Copy Constructors
and
Overloaded Assignment

When do we make copies of an object?

1) When passing them to a function by value

2) When returning them from a function by value

3) When creating a new object that is initialized with a copy of an existing object

4) When assigning objects (x = y)

1. Items 1, 2 and 3 are handled by the copy constructor.
2. Item 4 is handled by overloading the assignment (=) operator.

What is a copy constructor?

- It's a constructor – it's used to construct new objects
- It does so by making a copy of an existing object
- We can do so explicitly

```
// construct t1
Time t1 (12, 34, 56);

// construct t2 by copying t1
Time t2 (t1);

// construct t3 by copying t1
Time t3 = t1;
```

The compiler may make copies when it needs them

Copy constructor syntax

The function prototype for every copy constructor is of the form:

```
ClassName::ClassName (const ClassName &);
```

Why is it necessary to for this parameter to be passed by reference? Why can't it be passed by value?

Why haven't we seen this before?

- The compiler provides a default copy constructor which up until now has been sufficient.
- The default copy constructor simply copies each of the data members from the existing object into the new object
- This is not sufficient if one or more of the data members points to dynamically allocated memory

Dynamic Memory Within a Class

- Sometimes a data member of a class points to dynamically allocated memory. When this occurs, we have to answer the following questions
  1. When will the dynamic memory be allocated?
  2. When will the dynamic memory be deallocated?
  3. What else is affected?

A potential security problem

- In more complex projects, you will often have pointers as private class members. It is critical that a copy constructor allocate new memory for each pointer in the new copy
  - The default copy constructor will just create a new pointer for the copy and give it the same value as the original pointer. So the copy and original will both point to the same data. This is a gross semantic error: changing the copy will change the original! How can this create a serious security problem?

A potential security problem

- Also, consider the “accessor” functions for your class, which exist simply to report the value of unchangeable private data members.
  - Why is it a security problem if your function returns a pointer to the data instead of a copy of the data? This can be a hard error to catch in languages like Java, which blur the distinctions of which variables are pointers and which are not.
- These are security problems, and debugging nightmares. Be careful to avoid them.

A Simple Array Class

One class that is often defined in C++ applications and libraries is a “smart” array. It has features that the built-in array doesn’t have such as automatic initialization and automatically checking indices to prevent a core dump. Other features are also possible.

We’ll use a such an array class to illustrate the impact of dynamic memory allocation within a class.

SmartArray

```
class SmartArray {
   public:
        SmartArray ( int size = 100 );
        // other members

   private:
        int m_size;
        int *m_theData;
};
```

Using SmartArray

Some SmartArray objects:

```
SmartArray a1 (50);      // 50 ints
SmartArray a2 (200);     // 200 ints
SmartArray a3;           // 100 ints by default
```

When Does the Memory Get Allocated?

The obvious answer to this question is,

"In the constructor."

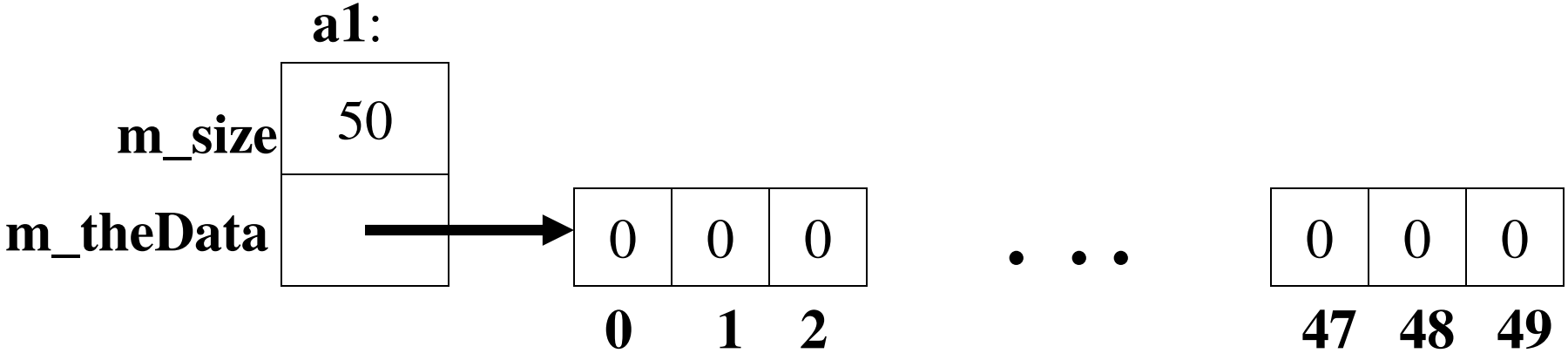
```
SmartArray::SmartArray (int size)
{
   m_size = size;
   m_theData = new int [ m_size];
   for (int j = 0; j < m_size; j++)
       m_theData [ j ] = 0;
}
```

