CS 246 NOTES

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Disclaimer: These notes are not meant to be a replacement for lecture. They are meant to be a method of learning for myself for LaTeX, and are meant to be used for reference or review of content. I share these in hopes that it helps others understand or review the content covered.

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Chapter 1

Introduction to Linux

1.1 History of the Shell

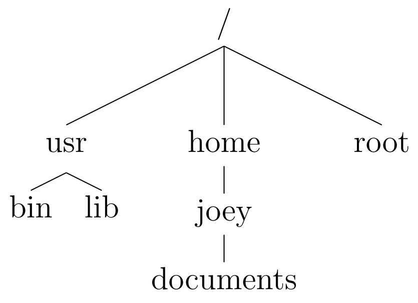
- Unix Shell (made in the 70's) called "shell" written by Bourne
- Other random shells made at the time, csh (c shell), ksh (korn shell)
- csh was revised into turbo shell3
- sh was named Bourne shell after many shells began appearing
- Bourne Again shell (bash) was created as a replacement for Bourne Shell

1.2 Linux File System

Composed of

- files (programs, data)
- directories (files/directories)

Directories form a tree-like structure



The initial or *root directory* of the tree or filesystem is known as “/” Absolute paths to a file in the file system always start with the root directory
Example: “/home/joey/document.txt”, “/usr/bin/firefox”
The *Current directory* is directory you are currently sitting in, which you can see by running

```
        $ pwd
```

which displays the absolute directory currently. *Relative paths* don’t start with a “/”. Examples: “joey/documents”, “./firefox”

1.2.1 Special Directories

- ”.” → current directory
- ”..” → refers to parent of current directory
- ”~” → your home directory, also you can just do ”cd” to get to home
- ”~userid” → is that users home directory

1.3 Linux Programs

Where ever you are while in directories, you can run programs via the command line.
Directories

- do not show any file starting with a dot
- using ”ls -a” will list out all of the files including hidden ones
- Wildcard matching:

aside: in linux there is no enforcement of what the extension means for a file e.g. binaries could be .txt, no special meaning
example: wanting to list files that end in .txt in the current directory ”ls *.txt”, ”*.txt” is called a globbing pattern
Shell substitues *.txt with every file in the current directory that matches the pattern onto the command line
echo $\implies$ simply echos whatever you type back
rm $\implies$ removes (deletes) files
cat $\implies$ concatenates the files listed

Ctrl + C to kill a process
note that when we do cat it just repeats what we type
It would be useful if we can capture it
done by cat > nameofafile.txt
But we need to do a clean exit, so Ctrl + D does an EOF to thevim program
Output redirection
Using < and also > and whatnot

Every program has 3 streams
Standard input, standard output and standard error
The standard output and error defaults to stream
Default input defaults to linked to keyboard
To redirect error e.g. program.exe 2> error.log

Permissions: 3 groups of 3 bits example: rwx r-x r– first 3 are what the owner can do second iwhat members of the group (except owner) can do other bits what all can do Inside each group we have a read bit, a write bit, and an execute bit. If the bit/permission is not set, it appears as a dash.
Permissions: for files read - read the content of the file write - modify the content of the file execute - execute the file as a program
for folders read - list the contents of the folder, globbing, tab completion write - add or remove files in the directory execute - directory can be navigated to e.g. cd
Changing permissions only the owner can change permissions chmod mode file mode ownership-class operators permissions u-user + add r g-group - remove w o-other = set permission exactly x a-all
example: give others the ability to read permissions chmod o+r file revoke execute permissions from group chmod g-x file make everyones permissions rx chmod a=rx file
scripts are text files containing a sequence of linux commands execured as a program example: print the date, current user, current directory # !/bin/bash date whoami pwd
if current directory i not in $PATH, run script as ./script
redirectoing to /dev/null will delete any buffer (black whole)
programs return a status code 0 - successfull non-zero - failure $? is set to the status code $0 is the name of the currently running file
Looping over a list ex. REname all .cpp files to .cc #/bin/bash for name in *.cpp; do mv $name $name%cppcc done
ex. How many times does $1 occur in $2 (file) # !/bin/bash x=0 for word in ‘cat $2‘; do if [$word = $1]; then $x=$(x+1) fi done echo $x
Good idea to put input variables in double quotes to code defensively so space delimited input is never executed
Testing - no one likes testing - create test suite before actual code Functional Testing - run every function at least once - within a function - cover different control flow - code coverage - variable ranges: positive/negative boundaries of ranges (edge cases) multiple simultaneous boundaries (corner case)
Regression Testing - new code does not break old code

1.4 C++

Bjorne Stroustrup -invented the idea of a class and created ”C with classes”
How can we tell an attempted read failed? If a read fails then cin.fail() is true if a read fails because EOF then cin.fail() is true and cin.eof() is true.
Example: Read all integers from stdin and echo to stdout Stop if non-integer or EOF is encountered. There is an implicit conversion from cin (iostream) to void * Since a pointer is some numeric value, it can be used in a condition Thus we can use just cin inside a condition cin is true if !cin.fail()
We are using ¿¿ as the ”get from” (input) operator Which also does bit shifts. Also cin ¿¿ a is an expression that returns cin When a read fails, a flag goes up in cin - the flag stays raised until we acknowledge a failure cin.clear() - lowers the flag cin.ignore() - skips over to the next character

