LECTURE 2

Pointers

A pointer contains an address in memory of a variable.

```
int i = 2;
int *p;       // p is a pointer to an int
p = &i;            // p stores the address of i. "&i" means address of i.
int j = 3 + *p;    // *p is the contents of what the pointer p points to.
                   // In this case, *p is the same as i which equals 2.
p = &j;            // Now p points to j. *p is now equal to j=5.
```

Think of computer memory as having addresses and values stored at those addresses.

```
                     Computer Memory
   Address (p)                                    Value (*p)
-------------------                            -------------------

   234938530    address of i                       2   value of i
   395720335    address of j                       5   value of j
```

So first `p = 234938530`, then later `p = 395720335`. If we write `(*p)++`, `(*p)` and therefore `j` is incremented from 5 to 6. `*` is called the *indirection* or *dereferencing* operator.

Pointers and Arrays

`float x[5]` is an array of 5 floating point numbers. `x[0]` is a float and `&x[0]` is the address of the first element of the array. Operators such as `<`, `==`, etc. work on pointers. Thus to set an array to zero, we can write

```
float x[100];
float *px;
for(px=&x[0];px<=&x[99];px++)  //px++ points to the next element of the array
  *px=0.0;
```

This is quite useful. Since `&x[0]` comes up a lot, it is often denoted by just `x`. So `px=x` is the same as `px=&x[0]`. `px<=x+99` is the same as `px<=&x[99]`.

Pointer Arithmetic

`px + int` is ok. For example, `px + 6` designates a place in memory that is 6 float places after `px`. The "6" is not in units of bytes; it is in units of the size of floats or whatever type `px` points to. Suppose we are given

```
float *pf;
char *pc;
```

Then if `pf`=20000 (address in bytes), `pf`+6=20000 + 6·4 since each float takes 4 bytes. Similarly if `pc`=10000, `pc`+6=10006 since each char takes 1 byte. The `sizeof` functions gives these sizes in bytes.

```
sizeof(float)=4
sizeof(char)=1
```

In general the `sizeof(type)` or `sizeof(object)` gives the size in bytes. `px - pf` gives an `int` that is the distance apart in `floats`, not in bytes.

Example: String copy

The function `strcpy` copies the string in array `t` into the array `s`.

```
void strcpy(char *s, char *t)
  {
  while ((*s=*t)!='\0')
         {
         s++;
         t++;
         }
  }
 main()
   {
   char t[]="hello";      //When an array is created, initialize its
   char s[100];           //size in memory. Don't write char t[];
   strcpy(s,t);          //Notice that there is no "call" statement as in
                           fortran.
   cout << s << endl;    //cout knows to print the whole string "hello"
   }
```

Or we could write

```
void strcpy(char *s, char *t)
  {
  while (*s++=*t++)      // *s++ is the same as *(s++). First step:
                         // s[0]=t[0], i.e., *s=*t. Then increment.
       ;                 // ";" is a blank statement.
  }
```

Since the value of `'\0'` is 0 or `false`, the `while` statement will run until the end of the string is reached. (See page 31 of textbook for operator precedence.)

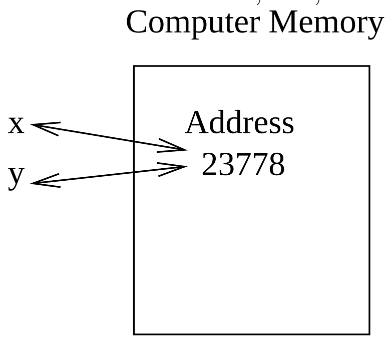
Function Calling, Passing Arguments by Value

In Fortran, suppose we have

```
subroutine blah(x)
real*8 x
x=3.0
end
```

```
      program main
      real*8 y
      y=4.0
      call blah(y)                  !blah replaces 4.0 by 3.0
      write(*,*) y                  !prints 3.0 as y's value
      stop
      end
```

`x` and `y` are synonyms for the same address, i.e., the same location in memory. So if you



change `y`, you change `x`.

What if you say

```
      call blah(4.0d0)?
```

This causes big problems because 4.0d0 is now 3.0d0. Later on `z=4.0d0` *might* give you 3.0d0 for `z`!

