**Recitation 4**

**Topics**

* Pointers, addresses address of operator, dereferencing pointer values
* The this keyword
* dynamic objects
* vectors of pointers
* one way association (implemented via pointers)
* Use of the Debugger with pointers and addresses

**Recitation**

**Today's recitation is "task based."  
Work through these Tasks on your own, making sure that you understand what is going on in each Task.  
The lab worker is here to help with any questions you might have.**

**Note that this content -will- be on the upcoming test and this is a great time to ask questions to see if you know the content.**

**Task 1:**  Create a new project, "rec04". Create a new C++ program, "rec04.cpp", which displays our required header information (your name, course, section, id). Run your program and be sure it is working properly before going on to the next task.

**Task 2:** Add the following code to main().

int x;

x = 10;

cout << "x = " << x << endl;

Rebuild and run the project.

**Task 3:**  We will be using the Debug facilities of Visual C++ to explore what is going on behind the scenes of our program.  Place the cursor in front of the line "int x;".  Right-click and select the option "run to cursor".

Several new windows should appear.  One of them is the output window of your program which should display as usual.  However, it may disappear at times while the Debugger returns you to your code.  You can always display the output window by clicking its button at the bottom of your screen, it has the MSDOS icon.

In Debug mode, your Visual C++ environment (if you use the default layout) displays four main windows: the code window or editor (upper left), the Solution Explorer window (upper right), the Variables window (bottom left), and the Call Stack/Breakpoint window (bottom right). Most of these windows contain tabs at the bottom for other displays in each window (for example the Autos, Locals and Watch 1 tabs in the Variables window). If you don't see a debug window, you can use the Debug menu, Windows submenu, to activate missing debug windows. If you don't see the Solution Explorer you can show it by using the View menu's Solution Explorer option.

Your program is waiting for you. In debug mode you are stepping through the execution of the program. You did "run to cursor" and now the program has stopped *before* executing the statement your cursor was on. A yellow arrow at the left of the editor/code window should be pointing to the assignment statement x=10;.  That is the next statement that will be executed. Select the "Locals tab" if it is not selected. There should be one variable displayed in the variables window:  x, which should have a "garbage" value. Garbage is a technical computer science term for a value that was not placed into a variable under the programmer's control and must never be used under any circumstances. The value displayed may be -858993460 but this might be different on your machine since this value is just whatever bits happened to be turned on in that memory location when the program used it for x. The assignment of 10 to x has not been executed, x was not initialized at define-time and x has not had user input into it, so x contains GARBAGE.

**Task 4:**  Execute the next statement by pressing the F10 key (step over).  The Variables window will change and display x with a value of 10 in red. Red indicates that a value has changed in memory. The yellow arrow will have moved to the next statement waiting to be executed.

**Task 5:**  In the Variables window, click the Watch tab. The Watch window allows the programmer to type in expressions (like the name of a variable or x\*y-17) to see the value of that expression AT THIS MOMENT in the program's execution. Click under the Name column in the first box. If you want to see the value of x (which means what's currently stored in x) you would type x. Do that now. You should see 10 under the Value column.

Memory can be considered to be a very large array of bytes.  Each byte has an address, starting with the first address at byte 0. Now that we know that x contains 10 - that 10 is stored in the memory location we call x, then "Where is x in the computer's memory?" is the next question. "Where is that 10 stored?" is the same question as "where is x?"

**Task 6:**  In C++ there is a "unary operator" (an operator that works on just one thing) that evaluates to where in memory something is. It's called the "address-of" operator. The address-of operator is notated as the ampersand. The expression&x yields the actual physical memory location where variable x is placed during the current execution of the program (it may be in a different location every time we run the program.) You can use the Watch window to see where x is. Enter &xin the watch under the name column. [Note that name is a pretty confusing header for the column because &x is not a "name." it's an expression.] The syntax for the address-of operator requires it to be to the left of the variable that we want to find out the address of.  The value might be 0x0012fed4 (very likely it will be different on your machine).  The 0x prefix indicates that the following digits are hexadecimal (base 16). This format is standardly used for memory locations. (Review or learn hexadecimal counting if you are not familiar with it.) In C++ you can type 0xB where ever you need the number 11 (in decimal) as in cout << 0xB; and the number 11 will appear in the output window.