A Picture of Memory

Given the instantiation

SmartArray a1(50);

we get this picture of memory:



When Does the Memory Get Deallocated?

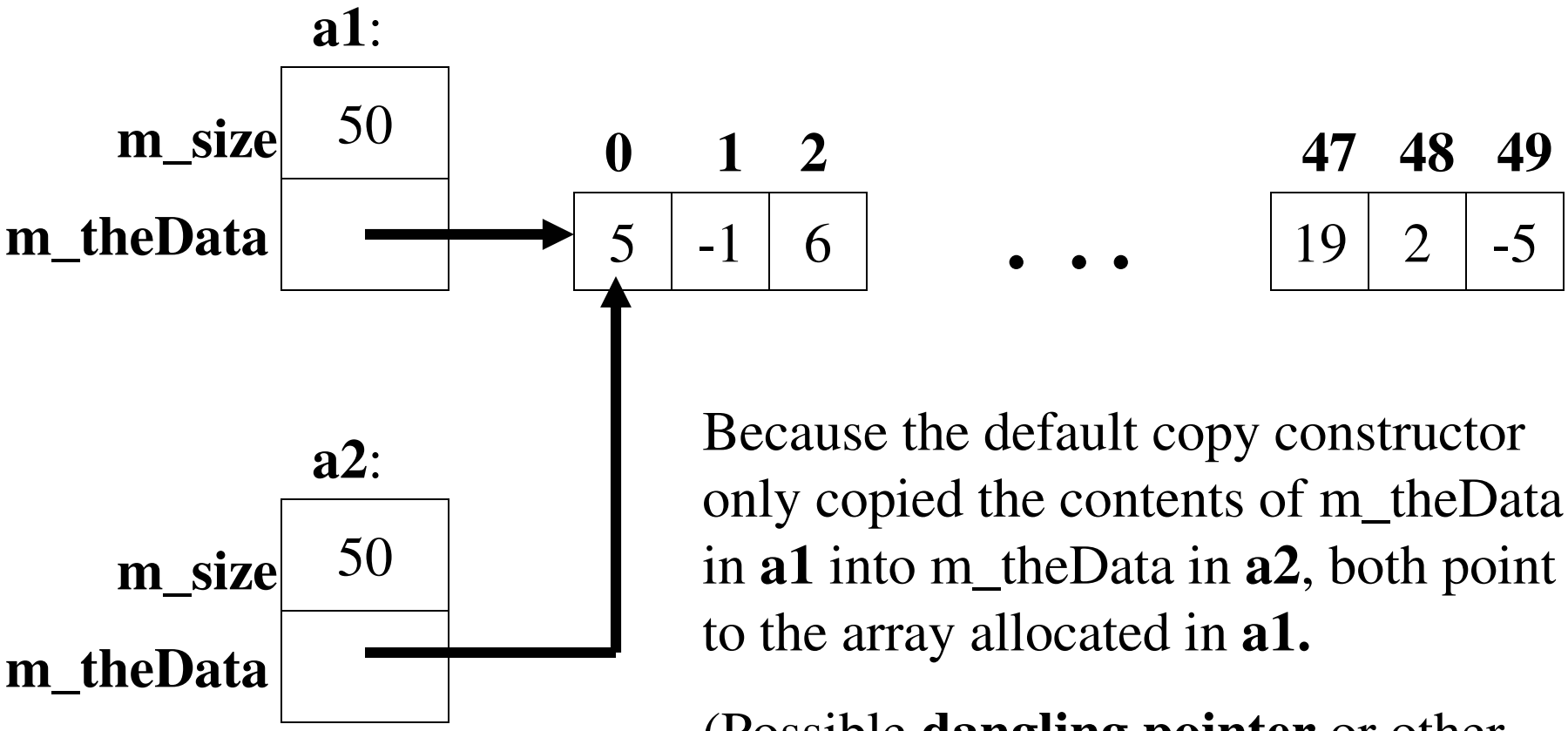
The intuitive answer is, “In the destructor.” The compiler provides us with a default destructor that deallocates the private data members. But this is not sufficient. If we relied on the default destructor, we’d create a memory leak because the memory pointed to by **m_theData** would not be freed.

```
SmartArray::~SmartArray (  )
{
  delete [  ] m_theData;
}
```