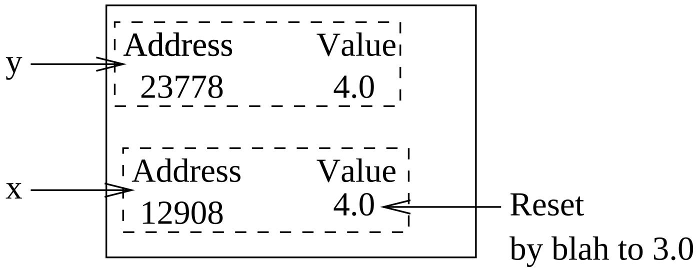
In C, you pass arguments to functions by value:

```
#include<iostream.h>

   void blah(double x)
      {
      x=3.0;
      }
   void main()
      {
      double y;
      y=4.0;
      blah(y);              //blah initially is passed the value 4.0 for x,
                            //but then sets x=3.0. blah doesn't change y.
      cout << y << endl;    //gives 4.0 as y's value
      }
```

`x` and `y` reside in different places in memory. `y` gets copied into `x`, the argument for `blah`. This is called "passing by value." The value for `y` doesn't actually change.

Computer Memory

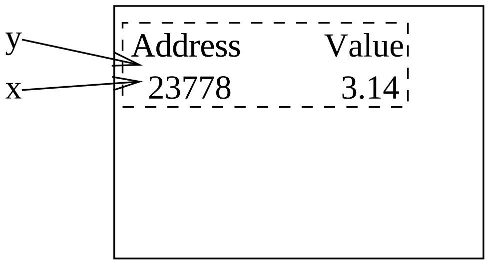


Fortran passes by address or reference.

Both ways of passing variables are useful. C++ lets you do both with **references**.

```
double x=3.14;
double &y=x;              //A reference variable must be initialized
                          //when it is declared.
```

Computer Memory



`y` is a *reference* to `x` which is a double variable. `y` is a synonym for `x`. `x` and `y` refer to the same place in memory. It acts exactly like the Fortran variable `y` in the subroutine `blah`.

```
x=2.0;        // now y=2.0
y=3.0;        // now x=3.0
cout << x << y << endl;     //yields 3.0 3.0
```

(No `*` needed for references.)

Why do we need references?

1. It is a convenient shorthand. Suppose you need to do manipulations of `x[18*i+j][32*k]` where `i, j` and `k` are fixed for a while. Then you could write

   ```
   double &rx=x[18*i+j][32*k];
   ```

   Now use `rx` everywhere as a reference, until `i` or `j` or `k` changes. Then define a new reference. For example, to construct a unit matrix, we could write

```
double mat[100][100];
for(i=0;i<100;i++)
  for(j=0;j<100;j++)
    {
    double &m=mat[i][j];
    if(i==j)
       m=1.0;
    else
       m=0.0;
    }
```

2. References are very useful for function calls.

```
void blah(double &x)
   {
   x=3.0;
   }
main()
   {
   double y;
   y=4.0;
   blah(y);
   cout << y << endl;   // yields y=3.0
   }
```

   This is really useful when you have "big" objects that you don't want to copy and pass to a function. It's more efficient to just tell the function where to find the object. But what if you say `blah(4.0)`? You're hosed.

After a reference variable has been declared, you can do nothing to access the reference variable itself. That's why a reference variable must be initialized when it is declared. Reference variables declared as arguments to functions are initialized when the function is called.

Constants

In Fortran we use `parameter` to set constant values. For example,

```
parameter (pi=3.14159)
```

C++ has `const`. For example,

```
const double pi=3.14159;
```

This line could go anywhere, whereas in Fortran, parameter statements are at the beginning of the program. If later on we write `pi=7.0;` we get a syntax error.

Constant Pointers

There are

1. pointers to `const floats`.

```
const float pi=3.14159;  // A const variable must be initialized when
                         // it is defined (except if it is declared
                         // with an extern statement, in which
                         // case it is defined elsewhere).
const float *ppi=&pi;
*ppi=7.0; //ERROR
```

2. "const pointers" to floats. Const pointers can't change the place they point to in memory.

```
float a;
float* const pa=&a;
*pa=7.0;            //OK to do this
float b;
pa=&b;             //ERROR!
```

3. "const pointers" to "const floats"

```
const float * const p = &pi;
*p = 7.0;                        //ERROR!
p=&b;                            //ERROR!
```

You can't change anything in this case.