C++ provides the type std::string for helping with string stuff (such as reading in strings)
this will read in characters until it hits a whitespace, then its done. i.e. go past any whitespaces until it hits the first whitespace Reads the next characters into a String, stopping at the next whitespace, ignoring any leading whitespace. Aside: to read the entire line (including whitespace) getline(cin, s) cin for strings is similar to scanf with %s format specifiers in C
Notice that cin ¿¿ i reads in an integer cin ¿¿ s reads in a string The exact same code to read either in, the only difference is the declared type (e.g. type of i or s variable)
C-style format specifiers do have their benefits int i = 95; cout ¡¡ i ¡¡ endl; // just prints out 95 in decimal What if we want hexidecimal, binary, boolean (true/false literal)? We use I/O manipulators to do that. Examples
cout ¡¡ hex ¡¡ i ¡¡ endl; (note hex is std::hex, we are working with namespace std) Sending hex to cout does not print anything. It makes cout change in way that says print any integers that are sent in as hexidecimal form Unless we do cout ¡¡ dec, to change the behaviour back to decimals
Moving along, what if we don't want to read in from keyboard (stdin). This "stream" abstraction we've been using as cin (specifically istream and ostream - in and out respectively) we can use the same way to open and "stream" a file. To read or write from files, we have file streams. They behave just like input and output streams.
The only difference in this example is how we initialize the file stream, requiring a file name! ifstream f("suite.tx"); //variable declaration and initalization type: ifstream varaible name: f parameters for initializing: "suite.txt" (string of filename)
We can attach a stream to a string and read/write from it include ¡sstream¿ So we have an istringstream -read from a string And ostringstream - write to a string
int low... int high... ostringstream ss; ss ¡¡ "Enter an integer between ¡¡ lo ¡¡ " and " ¡¡ high;
Default Arguments: in c++ we can specify default arguments void printSuiteFile(string filename="suite.txt) ¡- is the default value
string s = ss.str(); cout ¡¡ s ¡¡ endl;
Benefit: Convert a number to a string How about reading a string? We can use an ostringstream
Strings in C++ In C we didn't have a built in string type, so instead we used arrays of characters. - needed careful memory management - was very easy to overwrite the null terminator
In C++ we do have a string type - not built in, but part of standard library std::string type -manage their own memory - safer to use string s = "sdgd"; can assign c string to a c++ string and c++ does a conversion
equality: c++ has all of the comparison type operators (==, ¿= ¡=)
ability to refer to individual characters In c++ we can still do s[0], s[1] for characters of a string
string concating in C: strcat in c++ s1 + s2 works!
Note: to get a c style string from a c++ string, we need to use string.c_str()
Overloading: Example: write functions that negate integers and one that negates bools
Pointers int n = 5; int *p = &n; cout ¡¡ p ¡¡ endl; //prints the pointer to n cout ¡¡ *p ¡¡ endl; // prints the int 5
int **pp; pp is a pointer to a pointer to an int. pp = &p;
Arrays Not to be confused with pointers int a[] = 1, 2, 3, 4 this way has a few restrictions of whats needed. the array needs a contiguous block of memory The name of the array is short form for the address of the first element in the array. a = &a[0] *a = a[0] -¿ first element
Structs
C syntax Struct Node int data; Struct Node * next; ;
Constants const int maxGrade = 100; Make as many tihngs constance as possible A constant must always be initialized

const int * p = &n; p is a pointer to a constant integer what you cant do is change the value of n through p
int * const p = &n p is a constant pointer to an integer
cin behaves similarly to scanf for scanf we pass the address of the variable we want to read into although cin ¿¿ x takes in not a pointer, it still acts as if it was given one
CPP has another pointer like type - a refernce int y = 10; int &z = y; z is a reference to y z is a constant pointer to y
a reference is a constant pointer with automatic dereferencing z = 12; (NOT *z = 12 - but this 'does' the same thing)
int *p = &z What happens here even is that p gets the address of y. In no case does z have an identity of it's own.
Cannot have a reference uninitialized its a constant pointer -¿ constant -¿ must be initialized
Can only create a reference to something that has an address. Note: anything that has an address is called an lvalue
Cannot create a reference to a pointer Cannot create a reference to a reference Cannot create a reference to an array Cannot create a reference to a pointer
Pass by Value struct ReallyBig f(ReallyBigStruct) results in copying over the entire struct In C we could pass a pointer to suppress the entire copy In CPP we can also use a reference to do similarly. void h (const ReallyBig &rb) will ensure rb does not get changed outside of scope.
Dynamic Memory Allocation CPP provides new and delete for allocation and deallocating. New is type aware, so it's less prone to errors
Node *np = new Node; as simple as that Since it is type aware it knows how much memory is needed for Node Once done, to reclaim memory delete np;
Dynamically allocating an array cin ¿¿ n; int * arr = new int[n], number of elements in the array Once done, to deallocate the array delete [] arr;
Operator overloading Give a special meaning to C++ operators for types we construct

Preprocessor - a program intercepts the code before it is compiled - transforms code
#include ¡iostream¿ this is a preprocessor directive This tells the preprocessor to paste the contents of iostream right here Look for iostream in the standard place that contains the cpp library
Also #include "..." - look for this file in my current directory
Another directive #define VAR VALUE tells the preprocesor to setup a variable called VAR with the value VALUE
The define directive orders the preprocessor to replace any occurrence of VAR with VALUE -does a search and replace
#define MAX 10 int array[MAX]; =¿ int array[10];
Define is a mechanism to specify constants. It's completely useless now as C and CPP now have const variable types which made define obsolete.
Preprocessor does nto know (or care) what would get generator by doing the "FIND AND REPLACE" of define.
Define constants are useful for conditional compilation Examples: In unix it might be int main()
While windows might require code to be int WinMain()
So instead you can use preprocessing to just change the code immediately, as so
#define Unix 1
#define Windows 2
#define OS Unix
#if OS == Unix
int main
#elif OS == Windows
int WinMain()
#endif

