CS205

C / C++

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Notes on Lab2

I've been rather disappointed by what I have seen of lab2 so far. I'm running your programs through automated scripts, trying different options (including some that must fail) and comparing the output to result known to be correct. Almost everybody fails the tests; sometimes for minor reasons (messages added to the output, see next slide), sometimes for things more serious (some fields not well recognized) and I have had several crashes. In the software industry, you cannot ship a program that doesn't pass successfully a series of tests. It's like crash tests in the automobile industry.

Notes on Lab2

Don't mix output and information

Messages (reminder of parameters, etc) are definitely helpful but look amateurish when they intermix with what the program outputs. Comment out debugging messages before submitting your program or use conditional compiling to turn them on or off.

output ➔stdout

everything else ➔stderr

Back to C++

I have introduced C++, it's time to take a look at some practical issues.

PHILOSOPHY

Anchored in reality

- Solve actual problems
- Reasonably easy to implement
- Work alongside prior languages (eg C)

One of the goals of Stroustrup was to create a language that could mix with other languages - and take advantage of all the functions already written.

Mixing C and C++

But because C++ supports overloading and C doesn't, the rules that the linker applies must be different depending on linking with a C or C++ function.

C++ code

Identified by name and parameters

library written in C

function code

Identified by name only

Not the same rules for functions!

Mixing C and C++

To let the linker know, a special syntax exists in C (that conditional compiling makes invisible in C) to tell that some functions are C and not C++ functions.

.h file

```
#ifdef __cplusplus
extern "C" {
#endif
   extern int    c_func1(char *arg);
   extern double c_func2(int arg1, int arg2);
#ifdef __cplusplus
}
#endif
```

Not the same rules for functions!

C++ classes again

```
#ifndef MATRICES_HPP
#define MATRICES_HPP
class matrix {
 private:
     short rows;
     short cols;
     double *cells;
 public:
     matrix(int r, int c);
     ~matrix();
     matrix *matrix_add(matrix *m);
     matrix *matrix_scalar(double lambda);
     matrix *matrix_mult(matrix *m);
     matrix *matrix_inv();
     double  matrix_det();
   };
#endif // ifndef MATRICES_HPP
```

can be implicit

constructor

destructor

We have seen a sample class, but it doesn't respect a number of rules that are considered "good practices"

Attributes should never be public

One rule that is more than a "good practice" is that attributes should NEVER be public. Object-oriented programming is all about "encapsulation", which simply means the privacy of attributes (and possibly some methods). A public attribute is a capital sin in object-oriented programming. It's the same in C++ as in Java or any language with classes that supports encapsulation (some languages such as Python have encapsulation of a sort, Javascript is rather murky in this respect).

Writing better classes

These are some rules frequently applied that help make the code more readable.

Capitalize class names

Method names start with lower case

Except constructors/destructors

Give special names to members

```
int _val;
```

or `int m_val;` (probably better)

NEVER start a name with two underscores

```
class Sample {
     int val;
  public:
     Sample();
     ~Sample();
     void setval(int val);
};

void Sample::setval(int val) {
   val = val;
}
```

None of these rules really matters for the compiler. But they simplify code. Suppose for instance that we have a method that takes a parameter with the same name as an attribute.

We can't write this, which doesn't make any sense for the compiler

```
class Sample {
     int val;
  public:
     Sample();
     ~Sample();
     void setval(int val);
};

void Sample::setval(int val) {
   this->val = val;
}

void Sample::setval(int val) {
   Sample::val = val;
}

void Sample::setval(int v) {
   val = v;
}
```

There are several various options that we can use.

We can use "this", implicit pointer to the current object.

Better, we can use the "scope operator"

Nothing says that implementation and prototype should be strictly identical.

```
class Sample {
     int m_val;
  public:
     Sample();
     ~Sample();
     void setval(int val);
};

void Sample::setval(int val) {
   m_val = val;
}
```

Having a special name for members removes any ambiguity in what is probably the easiest and simplest way.

```
class Sample {
     int m_val;
  public:
     Sample();
     Sample(int val):m_val(val) {};
     ~Sample();
     void setval(int val);
};
```

Note that C++ supports a special syntax in which you can supply after the name of a constructor the name of an attribute called like a function; it means that it it initialized with this value. If initialization is the only thing that the constructor does, the body may be empty and no other implementation is needed.

