STRUCTS 'N CLASSES

Dynamic Memory Review

- How do we dynamically declare an array of 100 **int**'s?
- How do we delete it?
- What happens if you forget to delete it (or you delete it incorrectly)?

Some string review

- How are strings represented in C++?
- What is a NULL terminator?
- How much memory should you allocate for a string?
- What very important thing do you need to do when putting characters into a string?
- What’s a fast way of declaring and initializing string variables?
- How do we embed a newline or a quotation mark in a string

Comparing Strings

```
char one[10], two[10];

strcpy( one, "hello" );
strcpy( two, "hello" );

if( other == name )
   cout << "same";
else
   cout << "different";
```

- Say we need to compare two strings...
- Can we do it this way?
- Would <, >, <=, or >= work any better?

Comparing Strings

- The usual way to compare strings is *lexicographically* - think phone book/dictionary
- One function to do this is **strcmp**:

```
int strcmp( const char* s1, const char* s2 )
```

strcmp returns an integer that is:

< 0 when s1 < s2
0 when s1 == s2
> 0 when s1 > s2

For more information...

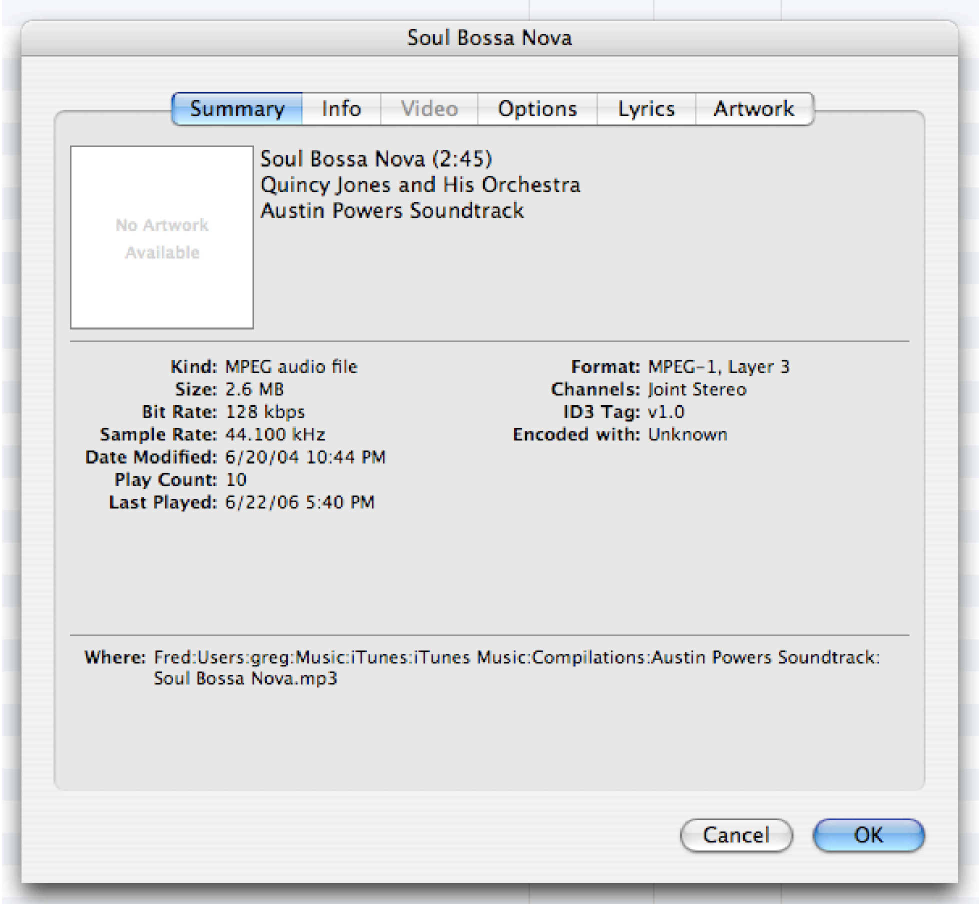
- The C standard library has many functions for working with strings:
  - formatting/modifying them
  - copying/manipulating them
  - converting them back and forth from integers, floats, etc.
  - ... and so on
- Google "string.h" and read about these if and when you need them!