**Task 7:**  There should also be a small square with a '+' sign to the left of &x.  Click it and it should expand to display more information and become a '-' sign.  The Watch window now shows the value of &x and under it, the value stored AT the address of x. This means the 10 is stored in the memory location that is the value of &x - 10 is stored where x is - of course!

Now, we will explore pointer variables.  Stop the Debugger (SHIFT-F5).

**Task 8:** Add the following below your code to main().

int\* p;

p = &x;

cout << "p = " << p << endl;

Run your program (Ctrl-F5). Does the value stored in p match the value you saw in the Watch window for the address of x? It should. What this code does is take the address of x (i.e., &x) and copy that value into p (using p =). That's the way a normal assignment statement works: evaluate the right hand side and copy that value into the left hand side. The only thing that might be new to you (if you've been asleep in lectue) is the *type* of p. Is p an int? No. Does it mean multiply int times p? No, of course not. This is a type you may not have seen before : pointer to int. The asterisk (\*) in a type name means "pointer to" and all pointers must be pointers to some other type. Here it's a pointer to an int.

The type "pointer to int" can hold the address of an int variable. So you can think of p as being able to hold the address of an int. It can hold where an int can be stored. We say that *p points to x* when p contains where x is.

Place the cursor on the line int\* p; and do Run To Cursor (right click and choose).

Look in the Locals window. What are the types of x and p? You should see int for x and int\* for p. What is the value of p? Garbage because it has not been initialized, assigned to or read into. Look in the Watch window. What are the types of x and &x? You should see int for x and int\* for &x.

So the type of the expression &x is int\* which is the type you used when you defined p. So it's fine to place the value &x (where x is) into the variable p to make p point to x (to make p contain the address of x).

Hit F10 (step over) and look in the Locals window. What value was stored in p?

p really is just a variable just as x is a variable. We can assign to it. Let's try something to emphasize the type differences between the type int and the type int\* (pointer to int).

**Task 9:** Try to assign the value for &x to p directly:

p = 0x0012fed4; // using the value from my Watch window

What happens?  
Read the error message. It should be something similar to:

error C2440: '=' : cannot convert from 'int' to 'int \*'

That's pretty clear for an error message for .NET!

0x0012fed4 is NOT an int\* value. It's an unsigned int most likely. Try just a plain old decimal integer value like 100000 and you will get the same error message.

Note that C++ is VERY STRICT about pointer types.

[We don't cover casting an integral value to a pointer to an int here - ask someone outside of lab.]

Note that the \* can be written several ways when indicating a pointer type and the compiler sees as all being exactly the same:

int\* p; // it's very clear that the \* is part of the type's name - the type is "pointer to int"

// PREFERRED

int \*p; // it looks the \* is part of the variable name but the compiler reads it as above

int \* p; // it looks more like multiplication but the compiler again reads it as above

// (probably NOT a good idea to use)

int\* p1, p2, \*p3; // This is compileable code but's it's VERY unclear as the type of i.

// Since the \* is part of the type's name, it's clear that p1 is an int\*; and it's pretty clear that

// p3 is an int\* but notice that it looks like p2 is also an int\* - but it's not!

// (definitely NOT a good idea to mix int and int\* definitions

**Task 10:**

Comment out p = 0x0012fed4;   
and Run To Cursor on

cout << "p = " << p << endl;

Look in the Locals window at p.  
There is a '+' sign just as there was in the Watch window for &x.  
Expand the '+'. What's there? 10  
That's what we saw when we expanded the '+' on the expression &x in the Watch window.  
10 is the value stored in x and p contains where x is. p points to x.  
Expanding the '+' tells the system to "*go to where this pointer value points*".  
Since p points to x (because it contains the address of x), we are looking at x when we follow p to where it points.  
This is called "*dereferencing a pointer*" in C++.

In C++ there is a unary operator for doing this dereferencing. It can only be used on something that is or contains an address - a pointer. p is of type int\* so it can contain the address of an int so we can derefernce it.