VERY IMPORTANT

Object creation/destruction

It's really important to understand in C++ when and how object are created/destroyed, because not understanding the rules can lead to unexpected crashes. First, a lot of functions (constructors, destructors) are automatically provided by C++ unless you supply on, but they aren't always suitable.

obj.cpp

```
#include <iostream>

using namespace std;

class ObjectType {
    private:
        string _name;

    public:

        ObjectType(string name) {
           _name = name;
           cout << "Creating object " << _name << endl;
        }
```

I'm creating a really basic class to illustrate it. I'm creating a constructor that takes a name ...

obj.cpp

... a second constructor that takes no parameter and creates an unnamed object, an a destructor. All of them display a message when called.

```
        ObjectType() {
           _name = "unnamed";
           cout << "Creating object " << _name << endl;
        }

        ~ObjectType() {
           cout << "Destroying object " << _name << endl;
        }
};
```

obj.cpp

```
int main() {
    ObjectType  o1;
    ObjectType *o2p = new ObjectType("o2");

    cout << "in main()" << endl;
    return 0;
}
```

In the first version of my program, I'm creating an object o1 (an object variable), then a dynamically created, Java-style named object, displaying a message and exiting.

```
$ g++ -o obj obj.cpp
$ ./obj
Creating object unnamed
Creating object o2
in main()
Destroying object unnamed
$
```

variable object

delete missing

What you see is that the default constructor was automatically called for o1, the variable object, and the destructor is automatically called when I quit the program. For o2, for which I explicitely called the constructor, the destructor is not called. I should also call it explicitely.

obj.cpp

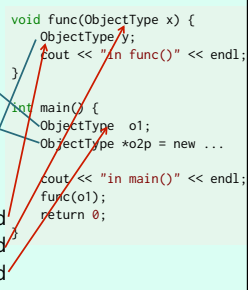
```
void func(ObjectType x) {
    ObjectType y;
    cout << "in func()" << endl;
}

int main() {
    ObjectType  o1;
    ObjectType *o2p = new ObjectType("o2");

    cout << "in main()" << endl;
    func(o1);
    return 0;
}
```

Let's add a call to a function that takes an object parameter (NOT an object pointer) and declare a local object variable.

```
$ g++ -o obj obj.cpp
$ ./obj
Creating object unnamed
Creating object o2
in main()
Creating object unnamed
in func()
Destroying object unnamed
Destroying object unnamed
Destroying object unnamed
$
```

I see two unnamed objects created ... and three destroyed, and the program doesn't crash! What is happening?

```
$ g++ -o obj obj.cpp
$ ./obj
Creating object unnamed
Creating object o2
in main()
Creating object unnamed
in func()
Destroying object unnamed
Destroying object unnamed
Destroying object unnamed
```



The additional object that is destroyed is the parameter, for which none of my constructors is called. The object is created by a "copy constructor" generated by C++, used to copy o1 into the stack. The object is freed when we return from the function.

Complex classes need to respect some rules

The compiler may provide a lot of automatic methods (constructor, destructor, copy) but there aren't always appropriate.

When classes become complex, they should be based on Coplien's canonical class

Coplien's Canonical Class

Jim Coplien is an academic/consultant very involved in software patterns, the AGILE methodology and so forth.


```
class T {
   public:
      T(); // Default Constructor
      T(const T&); // Copy Constructor
      ~T(); // Destructor (may be virtual)
      T &operator=(const T&);
            // Assignment operator
};
```

Don't forget the semi colon after the class definition, that must be the only place were a semi colon follows a closing curly bracket.

Coplien's Canonical Class

Why a default constructor?

```
class T {
   public:
      T(); // Default Constructor
      T(const T&); // Copy Constructor
      ~T(); // Destructor (may be virtual)
      T &operator=(const T&);
            // Assignment operator
};
```

As an example, let's create a class that implements a special data type that exists in the Oracle database management system (extract from the Oracle docs below) . We'll have a "year precision" but we won't do anything with it, at it's irrelevant to the current purpose.

INTERVAL YEAR [(year_precision)] TO MONTH

Stores a period of time in years and months, where year_precision is the number of digits in the YEAR datetime field. Accepted values are 0 to 9. The default is 2. The size is fixed at 5 bytes.

YearToMonth.hpp

```
#ifndef YEARTOMONTH_HPP
#define YEARTOMONTH_HPP

class YearToMonth {
    short m_years;
    short m_months;

  public:
     YearToMonth(short years);
     YearToMonth(short years, short months);
};

#endif
```

Let's create two constructors, which are easily distinguished by their number of parameters.