#define VAR -define a variable VAR - it's value is the empty string
#if def VAR
blagh
#ifndef VAR
blagh
#endif
Note doing #if 0 sadasfaf afasf asfasf #endif -super duper way of commenting out code
Moreso we can specify defines from command line. e.g. g++ program.cc -DOS=Unix -o program
Will #define OS Unix for you through the command line
Mind you if you do #define DEBUG -¿ gets the empty string value g++ -DDEBUG *.cc -¿ value is given 1
Separate compilation -split programs into composable modules Interface: .h type definitions, fucntion headers... Implementation: .cc, actual implementation
Ways to compile g++ *.cc (glob all files), if all .cc files are part of the program and you dont compile - header files included inside .cc - never include cc file
g++ argument "-c" just compile. creates an object file, binaries for code ld (linker) is the matchmaker that links the files together
Hard to keep track of whats being included have IFDEFS in our headers!
Classes Big innovation of OOP You can put functions inside a struct A class is a struct type that can have functions For now we will only regard classes as a struct which contains functions
Functions defined inside a class are called "member functions" or methods
Say we have a struct Student with a function grade(); When we access the structs fields inside it's

methods, we may use "final" "midterm" as variables, Where a when we access the method from the struct we are specifically detailing that structs instances
The distinction between fucntions and methods is that a method contains a hidden (implicit) parameter called "this" which is a pointer to which the object that this pointer was called
Initializing Structs Student billy = 60, 70, 80 C style initialization of an object - restrictive
CPP provides th abiity to write constructors which are functions used to construct objects
Struct Studenet int assigs, mid, final;
note fcn name is same as class name Student (int assigs, int mid, int final) this.assigs = assigs; this.mid = mid; this.final = final;
Now using our constructor Student billy(60,70,80); Student billy = Student(60,70,80);
And on the heap Student * pBilly = new Student(60,70,80);
Advantages of writing constructors - full CPP functionality is available -default parameter values Student(int assigs = 0, int mid=0, int final=0) regular constructor
If you want to default all parameters (so pass nothing) You want to do Person per; and it uses all of the default parameters for the constructor
Initializing Objects every class comes with a default no argument constructor. - calls default constructors on fields (if they have constructors)
e.g. Vec v; // default constructor ran
Note: the builtin (default) constructor goes away as soon as you write any constructor for the class
Once we've defined a struct with our own constructor, we can no longer do
Struct Vec int x; int y;
Vec (int xx, int yy = 2) this-¿x = xx; this-¿y = yy; ;
Vec v1(1,2); Vec v2 = new Vec(1,2); Vec v(1);
Vec v; // won't compile Vec v (1,2); //ok! Another thing you loose when you build your own constructor is c-style initializing Vec v = 1,2 ; // wont compile
Q: What if my class has constant as reference fields? struct MyStruct const int myConst; int &myref; ;
COnstants and references must be initalized! Ok, to initalize them
struct MyStruct const int myConst = 5; int &myRef = z; ;
inializers are not allowed though for fields! (won't compile) What you most likely want is that each object gets it's own constant independant of the class Each instance of myStruct gets its own myConst and myRef Why should they have the same value?
Q: Can we initliaze these inside the construcotr body? A: No, it's too late. by the time the constructor body executes constants and references should have already been initialized
Struct Person
int x; int y; Struct Wallet w;
;
new Person(); Wallet w = new Wallet();
When an object is created, 1) space is allocated (stack or heap) 2) fields are initialized: default constructors are executed for all fields that have default constructors 3) constructor body runs
hijack step 2: done by a member initialization list
Struct MyStruct const int myConst; int &myref;
int x;
MyStruct(int c, int &r, int xx): myConst(c), myref(r), x(xx) CONSTRUCTOR ; -This sort of syntax is only allowed for constructors -You are not restricted to just constants and references
Another example of the member list Struct Student int assigs, mid, final; Student(int assigs, int mid, int final): assigs(assigs), mid(mid), final(final) ;

