

Pointers and Dynamic Arrays

Pointer Introduction

- Pointer definition:
 - Memory address of a variable
- Recall: memory divided
 - Numbered memory locations
 - Addresses used as name for variable
- You've used pointers already!
 - Call-by-reference parameters
 - Address of actual argument was passed

Pointer Variables

- Pointers are "typed"
 - Can store pointer in variable
 - Not int, double, etc.
 - Instead: A POINTER to int, double, etc.!
- Example:
double *p;
 - p is declared a "pointer to double" variable
 - Can hold pointers to variables of type double
 - Not other types!

Declaring Pointer Variables

- Pointers declared like other types
 - Add "*" before variable name
 - Produces "pointer to" that type
- "*" must be before each variable
- `int *p1, *p2, v1, v2;`
 - p1, p2 hold pointers to int variables
 - v1, v2 are ordinary int variables

Addresses and Numbers

- Pointer is an address
- Address is an integer
- Pointer is NOT an integer!
- C++ forces pointers be used as addresses
 - Cannot be used as numbers
 - Even though it "is a" number

Pointing

- Terminology, view
 - Talk of "pointing", not "addresses"
 - Pointer variable "points to" ordinary variable
 - Leave "address" talk out
- Makes visualization clearer
 - "See" memory references
 - Arrows

Pointing to ...

- `int *p1, *p2, v1, v2;`
`p1 = &v1;`
 - Sets pointer variable p1 to "point to" int variable v1
- Operator, `&`
 - Determines "address of" variable
- Read like:
 - "p1 equals address of v1"
 - Or "p1 points to v1"

Pointing to ...

- Recall:
`int *p1, *p2, v1, v2;`
`p1 = &v1;`
- Two ways to refer to v1 now:
 - Variable v1 itself:
`cout << v1;`
 - Via pointer p1:
`cout << *p1;`
- Dereference operator, `*`
 - Pointer variable "dereferenced"
 - Means: "Get data that p1 points to"

"Pointing to" Example

- Consider:
v1 = 0;
p1 = &v1;
*p1 = 42;
cout << v1 << endl;
cout << *p1 << endl;
- Produces output:
42
42
- p1 and v1 refer to same variable

& Operator

- The "address of" operator
- Also used to specify call-by-reference parameter
 - No coincidence!
 - Recall: call-by-reference parameters pass "address of" the actual argument
- Operator's two uses are closely related

Pointer Assignments

- Pointer variables can be "assigned":

```
int *p1, *p2;
```

```
p2 = p1;
```

- Assigns one pointer to another
- "Make p2 point to where p1 points"

- Do not confuse with:

```
*p1 = *p2;
```

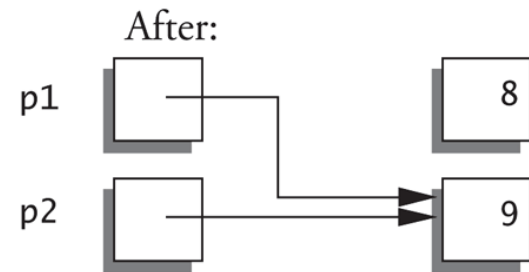
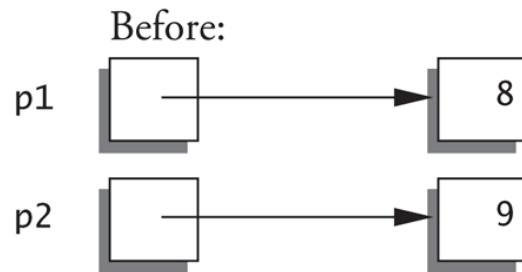
- Assigns "value pointed to" by p1, to "value pointed to" by p2

Pointer Assignments Graphic:

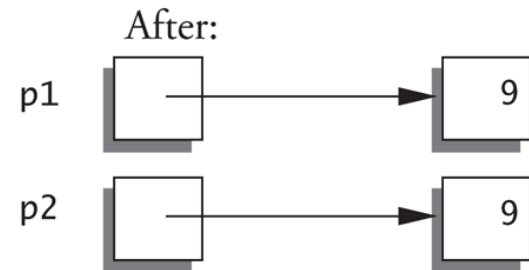
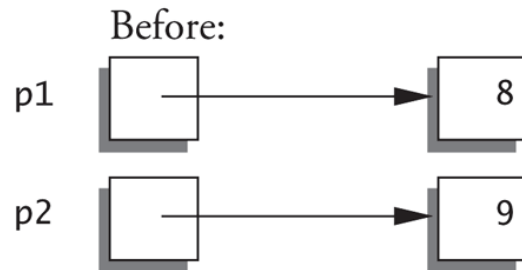
Display 10.1 Uses of the Assignment Operator with Pointer Variables