YearToMonth.cpp

```
#include <iostream>
#include "YearToMonth.hpp"

using namespace std;

YearToMonth::YearToMonth(short years) {
    m_years = years;
    m_months = 0;
}

YearToMonth::YearToMonth(short years, short months) {
    m_years = years;
    m_months = months;
}
```

Implementation is straightforward.

test1.cpp

```
#include <iostream>
#include "YearToMonth.hpp"

using namespace std;

int main() {
    YearToMonth ytm1(1,7);
    YearToMonth ytm2(0,6);
    cout << "Objects created" << endl;
    return 0;
}
```

```
$ ./test1
Objects created
$
```

A small test program compiles and runs nicely.

test2.cpp

```
#include <iostream>
#include "YearToMonth.hpp"

using namespace std;

int main() {
    YearToMonth ytm1(1,7);
    YearToMonth ytm2(0,6);
    YearToMonth ytm_array[10];
    cout << "Objects created" << endl;
    return 0;
}
```

Now let's suppose that we'll need quite a number of YearToMonth objects and want to create an array.

```
$ g++ -o test2 test2.cpp YearToMonth.o
test2.cpp:10:17: error: no matching constructor for initialization of
      'YearToMonth [10]'
    YearToMonth ytm_array[10];
                ^
./YearToMonth.hpp:10:6: note: candidate constructor not viable: requires
single
      argument 'years', but no arguments were provided
     YearToMonth(short years);
     ^
./YearToMonth.hpp:11:6: note: candidate constructor not viable: requires 2
      arguments, but 0 were provided
     YearToMonth(short years, short months);
     ^
./YearToMonth.hpp:4:7: note: candidate constructor (the implicit copy
      constructor) not viable: requires 1 argument, but 0 were provided
class YearToMonth {
      ^
1 error generated.
$
```

Epic failure

The reason is multiple:

1) If you define no constructor, the C++ compiler will create a default one, which will basically reserve a number of bytes the size of one object
2) As soon as you define a constructor, no default constructor will be created
3) You cannot specify any parameter when you create an array of objects. You cannot initialize it like a C array of structures, because attributes are private. Stuck.

Note that the requirement for having a default constructor can also be found in some Java components (Java beans), for related reasons.

Coplien's Canonical Class

Why a default constructor?

Because of arrays

```
class T {
  public:
    T(); // Default Constructor
    T(const T&); // Copy Constructor
    ~T(); // Destructor (may be virtual)
    T &operator=(const T&);
          // Assignment operator
};
```

Moreover

Many libraries (including the standard C++ library) require a default constructor for creating temporary objects.

If there is no constructor at all, the compiler tries to build a default one – hazardous initialization.

Some compilers may set all the bytes to 0 (which may or may not be appropriate), some compilers may not try to initialize anything.

YearToMonth.hpp

```
#ifndef YEARTOMONTH_HPP
#define YEARTOMONTH_HPP

class YearToMonth {
    short m_years;
    short m_months;

  public:
    YearToMonth(short years=0);
    YearToMonth(short years, short months);
};

#endif
```

Note that "default constructor means "Constructor that accepts no parameters"

Enough to fix the problem

It can be a constructor without any parameter, or a constructor for which all parameters have a default value (note: default values are only specified in the method prototype, not in the implementation)

Coplien's Canonical Class

Why a destructor?

```
class T {
  public:
    T(); // Default Constructor
    T(const T&); // Copy Constructor
    ~T(); // Destructor (may be virtual)
    T &operator=(const T&);
          // Assignment operator
};
```

Because of heap memory

We'll talk about "virtual" in a later class

It's the same problem as with the matrix structure in C: if the object allocates heap memory in the constructor or at a later stage in its life, this will not be freed by the default destructor and will lead to memory leaks.

Coplien's Canonical Class

Why a copy constructor?

```
class T {
  public:
    T(); // Default Constructor
    T(const T&); // Copy Constructor
    ~T(); // Destructor (may be virtual)
    T &operator=(const T&);
          // Assignment operator
};
```

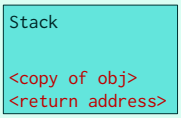
The copy constructor is also an interesting problem, strongly linked to heap memory allocation and destructors.

Copy constructor

CREATES a new object from a previous one (different from assignment)

Created by default (byte by byte copy)

Used when objects are passed by value to a function, or returned by a function




```
...
a = f(obj);
...
```

Copy constructor

CREATES a new object from a previous one (different from assignment)

Created by default (byte by byte copy)

Used when objects are passed by value to a function, or returned by a function

```
T(const T&); // Copy Constructor
```

If it were passed by value there would be a chicken-and-egg problem

Copy constructor

Necessary when pointers to heap areas inside the object

If your object is a plain object, such as a YearToMonth object, there is no problem, and the default copy constructor works fine.

```
class Dummy {
    int *m_tab;
    int  m_sz;
  public:
     Dummy(int sz=5);
     ~Dummy();
};

Dummy::Dummy(int sz) {
    cerr << "Constructor called" << endl;
    m_sz = sz;
    m_tab = new int[sz];
}

Dummy::~Dummy() {
    cerr << "Destructor called" << endl;
    delete[] m_tab;
}
```

Let's define a class for objects that contain an array of integers, dynamically created by the constructor.

