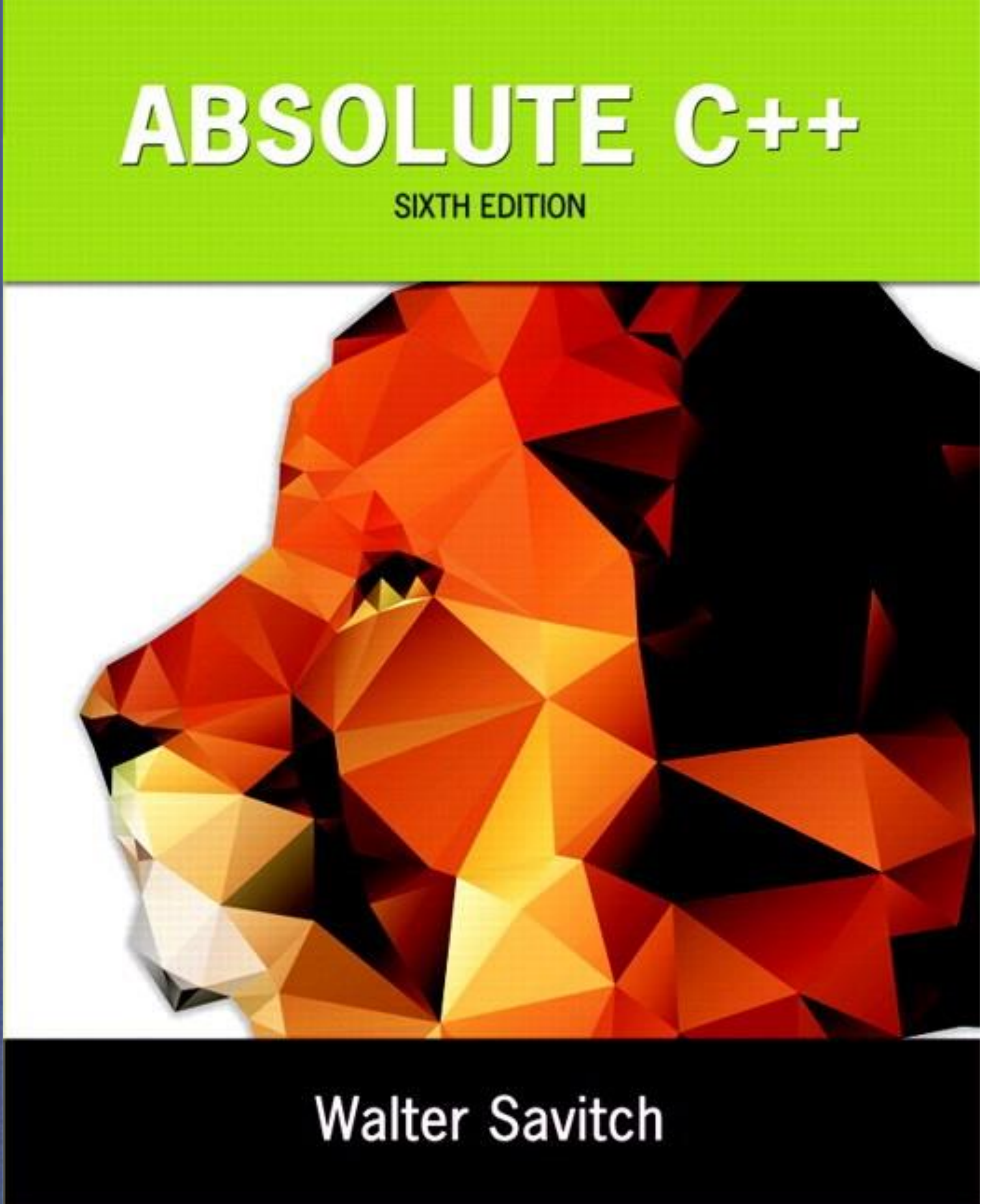


Chapter 10

Pointers and Dynamic Arrays

Learning Objectives

- Pointers
  - Pointer variables
  - Memory management
- Dynamic Arrays
  - Creating and using
  - Pointer arithmetic
- Classes, Pointers, Dynamic Arrays
  - The *this* pointer
  - Destructors, copy constructors

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! (unless typecast, but could be dangerous)

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!
  - Not crazy → abstraction!
- 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 "derereferenced"
  - 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

