Pointers and Addresses

- The **address operator** (&) returns the address of a variable.

  ```cpp
  int x;
  cout << &x << endl;  // 0xbffffb0c
  ```

- **Pointer**: a variable that stores the address of another variable, providing indirect access to it.

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

Dereferencing and initializing

- The unary operator * is the **dereferencing operator**.

  ```cpp
  *ptr is an alias for the variable that ptr points to.
  ```

- **Initialization**:

  ```cpp
  int x = 10;
  int *ptr;  //declaration, NOT dereferencing
  ptr = &x;  //ptr gets the address of x
  *ptr = 7;  //the thing ptr pts to gets 7
  ```

- **ptr is a pointer to an int**, and it is initialized to the address of x.

Pointers as Function Parameters

- **Use pointers to implement pass by reference**.

  ```cpp
  //prototype: void changeVal(int *);
  void changeVal (int *val) {
    *val = *val * 11;
  }

  int main() {
    int x;
    cout << "Enter an int " << endl;
    cin >> x;
    changeVal(&x);
    cout << x << endl;
  }
  ```

- **How is it different from using reference parameters?**
Pointers and Arrays

You can treat an array variable as if it were a pointer to its first element.

```cpp
int numbers[] = {10, 20, 30, 40, 50};
cout << "first: " << numbers[0] << endl;
cout << "first: " << *numbers << endl;
cout << &(numbers[0]) << endl;
cout << numbers << endl;
```

Output:
```
first: 10
first: 10
0xbffffb00
0xbffffb00
```

Note: array[index] is equivalent to *(array + index)

Pointers and Arrays

• pointer operations * + can be used with array variables.

```cpp
int list[10];
cin >> *(list+3);
```

• subscript operations: [ ] can be used with pointers.

```cpp
int list[] = {1,2,3};
int *ptr = list;
cout << ptr[2];
```

Pointer Arithmetic

• When you add a value n to a pointer, you are actually adding n times the size of the data type being referenced by the pointer.

```cpp
int numbers[] = {10, 20, 30, 40, 50};
// sizeof(int) is 4.
// Let us assume numbers is stored at 0xbffffb00
// Then numbers+1 is really 0xbffffb00 + 1*4, or 0xbffffb04
// And numbers+2 is really 0xbffffb00 + 2*4, or 0xbffffb08
// And numbers+3 is really 0xbffffb00 + 3*4, or 0xbffffb0c
```

Output:
```
second: 20
second: 20
size: 4
0xbffffb00
0xbffffb04
```

Comparing Pointers

• pointers (addresses) maybe compared using the relational operators:

```
< <= > >= == !=
```

• Examples:

```cpp
int arr[25];
cout << (&arr[1] > &arr[0]) << endl;
cout << (arr == &arr[0]) << endl;
cout << (arr <= &arr[20]) << endl;
cout << (arr > arr+5) << endl;
```

• What is the difference?

- `ptr1 < ptr2`
- `*ptr1 < *ptr2`
Dynamic Memory Allocation

- When a function is called, memory for local variables is automatically allocated.
- When a function exits, memory for local variables automatically disappears.
- Must know ahead of time the maximum number of variables you may need.
- Dynamic Memory allocation allows your program to create variables on demand, during run-time.

The new operator

- “new” operator requests dynamically allocated memory for a certain data type:
  ```cpp
  int *iptr;
  iptr = new int;
  ```
- new operator returns address of newly created anonymous variable.
- use dereferencing operator to access it:
  ```cpp
  *iptr = 11;
  cin >> *iptr;
  int value = *iptr / 3;
  ```

Dynamically allocated arrays

- dynamically allocate arrays with new:
  ```cpp
  int *iptr;  //for dynamically allocated array
  int size;
  cout << "Enter number of ints: ";
  cin >> size;
  iptr = new int[size];
  for (int i=1; i<size; i++) {
    iptr[i] = i;
  }
  ```
- Program will throw an exception and terminate if not enough memory available to allocate.

delete!

- When you are finished using a variable created with new, use the delete operator to destroy it:
  ```cpp
  int *ptr;
  double *array;
  ptr = new int;
  array = new double[25];
  ...
  delete ptr;
  delete[] array;  // note [] required for dynamic arrays!
  ```
- Do not “delete” pointers whose values were NOT dynamically allocated using new!
- Do not forget to delete dynamically allocated variables (Memory Leaks!!).
Returning Pointers from Functions

- functions may return pointers:
  
  ```c
  int * findZero (int arr[]) {
    int *ptr;
    ptr = arr;
    while (*ptr != 0)
      ptr++;
    return ptr;
  }
  ```

- The returned pointer must point to
  - dynamically allocated memory OR
  - an item passed in via an argument

NOTE: if the function returns dynamically allocated memory, then it is the responsibility of the calling function to delete it.