What Else Is Affected?

- This time the answer is not so obvious.
- Consider the problems we want to avoid with dynamic memory:
  - dynamically allocated memory to which multiple things point (a probable **logic error**)
  - dynamically allocated memory to which nothing points (a **memory leak**)
  - a pointer that points “nowhere” (**dangling pointer**)
- All of these situations may arise when we wish to make a copy of a SmartArray object.

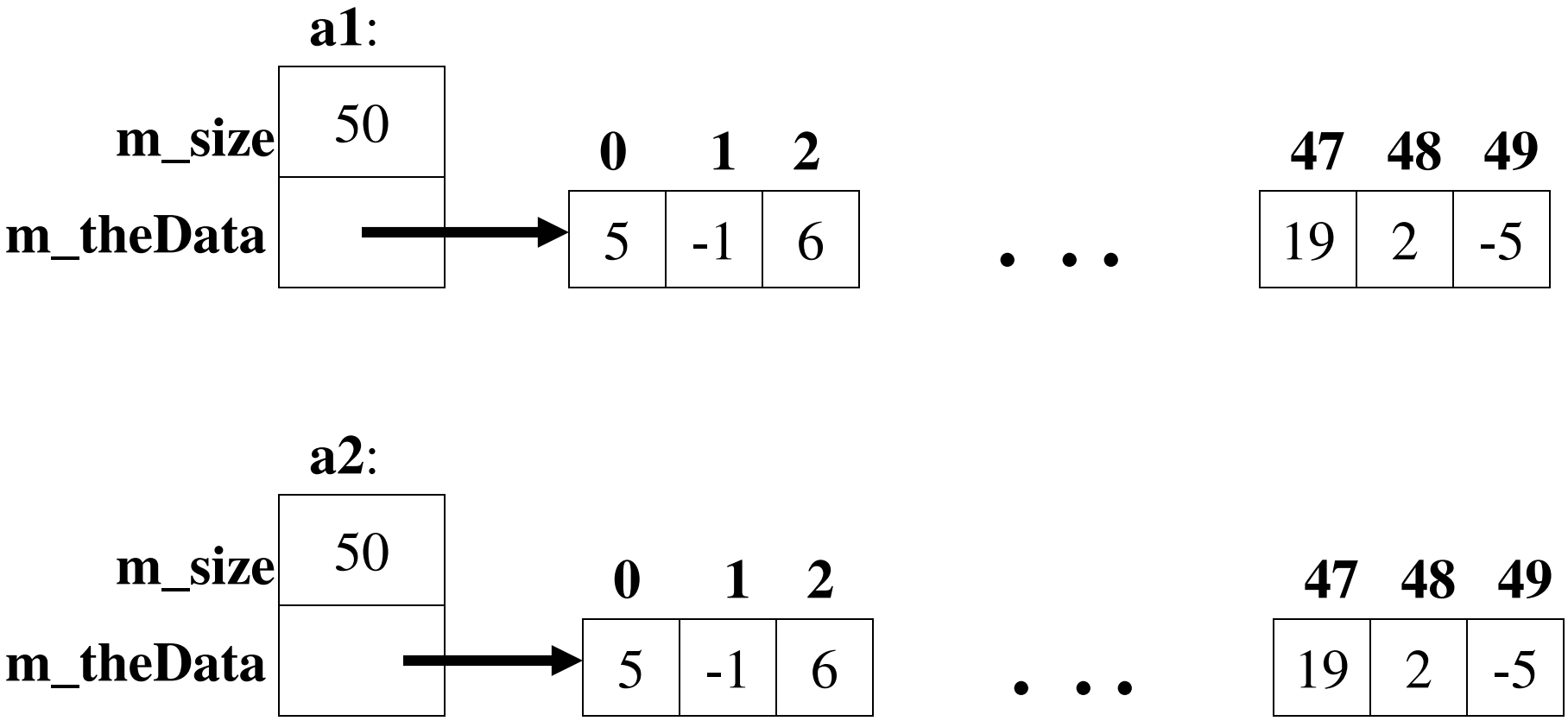
Effect of Default Copy Constructor (shallow copy)