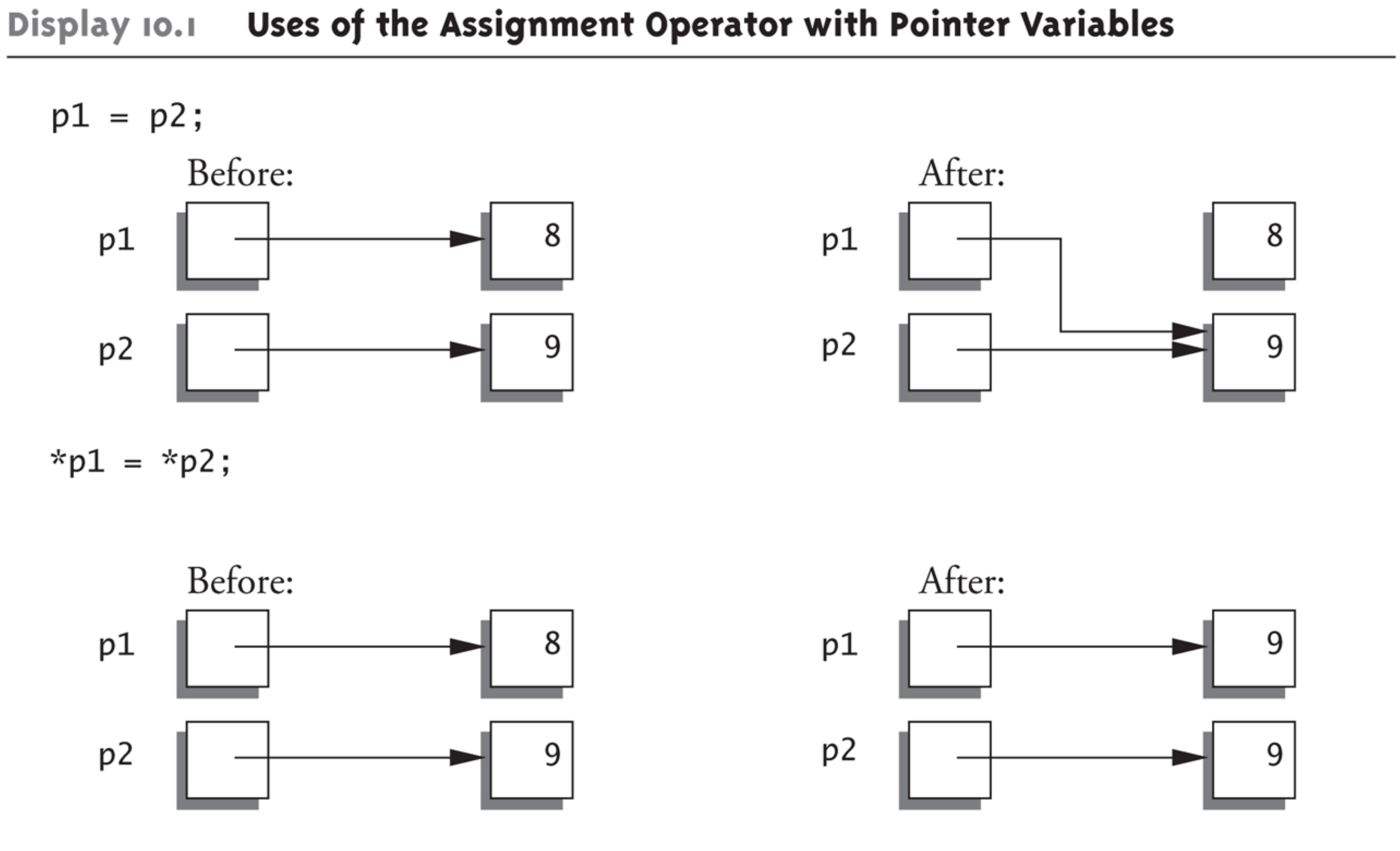
& Operator

- 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



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: **Display 10.2** Basic Pointer Manipulations (1 of 2)

Display 10.2 Basic Pointer Manipulations

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

int main( )
{
    int *p1, *p2;

    p1 = new int;
    *p1 = 42;
    p2 = p1;
    cout << "*p1 == " << *p1 << endl;
    cout << "*p2 == " << *p2 << endl;

    *p2 = 53;
    cout << "*p1 == " << *p1 << endl;
    cout << "*p2 == " << *p2 << endl;
```

Basic Pointer Manipulations Example: **Display 10.2** Basic Pointer Manipulations (2 of 2)

```
    p1 = new int;
    *p1 = 88;
    cout << "*p1 == " << *p1 << endl;
    cout << "*p2 == " << *p2 << endl;