Display 10.1 Uses of the Assignment Operator with Pointer Variables

`p1 = p2;`



`*p1 = *p2;`



The new Operator

- Since pointers can refer to variables...
 - No "real" need to have a standard identifier
- Can dynamically allocate variables
 - Operator *new* creates variables
 - No identifiers to refer to them
 - Just a pointer!
- `p1 = new int;`
 - Creates new "nameless" variable, and assigns p1 to "point to" it
 - Can access with `*p1`
 - Use just like ordinary variable

Basic Pointer Manipulations Example: (1 of 3)

Display 10.2 Basic Pointer Manipulations

```
1  //Program to demonstrate pointers and dynamic variables.
2  #include <iostream>
3  using std::cout;
4  using std::endl;

5  int main( )
6  {
7      int *p1, *p2;

8      p1 = new int;
9      *p1 = 42;
10     p2 = p1;
11     cout << "*p1 == " << *p1 << endl;
12     cout << "*p2 == " << *p2 << endl;

13     *p2 = 53;
14     cout << "*p1 == " << *p1 << endl;
15     cout << "*p2 == " << *p2 << endl;
```

Basic Pointer Manipulations Example: (2 of 3)

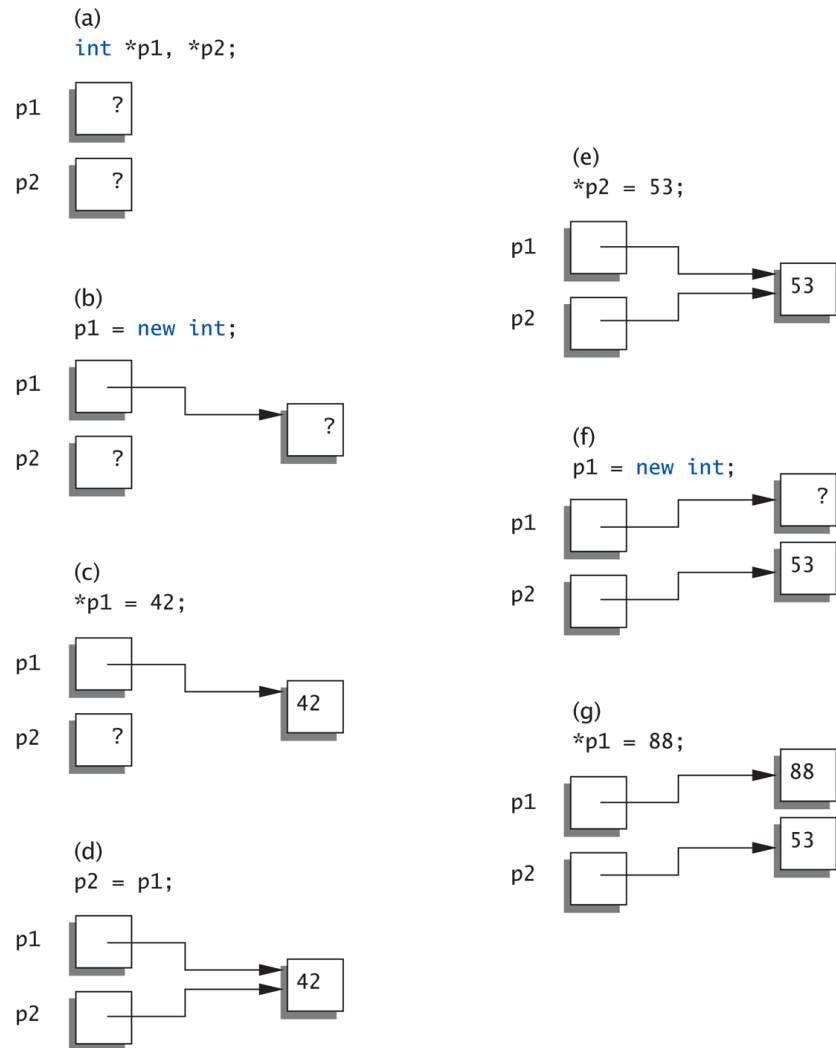
```
16     p1 = new int;  
17     *p1 = 88;  
18     cout << "*p1 == " << *p1 << endl;  
19     cout << "*p2 == " << *p2 << endl;  
  
20     cout << "Hope you got the point of this example!\n";  
21     return 0;  
22 }
```

SAMPLE DIALOGUE

```
*p1 == 42  
*p2 == 42  
*p1 == 53  
*p2 == 53  
*p1 == 88  
*p2 == 53  
Hope you got the point of this example!
```

Basic Pointer Manipulations Example: (3 of 3)

Display 10.3 Explanation of Display 10.2



More on new Operator

- Creates new dynamic variable
- Returns pointer to the new variable
- If type is class type:
 - Constructor is called for new object
 - Can invoke different constructor with initializer arguments:
`MyClass *mcPtr;`
`mcPtr = new MyClass(32.0, 17);`
- Can still initialize non-class types:
`int *n;`
`n = new int(17);` `//Initializes *n to 17`