Messages will help us see better what happens.

test.cpp

```
#include <iostream>

#include "Dummy.hpp"

using namespace std;

int main() {
   Dummy dum(3);

   cout << "Object created" << endl;
   return 0;
}
```

```
$ ./test
Constructor called
Object created
Destructor called
$
```

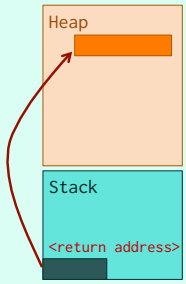
when declaring dum

when leaving main()

test2.cpp

```
#include <iostream>

#include "Dummy.hpp"

using namespace std;

void f(Dummy dum) {
   cerr << "In function f()" << endl;
}

int main() {
   Dummy dum(10);
   f(dum);
   cerr << "Leaving main()" << endl;
   return 0;
}
```

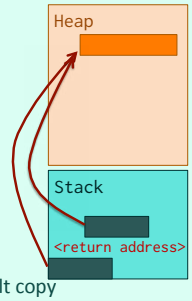
Now let's pass dum to a function



First we create dum

test2.cpp

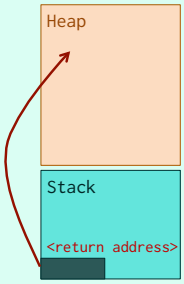
```
#include <iostream>

#include "Dummy.hpp"

using namespace std;

void f(Dummy dum) {
   cerr << "In function f()" << endl;
}

int main() {
   Dummy dum(10);
   f(dum);
   cerr << "Leaving main()" << endl;
   return 0;
}
```



When we call the function, the default copy constructor copies every byte, including the pointer to the array.

test2.cpp

```
#include <iostream>

#include "Dummy.hpp"

using namespace std;

void f(Dummy dum) {
   cerr << "In function f()" << endl;
}

int main() {
   Dummy dum(10);
   f(dum);
   cerr << "Leaving main()" << endl;
   return 0;
}
```



When we leave the function, the destructor is called for the copy and frees memory, including the array.

test2.cpp

```
#include <iostream>

#include "Dummy.hpp"

using namespace std;

void f(Dummy dum) {
   cerr << "In function f()" << endl;
}

int main() {
   Dummy dum(10);
   f(dum);
   cerr << "Leaving main()" << endl;
   return 0;
}
```

When we leave `main()`, the destructor is called for dum and attempts to free the array, which is already gone.

```
$ ./test2
Constructor called
In function f()
Destructor called
Leaving main()
Destructor called
test2(2490,0x7fff79335300) malloc: *** error for object
0x7fb56a500000: pointer being freed was not allocated
*** set a breakpoint in malloc_error_break to debug
Abort trap: 6
$
```

Freeing the copy and memory in the heap

Freeing the original

Already freed

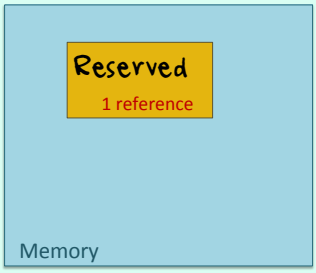
Here is what it gives without pictures

"C makes it easy to shoot yourself in the foot; C++ makes it harder, but when you do it blows your whole leg off."

Bjarne Stroustrup

Why doesn't it happen with Java?

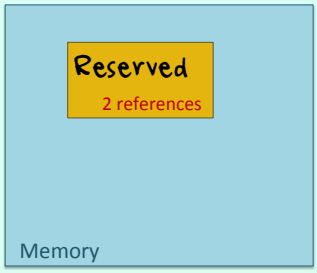
The garbage collector counts references



`Object o = new ...`

Everytime something points to a memory area, a count is kept. When you create a new object, the count is 1.

The garbage collector counts references

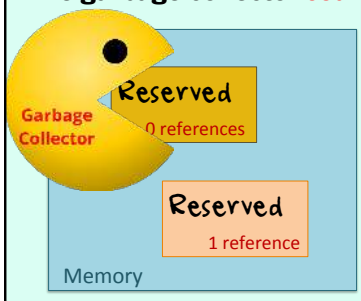


`Object o = new ...`

`Object o2 = o;`

If a second reference points to the same area, the count becomes 2.

The garbage collector counts references



Memory is only freed when the count is 0..

```
Object o = new ...
Object o2 = o;
o = new Object ...
o2 = null;
```

If you assign a new value to o, the count will become 1, then 0 when o2 also refers to something else.

Easier on the programmer

BUT First you can always encounter cases with references on references on references that Java will have trouble to handle.

Everything has a cost

Memory management uses some resources.

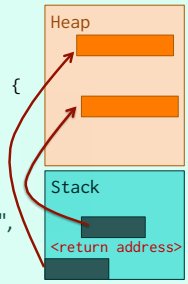
Junior developers can have many things wrong

I have seen several cases where objects were created and changed faster than the garbage collector could free memory.

And you thought memory management in C is complicated?