So Far, We Can:

- Declare and use simple data types (int, float, char, bool, etc.)
- Use those data types in arrays
- This isn't enough, though: most complicated programs require *groups* of information, all neatly stored together

Motivation...

- Example: MP3 ID3 tags
- We might want to store name, bit rate, year, length, artist, album, etc.
- We've learned no convenient way of doing this, short of maybe declaring a variable for each item.
- This quickly becomes unworkable




```
char name[255];
int year;
float length;
int rate;
```

Introducing `struct`!

- ... but it makes more sense to group them all together in a single data type, which we get to define
- We can do this with a C++ concept called a structure

`struct` keyword signals the start of a structure definition

name of the structure type we're creating

```
struct id3Tag
{
    char name[255];
    int year;
    float length;
    int rate;
};
```

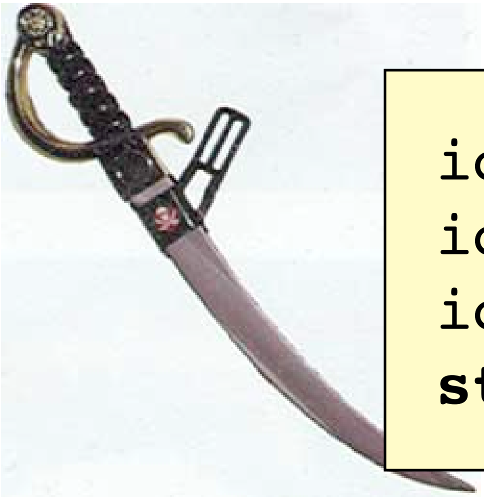
struct contents enclosed between curly brackets

these are the *members* of the structure

structure definitions must end with a semicolon

Our Very Own Data Type!

- So now we have our very own data type, called `id3Tag` that we can use - at this point `id3Tag` can be treated just like any built-in type
- We can declare variables of type `id3Tag` the same way we would with any other type:



```
id3Tag soulBossaNova;
id3Tag* ptrToSong;
id3Tag U2[50];
struct id3Tag ticketToRide;
```

- Note that we can also treat the word struct like it's part of the type - this is a holdover from C

The Rules

- Structure members can be of any type
- Arrays can be structure members
- A structure can be a member of another structure
- A structure **can't** contain an instance of itself.
- It **can**, however, contain pointers to itself.

```
struct node  // bad
{
    int payload;
    node variable;
};
```

```
struct node // good
{
    int payload;
    node* variable;
};
```

Accessing structures

- Statically allocated structures are accessed using the dot operator (the period):

```
id3Tag soulBossaNova;
soulBossaNova.year = 1982;
cout << soulBossaNova.year << endl;

id3Tag U2[50];
strcpy( U2[5].name, “Beautiful Day” );
```

- Members of a structure can be accessed and used like regular variables, because they *are* regular variables - just grouped with others.

Accessing structures 2

- Accessing through a pointer (as with any dynamically created structure) uses a different access mechanism: the arrow (–>) operator

```
id3Tag* soulBossaNova = new id3Tag;
soulBossaNova->year = 1982;
```

- Mixing up access operators will cause a compiler error
- What would be another way of accessing the `year` member?

Accessing structures 2

```
id3Tag* soulBossaNova = new id3Tag;
soulBossaNova->year = 1982;
```

- Note that we're doing dynamic memory allocation here - this works the same way as it does for all the "regular" types
- This is where dynamic allocation actually gets useful (we see this more later)
- Remember, we have to clean up after ourselves:

```
delete soulBossaNova;
```

Accessing structures 3

- You can treat variables within a structure exactly as if they were “regular” variables
- Each of them has the same type and characteristics they would have if they were not in a structure
- The structure serves only to group these variables together - it doesn’t change their individual properties