In this case note that in field(param), FIELD is ALWAYS just looked at as a field, and PARAM is ONLY looked at as parameters in this syntax Another advantage of member initialization lists is that they [can] be more efficient then initializing inside the constructor body (due to default initilization being run and initializing all fields twice if re initializing in cosntructor body) [if all the fields are primative types they won't be initialized and it won't make a difference anyways as primate initiliazation isn't much]
Fields are initialized in the order in which they are declared -irrespective of the order appear in the in the members initialization list -most compilers give you a warning if your order in the initialization list was different than the order of declaration
more initialization stuff Student billy(60,70,80); and we have bobby is a copy of billy Student bobby = billy; To construct a new object as a copy of an existing object we use the copy constructor
-you get a default copy ctor for free (makes a copy field to field) Every class comes with: -default constructor -default copy constructor - copy assignment operator - destructor
Struct Student int assigs, mid, final; Student(int assigs, int mid, int final): assigs(assigs), mid(mid), final(final)
Student(const Student &other): assigs(other.assigs), mid(other.mid), final(other.final) ;
Student bob(1,2,3); Student billy(bob);
Default copy constructor might not do what you expect it to do
Struct Node int data; Node * next;
Node (int data, Node *next): data(data), next(next)
Node (const Node &other) : data(other.data), next(other.next) ;
Node *n = new Node(1, new Node (2, new Node(3, 0)));
Node m = *n; // runs copy Node *p = new Node (*n);
I wanted three linked lists that are copies of eachother Unfortunately we only got NEW first nodes, but the rest of the list is the same for each list (points to the same elements) We get whats called a shallow copy
DEEP COPY Struct Node
Node(const Node &others): data(others.data), next(other.next ? new Node(other.next) : 0)
;
When copies are made 1) Copy constructor: create an object from an existing one default copy constructor copies all fields (shallow) Sometimes we need deep constructors Example of copy: student bobby = billy; // copy constructor
2) when a function passes an object by value 3) when a function returns an object The copy constructor must take others by reference - infinite recursion if called by value (attempts the copy constructor as it passes in)
Destructor When an object is destroyed a method called the destructor is run - a stack allocated object is destroyed when it goes out of scope - a heap allocated object is destroyed when it goes out of scope - default destructor is built in. calls the default constructor on fields if available
Node * np = new Node(1, new Node(2, new Node(3,))); 1) -np will go out of scope - no destructor got called because np is a pointer - linked list still there, so we have a memory leak 2) delete np - calls the default constructor for the object *np, (np points to) - node 1 is deleted, node 2 and 3 are leaked
To reclaim all memory, we must write our own destructor struct Node int data; Node * next;
Node() //calls destructor on all fields delete next;

1.5 Seperate Compilation for Classes

interfaces (.h file): struct definition and function headers implementation (.cc file): full implementation

Node.h #ifndef NODE_H #define NODE_H stuct Node int data; Node * next; Node (int data, Node * next); Node(const Node &other); ; #endif

Node.cc #include "Node.h" Node(int data Node *next): data(data), next(next) Node(const Node &other): data(other.data), next(other.next ? new Node(*other.next) : 0)

-But here we have that the compiler is unable to determine that these are methods defined in Node.h

-Prefix the method with Node::!

Node.cc #include "Node.h" Node::Node(int data Node *next): data(data), next(next) Node::Node(const Node &other): data(other.data), next(other.next ? new Node(*other.next) : 0)

:: is known as the scope resolution operator Another option is using namespaces to do the same thing for the entire .cc context

1.6 Assignment operator

Student billy(60, 70, 80); //constructor with 3 args Student bobby = billy; // copy constructor Student jane; // 0 argument constructor jane = billy; // jane already existed What happens is jane is modifying it's fields to be come a copy of billy (not using copy constructor, no new object is created)

You get a default assignment operator! Need to write your own if dealing with dynamic memory

```
struct Node {
        Node &operator=(const Node &other) {
                data = other.data;
                next = other.next;
                return *this;
        }
};
```

Want a deep copy

```
Node &Node::operator=(const Node &other) {
        data = others.data;
        *next = (others.next) ? *others.next : 0; % mine
        next = new Node (*(other.next)); % on board
        next = others.next ? new Node(*others.next) : 0; % board, null ↩
           fix
        return *this;
}
```

Memory leak: not deallocating whatever next originally points to

```
Node &Node::operator=(const Node &other) {
        data = other.data;
        delete next;
        next = others.next ? new Node(*others.next) : 0;
}
```

When implementing the operator= always check for self assignment if (this == &others), meaning if they are the pointing to the same address and same object return *this;

If new fails (no memory), nex is a dangling pointer. what we want is ALL OR NOTHING
Delay the delete

```
Node &Node::operator=(const Node &other) {
        if (this == &other) return *this;
        Node *tmp = next;
        next = other.next ? new Node(*other.next) : 0;
        data = other.data;
        delete tmp;
        return *this;
}
```

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Assignment operator continued
Copy and swap idiom for assignment operator

```
struct Node {
        void swap(Node &other) {
                int tdata = data;
                data = other.data;
                other.data = tdata;
                Node *tnext = next;
                next = other.next;
                other.next = tnext;
        }
        Node &operator= (Node &other) {
                Node tmp = other; // copy ctor, deep copy
                swap(tmp);
                return *this;
        }
};
```

Is there a memory leak? No, because tmp is stack allocated and the destructor is called when tmp goes out of scope (assuming a properly implemented destructor)

Rule of 3
If you need to write a custom version of

- copy constructor
- destructor
- operator=

then you usually need to write all three
operator= is a member function When an operator is declared as a member function, *this* plays the role of the left hand operand

```
struct Vec {
        int x,y;
        Vec operator+(const Vec &other) {
                Vec v(x + other.x, y + other.y);
                return v;
        }
        Vec operator*(const int k) {
                Vec v(x * k, y * k);
                return v;
        }
};
```

If we want to do scalar multiplication with the reverse we have to have a standalone function outside of the class

```
Vec operator+(const int k, const Vec &v) {
        return v * k;
}
```

CPP tells you which operators MUST be implemented as a member function

- operator=
- operator[]
- operator-¿
- operator()
- operator T(), where T is some type

```
struct Vec{
        ostream & operator<<(ostream &out) {
                out << x << " " << y << endl;
        }
};
```