Add these statements after your code in main().

cout << "p points to where " << \*p << " is stored\n";

cout << "\*p contains " << \*p << endl;

The expression \*p is the *dereference operator* applied to the variable p.  
This tells the computer to follow the pointer value stored in p (the address stored in p) and get the value stored there. The 10 we stored in x is what \*p is referring to. \*p is a memory location just like x is.

\*p and x refer to the same memory because we did p = &x;

**Task 11:** Can we change x using p?

Add this statement after your code in main().

\*p = -2763;

cout << "p points to where " << \*p << " is stored\n";

cout << "\*p now contains " << \*p << endl;

cout << "x now contains " << x << endl;

Place the cursor on \*p = -2763; and Run To Cursor.  
Look at x and p (make sure the '+' is expanded so you can see the value p points to).  
Both 10's are red because when 10 was assigned to x, it changed the memory that p points to.

Hit F10 (step over) and watch x and p and the expanded p.

There is now a red -2763 in both places in the Locals window because both places refer to the same memory location.

**Task 12:** Add the following code

int y(13);

cout << "y contains " << y << endl;

p = &y;

cout << "p now points to where " << \*p << " is stored\n";

cout << "\*p now contains " << \*p << endl;

\*p = 980;

cout << "p points to where " << \*p << " is stored\n";

cout << "\*p now contains " << \*p << endl;

cout << "y now contains " << y << endl;

What's going on? Since p is just a variable, we can assign to it as long as what we assign is a pointer value.  
We made p point to y and changed y through p.

**Task 13:** Add the following code

int\* q;

q = p;

cout << "q points to where " << \*q << " is stored\n";

cout << "\*q contains " << \*q << endl;

Look at all the ways to get to the place we call y. (Expand the '+' for q.)

As long as the types are the same, pointer values can be assigned. We say that the above code makes p and q point to the same place (y).

**Task 14:** We said earlier that C++ is very strict on types when dealing with pointers.  
Let's explore.  
Define double variable named d and initialize it to 33.44.  
Define a variable named pD that can contain a pointer to a double and initialize it so that it points to d.

double d(33.44);

double\* pD(&d);

\*pD = \*p;

\*pD = 73.2343;

\*p = \*pD;

\*q = \*p;

pD = p;

What lines are the compilation errors on?  
The VERY STRICT type rule for pointers is that there is NO COERCION between any pointer types.  
An int\* cannot be cast to a double\* even though an int can be cast to a double.  
A double\* cannot be cast to an int\* even though a double can be cast to an int (with truncation).

Comment out the error lines and step through this code looking at the Locals window.

**Task 15:** What about const pointers and their values and access?  
Copy this code in your program and uncomment the commented lines to see what's allowed and what's not.  
Note that there are four ways to deal with const-ness when dealing with pointers.

int joe( 24 );

const int sal( 19 );

int\* pI;

// pI = &joe;

// \*pI = 234;

// pI = &sal;

// \*pI = 7623;

//const int\* pcI;

// pcI = &joe;

// \*pcI = 234;

// pcI = &sal;

// \*pcI = 7623;

//int\* const cpI;

//int\* const cpI(&joe);

//int\* const cpI(&sal);

// cpI = &joe;

// \*cpI = 234;

// cpI = &sal;

// \*cpI = 7623;

//const int\* const cpcI;

//const int\* const cpcI(&joe);

//const int\* const cpcI(&sal);

// cpcI = &joe;

// \*cpcI = 234;

// cpcI = &sal;

// \*cpcI = 7623;

**Task 16:**

The syntax for defining a variable is:  
TYPE variableName;

TYPE can be *any* type.  
  
For pointer types, \* is part of the type's name: TYPE\* is a pointer to TYPE type.

TYPE\* variableName; // can hold a pointer to TYPE value

If you've defined a struct, isn't that a type?  
So it follows that we can have pointers to structs.

Add this struct definition to your code.

struct Complex {

double real;

double img;

};

and define a variable named c initialized to the complex value (11.23,45.67)  
and define a variable named pC initialized to point to c.

Complex c = {11.23,45.67};

Complex\* pC(&c);

How do you access the fields in this variable? Try writing them on the screen.  
When you deference a pointer to a type you get a thing of the type that the pointer points to.  
\*p is of type int. \*pD is of type double. So when you dereference a pointer to a Complex struct, you get a Complex struct. So try this:

cout << "real: " << \*pC.real << "\nimaginary: " << \*pC.img << endl;

What's wrong? The precedence of operators is giving you a problem. The operator \* (dereference) has a LOWER precedence than the operator . (member access) so the solution is parentheses.