Deep copy versus *Shallow copy*

```
Dummy::Dummy(const Dummy& dum) {
    m_sz = dum.m_sz;
    m_tab = new int[m_sz];
    for (int i = 0; i < dum.m_sz; i++) {
       m_tab[i] = dum.m_tab[i];
    }
}
```



If we want to be safe, we need a copy constructor that performs a "deep copy", which means that it also allocates and copies anything that the original object points to.

Coplien's Canonical Class

Why a copy constructor?

To have a destructor-safe deep copy

```
class T {
  public:
    T(); // Default Constructor
    T(const T&); // Copy Constructor
    ~T(); // Destructor (may be virtual)
    T &operator=(const T&);
          // Assignment operator
};
```

Coplien's Canonical Class

Assignment operator?

```
class T {
  public:
    T(); // Default Constructor
    T(const T&); // Copy Constructor
    ~T(); // Destructor (may be virtual)
    T &operator=(const T&);
          // Assignment operator
};
```

You can redefine operators in C++

http://en.wikipedia.org/wiki/Operators_in_C_and_C%2B%2B

Long and impressive list. In practice only a few operators will be overloaded.

Back to YearToMonth

```
class YearToMonth {
    short m_years;
    short m_months;
  public:
    YearToMonth(short years=0);
    YearToMonth(short years, short months);
    void add(const YearToMonth ytm);
    void print();
};
```

We may want to define two methods: one to add another YearToMonth to the current one, and one to display the object.

Back to YearToMonth

```
void YearToMonth::add(const YearToMonth ytm) {
    m_years += ytm.m_years;
    m_months += ytm.m_months;
    if (m_months > 11) {
       short y = m_months / 12;
       m_years += y;
       m_months -= y * 12;
    }
}
```

Back to YearToMonth

```
void YearToMonth::print() {
    if (m_years > 0) {
       cout << m_years << " year" << (m_years > 1 ? "s" : "");
       if (m_months > 0) {
          cout << " ";
       }
    }
    if (m_months > 0) {
       cout << m_months << " month" << (m_months > 1 ? "s" : "");
    }
    cout << endl;
}
```

Back to YearToMonth

You can do more natural by overloading + (or +=) and <<

Our add() is in fact more like +=

`operator`*`symbol`*`()`

C++ knows a lot of functions/methods named operator<symbol>() which can be used as such or simply as the symbol. For instance, operator+() allows to redefine addition.

BIG QUESTION

Function or method ?

Many operators may be redefined either as functions or operators (the Wikipedia page mentioned earlier lists what the operator redefinition should look like in both cases). Which one should be used?

Redefine <<

Sometimes there is no choice. Let's say that we want to redefine writing an object to a stream.

```
cout << ... << object << ... << endl;
```

get a stream of things already on their way out (parameter)

Write more stuff

Return a stream to which more things may be added

Because of the way streams are used, the operator must take a stream pointer as input, write stuff to it, and return the stream pointer.

Redefine <<

Method?

```
class T {
  public:
    ostream &operator<<(ostream &os){
       // code here ...
       return os;
     }
};
```

If we implement it as a method, it should look like this.

Redefine <<

Method?

```
T t;

t.operator<<(cout);
```

However, calling the method is equivalent to this: `t << cout;`

Not the way it is used

cout is normally on the left side. It should be an ostream method

Not possible to add a method to ostream

Redefine <<

YearToMonth.hpp

Function

Method?

```
class YearToMonth {
    short m_years;
    short m_months;
  public:
    YearToMonth(short years=0);
    YearToMonth(short years, short months);
    void add(const YearToMonth ytm);
};

ostream &operator<<(ostream &os,
                    const YearToMonth &ytm);
```

So it should be a function, but it should be able to access the attributes.

Redefine <<

YearToMonth.hpp

```
#include <iostream>
class YearToMonth {
    short m_years;
    short m_months;
  public:
    YearToMonth(short years=0);
    YearToMonth(short years, short months);
    void add(const YearToMonth ytm);
friend std::ostream &operator<<(std::ostream &os,
                                const YearToMonth &ytm);
};
```

~~Function Method?~~

Either we have methods to return each one (clumsy), hide nothing, or we allow the function to see them

Don't use a namespace in a header file

YearToMonth.cpp

```
using namespace std;

ostream &operator<<(ostream &os,
                    const YearToMonth &ytm) {
    if (ytm.m_years > 0) {
       os << ytm.m_years << " year"
          << (ytm.m_years > 1 ? "s" : "");
       if (ytm.m_months > 0) {
          os << " ";
       }
    }
    if (ytm.m_months > 0) {
       os << ytm.m_months << " month"
          << (ytm.m_months > 1 ? "s" : "");
    }
    return os;
}
```

The "friend" mechanism is hated by object-orientation purists.