Because the default copy constructor only copied the contents of m_theData in **a1** into m_theData in **a2**, both point to the array allocated in **a1.**

(Possible **dangling pointer** or other **logic** problem!)

The picture of memory we want (deep copy)



SmartArray Copy Constructor

```
SmartArray::
SmartArray (const SmartArray& array)
{
  m_size = array.m_size;
  m_theData = new int [ m_size ];
  for (int j = 0; j < m_size; j++ )
     m_theData[j] = array.m_theData [j];
}
```

When Is the Copy Constructor Invoked?

Silently by the compiler when we

- Pass by value:

```
void someFunction(SmartArray array);
```

- Return by value:

```
SmartArray someFunction(parameters)
{
        SmartArray temp;
        // code manipulating “temp”
        return (temp);
}
```

When Is the Copy Constructor Invoked? (cont'd)

- Explicitly by us upon construction

```
SmartArray a1;

// constructing a2 as a copy of a1
SmartArray a2 = a1;
```

OR

```
SmartArray a2(a1);
```

What's an assignment operator?

- The assignment operator is the function operator=
- It's called when we assign one existing object to another existing object

```
Time t1 (12, 34, 56);
Time t2;
t2 = t1;    // object assignment
```

Why haven't we heard of this before? (this may sound familiar)

- The compiler provides a default assignment operator, which up until now has been sufficient.
- The default assignment operator simply copies each of the data members from the existing object on the right hand side into the existing object on the left hand side.
- This is not sufficient if one or more of the data members points to dynamically allocated memory

Assigning SmartArray Objects

Consider the following code:

```
SmartArray a1 ( 50 );
SmartArray a2 ( 50 );

// some code to manipulate a1
// some code to manipulate a2
// now assign a1 to a2
a2 = a1;
```

Assignment Operator

The statement

```
a2 = a1;
```

calls the assignment operator (operator=)

for the SmartArray class.

- If we don't provide operator=, the compiler uses the default behavior
- Like the default copy constructor, the default assignment operator does a member-by-member (**shallow**) assignment.