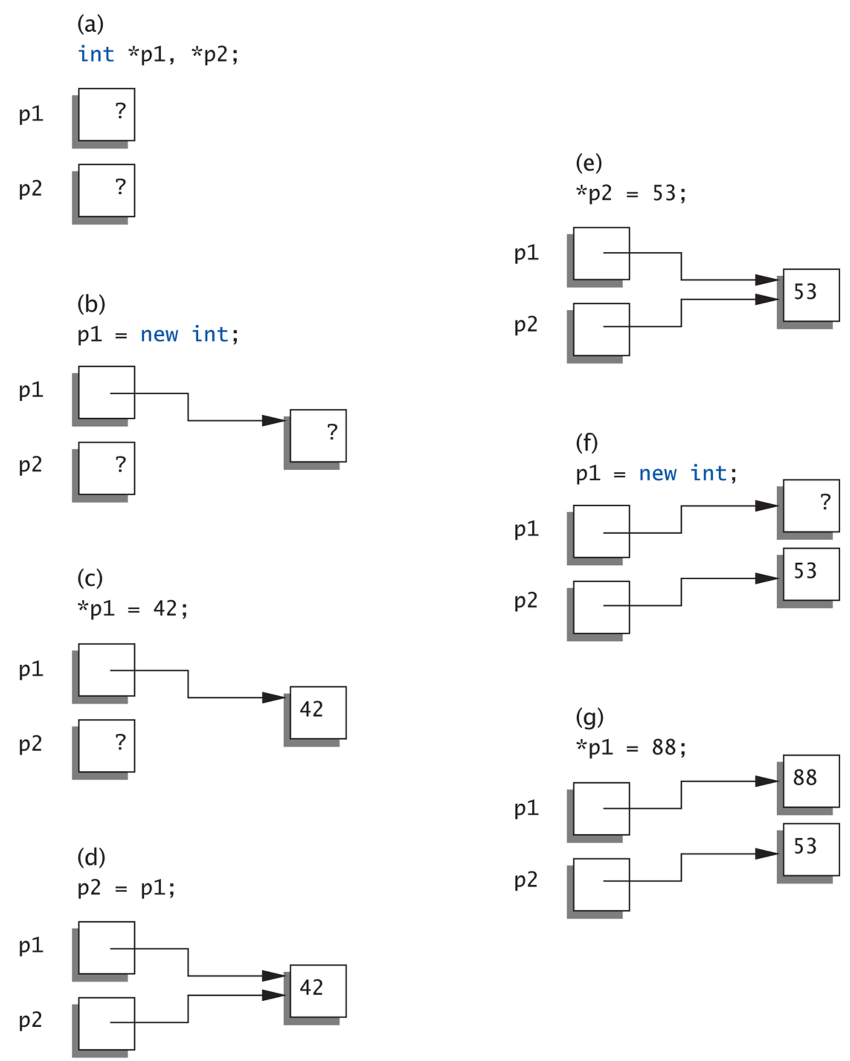
    cout << "Hope you got the point of this example!\n";
    return 0;
}
```

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 Graphic: **Display 10.3** Explanation of Display 10.2

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)   // NULL represents empty pointer
{
    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
- NULL represents the empty pointer or a pointer to nothing and will be used later to mark the end of a list

C++11 nullptr

- NULL is actually the number 0 and can lead to ambiguity

```
void func(int *p);
void func(int i);
```

- Which func is invoked given **func(NULL)**? Both are equally valid since NULL is 0
- C++11 resolves this problem by introducing a new constant, **nullptr**
- **nullptr** is not 0
- Can use anywhere you could use NULL

Freestore Size

- Varies with implementations
- Typically large
  - Most programs won't use all memory
- Memory management
  - Still good practice
  - Solid software engineering principle
  - Memory IS finite
    - Regardless of how much there is!

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"
    - Literally "destroys" memory

Dangling Pointers

- delete p;
  - Destroys dynamic memory
  - But p still points there!
    - Called "dangling pointer"
  - If p is then dereferenced (*p)
    - Unpredicatable 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
  - Eliminate 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
- Best illustrated with example…

Call-by-value Pointers Example: **Display 10.4** A Call-by-Value Pointer Parameter (1 of 2)

Display 10.4 A Call-by-Value Pointer Parameter

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

typedef int* IntPointer;

void sneaky(IntPointer temp);

int main( )
{
    IntPointer p;

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

Call-by-value Pointers Example: **Display 10.4** A Call-by-Value Pointer Parameter (2 of 2)

```
    sneaky(p);

    cout << "After call to function *p == "
         << *p << endl;