Test4.cpp

```
#include <iostream>

#include "YearToMonth.hpp"

using namespace std;

int main() {
    YearToMonth ytm1(1, 7);
    cout << "ytm1 is " << ytm1 << endl;
    return 0;
}
```

And now we can display a YearToMonth in a very natural way.

```
$ ./test4
ytm1 is 1 year 7 months
$
```

Coplien's Canonical Class

The assignment operator recommended by Coplien IS a method, because we are only dealing with objects of the class.

```
class T {
  public:
    T(); // Default Constructor
    T(const T&); // Copy Constructor
    ~T(); // Destructor (may be virtual)
    T &operator=(const T&);
          // Assignment operator
};
```

But this is a method!

Function or method ?

Rule: if the current object plays the lead part method, otherwise function

Function or method ?

++ ? Method (affecting the current object)

+ ? Takes two objects, returns a third one: friend function.

Coplien's Canonical Class

```
class T {
   public:
      T(); // Default Constructor
      T(const T&); // Copy Constructor
      ~T(); // Destructor (may be virtual)
      T &operator=(const T&);
            // Assignment operator
};
```

returns a reference for right-hand chaining a = b = c;

Assignment operator

Same problems as copy except that you aren't creating a new object.

Copy operator = new material

Assignment operator

Same problems as copy except that you aren't creating a new object.

Copy operator = new material

Assignment operator = old material

Possibly a need for deleting, then recreating memory areas.

As C and C++ are mostly (although not exclusively) used for system programming, we are going to be briefly acquainted with what is known as "system calls". As C is historically closely linked to Unix, most of what we'll see is related to Unix-like systems.

System Calls

Just an introduction ...

MOSTLY UNIX/LINUX

Unix/Linux manual pages

1 – General commands

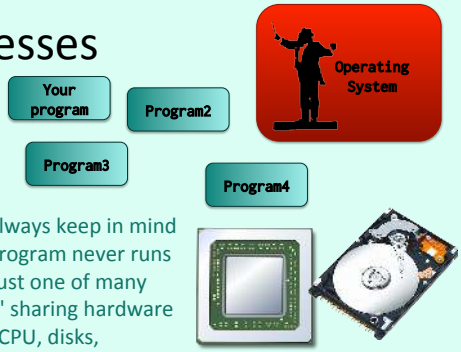
2 – System calls

3 – C library functions

4 – File formats

Getting information about a command (or C function) is performed on a Unix system by typing "man <name>" in a console. The "manual" is divided into several sections, a full one is devoted to system calls (to show how important they are).

processes



You must always keep in mind that your program never runs alone. It's just one of many "processes" sharing hardware resources (CPU, disks, memory) and coordinated by an all-powerful set of programs, the operating system (abbreviated to OS).

Whenever your program needs a resource, it must issue a request to the OS - a "system call".

Some requests are considered to be "standard"

`fopen(), fread(), fwrite()`

`malloc() / new`

Others are more "advanced"

Low level I/Os

Process management/communication

`man fopen`

Many standard C functions that you have been using are merely wrappers around system calls that present a more programmer-friendly interface. Check for instance what the manual says about a function such as `fopen()`

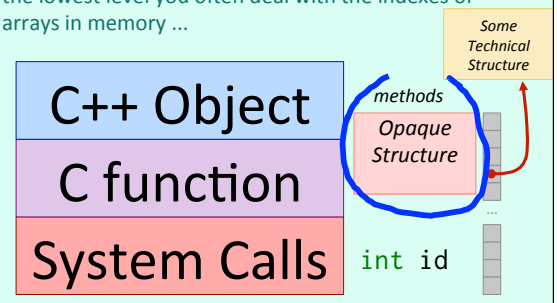
```
FOPEN(3)                BSD Library Functions Manual                FOPEN(3)

NAME
     fdopen, fopen, freopen -- stream open functions

LIBRARY
     Standard C Library (libc, -lc)

SYNOPSIS
     #include <stdio.h>

     FILE *
     fdopen(int fildes, const char *mode);

     FILE *
     fopen(const char *restrict filename, const char *restrict mode);

     FILE *
     freopen(const char *restrict filename, const char *restrict mode,
         FILE *restrict stream);
```

Section 3 = C functions

```
SEE ALSO
     open(2), close(3), fileno(3), fseek(3), funopen(3)

STANDARDS
     The fopen() and freopen() functions conform to ISO/IEC 9899:1990
     (``ISO C90'').  The fdopen() function conforms to IEEE Std 1003.1-1988
     (``POSIX.1'').

BSD                             January 26, 2003
```

When you scroll to the very end, you see in the SEE ALSO section a reference to the system call `open()` which is what `fopen()` actually calls. `open()` returns an integer that identifies the stream, not an opaque `FILE *`, it takes combined numerical flags to specify the mode instead of "a", "w" or "r", but functionalities are similar.