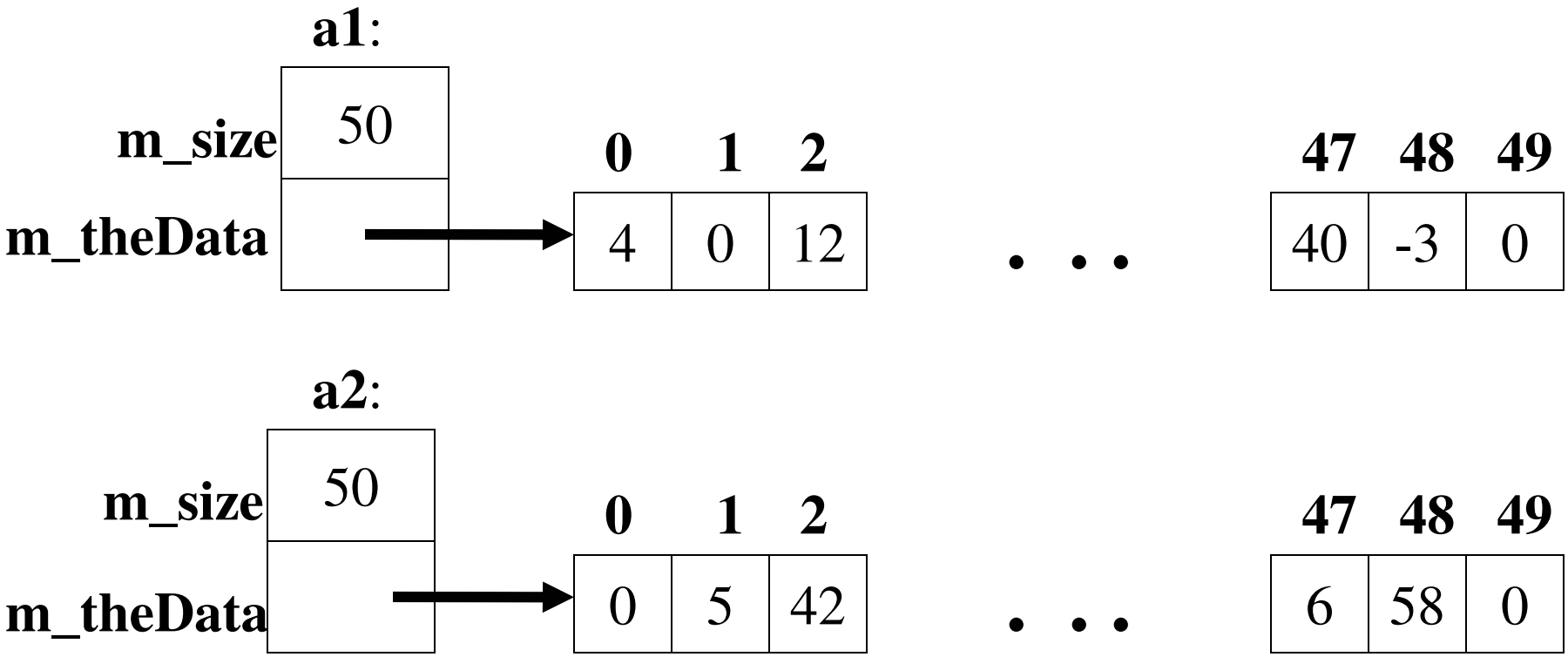
Default Assignment Code

Conceptually, the default assignment operator for SmartArray contains the following code

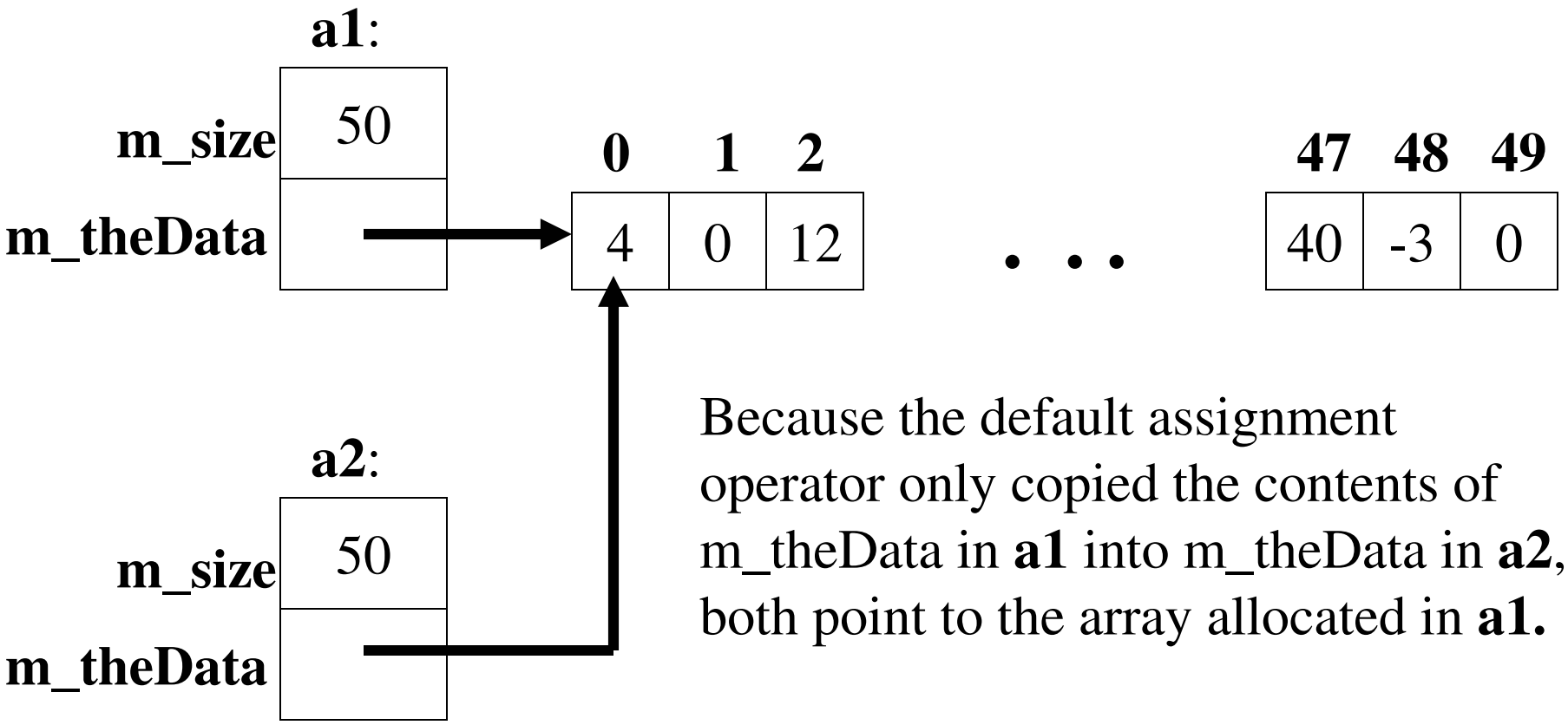
```
m_size = rhs.m_size;
m_theData = rhs.m_theData;
```