Passing Structures

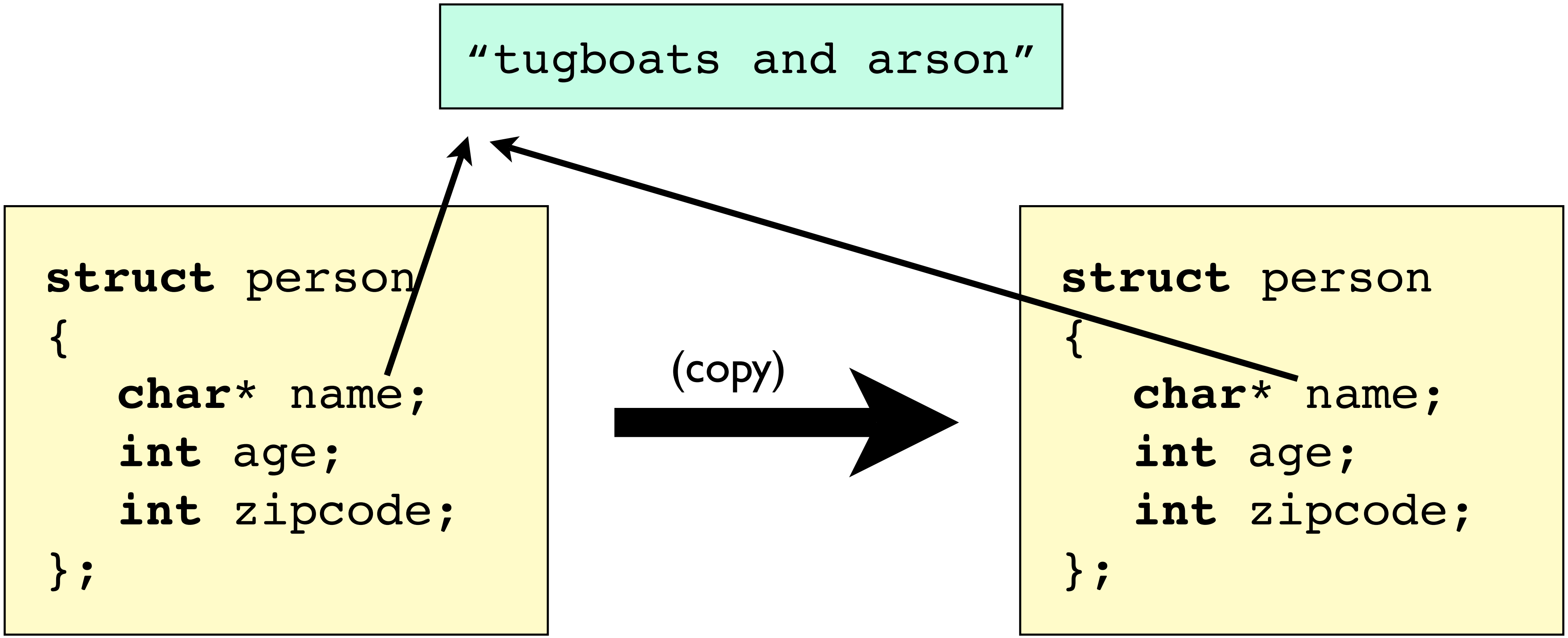
```
struct video
{
   int* frame;
   int list[10];
   int title;
};
```

```
void func( video v );
```

- A structure can be passed as a parameter to a function, just like any other type
- By default, structures are passed by value.
- When/why would you want to pass by reference instead?
- What are some potential problems in passing by value?

Passing Structures By Value

- When structures get passed by value, each member of the structure gets *copied*.
- This becomes a problem when a structure contains pointers:

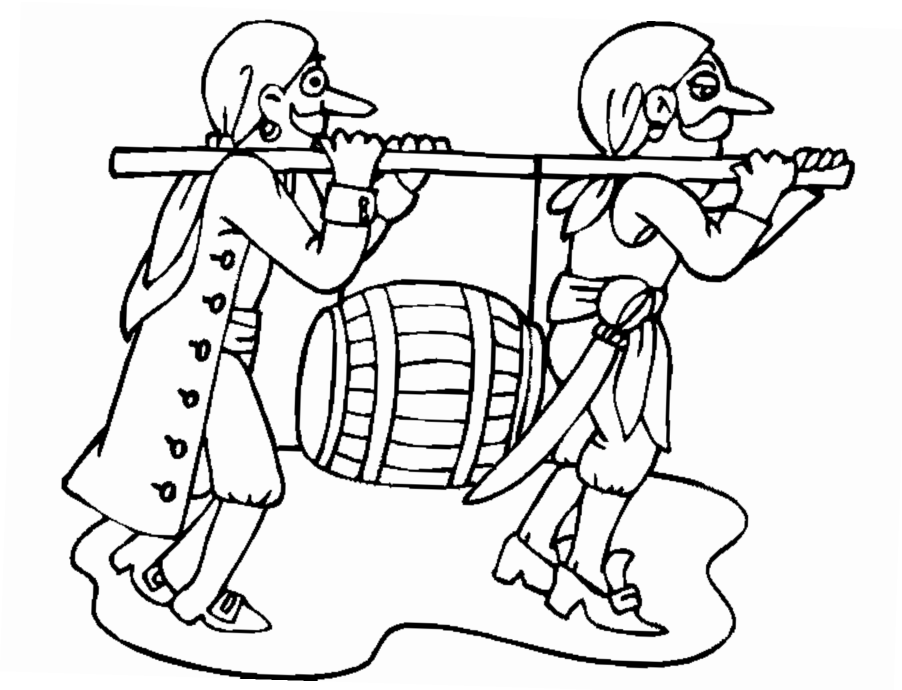


... back to structures

- Structures can include pointers to other structures of the same type
- This is how we can start to create more complicated data structures: lists, trees, graphs, etc.
- An example (from a few slides back): here's what each node of a linked list looks like:

```
struct node
{
    int payload;
    node* next;
};
```

points to another instance of the node structure



Example: Linked Lists

- Let's make a simple linked list structure
- ... and some code that will add integers to it
- This will tie directly into your assignment!

Project Two

Write a program that allows the user to enter words and counts their frequency

- Use an alphabetized linked list that stores the word and its count
- Whenever a word is encountered, insert it in the list (if it isn't there already) and increment its count
- At the end, print out all the words (in alphabetical order) and their frequency

Project Two

The tricky bits:

- Checking if a given word is already in the list
- Inserting into the linked list (in alphabetical order)
  - ... these two can be done in one step!
- Properly cleaning up the linked list

Structures, cont.

- Structures are essentially a concept from C
- They have several limitations:
  - copying them can be a pain
  - You can easily have uninitialized data (everybody forgets sometime!)
  - The program using the struct has full access to everything in it

Full Access

- The program using the struct has full access to everything in it
- Why can this be a problem?
- Sometimes you want to put restrictions on what data a variable can contain:

If you were designing a clock, you'd probably want to ensure that 0 <= minute <= 59 ...

... but nothing would stop you from writing code like this:

```
Time curTime;
curTime.minute = 85;
```

Object Oriented Programming

- Object Oriented Programming (OOP) is a methodology that addresses some of these limitations.
- Structures are intended to hold data, but most problems require both data *and* the logic that operates on that data
- OOP gives us that abstraction, by letting us couple the data together with functions that do stuff with that data.

OOP Basics

- Let's say you want to do a lot of work with 3D vectors. For a 3D vector, you have:
  - **Data:** x, y, z (all floating point numbers)
  - **Operations:** addition, normalization, etc.
- We can bring these things together by defining an **abstract data type**.
- But first... how would we use a struct to represent the data parts?

`vector3D` as a structure

```
struct vector3D
{
   float x;
   float y;
   float z;
};
```

This is how we would define a struct to handle the data side of things.

- Remember: this is a *definition* of a structure. Here we *define* what data is going to be in the structure - the data itself doesn't exist until we make an *instance* of this structure.
- So how do we add the other part of an ADT - the operations that use this data?

introducing: `class`

We define an ADT in C++ using the `class` keyword.
Here's the `class` version of the `vector3D` structure:

```
class vector3D
{
public:
    float x;
    float y;
    float z;
};
```

We're now using `class` here instead of `struct`.

We have this new `public` keyword sitting there. We'll get to this in a bit.