Pointers and Functions

- Pointers are full-fledged types
 - Can be used just like other types
- Can be function parameters
- Can be returned from functions
- Example:
`int* findOtherPointer(int* p);`
 - This function declaration:
 - Has "pointer to an int" parameter
 - Returns "pointer to an int" variable

Memory Management

- Heap
 - Also called "freestore"
 - Reserved for dynamically-allocated variables
 - All new dynamic variables consume memory in freestore
 - If too many → could use all freestore memory
- Future "new" operations will fail if freestore is "full"

Checking new Success

- Older compilers:

- Test if null returned by call to *new*:

```
int *p;  
p = new int;  
if (p == NULL)  
{  
    cout << "Error: Insufficient memory.\n";  
    exit(1);  
}
```

- If new succeeded, program continues

new Success – New Compiler

- Newer compilers:
 - If new operation fails:
 - Program terminates automatically
 - Produces error message
- Still good practice to use NULL check

delete Operator

- De-allocate dynamic memory
 - When no longer needed
 - Returns memory to freestore
 - Example:

```
int *p;  
p = new int(5);  
... //Some processing...  
delete p;
```
 - De-allocates dynamic memory "pointed to by pointer p"

Dangling Pointers

- delete p;
 - De-allocates dynamic memory
 - But p still points there!
 - Called "dangling pointer"
 - If p is then dereferenced (*p)
 - Unpredictable results!
 - Often disastrous!
- Avoid dangling pointers
 - Assign pointer to NULL after delete:
delete p;
p = NULL;

Dynamic and Automatic Variables

- Dynamic variables
 - Created with new operator
 - Created and destroyed while program runs
- Local variables
 - Declared within function definition
 - Not dynamic
 - Created when function is called
 - Destroyed when function call completes
 - Often called "automatic" variables
 - Properties controlled for you

Define Pointer Types

- Can "name" pointer types
- To be able to declare pointers like other variables
 - Eliminates need for "*" in pointer declaration
- `typedef int* IntPtr;`
 - Defines a "new type" alias
 - Consider these declarations:
`IntPtr p;`
`int *p;`
 - The two are equivalent

Pitfall: Call-by-value Pointers

- Behavior subtle and troublesome
 - If function changes pointer parameter itself → only change is to local copy
 - If function dereferences pointer parameter and changes its value → then change is reflected outside the function
- Best illustrated with example...

Call-by-value Pointers Example: (1 of 2)

Display 10.4 A Call-by-Value Pointer Parameter

```
1  //Program to demonstrate the way call-by-value parameters
2  //behave with pointer arguments.
3  #include <iostream>
4  using std::cout;
5  using std::cin;
6  using std::endl;

7  typedef int* IntPtr;

8  void sneaky(IntPtr temp);

9  int main( )
10 {
11     IntPtr p;

12     p = new int;
13     *p = 77;
14     cout << "Before call to function *p == "
15          << *p << endl;
```

Call-by-value Pointers Example: (2 of 2)

```
16     sneaky(p);  
  
17     cout << "After call to function *p == "  
18         << *p << endl;  
  
19     return 0;  
20 }  
21 void sneaky(IntPointer temp)  
22 {  
23     *temp = 99;  
24     cout << "Inside function call *temp == "  
25         << *temp << endl;  
26 }
```

SAMPLE DIALOGUE

Before call to function *p == 77
Inside function call *temp == 99
After call to function *p == 99

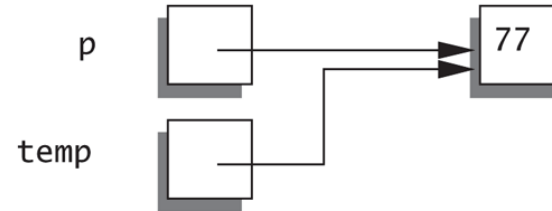
Call-by-value Pointers Graphic: The Function Call sneaky(p)

Display 10.5 The Function Call sneaky(p);

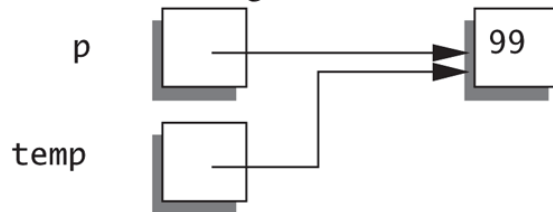
1. Before call to sneaky:



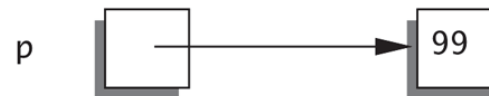
2. Value of `p` is plugged in for `temp`:



3. Change made to `*temp`:



4. After call to sneaky:



Dynamic Arrays

- Array variables
 - Really pointer variables!
- Standard array
 - Fixed size
- Dynamic array
 - Size not specified at programming time
 - Determined while program running

Array Variables

- Recall: arrays stored in memory addresses, sequentially
 - Array variable "refers to" first indexed variable
 - So array variable is a kind of pointer variable!
- Example:
`int a[10];`
`int * p;`
 - a and p are both pointer variables!