Prior To Assignment

We have a picture something like this:



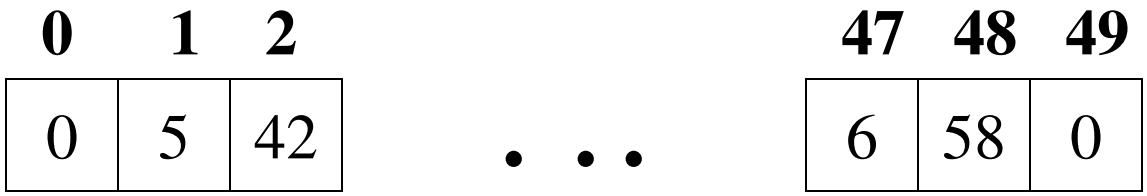
After Default Assignment



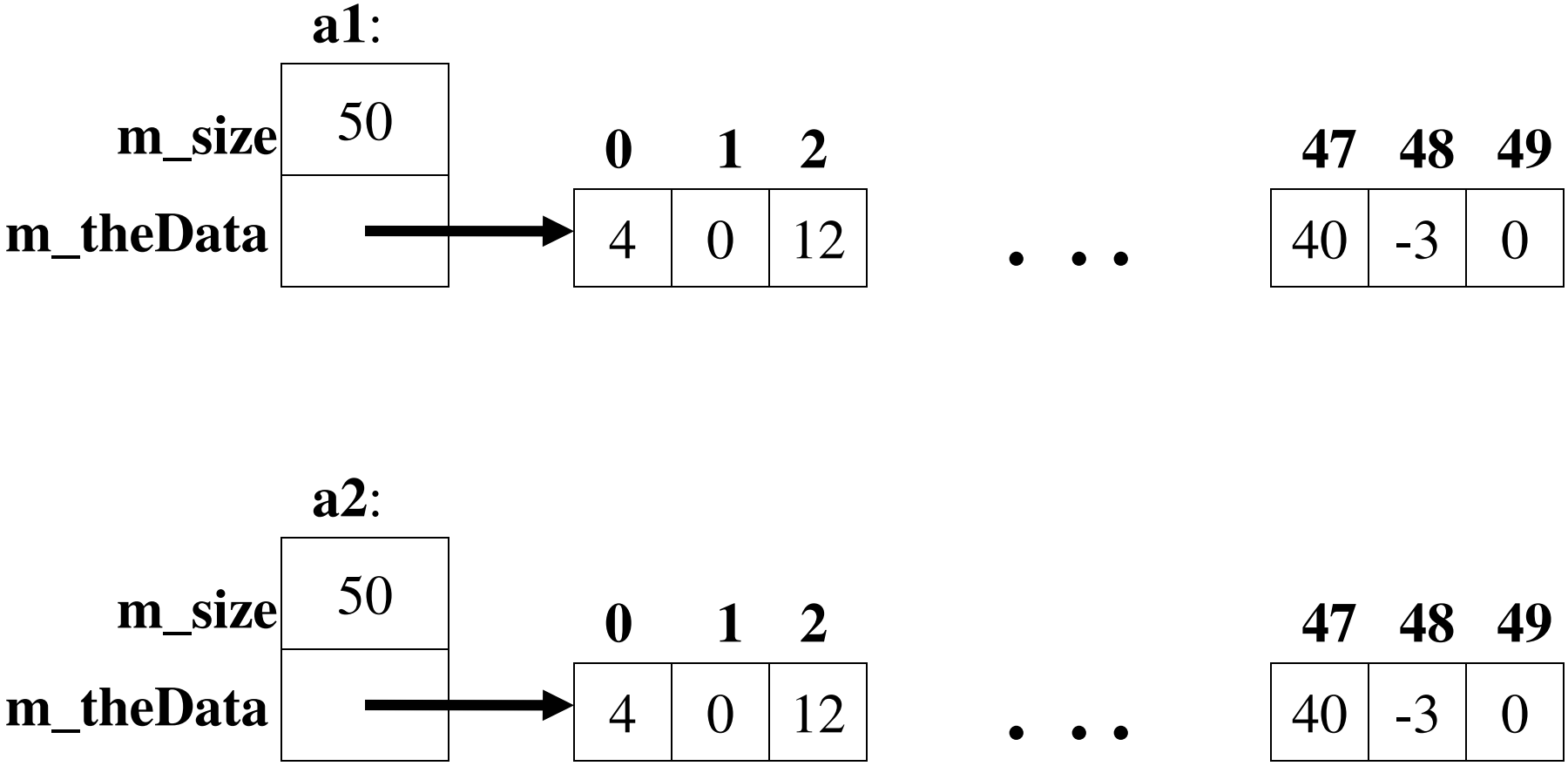
Because the default assignment operator only copied the contents of m_theData in **a1** into m_theData in **a2**, both point to the array allocated in **a1.**