NOTE: the return type of this function is (int *) or pointer to an int.

int *duplicateArray (int *arr, int size) {
  int *newArray;
  if (size <= 0)         //size must be positive
    return NULL;        //NULL is 0, an invalid address
  newArray = new int [size];  //allocate new array
  for (int index = 0; index < size; index++)
    newArray[index] = arr[index]; //copy to new array
  return newArray;
}

int a [5] = {11, 22, 33, 44, 55};
int *b = duplicateArray(a, 5);
for (int i=0; i<5; i++)
  if (a[i] == b[i])
    cout << i << " ok" << endl;
delete [] b;  //caller deletes mem

/* Parameters*/
int a [5] = {11, 22, 33, 44, 55};
int *b = duplicateArray(a, 5);
for (int i=0; i<5; i++)
  if (a[i] == b[i])
    cout << i << " ok" << endl;
delete [] b;  //caller deletes mem

/* Output*/
0 ok
1 ok
2 ok
3 ok
4 ok

Structures

- A structure stores a collection of objects of various types
- Each element in the structure is a member, and is accessed using the dot member operator.

```c
struct Student {
int idNumber;
string name;
int age;
string major;
};
```  

```c
Student student1, student2;
student1.name = “John Smith”;
Student student3 = {123456,”Ann Page”,22,”Math”};
```

Valid operations over entire structs:
- assignment: `student1 = student2;`
- function call: `myFunc(gradStudent,x);`

Invalid operations over structs:
- comparison: `student1 == student2`
- output: `cout << student1;`
- input: `cin >> student2;`
- Must do these member by member
Arrays of Structures

- You can store values of structure types in arrays.
  
  ```cpp
  Student roster[40]; //holds 40 Student structs
  ```

- Each student is accessible via the subscript notation.
  ```cpp
  roster[0] = student1; //copy student1 into 1st position
  ```

- Members of structure accessible via dot notation
  ```cpp
  cout << roster[0].name << endl;
  ```

Arrays of Structures: initialization

- To initialize an array of structs:
  ```cpp
  struct Student {
      int idNumber;
      string name;
      int age;
      string major;
  };

  int main()
  {
      Student roster[] = {
          {111222,"Jack Spade",18,"Physics"}
      };
  }
  ```

Arrays of Structures

- Arrays of structures processed in loops:
  ```cpp
  Student roster[40];
  
  //input
  for (int i=0; i<40; i++) {
      cout << "Enter the name, age, idNumber and " << "major of the next student: \n";
      cin >> roster[i].name >> roster[i].age >> roster[i].idNumber >> roster[i].major;
  }
  
  //output all the id numbers and names
  for (int i=0; i<40; i++) {
      cout << roster[i].idNumber << endl;
      cout << roster[i].name << endl;
  }
  ```

Passing structures to functions

- Structure variables may be passed as arguments to functions:
  ```cpp
  void getStudent(Student &s) {  // pass by reference
      cout << "Enter the name, age, idNumber and " << "major of the student: \n";
      cin >> s.name >> s.age >> s.idNumber >> s.major;
  }
  
  void showStudent(Student x) {
      cout << x.idNumber << endl;
      cout << x.name << endl;
      cout << x.age << endl;
      cout << x.major << endl;
  }
  
  // in main:
  Student student1;
  getStudent(student1);
  showStudent(student1);
  ```
Pointers to structures

- We can define pointers to structures
  
  ```
  Student s1 = {12345, "Jane Doe", 18, "Math"};
  Student *ptr = &s1;
  ```

- To access the members via the pointer:
  
  ```
  cout << *ptr.name << end;  // ERROR: *(ptr.name)
  cout << (*ptr).name << end;
  ```

- dot operator has higher precedence, so use ():
  
  ```
  cout << (*ptr).name << end;
  ```

- or equivalently, use ->:
  
  ```
  cout << ptr->name << end;
  ```

Dynamically Allocating Structures

- Structures can be dynamically allocated with new:
  
  ```
  Student *sptr;
  sptr = new Student;
  sptr->name = "Jane Doe";
  sptr->idNum = 12345;
  ...
  delete sptr;
  ```

- Arrays of structures can also be dynamically allocated:
  
  ```
  Student *sptr;
  sptr = new Student[100];
  sptr[0].name = "John Deer";
  ...
  delete [] sptr;
  ```