Everything else is *exactly the same!* Right now this behaves *exactly* like our `struct` version.

introducing: `class`

doesn't work!

```
class vector3D
{
public:
     float x = 3.0;
     float y = -1.5;
     float z = 42.0;
};
```

works fine

```
class vector3D
{
public:
     float x;
     float y;
     float z;
};
```

- Again, like a struct, this isn't an actual usable object yet - it's a *definition* of what an object will look like when we get around to making one of this type.
- So we can't initialize variables here (does it make sense why not?)

Adding methods

- We’ve got the data part defined: now we need to need to define the operations part.
- You do that by adding functions that belong to the class (these are often called **methods**, or sometimes **member functions**).
- The point of these methods is to operate on the data within the class.
- Maybe we often need to calculate the length of a 3D vector. How do we add a method to do that?

Adding methods 2

```
class vector3D
{
public:
    float length();

    float x;
    float y;
    float z;
};
```

- Now we've added length(), a method to calculate the Euclidean length of the vector (just an example - the math isn't important).
- Note that this is just a declaration (or prototype) of the function - we still need to define the body of the method!

Adding methods 3

```
class vector3D
{
public:
    float length();

    float x;
    float y;
    float z;
};

float vector3D::length()
{
    float dist;
    dist = x*x + y*y +z*z;
    return sqrt(dist);
}
```

The body of a function is often defined outside of a class declaration.

We tell the compiler that this function belongs to the class `vector3D` using the *scope resolution operator* (::)

```
float vector3D::length()
{
    // body goes here
}
```

Adding methods #4

```
class vector3D
{
public:
    float length();

    bool isOnFire()
    {
        return false;
    }

    float x;
    float y;
    float z;
};

float vector3D::length()
{
    float dist;
    dist = x*x + y*y +z*z;
    return sqrt(dist);
}
```

We can also define methods within the body of the class itself.

isOnFire() is completely defined within the function declaration; no external body is required (or allowed) for this function.

Adding methods 5

```
class vector3D
{
public:
    float length();

    float x;
    float y;
    float z;
};

float vector3D::length()
{
    float dist;
    dist = x*x + y*y +z*z;
    return sqrt(dist);
}
```

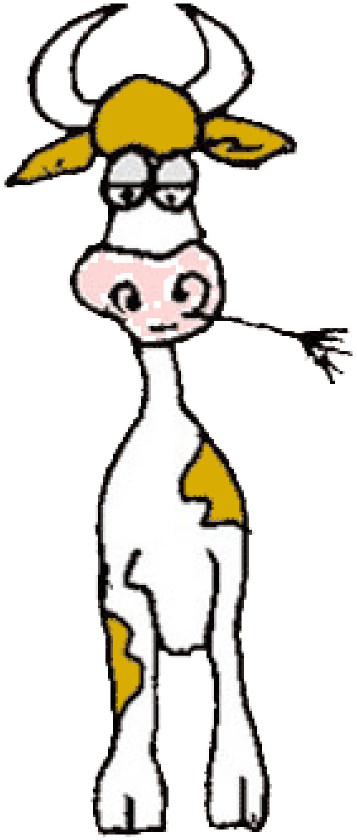
- *Every* method that belongs to a class *must* be declared in the class declaration!
- This isn't like regular functions, where you can just define a function without giving it a prototype first
- The prototype goes in the class declaration

Classes and Scope

```
class vector3D
{
public:
    float length();

    float x;
    float y;
    float z;
};

float vector3D::length()
{
    float dist;
    dist = x*x + y*y +z*z;
    return sqrt(dist);
}
```

- Every class defines its own scope: x, y, and z are all part of vector3D's scope
- Every method in a class has access to that scope
- So, length() can access x, y, and z as if they were local variables
- Can two classes have member variables with the name "distance"?

Access Controls



- Remember this example from earlier?
- We wanted to avoid letting code set the minute variable to something invalid
- If Time is a struct, nothing prevents us from setting minute to something weird.

If you were designing a clock, you'd probably want to ensure that 0 <= minute <= 59 ...