In Fact, It's Worse

What happened to the memory that a2 used to point to? We've also caused a memory leak.



We want this picture without a memory leak



SmartArray::operator= (A First Attempt)

```
void SmartArray::operator= (const SmartArray& rhs)
{
        // free the memory for the current array
        delete [ ] m_theData;

        // now make a deep copy of the rhs
        m_size = rhs.m_size;
        m_theData = new int [ m_size ];
        for (int j = 0; j < m_size; j++ )
                m_theData[ j ] = rhs.m_theData [ j ];
}
```

We're Not Done Yet

Recall that it's desirable for our objects to emulate the built-in types. In particular, we can do the following with built-in types:

```
int bob, mary, sally;
bob = mary = sally;       // statement 1
bob = bob;                // statement 2
(bob = mary) = sally;     // statement 3
```

So our objects should also support these statements.

Analysis of These Statements

1. Statement 1 is a common thing to do – it's called **cascading assignment**. To accomplish this, operator= must return a reference to a SmartArray.
2. Statement 2 is meaningless, but allowable by the language. To support this without causing a problem, operator= must check for this case (this is called **self-assignment**).
3. Statement 3 is odd, but valid. To support this, operator= must return a **non-const** reference to a SmartArray. (Debatable -- your text does not do this.)

```
SmartArray&                    // non-const reference
SmartArray::operator= (const SmartArray& rhs)
{
   if (this != &rhs)           // not  bob = bob
   {
        // free the memory for the current array
        delete [ ] m_theData;

        // make a copy of the rhs
        m_size = rhs.m_size;
        m_theData = new int [m _size ];
        for (int j = 0; j < m_size; j++ )
                m_theData[ j ] = rhs.m_theData [ j ];
   }
   return (*this);        // for cascading assignment
}
```

Exercises For the Student

1) For the following statements, determine if the method called is a “regular” constructor, copy constructor, or operator= .

    a. SmartArray a1;
    b. SmartArray a2(a1);
    c. SmartArray a3 = a2;
    d. SmartArray a4(100);
    e. a1 = a4;

Exercises For the Student (con't)

2. Suppose operator= for SmartArray did not contain the statement if (this != &rhs); i.e., we allowed self-assignment. Draw the picture of memory that results from the following statements:

```
SmartArray a1( 3 );
a1 = a1;
```