Note the vector has to be on the left hand side as this is a member function (which can be annoying)
Arrays of objects

```
struct Vec {
        int x,y;
        Vec(int x, int y): x(x), y(y) { }
};

Vec vectors[3];
Vec * myvectors = new Vec[10];
```

But both of these methods don't compile as they need the default constructor for the vectors to initialize them all.
Stack allocated array: - use aray initialization

```
Vec vectors[3] = { Vec(1,2), Vec(3,4), Vec(5,6) };
```

Heap allocated array: - give a default constructor - create an array of pointers to objects

1.7 Constants revisted

```
void f(const Node &n) { ... }
```

- this means you cannot modify the values of n's fields Q: Can I call methods on a const object A: yes you can, as long as the method promises it's behaviour (takes in const also)

```cpp
struct Student {
        int assigs, mid, field;
        float grade() {
                return assigs * 0.4 + mid * 0.2 + final * 0.4;
        }
        // const objects can call const methods, we have to explicitly ↩
           state const3
};
```

Want to track how many times grade is called on each student

```cpp
struct Student {
        int assigs, mid, final;
        int numMethodCalls;
        float grade const() {
                ++numMethodCalls;
        return ...;
        }
        // want to be able to modify numMethodCalls by delcaring the ↩
           field mutable
        // mutable int numMethodCalls;
};
```

1.8 SE Topic: Design Patterns

If you have a situation like THIS, then THIS is a good programming technique to solve the problem. Singleton Pattern We have a class C, and we want to ensure only one instance of C is ever created, no matter how many times we request a new instance C++ static members Static field: is associated with the class itself and no instance of the class - per class rather than per object

```cpp
struct Student {
        static int numInstances;
        Student(...) ... {
                ++numInstances;
        }
};
```

This will keep track of how many students there are
Initializing the static variable in the .cc file

```cpp
int Student::numInstances = 0;
```

Static member functions (or static methods) - not dependant on any object (no this parameter) Restrictions on static member functions - can only access static fields - can only call other static methods

```cpp
struct Student {
        static int numInstances;
        static void printInstances() {
                cout << numInstances << endl;
        }
};
```

It can reference numInstances because numInstances hasalso been declared static

```
Student Billy(...);
Student Bobby(...);
Student::printInstances();
```

Singleton Pattern We have a class C and we want to ensure that only one instance (object) of C is created in the program. Example: program to monitor financines Wallet class - only have one wallet Expense class - many, each has access to wallet
We want to guarantee that some piece of code runs at the very end of the program Solution: Borrow something from C: Function atexit (part of ¡cstdlib¿ - takes one argument, name of function that takes no arguments and returns nothing
Encapsulation: We want to control how objects are used - hide implementation details - want clients to use objects as black boxes (capsules) - clients should interact only through provided (exposed) interfaces
Lets redo vector and hide it's fields

```
struct Vec {
        Vec(int x, int y): x(x), y(y) {}
        private:
                int x,y;
        public:
                vec operator+(...)...
};
```

x and y are private not accessible to outsiders
Introducing the new keyword class, by default their visibility is private while structs have public visibility
Advice: keep fields private YOu can provide getters (accessors) and setters (mutators)
By using getters andsetters you can insist on program invarience "statement about your program that is always true for the execution"
You can change implementation details — situation Don't want to implement getters still want fields to be private want to implement printing of the fields (operator¡¡) but this needs access to fields
class vector can declare operator¡¡ to be a friend

```
class Vec {
        int x,y;
        public:
                ...
                friend ostream& operator<<(...) ...
```

Note operator¡¡ is not a member function, but it's saying that the function will have access to the fields, as so

```
ostream& operator<<(ostream &out, const Vec&v) {
        out << v.x << " " << v.y << endl;
        return out;
}
```

Friend - class has some private fields - no access methods - want some functio nto have acess to fields - declare that function a friend Breaks encapsulation - so make as few friends as possible
System Modelling - relationships between classes - UML : Unified Modelling Language a class in uml is a box with three sections

—————————- - Vec - ¡- name of clas —————————- - -x : integer - ¡- fields of class (optional) - -y : integer - —————————- - +getX(): Integer - ¡- methods of class (optional) - +getY(): Integer - —————————-

- indicates private visibility + indicates public visibility
Relationship 1: Composition

```
class Vec{
        int x,y,z;
        public:
                Vec(int x, int y, int z): x(x), y(y), z(z) { }
};
class Plane{
        Vec v1, v2;
        public:
                Plane() { -- }
};
```

But note

```
Plane p;
```

Doesn't work, because there is no default constructor for Vec! This is due to the three things that happen when a constructor is run How about when an object is destroyed? 1) the destructor body runs 2) destructors for fields run (in the reverse declaration order) 3) memory deallocated
If you don't have or want default constructors, for vec in this case

```
Plane::Plane(): v1(1,0,0), v2(0,1,0) { }
```

—– back to uml —– Embedding one object (e.g. Vec) inside another object In which case plane is called composition The relationship between Plane and Vector is a "owns a" relationship
Typically if A owns a B - B has no existence on it's own If A is destroyed so is B. If A is copied so is B.
So we have A box ¡¿—-¿ B box (closed diamond at tail)
Relationship 2: Aggregation Compare parts in a catalogue (owns a) vs parts in a catalogue Catalogue contains parts but the parts exists on their own. This is a "has a" relation. If A "has a" B, B can exist on it's own but A has a listing of B - B can exist on it's own - if A is destroyed, B lives - if A is copied, B is not (shallow copy)
A box ¡¿—–¿B box (OPEN DIAMOND AT TAIL!) Implemented via pointer.
Relationship 3: Inheritance - program to track my collection of books

```
class Book {
        string title, author;
        int numPages
        public:
         ---
};
class CSBook {
        string title, author;
        int numPages;
        string language;
        public:
         ---
};
```

```
class ComicBook {
        string title, author;
        int numPages;
        string hero;
        public:
         ---
};
```