Very often System programming is much easier when you create objects that wrap around C functions that themselves call the system. At the lowest level you often deal with the indexes of arrays in memory ...

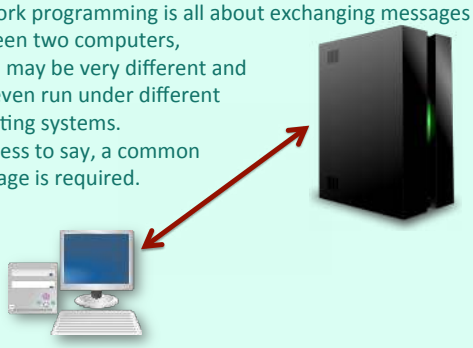


Network Programming

(a short overview)

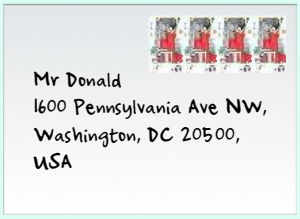
Functions that deal with network programming in C all belong to section 2 in the manual. Most of them were initially created for a Unix-like system called "BSD" that was developed in Berkeley in the 1970s, concurrently to the official Bell Labs Unix (often referred to as "System V"). Later, good ideas from both systems were merged into newer Unix systems.

Network programming is all about exchanging messages between two computers, which may be very different and may even run under different operating systems. Needless to say, a common language is required.



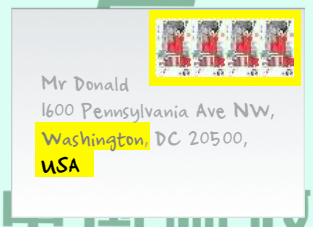
Networking is very similar to snail-mail. You may want to send a message (say a nice card) and you need put it into an envelope.

Then you need to affix a stamp (or several stamps), and write down an address, let's say in the US.



Then you can handle it to China Post.

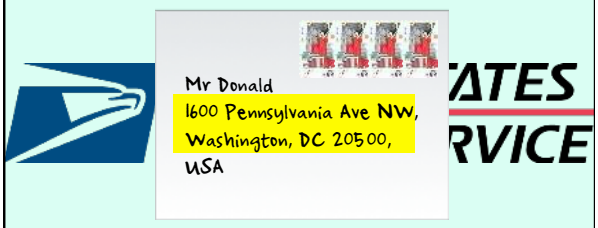
China Post are not interested in your message. They don't care about whom you are writing to, they dont care about the street nor the precise part of Washington.



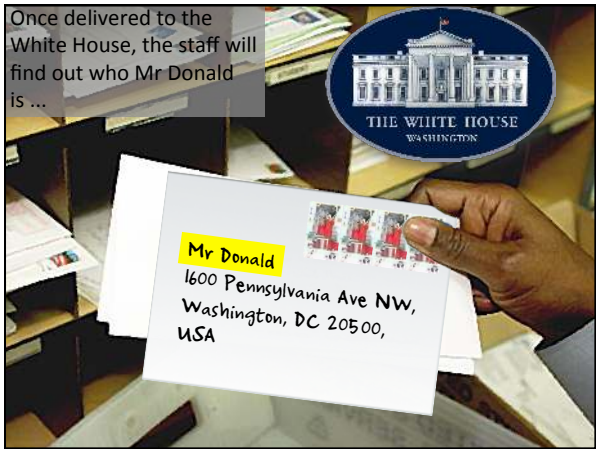
They only care about the stamps being correct, the country and, for a country as big as the US, the airport where they fly that is closest to the destination. It may be Los Angeles ...

So your card will be sent to the US.

Once there, it will be handled by USPS (United States Postal Services); they only care about the precise address in Washington.

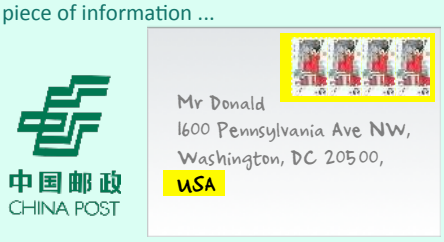


In fact, they must first care about taking the letter to Washington, and about the precise address only when in Washington.



Several layers of information

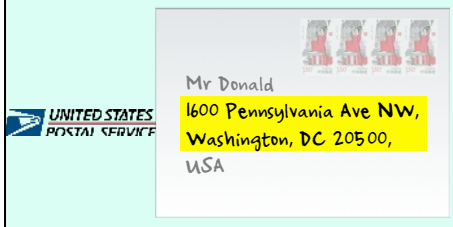
What is interesting is that each intermediary only looks at one piece of information ...



Each one relevant to one go-between

Several layers of information

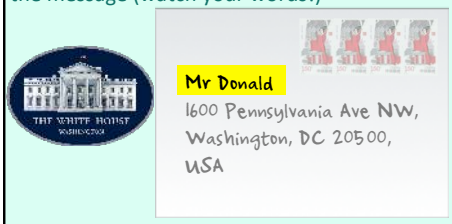
...then handles the message to someone else ...