The rule is that the "const ness" applies to the thing immediately to the right of the `const` keyword. You can also read the declaration backward. For example, `float* const pa` can be read "pa is a constant pointer to a float."

Const in Function calls

```
void func(const double &x)
  {x=3.0;}                      //ERROR
```

`const` should appear everywhere possible in function arguments. It's more efficient if the compiler knows that those arguments won't be changed, and it prevents bugs. For example, writing

```
void strcpy(char* s, const char* t);
```

prevents bugs.

```
double abs(double x)       //Ok. Pass by value.
   {....}

double abs(double &x)     //BAD! because you could change x.

double abs(const double &x)   //Good way to do things.
```

Function Prototypes (declarations versus definitions)

If the program is in separate files, or if the function is defined later in the file, you need to declare the function. A declaration tells you the function is there but doesn't define it and tell you how it works. An example of a declaration is

```
double abs(const double &x);      // The ";" replaces {}.
                                  // The "x" is optional.
```

You can put this declaration anywhere in the program before `abs` is used.

New and Delete

In Fortran we dimension arrays as follows:

```
      parameter(maxsize=1000)
      real*8 vec(maxsize)
```

This means you have to recompile every time you have a different size for `vec`. Or you just make `maxsize` bigger than any conceivable size that `vec` could need. But this wastes memory.

In C++, we still have to dimension arrays and allocate memory, but we can do it efficiently by using `new` as in this example:

```
double *vec;                   //pointer to a vector
cin >> n;
vec = new double[n];
```

This allocates 8n bytes of memory for `vec` and gives you a pointer to it. The next call to `new` will give you a pointer to a new location in memory.

`delete` is used to give back the memory once the program is finished with it. So once the program is finished with `vec`, it executes

```
delete []vec;
```

and returns the allocated memory to the heap. This works not just for arrays, but also for single objects:

```
double *pa;
pa=new double;
delete pa;
```

Objects created by `new` don't go away until you call `delete`. For example,

```
void badfunction()
   {
   double *px=new double[1000];
   }
```

Once the program is finished executing `badfunction`, it throws away `px` but the system has still set aside the memory and you can never get it back! This is called a "memory leak"; it's a C++ programmer's worst nightmare.

Once you've allocated the pointer, you can treat it like an array. It works exactly like an array. For example,

```
float *a;
a=new float[100];
for(i=0;i<100;i++)
  a[i]=1.0;
```

When do you use delete? The rule of thumb is to use delete to deallocate memory if you have used new to allocate it. If you haven't used new, don't use delete. For example,

```
float *a = new float[100];
float b[100];
//stuff
delete []a;       //use delete for array a because you used new
// don't need delete for array b because you didn't use new
```

Pointer Arrays; Pointers to Pointers

Since pointers are variables themselves, they can be stored as arrays just as other variables can. For example, consider the beginning of a program that sorts lines of text alphabetically:

```
#define MAXLINES 5000        //max number of lines to be sorted
char *lineptr[MAXLINES];     //pointers to text lines
```

Aside: The `define` statement is a preprocessor command that replaces all subsequent occurrences of `MAXLINES` with `5000` (except if `MAXLINES` appear in quotes "`MAXLINES`"). In general `define` statements have the form

```
#define   name   replacement text
```

The preprocessor will replace all subsequent occurrences of *name* with *replacement text* in the source file being compiled. `define` statments are often in header (`.h`) files that are included in `.cc` source files. The `replacement text` can be an expression or a statement. For example,

```
#define  forever  for(;;)      //infinite loop

#define  max(A,B)  ((A) > (B) ? (A) : (B))
```

Names may be undefined with `#undef`.