We want an array that contains Books, CSBooks, Comics. In C: 1) use something called union

```
union BookType {
        Book *b;
        CSBook *csb;
        Comic *c;
};
BookType myBooks[20];
```

2) array of void *. Same problem (don't know what the type is) - bad (worse) for same reason
Both options subvert the C++ type system which are there to help us ——————— In C++, this is a third option - Use Inheritance Relationship 3: Inheritance, "is a"

```
class CSBook: public Book {
        string language;
};
class Comic: public Book {
        string hero;
};
```

The book class stays the same, and is called the base class (or super class... or the parent class)
The other two classes are derived classes (or sub class... or child class)
- subclasses inherit all fields and methods from the super class - CSBook inherits title, author and numpages - any method that can be called on a Bok object can be called on a CSBook object
In a book fields are private CSBook has inherited these fields. But NO CSBook cannot access these fields So we cannot do csb.author or any of the fields
Costructing CSBook even if we don't have access

```
class CSBook: public Book {
        string language;
        public:
                CSBook(string title, string author, int numPages, ↩
                   string language) : language(language) {
                super();
                }
};
```

```
class Book {
        string title, author;
        int numPages;
        public:
                Book(stirng title, string author, int numPages): title(↩
                   title), author(author), numPages(numPages) { }
};

```

```
class CSBook: public Book {
        string language;
        public:
         ----
};

class Comic: public Book {
        string hero;
        public:
         ----
};
```

How to create a CSBoo if I cannot access the inherited fields because they are private in the superclass. When an object is created 1) space is allocated 2) constructor of super class part of the object 3) field initialization 4) ctor body runs

```
CSBook::CSBook(string title, string author, int numPages, string ↩
   language): Book(title, author, numPages), language(language) { }
```

This solves the problem that we can't access the fields by initializing them as so, and it also takes the place of step 2 as we construct it.
If the superclass oes not have a default ctor you must explicitly use a non-default ctor in the init list.

```
class Book{
        protected:
                string title, author;
                int numPages;
                public:
                        ----
```

What protected does is allows the subclasses of book to have full access to anything that has protected visibility.

```
class CSBook:public Book{
        string language
        void addAuthor(string auth) {
                author = autho;
        }
```

protected access in Book for author
<u>Advice</u> Not make fields visible. Make fields private Instead provide mutator methods to subclasses (so protected) e.g. setAuthor. This makes it so that ONLY the base class changes it's own field (through it's own mutator)
UML: A CSBook IS A book A Comic IS A Book
Book CSBook Comic
(inherited class gets pointed at)
How about a method to tell us if a book is heavy? Although a CS book is only heavy for 500 pages.

```
class Book {
        public:
                bool isItHeavy() { return numPages > 200; }
};
class CSBook:public Book {
        public
                bool isItHeavy() { return numPages > 500; }
};
class Comic:public Book {
        public:
                bool isItHeavy() { return numPages > 30; }
};
Book b("abc", "xyz",  50);
b.isItHeavy(); //false
Comic c("A big Comic", "xyz", 40, "Nomair");
c.isItHeavy(); //true
// decided at compile time that to run Comic's isItHeavy
Book b2 = Comic("A big comic", "xyz", 40, "Nomair");
b2.isItHeavy(); // false
// uses a Book's isItHeavy function
```

When you assign a Comic object to a Book, the extra Comic methods and fields are 'sliced' away. If you access a subclass through a superclass variable it is sliced (coerced) into the subclass When accessing objects through pointers, slicing is NOT necessary

```
Comic cb(_, _, 40, _);
Book *pb = &cb;
Comic *pCB = &cbl;
pCB->isItHeavy(); // true
pb->isItHeavy(); // false
```

Copiler uses the type of the pointer (reference) to devide which method to call. It does not consider the actual type of the object.
We probably want the decision of which method to execute be based on the type of the object this pointer points to, and not the declared type of the pointer.
Declare the method as VIRTUAL

```
class Book {
        public:
                virtual bool isItHeavy() { --- }
};
```

Virtual Methods choosen whcih class's method to run based on the object at run time (Dynamic Dispatch)
Virtual Methods

```
class Book {
        public:
                virtual bool isItHeavy() { --- }
};
class Comic : public Book {
        public:
                bool isItHeavy() { --- }
};
Comic cb(---,40,--);
Book *pB = &cB;
Comic *pCB = &cb;
Book &rb = cb;
```

```
pB->isItHeavy(); //true
pCB->isItHeavy(); //true
rb.isItHeavy(); //true
```

Virtual Method: method chosen to be executed based on the type of the object at runtime. THERE IS A COST INVOLVED IN DYNAMIC DISPATCHING
Polymorphism(many forms) Book *collection[20]; //Book, CSBook, Comic for (int i = 0; i ¡ 20; i++) cout ¡¡ collection[i]-¿isItHeavy() ¡¡ endl;
Ability to accommodate multiple types under the same abstraction
Destructor Revisited

```
class X {
        int *x;
        public:
                X(int n): x(new int[n]) { };
                ~X() { delete [] x; };
};
class Y: public X {
        int *y;
        public:
                Y(int m, int n): X(n), y(new int[n]) { };
                ~Y() { delete [] y;};
};
X *myx = new X(5);
delete myx;
Y *myy = new Y(10, 5);
delete myy;
X *foo = new Y(10, 5);
delete foo;
```