... but nothing would stop you from writing code like this:

```
Time curTime;
curTime.minute = 85;
```

Public Access


```
class vector3D
{
public:
    float length();

    float x;
    float y;
    float z;
};

int main()
{
    vector3D v;
    v.x = 1.5;
}
```

- This brings us back to the mysterious `public` keyword.
- Any variables declared in the public section can be accessed by *any* part of the program
- Any function in the public section can be called by any part of the program
- `main()` can modify `v.x`, because `x` is public

Private Access

```
class vector3D
{
public:
    float length();

private:
    float x;
    float y;
    float z;
};

float vector3D::length()
{
    float dist;
    dist = x*x + y*y +z*z;
    return sqrt(dist);
}

int main()
{
    vector3D v;
    v.x = 1.5;  // bad!
}
```

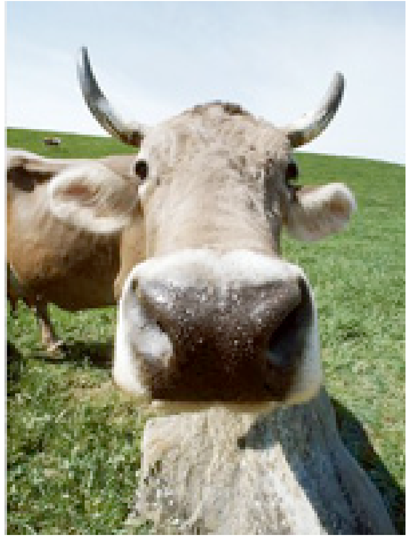
- **private** is another access specifier that we use to "hide" member variables
- The only functions that can access private variables are methods in *that class*
- Likewise, private functions (methods) can only be called by other methods in the same class
- Now, main() can't access x!

Access Specifiers

```
class vector3D
{
public:
    float length();
    void  flip();

private:
    void doPrivateStuff();
    void doubleUp();
    float calcTangent();

    float x;
    float y;
    float z;

public:
    void normalize();
};
```

- **`public`** and **`private`** start their own sections: everything in that section has that access attribute (until a new section starts)
- If you don't specify, the default access specifier for a class is *private*
- There's also a third access specifier: **`protected`**
- We'll talk about that one later on in the course.

Creating Instances of an Object



- So far, remember, we've just defined the class
- The process of using that class definition to make a real, usable object is called **instantiation** - this allocates memory for the object and lets you do stuff with it (how *much* memory do we need?)
- You make instances of the class the same way you do for any other type:

```
vector3D vec;
vector3D* ptr = new vector3D;
```

Using Objects

- Once you've instantiated an object, you access its members the same way you access a structure
- We access class methods the same way: using the dot operator (.) or the arrow operator (–>)

```
// declared statically
vector3D vec;
vec.x = 42;
cout << vec.length() << endl;

// declared dynamically
vector3D* ptr = new vector3D();
ptr->x = 42;
cout << ptr->length() << endl;
```

What has to be true in order for this code snippet to compile?

Accessor Methods

```
class time
{
private:
    int tHour;
    int tMinute;
    int tSecond;
};

int main()
{
    time t;

    // bad!
    t.tHour = 9;

    return 0;
}
```

- Once we've declared variables private, how does outside code (e.g. main) get access to them?
- They can't access them directly...
- The only code that *can* access private variables are member functions.
- So we need member functions to access these variables for us.

Accessor Methods

```
class time
{
public:
    int hour();
    void setHour( int h );

private:
    int tHour;
    int tMinute;
    int tSecond;
};

int main()
{
    time t;
    t.setHour( 9 );
    cout << t.hour();
    return 0;
}
```

- The accessor methods themselves are public, so they can be called by anything
- The set accessor method can also make sure that the data is valid:

```
void time::setHour( int h )
{
    if( h > 12 )
        h = 12;
    if( h < 1 )
        h = 1;
    hHour = h;
}
```

encapsulation

- A class's *interface* is made up of the public methods you use to interact with the class.
- Accessor methods are used to separate *interface* from *implementation*
- This process is called **encapsulation**.
- The idea: hide all the class implementation details from the code that is using the class - no outside code should *have* to know the details!
- You don't need to know how a car works in order to drive one - just how to use the car's "interface"!

benefits of encapsulation

- One major reason for encapsulation:
- As long as a class's interface stays consistent, this lets you completely change the way a class works internally and not "break" any code that relies on the class
  - Say we wanted to change our time class to store an *epoch* instead: the number of seconds since midnight.
  - As long as the time interface stays consistent, we just have to write the accessor functions and no other code has to change.