Array Variables → Pointers

- Recall previous example:

```
int a[10];  
typedef int* IntPtr;  
IntPtr p;
```

- a and p are pointer variables
 - Can perform assignments:
 - p = a; // Legal.
 - p now points where a points
 - To first indexed variable of array a
 - a = p; // ILLEGAL!
 - Array pointer is CONSTANT pointer!

Array Variables → Pointers

- Array variable
`int a[10];`
- MORE than a pointer variable
 - "const int *" type
 - Array was allocated in memory already
 - Variable 'a' MUST point there...always!
 - Cannot be changed!
- In contrast to ordinary pointers
 - Which can (& typically do) change

Dynamic Arrays

- Array limitations
 - Must specify size first
 - May not know until program runs!
- Must "estimate" maximum size needed
 - Sometimes OK, sometimes not
 - "Wastes" memory
- Dynamic arrays
 - Can grow and shrink as needed

Creating Dynamic Arrays

- Very simple!
- Use new operator
 - Dynamically allocate with pointer variable
 - Treat like standard arrays
- Example:

```
typedef double * DoublePtr;  
DoublePtr d;  
d = new double[10]; //Size in brackets
```

 - Creates dynamically allocated array variable *d*, with ten elements, base type double

Deleting Dynamic Arrays

- Allocated dynamically at run-time
 - So should be destroyed at run-time
- Simple again. Recall Example:
d = new double[10];
... //Processing
delete [] d;
 - De-allocates all memory for dynamic array
 - Brackets indicate "array" is there
 - Recall: *d* still points there!
 - Should set d = NULL;

Function that Returns an Array

- Array type NOT allowed as return-type of function
- Example:
`int [] someFunction(); // ILLEGAL!`
- Instead return pointer to array base type:
`int* someFunction(); // LEGAL!`

Pointer Arithmetic

- Can perform arithmetic on pointers
 - "Address" arithmetic
- Example:

```
typedef double* DoublePtr;  
DoublePtr d;  
d = new double[10];
```

 - d contains address of d[0]
 - d + 1 evaluates to address of d[1]
 - d + 2 evaluates to address of d[2]
 - Equates to "address" at these locations

Alternative Array Manipulation

- Use pointer arithmetic!
- "Step thru" array without indexing:

```
for (int i = 0; i < arraySize; i++)  
    cout << *(d + i) << " " ;
```
- Equivalent to:

```
for (int i = 0; i < arraySize; i++)  
    cout << d[i] << " " ;
```
- Only addition/subtraction on pointers
 - No multiplication, division
- Can use ++ and -- on pointers

Multidimensional Dynamic Arrays

- Yes we can!
- Recall: "arrays of arrays"
- Type definitions help "see it":

```
typedef int* IntArrayPtr;  
IntArrayPtr *m = new IntArrayPtr[3];
```

 - Creates array of three pointers
 - Make each allocate array of 4 ints
- ```
for (int i = 0; i < 3; i++)
 m[i] = new int[4];
```

  - Results in three-by-four dynamic array!



# Back to Classes

- The -> operator
  - Shorthand notation
- Combines dereference operator, \*, and dot operator
- Specifies member of class "pointed to" by given pointer
- Example:

```
MyClass *p;
p = new MyClass;
p->grade = "A";
equivalent to:
(*p).grade = "A";
```

# The this Pointer

- Member function definitions might need to refer to calling object
- Use predefined *this* pointer

- Automatically points to calling object:

Class Simple

```
{
public:
 void showStuff() const;
private:
 int stuff;
};
```

- Two ways for member functions to access:  
cout << stuff;  
cout << this->stuff;

# Need for Destructors

- Dynamically-allocated variables
  - Do not go away until "deleted"
- If pointers are only private member data
  - They dynamically allocate "real" data
    - In constructor
  - Must have means to "deallocate" when object is destroyed
- Answer: destructor!

# Destructors

- Opposite of constructor
  - Automatically called when object is out-of-scope
  - Default version only removes ordinary variables, not dynamic variables
- Defined like constructor, just add ~
  - ```
MyClass::~~MyClass()  
{  
    //Perform delete clean-up duties  
}
```

Summary

- Pointer is memory address
 - Provides indirect reference to variable
- Dynamic variables
 - Created and destroyed while program runs
- Freestore
 - Memory storage for dynamic variables
- Dynamically allocated arrays
 - Size determined as program runs