But this leaks memory as it doesn't call the Y destructor and doesn't destroy the Y memory. (calls X destructor, array y untouched) Fix: make the destructor in the base class virtual.
Pure Virtual Methods

```
class Student {
        protected:
        int numCourses;
        public:
                virtual int fees();
};
class Regular: public Student {
        public:
                int fees() { return 700 * numCourses; };
};

class Coop: public Student {
        public:
                int fees() { return 800 * numCourses; };
};
```

Note we haven't given just a Student object an implementation for fees! We just need to instead use

```
virtual int fees() = 0;
```

pure - virtual method - no implementation - if a class contains at least one pure virtual method you cannot create objects of this class2 - such a class is called an abstract class
If a class has no pure virtual method it is called a concrete class
If you inherit an abstract class, unless you implement those pure virtual methods it is also an abstract class (cannot have an object)
Virtual methods in UML The way we denote a virtual method (declared virtual), we put the method name in italics. If it is an abstract class, we put the name of that class in italics
Static (field or method) in UML is underlined If it's protected it has a hashtag (- for private, + for public)
(open diamond and arrow - as a) (closed diamond and arrow - owns a) (just an arrow - is a)
Whenever we are constructing a subclass (has inherited another class) You must create/initialize the super class first
Copy ctor,

```
class Book {
        public:
                Book(const Book &other);
                // copy ctor for book
};

class CSBook {
        //no copy ctor
};
CSBook b(----);
CSBook c = b;
// default copy ctor for CSBook runs, but then it also calls the ↩
   implemented copy ctor for Book and then does a field for field ↩
   assignment of the rest (CSBook only stuff e.g. language field)
```

1) call copy ctor for book 2) field for field assignment (language)

```
CSBook::CSBook(const CSBook & other): Book(other), language(language) {↩
    }
// operator = is similar
Book & Book::operator=(const Book &other) {
        ---
        return *this;
}
```

CSBook::operator= not implemented Default operator= for CSBook c = b; 1) call operator = on Book (book part is constructed) 2) do field by field assignment on the remaining CSBook fields (e.g. languages)

```
CSBook & CSBook::operator=(const CSBook & other) {
        Book;:operator=(other);
        language = other.language;
        return *this;
}
```

The problem:

```
CSBook b1(---), b2(---);
Book *pb1 = &b1;
Book *pb2 = &b2;
*pb1 = *pb2;
```

```
CSBook b1(---), b2(---);
Book *pb1 = &b1;
Book *pb2 = &b2;
*pb1 = *pb2;
//Partial Assignment, problem because Book::operator= is NOt virtual
class Book {
        public:
                virtual Book &operator=(const Book &other);
};
class CSBook {
        public
                CSBook &operator=(const CSBook &other);
        // but note... this is NOT the same function as our virtual ↩
           function
                Book &operator=(const Boot &other);
                // overrides Book::operator= operator
};
CSBook c(---);
c = Book(---); //c's language will have garbage
c = Comic(---); //c's language will be a superhero
//MIXED ASSIGNMENT (BAD!)
```

If operator= is not virtual, we get partial assignment with pointers to base class If operator= is virtual, we get mixed assignment Advice: make superclass abstract Abstract Book ————–ˆ——— RegBook CSBook Comic

```
class AbstractBook {
        string title, author;
        int numpages;
        protected:
                AbstractBook &operator=(const AbstractBook &other);
        public:
                AbstractBook(---);
                virtual ~AbstractBook() = 0;
        // dtor is pure virtual, now the class is abstract
        // pure virtual methods CAN have an implementation
};
//abstractbook.cc
AbstractBook::~AbstractBook() { } //required to compile!
//regbook
class RegBook: public AbstractBook {
        public:
                RegBook &operator=(const RegBook &other) {
                        AbstractBook::operator=(other);
                        return *this;
                }
};
```

By making the AbstractBook operator= protected, we ensure that we cannot do

```
AbstractBook * b = AbstractBook * b2;
```

so we do not run into any errors on assignments
Observer design pattern Publish-subscribe model
Publisher (subject): generates data Subscriber (observer): receives data and reacts to it
Spreadsheet cell: subject Graph (grouping): observer
AbstractSubject +attack() +detach() +notifyObservers()
AbstractObserver +notify()
ConcreteSubject +getState()
ConcreteObserver +notify()
(AbstractSubject HAS A abstract observer)
(ConcreteObserver HAS A ConcreteSubject) For the getState to find the change
1) new data has been generated 2) notify all observers through notifyObserver 3) observer calls concretesubject to get the change
Decorator Pattern Add features to an object at runtime e.g. Base Window -decorator: Scrollbar, menu, tooltips
Componenet (HAS A Decorator) +operator() -¿ pure virtual
Concrete Component -¿ plain vanilla base window (IS A COMPONENT) +operator()
Decorator - (IS A COMPONENT) +operator() -¿ pure virtual
SomeDecA (IS A DECORATOR, both) SomeDecB +operator()
Pizza example
Pizza +price() +desc()
CrustAndSauce (is a Pizza), base pizza +price() +desc()
Decorator, Pizza *base
//below are decorator subclasses StuffedCrust +price() +desc()
Topping +price() +desc()
DippingSauce +price() +desc()

```
Pizza *p = new CrustAndSauce;
p = new StuffedCrust(p);
p = new Topping("cheese", p);
p = new Topping("anchovies", p);
delete p;
```