Don't simply copy and paste the next code into your .NET IDE.

Try typing it and watch what the IDE does when you get to the '.' in (\*pC). The IDE shows you what can follow the dot the type of (\*pC) is struct Complex.

cout << "real: " << (\*pC).real << "\nimaginary: " << (\*pC).img << endl;

The notation (\*pC). is a bit clumsy and as often is the case in C++, its designers added an operator specifically for this purpose. The operator is written -> and often pronounced "arrow" but really means "dereference operator for pointer to struct or class" which is really too long to pronounce. The -> operator ONLY works on pointer to struct (or class) types. It must have an object as its left hand operand and the name of a member of the type as its right hand operand.

Now try the ***correct*** way to deference a pointer to a Complex object:

cout << "real: " << pC->real << "\nimaginary: " << pC->img << endl;

In the Watch window type the expression pC->real to see that this really is an expression that evaluates to what is stored in the real field of the object that pC points at.

**Task 17:**

What about pointers to class objects?  
Copy this code into your program to see how this works.

class PlainOldClass {

public:

PlainOldClass() : x(-72) {}

int getX() const { return x; }

void setX( int val ) { x = val; }

private:

int x;

};

PlainOldClass poc;

PlainOldClass\* ppoc( &poc );

cout << ppoc->getX() << endl;

ppoc->setX( 2837 );

cout << ppoc->getX() << endl;

**Task 18:**

Consider if you decided that a good name for the parameter in the mutator was x.  
How will this mess things up?  
Think about changing your code in this way:

class PlainOldClass {

public:

PlainOldClass() : x(-72) {}

int getX() const { return x; }

void setX( int x ) { x = x; } // HMMMM???

private:

int x;

};

Type this code in and see if the correct assignment happens.  
There needs to be a way to talk about the object being worked on while a method is running.  
That is the "this" pointer.  
It's as if there were actually a "hidden" parameter to each method of type ClassName\* that the system intializese to be the address of the object that method is invoked on.

Like this:

int getX( *const PlainOldClass\* const this = &poc* ) const { return x; }

void setX( *PlainOldClass\* const this = &poc,* int x ) { x = x; } // Still HMMMM???

We can't write code like that, but that's the concept.  
Now"this" pointer.to make sure which x is which:

void setX( int x ) { this->x = x; } // No confusion!

Type the new and improved mutator code into your program and see that it works..

**Task 19:** Let's get dynamic.

Everything we have done to this point has dealt with variables that were named and created in our program.  
That means the memory for them is grabbed in RAM when the program is loaded and where these kinds of variables are in RAM cannot change while the program is running.

Sometimes a program might need to have more memory than the defined variables and parameters written in the code.  
Operating systems reserve some RAM to given to programs for this purpose.  
This area of RAM is called the *heap* (another name is *dynamic memory*) (yet another name is the *free store*).  
This is called dynamic memory (as opposed to "static" memory).  
In C++ the way to request more memory of the operating system is the operator: *new*.  
new yields a pointer value that points to the heap memory the system lets the program use.  
There's only a finite quantity of RAM used as the heap so a good program should released any heap memory back to the OS so it can reuse it.  
In C++ the operator *delete* does this.

When requesting dynamic memory, we must specify the type we want.  
It's illegal to delete anthing that isn't on the heap, like a regular variable or parameter.

Add the following code.

int\* pDyn = new int(3); // p points to an int initialized to 3 on the heap

\*pDyn = 17;

Run to cursor on the definition with initialization. (The first of these two lines is an initialization, not an assignment.)

Expand the '+' on pDyn. That's garbage.  
Hit F10 to do the initialization.  
The value stored is an address on the heap.   
Hit F10 to do the assignment.  
There's the 17 on the heap, pointed to by pDyn;

Where is the heap?  
Check the address where this 17 is:

cout << "The " << \*pDyn << " is stored at address " << pDyn<< " which is in the heap\n";

Notice that the value stored in pDyn is shown on the screen. The output system displays pointer values in hexa decimal format..