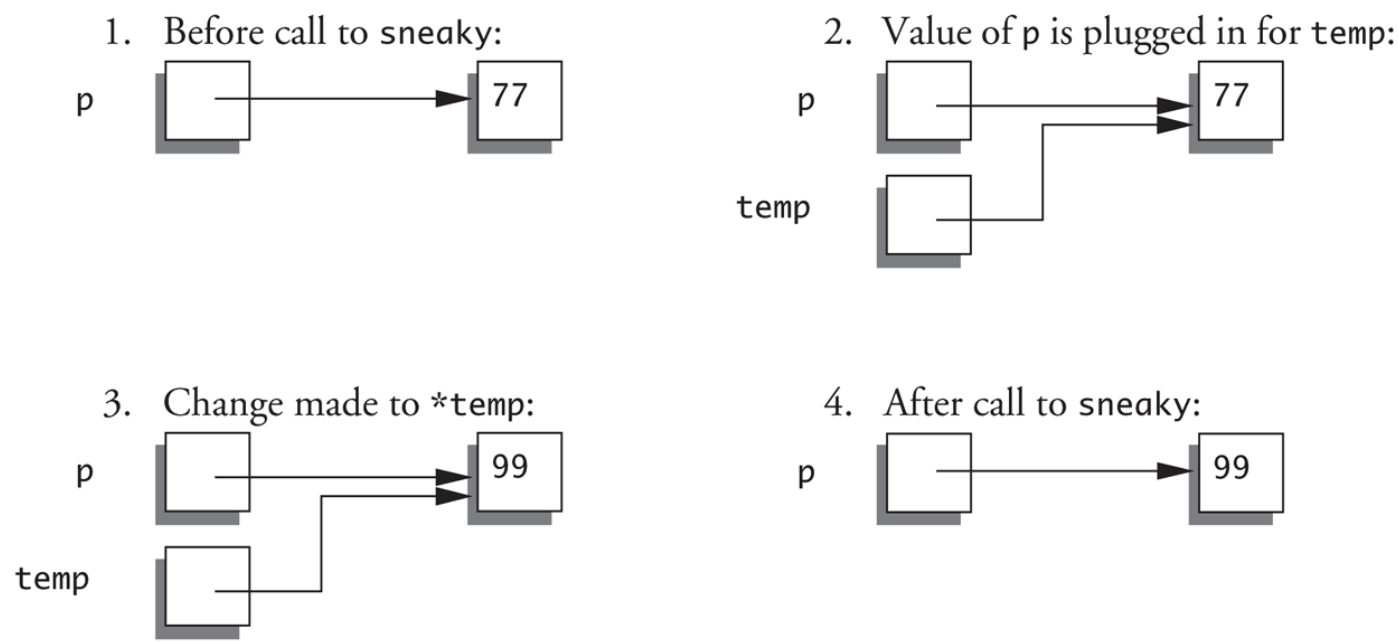
    return 0;
}
void sneaky(IntPointer temp)
{
    *temp = 99;
    cout << "Inside function call *temp == "
         << *temp << endl;
}
```

SAMPLE DIALOGUE

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

Call-by-value Pointers Graphic: **Display 10.5** The Function Call sneaky(p);

Display 10.5 **The Function Call** `sneaky(p);`



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;
```

Overloading Assignment Operator

- Assignment operator returns reference
  – So assignment "chains" are possible
  – e.g., a = b = c;
    - Sets a and b equal to c
- Operator must return "same type" as it's left-hand side
  – To allow chains to work
  – The *this* pointer will help with this!

Overloading Assignment Operator

- Recall: Assignment operator must be member of the class
  - It has one parameter
  - Left-operand is calling object
    s1 = s2;
    - Think of like: s1.=(s2);
- s1 = s2 = s3;
  - Requires (s1 = s2) = s3;
  - So (s1 = s2) must return object of s1"s type
    - And pass to " = s3";

Overloaded = Operator Definition

- Uses string Class example:

```
StringClass& StringClass::operator=(const StringClass& rtSide)
{
	if (this == &rtSide)		// if right side same as left side
		return *this;
	else
	{
		capacity = rtSide.length;
		length
		length = rtSide.length;
		delete [] a;
		a = new char[capacity];
		for (int I = 0; I < length; I++)
			a[I] = rtSide.a[I];
		return *this;
	}
}
```

Shallow and Deep Copies

- Shallow copy
  - Assignment copies only member variable contents over
  - Default assignment and copy constructors
- Deep copy
  - Pointers, dynamic memory involved
  - Must dereference pointer variables to "get to" data for copying
  - Write your own assignment overload and copy constructor in this case!

Destructor Need

- 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
    }
    ```
    ```

Copy Constructors

- Automatically called when:
  1. Class object declared and initialized to other object
  2. When function returns class type object
  3. When argument of class type is "plugged in"
     as actual argument to call-by-value parameter
- Requires "temporary copy" of object
  – Copy constructor creates it
- Default copy constructor
  – Like default "=", performs member-wise copy
- Pointers → write own copy constructor!

Summary 1

- 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

Summary 2

- Class destructor
  - Special member function
  - Automatically destroys objects
- Copy constructor
  - Single argument member function
  - Called automatically when temp copy needed
- Assignment operator
  - Must be overloaded as member function
  - Returns reference for chaining