introducing **const**

```
class time
{
public:
     int hour() const;
    void setHour();

private:
    int tHour;
    int tMinute;
    int tSecond;
};

int time::hour() const
{
    // this is an error!
    tSecond = 10;
}
```

- Defining good interfaces also can protect you from your *own* mistakes
- For example... accessor methods that get variables can be marked as read-only, so the compiler will generate an error if that method tries to modify anything in the class
- This is done with C++ keyword **const**, which has been sadly neglected until now

const methods

```
class time
{
public:
     int hour() const;
    void setHour();

private:
    int tHour;
    int tMinute;
    int tSecond;
};

int time::hour() const
{
    // this is an error!
    tSecond = 10;
}
```

The keyword **const** comes *after* the method name - think of it as part of the function name

It also has to be there in the function definition

Since hour() is marked **const**, it can't modify anything in the class without causing a compiler error.

`const` methods

```
int global = 42;

void changeGlobal()
{
    global++;
}

class time
{
public:
    int hour() const;
    void setHour( int h )
    {
        tHour = h;
    }

private:
    int tHour;
    int tMinute;
    int tSecond;
};
```

```
int time::hour() const
{
    return tHour;
}
```

```
int time::hour() const
{
    changeGlobal();
    return tHour;
}
```

```
int time::hour() const
{
    setHour( 11 );
    return tHour;
}
```

Which of these versions of the hour() method will compile?

`const` parameters

- `const` is especially useful for references
- Pass-by-reference is efficient, but leaves parameters open to getting changed in ways you might not expect
- If the function accepts a *const reference*, you have some assurance that parameters will remain unchanged!

```
struct bigData { ... };

int sneakyFunc( bigData& b )
{
    b.count++;
    return b.number*3;
}

int main()
{
    bigData data;
    sneakyFunc( data );
}
```

we can change sneakyfunc to:

```
int sneakyFunc( const bigData& b )
```

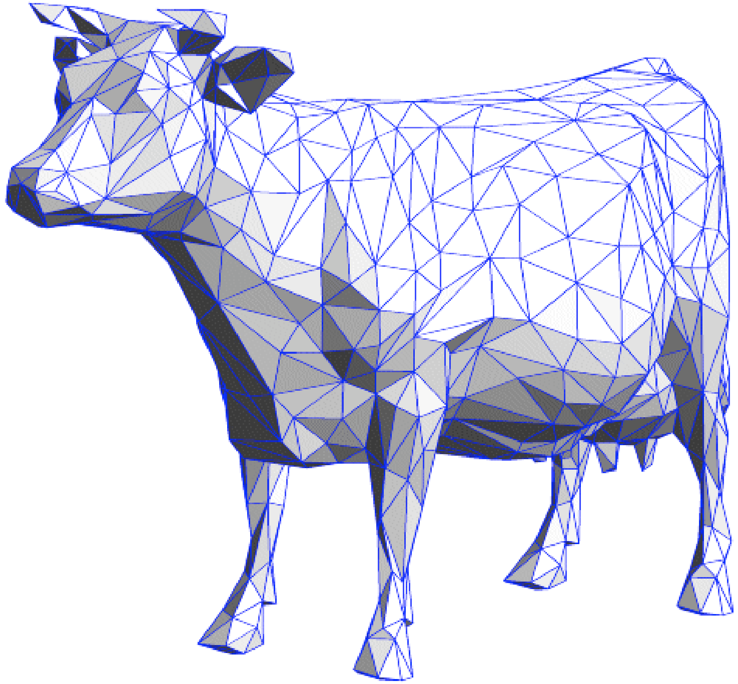
Then it can't change any values inside b, because the parameter is marked const. By adding const we ensure b remains unchanged.

... and finally ...

- There's the const variable. Useful for things like mathematical constants:

```
const float pi = 3.14159265;
```

- Any variable can be declared const; once it is initialized, it can't be changed.



Fun With Code!

- Let's write a circle class with:
  - a radius
  - get/set member functions
  - methods to calculate area and circumference