**Task 20:** Now let's release this dynamically allocated int back to the OS. But first, let's look at what's in pDyn. And then look again after we do the delete.

cout << pDyn << endl;

delete pDyn;

cout << pDyn << endl;

The OS can now reuse the space where that int 17 was.  
Notice however that pDyn is still holding the address of that int!  
delete does not set the pointer variable to NULL! (discussed in the next Task).  
You SEE that delete does NOTHING to the pointer variable.  
The heap space it points to is released (deleted).

Our program *should not* access that space since we gave it back to the OS. But can we?

cout << "The 17 might STILL stored at address " << pDyn<< " even though we deleted pDyn\n";

cout << "But can we dereference pDyn? We can try. This might crash... " << \*pDyn << ". Still here?\n";

The system may have already reused that space on the heap!  
A good thinking programmer would not want to reuse memory she has released back to the OS but C++ does nothing to enforce this.  
The issue here is that the delete operator does NOT change the contents of the pointer variable.  
It's our job as good programmers to put some value into that variable that indicates that it no longer validly points anywhere.

**Task 21:** NULL

C++ has the value NULL built it.  
NULL means not pointing to anything.  
It's actually the value zero.  
So to indicate that we no longer have a valid pointer, we need to set NULL as the value:

after the statement: delete pDyn; we would normally write:

pDyn = NULL;

to indicate that we deleted the pointer.

We will often initialze a pointer variable to NULL so that we are can more easily find illegal dereferencing errors.

double\* pDouble( NULL );

Add these lines to your code.

**Task 22:** dereferencing NULL

Setting NULL is good because it's dereferencing a NULL pointer will generate an error.  
Save your program before executing the next statement.  
Your program is going to crash.  
.NET will handle this error in different ways, depending on which version of .NET and which version of XP you are running.  
(Your program doesn't actually crash since you are working in an IDE but if you run this code by double clicking the .exe file, you will not be in a protected environment with a safety net built in)

cout << "Can we dereference NULL? " << \*pDyn << endl;

cout << "Can we dereference NULL? " << \*pDouble << endl;

Comment out those lines of code after you've seen them crash your program.

**Task 23:**

Think about that "this" pointer - can it ever be NULL (contain the value NULL)?   
DUH!!! It's the address of the object that a method is invoked on.  
How can it ever be not pointing to somethng?

**Task 24:** deleting NULL

It's not an error to delete a pointer that contains NULL:

double\* pTest = new double( 12 );

delete pTest;

pTest = NULL;

delete pTest; // safe

**Task 25:** however...

It is an error to delete a pointer that has already been deleted.  
After the delete, your program has no right to deal with that pointer value - it was returned to the system.

short\* pShrt = new short( 5 );

delete pShrt;

delete pShrt;

However, how different compilers deal with this varies greatly.  
What does MS .NET do?

Comment out the second delete and see if things get better.

**Task 26:** What about named memory locations - can they be deleted?  
Try these.

long jumper( 12238743 );

long\* ptrTolong( &jumper );

delete ptrTolong;

double dAr[ 3 ];

delete dAr;

No, delete can only be used with heap (or free store) (or dynamically allocated) memory - unnamed memory.

**Task 27:** Vectors of pointers to dynamic objects

vector<Complex\*> compli;

Complex\* tmpPCmplx; // grab heap space for 3 Complex objects and "store" them

// in the vector. We are really storing the Complex objects

// we think of this as "storing" them

for ( size\_t ndx = 0 ; ndx < 3 ; ++ndx ) {

tmpPCmplx = new Complex;

tmpPCmplx->real = ndx;

tmpPCmplx->img = ndx;

compli.push\_back( tmpPCmplx );

}

// display them

for ( size\_t ndx = 0 ; ndx < 3 ; ++ndx ) {

cout << compli[ ndx ]->real << endl;

cout << compli[ ndx ]->img << endl;

}

// release them

for ( size\_t ndx = 0 ; ndx < 3 ; ++ndx ) {

delete compli[ ndx ];

}

// clear the vector

compli.clear();

Note carefully that .clear() does NOT issue a delete on the things inside the vector. The programmer must traverse the vector and delete each Complex  
on the heap, pointed to by the pointer values stored in the vector.