Back to arrays of pointers: The declaration for `lineptr`

```
char *lineptr[MAXLINES];     //pointers to text lines
```

says that `lineptr` is an array of `MAXLINES` elements, each element of which is a pointer to a `char`. That is, `lineptr[i]` is a character pointer, and `*lineptr[i]` is the character it points to, the first character of the ith saved text line. Since `lineptr` is itself the name of an array, it can be treated as a pointer. Thus it is a pointer to pointers. (How's that for confusing?) We can initialize a pointer array as follows:

```
char *name[] = {"Dopey", "Sleepy", "Doc"};
```

Notice that each string is a different length. `name` goes from `name[0]` to `name[2]`, and each element of `name` is a pointer to a string.

Another use for a pointer to an array is two dimensional arrays. Given the definitions

```
int a[10][20];
int *b[10];
```

then `a[3][4]` and `b[3][4]` are both legal references to a single `int`. `a` is a true two dimensional array; each row of `a` has 20 int–sized elements. However, the important advantage of the pointer array is that the rows of the array may be of different lengths. That is, each element of `b` need not point to a twenty–element vector; some may point to two elements, some to fifty, and some to none at all. So `b` doesn't waste memory.

If a multi–dimensional array is passed to a function, the function declaration typically looks like

```
func(int a[]); or func(int *a);          //for a 1D array

func(int a[][]); or func(int **a);       //for a 2D array

func(int a[][][]); or func(int ***a);    //for a 3D array
```

These arrays are dimensioned elsewhere in the program and passed to the function. Here is an example of how to use new and delete for a two dimensional array:

```
#include <iostream.h>

void func(int **p);
void main()
  {
```

```
 //Create a 2D array of integers p[5][2]

 int** p;
 p=new int*[5];                //create array of 5 pointers to integers
 for(int i=0;i<5;i++)
  p[i]=new int[2];             //create row with 2 integers

 func(p);                      //pass name of array without **

 for(int i=0;i<5;i++)
 delete []p[i];                //delete in reverse order of creation

 delete []p;
}


void func(int **p){
  int n=0;
  for(int i=0;i<5;i++)
    for(int j=0;j<2;j++)
   {p[i][j]=n++;
   cout << i << " "<<j<< " "<< p[i][j]<<endl;}
}
```

In C and C++, elements of arrays are stored by row, so that the rightmost subscript, or column, varies fastest as elements are accessed in storage order. In Fortran, elements of arrays are stored by column so that the first subscript, or row, varies fastest as elements are accessed in storage order.

Pointers to Functions

In C and C++, a function is not a variable, but it is possible to define pointers to functions, which can be assigned, placed in arrays, passed to functions, returned by functions, and so on. A function name alone refers to its address. The following does *not* declare a pointer to a function:

```
int *pFn();
```

Instead, this declares a function that returns a pointer to an integer. The `( )` takes effect first because it has a higher precedence than `*`. To get the desired effect, parentheses are required:

```
int (*pFn)(float);
```

Now the `*` takes effect first. This is read as "pFn is a pointer to a function that takes a float argument and returns an int." In use, its syntax is similar to that of an array:

```
int anotherFn(float f);      //Some function, defined somewhere
void myFunc(float x)
  {
    int (*pFn)(float);      //Declare a pointer to a function
    pFn = anotherFn;        //A function name alone refers to its address.
    (*pFn)(x);              //Call the function pointed at by pFn
  }
```

In the last line the extra parentheses are necessary when calling `*pFn` because the precedence of `( )` is higher than that of `*`. If we had just written `*pFn(x)`, the program would interpret `pFn` as a function of `x` that returns a pointer and `*pFn(x)` is the value pointed at by `pFn(x)`.

Pointers to functions are used a lot in Numerical Recipes. (*Numerical Recipes in C: The Art of Scientific Computing* by W. H. Press, S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery (Cambridge Univ. Press, 1992) is an excellent text on scientfic computing techniques. They have a homepage at http://www.nr.com where you can download the text of the book.) For example suppose you want to integrate a function `func(x)` over `x` from `a` to `b` using Simpson's rule. The declaration found in Numerical Recipes is

```
float qsimp(float (*func)(float), float a, float b);
```

Here a pointer to `func` is passed to the integration routine `qsimp`. `qsimp` returns the value of the integral as a `float`. To use `qsimp`, we would write something like:

```
float function(float);
float integral = qsimp(function, a, b);
```

Notice that the argument of `qsimp` is just `function`, not `&function` since the name of the function by itself refers to the address of the function.