Each one relevant to one go-between

Several layers of information

... until it reaches the addressee (or his secretaries) who reads the message (watch your words!)



Go-betweens only read what is relevant to them

It works exactly the same with computer networks

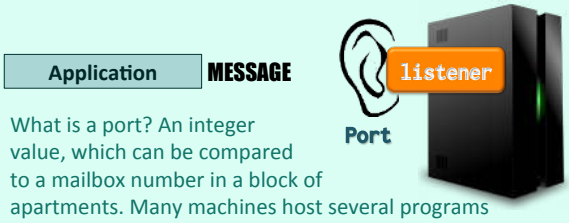
When you send a message over a network, it must reach a computer that may not be in the same network as you are. You message will be sent from machine to machine, being forwarded by dedicated computers known as routers, will hop from network to network through "gateways" that are computers connected to two networks at once, and your message will be wrapped into information only used by the intermediaries.

Need for PROTOCOLS

Once again, for everybody to understand, you must follow certain sets of rules, known as a "protocol", in the same way that you are supposed to provide some special information in the address on an envelope, and to write it in a special way (not country and zipcode at the top) so that it's understood in any post-office.

Several protocols exist for sending messages, the one that over the years has become the most popular, the one that is used over the Internet, is known as TCP/IP.

For your application to send a message successfully, there must be a special program (generically called "listener" here) ready to receive it. With TCP/IP, this listener is attached to what is called a "port".



What is a port? An integer value, which can be compared to a mailbox number in a block of apartments. Many machines host several programs that can receive messages and reply to them.

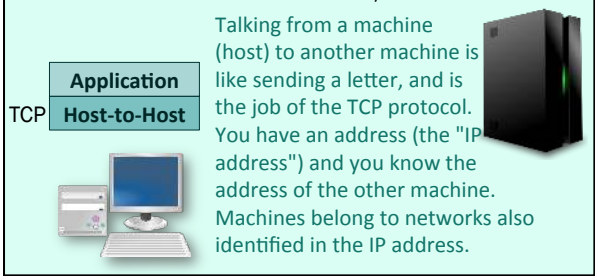
Port numbers are specific to a service.

Flickr: Newtown grafitti

IP address 4 bytes (32 bits) `198.51.100.97`

Network address / Machine address

Mask `1111 ... / 000 ...`



TCP: Application / Host-to-Host

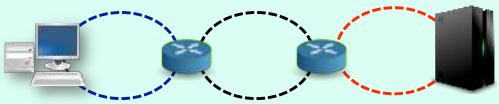
Talking from a machine (host) to another machine is like sending a letter, and is the job of the TCP protocol. You have an address (the "IP address") and you know the address of the other machine. Machines belong to networks also identified in the IP address.

IP address 16 bytes (128 bits) `2001:0db8:85a3:0000:0000:8a2e:0370:7334`

"Internet of Things"

TCP: Application / Host-to-Host

We are running out of traditional 32-bit addresses and much larger adresses are introduced, with a view to the "Internet of Things" in which anything will have an address.



IP: Application / Host-to-Host / Internet

"Internet" means "Inter Network" and is about transferring data from network to network. Obviously the job of the "Internet Protocol", better known as IP. It's like one postal network handling mail to another.

To reach another network, you must transfer via a machine on your network (Gateway) that is also connected to another network. Routers on your network will take you there.

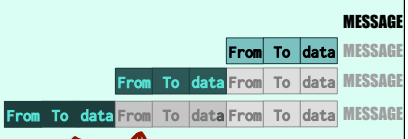
Application
Host-to-Host
Internet
Network Access

Network programming is usually presented as several independent layers that only communicate with the next one, in the same way as snail-mail. Each layer is in charge of checking some part of the information and handling the message to adjacent layers.

Application
Host-to-Host
Internet
Network Access

Each layer adds the information it needs, and considers the message to be what was handled to it by the preceding layer (the original message, PLUS layer specific data)

Application
Host-to-Host
Internet
Network Access



Will be modified by the various machines on the route

You sometimes have a suffix (to check that there is no transmission error)

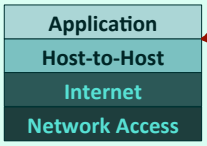
To MAC	From MAC	Network Protocol	*Message*	Checksum
6 bytes	6 bytes	2 bytes	Max 1518 bytes	4 bytes

This is the lowest level message. The MAC(hine) address is a kind of serial number that identifies a network card.

Slice and dice big messages

Chunks that are sent are relatively small (1518 bytes at most). Big messages are reassembled at destination.

Where does C network programming hit?



Most operating systems are written in C and this language is frequently used for low layers as well.