**Task 28:** Now consider reading a file of data and storing it on the heap, accessable from a vector of pointers:

class Colour {

public:

Colour( const string& name, unsigned r, unsigned g, unsigned b )

: name(name), r(r), g(g), b(b) {}

void display() const {

cout << name << " (RBG: " << r << "," << g<< "," << b << ")";

}

private:

string name; // what we call this color

unsigned r, g, b; // red/green/blue values for displaying

};

vector< Colour\* > colours;

string inputName;

unsigned inputR, inputG, inputB; // fill vector with Colours from the file

// this could be from a file but we are using the keyboard for now

// (do you remember the keystrokes to indicate "end of file" at the keyboard?)

while ( cin >> inputName >> inputR >> inputG >> inputB ) {

colours.push\_back( new Colour(inputName, inputR, inputG, inputB) );

}

// display all the Colours in the vector:

for ( size\_t ndx = 0; ndx < colours.size(); ++ndx ) {

colours[ndx]->display();

cout << endl;

}

Here are some colours with their RGB values for testing:  
Black 255 255 255   
White 0 0 0  
Azure 10 110 237  
DeepPurple 240 72 261

**Task 29:** One way association - implemented using a pointer.   
When we buy or build an amp, it is not connected to any speaker system.  
We would like to be able to model this relationship of connecting speaker systems to amps.  
This relationship is an association.   
Note the use of a pointer data member, pointing to the attached speakers and the use of the -> dereference operator to allow the amp to send a signal to the speaker system to be interpretted as a vibration of it's cone - thus making sound.

class SpeakerSystem {

public:

void vibrateSpeakerCones( unsigned signal ) const {

cout << "Playing: " << signal << "Hz sound..." << endl;

cout << "Buzz, buzzy, buzzer, bzap!!!\n";

}

};

class Amplifier {

public:

Amplifier( ) : attachedSpeakers( NULL ) {}

void attachSpeakers( const SpeakerSystem& spkrs )

{

if( attachedSpeakers )

cout << "already have speakers attached!\n";

else

attachedSpeakers = &spkrs;

}

void detachSpeakers()

{ attachedSpeakers = NULL; }

// should there be an "error" message if not attached?

void playMusic( ) const {

if( attachedSpeakers )

attachedSpeakers -> vibrateSpeakerCones( 440 );

else

cout << "No speakers attached\n";

}

private:

const SpeakerSystem\* attachedSpeakers;

};

Create some speaker systems and amplifiers.   
Play with playing music on various system configurations.   
How do you cause a SpeakerSystem to become attached to an amplifier?

In a one-way association, the associated object (SpeakerSystem here) does not need to know anything about or communicate with the object it is associated with (Amplifier here).   
If either of these situations is needed, then two-way association would be required (one-way would be the wrong design decision).   
Are there any issues that might need to be considered that a one-way association cannot deal with in this problem?

When you get to a method call, do an F11 (Step Into) to see where execution goes.   
Keep using F11 to see execution transfer to the SpeakerSystem code.   
Especially note the "this" pointer.

**Task 30:** Association between two objects of the same type (spousal relationships)   
There should be a lot more checking before moving in with someone than is done here!

class Person {

public:

Person( const string& name ) : name(name) {}

void movesInWith( Person& newRoomate ) {

roomie = &newRoomate; // now I have a new roomie

newRoomate.roomie = this; // and now they do too

}

string getName() const { return name; }

// Don't need to use getName() below, just there for you to use in debugging.

string getRoomiesName() const { return roomie->getName(); }

private:

Person\* roomie;

string name;

};

// write code to model two people in this world

Person joeBob("Joe Bob"), billyJane("Billy Jane");

// now model these two becoming roommates

joeBob.movesInWith( billyJane );

// did this work out?

cout << joeBob.getName() << " lives with " << joeBob.getRoomiesName() << endl;

cout << billyJane.getName() << " lives with " << billyJane.getRoomiesName() << endl;

When you get to the method calls above, do an F11 (Step Into) to see where execution goes.  
Keep using F11 to see execution transfer.  
Especially note the "this" pointer.