Factory Method Pattern
Enemy class, two types of enemies (Turtle, Bullet)
Level class, two types of levels (Normal, Castle) Normal level, mostly turtle Castle level, mostly bullets
Want a method to generate an enemy dependant on the level. Don't explicitly use constructor
Write a method to create and return a pointer to an enemy -¿ factory method

```
class Level {
        public:
        virtual Enemy * createEnemy() = 0;
};
class Normal: public Level {
        public:
                Enemy * createEnemy() {
                // mostly turtles
                }
};
```

```
class Castle: public Level {
        public:
                Enemy * createEnemy() {
                // mostly bullets
                }
};
Level *l = new Noraml;
Enemy *e = l->createEnemy();
```

So here we are calling a factory method, not a constructor directly
How about a new boss Enemy? If Boss is not to appear in Normal level
Only need to change Castle::createEnemy() Key benefit: the client code is not affected - whether createEnemy returns a new object (enemy) as an existing one (Boss) - client does not need to know
Template Method Pattern
Want subclasses to override some behaviour, but use superclasses remaining behaviours

```
class Turtle: public Enemy {
        public:
                void draw() {
                        drawHead();
                        drawShell();
                        drawTail();
                }
        private:
                void drawHead() {

                }
                virtual void drawShell() {

                }
                void drawTail() {

                }
};

class RedTurtle: public Turtle {
        private:
                void drawShell() {

                }
};
```

Now we will talk about Templates! (unrelated to the pattern)

```
class Node {
        int data;
        Node * next;
}; //linked list of ints
```

We don't want to use separate linked lists for different types We can write Node as a template, which is a class parameterized by one or more types Strategy: replace the int with a variable which we will specialize as needed

```
template <typename T> class Node {
        T data;
        Node<T> * next;
        public:
                Node(T data, Node<T> *next) : data(data), next(next) { ↩
                   }
                T getData() { return data; }
                Node<T> *getNext() { return next; }
};
Node<int> *intlist = new Node<int>(0, new Node<int>(2,0));
Node<char> *charlist = new Node<char>('a', new Node<char>('b',0));
```

The compiler (on seeing a specialization for the first time), replaces each occurrence of T with int, to create a class (preprocessing step) - is type safe
Visitor Design Pattern Purpose: double dispatch -¿ choose a method based on runtime type of 2 objects ENemy: subclasses turtle bullet
Weapon: subclasses rock stick
1) virtual void Enemy::strike(weapon &w); -¿ decisions based on runtime type of enemy
2) virtual void weapon::strike(Enemy &e); -¿ decision based on runtime type of weapon
Trick is to combine overriding and overloading

```
class Enemy {
        public:
                virtual void strike(Weapon &w) = 0;
};
class Turtle: public Enemy {
        public:
                void strike(Weapon &w) {
                        w.useOn(*this);
                }
};
class Bullet: public Enemy {
        public:
                void strike(Weapon &w) {
                        w.useOn(*this);
                }
};
class Weapon {
        public:
                virtual void useOn(Turtle &t) = 0;
                virtual void useOn(Bullet &b) = 0;
};
class Stick {
        public:
                void useOn(Turtle &t) {
                // stick used on turtle
                }
                void useOn(Bullet &b) {
                // stick used on rock
                }
};
```

```
class Rock {
        public:
                void useOn(Turtle &t) {
                // rock used on turtle
                }
                void useOn(Bullet &b) {
                // rock used on rock
                }
};

Enemy *e = new Bullet;
Weapon *w = new Stick;
e->strike(*w);
```

Visitor design pattern - add functionality to a class hierarchy without changing the code in this hierarchy - if the class hierarchy is configured to accept 'visitors'

```
class Book {
        public:
                virtual void accept(BookVisitor &v){
                        v.visit(*this);
                }
};

class CSBook: public Book{
        public:
                void accept(BookVisitor &v) {
                        v.visit(*this);
                }
};

class Comic: public Book{
        public:
                void accept(BookVisitor &v) {
                        v.visit(*this);
                }
};

class BookVisitor {
        public:
                virtual void visit(Book &b) = 0;
                virtual void visit(CSBook &b) = 0;
                virtual void visit(Comic &b) = 0;
};
```

Ex: add a way to track how many of each type of book I have Book -¿author CSBook -¿langauge Comic-¿ hero
so "C++" -¿ 5 "Superman" -¿ 2 So wecan use a map¡string, int¿!

```
map<string,int>
virtual void update();
```

```
class Catalogue: public BookVisitor {
        map<string,int> theCat;
        public:
        map<string,int> getCat() {
                return theCat;
        }
        void visit(Book &b) {
                theCat[b->getAuthor()]++;
        }
        void visit(CSBook &b) {
                theCat[b->getLanguage()]++;
        }
        void visit(Book &b) {
                theCat[b->getHero()]++;
        }
};
```

Linked list that alternates between int/chars (assume appropriate include guards)

```
a.h
class AList {
        int data;
        Blist * next;
};
b.h
class BList {
        char data;
        AList * next;
};
```

Problem: cyclic includes Solution: