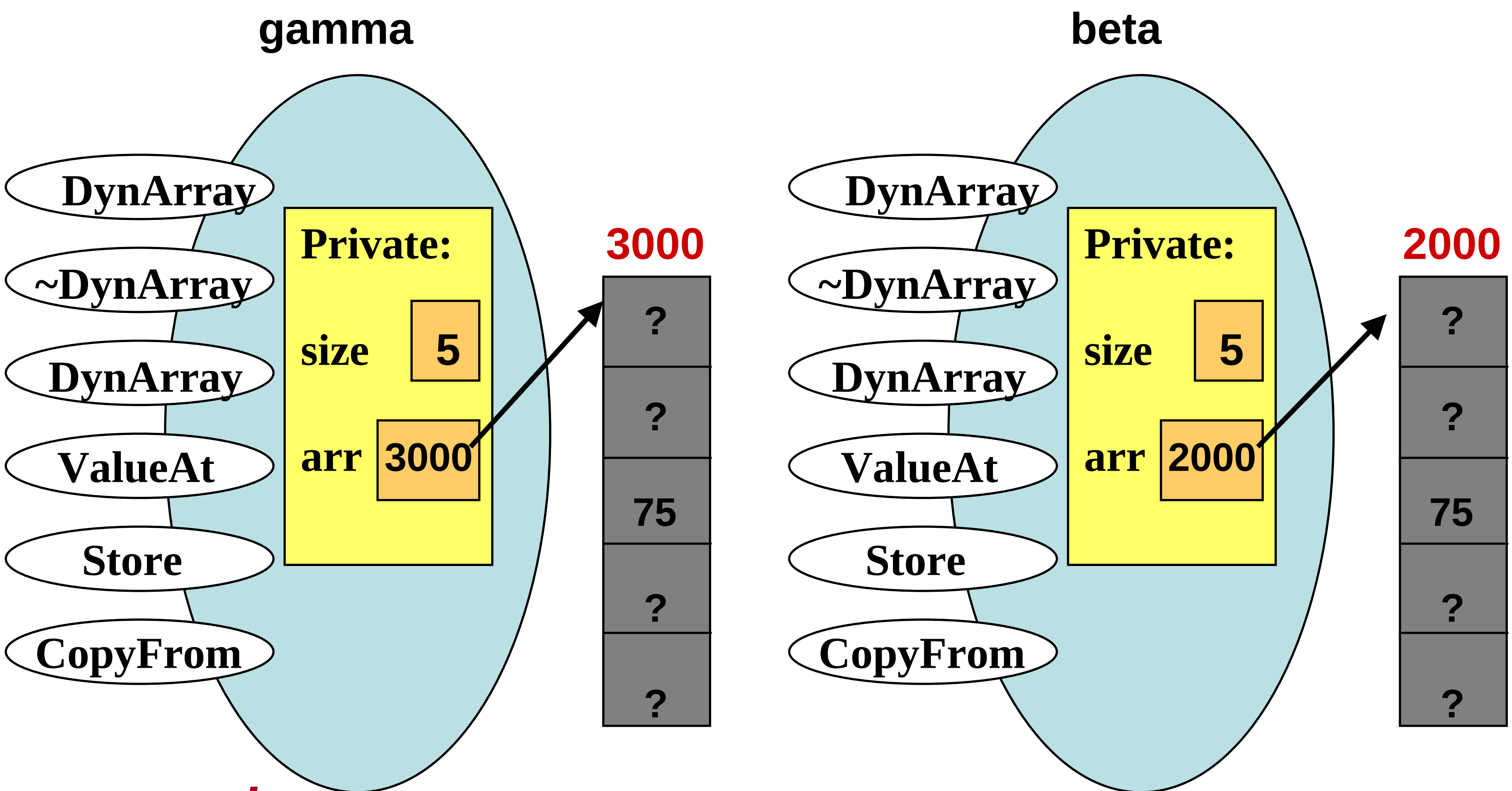
```
DynArray::DynArray(const DynArray& otherArr)
  // Copy constructor
  // Implicitly called for deep copy in
  // initializations
  // POST:  If room on free store THEN
  //  new array of size otherArr.size is created
  //  on free store && arr == its base address
  //     && size == otherArr.size
  //  && arr[0..size-1] == otherArr.arr[0..size-1]
  //  ELSE error occurs
{
    int i;
    size = otherArr.size;
    arr = new  int[size]  //Allocate memory for copy

    for (i = 0; i< size; i++)
        arr[i] = otherArr.arr[i];  // Copies array

}
```

What about the assignment operator?

- **The default method used for assignment of class objects makes a shallow copy**

- **If your class has a data member that points to dynamic data, you should write a member function to create a deep copy of the dynamic data**

gamma.CopyFrom(beta);



deep copy

```
void  DynArray::CopyFrom (/* in */ DynArray  otherArr)
   // Creates a deep copy of otherArr
   // POST:  Array pointed to by arr@entry deallocated
   //   &&  IF room on free store
   //      THEN new array is created on free store
   //       && arr == its base address
   //       && size == otherArr.size
   //       && arr[0..size-1] == otherArr[0..size-]
   //       ELSE halts with error message
{
    int i;
    delete[ ]  arr;        // Delete current array
    size = otherArr.size;
    arr = new int [size]; // Allocate new array

    for (i = 0; i< size; i++)  // Deep copy array
        arr[i] = otherArr.arr[i];
}
```